# Behaviour and Short Term Effects of Two Fires in Regenerated Karri (*Eucalyptus diversicolor*) Forest

by W.L. McCaw

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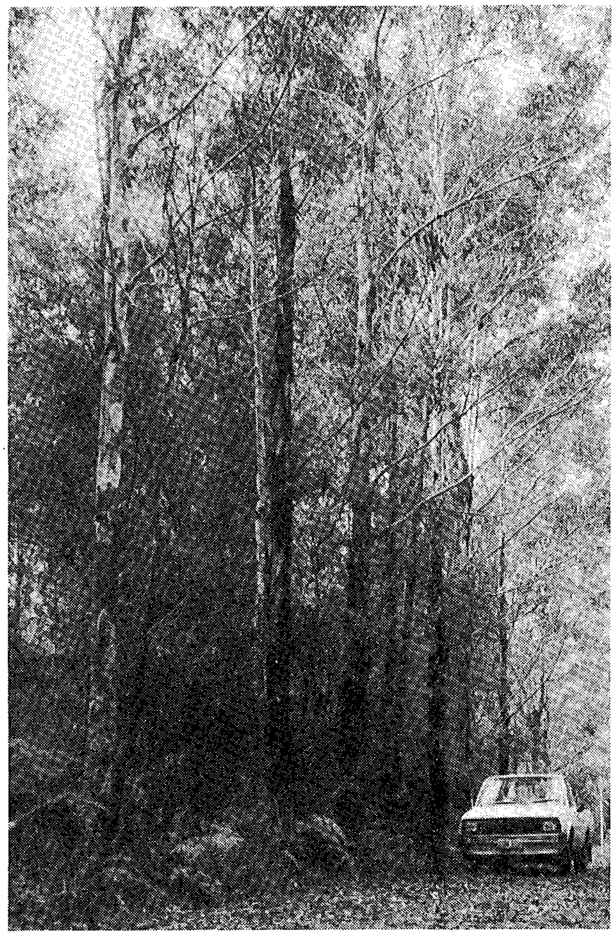

Karri forest regenerated in 1972 following clearfelling with seed trees, now 12 years old. Codominant trees are 20-22 m tall. This stand is on a high quality site in Warren Block.

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BEHAVIOUR AND SHORT TERM EFFECTS OF TWO FIRES IN REGENERATED KARRI (*Eucalyptus diversicolor*) FOREST

by

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## SUMMARY

Two 30-ha areas of regenerated karri forest (aged 12 and 15 years) were burnt in February 1985 as part of a program to examine the behaviour and effects of fire in young stands. Collapsed thickets of dead *Acacia urophylla* were a major component of the fuel at both sites.

Wide ignition spacing and stable evening weather conditions resulted in low fire intensities (<350 $kW.m^{-1}$) with scorch heights below 15 m. However, higher fire intensities (estimated up to 1500 $kW.m^{-1}$) rapidly developed under the influence of slope, wind and close ignition spacing, even in relatively moist fuels (15 per cent moisture content). Fire intensities above 600 $kW.m^{-1}$ fully scorched the codominant trees and caused some localised defoliation. Plots have been established to monitor tree damage and growth following each fire.

Guidelines for operational burning developed from this study have been successfully used to prescribe low intensity fires in several other stands of young regrowth.

# INTRODUCTION

Fire is excluded from regenerated karri (*Eucalyptus diversicolor*) forest until the young trees have developed sufficient height and bark thickness to withstand an initial burn of low intensity. On most sites karri regrowth will require protection from fire for at least 15 years. It is anticipated that regrowth stands older than 15 years will be progressively incorporated into the program of fuel reduction burning currently undertaken in the southern forests (Bradshaw and Lush 1981).

A research program was commenced in 1981 with the aims of:

(1) determining conditions of fuel and weather suitable for prescribing low intensity fires to remove ground fuel in young karri regrowth; and

(2) determining the impact of low intensity fire on the future growth and productivity of young stands.

Operational trials are an important facet of this research program as they provide opportunity to evaluate burning guidelines developed from small plot experiments and to examine the effect of slope, lighting technique and other scale factors on fire behaviour. Fire control personnel can also gain valuable experience through early involvement in the application of research findings.

Regrowth forest was burnt experimentally during the 1984-85 season at two sites south of Pemberton (Fig. 1):

(1) 12-year-old regrowth (regenerated 1972) at Curo Road, Warren Block (see title page); and

(2) 15-year-old regrowth (regenerated 1969) at Crowea Road, Crowea Block.



