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Prescribing low intensity fire to kill wildings in Pinus radiata *plantations in Western Australia*

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Summary

Dense thickets of self-sown *Pinus radiata* (wildings), which develop after thinning operations in mature *P. radiata* plantations in Western Australia, are an additional source of fuel and have been observed to promote crown fire development during wildfires and frustrate wildfire suppression activities.

One of the techniques investigated for controlling pine wildings, low intensity prescribed fire, has been effective in killing wildings. Pine wildings died after experiencing full crown scorch or defoliation. The height to which pine wildings were scorched, hence the level of mortality, was found to be related to fire intensity. Intensities of up to 200 kW m^{-1} can be prescribed to kill most wildings up to 5 m tall. Any reductions in stocking and basal area of wildings will be a positive contribution to protecting *P. radiata* plantations from wildfire.

No response in the growth rate of crop trees as a result of the reduction of abundance of pine wildings by fire was detected.

Introduction

In the south-west of Western Australia, there are about 60 000 ha of State pine plantations of which some 33 000 ha are of *P. radiata* D. Don. These plantations represent a valuable wood resource for the State and supplement production from native hardwood forests. Protection of the fire-sensitive *P. radiata* plantations from wildfires and ensurance of maximum wood production are crucial management goals.

Each year, mature crop trees shed a considerable quantity of seed onto the plantation floor. In heavily stocked stands with a dense canopy, seedlings rarely develop. However, following thinning operations, which open up the canopy and increase the amount of light reaching the forest floor, numerous pine seedlings emerge and quickly develop into small trees (wildings). Dense thickets of wildings exist in almost all plantations which have been thinned at least twice.

Plantation managers are concerned that wilding thickets may seriously hamper fire protection and fire control operations in and around the plantations. Pine wildings are seen as an additional source of flammable fuel conducive to the spread of severe crown fires under adverse weather conditions. They also limit access for wildfire suppression activities and for timber stand-improvement operations. This is particularly important in areas designated as fuel-reduced buffers in which suppression activities would concentrate in the event of a wildfire.

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Managers are also concerned that wildings may compete with crop trees for nutrients and moisture.

A number of techniques for effectively controlling pine wildings are under investigation. These include mechanical and chemical treatments and the use of prescribed fire.

The aims of this study were to determine the application and limitations of fire as a means of controlling wildings and to determine whether or not removal of wildings using prescribed fire was beneficial to the growth of crop trees in the short term. In order to achieve these aims, the following hypotheses were tested:

(1) *P. radiata* wildings would die as a result of complete crown scorch by fire.

(2) The height to which crowns of *P. radiata* wildings are scorched by fire is a function of Byram's (1959) fire intensity calculation.

(3) The rate of diameter growth of crop trees would increase after removal of wildings by fire.

Methods

The size-class structure of wilding populations varies throughout *P. radiata* plantations and is probably a function of site productivity, past silvicultural regime and plantation age. Six sites were selected for the study, representing the range of wilding populations common to Blackwood Valley plantations near Nannup and Kirup in Western Australia.

Table 1. Past thinning and current stocking and basal area of *Pinus radiata* plantations at six study sites inthe Blackwood Valley, Western Australia.

Study site	Year planted	Thinning prescription (stems ha^{-1})	Stocking (stems ha^{-1})	Basal area (m^2 ha^{-1})	Other comments
1	1956	1969; 1731 to 750 1978; 750 to 250	100	21	Windthrow from Cyclone Alby, 1979
2	1957	no data	280	31	
3	1956	1968; 1731 to 750 1979; 750 to 100	82	17	Thinned after Cyclone Alby, 1979
4	1960	1978; 1370 to 400 1985; 400 to 200	133	12	
5	1958	1975; 1370 to 625 1980; 625 to 250	122	17	Wildings slashed with a hydro axe machine in 1985
6	1952	1966; 1731 to 750 1972; 750 to 250 1977; 250 to 125	89	18	

Each study site was about 2 ha. Two duplicated treatments were planned for each site, these being:

(1) Treatment 1 — unburnt control.

(2) Treatment 2 — low intensity (< 200 kW m^{-1}) fire under moist fuel conditions (fine fuel moisture content greater than 14%).

