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Post-fire recruitment of red tingle (*Eucalyptus jacksonii*) and karri (*Eucalyptus diversicolor*) following low-moderate intensity prescribed fires near Walpole, south-west Western Australia

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ABSTRACT

This study examined the emergence and survival of red tingle and karri seedlings following low to moderate intensity fuel reduction burning at two sites near Walpole. Most seedlings emerged on burnt ground created by the combustion of litter and twigs, but some also emerged on the charred surface of fallen logs. Red tingle seedlings were more than twice as common as karri seedlings at both sites during the first spring following burning. The proportion of 1 m^2 sample quadrats containing red tingle seedlings declined from 43 per cent in October 1996 to 5 per cent by March 1998, while the proportion containing karri declined from 43 per cent to 23 per cent over the same period. Few of the surviving seedlings exhibited dynamic growth or appeared likely to develop into saplings. Small gaps created by natural tree fall were no better stocked than areas beneath an intact forest canopy. The presence of red tingle and karri seedlings following low to moderate intensity fires used for fuel reduction may not therefore lead to recruitment of even-aged sapling cohorts of these species.

INTRODUCTION

Forests around Walpole (34° 59' S, 116° 44' E) on the south coast of Western Australia are notable for the presence of several locally endemic eucalypts including red tingle (*Eucalyptus jacksonii* Maiden), yellow tingle (*E. guilfoylei* Maiden), Rates tingle (*E. brevistylis* Brooker) and red flowering gum (*Corymbia ficifolia* (F. Muell) Hill & Johnson, formerly *E. ficifolia*). Red tingle may attain a height of 70 m and stem diameter in excess of 4 m at maturity (Boland *et al.* 1985). Large trees commonly have prominent buttressing on the lower stem. Red tingle occurs in open and tall open forests on well drained granitic soils between the Deep and Bow Rivers within 8 km of the coast (Wardell-Johnson and Coates 1996). Associated trees include yellow tingle, karri (*E. diversicolor* F. Muell.), marri (*Corymbia calophylla* (R. Br.) Hill & Johnson, formerly *E. calophylla*), and less commonly jarrah (*E. marginata* Donn. ex Smith). Forests containing red tingle have been recognized and mapped as distinct associations on forest type maps prepared for the south-west of Western Australia (Bradshaw *et al.* 1997; Mattiske and Havel 1998).

Forests containing red tingle have long attracted interest because of their majestic appearance and restricted occurrence (Fernie and Fernie 1989), and recent scientific studies have also drawn attention to distinctive aspects of their biology and ecology (MacFarlane and Wardell-Johnson 1996; Wardell-Johnson and Coates 1996). The extant area of forest containing red tingle is estimated to be 6129 ha (Anon. 1998), of which 85 per cent is within the Walpole-Nornalup National Park. The Park also contains open forests and woodlands of jarrah, shrublands in swampy terrain, and coastal woodlands on stabilized aeolian dunes (Wardell-Johnson *et al.* 1989).

Fire has an important influence on the management of the Walpole-Nornalup National Park. Karri and tingle forests accumulate a deep organic layer of litter, bark and twigs which may weigh more than 50 t ha^{-1} in stands unburnt for 50 years (Wardell-Johnson 1997). This organic layer becomes dry enough to burn for several months during summer and early autumn and is capable of supporting intense forest fires. High intensity wildfires burnt much of the karri-tingle forest around Walpole in 1937 and 1950/51. Further karri-tingle forest within the Park was burnt by wildfire in January 1987.

Since the early 1970s park managers have used prescribed fire to reduce fuel loadings in strategic areas of the Walpole-Nornalup National Park in order to limit the potential extent and severity of unplanned fires. The current management plan for the Park (Smith *et al.* 1991) specifies three alternative fire regimes for areas of red tingle and karri forest. These are: fire exclusion for the 10-year duration of the plan; prescribed burning at intervals of 10–20 years to provide structural diversity in the forest understorey; and prescribed burning at 6–8 year intervals to limit the accumulation of ground fuels.