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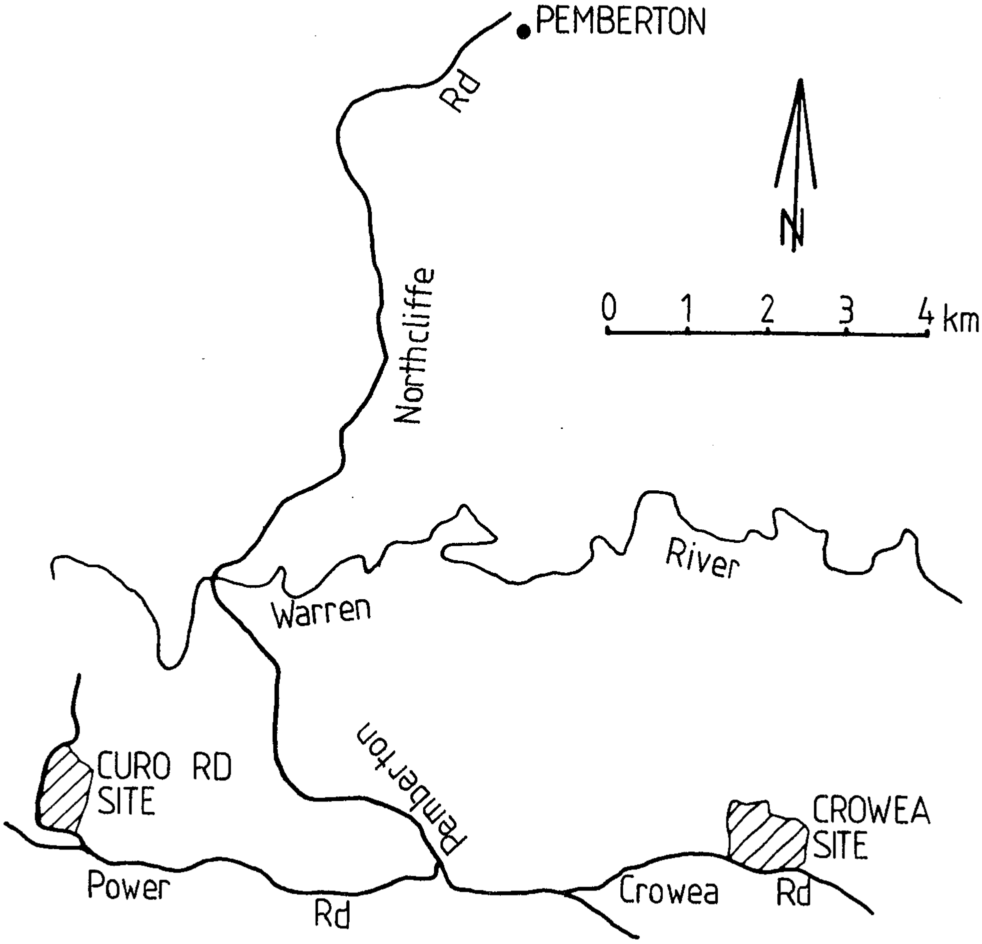



Figure 1: General locality map showing the two experimental sites.

The regrowth at both sites is predominantly even-aged, having been established from retained seed trees following logging and slash burning (White and Underwood 1974). These sites were selected for the study because of suitable shape, good access, uniform fuel type and advanced tree development. Each site was about 30 ha in area.

This report describes the behaviour and short term effects of each fire, and discusses factors that should be considered when prescribing fires in regenerated stands.

## METHODS

The silvicultural characteristics of each stand were sampled systematically in September 1984 at points on a 100 x 100 m grid (Curo Rd n = 29 points, Crowea Rd n = 30 points). The diameters of all trees ⩾ 5 cm dbhob within 5 m radius of each point were measured and used to calculate stocking and basal area. Pre-burn fuel weights were sampled at eight locations at Curo Rd and four locations at Crowea Rd, selected to represent the range of fuel conditions in each stand. At each location litter fuel was collected down to mineral earth on five 0.04 $m^2$ quadrats. Trash fuel, comprising aerated dead woody material up to 25 mm diameter, was collected on a 2.5 $m^2$ quadrat to 0.6 m height above ground. This intensity of fuel sampling was considered adequate for the study as the fuel characteristics of young regrowth have already been studied in detail (McCaw, in prep.). In the month prior to burning, litter fuel samples were collected daily at about 1500 hours and subsequently oven-dried to determine moisture content. Daily forecasts of maximum temperature, minimum relative humidity, and the strength and direction of winds were used, together with measured fuel moisture content, to select suitable days for burning.

During each fire temperature, relative humidity (RH) and wind speed at 1.5 m above ground were measured in adjacent forest of similar height and canopy density to that being burnt. Temperature, RH, and wind speed at 30 m above ground were also measured in a nearby open area. At the beginning and end of each fire samples of surface litter, profile litter and trash (Sneeuwjagt and Peet 1976) were collected for oven-dry moisture determination, and additional samples of surface litter were collected at hourly intervals during each fire. At the Crowea fire the moisture uptake of baskets of litter was determined by hourly weighing, in order to overcome the variability inherent in random samples taken from the litter bed. Ground observers estimated flame height, flame angle and fire spread rate, but estimates of fire behaviour were generally confined to the perimeter of each area because of safety considerations. Fire intensity (Byram 1959) was calculated from the known range of fuel weight and observed spread rates.

Colour air photographs of each site were taken at 1:2500 scale one month before, and about one month after burning. Post-burn photography was used to measure crown scorch and identify unburnt areas of fuel. Two months after burning, plots to monitor tree damage and recovery were established at each site in uniform regrowth where the codominant trees had been:

(1) defoliated (only at Curo Road);
(2) scorched to full tree height;
(3) less than fully scorched.

Control plots were also established in adjacent regrowth forest from which fire had been excluded.

Each plot contained at least 30 trees greater than 10 cm diameter for which the following characteristics were recorded:

(1) height and extent (per cent) of crown scorch;
(2) stem diameter (over bark) at 0.5 and 1.3 m;
(3) bark thickness at 0.5 and 1.3 m;
(4) existing stem defects.

The heights of the two tallest trees in each plot were measured with a clinometer, and used as a reference for estimating the heights of the remaining trees. Unburnt fuel and fresh litter were collected separately from ten 0.04 $m^2$ quadrats in each plot. Plots will be remeasured annually for the next five years to examine tree damage and growth.