The study sites were representative of older hill-side plantations in the Blackwood Valley. A summary of the management history and stand characteristics at the time of the study is presented in Table 1.

At each of the six sites, four plots (each 70 m x 50 m) were constructed using a bulldozer to clear a 3 m wide mineral earth firebreak around each plot. Two of the plots were to be burnt and two were to be unburnt controls. Five quadrats (each 7 m x 5 m) were systematically located in each plot giving a total of 120 quadrats in all (6 sites x 4 plots x 5 quadrats). The quadrats were numbered and permanently marked with 0.3 m high wire pins at each corner. The pine wildings at the study sites ranged in size from small seedlings a few centimetres high to trees up to 15 m high. Initially, it was intended that all living wildings in each quadrat be tagged and measured. However, the frequent high numbers of small plants encountered made it impractical to attempt this, so the wildings were separated into two classes based on height. Wildings less than 1 m high were called seedlings and simply counted. Taller wildings were individually numbered using metal tags. The stem diameter of each tagged plant was measured at 0.1 m above ground and its height was recorded. The density of plants in both height classes was expressed in numbers per hectare. Basal area of tagged wildings in each quadrat was calculated from stem diameter measurements. The basal area of crop trees near each quadrat (7 m x 5 m) was estimated using a X2 dioptre wedge prism from the centre of each quadrat.

In order to assess the physical effects of fire on crop trees, 20 trees at each site were individually numbered and their stem diameter (dbhob) was measured. In all, 120 crop trees were used to gauge the level of crown and bole damage as a result of these experimental fires. All trees selected were deemed to be healthy and free of visible signs of injury prior to burning.

The quantity of needlebed fuel in each quadrat (7 m x 5 m) was estimated by measuring the needlebed depth and using a relationship between depth and quantity (t ha^{-1}) developed by Sneeuwjagt and Peet (1985). The quantity of dead and downed coarse wood material ($\geq$ 10 mm diameter) such as limbs, non-commercial logs and tops was measured using a line intercept method (van Wagner 1968). The quantity of additional fuel contributed by live pine wildings was estimated using a technique described by Burrows (1981a).

Plots were burnt (Treatment 2) using continuous lines of fire under cool, moist conditions in May 1986. An electronic weather station, set up some 200 m from the plots and in similar forest, provided ten minute records of wind speed and direction (at 2 m above the forest floor), air temperature and relative humidity. The moisture content of the needlebed was determined from six samples (each about 50 g) taken at hourly intervals during the experimental burns and then later oven-dried in the laboratory. Fire behaviour measures included rates of spread of fire through each quadrat and flame height. Fire intensity (kW m^{-1}) for each quadrat was calculated using Byram's (1959) equation. The quantity of fine fuel burnt was determined by measuring the quantity of needlebed remaining after the fire (using the technique described for the pre-burn measure) and subtracting this from the pre-burn quantity. The line intercept method (van Wagner 1968) was used to measure the quantity of dead and downed woody material (≥ 10 mm diameter) remaining after the fires. The quantity of woody material consumed was calculated by subtracting the post-burn from the pre-burn quantity. All post-burn fuel measurements were made within three days of the fire.

In July 1986, all study sites were visited in order to measure the height of scorch to the crowns of wildings and crop trees. It was too soon after the fire to determine visually whether any trees had been killed. The scorch height of each tagged wilding was measured using height sticks, or a clinometer if the height exceeded 10 m. In some quadrats where all tagged wildings were defoliated, then the scorch height was recorded from measurements of scorch height on the crop trees, tagged and untagged, on the quadrat. In addition, the scorch height on all tagged crop trees was measured.

The study sites were visited again in December 1986. By this time, tree mortality was clearly visible. In all quadrats and all plots, tagged wildings were classed as live or dead and the numbers of live seedlings (wildings < 1 m tall) were counted. No other measures were made on the wildings. The extent of fire-caused bole damage to tagged crop trees was gauged by measuring the height to which cambium had been killed along the bole. This was done by firstly identifying the side of the bole which had experienced most heat. This was generally on the leeward side due to the "chimney" effect (Gill 1974, Burrows 1987a) and was recognised by extensive charring of the bark and prolific resin exudation. Exceptions to this occurred when trees were near heavy, woody fuels such as logs. Then, most bark charring was on the side of the bole facing the log. Commencing near ground level, a small (10 mm x 10 mm) block of bark was chiselled out to reveal the cambium. If the cambium was dead (yellow-brown), then another block of bark was removed 10 cm further up the bole. This process continued until live cambium (white) was exposed. The height to live cambium was measured. In addition, the extent of resin exudation through fissures in the bark was subjectively rated as normal, moderate or heavy. The maximum height of bark charring was also measured on all tagged crop rates in the burnt treatments.

