Fire Management Branch
Department of Conservation and Environment
ISBN 0-7306-2641-5

FUEL REDUCING A STAND OF EUCALYPT REGROWTH IN EAST GIPPSLAND - A CASE STUDY

RESEARCH REPORT No. 33
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August 1992

SUMMARY

Planning and operational factors that should or must be considered when implementing prescriptions for fuel reducing stands of eucalypt regrowth are identified and discussed, based on a case study conducted on 3 April 1990 in a 16 year-old stand with a bracken understorey at Buchan South, East Gippsland, Victoria.

Fuel and stand characteristics were measured prior to the burn. Spot fires were ignited in a grid pattern throughout the 15ha study site and the behaviour of one of the fires was measured. Mild weather conditions with wind speeds generally less than 5km/h and forest fire danger indices less than 5 prevailed during the burn. Fire behaviour varied considerably, with about two-thirds of the area being burnt by fires with rates of spread of between 10 and 50 m/h and fireline intensities of between 50 and 240 kW/m. Higher intensity fire behaviour occurred in dense bracken fuels with a maximum rate of spread of 94 m/h and fireline intensity of 460 kW/m.

An analysis of the scorch and fire behaviour data showed that rates of spread of greater than about 50 m/h or fireline intensity of greater than about 240 kW/m caused excessive damage to the upper crowns of trees in this stand of dominant height 14m. Stem damage, caused mostly by burning logging debris, occurred to 9% of stems.

The planning and operational actions that are recommended to be implemented by staff to achieve fuel reduction burning objectives without causing unacceptable damage include:-

* Prepare adequate control lines and fall stags on boundaries.
* Measure stand height.
* Measure litter and shrub fuel loads and assess shrub fuel distribution.
* Construct rough walking tracks to give lighting crews easier and safer access within the burning unit.
* Monitor broadscale weather patterns.
* Monitor and measure local weather.
* Monitor and measure fuel moisture content.
* Predict rate of spread using the McArthur forest fire danger meter (in the absence of other, fuel type specific, fire behaviour guides for fuel reduction burning).
* Ignite a test fire on level ground and, after at least 20 minutes, measure the rate of spread.
* Use the test fire rate of spread and the slope on the area to be burnt to plan the spacing of ignitions.
* Ignite the burn boundaries with spot fires.
* Ignite the stand with a planned, widely spaced grid system of spot fires.
* Ignite spot fires to burn up-slope only on slopes less than about 10°.
* Plan for spot fires to join in the late afternoon or early evening.
* Conduct a second stage burn if coverage from the first stage is less than about 50%.

INTRODUCTION

Regrowth forests[1] in East Gippsland present one of the greatest fire hazards and fuel reduction challenges facing Victorian forest managers. Many of the forest types of East Gippsland have an understorey which is elevated, highly flammable and which is often combined with high levels of litter fuel and the presence of stringybark eucalypts with a high potential for generating spot fires to present one of the highest fire hazards found in Australian forests. Fuel reduction burning, which is the primary tool for reducing fuel quantity and hence the impact of wildfire in a range of Victorian and Australian forests (McArthur 1962, Luke and McArthur 1978) has not generally been applied to regrowth forests because of difficulties of implementing the practice in the hazardous fuel types found in East Gippsland (see Buckley 1990) and concerns about possible damage to young trees. Consequently, protecting regrowth forests has been limited to conducting pre-suppression works outside the regrowth forests and by aiming to detect and suppress quickly any wildfires that do occur.

The state and national importantance of protecting these forests from wildfire is shown by the existence of several research projects. Prescriptions for fuel reducing regrowth forests of *Eucalyptus diversicolor* (Karri) in Western Australia have been developed by McCaw[2] (pers. comm.) following research into fire behaviour in young Karri stands (McCaw 1986). Similar research is also being conducted by the Bushfire Research Unit (BRU) of the CSIRO Division of Forestry in the mixed species regrowth forests of south-east New South Wales. In 1987, recognizing the need for improved fuel management in the regrowth forests of East Gippsland, the Fire Management Branch of Victoria's Department of Conservation and Environment (DCE) initiated a fire research project, with the aims of investigating the factors affecting low intensity fire behaviour and of developing prescriptions for fuel reducing these forests. Results from this Victorian research may now offer the planning and operations staff of DCE the prospect of achieving fuel reduction burning objectives in these forests without causing unacceptable levels of damage.

Draft prescriptons for fuel reducing regrowth forests with a *Pteridium esculentum* (Austral Bracken) fuel type were applied during an operational burn conducted on 3 April 1990. This operation was conducted in old growth and 16 year old regrowth forest, located as is shown on Figure 1, at Buchan South in the Nowa Nowa Operations Area of Bairnsdale Region. A study site of 15ha, which is shown on Figure 2, was selected from within the regrowth stand for the purpose of applying these prescriptions on a modest operational scale and of evaluating the results of the burning operation.

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1 Defined as forests which are predominantly even-aged and less than 40 years old (Radic 1990)

2 Lachlan McCaw, Research Scientist, CALM, Manjimup, W.A.

Figure 1. Location of the fuel reduction burn conducted at Buchan South, Nowa Nowa Operations Area on 3 April 1990.

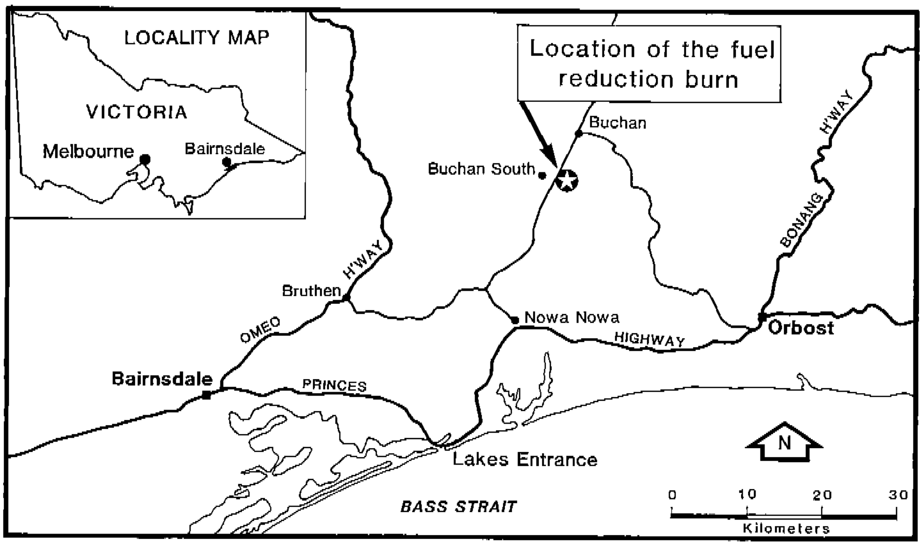
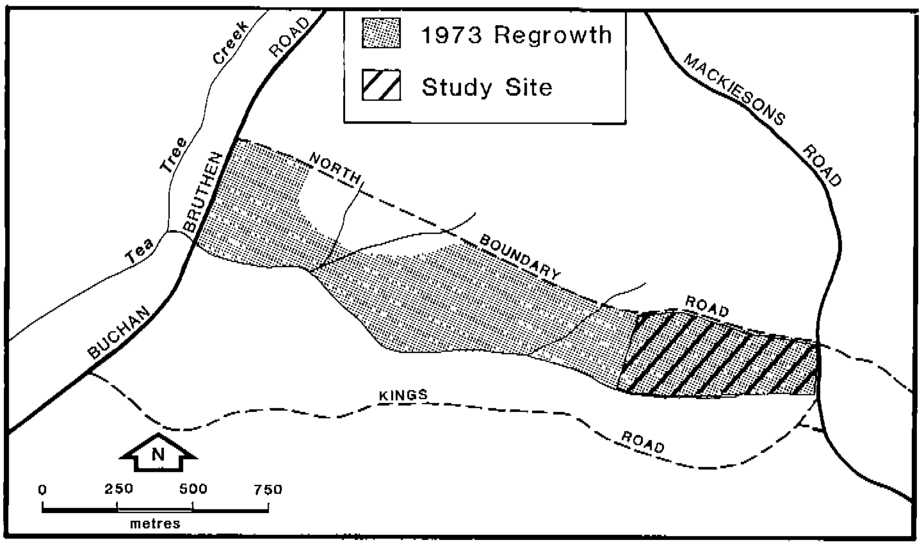


Figure 2. Location of the study site within the 16 year-old regrowth stand.



Prescriptions and fire behaviour guides for conducting fuel reduction burning in regrowth forests with *Pteridium esculentum* (Austral Bracken) or *Tetrarrhena juncea* (Wiregrass) fuel types in East Gippsland will be presented in subsequent reports. The aim of this case study is to identify and discuss the planning and operational factors[1] that should or must be considered when implementing prescriptions for fuel reducing stands of eucalypt regrowth.

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1 Planning and Technical staff involved with fuel reduction burning, but with less interest in the details of measurement techniques which are described in the Methods section of this report, are encouraged to proceed directly to both the Results and Discussion sections.