## COMPARISON OF SITE AND STAND CHARACTERISTICS

Despite the three-year (20 per cent approx.) difference in age the stand at Crowea Rd was only slightly taller (1 m) and more advanced in basal area (10 per cent approx.) than the stand at Curo Rd (Table 1). At Crowea Rd there were almost twice as many stems/ha ⩾ 5 cm dbh as at Curo Rd, but a similar stocking of stems/ha ⩾ 20 cm dbh. Many of the additional stems in the stand at Crowea Rd were in the sub-dominant and suppressed crown classes and would not be considered potential crop trees.

Table 1 STAND AND FUEL CHARACTERISTICS OF REGENERATED KARRI FOREST PRIOR TO BURNING. STANDARD ERRORS OF MEANS ARE SHOWN IN PARENTHESIS.

| Site | Age (yr) | Codominant Height Range (m) | Basal Area ($m^2.ha^{-1}$) | Stems/ha | | Fuel Weight ($t.ha^{-1}$) | | |
|---|---|---|---|---|---|---|---|---|
| | | | | 5 cm dbh | 20 cm dbh | Litter | Trash | Total |
| Curo Rd | 12 | 20-22 | 20.2 (2.5) | 965 (152) | 213 (45) | 11.2 (0.9) | 12.2 (2.9) | 23.4 (3.8) |
| Crowea Rd | 15 | 21-23 | 22.1 (2.8) | 1702 (203) | 203 (37) | 15.3 (0.5) | 14.0 (1.9) | 29.3 (2.1) |

*Acacia urophylla* had been the dominant understorey species at both sites following regeneration burning, but the thickets of this species had collapsed and been incorporated into the trash fuel layer (Fig. 3). At the time of burning the live understorey consisted mainly of scattered hazel (*Trymalium spathulatum*) 6-10 m tall, which tended to occur in greater density on areas where the soil had been extensively disturbed during logging. There was a band of rushes (*Lepidosperma* sp.) 20-50 m wide in a gully on the western side of the Curo Rd site.

The fuels at each site were composed of roughly equal proportions (by weight) of litter and trash, but the total fuel weight at Crowea was about 6 $t.ha^{-1}$ greater than that at Curo Rd (see Table 1).

Both sites were located on broad ridges with average slopes of 2-3°, but Curo Rd site had a narrow gully on the western side flanked by slopes of 6-8°.

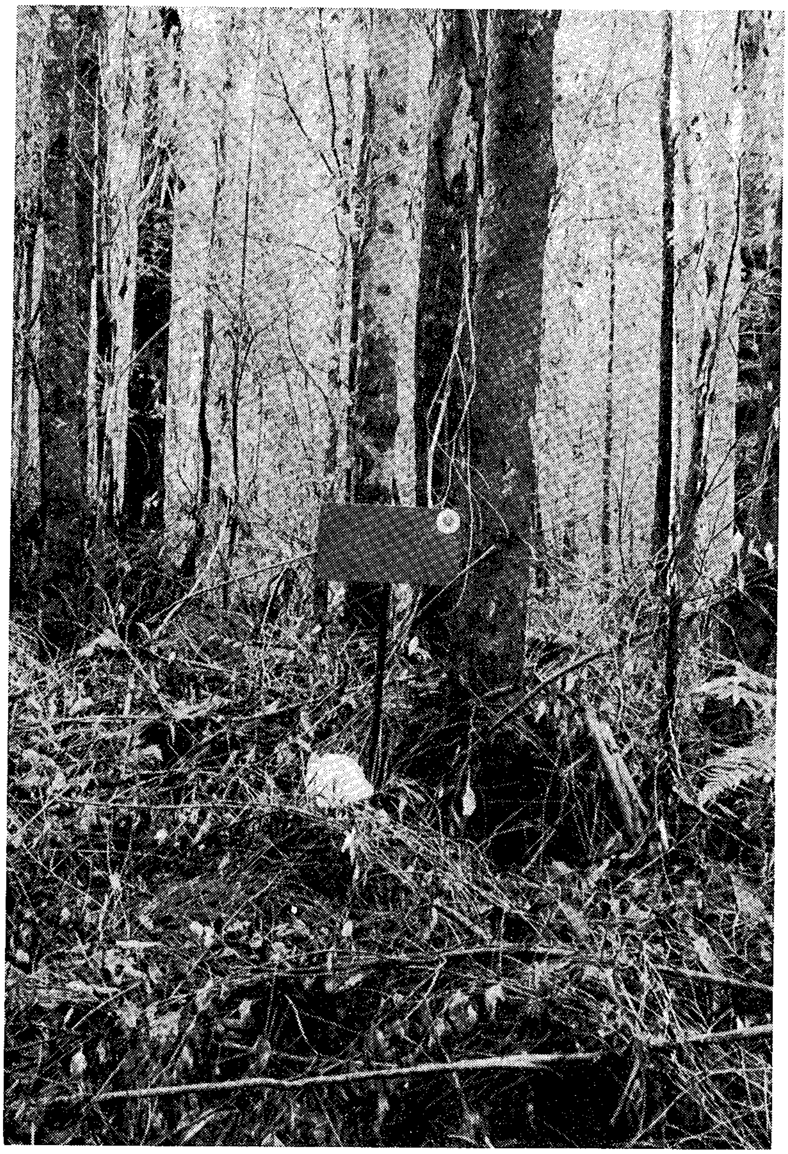


Figure 3: Heavy fuel (25-30 $t.ha^{-1}$) composed of dead *Acacia* scrub and small karri branches in 12-year-old regrowth. Heavy fuels such as this are associated with areas of the stand where the basal area exceeds 30 $m^2.ha^{-1}$.