The stem diameter (dbhob) of all tagged crop trees was measured again in January 1988 (some 20 months after the experimental fires).

Method of analysis

To test the hypothesis that *P. radiata* would be killed by fire which caused complete crown scorch, all scorch height and mortality data from the tagged wildings in the burnt quadrats were pooled for analysis. A ratio of scorch height to total height was used as a measure of the extent of crown damage by scorching. Thus, a crown scorch ratio of 1 meant total crown scorch and a ratio of 0 mean no crown scorch. The scorch ratio was calculated for every tagged wilding (i.e. ≥ 1 m) in the burnt quadrats, and scorch ratio classes were plotted against the percentage of trees in each class which were recorded as dead after the experimental fire treatment.

In order to examine the relationship between Byram's fire intensity and scorch height to *P. radiata*, the mean scorch height of tagged wildings (≥ 1 m) was calculated for each quadrat (7 m x 5 m) and regressed against the mean fire intensity (Byram 1959) calculated for that quadrat. Data were again pooled and a correlation coefficient determined for the 60 burnt quadrats (6 sites x 2 plots burnt x 5 quadrats in each plot).

For each site, the mean diameter increment of the 20 crop trees tagged in the burnt plots was compared with that of the 20 crop trees in the unburnt plots. A Student's "t" test was used to determine whether the difference in mean diameter increment was significant at the 0.05 probability level.

Results

Pine wildings died when fire defoliated or completely scorched their crowns. About 90% of those exceeding 1 m in height died when crown scorch exceeded 80%, but 88% of the same size class with less than 60% of scorched crown survived (see Figure 1). A total of 434 wildings (≥ 1 m) were sampled in all burnt quadrats.

A summary of conditions of fire behaviour, fuels and weather experienced during the experimental fires is contained in Table 2.

Fire intensity (Byram 1959) correlated well with the height to which wildings were scorched. Mean fire intensity per site ranged from 28 kW m^{-1} to 170 kW m^{-1}, which is within Cheney's (1981) classification of a low intensity fire. The mean scorch height of wildings calculated for each quadrat

Table 2. Average conditions of fuel, weather and fire behaviour during the experimental fires in *Pinus radiata* plantations.

Site	Weather			Fuel					Fire behaviour		
	Temp (°C)	RH (%)	Wind (km h⁻¹)	1 SMC (%)	2 PMC (%)	3 Fine (t ha⁻¹)	4 Coarse (t ha⁻¹)	5 Wilding (t ha⁻¹)	Mean rate of spread (m h⁻¹)	Mean flame height (m)	Intensity range (kW m⁻¹)
1	23	54	4.3	17	—	3.4	57	8.0	95	0.5	88–605
2	16	65	5.0	23	69	5.5	0	1.6	10	0.1	20– 57
3	22	51	2.0	16	54	2.1	10	9.9	100	0.5	45–296
4	18	60	6.0	16	—	2.0	12	—	62	0.3	36–145
5	25	26	4.3	18	36	1.7	0	—	50	0.3	22–106
6	20	51	1.0	15	20	7.5	12	8.3	18	0.2	24–124

1. SMC = surface moisture content or the moisture content of the top 10 mm of needlebed (% oven dry weight)
2. PMC = profile moisture content or the average moisture content of the entire needlebed profile (% oven dry weight)
3. Fine fuel = fuel particles ≤ 10 mm diameter (needles and twigs)
4. Coarse fuel = fuel particles > 10 mm diameter (tops and logs)
5. Wilding fuel = fine fuel (needles) contributed by wildings and which could burn in a crown fire

ranged from 1.5 m to 8.8 m. Occasionally, crop trees were scorched up to 20 m high. The regression equation for predicting scorch height from fire intensity (I) for the range of data of this study was:

Scorch height (m) = $0.248\ I^{0.66} - 0.41$ ($R^2 = 0.95$)

This regression is graphed in Figure 2 with van Wagner's (1973) relationship developed from studies in Canadian forests. His relationship is based on intensity (I) to the power of ⅔. In order to compare these results with his, correlation coefficients (R^2) were calculated for regressions of scorch height (Sc) on various exponents of I, ranging from I to the power of 0.2 to 2.0. The R^2 values for each regression are graphed with the various exponents of I in Figure 3.