METHODS

Stand and site characteristics

The forest type which covered the fuel reduced area was classified as Open Forest III (27-40 m) (Land Conservation Council 1982). The dominant tree species was *Eucalyptus globoidea* (White Stringybark) with associated tree species which included *Eucalyptus consideniana* (Yertchuk) and *Eucalyptus cypellocarpa* (Mountain Grey Gum). Within the study site, *Eucalyptus globoidea* was the dominant tree species and *Acacia mearnsii* (Black Wattle) occurred as a scattered understorey species. *Kunzea ericiodes* (Burgan) grew in thickets, mainly along the drainage lines and *Pteridium esculentum* (Austral Bracken) was the major shrub species.

The regrowth stand had been established by natural regeneration following sawlog harvesting in autumn 1973 and slash burning in winter 1973, and covered about half of the total burn area of 131 ha. The flank of a severe wildfire, which had started in private property about 0.5km south west of this block on 30 September 1980, had burnt at least some of this regrowth stand ten years previously.

The stand characteristics of diameter distribution, stocking, stand basal area and dominant height were assessed prior to the burn and were then compared with the values, identified by McCaw (pers. comm.), which should be exceeded before prescribing fuel reduction burning in regrowth *Eucalyptus diversicolor* forests[1]. A technique of variable probability sampling (Dilworth and Bell, 1985) was used to determine these stand characteristics. Six plots were systematically located on a transect, as is shown on Figure 3, and, at each plot, a five factor (m^2/ha) basal area wedge was used to determine the number of "in" trees. These, and other trees were classified for discussion purposes as being of dominant, co-dominant, intermediate or suppressed form. The diameter (DBHOB) of each "in" tree was measured over-bark at breast height (1.3m) (stems less than 5cm DBHOB were not tallied) and the height of the three largest diameter "in" trees, excluding any that were suppressed or intermediate, was measured and averaged to determine dominant height.

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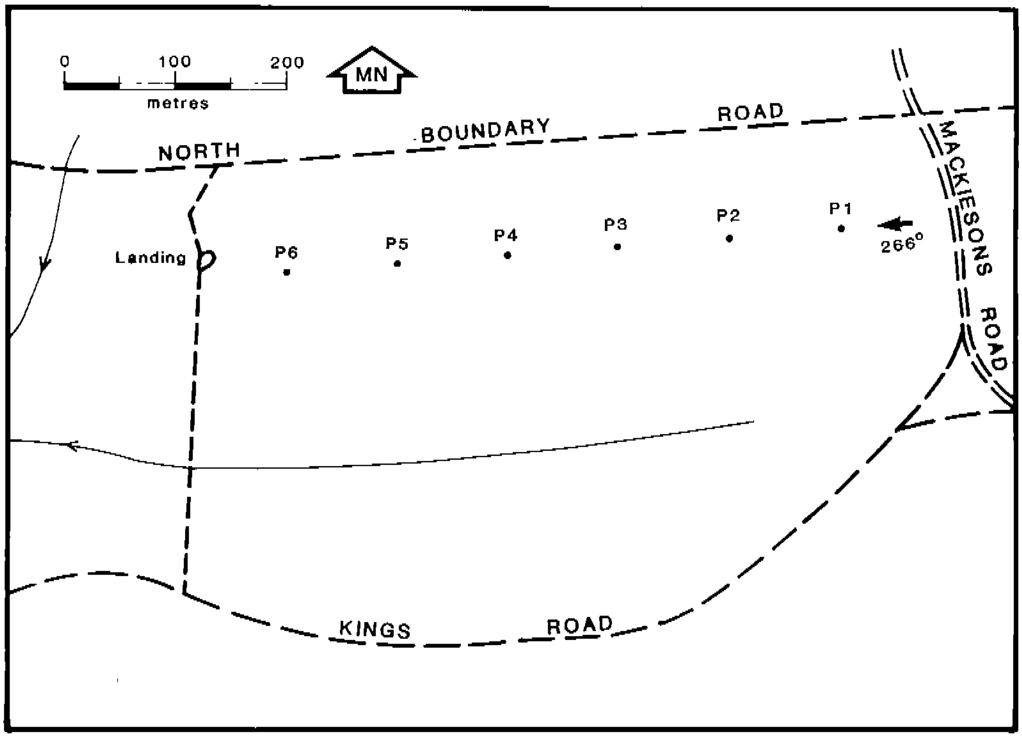
1 More than 30% of at least five and preferably ten sample points should meet the following criteria:-

*at least 250 stems/ha should be greater than or equal to 20cm diameter (used as an index of stand development and hence ability to withstand low intensity fire).
*basal area greater than 20 m^2/ha
*co-dominant height greater than or equal to 18m

Figure 3. Location of the plots used to sample stand characteristics within the study site.



Slopes on the study site were mostly less than 5° but increased to up to 10° adjacent to the main gully. Roads surrounded the area to be burnt and additional widening of these control lines was not required to achieve a satisfactory standard of pre-burn edge control.

Fuels

Fine fuel load and arrangement were assessed two weeks prior to the burn. The following classes of fine fuel (fuel less than 6 mm in thickness) were defined:

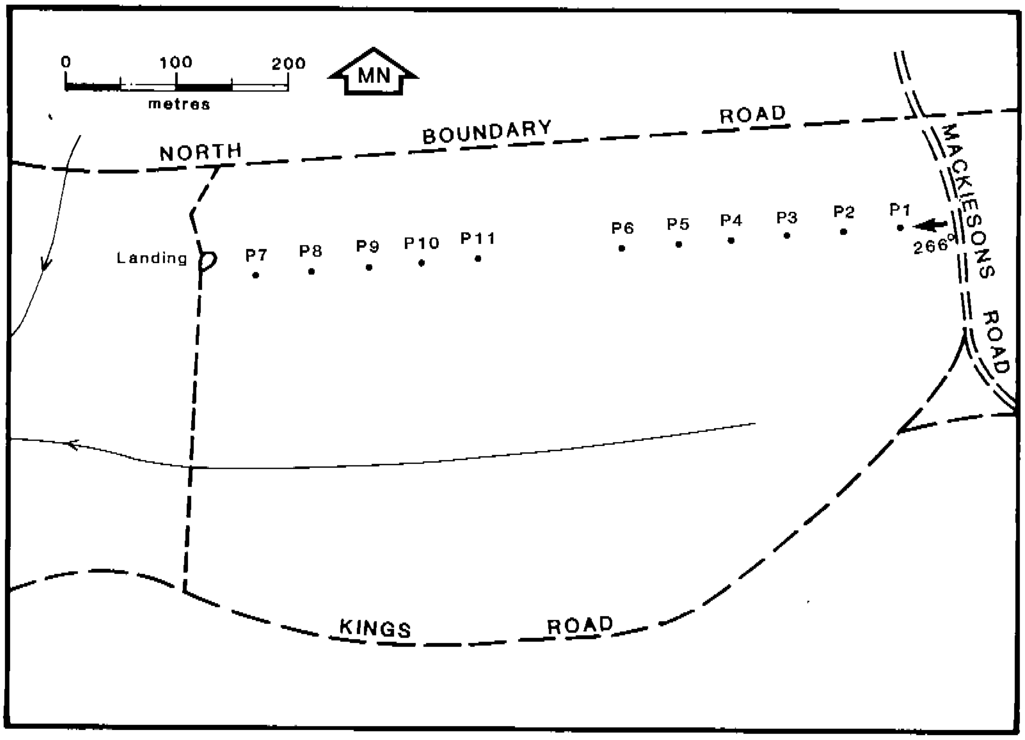
Litter bed fuel: Dead fine fuel, including surface fuel and fuel lower in the fuel profile. Those fuels such as eucalypt capsules and charcoal which do not ignite or burn readily were excluded.

Elevated dead fuel: Dead fine fuel forming part of, or being suspended in, the shrub layer.

Living shrub fuel: Living understorey fine fuel less than 2 m above ground level.

Fine fuel load was assessed by destructively sampling eleven square plots, each of area 0.37 m^2. These plots were systematically located 50 m apart on a transect that was aligned, as is shown on Figure 4, to sample the fuel characteristics of the study site. The sampling frame was subjectively placed at each sampling point to be representative of the fuels at that point. Fuels were sorted into each fuel class and then weighed at the sampling point using a Salter 1 kg spring balance (measured to the nearest 5 g or 0.1 t/ha wet weight). Five samples of each fuel class were collected in jars for subsequent oven drying and weighing to enable the wet weight of each fuel sample to be adjusted for moisture content. Coarse fuels, defined as fuels greater that 6 mm thickness (including old log material), were not measured either before or after the burn.

Figure 4. Location of the plots used to sample fuels within the study site.



The height of the shrub layer at each sample plot was measured prior to destructive sampling. Also, the density of the shrub layer in the immediate vicinity of each plot was assessed on a subjective scale from 1 (sparse) to 5 (dense).

Bark fuels on trees within about 20m of the fuel sampling transect were assessed prior to the burn using broad hazard classes as defined by Wilson (1992) based on bark type, amount of loose bark and blackening of the bark by previous fires. A formal survey of bark hazard was not conducted after the burn.