Disturbance by fire is an important trigger for regeneration of karri and other tall eucalypts (White and Underwood 1974; Breidahl and Hewett 1995; Florence 1996). The existence of densely stocked regrowth stands of red tingle and karri resulting from the 1937 and 1951 wildfires at Walpole provides clear evidence of the role played by high intensity fire in the regeneration process (Fig. 1). However, little is known about the extent of regeneration that may result from low to moderate intensity fires including those prescribed for fuel reduction. The only formal study of regeneration in red tingle forest is that of Wardell-Johnson (1997), who examined a number of sites one to two years after moderate intensity fire and found that regeneration of red tingle and karri was predominantly of seedling origin rather than from existing advance growth. The extent of regeneration following prescribed fires may be an important consideration in the management of stands in the late-mature and senescent stages of development (Bradshaw and Rayner 1997) where recruitment of a new cohort is desirable. For recruitment to occur, conditions must not only be favourable for seedling establishment but also for progression into subsequent development stages. Recruitment can be affected by the timing and intensity of fires, particularly during the establishment and juvenile stages of development when saplings are fire-sensitive.

Survival and early development of red tingle and karri seedlings were investigated following fuel reduction burning at two sites near Walpole in autumn 1996. This study sought information about the extent of seedling emergence in relation to seedbed conditions and overstorey canopy cover, and the fate of seedlings over the two-year period following burning.

Figure 1. Densely stocked pole stand of red tingle dating from the 1937 wildfire, Walpole Nornalup National Park.

METHODS

Emergence, survival and growth of red tingle and karri seedlings were studied in stands of mature forest at Shedley Drive and Anderson Road, located respectively 6 km west and 13 km east of Walpole. Both sites were at an elevation of about 100 m above sea level. The site at Shedley Drive had last been burnt by prescribed fire in spring 1988, while the Anderson Road site had remained unburnt since a wildfire in 1951. During August 1996 two transects were established at each location, one in an area where the forest canopy was intact (70–80 per cent cover), and the other in a gap up to 50 m in diameter resulting from natural tree fall. Each transect comprised 10 circular quadrats 1 m^2 in area spaced at 10 m intervals. The number of seedlings of each eucalypt species was recorded within quadrats at approximately monthly intervals between August 1996 and March 1997, and then again during June 1997 and March 1998.

The location of individual seedlings was identified with coloured markers in order to allow detailed assessment of emergence and mortality during the course of the study. Seedbed conditions within quadrats were assessed on the basis of the nature of the seedbed and the degree of fuel consumption. Categories of seedbed distinguished in the field were: unburnt mineral soil; burnt ground created by combustion of litter and twigs; ashbed created by combustion of large woody debris; and the charred surface of logs which had fallen prior to the burn. Basal area of overstorey and intermediate trees was determined by measuring the diameter of all trees >5 cm d.b.h.o.b. in a 0.1 ha plot defined by a distance 5 m either side of the transect centre line. The codominant height of overstorey and intermediate trees within each transect was measured with a hypsometer.

Care was taken to examine the distinctive features of cotyledons and juvenile leaves on each species to ensure that seedlings were correctly identified. Seed of known source was germinated and grown at the CALM Research Centre in Manjimup to confirm observations of seedling characteristics made in the field.

RESULTS

Both sites were burnt during dry conditions in early autumn (Table 1). Fuels were ignited with drip torches using an ignition pattern that resulted in low to moderate intensity fire behaviour in mature red tingle-karri forest. Forward rates of fire spread were 15–40 m h^{-1} and flame heights ranged from 0.5 to 2 m, occasionally flaring to 3 m. About 15 per cent of the area of tingle-karri forest within the boundaries of each prescribed burn experienced crown scorch 12 m or more above ground.

The stand at Shedley Drive consisted primarily of mature red tingle and occasional karri, although no karri were present within the sample transects (Table 2). The basal area of red tingle on the transect beneath the intact canopy was 205 m^2 ha^{-1}, with an additional 22 m^2 ha^{-1} of *Allocasuarina decussata* forming a dense intermediate stratum up to 20 m tall. The transect located in the gap had less than half the basal area of the transect beneath the intact canopy and included only a small contribution of *A. decussata*. At Anderson Road the stand comprised scattered mature trees with an intermediate stratum of pole-sized red tingle and karri up to 35 m tall, and *A. decussata* up to 20 m tall. Stocking of red tingle and karri was more than six times greater at Anderson Road than at Shedley Drive, but the combined basal area was substantially lower

TABLE 1

Weather conditions and fuel dryness during prescribed burning of red tingle-karri forest. Maximum air temperature and 3.00 p.m. relative humidity are shown for the sequence of days over which prescribed burning took place at each site. Surface and profile moisture contents were predicted from weather observations at CALM Walpole using the Forest Fire Behaviour Tables for Western Australia (Sneeuwjagt and Peet 1985).

