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Prescribed burning of thinning slash in regrowth stands of karri (*Eucalyptus diversicolor*) - an operational trial using helicopter ignition

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ABSTRACT

This paper reports on an operational trial that was undertaken to evaluate the use of a helicopter-mounted incendiary machine for igniting thinning slash fuel in a regrowth stand of karri. Twenty hectares of commercially thinned 24-year-old regrowth were burnt according to a prescription developed from a prior experimental study. The burning prescription specified a moderately dry surface litter layer, a moist litter profile (>90 per cent moisture content), light winds, mild air temperatures (<25°C) and moderate relative humidity (>45 per cent). Fuel moisture contents were within the prescribed range during the burn but air temperatures were up to 7°C higher than prescribed and the Soil Dryness Index was above the recommended upper limit. Most thinning slash fuel <25 mm diameter and about half the litter load was consumed, leaving an average loading of unburnt litter residue of 11.4 t ha^{-1}. Fire-caused stem damage affected 78 stems ha^{-1} of retained crop trees while 212 stems ha^{-1} remained undamaged; the basal area of undamaged trees was 14.2 m^{2}ha^{-1}. Overall, the objectives set for fire behaviour, fuel consumption and tree damage were achieved, thereby validating the prescribed burning guidelines developed from the earlier study. The trial clearly demonstrated the effectiveness and flexibility of a helicopter for igniting prescribed fires in thinned regrowth stands.

INTRODUCTION

Thinning of even-aged regrowth stands is an important element of silvicultural practice in the tall open eucalypt forests of south-eastern and south-western Australia (Bradshaw 1985; Goodwin 1990; Kerruish and Rawlins 1991). By concentrating growth on selected trees, thinning provides a means of increasing sawlog yields from young, even-aged stands while at the same time salvaging a considerable volume of wood that would otherwise be lost to competition-induced mortality. In multiple use karri (*Eucalyptus diversicolor*) forests in south-west Western Australia (WA), commercial thinning of regenerated stands may be undertaken once stand top height exceeds 30 m (Bradshaw 1992). For most stands this represents an age of 20 to 30 years, depending on site index (Rayner 1991).

As is the case for all fire-prone forests, effective fire protection is an essential prerequisite for sustained yield management of forests in south-west WA. Strategic buffer zones within the south-west forests are subject to rotational fuel reduction burning to minimize the threat to life, property and forest values from large, uncontrolled fires. Logging and regeneration activities are directed to adjacent areas of forest from which fire is temporarily excluded, with the expectation that prescribed burning will progressively be reintroduced to regrowth stands as they develop to a fire-tolerant stage. Delay in the reintroduction of prescribed burning to regrowth stands will affect the schedule of harvesting in adjacent mature forest and therefore has the potential to disrupt sawlog supply to the timber industry. Accordingly, the development of prescribed burning techniques applicable to regrowth stands, both thinned and unthinned, is a high priority for research.

Following regeneration, fire is routinely excluded from regrowth stands for at least 15 years to allow the dominant and codominant trees to attain the height and bark thickness necessary to tolerate low intensity fire without damage to crowns or stems. Some regrowth stands are burnt prior to first thinning to reduce accumulated litter and woody fuel (McCaw 1986), but currently most stands remain unburnt until after first thinning. Thinning operations contribute additional dead fuel from the crowns and stems of felled trees and understorey shrubs, much of it remaining as elevated fuel in heaps. Consequently, dead fuel loadings in thinned stands are substantial and may amount to 76 t ha^{-1} of material <100 mm diameter (McCaw *et al.* unpublished manuscript). The more open canopy of thinned stands allows increased sunlight and wind penetration into the stand with the result that fuels may be sufficiently dry to carry fire between October and April each year. In contrast, the fire season in unthinned stands is considerably shorter and only extends from December to March in most years (McCaw, unpublished data).