Fuel moisture content

The moisture content of the fine fuel on the day before, and the day of, the fuel reduction burn was determined by collecting fuel samples in jars for subsequent oven drying and weighing. Fuel samples were collected from the litter bed fuel (surface and profile litter) and elevated dead fuel classes. The type of sample collected as being representative of each of these defined fuel classes was:

Elevated dead fuel:	Dead bracken forming part of, or being suspended in, the shrub layer.
Surface litter:	Dead fine fuels (mainly leaves and petioles) found in the top 1.0 cm of the litter bed and either exposed to the weather elements of sun and wind or, as were most fuels, shaded by the shrub layer.
Profile litter:	Dead fine fuels situated below the surface litter in the litter bed. Fuels in this class were absent where the litter fuel loads were low.

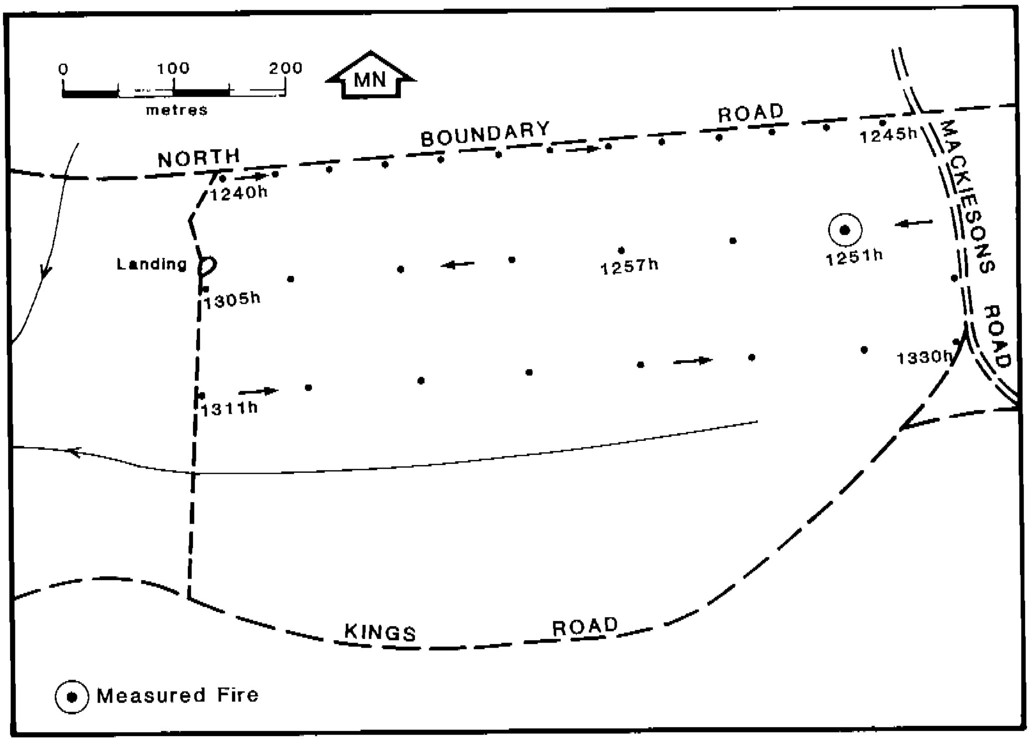
Weather

Weather variables were measured on-site on the day prior to, and on the day of, the burn. Dry bulb and wet bulb temperatures were measured using an Assman psychrometer. Wind speed at canopy level was estimated using the Beaufort Scale (Bureau of Meteorology 1984) and was measured at a height of 1.5 m above ground level within the forest and adjacent to the site using a Dwyer hand-held anemometer. Cloud cover was assessed by estimating the number of eighths of the sky that were covered by cloud (Bureau of Meteorology 1984). Rainfall was measured by a rain gauge located in the open, 2.5 km south west of the study site, on the property of Mr and Mrs P. Lord. The metric Byram Keetch Drought Index (Keetch and Byram 1968) was calculated from rainfall and temperature data that had been recorded at Nowa Nowa, 19 km south of the study site. The equations developed by Noble *et al.* (1980) were used to calculate the McArthur forest fire danger index (Luke and McArthur 1978) using the Nowa Nowa and on-site data.

Lighting technique

The principles of conducting low intensity fuel reduction burning as described by McArthur (1962) were used in planning the ignition pattern of the study site. The ignition pattern and light-up times are shown on Figure 5. Initially, edge control on the northern boundary was established by igniting spot fires 50 m apart and allowing these fires to spread and meet. Wind speed at canopy level at 1240 hours, when the north west corner of the study site was ignited, was a very light 0-5 km/h with a wind direction which was variable but predominantly easterly. The crew from the Nowa Nowa Operations Area commenced to ignite the broader area outside the boundaries of the study site at about this time, principally using strip lighting techniques.

Figure 5. Ignition pattern, location of the "measured fire" and times of ignition of the fuel reduction burn conducted on 3 April 1990.



The interior of the study site was lit at points 100m apart and access for the lighting crew was facilitated by rough walking tracks. Lighting commenced at 1251 hours and was completed 50 minutes later at 1330 hours. A D3 bulldozer (50 kW class) had previously been used to construct the two rough walking tracks which were aligned east-west across the study site and constructed with the "blade-up" so as to ensure that the shrub layer was knocked down whilst causing minimal disturbance to the litter layer. Each spot fire was ignited by partially wetting a 0.5 m diameter patch of fuel with the diesel/petrol mixture from an unignited drip torch, and then igniting the fuel with a fusee match. Each planned ignition was thus assured and there was no possibility of any accidental ignitions from an ignited drip torch.

Fire behaviour

Fire spread, flame height and other fire behaviour characteristics of the spot fire that was ignited at 1251 hours in the north east corner of the study site (see Figure 5) were observed in detail. The location of a given observation, such as fire perimeter at a given time, was determined by reference to pig-tail pins which had previously been placed at 10m intervals along six lines which radiated out from the ignition point. Due to the change of direction of the head fire during the burn, four additional pins were added in the south westerly direction, and their locations were measured at a later time. The ground slope in the direction of each pin line was also measured. The time when the fire perimeter reached each 10m pin was noted, as was, at other convenient times, the location of the fire perimeter in between pins. Flame height, defined as the vertical distance between the tip of the flame and ground level and expressed as a mean height which excludes occasional flame flashes (Luke and McArthur 1978), was estimated by reference to 1m and 2m height marks on trees located adjacent to each pin. A number marked on each of these trees, corresponding to the distance of the pin from the point of ignition, helped to orientate the observer.

The rates of spread of the fire in each of the measured directions were calculated from the time interval between successive points where the location of the fire perimeter was recorded. The resulting rate of spread data were difficult to interpret because they were based on distance intervals rather than on a constant time interval. A time interval of 20 minutes had previously been selected as a reasonable period over which to integrate the fuel and weather factors which determine fire spread and to compare sensibly rates of spread in different time intervals of this and other fires. Hence, for each measured direction, and as is shown in the example in Table 1, the distance based rates of spread which were calculated within each 20 minute time interval were proportioned, based on the number of minutes that the fire perimeter burnt at that rate, to calculate 20 minute fire spread and hence, 20 minute rate of spread.

Table 1. Sample calculation of rate of spread over time intervals of twenty minutes (in the western direction).

Time (hours)	Distance (m)	Distance based rate of spread (m/h)	Twenty minute time intervals	Time (hours)	Time (minutes) at rate of spread (m/h)	Calculated 20 minute fire spread (m)	Time based rate of spread (m/h)
1251	0		**0**	1251			
			20	1311	20 at 25.0	8.3	**25**
1315	10	25.0			4 at 25.0		
			40	1331	16 at 31.6	10.1	**30**
1334	20	31.6			3 at 31.6		
			60	1351	17 at 13.0	5.3	**16**
			80	1411	20 at 13.0	4.3	**13**
1420	30	13.0			9 at 13.0		
			100	1431	11 at 75.0	16.0	**48**
1436	50	75.0					

The fire perimeter was described in terms of three zones: the head fire, flank fires and back fire (Burrows 1984). The rate of spread of the head fire burning on level ground was predicted by the McArthur forest fire danger meter using the relevant equation[1] developed by Noble et al. (1980). The actual rate of spread and fuel quantity data were used to calculate the quantitive expression of fire behaviour, fireline intensity.[2]

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1 R = 0.0012.F.W where R denotes the rate of forward spread (km/h), F denotes the fire danger index and W denotes the weight of the fine fuel (t/ha).

2 Fireline intensity was devised by Byram (1959) as a measure of fire behaviour. It is the rate of energy release per unit length of fire front and is defined by the equation I = Hwr where I denotes the fireline intensity (kW/m), H denotes the heat yield of fuel (kJ/kg), assumed to be 16,000 kJ/kg (Luke and McArthur 1978), W denotes the dry weight of fine fuel consumed (kg/m^2) (mean total less mean unburnt) and R denotes the forward rate of spread (m/s).