	SHEDLEY DRIVE	ANDERSON ROAD
Date of ignition	6 March 1996	11 March 1996
Duration of burn	3 days	4 days
Soil Dryness Index (mm)	113[a]	123[a]
Surface Moisture Content (%)	17-16-16	26-18-13-13
Profile Moisture Content (%)	36-34-30	39-37-35-33
Maximum temperature (°C)	20-26-32	24-24-28-24
Relative humidity at 3.00 p.m. (%)	67-47-49	81-58-55-47

[a] For operation purposes in Western Australia the Soil Dryness Index is expressed in units of mm x10, making these values 1130 and 1230 respectively.

TABLE 2

Stand characteristics for transects located beneath an intact canopy and in natural tree fall gaps.

	SHEDLEY DRIVE		ANDERSON ROAD	
	CANOPY	GAP	CANOPY	GAP
Basal area (m^2 ha^{-1})				
E. jacksonii	205	84	68	46
E. diversicolor	-	-	24	2
A. decussata	22	3	4	3
Total	227	87	96	51
Stems per ha				
E. jacksonii	60	50	350	280
E. diversicolor	-	-	40	60
A. decussata	290	40	90	160
Total	350	90	480	500
Height (m)				
Overstorey	50	59	44	37
Intermediate	18	35	35	33

owing to the smaller average tree size. Many of the mature trees at Anderson Road were severely damaged as a result of previous wildfires.

Seedlings began to emerge in April 1996 and continued to emerge for a further seven months until late spring. Both red tingle and karri germinated on a variety of seedbeds including burnt ground and the charred surface of fallen logs. The occurrence of seedlings was proportional to the area of each type of seedbed (Table 3), with more than 90 per cent of seedlings emerging on burnt ground. Seedlings were also observed on ashbeds and on unburnt mineral soil but these seedbed types were absent from, or uncommon, in sample quadrats.

Red tingle seedlings were distinguished by their relatively large cotyledons (typically 10–15 mm wide) and elliptic seedling leaves which were opposite, sessile and bright green in colour with prominent veins (Fig. 2). Karri seedlings had smaller cotyledons (<10 mm wide) with a distinct dumbbell (emarginate) shape, and ovate seedling leaves that were opposite and petiolate.

The number of red tingle seedlings peaked in October 1996 at both sites, while karri seedling numbers peaked in September at Anderson Road and in November at Shedley Drive (Fig. 3). Red tingle seedlings were more than twice as common as karri seedlings at both sites, and overall seedling numbers were higher at Anderson Road than at Shedley Drive. In October 1996, 60 per cent of quadrats contained seedlings of one or both species and 43 per cent of quadrats contained one or more red tingle seedlings (Table 4). Forty per cent of quadrats were unstocked with either species. Seedling densities varied considerably