## THE CURO ROAD FIRE

### Prescription for Burning

The conditions of fuel moisture and weather prescribed for the fire were based on results obtained from burning small (0.5 ha) experimental plots of karri regrowth, and on operational experience of fire in mature karri forest. The aim was to prescribe the mildest conditions that could be expected to result in a relatively complete burnout, with at least 80 per cent of the area burnt during the first lighting (Table 2).

It was considered desirable to proceed with initial lighting as soon as litter fuels became dry enough to burn, in order to minimise the potential for ignition of large logs which, once alight, may cause considerable damage to individual trees through prolonged heating. Studies of fuel moisture in regrowth stands (McCaw, unpublished data) have shown that litter fuels in regrowth will not generally be available for burning until the Soil Dryness Index (Mount 1972) exceeds 800.

As the area was to be lit by ground crews it was necessary to clearly mark walking paths prior to ignition. Seven lines were established at 100-m intervals oriented east-west across the site. The position of the lines dictated the spacing and direction of lighting strips leaving the distance between spot fires to be adjusted according to prevailing conditions on the day of the burn.

Several lightings attempted in January and early February were largely unsuccessful because of damp fuels.

**Table 2** PRESCRIBED AND ACTUAL CONDITIONS DURING FIRES AT CURO ROAD AND CROWEA ROAD.

| Site | Operation | Fuel Moisture (a) (%) | | | Wind | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Surface Litter | Profile Litter | Trash | Direction | Strength ($km.h^{-1}$) | Fire Danger Index (b) ($m.h^{-1}$) | Soil Dryness Index (mm x 10) | Comment |
| Curo Rd | Initial Prescription | 16-18 | 20-30 | 12-18 | SW-SE | 15-20 | 20-24 | 600-800 | Monitor fuel moisture and aim to burn at lowest possible value of Soil Dryness Index. |
| | Burning Conditions on 6.2.85 | 15 | 30 | 12 | E | 20-25 | 43 | 966 | Lit at 100 x 50 m commencing at 1430 hours. |
| Crowea Rd | Initial Prescription | 12-14 | 20-30 | 12-15 | SE | <15 | 24-28 | 1000-1200 | Prescription drawn up based on experience at Curo Road. |
| | Burning Conditions on 13.2.85 | 11 | 18 | 13 | SE | <20 | 40 | 1151 | Ignited at 150 x 100 m commencing 1630 hours. |

(a) Minimum level of fuel moisture during burn determined from oven-dry samples.
(b) Calculated fron Sneeuwjagt and Peet (1976) using minimum fuel moisture and maximum average wind speed, and corrected for average slope.

Details of Burning (On 6 February 1985)

Lighting

The spacing of ignition spots along the walking lanes was set at a 50-m interval on the basis of measured fuel moisture content and the observed spread rates of several test fires. This resulted in a lighting pattern of 100 x 50 m, with burnout expected after 2-2.5 hours. Lighting commenced at 1430 hours with crews working in echelon formation against the prevailing easterly wind and was complete by 1520 hours. Spot fires were difficult to ignite and initially slow to spread, reflecting the damp condition of the fuels (see Table 2).