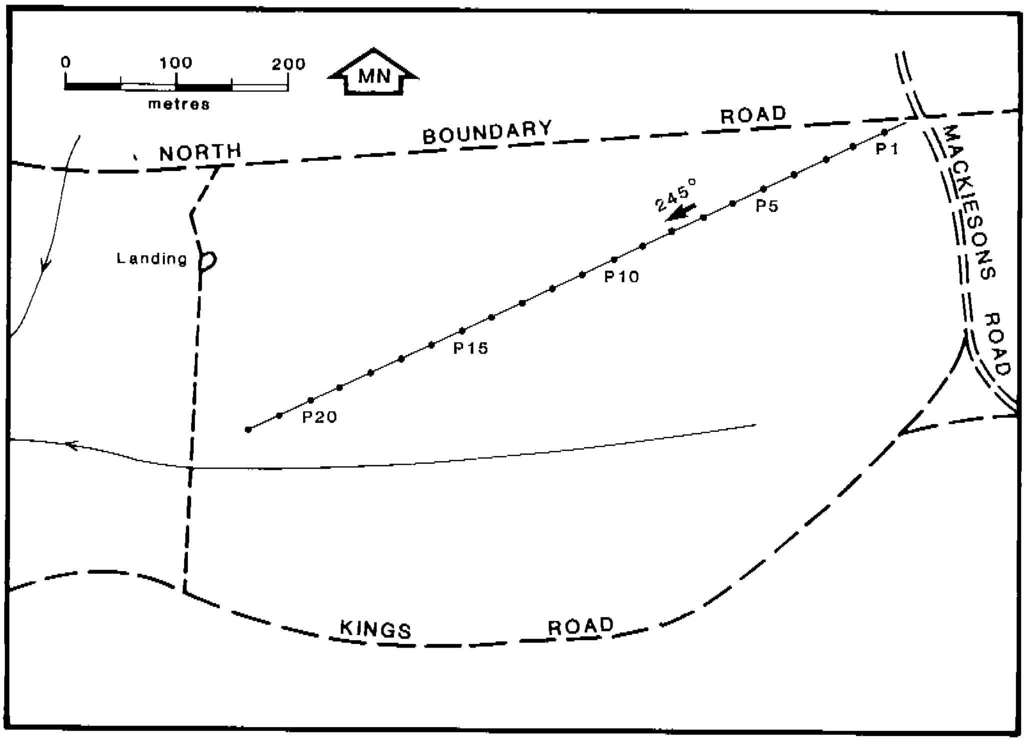
Fire control

Patrol of the boundaries of the fuel reduction burn, to ensure that the burn did not "escape" from the planned area, was the responsibility of the crew from the Nowa Nowa Operations Area. This five person crew was equipped with two, 400 litre slip-on units.

Crown scorch, stem damage and hazard reduction

Scorch height was measured on trees burnt by different zones of the "measured fire" at distances of between 15 m and 56 m from the point of fire ignition. Scorch height over the remainder of the study site was determined by measuring maximum scorch height on 22 plots, each of 20 m diameter, located, as is shown on Figure 6, along a 660 m transect that was aligned to sample the range of the fire behaviour within the study site. The proportion of stems for which scorch height was greater than 12 m (2 m less than the mean dominant height) was calculated as an estimate of the percentage of stems with an unacceptable level of upper crown scorch.

Figure 6. **Location of the plots used to sample scorch height and of the transect used to sample stem damage within the study site.**



Stem damage was assessed, using a sampling technique that had been developed by Cheney *et al.* (1990), on 1.5% of the study area in a 4 m wide strip located on the same transect that was used to assess scorch height. Any death of the vascular cambium of regrowth stems was not apparent, unless the overlying bark was completely burnt, until subsequent tree growth caused the bark to split along the occluding edge of the scar. Consequently, the stem damage survey was delayed until ten months after the burn when all of this stem damage was evident. Within this transect, all trees with diameter greater than 10 cm were examined for fire damage, and the distance from each fire-damaged tree to a possible major heat source (such as an old log from previous harvesting) was measured. The diameter of each damaged tree was measured and the species was recorded.

The amount of fine fuel that remained unburnt was not measured, but was estimated immediately after the burn, based on measurements that had been made following similar experimental fires. The percentage of the area of the study site that was burnt was also estimated.

RESULTS

Stand characteristics

The data on stand characteristics are summarised in Table 2 and show a mean dominant height of 14 m, a mean basal area of 23 m^2/ha and a mean stocking of 1020 stems/ha, of which a mean of 170 stems/ha were greater than or equal to 20 cm DBHOB. The stand density, however, varied considerably over the study site with a stocking of less than 400 stems/ha in two of the six plots. There were no old growth stems on the study site and the mean diameter of the 27 "in" trees was 18.9 cm (standard deviation 5.0). Based on this data, the stand at the study site did not meet the minimum height prescription applied to *Eucalyptus diversicolor* regrowth, was borderline in the minimum stocking prescription of stems greater than or equal to 20cm diameter and exceeded the minimum prescription for basal area.

Table 2. Stand characteristics of the study site.

Plot no.	Dominant height[1] (m)	Regrowth basal area (m^2/ha)	Stocking (no. stems/ha)					
			Diameter class (cm)					
			5.0-9.9	10.0-14.9	15.0-19.9	20.0-24.9	25.0-29.9	Total
1	14	10	0	0	200	130	0	330
2	15	45	0	1,250	800	250	0	2,300
3	14	5	0	0	0	0	90	90
4	14	20	0	0	200	130	170	500
5	14	30	0	830	600	130	0	1,560
6	14	25	0	830	400	130	0	1,360
Mean	14	23	0	490	370	130	40	1,020
S*	0.4	14	0	550	290	80	70	860

[1] The mean height of the three largest diameter "in" trees of dominant or co-dominant form.
* Standard deviation

Fuels

The data on fine fuel load, which are summarised in Table 3, show a mean total fine fuel load of 12.8 t/ha, comprising a mean of 8.1 t/ha of litter, 2.6 t/ha of living shrub fuel and 2.1 t/ha of elevated dead fuel. The average shrub height was 1.3 m. Large quantities of old log and branch material, which had not been burnt by the slash burn following harvesting, were observed on the forest floor.

Table 3. Fine fuel load, shrub density and shrub height data.

Plot number	Shrub height (m)	Shrub density (1-5)	Fine fuel load (t/ha)				
			Elevated dead fuel	Living shrub fuel	Total shrub fuel	Litter bed fuel	Total fine fuel
1	1.4	4	2.4	5.3	7.7	14.8	22.5
2	1.6	5	3.3	1.9	5.2	10.2	15.4
3	1.1	5	2.0	1.2	3.2	4.9	8.1
4	0.9	1	0.0	0.7	0.7	10.0	10.7
5	1.7	4	4.1	3.0	7.1	5.9	13.0
6	1.2	4	4.1	3.0	7.1	6.6	13.7
7	1.1	3	0.0	3.0	3.0	11.6	14.6
8	1.3	3	1.1	1.9	3.0	4.0	7.0
9	1.3	3	3.3	0.0	3.3	7.1	10.4
10	1.2	3	0.0	2.7	2.7	8.4	11.1
11	1.3	5	3.3	5.6	8.9	5.7	14.6
Mean	1.3	-	2.1	2.6	4.7	8.1	12.8
S[1]	0.2	-	1.6	1.7	2.6	3.3	4.2

[1] Standard deviation

The loosely held bark on the assessed *Eucalyptus globoidea* and *Eucalyptus consideniana* stems, and on stems throughout the study site, was sufficient to cause significant spotting. The bark hazard was uniformly classed as "Very High".

Fuel moisture content

Fuel moisture content data for 2 April 1990, the day before the burn, are shown in Table 4. The mean moisture content of exposed surface litter in the early afternoon was 14%, of shaded surface litter was 16%, of elevated dead fuel was 18% and of profile litter was 32%.

Table 4. Fine fuel moisture content of fuels on 2 April 1990, the day prior to the fuel reduction burn.

Time (hours)	Fine fuel moisture content (% ODW)			
	Elevated dead fuel	Exposed surface litter	Shaded surface litter	Profile litter
1305 to 1320	17	14	17	30
	18	14	16	33
Mean	18	14	17	32

Fuel moisture content data for 3 April 1990, the day of the burn, are shown in Table 5. During the 135 minute period from 1255 to 1510 hours, the mean moisture content of exposed surface litter was 11%, of shaded litter was 13%, of elevated dead fuel was 15% and of profile litter was 34%.

Table 5. Fine fuel moisture content of fuels on 3 April 1990, the day of the fuel reduction burn.

Time (hours)	Fine fuel moisture content (% ODW)			
	Elevated dead fuel	Exposed surface litter	Shaded surface litter	Profile litter
1255 - 1315	16	9	12	48
	13	-	13	49
1354 - 1415	15	13	16	37
	16	-	12	20
1455 - 1510	16	10	12	17
	16	-	15	30
Mean	15	11	13	34
s[1]	1.2	2.1	1.6	13.6

[1] Standard deviation

Weather

The seasonal weather trend at Nowa Nowa over the 1989-90 summer was characterized by a steadily rising drought index from mid-December to early February. Rainfall, which totalled 61 mm, fell during the first half of February and reduced the Byram Keetch Drought Index to 90. March was relatively dry and on 27 March the Byram Keetch Drought Index peaked for the season at 144, prior to 16 mm of rain falling on 27 and 28 March. The Byram Keetch Drought Index was 117 on the day before the burn and 118 on the day of the burn. Recent rainfall at the study site was 13mm, which had fallen seven days prior to the burn and consequently, the drought factor indicated by the McArthur forest fire danger meter was 10.