In 1991 the Western Australian Department of Conservation and Land Management commenced a study to examine the feasibility of prescribed burning following thinning of even-aged karri stands. Fire characteristics, fuel consumption and tree damage were investigated by conducting small scale (<2 ha) experimental fires over a range of conditions, and the results of this study used to develop guidelines for prescribed burning (McCaw *et al.* unpublished manuscript). Changes in fuel nitrogen storage as a result of burning were examined in conjunction with the experimental fires (O'Connell and McCaw unpublished manuscript). In forest fire management, there is a need to validate the findings of detailed experimental studies at an operational scale where variation in terrain and stand conditions can influence the outcome of operations. The method and pattern of ignition can also have a profound influence on the behaviour of prescribed fires. The difficult ground conditions typical of regrowth karri stands generally preclude safe and efficient use of manual lighting crews, except along tracks and where walking lanes have been constructed. For this reason, implementation of prescribed burning on an operational scale will necessitate the use of aerial ignition techniques. Even-aged regrowth stands suitable for thinning tend to be dispersed through the forest in relatively small compartments, as logging coupes in karri forest types have seldom exceeded 100-150 ha in area. Helicopters offer great flexibility in lighting pattern and can be used more effectively on small or irregularly shaped compartments than is the case for fixed-wing aircraft. This paper reports on an operational trial that was undertaken to evaluate the use of a helicopter-mounted ignition system for prescribed burning of karri thinning slash, according to the guidelines developed from the prior experimental study.

METHODS

Study Area

Prescribed burning was undertaken in a 20 ha stand of thinned, even-aged karri regrowth in Boorara 13 compartment (34° 42' S 116° 16' E), about 15 km south-east of Northcliffe, WA. This stand was silviculturally regenerated from seed trees following harvesting and high intensity slash burning in 1969, and had subsequently been protected from fire up until the time of prescribed burning in November 1993. During early 1992 the stand was commercially thinned using a tree harvester to remove uncompetitive and poorly-formed trees; wood products removed during thinning included small sawlogs and chipwood down to a small end diameter of 75 mm. Retained trees were mostly dominants and codominants, with occasional veteran trees of large diameter (>2 m diameter at breast height over bark - d.b.h.o.b.) scattered among the regrowth. Stand top height in 1992 was 31 m, corresponding to a site index (Rayner 1991) of 46 m at age 50 years. The stand was situated on a broad ridge with average slopes of about 10° and maximum slopes of 20°. Elevation ranged between 60 m and 100 m above sea level (Fig. 1).

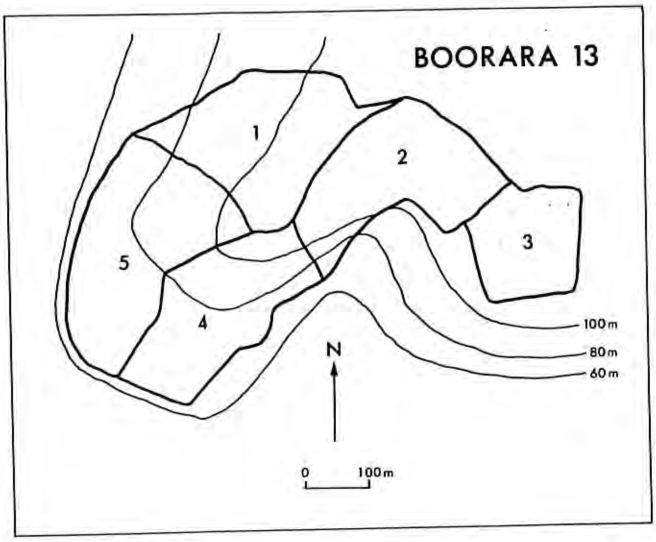

Figure 1. Map showing elevation contours and the layout of burning cells within the stand at Boorara 13.

Prescription for Burning

Weather and fuel moisture conditions prescribed for burning at Boorara 13 were based on the results of experimental fires conducted in a comparable thinned stand at Boorara 2 (Table 1), and are summarized in Table 2. The essential features of the burn prescription were: a moderately dry surface litter layer to ensure good ignition and fire spread between slash heaps; a moist litter profile and low Soil Dryness Index[1] (SDI) (Mount 1972; Burrows 1987) to limit the consumption of deep litter beds and woody fuel >25 mm diameter; light winds; and mild air temperature and relative humidity conditions to minimize the extent of crown scorch to retained trees in the stand. Burning under these conditions was expected to consume a high proportion (>80 per cent) of woody fuel <25 mm diameter and up to 60 per cent of the litter load. Results from the experimental study indicated that some fire-caused damage to retained trees was likely to occur even during low intensity fires, but not affecting more than about 80 stems per ha (stems ha^{-1}).