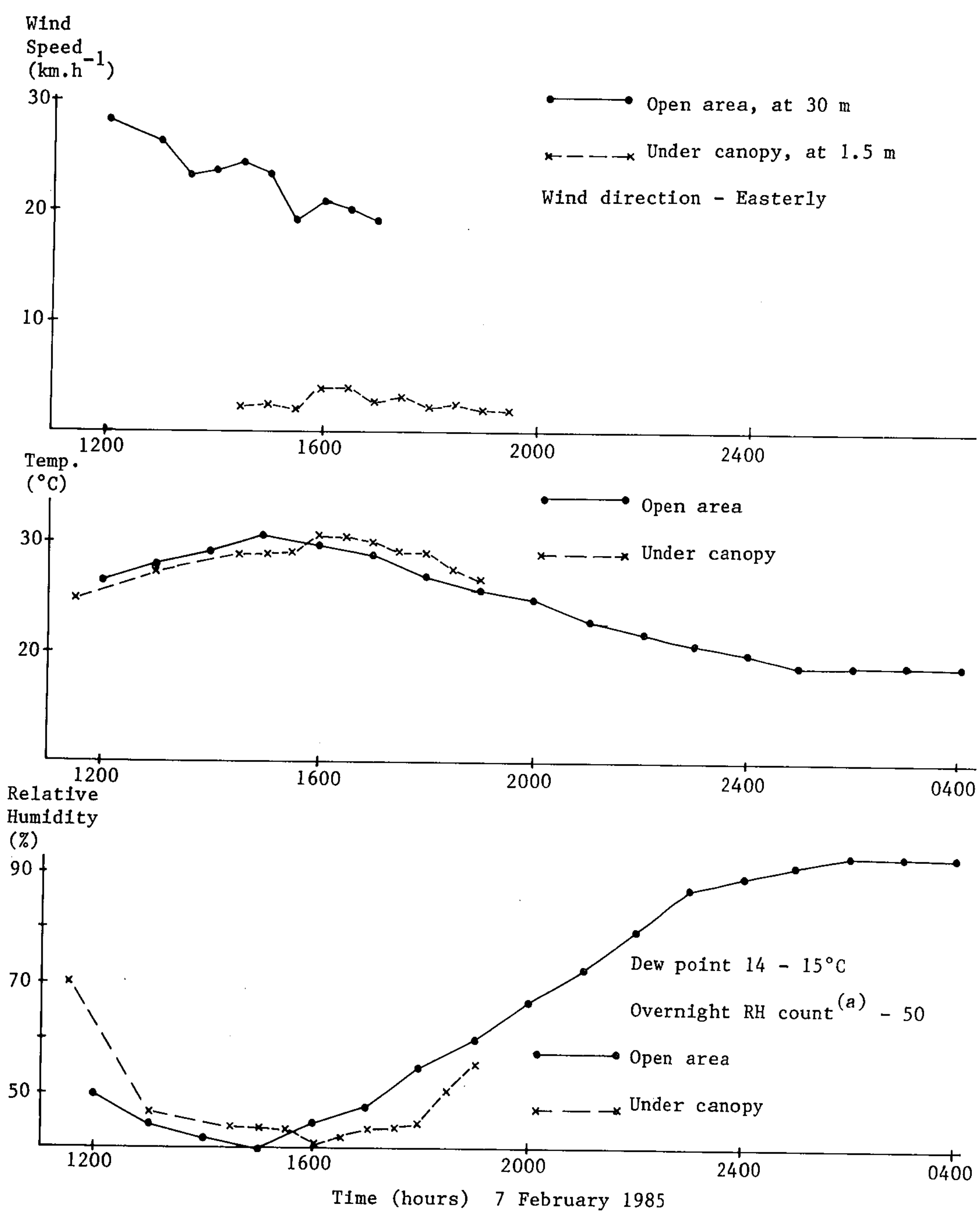
Weather

Maximum temperature (31°C) and minimum RH (40 per cent) were recorded between 1500 and 1530 hours in the open and about an hour later at the weather station in the forest, although the actual values were similar (Fig. 4). Wind speeds beneath the canopy did not exceed 2.5 $km.h^{-1}$ before 1530 hours and were about 1/10 of the 30-m tower wind speed.

Fire Behaviour

Fire intensities were generally low along the northern, eastern and southern boundaries of the burn. In heavy fuels the fires spread at 25-30 $m.h^{-1}$ with flame heights around 1-1.5 m, and fire intensities of up to 400 $kW.m^{-1}$ but fire intensities were correspondingly lower in lighter fuels. Fire fronts were observed to link 1.5-2 hours after ignition.

However, fire intensities were considerably greater on the western side of the burn. Violent fire behaviour developed at about 1540 hours from several spots ignited in the dense rushes along the gully. The spots rapidly joined to form a distinct front burning eastwards up an 8° slope above the gully towards the broad top of the ridge. Flames were estimated to be 2-4 m high, and spreading at 80-120 $m.h^{-1}$, so that peak fire intensities probably reached about 1700 $kW.m^{-1}$. Flames flared up through standing scrub and into the forest canopy and defoliated trees 20-25 m in height.




(a) Overnight RH count is a cumulative measure of humidity and represents the area enclosed by the overnight RH trace (to 0800 hours) and the 70 per cent RH level (Sneeuwjagt and Peet 1976).

Figure 4: Weather conditions during the Curo Road fire.

Wind speed recorded under the canopy increased to around 4 $km.h^{-1}$ during this time although tower wind speeds were generally constant. The weather station was directly opposite the most intense section of the fire and the elevated wind speeds were almost certainly due to convective indraught by the fire. The strong convective winds escalated the spread of spot fires on adjacent lines with the result that 7-8 ha on the western side of the block was largely burnt-out by 1600 hours. Average spread rates would therefore have exceeded 50 $m.h^{-1}$ with associated fire intensities of about 600 $kW.m^{-1}$ or greater.

A dense plume of black smoke was blown directly westwards at height of 200-300 m across 12-year-old regrowth similar to that in the study area. At 1600 hours the Pemberton spotter aircraft reported three ground fires and a large stag tree* alight west of Curo Road. Hopover fires were burning at 25-30 $m.h^{-1}$ and with similar fire behaviour to that observed in the quieter areas of the main burn, despite heavy fuels, slopes of 8-10° and an easterly aspect exposed to the prevailing wind. Crews constructed about 400 m of fire line that night using hand tools, and the 7 ha hopover fire was contained with a bulldozer the following morning. The fire spread at an average rate of 10-15 $m.h^{-1}$ overnight but did not cross the 1-m wide hand-raked trail. Mopping up continued for the next two days.

## Short Term Fire Effects

Scorch heights were generally low around the perimeter of the main burn and about 60 per cent of the area was not scorched to the full height of the codominant trees (Fig. 5). The section on the western boundary which had experienced fire intensities above 600 $kW.m^{-1}$ was fully scorched and had been defoliated in several patches of up to 0.5 ha. Scorch heights were generally below 15 m in the area burnt overnight in the hopover fire.

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*. Dead tree emergent above the general level of the canopy.

Litter and trash fuels burnt away to leave a fine white ash and only a small quantity of charred duff (0.2-1.0 $t.ha^{-1}$), even where fire intensity had been low. Several patches of up to about 1 ha in area remained unburnt, probably because the fire had been unable to carry across light fuels on old disturbed areas.