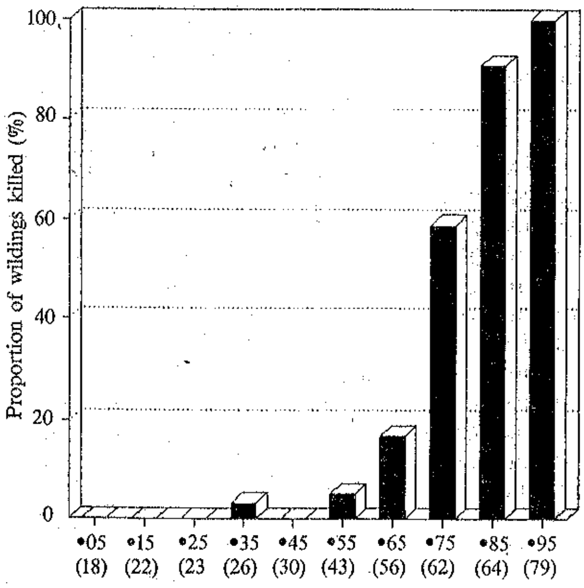

Figure 1. Relationship between crown scorch ratio (height of crown scorch: total tree height) and tree mortality for *Pinus radiata* wildings taller than 1 m. The number of wildings in each crown scorch ratio class is shown in brackets.

The effects of low intensity fires on pine wildings of different heights is summarised in Table 3. Changes in the basal area (m² ha⁻¹) of wildings equal to or taller than 1 m are also shown in the same table. Mortality was highest in the shortest height classes and almost all the seedlings (< 1 m tall) were killed. The average fire intensity experienced at study site 6 (68 kW m⁻¹) was too low to have any substantial effect on the large wildings (Table 3).

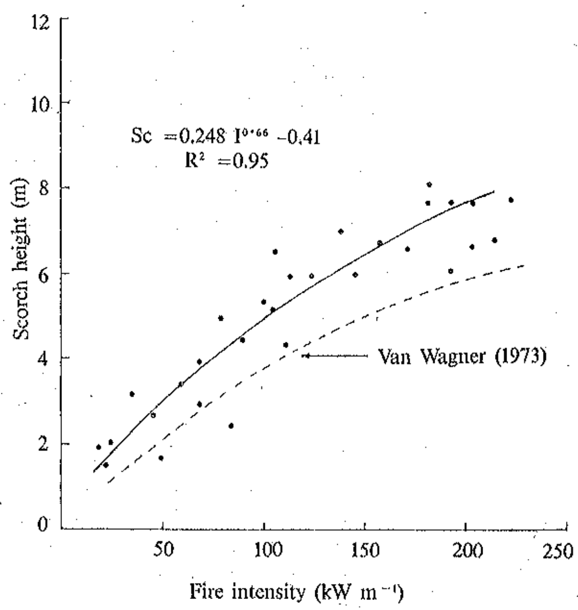

Figure 2. Relationships between scorch height (Sc) and fire intensity (I) from experimental fires.

Table 3. Number and basal area of pine wildings in the burned quadrats before and after a low-intensity prescribed fire. Basal area (m^2 ha^{-1}) was calculated for wildings taller than 1 m.