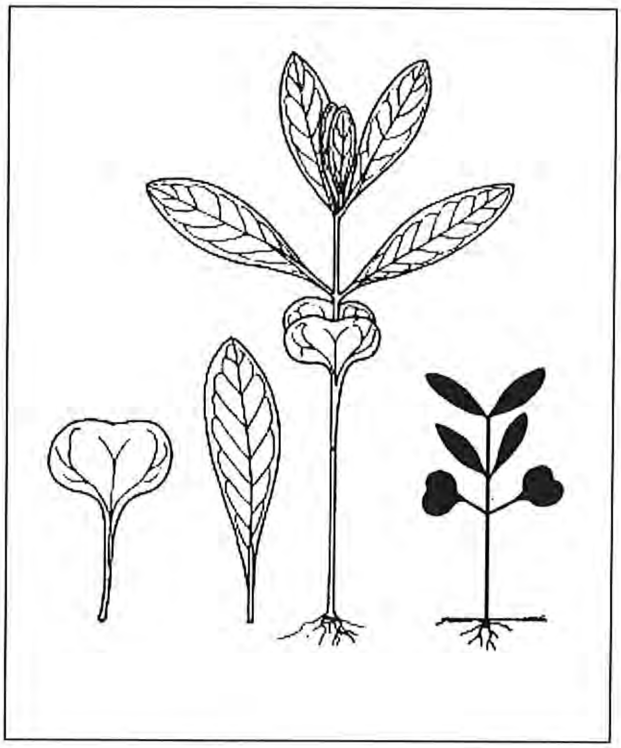

Figure 2. Drawing of a seven-month old red tingle seedling showing the large cotyledons and prominent leaf veins characteristic of this species. The actual height of the specimen was 75 mm.