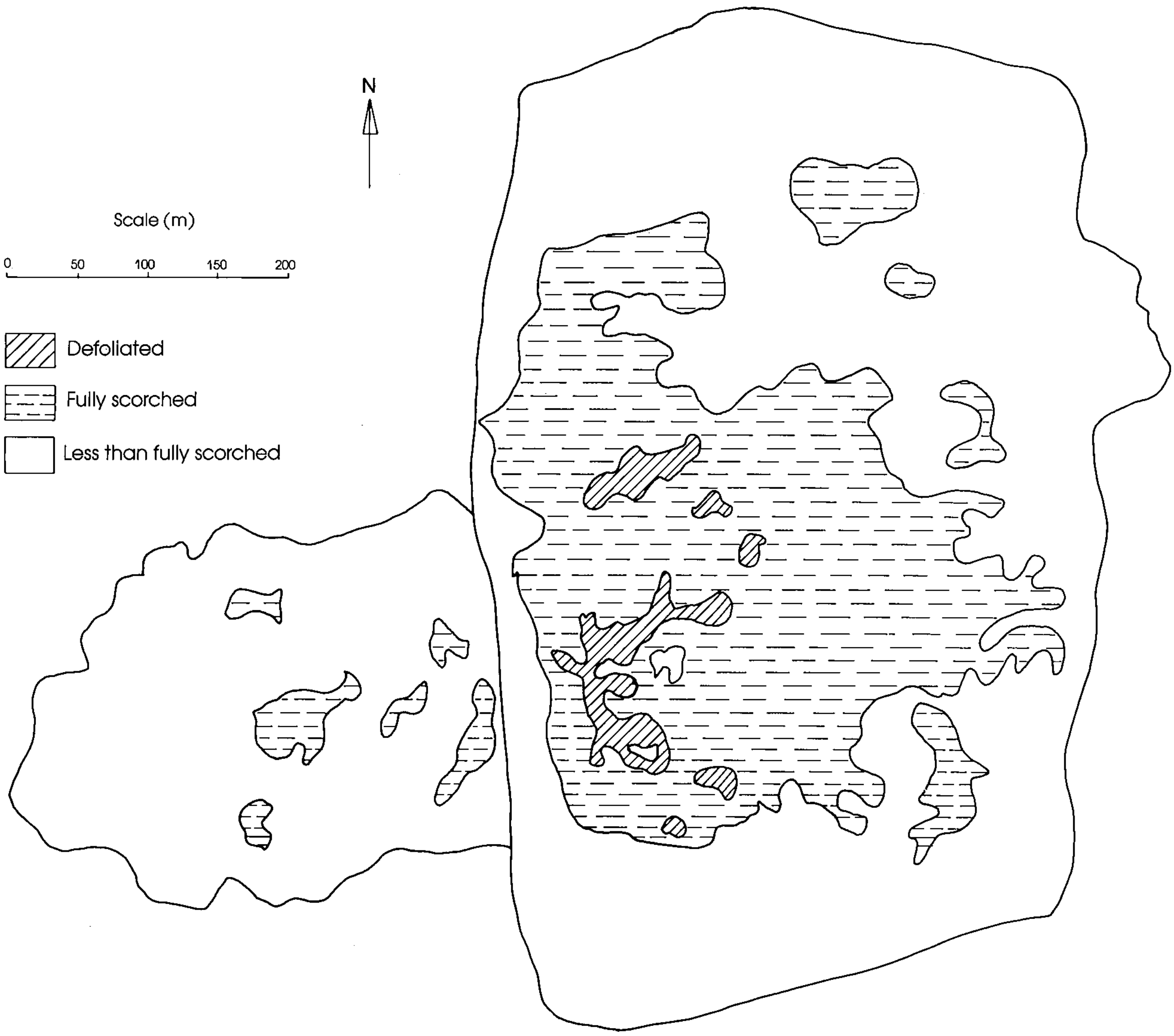


Figure 5: Crown scorch patterns in the main burn and hopover fire area at Curo Road, mapped from aerial photographs.

## THE CROWEA ROAD FIRE

### Prescription for Burning

The prescription employed at Crowea Road aimed to duplicate the stable, low intensity fire behaviour observed during the late evening and night at Curo Road. Key features of the prescription were:

(1) dry fuels to facilitate good ignition and promote fire spread across light fuels;
(2) low wind speeds;
(3) wide ignition spacing to minimise interaction between spot fires;
(4) falling Fire Danger Index (see Table 2).

The burn was to be ignited from aircraft as this allowed greater flexibility in the lighting pattern than that at Curo Road where the orientation and spacing of walking lanes was fixed. Lighting plans were prepared for several directions of prevailing wind utilising combinations of edge lighting and flight lines.

### Details of Burning (on 13 February 1985)

#### Ignition

Ground crews commenced lighting at 1600 hours with spot fires at 100-m intervals along the north western edge according to the predetermined lighting strategy for south-east winds. Lighting continued along the northern boundary and was complete by 1645 hours. At 1630 hours the aircraft dropped incendiaries at 100-m intervals along the two flight lines which were oriented east-west across the burn. The spacing of ignition was about 150 x 100 m on the eastern half of the site but considerably wider (up to 250 x 150 m) in the western half because of the greater distance between flight lines and the failure of several incendiaries.