TABLE 1

Stand characteristics for thinned karri regrowth at Boorara 13 (this study) and at Boorara 2 where the burning prescription was developed.

CHARACTERISTIC	BOORARA 13	BOORARA 2
Site index (age 50)(m)	46	48
Year of regeneration	1969	1969
Age when burnt (years)	24	22
Stocking retained (stems ha^{-1})	328	337
Basal area retained (m^2ha^{-1})	20.8	19.5
Mean tree d.b.h.o.b. (cm)	27	26

[1] The SDI represents the amount of rainfall required to bring the soil back to a saturated condition at field capacity, which for most soils is about 200 mm of available moisture. In this paper SDI values are expressed in millimetres of moisture for consistency with SI units. For use in fire control in Western Australia the SDI is routinely expressed in millimetres x10.

TABLE 2

Prescribed and actual conditions for burning thinning slash at Boorara 13 on 23 and 24 November 1993.

VARIABLE	PRESCRIBED	ACTUAL		
		23 NOV	24 NOV	
		(1700 h)	(1200 h)	(1330 h)
Air temperature (°C)	20-25	21	29	32
Relative humidity (%)	60-45	65	43	34
In-forest wind speed (km h^{-1})	<2.8	<1	2.9	2.9
Wind direction	SE	SE	W	WNW
Fuel moisture content (%)				
-surface litter	12-18	ridge 12 l'slope 17	ridge 14 l'slope 19	(A)
-profile litter	>80	ridge 133 l'slope 97	ridge 98 l'slope 113	- -
Soil Dryness Index (mm)	<40	65	68	

(A) Fuel moisture content not sampled at 1330 hours.

Data Collection

In preparation for prescribed burning the stand was divided into five cells, each about 4 ha in area, separated by bulldozed mineral earth tracks. Stand and fuel characteristics prior to burning were assessed during August 1992 on transects established in each of the burn cells. Sample points were marked at 10 m intervals along transects and d.b.h.o.b. of trees within a 5 m radius of each point measured to the nearest centimetre. Trees were numbered to permit relocation following burning. The location and dimensions of existing stem wounds where the cambium had been damaged were recorded for 348 trees. Logs and other woody debris >20 cm diameter within 2 m of trees were noted. Fuel characteristics in thinned regrowth have previously been described in detail by McCaw *et al.* (unpublished manuscript). As the resources available for field work were limited, fuel assessment was confined to measuring the average depth of thinning slash within a 5 m radius of each sample point, to the nearest 0.2 m, using a calibrated height pole.

Ignition took place over two days (see below). During this time air temperature and relative humidity were recorded with an aspirated hygrometer at intervals of 1 to 2 hours. A sensitive cup anemometer was used to measure the average in-forest wind speed (at 1.5 m height above ground) over these same intervals. Samples of dead leaves and twigs $\leq$6 mm in diameter from the uppermost 10 mm of the litter layer (referred to subsequently as surface litter), and of the entire litter profile above mineral soil were collected from ridge and lower slope positions within the stand on both days. On each occasion three samples (each 30-50 g oven dry weight) were collected, sealed in air-tight tins and subsequently oven dried in the laboratory to determine moisture content. A representative SDI for the study site was calculated using rainfall and air temperature data from Northcliffe with a canopy interception function for mature open karri forest and an appropriate evapotranspiration table from Burrows (1987). Experienced observers recorded fire behaviour characteristics during the burn, including forward rates of spread and flame heights.

The helicopter used during lighting operations was a Bell Jet-Ranger which carried a crew of three (pilot, navigator, and incendiary machine operator). Incendiary capsules were of the 'ping-pong ball' type and were deployed from an incendiary machine mounted within the helicopter cabin.