The synoptic situation on 2 April 1990, the day before the fuel reduction burn, is shown on Figure 7 and indicates that a slow moving high pressure system was centred south of Adelaide. Weather observations taken at the study site during the early afternoon are shown in Table 6 and characterise an overcast, cool to mild afternoon with a light (6-11 km/h) to gentle (12-19 km/h) south westerly breeze.

Figure 7. The synoptic situation on 2 April 1990, the day before the fuel reduction burn (Bureau of Meteorology).

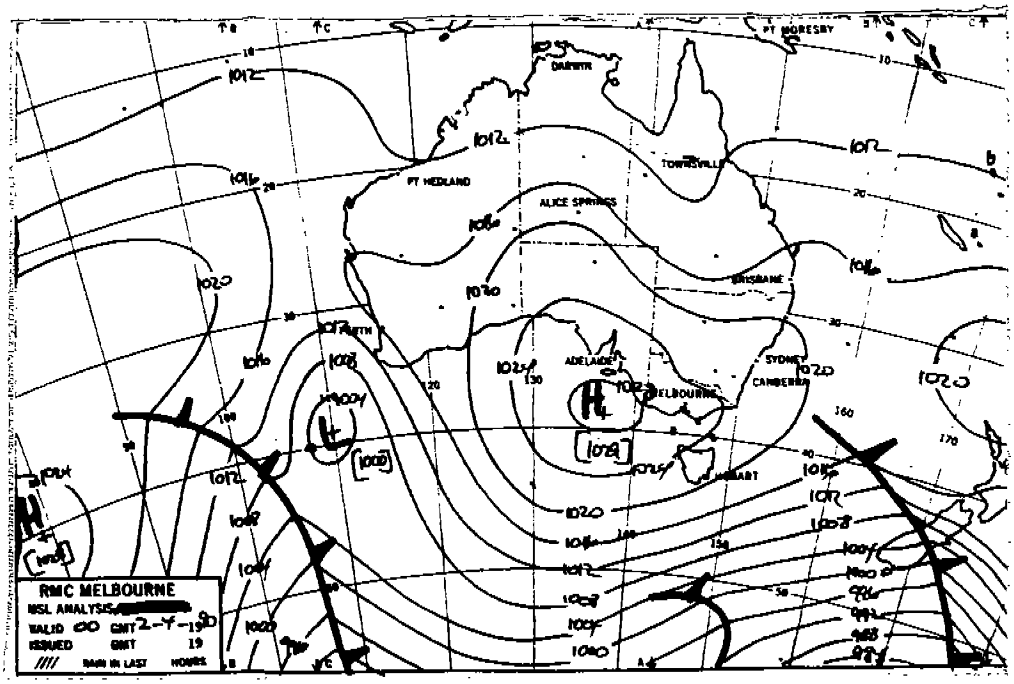
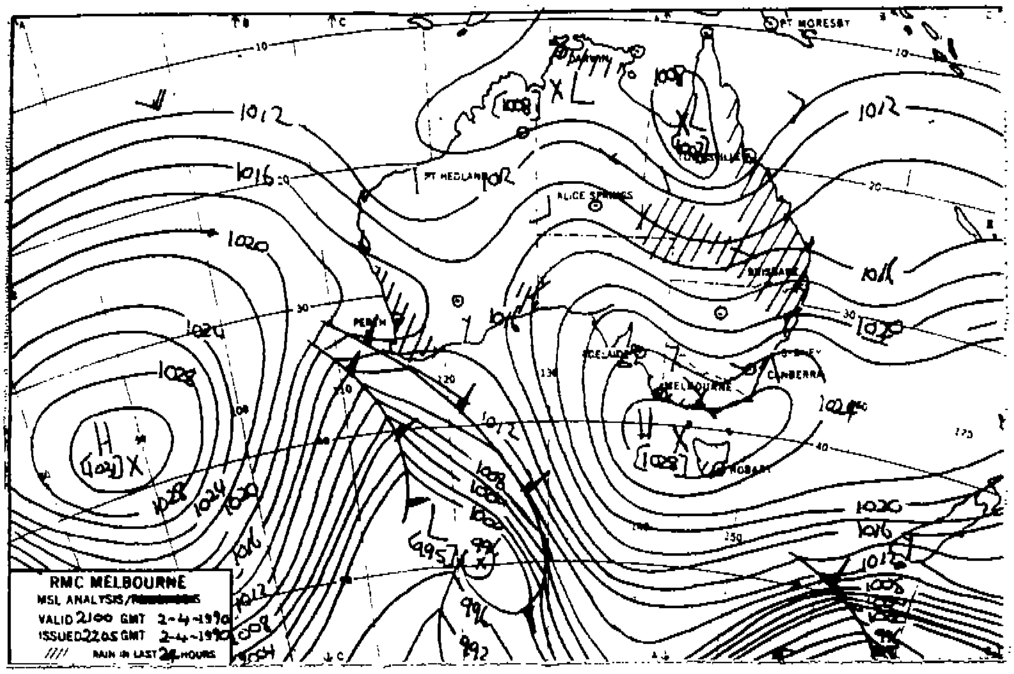


Table 6. Weather observations and fire danger indices at the study site on 2 April 1990, the day prior to the fuel reduction burn.

Time (hours)	Temperature (°C)	Relative humidity (%)	Wind speed at canopy (km/h)	Wind direction	Cloud cover	Fire danger index
1300	17.0	59	12-19	SW	7/8	4
1325	17.3	54	6-11	SW	7/8	4
1400	18.0	52	6-11	SW	7/8	5

The synoptic situation on 3 April 1990, the day of the fuel reduction burn, is shown on Figure 8 and indicates that the high pressure system was centred south of Melbourne. The District forecast for East Gippsland issued at 0630 hours was for early morning fog patches followed by a fine, cool to mild day with sunny periods and light to moderate south east winds. The weather estimates for Orbost, 32 km south east of the study site, were for a maximum temperature of 18°C, a minimum relative humidity of 60% and south to south east winds of 25 km/h.

Figure 8. The synoptic situation on 3 April 1990, the day of the fuel reduction burn (Bureau of Meteorology).



Weather observations taken at the study site are shown in Table 7 and characterise a fine, mild afternoon with uniform conditions of temperature and relative humidity. Winds were calm or light (0-5 km/h), east to north easterly, except for approximately twenty minutes from 1400 hours when the wind speed increased to a gentle breeze (12-19 km/h). The fire danger index varied within the Low fire danger class from 3 to 5.

Table 7. Weather observations and fire danger indices at the study site on 3 April 1990, the day of the fuel reduction burn.

Time (hours)	Temp. (°C)	Relative humidity (%)	Wind speed at canopy (km/h)	Wind speed at 1.5 m (km/h)	Wind direction	Cloud cover	Fire danger index
1155	19.5	56	0-5	*	S (var.)	1/8	4
1225	19.9	56	0-5	*	E (var.)	1/8	4
1250	20.2	60	0-5	*	NE	1/8	3
1325	20.0	56	0-5	*	E (var.)	1/8	4
1350	21.0	57	0-5	*	E	1/8	4
1400	21.0	57	12-19	-	E	1/8	5
1420	21.0	57	0-5	*	E	0-1/8	4
1440	20.2	57	0-5	*	E	0-1/8	4

* The wind speed did not register on the Dwyer hand-held anemometer

Fire behaviour

The predicted rate of forward spread of an individual fire burning at a fire danger index of 4 was 60 m/h and at a fire danger index of 5 was 80 m/h. The actual spread of the "measured fire" at time intervals of 20 minutes is shown on Figure 9 and the fire behaviour variables of rate of spread, flame height and fireline intensity are shown in Table 8. The "measured fire" burnt slowly during the first 60 minutes after ignition, with the head fire developing towards the west under the influence of a very light wind. Fire behaviour of the head fire 45 minutes after ignition, with a fireline intensity of about 145 kW/m, is shown on Photo 2. The rate of spread of the head fire between 20 and 40 minutes after ignition was 30m/h, flame height was 0.5 to 1.5m and fireline intensity was 145 kW/m.

From about 60 minutes after ignition, or 1350 hours, the head fire direction changed to the south west following a shift in wind direction. The rate of spread of the head fire between 60 and 80 minutes after ignition increased to 68 m/h, flame height was 1.0 to 3.0m and fireline intensity was 335 kW/m. The rate of spread increased further between 80 and 100 minutes after ignition to 94 m/h, flame height was 1.5 to 3.0m and fireline intensity was 460 kW/m.

From about 100 minutes after ignition, the head fire approached the adjacent fire that was burning upslope and flame height increased for a short time to 4.0m. This junction zone was 93m from the point of ignition and was the zone of maximum fire activity observed within the study site.