### Weather Conditions and Fuel Moisture

Maximum temperature and minimum RH were recorded just before 1700 hours and fuel moisture content was at the minimum level for the day when ignition took place (Fig. 6). RH and fuel moisture rose steadily after this time as the temperature fell. Prevailing winds were consistently from the south-east and declined in strength after 1700 hours. Wind speeds in the forest were generally less than 3 $km.h^{-1}$ and the elevated values recorded from 1800-1900 hours were probably caused by fire activity adjacent to the weather station.

Fire Behaviour

Spot fires burnt steadily into the evening with average spread rates of 15-20 $m.h^{-1}$, so that fire intensities would have been about 350 $kW.m^{-1}$ in heavy trash fuels and correspondingly lower in lighter fuels. Fires generally maintained a circular shape because of the low wind speeds beneath the forest canopy. The fire burnt throughout the night despite the humid conditions, but mean spread rates had declined to 12-15 $m.h^{-1}$ by 0500 hours on the following morning. Light drizzle fell sporadically during the night and more substantial rain extinguished any remaining fire by 1200 hours on 14 February 1985. About 85 per cent of the block was burnt-out overnight but an unburnt strip remained along the southern boundary which had not been lit.

Short Term Fire Effects

About 70 per cent of the stand was not scorched above 15 m height and codominant trees in these areas retained at least several metres of green crown. Scorch heights were higher along the northern boundary which burnt before the onset of cooler evening conditions, and where fires had coalesced.

Litter and trash burnt completely and no unburnt duff was collected during the post-burn sampling. The absence of unburnt litter reflects the high Soil Dryness Index at the time of the burn.

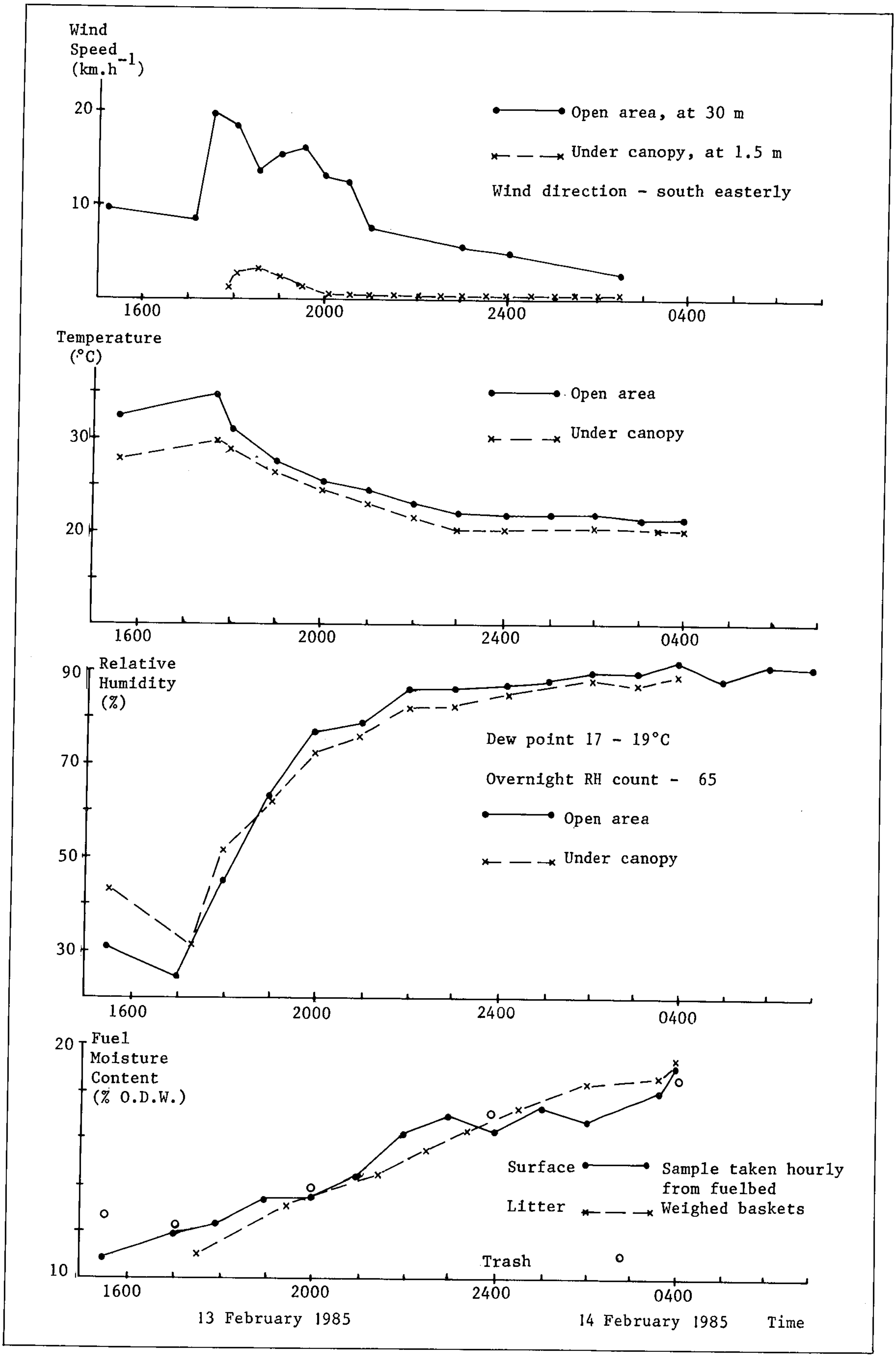


Figure 6: Weather conditions and fuel moisture during the Crowea Road fire.