Two months after prescribed burning, the extent of fuel consumption at each sample point was assessed visually according to the following rating system:

Litter fuel	- partially burnt, with litter residue remaining - completely burnt, with mineral soil exposed
Thinning slash	- thinning slash <25 mm diameter mostly unburnt (Low) - thinning slash <25 mm diameter partially consumed (Moderate) - thinning slash >25 mm diameter substantially consumed (High)

Where present, unburnt litter residue was collected from a 0.04 m^2 quadrat and later oven dried to determine loading in t ha^{-1}. During the same assessment, the height of crown scorch (m) and proportion of crown volume scorched (none, <50 per cent, >50 per cent) at each sample point were estimated visually.

Eleven months after burning, all numbered trees were re-examined and the location and dimensions of additional fire-caused wounds recorded. Where necessary, dead bark was removed with an axe to expose the full extent of dead cambium on the stem.

RESULTS

Fuel Characteristics and Burning Conditions

Fuels within the thinned stand consisted of leaf litter on the forest floor, a layer of elevated thinning slash and crushed understorey scrub, and old log debris left behind from the regeneration cut of 1969. McCaw *et al.* (unpublished manuscript) reported that the mean loading of dead fuel <50 mm diameter over bark in 22-year-old thinned karri regrowth was 62.8 t ha^{-1}, comprising 23.4 t ha^{-1} of litter, 8 t ha^{-1} of bark and wood <6 mm, 13.6 t ha^{-1} of wood 6-25 mm and 17.8 t ha^{-1} of wood 25-50 mm. Live understorey shrubs were not a significant component of the fuel loadings at Boorara 13 or at the stand described by McCaw *et al.* (unpublished manuscript).

Fuel assessment undertaken at the site indicated that about 80 per cent of the ground area was occupied by thinning slash fuel, with the remainder occupied by litter bed fuel or exposed soil on extraction tracks. The fuel bed was ≤0.2 m deep over half the site, and ≤0.6 m deep over 75 per cent of the site (Fig. 2). The maximum depth of thinning slash encountered during sampling was 1.5 m.

In the three weeks prior to burning rainfall was recorded at Northcliffe on 1 November (10.5 mm) and 16 November (3.5 mm). Prescribed burning was conducted over two days, commencing late in the afternoon of 23 November 1993 and continuing the following day. Weather and fuel moisture conditions on 23 November were within the range prescribed for each variable, except for the SDI which at 65 mm exceeded the prescribed upper limit of 40 mm (Table 2). Conditions had been suitable for lighting operations throughout the day but the helicopter was not available earlier because it was engaged in prescribed burning operations elsewhere. Following its arrival at 1700 hours (Western Standard Time) the helicopter dropped incendiary capsules in a grid pattern at an approximate spacing of 30 m x 30 m across the northern third of the stand in the area above the 100 m elevation contour (Fig. 1). Overnight, an area of about 6 ha on the ridge and upper slopes was burnt by low intensity fire with mean flame heights of 0.5 to 0.7 m, and spread rates in the range 12-20 m h^{-1}.

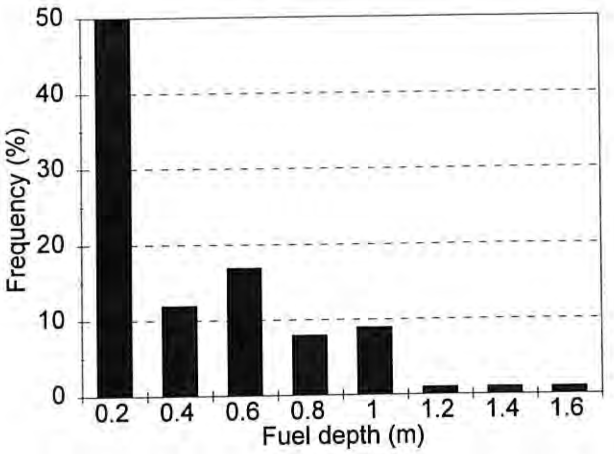

Figure 2. Frequency histogram showing depth of thinning slash fuel at 136 sample points prior to burning. Data from all five cells have been pooled.