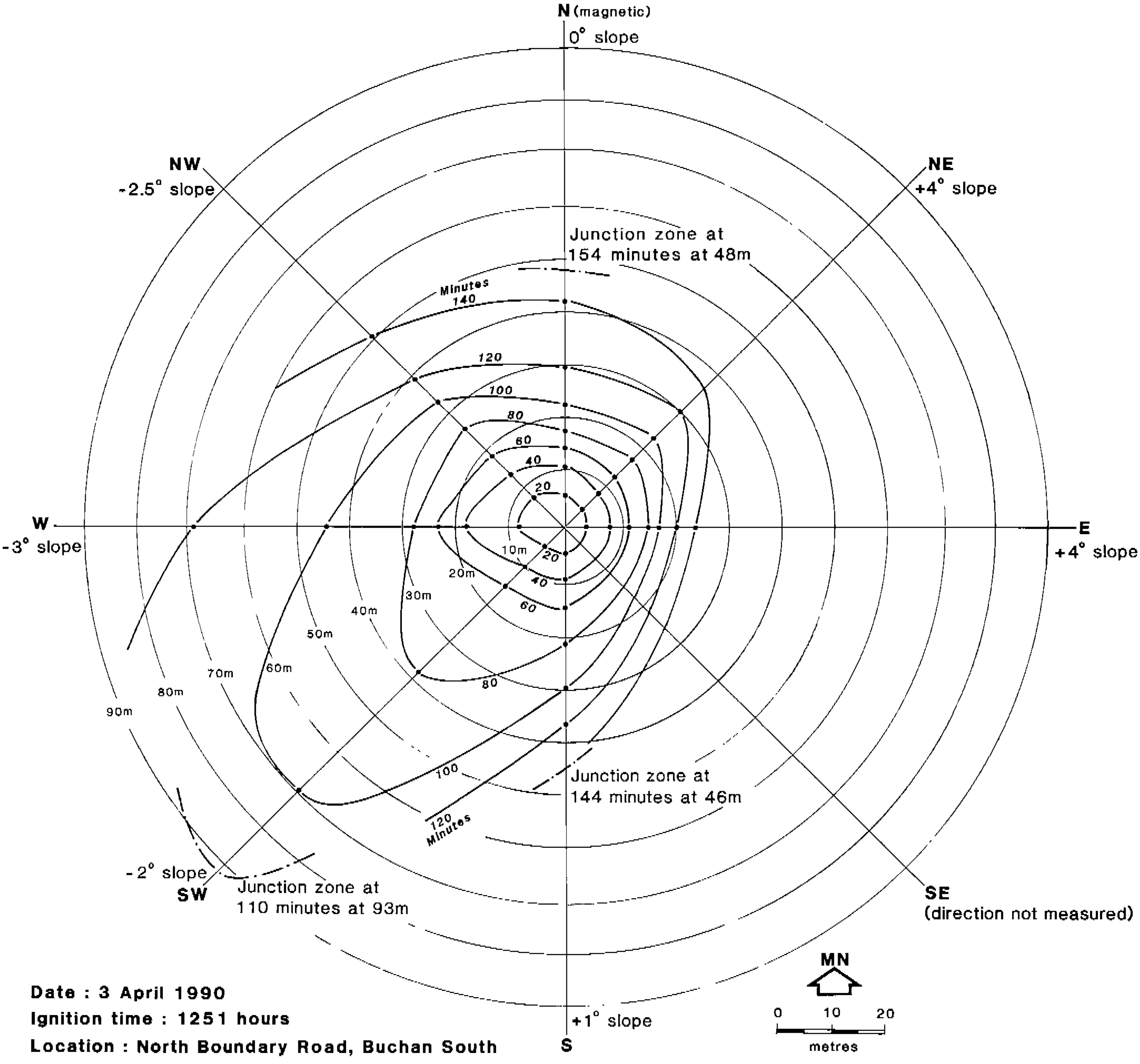
The behaviour of the flank fire zones and back fire zone of the "measured fire" was much milder. For example, the flank which burnt in the north west direction during the 140 minutes after ignition, had a rate of spread of between 15 and 34 m/h and fireline intensity of between 75 and 165 kW/m. Flame height was generally 0.5 to 1.5 m.

The spot fires that were ignited from 1240 to 1245 hours along North Boundary Road had largely joined by 1345 hours, although some small sections required re-lighting. It was generally not possible to observe directly the head fire behaviour of the other spot fires which had been ignited over the remainder of the study site. However, the head fire behaviour of these fires in the dense bracken and low eucalypt density areas was probably similar to that observed on the measured fire but of a lower intensity in the sparser bracken areas.

The behaviour of the flank and back fires of these other spot fires was similar to that observed on the "measured fire", with the flank fire zones joining together from about 1515 hours. In the areas of lower bracken density, the increase in fire behaviour in these junction zones was observed to be much less than had occurred in the head fire junction zone of the "measured fire".

Flames easily ignited the stringybark fuel of the *Eucalyptus globoidea* and *Eucalyptus consideniana* stems, even when the fire front was burning at a rate of spread of less than 20m/h. Dead old growth trees (known as stags) on the study site ignited easily and continued to burn after the fire front had passed. Similarly, the old log material often ignited and continued to burn which caused some logs to be consumed and most to be partly charred.

Figure 9. **Spread of the "measured fire" at 20 minute time intervals from ignition.**



Date : 3 April 1990
Ignition time : 1251 hours
Location : North Boundary Road, Buchan South

Table 8. Fire behaviour of the "measured fire".

Direction from ignition	Fire zone	Slope (degrees)	Time after ignition (min)	Rate of spread[1] (m/h)	Flame height[2] (m)	Fireline intensity (kW/m)
east	back fire	+4	20	13		65
			40	13	0.3	65
			60	11		55
			80	10		50
			100	10	0.3	50
			120	10	0.5 - 1.0	50
			140	10		50
north east	back fire	+4	20	13		65
			40	13	0.5	65
			60	13		65
			80	14	0.5	70Ã
			100	17		85
			120	22	0.5	110
north	flank fire	0	20	18		90
			40	15	0.5	75
			60	10		50
			80	10	0.5	50
			100	15		75
			120	21	1.0	105
			140	37		180
north west	flank fire	-2.5	20	23		115
			40	17	0.5	85
			60	15	1.5	75
			80	21	0.5	105
			100	21		105
			120	18	1.0	90
			140	34	0.5	165
west	head fire	-3	20	25	0.5	120
	head fire		40	30	0.5 - 1.5	145
	head fire		60	16		80
	flank fire		80	13		65
	flank fire		100	48	1.5 - 2.5	235
	flank fire		120	75		365
south west	flank fire	-2	20	15		75
	flank fire		40	15		75
	flank fire		60	18	0.8 - 1.0	90
	head fire		80	68	1.0 - 3.0	335
	head fire		100	94	1.5 - 4.0	460
south	flank fire	+1	20	15		75
			40	16	1.0	80
			60	17		85
			80	19	0.5	95
			100	25	1.0 - 2.0	120
			120	21	1.0	105
			140	21		105

1 Calculated from the spread distance during the previous 20 minutes.
2 Observed during the previous 20 minutes.

Fire control

Control problems were not experienced at this burn. As wind speed was very light later in the afternoon, the crew from Nowa Nowa was able to be released to another burning operation.

Crown scorch, stem damage and hazard reduction

Scorch height varied considerably within the area that was burnt by the "measured fire" as is shown in Table 9. Maximum scorch height corresponded to the increased fire behaviour in the head fire zone from about 70 minutes after ignition. Full crown scorch of intermediate stems occurred within this zone and the crowns of some dominant and co-dominant stems were also completely scorched, although most retained some green foliage at the very top of the crown. Scorch height within the flank and back fire zones ranged from less than 4 m to 11 m.

Table 9. Scorch height of stems on the area burnt by the "measured fire".

Fire zone	Direction from ignition	Distance from ignition (m)	Maximum scorch height (m)	Comments
head fire	SW	40	15	Full crown scorch of dominant stems
head fire	SW	56	12	Full crown scorch of intermediate stems
flank fire	W	35	9	
flank fire	NW	30	7	
flank fire	N	20	9	
flank fire	S	15	11	
flank fire	S	15	10	
back fire	NE	25	8	
back fire	NE	40	5	
back fire	E	15	<4	

Scorch height also varied considerably over the study site as is shown in Table 10. The mean maximum scorch height was 10 m but maximum scorch height was greater than 12 m on 20% of the burnt plots. However, as the height of the dominant stems on some of these plots was less than the mean dominant height of 14, some crowns of dominant stems were fully scorched on 35% of the burnt plots.

Table 10. Maximum scorch height data from the study site.

Plot number	Maximum scorch height (m)	Some crowns of dominant stems fully scorched	Plot number	Maximum scorch height (m)	Some crowns of dominant stems fully scorched
1	11	yes	12	10	yes
2	unburnt	-	13	14	yes
3	9	no	14	15	yes
4	8	no	15	16	yes
5	9	no	16	13	yes
6	11	no	17	10	no
7	8	no	18	7	no
8	6	no	19	9	no
9	9	no	20	8	no
10	10	no	21	7	no
11	11	yes	22	unburnt	-
Mean				10	
Standard deviation				2.7	

Cambial damage occurred to 9%, or 13 of the 150 stems assessed for stem damage. Of those 13 stems, 10 were *Eucalyptus consideniana* stems, of mean DBHOB 15.0 cm (standard deviation 3.8), and 3 were *Eucalyptus globoidea* stems, of mean DBHOB 15.1 cm (standard deviation 5.3).

Four sources of stem damage were identified. Of the 13 damaged stems, one was damaged by a burning stump, one was damaged by a burning dead stem and three were damaged by an unidentified source which may have been heat from the flame front. The remaining eight stems were damaged by burning logging debris, located up to 1.7 m away.