Site		Height class (m)											Total numbers	Basal area (m^2 ha^{-1})
		1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10+		
1	Before	3	2	4	4	4	10	5	15	10	8	6	70	14.2
	After	0	0	1	0	1	2	3	4	5	2	4	22	3.8
2	Before	185	12	28	4	1	2						232	0.4
	After	9	5	19	2	1	1						37	0.2
3	Before	13	20	44	39	22	12	10	5			1	166	10.2
	After	0	8	29	30	19	11	9	5			1	112	5.3
4	Before	55											55	0
	After	0											0	0
6	Before	19	24	23	33	21	17	16	11	6	5	8	183	19.8
	After	0	17	19	30	19	17	16	11	6	5	8	148	19.4

Fire intensity varied considerably between quadrats within plots. Rate of fire spread fluctuated with wind shifts and fine fuel quantity varied within the plots. The ranges of fire intensity are shown in Table 2.

The mean diameter of tagged crop trees measured before and 20 months after burning and the mean diameter increments over this period are shown in Table 4. The extent of crown and bole damage to the crop trees caused by the burn is shown in the same Table.

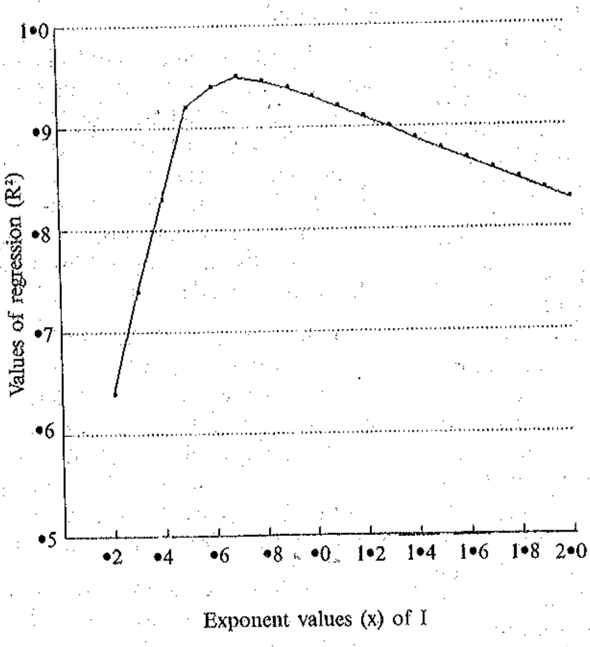

Figure 3. Regression R^2 values plotted with the exponent of intensity (I) in equations of the form; scorch height $= I^{(x)} - K$.

Discussion

Crown scorch, defoliation and cambial damage resulting in stem girdling at or near ground level were the most likely causes of death of pine wildings. Unlike many native species, *P. radiata* does not have the capacity to resprout following the death of above-ground tissue following fire. While we were not able to prove cause of death, we were able to demonstrate that mortality was directly related to the extent of crown scorch (Figure 1) and that crown scorch was directly related to Byram's measure of fire intensity (Figure 2). Tree mortality following high levels of crown scorch or defoliation has been reported for *Pinus* species (van Wagner 1970, Rawson *et al.* 1983). However, these workers studied mature trees with thick insulating bark. The pine wildings studied here did not have plated bark so were probably more prone to cambial damage. Whatever the cause, probability of death can be predicted from scorch height. Therefore, scorch height may be related to the temperatures reached at the cambial layer if the primary cause of death was stem girdling.

The relationship between Byram's fire intensity and scorch height developed by this study has a similar form to that reported by van Wagner (1973) as shown in Figures 2 and 3. For a given fire intensity, van Wagner's relationship predicts a lower scorch height than the relationship reported here. We attribute this to the high quantity of coarse ground fuels (such as tops, limbs and logs) which burnt during our experimental fires, but which are not accounted for by Bryam's calculation of fire intensity. Another reason for differences may include variation in foliar moisture content. Our studies were conducted in autumn when soils were dry. It is possible that the trees may have been under drought stress, so were more prone to scorching and death.

Table 4. Mean *Pinus radiata* crop tree diameters (dbhob) before and 20 months after low intensity experimental fires. Crown scorch and bole damage were measured 6 months after the fires.