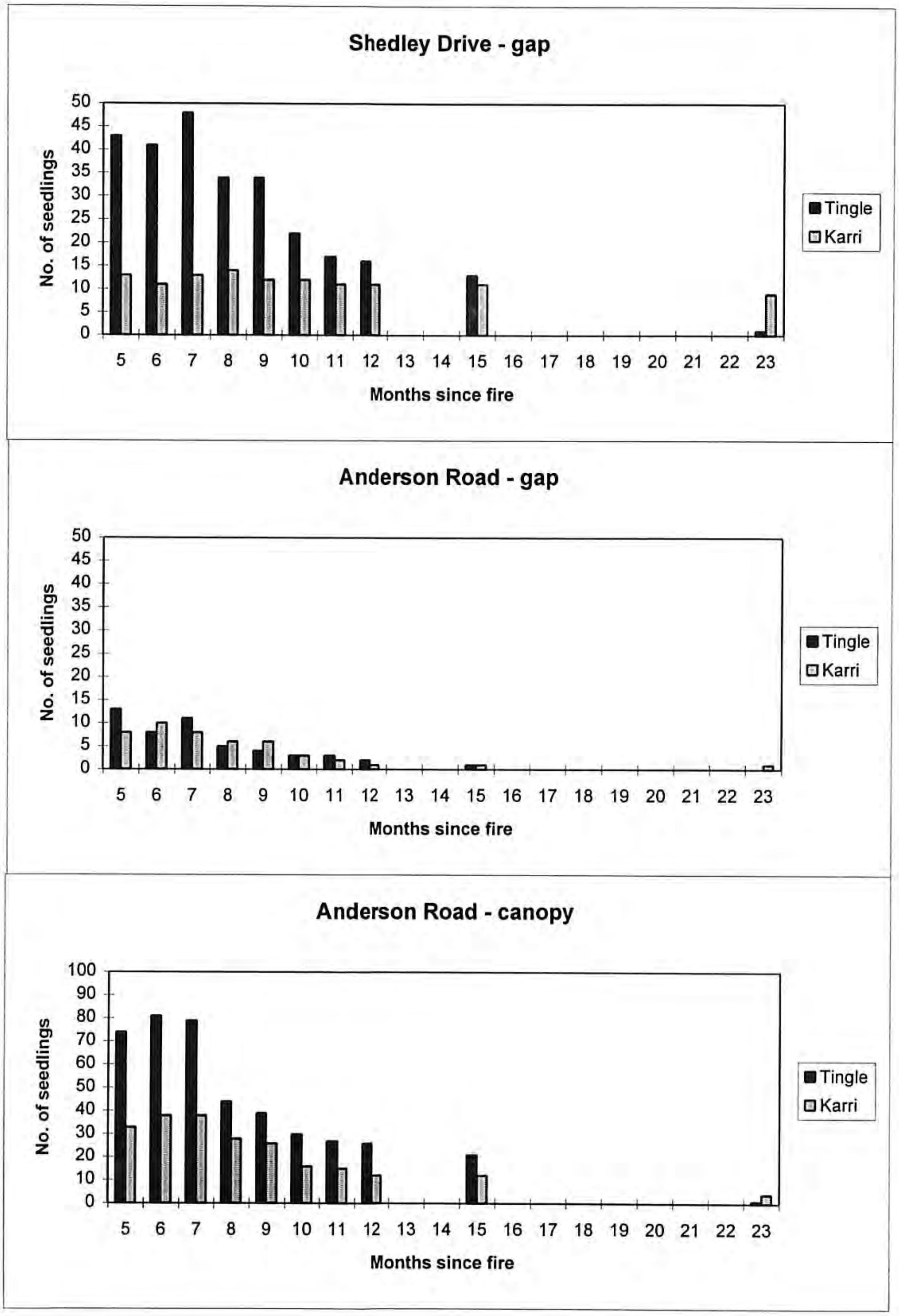

Figure 3. Numbers of red tingle and karri seedlings recorded on transects at Shedley Drive and Anderson Road between August 1996 and March 1998. Each transect comprised 10 m² of sample area. Data for the intact canopy transect at Shedley Drive have not been plotted as only two seedlings were recorded.

TABLE 3

Occurrence of seedlings by seedbed type based on pooled data for forty 1 m^2 quadrats.

SEEDBED TYPE	PERCENTAGE OF AREA OCCUPIED BY SEEDBED	NUMBER AND (%) OF SEEDLINGS	
		RED TINGLE	KARRI
Burnt	90	134(*96*)	59(*100*)
Old log surface	6	(*4*)	-
Bare ground	4	-	-

TABLE 4

Number of quadrats in each transect containing seedlings in October 1996 and March 1998. Each transect comprised ten 1 m^2 quadrats.

	SHEDLEY DRIVE				ANDERSON ROAD			
	CANOPY		GAP		CANOPY		GAP	
	1996	1998	1996	1998	1996	1998	1996	1998
Red tingle only	1	0	1	1	4	1	1	0
Karri only	0	0	5	6	0	2	2	1
Both species	0	0	3	0	4	0	3	0
No seedlings	9	10	1	3	2	7	4	9

between quadrats, with the most heavily stocked quadrats containing up to 32 red tingle seedlings per m^2 and up to 17 karri seedlings per m^2. Stocking was poorest on the transect beneath the intact forest canopy at Shedley Drive where only one quadrat contained a live seedling in October 1996. Poor stocking on this transect reflected an absence of successful germination and emergence rather than high seedling mortality. The situation was reversed at Anderson Road where the transect beneath the intact forest canopy was more heavily stocked than the transect in the gap.

The number of red tingle seedlings declined progressively from November 1996 to March 1998, so that two years after burning only one red tingle seedling survived at each site (Fig. 3). Both surviving seedlings were about 0.3 m tall in March 1998 and were not exhibiting dynamic growth. Over the same period, the number of karri seedlings declined substantially at Anderson Road, but not at Shedley Drive. The two most dynamic karri seedlings were located together in a quadrat in the gap transect at Shedley Drive. These individuals were respectively 1.3 m and 2.3 m tall in March 1998 and appeared to be growing vigorously and out-competing adjacent understorey shrubs. Seedlings of red tingle and karri exhibiting dynamic growth were observed outside the sample quadrats, commonly on ashbeds beneath relatively open parts of the forest canopy. Most surviving karri seedlings within the quadrats were less than 0.4 m tall and appeared unlikely to remain competitive with the understorey.

DISCUSSION

This study has shown that conditions favourable for the emergence of red tingle and karri seedlings can occur in the first year following a fire of low to moderate intensity in mature forest. The status of the seed crop on mature red tingle and karri trees at the two sites prior to burning is not known, but the emergence of seedlings in 60 per cent of sample quadrats confirms that viable seed was present in the crowns of some mature trees. Evidence from this study, together with the existence of regrowth stands dating from wildfires in 1937 and 1951 and post-logging burns of the early 1970s, strongly suggests that both species carry a crop of seed in most years. The magnitude of the seed crop is likely to vary from year to year in response to a variety of influences including climatic factors, pollinator activity, insect damage and fire (Loneragan 1979; Breidahl and Hewitt 1995).

Seedlings emerged on a range of seedbed types including ashbeds, burnt ground resulting from combustion of the organic litter layer, and the charred surface of fallen logs. Both sites were burnt during dry conditions in autumn and the litter layer was almost entirely consumed, thereby maximizing the area of receptive seedbed prepared.