Not all of the study site was actually burnt. Some small areas dominated by *Acacia mearnsii* and *Kunzea ericoides* (which carried low litter fuel loads) remained unburnt, as did some small areas of eucalypt litter and bracken fuels. Two of the 22 plots (9%) assessed during the crown scorch survey had not been burnt. Hence, about 90% of the study site was fuel reduced.

The "Very High" bark hazard was not reduced on those stems where only the lower section of the stem had been charred. However, the bark hazard was reduced to a "Moderate" hazard on a limited number of stems where higher intensity fire behaviour had burnt loose bark from most of the stem and to a "High" hazard on about half of the stems where the lower and mid sections of the stem had been charred.

Flames scorched but did not consume the bracken fuel in some of the back and flank fire zones of individual fires where rates of spread were about 10m/h. In comparison, the higher intensity fire behaviour of the head fire and other flank fire zones consumed most litter and shrub fine fuel. The fine fuel load that remained unburnt was estimated to have a mean of 2 t/ha.

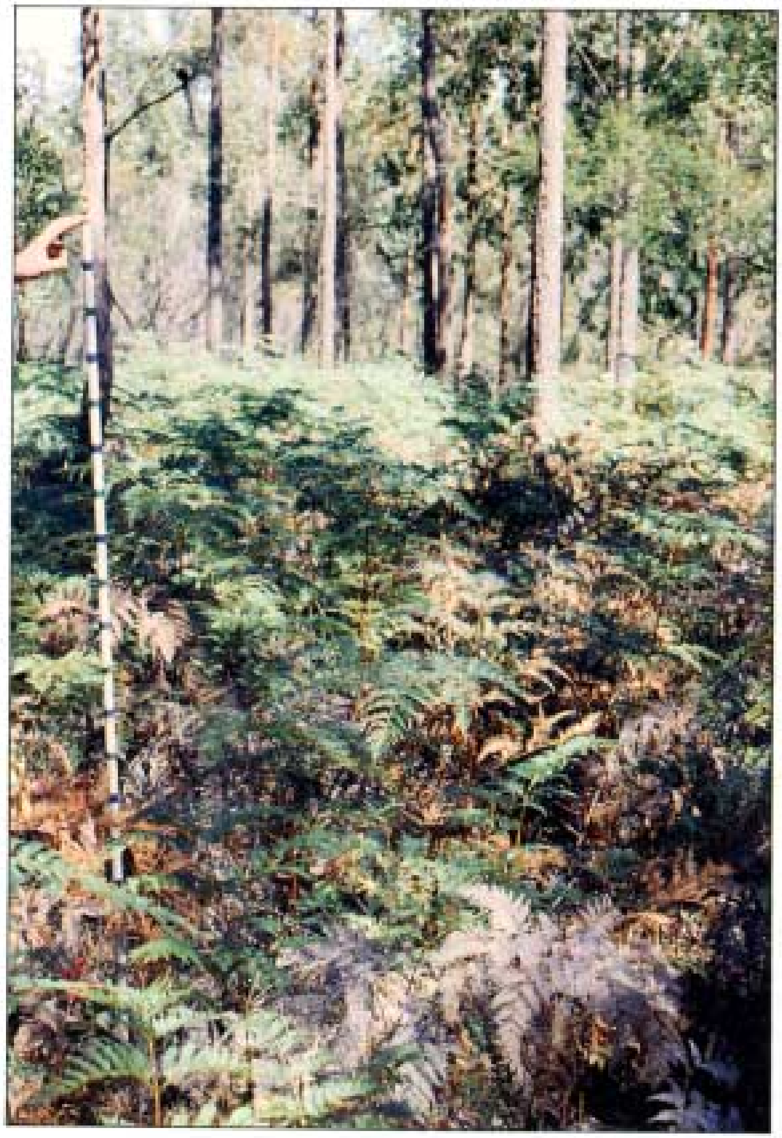


Photo 1.
Dense bracken fuels in an area of lower eucalypt density (height pole = 2.0m)

Photo 2 Fire behaviour of the head fire burning in a westerly direction, 45 minutes after ignition, with a fireline intensity of about 145 kW/m. Note the burnt bracken stems in the foreground.

DISCUSSION

The fuel reduction burning operation demonstrated that under very mild conditions successful fuel reduction in regrowth forests can be achieved. However, if burning operations in regrowth stands are to achieve good coverage without causing unacceptable damage, each of the factors which contribute towards low intensity fire behaviour, including fuels, weather, fuel moisture content, slope and lighting pattern, together with stand characteristics, must be carefully considered in both the planning and implementation stages.

Stand height needs to be measured, so that a scorch height limit (and hence limits of rate of spread and flame height) can be prescribed to avoid upper crown scorch. Although stand height is related to stand age, growth rates of mixed species forests vary widely in East Gippsland (Incoll 1974, Incoll pers. comm.) and hence stand age should be used as only a guide to, and not replace measurement of, stand height. At the study site, where the height of dominant trees averaged 14m, a rate of spread of about 50 m/h or a fireline intensity of about 240 kW/m was found to cause unacceptable levels of crown scorch. The consequence of assuming a stand height that is higher than actual, and hence prescribing and then achieving fire behaviour which causes widespread upper crown scorch, is the rapid return of available fuel to the site (Luke and McArthur 1978), high visual impact and a significantly reduced rate of basal area growth (Incoll 1981).

Estimating the number of stems that are greater than a minimum prescribed diameter, as an index of stand development and hence ability to withstand low intensity fire, should normally be required only in stands which are of the minimum prescribed dominant height. However, the results of future operational burning may indicate that this criteria need not be measured at all. The technique of variable probability sampling used in this study is recommended because it is simple to apply, although the stand should also be stratified into two or more density classes prior to sampling to improve the accuracy of the estimate.

Fuel quantity should be measured, as it is directly proportional to the rate of spread (Luke and McArthur 1978) and hence provides an objective basis on which to predict fire behaviour and to prepare appropriate prescriptions for individual stands. Clearly, more conservative prescriptions must be prepared as fuel load increases. Litter bed fuel loads can be relatively easily measured using equipment and techniques currently available to field officers. However, measuring shrub fuel load involves a more complex procedure for correcting for moisture content, and the impact of elevated shrub fuel on rate of spread is less well defined. McArthur (1962) added the dry weights of shrub components to the litter weight and classified the result as available fine fuel. Sneeuwjagt and Peet (1985) apply a "scrub flammability factor" of between 0.5 and 5 to the dry weights of shrub fuel components to account for the combined impact of scrub flammability and the percentage of dead scrub material on rate of spread, but the factors lack a strong experimental basis (McCaw pers. comm.). Until detailed shrub hazard guides are available for elevated fuel types in Victorian forests, estimates of total fuel load should, as recommended by McArthur (1962), combine estimates of both litter and shrub fuel dry weights.

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1 Bill Incoll, Scientist, Timber Assessment, DCE, Kew

Shrub fuel distribution should be assessed because, as was clearly demonstrated in this study, increased fire behaviour can be expected in any area of dense, elevated fuel. Prescriptions must therefore be implemented conservatively in these hazardous fuel types.

The combined affects of an increase in shrub fuel load and density and an increase in windspeed caused the dramatic increase in fire behaviour of the head fire of the "measured fire" from about 1400 hours. The wind speed at the height of the flames was increased when the wind speed at canopy level increased for about 20 minutes to 12-19 km/h and was further increased as a consequence of a decrease in stand density and hence an increase in wind penetration into the stand. Unfortunately, as the wind speed increase overlapped two of the 20 minute time intervals, distinguishing the separate effects of changes in fuel and wind speed was not possible. Burning operations in elevated fuel types will require conditions of very low wind speed to be successful although scorch of upper crowns may still be expected in poorly stocked areas of young stands.

Monitoring the broadscale weather pattern and monitoring and measuring local weather conditions and the moisture content of fine fuel is important when preparing to conduct any fuel reduction burn, but is even more important in regrowth stands. Weather patterns should be monitored to select a slow moving high pressure system, such as the one that was selected for this burn, which produces stable atmospheric conditions, low wind speeds and cool to mild conditions.

Fuel moisture content must be measured prior to conducting the burn. The moisture content of the fuel is directly related to fuel flammability and hence fire behaviour (Luke and McArthur 1978) and follows a drying pattern of increasing fuel availability following rainfall and also a diurnal pattern responding to changing temperature and relative humidity (Luke and McArthur 1978). The profile layer of fuel at the study site was damp or moist on the day prior to and the day of the burn, which is a condition identified by McArthur (1962) as a pre-requisite of fuel reduction burning. However, although the moisture content of surface fuels during the burn was ideal for burning old growth forests, it was drier than desirable, as evidenced by the levels of scorch associated with the more intense fire behaviour, for burning this stand of regrowth. Conditions of higher moisture content of surface fuel would have occurred earlier in the drying cycle or later in the afternoon of the day of the burn; it is these conditions of higher surface fuel moisture combined with a damp or moist profile that are required for successful burning in regrowth forests.

Temperature, and in particular relative humidity, must be measured prior to conducting any burn to determine that these parameters are within prescription and they should continue to be monitored during the burn because of their close relationship with fuel moisture content (Luke and McArthur 1978). In particular, a sudden drop in relative humidity will indicate an impending decrease in fuel moisture content and hence should alert the supervising officer to an imminent increase in fuel flammability and fire behaviour.