On 24 November air temperature at the site exceeded the forecast maximum of 28°C and minimum relative humidity fell below the forecast minimum of 39 per cent, and together with the SDI were outside the prescribed range (Table 2). Conditions were hotter and drier than expected owing to the influence of a low pressure trough which directed dry northerly winds from the interior of WA over the lower south-west of the State. Wind speed and direction were as forecast, with observed wind speeds only marginally above the prescribed range. The decision to continue lighting operations took account of the fact that profile litter moisture content samples taken on the previous day were within the prescribed range and the litter profile would not have dried appreciably overnight. Test fires lit during the morning of 24 November exhibited appropriately mild fire behaviour, consistent with that prescribed. As on the previous afternoon surface litter samples collected from the ridge were substantially drier than those from the lower slope (Table 2); however, in the case of profile litter samples the difference between the moisture content of samples from the ridge and lower slope was not consistent from one day to the next, reflecting the considerable variability in the dryness of the litter profile. From 1200-1220 hours the helicopter lit along the contour about 20 m downslope from the edge of the area that had burnt-out overnight, placing incendiaries at intervals of 50-70 m. Most incendiary capsules succesfully ignited the thinning slash fuel, and the resulting fires tended to develop an elongated elliptical shape owing to the different rates of spread up and down the slope. Flames were typically 0.7-1 m high, but flared up to about 3 m in heaped slash on the edge of the central access track, probably because of the greater exposure of the fine fuels in this area to sunlight and wind. Flames were also prone to flaring in shoots from stump coppice, particularly in Cell 5 which had been thinned some months before the remainder of the area and as a result was densely stocked with coppice shoots up to 3 m tall. Further lighting was undertaken from the helicopter between 1420-1430 hours to fill in several gaps in the ignition pattern, after which it departed from the site. Fires continued to spread throughout the afternoon until the compartment was largely burnt-out by 1800 hours.

Post-fire assessment indicated that 94 per cent of the area had been burnt, with most of the unburnt area concentrated in one patch at the bottom of the easterly facing slope. Of the points that had been burnt, 85 per cent retained a layer of litter residue (Fig. 3a), with the average residue loading being 11.4 t ha^{-1}. The highest proportion of area burnt to mineral soil (28 per cent, Fig. 3a) and the lowest residue loading (8.5 t ha^{-1}) were in Cell 3 which was located on the top of the ridge. Slash consumption was rated as moderate (most slash <25 mm diameter consumed) over about 70 per cent of the area, with consumption rated as low over most of the remainder (Fig. 3b). Consumption of slash did, however, vary between cells, being greatest in Cell 3 and least in Cell 5.