	Site	No. trees measured	Diameter (cm) Before	Diameter (cm) After	Diameter increment (cm)	Height of crown scorch (m)	No. trees with unacceptable bole damage
1	Burnt	20	52.1	53.7	1.6	7.8	12
	Unburnt	20	49.0	50.8	1.8		—
2	Burnt	20	39.3	40.6	1.3	2.1	0
	Unburnt	20	36.7	37.7	1.0		
3	Burnt	20	49.5	50.9	1.4	6.0	6
	Unburnt	20	53.6	55.3	1.7		
4	Burnt	20	33.3	35.6	2.3	3.2	2
	Unburnt	20	34.5	37.1	2.6		
5	Burnt	20	42.0	43.3	1.3	2.1	0
	Unburnt	20	43.1	44.6	1.5		
6	Burnt	20	53.1	54.8	1.7	2.8	1
	Unburnt	20	51.1	52.6	1.5		

Note:
1. Bole damage was considered unacceptable if cambium was killed to a height greater than 0.5 m.
2. No significant difference in mean dbhob and mean dbhob increment within sites at the 0.05 level.

In *P. radiata* plantations, fire intensity can be used to predict the level of crown scorch and therefore, wilding mortality. When wildings experienced scorch to more than 80% of the crown height, then there was an 88% chance that the plants would die. Therefore, a fire of prescribed intensity of around 200 kW m^{-1} would scorch wilding crowns to about 8 m tall and kill most plants up to 10 m tall. Normally, fire of this intensity would not damage mature crop trees (Billing 1979 unpubl., Woodman and Rawson 1982 unpubl.). The crown and bole damage to crop trees reported here was unacceptable at site 1. This was caused by the combustion of unusually high quantities of coarse fuels caused by windthrow associated with cyclone Alby. In another study a long duration of heating by burning logs within 1 m of the base of trees caused substantial bole damage to *Eucalyptus marginata* and *E. calophylla* (Burrows 1987a). Therefore, it is imperative that logs and other woody fuels be cleared from the base of crop plantation trees prior to prescribed burning in order that the commercial value of the stand not be reduced or openings not be created for secondary degrade by insect and fungal attack (McCaw 1983). An alternative to clearing coarse fuels is to set fires under conditions such that only the fine fuels will burn. This means burning in spring when fine fuels are dry enough to burn, but coarse fuels are too moist to burn (Burrows 1987b). Fortunately, the problem of high quantities of coarse fuels is not widespread throughout the Blackwood Valley plantations.

A uniform fire intensity of 200 kW m^{-1} will succeed in removing most wildings up to 10 m tall. However, achieving a uniform intensity over a plantation is unlikely. Ideally, fire intensity should not exceed about 250 kW m^{-1} otherwise crop trees will be scorched and will suffer stem damage (Rawson *et al.* 1983, Burrows *et al.* 1988). Therefore, an intensity range of about 100–200 kW m^{-1} is a more realistic and achievable objective. This should ensure that most wildings less than about 5 m will be killed by fire without causing damage to crop tress. Such fires are safe to implement and can be controlled.

The abundance and height class structure of the wilding population may also be controlled by regulating the basal area and stocking of crop trees. Heavy thinning of crop trees and low crop tree basal area, is likely to promote the abundance and growth of wildings. By integrating silviculture and fire protection operations, a management strategy which results in fewer wildings can be achieved. This aspect needs further study.

Over the duration of this study (20 months) there was no evidence of differences in crop tree stem diameter growth between treatment and control plots. It is possible that a sample of 20 trees is too small to adequately determine growth differences. It is also possible that the study period was too short to detect growth responses by the mature crop trees resulting from the treatment.

While wilding reduction using controlled fire did not realise any short term growth responses, gains to fire control were substantial. Within 20 months of burning, wildings which had been killed by fire, lost their needles to the forest floor and many stems

Table 5. Low intensity fire prescription to kill most pine wildings up to 5 m tall for older plantations (25+) and up to 3 m for younger plantations (15–25).

Burn season	Plantation age	Weather				Fuel		Fire behaviour		
		(1) SDI	Temp °C)	(2) RH (%)	Tower wind (km h^{-1})	(3) SMC (%)	(4) PMC (%)	(5) ROS (m h^{-1})	Intensity (kW m^{-1})	Scorch height (m)
Spring	25+	350	20–25	45–85	15–20	14–20	40+	40–80	100–200	4–7
	15–25	250	18–22	50–60	10–15	16–22	40+	25–50	60–120	3–5
Autumn	25+	SDI to drop by 500 units from Summer maximum.								
	15–25	Other conditions as for Spring.								