## DISCUSSION

### Fuel Moisture

The fuels in the regrowth at both sites were slow to dry and had similar characteristics to those found in the wetter types of mature karri forest. This finding is in agreement with a more comprehensive study of fuel moisture regimes made in several regrowth stands (McCaw, unpublished data). Predictions of moisture content for fuel types 1 and 2 in mature karri forest (Sneeuwjagt and Peet 1976) can be used as a guide for many regrowth stands 10-20 years old. Local variation in forest type should be taken into account as mixed marri/karri regrowth may have an open understorey that will dry more rapidly than the dense scrub characteristic of better karri sites. Further work is also needed to predict fire behaviour in stands with an understorey of rush species (*Lepidosperma* sp.) that may burn readily at high moisture content. This fuel type is common in karri forest types found close to the coast.

Fuel moisture contents of 15 per cent or below were required for satisfactory ignition. However, once alight, trashy fuels burnt steadily up to a moisture content of 19 per cent even when the prevailing conditions were humid. Conditions of low but increasing fuel moisture are characteristic of the early evening after a warm dry day. The fact that winds generally stabilise and decline in strength at this time of day will further promote stable fire behaviour. Rising RH and falling temperature also helps to minimise crown scorch heights.

### Wind Speed

The dense canopy of regrowth forest restricts the penetration of wind into the stand. The ratio of wind speed in the open (at 30 m) to wind speed in the forest (at 1.5 m) was generally in the range 8:1 to 10:1 at both sites, but natural gaps in the canopy and combustion of low scrub during a fire would encourage greater wind penetration into the stand, which could increase fire intensity. Low wind speeds are important if stable, low intensity fire behaviour is to be maintained in heavy fuels. At wind speeds of less than about 2.5 $km.h^{-1}$ (measured at 1.5 m) flames were observed to backburn with the result that the fuel bed was not preheated in advance of the fire. Therefore, burning in regrowth forest should be restricted to conditions were the prevailing winds do not exceed 20 $km.h^{-1}$ (measured in the open at 30 m).

The strong easterly winds during the burn at Curo Road are unlikely to have been directly responsible for the initial development of the intense fire behaviour. In fact the main fire front developed on a sheltered, westerly aspect and spread uphill against the prevailing wind. However, it is possible that turbulence created by the strong winds blowing across the ridge may have created a localised wind in the gully on the western aspect, possibly blowing at a different direction to the prevailing easterly stream. The strong prevailing wind would have increased the distance for which burning material was carried into the adjacent forest.

Fire Behaviour and Lighting Pattern

Current fire behaviour tables for mature karri forest predict the spread rate of a fire according to the available fuel load, fuel moisture, wind speed and slope. Predictions of fire behaviour made for regrowth with similar fuel characteristics and wind profiles to mature karri forest should therefore be reasonably accurate. This generally proved to be the case for low intensity fires and measured spread rates were within about ± 5 $m.h^{-1}$ of the predicted rate for karri type 1 and 2. The accuracy of predictions of fire behaviour at higher intensities could not readily be examined because there were insufficient reliable data.

Lighting pattern has an important effect on fire behaviour, and this is well illustrated by the comparison of fire behaviour between the hopover fires and the main burn at the Curo Road site. The moderate behaviour of the widely spaced (>100 m apart) hopover fires was in direct contrast to the intense fire behaviour on the adjacent section of the main burn despite similar fuel, slope and forest type. The key difference was the rapid development of the large fire front in the rushes along the gully and the subsequent interaction with other nearby spots. This effect would have been reduced if the initial lighting had been more widely spaced and could have been avoided by not lighting directly in the creek.

To minimise the likelihood of flare-ups, the lighting pattern should be as wide as possible consistent with achieving burn-out in the time available.

Fire Suppression

Regrowth stands are characterised by thick scrub, heavy fuels and poor visibility. These factors together make suppression with hand tools difficult even at low fire intensities, and potentially dangerous under more severe conditions. Old snig tracks are the only areas where trails for hand suppression can be constructed rapidly, or where machines can work without causing serious damage to the regrowth. The current program of selecting and marking fire access routes prior to regeneration should be maintained and extended to older regrowth stands. Stag trees ignite readily during dry conditions when regrowth fuels are available for burning. Trees alight around the perimeter of regenerated coupes will require costly mop-up during fire operations, and those that eventually fall may cause considerable damage to the developing stand. These observations provide support for continuation of the current program of stag tree removal in clearfelled forest.

# CONCLUSIONS

The behaviour and effects of fire in regenerated forest need to be well understood before such stands can be burnt confidently as a routine operation. This study has shown that low intensity fires (<350 $kW.m^{-1}$) can be prescribed in regrowth forest where the scrub layer has largely collapsed. Burning conditions and lighting pattern must be carefully selected in order to prevent flare-ups which may damage the trees.

The effects of fire on the growth rate and quality of each stand are being monitored and will be discussed in subsequent publications. Guidelines for operational burning developed from this study have been successfully used to prescribe low intensity fires in 18-year-old regrowth at Weld block, and 16-year-old regrowth at Boorara block. The program of operational burning trials will be continued in subsequent years to evaluate lighting techniques appropriate for larger areas, and for steep slopes.

## ACKNOWLEDGEMENTS

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