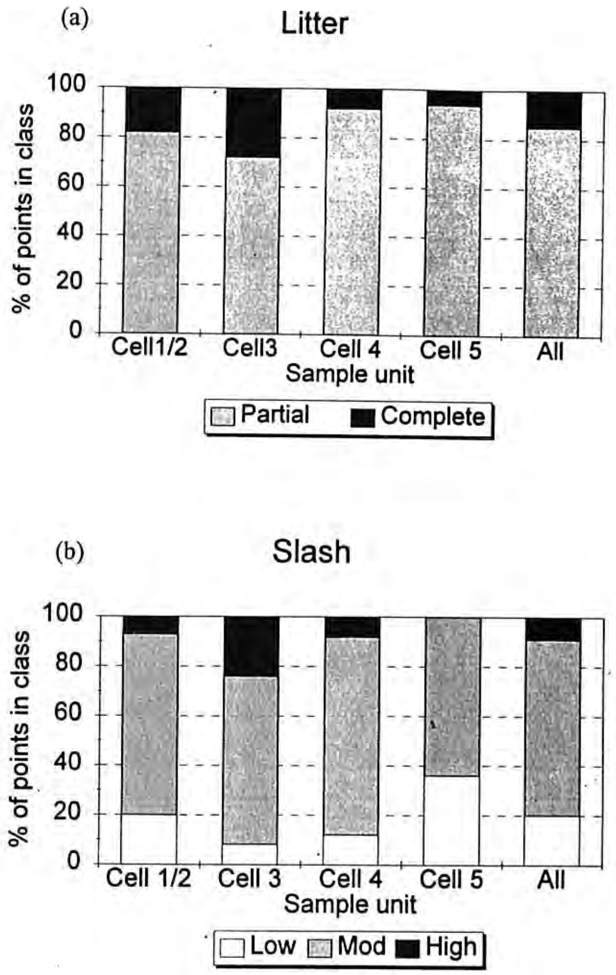

Figure 3. Histograms showing the proportion of sample points from individual cells and the whole site allocated to different fuel consumption rating classes for (a) litter fuel and (b) thinning slash fuel.

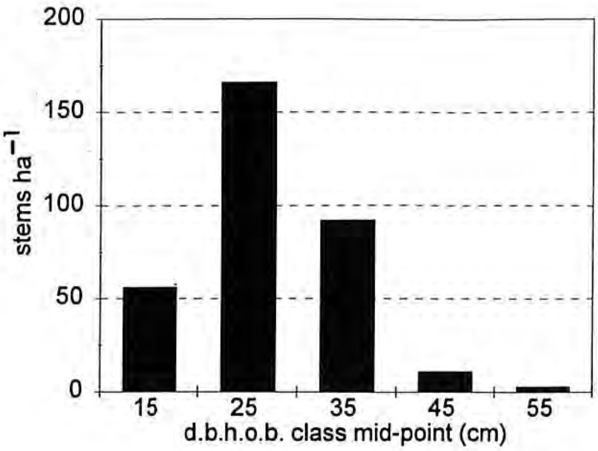

Figure 4. Stocking of trees ≥10 cm d.b.h.o.b. in 10 cm diameter classes (n = 348).

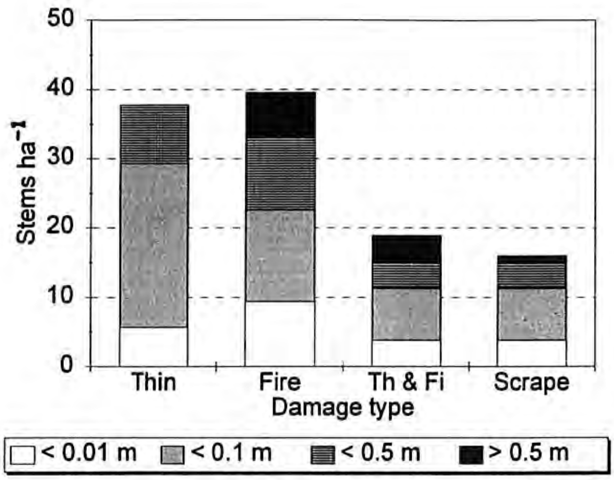

Figure 5. Stocking (stems ha^{-1}) of trees exhibiting stem damage, including only thinning-caused wounds (Thin), only fire-caused wounds (Fire), both thinning and fire-caused wounds (Th & Fi), and wounds associated with superficial bark scraping (Scrape). Data from all cells have been pooled, and columns show the frequency of damaged trees by wound-area class.

Stand Characteristics and Tree Damage

Following thinning, the stand had an average stocking of 328 stems ha^{-1} and a basal area (b.a.) of 20.8 m^2ha^{-1} (Table 1). Most trees were 20-40 cm d.b.h.o.b. (Fig. 4), with mean tree diameter being 27 cm. Stem damage caused by the thinning operation affected 38 stems ha^{-1} (equivalent to a b.a. of 2.4 m^2ha^{-1}), with most wounds between 0.01 m^2 and 0.1 m^2 in area and none exceeding 0.5 m^2 in area (Fig. 5).

Following prescribed burning, crown scorch heights were less than about 15 m over 76 per cent of the burnt area, with the result that the canopy remained unscorched. Twelve per cent of the area experienced scorch to <50 per cent of crown volume, while the remaining 12 per cent of the area was scorched to >50 per cent of crown volume with corresponding scorch heights in excess of 25 m. Crown scorch was concentrated in Cells 3 and 5, and only occasional trees in the other cells were scorched. Eleven months after burning, fire-caused stem wounds were recorded on trees that had no damage prior to burning, as well as on trees that had been damaged during the thinning operation.