(1) SDI = Soil Dryness Index (Mount 1972)
(2) RH = Relative Humidity
(3) SMC = Surface Moisture Content (top 10 mm of needlebed)
(4) PMC = Profile Content (entire needlebed)
(5) ROS = Rate of Spread of fire.

collapsed. While the total fuel quantity contributed by wildings may not have altered substantially, it was redistributed in a less flammable state. The needles which fell on the forest floor would most likely break down.

Live pine canopy needles will burn under certain weather conditions and crown fires are not uncommon in pine plantations (Rawson *et al.* 1983). Removing the wilding crowns reduces both the quantity and the continuity of fuel likely to burn in a crown fire (Williams 1977). It is not possible to accurately predict the likely changes in potential fire behaviour as a result of removing wildings, as such fire behaviour models do not exist for crown fires. However, we assume that any reduction in fuel quantity and continuity will result in reduced crown fire spread rate and intensity. This is particularly important in plantation areas managed as fuel-reduced buffers or crown-fire-free zones.

While a single fire treatment can effectively reduce the abundance of wildings, we believe this is not a permanent solution. It is highly likely that in time (probably 5–10 years after fire) wildings will regenerate from seed to pre-fire conditions. A management strategy of frequent cyclic burning in *P. radiata* plantations to control wildings could have several disadvantages. Firstly, there is always the risk of damage to valuable crop trees. Secondly, this type of intensive burning is expensive and demanding on limited resources, which may be better deployed elsewhere. Thirdly, the number of days when weather and fuel conditions are ideal for carrying out wilding eradication burns are likely to be few, further constraining the operation. Finally, there is a possibility that frequent cyclic burning may cause nutrient losses in pine plantations. Therefore, we recommend that prescribed fire be initially used to reduce wildings in strategic areas such as fuel-reduced buffers. These areas should then be seeded with pasture species and grazed. Where grazing is practised in the Blackwood Valley plantations, it is very effective in preventing wilding regeneration and also reduces fuel loadings (Burrows 1981b). The introduction of clover has additional nutritional benefits (McKinnell 1979).

Low-intensity fuel-reduction prescribed burning is already a routine operation in softwood plantations in Western Australia (Sneeuwjagt and Peet 1985, Burrows *et al.* 1988). Planning and procedures for prescribing fires to reduce pine wildings should be carried out in the same manner. Table 5 is a guide to prescribing fire to remove most pine wildings less than about 5 m tall. Burning can be carried out in either spring or autumn and the choice of season will depend on the works program. Whatever the season, it is imperative that coarse fuels such as logs, are damp. This is reflected in the Soil Dryness Index limits shown in Table 5. If coarse fuels are dry, they will catch alight and could cause commercial damage to crop trees. Smouldering logs near the burn boundary will need to be extinguished to minimise the risk of fire escape at a later date. This added mop-up is costly. Where the consumption of fine fuels has been incomplete, smouldering logs can cause re-ignitions on warmer, drier days.

As with prescribed burning in *P. radiata* plantations, wilding eradication burns should only be attempted in stands of crop trees older than 15 years (see Table 5). Younger trees will be vulnerable to bole and crown damage. Larger trees, which are generally older, are more resistant to fire damage as they have thicker bark and their crowns are further from the fuel bed. This is reflected in Table 5, where we have prescriptions based on the age of crop trees.

The temperature, wind, relative humidity and fuel moisture limits shown in Table 5 should result in the given fire behaviour, including the fire intensity necessary to kill wildings to 5 m. This prescription applies for fuels on level ground and the appropriate slope corrections to fire behaviour should be made where necessary (McArthur 1967).

Conclusion

Low-intensity prescribed fire can be used to kill *P. radiata* wildings less than about 5 m tall without causing damage to crop trees. This treatment should be applied to plantation zones designated as fuel-reduced buffers to optimise protection against wildfires.

It is most likely that wildings will regenerate some time after the initial prescribed fire, so other strategies, such as pasture establishment and grazing, may need to be investigated.

No response in crop tree growth rate was detected following the reduction of wilding abundance by fire. However, the interations between wildings and crop trees in *P. radiata* plantations warrant further research.

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