Preparing mineral earth control lines prior to conducting burning operations is standard practice within DCE. Wider control lines should be constructed to facilitate effective edge control in fuel types with elevated shrub fuels, which cause higher flame heights, and with "stringybark" eucalypts, which cause spotting, than in other, less hazardous, fuel types. Further strengthening of these control lines is required when stags are located adjacent to the burn boundary. These stags are found commonly in regrowth forests, ignite easily, burn for a long time and are a major source of spot fires. Based on the experience gained at other experimental burns, the felling of the stags within 10 m of control lines is recommended.

Lighting technique along road and track boundaries must be given particular care, because the fuels adjacent to these boundaries are often more exposed and hence drier than fuels within the stand. Widely spaced point ignition, as successfully used at this burn, and located at least 50m apart, is recommended. This technique takes longer to establish a continuous burnt edge than the commonly used line technique of ignition, but achieves the result with lower fire intensity and less damage. An alternative is to conduct a two stage operation beginning during the previous winter or late autumn, when fuels within the stand are too wet to burn and edge fuels are just dry enough to burn, using the line ignition technique.

Lighting technique within the stand is also critically important and must involve a planned grid system of spot fires. McArthur (1962) introduced this systematic lighting technique which ensures that, provided fires are ignited under suitable weather and fuel moisture conditions, higher fire intensities are restricted to the area burnt by the head fire[1] and junction zones. At this study site, about one-third of the site had unacceptable levels of crown scorch, but, as a consequence of the lighting technique, about two thirds of the site was burnt at intensities of between 50 and 250 kW/m with acceptable levels of scorch. Use of the spot ignition technique is essential for successful fuel reduction burning in regrowth stands.

Selecting the spacing of fire ignitions is a factor controlled by the burning conditions, fuel type and topography (McArthur 1962) and by the available burn out time. An intense ignition pattern results in an early burn out, but increases the area that is burnt by higher fire intensities in junction zones, whereas a wider spacing of ignition points decreases the area burnt by junction zones. Importantly, fire behaviour in junction zones can be minimized by planning for the separate fires to meet in the late afternoon or early evening when fuel moisture content is rising.

Planning the ignition pattern requires that the rate of spread be both predicted and observed. In Western Australia, rate of spread in the major commercial forest types can be predicted using detailed fire behaviour models (Sneewwjagt and Peet 1985). However, in Victoria, the fire behaviour guidelines for fuel reduction burning contained in both Leaflet 80 (McArthur 1962) and the Control Burning Meter Mk2 (FCV 1970) have not been metricated and are no longer used directly in DCE field operations. Prior to lighting a fuel reduction burn, and in the absence of such guides, a rate of spread on level ground should be predicted using the McArthur forest fire danger meter (with a clear understanding that a high degree of precision should not be expected and that the meter is more generally used to determine broad fuel reduction burning conditions) and then verified by lighting a test burn. The test burn should be allowed to spread for at least 20 minutes, and then the distance of fire spread measured over the next 20 minutes and converted to an estimate of rate of spread in units of meters per hour. If the fire exceeds the maximum prescribed rate of spread, then the fire should be extinguished and burning plans either delayed or cancelled.

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1 Assuming low wind speed and flat terrain, the area burnt by the head fire of a single spot fire is about one-third of the burnt area. In comparison, the area burnt by the head fire of closely spaced spots or of a continuous line of fire is about five sixths of the burnt area. (Forestry Commission, Tasmania 1984).

Head fire rate of spread can then be used to plan the spacing of point ignitions. For a grid of point ignitions lit in strips across the wind direction, the distance between strips should equal, as recommended by Sneeuwjagt and Peet (1985), the hours of burning time available multiplied by the rate of spread (corrected for slope using the slope factors identified by McArthur (1962)). Sneeuwjagt and Peet (1985) recommend that the distance between ignition points be half of the distance between strips. However, in the regrowth forests of East Gippsland, to accommodate varying topography and possible changes in wind direction during the burn, as occurred at the study site and which commonly occur because of the effects of a sea breeze, reducing the number of ignitions by using a square ignition pattern is recommended.

Slope must be considered carefully when planning the ignition pattern of a fuel reduction burn in regrowth forest. Although slope was not a significant factor at the study site, a 10° slope will double rate of spread and a 20° slope will increase rate of spread fourfold (McArthur 1962, Luke and McArthur 1978). In general, but depending on the actual rate of spread on level ground, fires should not be ignited to burn uphill on slopes greater than about 10°. Rather, fires should be ignited to burn down or across these steeper slopes.

Igniting fuels by hand away from tracks is a physically demanding and potentially hazardous practice in many East Gippsland forests where the shrub fuel arrangement impedes progress and limits visibility. Constructing rough walking tracks with a D3 bulldozer, as demonstrated at the study site, can successfully solve this problem. However, as the alignment and distance between strip lines is then pre-set, light up time must be varied to ensure the desired burn-out time. Aerial ignition may offer the prospect of fuel reducing larger areas of regrowth forest at a lower cost per hectare than can be achieved with ground crews. However, this may depend on fuel type as other experience gained in burning Wiregrass fuels suggests that aerial incendiaries may not achieve a high rate of successful ignition at the higher conditions of fuel moisuture content which are required to obtain very low intensity fire behaviour in these fuels. The Aerial Drip Torch[1], subject to further development of the ignition timing system, may offer potential to overcome this problem. In either case, both cost effectiveness and close control of the ignition pattern are required.

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1 An ignition system designed to dispense gelled petroleum in large droplet form for lighting fires for a variety of forest management objectives.

Potential damage from fire to the cambium of regrowth trees during autumn when coarse fuels are often still dry, and the subsequent entry of wood decay fungi and wood destroying insects into the stems, is of major concern to forest managers. However, the level of stem damage measured at the study site was much lower than the unacceptable levels of 25 to 50% which were measured by Cheney et. al. (1990) and Buckley and Corkish (1991) in some regrowth stands where "slash" fuels had been fuel reduced following thinning. The major source of stem damage identified in this study and also in the studies following the thinning and burning of slash, was the burning old log debris. In East Gippsland, large volumes of un-merchantable stem and branch material, which can average between 159 and 235 t/ha (Buckley and Corkish 1991), remain in regrowth stands regenerated following sawlog-only harvesting. The Byram Keetch Drought Index (Keetch and Byram 1968), which is a measure of the seasonal dryness of the soil profile and of these logs and hence is also a measure of the potential of these logs to ignite and continue to burn, was high at the time of this burn and significant damage from this source could have been expected. The actual level of stem damage was encouragingly low, particularly as operational burning in unthinned regrowth forests in East Gippsland will be largely confined to these autumn months, when seasonal weather conditions are more favourable, rather than to spring. However, the results of this burn need to be combined with the stem damage results from other experimental burns, conducted under both similar and different seasonal conditions, before the overall potential of fuel reduction burning of low intensity to damage regrowth stems in unthinned stands can be reliably assessed.

Operational burning in regrowth forests should aim to achieve levels of burn coverage as recommended by Sneeuwjagt (1981), Underwood *et al.* (1985) and Buckley (1990) of 60 to 80%, to be effective against subsequent wildfires. Burn coverage under the prevailing wind conditions is primarily affected by the range within the burn area of fuel moisture content above and below the level where fires self extinguish. This is determined by the variation in aspect, slope, fuel type and forest cover. Although not the case at the study site, aspect and slope both vary widely in many of the regrowth forests of East Gippsland and, consequently, fuel moisture content will often vary considerably within burning units and burn coverage will often be less than desirable. If coverage of less than about 50% is achieved, a second stage burn should be planned and conducted.

Due to increased monitoring and detailed lighting patterns, resource requirements in both the planning and operational phases will be higher compared with operations conducted in old growth forests. Costs of burning ($/ha) will be higher and productivity (ha/h) lower. These additional resources will be required to be allocated to achieve the aims of maximizing hazard reduction and minimizing stem and crown damage.

CONCLUSION

A fuel reduction burn was successfully conducted in the stand of 16 year-old regrowth at the study site, although levels of upper crown scorch were higher than desirable. Achieving good coverage without causing unacceptable damage is possible but depends on appropriate site appraisal and careful planning and implementation. By combining good burning practice with appropriate prescriptions covering stand characteristics, weather, fuel moisture content and fire behaviour, fuel reduction burning in the regrowth forests of south east Australia can significantly improve fuel management and consequently can increase the protection of these important forests from wildfire.

ACKNOWLEDGEMENTS

The critical comments and suggestions on the contents of this report by Andrew Wilson, Senior Fire Research Officer, Peter Billing, Fire Operations Officer and Kevin Tolhurst, Fire Effects Research Officer are gratefully acknowledged.

I wish to thank the following DCE staff who have ably assisted with field aspects of this study: Greg Larkins, Operations Area Supervisor, Darrin McKenzie, Planning Officer, Technical Assistants Joe Stephens and Wayne Long and crew members Adrian Bambrook, Phillip Mills, Gordon Holloway, Peter Brunton, Kate Sandy, Ken Judd and Craig Dorrier.

Grateful thanks are also extended to Word Processing Officers Leoni Warren, Irene Gwizdek and Linda Ingham for the word processing and to Alicia McShane, Draughting Officer, for draughting the maps and diagrams in this report.

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