About 40 stems ha^{-1} (b.a. = 2.2 m^2ha^{-1}) of previously unaffected trees were damaged by burning, and 19 stems ha^{-1} (b.a. = 1.1 m^2ha^{-1}) of trees already damaged by thinning developed additional wounds as a result of burning (Fig. 5). A further category of damage was recognized for trees that had experienced superficial scraping of the bark on the lower stem during thinning, and which subsequently developed cambial wounds directly beneath the bark scrapes; trees in this category represented a further 16 stems ha^{-1} (b.a. = 0.8 m^2ha^{-1}). Fire-caused wounds were most frequently 0.01-0.1 m^2 in area, but some exceeded 0.5 m^2 in area and extended for several metres up the stem. On average only 4 stems ha^{-1} (b.a. <0. 1 m^2ha^{-1}) of sample trees had died 11 months after burning. In burnt areas of the stand the residual stocking of trees without any stem damage from either thinning or fire was 182 stems ha[1], representing a basal area of 11.9 m^2ha^{-1}. In addition, a further 30 stems ha^{-1} (b.a. = 2.3 m^2ha^{-1}) remained unburnt and were therefore not subject to any fire damage. The incidence of fire-caused stem damage, including mortality and wounds associated with superficial bark scraping, was found to be significantly greater ($p < 0.01$) on trees that were within 1 m of old log debris than for trees that were 1-2 m from debris (Table 3). Thirty-eight per cent of trees that were within 1 m of log debris were damaged by fire, compared with only 22 per cent of trees that were further than 1 m but less than 2 m from logs.

TABLE 3

Incidence of fire-caused stem damage and mortality for trees >10 cm d.b.h.o.b. with old log debris ≤1 m and 1-2 m from the stem.

	No. TREES				
Log distance from stem	Undamaged	Damaged	Total	$\chi 2$	p
≤1 m	49	30	79		
1-2 m	184	53	237		
All	233	83	316	6.67	<0.01

DISCUSSION

Fuel accumulation in regrowth karri stands is principally determined by the age of the stand and the nature of the shrub understorey, and to a lesser extent by stand density (McCaw, unpublished data). Although pre-burn fuel was not assessed quantitatively at Boorara 13, the similarity of this stand to the stand at Boorara 2 where the experimental study was conducted makes it reasonable to assume that fuel loading and structure were comparable. Based on this assumption it is estimated that about half the litter loading was consumed during prescribed burning at Boorara 13. This is within the range of litter consumption reported for similar burning conditions by McCaw *et al.* (unpublished manuscript). Consumption of slash fuel during prescribed burning at Boorara 13 was not assessed quantitatively. The results of this study should therefore be regarded as providing a general indication of the extent of damage to retained trees that may be expected from prescribed burning. However, the type, amount and condition of fuels may vary from one thinned stand to another, with the result that levels of tree damage following prescribed burning may also vary.

An important factor that may have influenced the outcome of this trial was the extent to which actual burning conditions matched those that were prescribed. Actual burning conditions differed from those prescribed in two main factors: air temperature and SDI. Air temperatures on 24 November were up to 7°C higher than prescribed, but despite this the moisture content of the surface litter remained within the recommended range throughout the morning. Surface litter fuels probably dried to below 12 per cent moisture content during the latter part of the afternoon, however, most of the area had burnt out by this time. Diurnal fluctuations in air temperature are unlikely to have had a significant effect on the dryness of the litter profile and woody components of the thinning slash fuel as these are influenced more by longer-term seasonal conditions, particularly rainfall. The relatively high air temperatures on 24 November may have contributed to elevated levels of crown scorch (Cheney *et al.* 1992), but overall only a small proportion of the stand (12 per cent) was scorched to an extent that would have adversely affected tree growth.