Burning in spring, or later in autumn, when the litter layer contains more moisture would tend to result in less complete fuel consumption and the retention of a layer of unburnt organic material known as 'duff'. Duff is not considered a receptive seedbed (Breidahl and Hewett 1995) and seedling emergence may therefore be reduced when burning is conducted under more moist fuel conditions. Unfavourable seedbed conditions may have contributed to the low level of seedling emergence beneath the intact canopy at Shedley Drive. Although the fire had removed the organic litter layer and exposed mineral soil, the ground rapidly became covered by a layer of dead *A. decussata* needles cast from the lower canopy following scorch. Ashbed sites are known to favour rapid initial growth of karri and other eucalypts (Hatch 1960; Loneragan and Loneragan 1964; Burrows *et al.* 1990), and probably also favour the growth of red tingle. The lack of ashbeds in the sample quadrats precluded a thorough comparison of growth between seedlings on and off ashbeds.

Seedling mortality during the period from October 1996 to March 1998 was greater for red tingle than for karri. Additional research is needed to determine whether this differential mortality is a consistent feature of the regeneration process in mixed stands of red tingle and karri, or simply a chance event under the particular conditions of this study. The generally high level of mortality experienced by seedlings of both species can probably be attributed primarily to water stress. Rainfall at Walpole was very much below average in the period from March to May 1996, but above average between June to October when the majority of seedlings emerged (Bureau of Meteorology 1996). Average falls were recorded during the first summer after burning (January to March 1997) when seedlings would have begun to experience water stress. Retention of an overstorey has been shown to increase the soil water deficit and level of mortality among jarrah seedlings in the northern jarrah forest (Stoneman *et al.* 1994). Dignan *et al.* (1998) found that an overstorey basal area exceeding 20 m^2 ha^{-1} adversely affected the survival of seedlings three years after sowing in partially cut stands of mountain ash (*Eucalyptus regnans* F. Muell.). They suggested that overstorey basal areas below 20 m^2 ha^{-1} may in fact have a beneficial shelterwood effect on seedlings, at least during the first few years following regeneration.

The effect of retained overstorey on seedling survival is likely also to be important in the context of the present study of mixed red tingle-karri stands. The large sized trees and high basal area typical of mature red tingle-karri stands mean that gaps of at least 3 to 4 ha are needed to reduce overwood competition, and substantially larger gaps may be necessary to eliminate edge effects altogether (Bradshaw 1992). Overstorey basal areas measured on the transects were large by Western Australian standards, particularly at the Shedley Road site. Basal areas for jarrah stands typically range from 20 to 40 m^2 ha^{-1} (Abbott and Loneragan 1986) while mature karri stands may attain basal areas of 50–80 m^2 ha^{-1} (Rayner[1] personal communication). Wardell-Johnson (1997) reported that the average basal area of red tingle in a sample of 30 plots was 48 m^2 ha^{-1}, with a maximum of 106 m^2 ha^{-1}. The Shedley Road site was re-visited in 1998 to check the calculated basal areas, and re-measurement confirmed the values shown in Table 2 for the two quadrats. Large basal areas (129 and 158 m^2 ha^{-1}) were also measured on two circular quadrats, each 0.1 ha in area, established near to the transect beneath the intact forest canopy. Circular quadrats minimize the ratio of perimeter to sample area and thus reduce the chance of error owing to inclusion or exclusion of large trees on the edge of the quadrat. Based on this additional field work we are confident that the basal area values presented in Table 2 are a true reflection of the level of overwood competition at the two study sites.

[1] Dr M. Rayner, CALM, Manjimup, Western Australia.

In conclusion, the presence of red tingle and karri seedlings following low to moderate intensity fires used for fuel reduction may not lead to successful recruitment of even-aged sapling cohorts of these species. While significant numbers of seedlings may emerge during the first year following fire, few of these appear likely to survive and develop into saplings beneath an intact forest canopy or in small gaps caused by isolated tree falls. The scale and intensity of disturbance required for effective recruitment in red tingle-karri forest is a subject worthy of further investigation.

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