The SDI is used in WA forests to reflect the dryness of soils, deep forest litter, logs and living vegetation. Burrows (1987) demonstrated strong correlations between the SDI and the moisture content of eucalypt logs in different situations (on-ground; elevated) and in different conditions (freshly cut; cured). The fact that the SDI at the time of the operational trial was higher than during most of the experimental fires at Boorara 2 may have contributed to increased combustion of old log debris and larger diameter components (>25 mm) of the thinning slash fuel. One consequence of increased fuel consumption could be an increased frequency of fire-caused damage to retained trees. The incidence of fire-caused damage to trees at Boorara 13 was in fact only slightly greater than at Boorara 2 (78 and 70 stems ha^{-1} respectively), and both stands retained a similar stocking and basal area of undamaged trees (212 stems ha^{-1} and 14.2 m^2ha^{-1} at Boorara 13; 214 stems ha^{-1} and 13.4 m^2ha^{-1} at Boorara 2). Damage to trees within 1 m of old log debris occurred with similar frequency in the two stands (38 per cent at Boorara 13; 43 per cent at Boorara 2). However, in view of the high value of young regrowth stands for future timber production it is recommended that the upper SDI limit for burning of thinning slash remain at 40 mm until the relationship between SDI, fuel consumption and subsequent tree damage has been more thoroughly investigated.

The thinning prescription for karri regrowth stands of 30 m top height specifies retention of 16 m^2ha^{-1} basal area of potential crop trees exhibiting desirable form and spacing. Results from both the experimental study at Boorara 2 and the operational trial at Boorara 13 indicate that if stands are burnt following thinning it is likely that less than 16 m^2ha^{-1} of crop trees will remain undamaged. Stem damage may predispose trees to decay and insect attack, resulting in loss of merchantable wood volume (McCaw 1983; Perry *et al.* 1985). Prediction of volume loss from stem wounds over the period of a rotation is complex, and depends on a number of factors including the location and extent of wounding, the rate of development and severity of degrade resulting from wounds, the length of time for which trees are retained, and the eventual utilization of the stem (McCaw 1983; White and Kile 1991). The option exists to remove damaged trees in subsequent thinnings, but a better understanding of wood degrade processes in karri is required to accurately predict the impact of damage on the volume and quality of wood products that may be produced from later thinnings, or at the time of final felling.

Variation in topography and aspect of the stand influenced fuel dryness and fire behaviour, and hence fuel consumption and crown scorch. Surface litter was consistently drier on the ridge than on lower slopes, while profile litter moisture content exhibited substantial variability in both topographic situations. The only substantial area of unburnt fuel occurrred on a lower slope with an easterly aspect; this tends to be a characteristically moist aspect in the karri forest. The extent of crown scorch in Cell 3 can probably be attributed to the greater fuel consumption on the ridge, together with the high ambient temperatures on 24 November when most of this cell was burnt. In the case of Cell 5, which was at lower elevation and on a generally southerly aspect, the extent of crown scorch was probably related to the presence of a dense stratum of stump coppice which tended to increase flame heights, rather than to the dryness of the fuel.

The contour lighting pattern employed at Boorara 13 was generally successful in achieving satisfactory fire behaviour and fuel consumption throughout most of the stand. The helicopter-mounted ignition system proved well suited to the task, providing a high level of accuracy in the placement of incendiary capsules and the manoeuvrability necessary for following the complex boundary of the compartment. Having several nearby stands available for burning on the one day would assist in reducing unit costs for helicopter ignition by maximizing the amount of lighting that could be undertaken while burning conditions were suitable.

CONCLUSION

The operational trial at Boorara 13 demonstrated that guidelines for prescribed burning of thinning slash in karri regrowth stands developed from a prior experimental study could be effectively implemented at an operational scale using a helicopter-mounted ignition system. Despite considerable variation in topography and aspect within the 20 ha study area, the crowns of retained crop trees remained unscorched over about three quarters of the burnt area, and only a few small patches remained completely unburnt. About a quarter of the retained trees in burnt areas of the stand suffered damage to the stem which may subsequently lead to wood degrade. The rate of development and ultimate extent of such degrade needs to be further investigated so that silvicultural costs and benefits of burning thinning slash can be properly evaluated. Factors critical to the success of operational prescribed burning in thinned stands include selection of appropriate conditions for burning, and careful planning and execution of lighting operations.

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