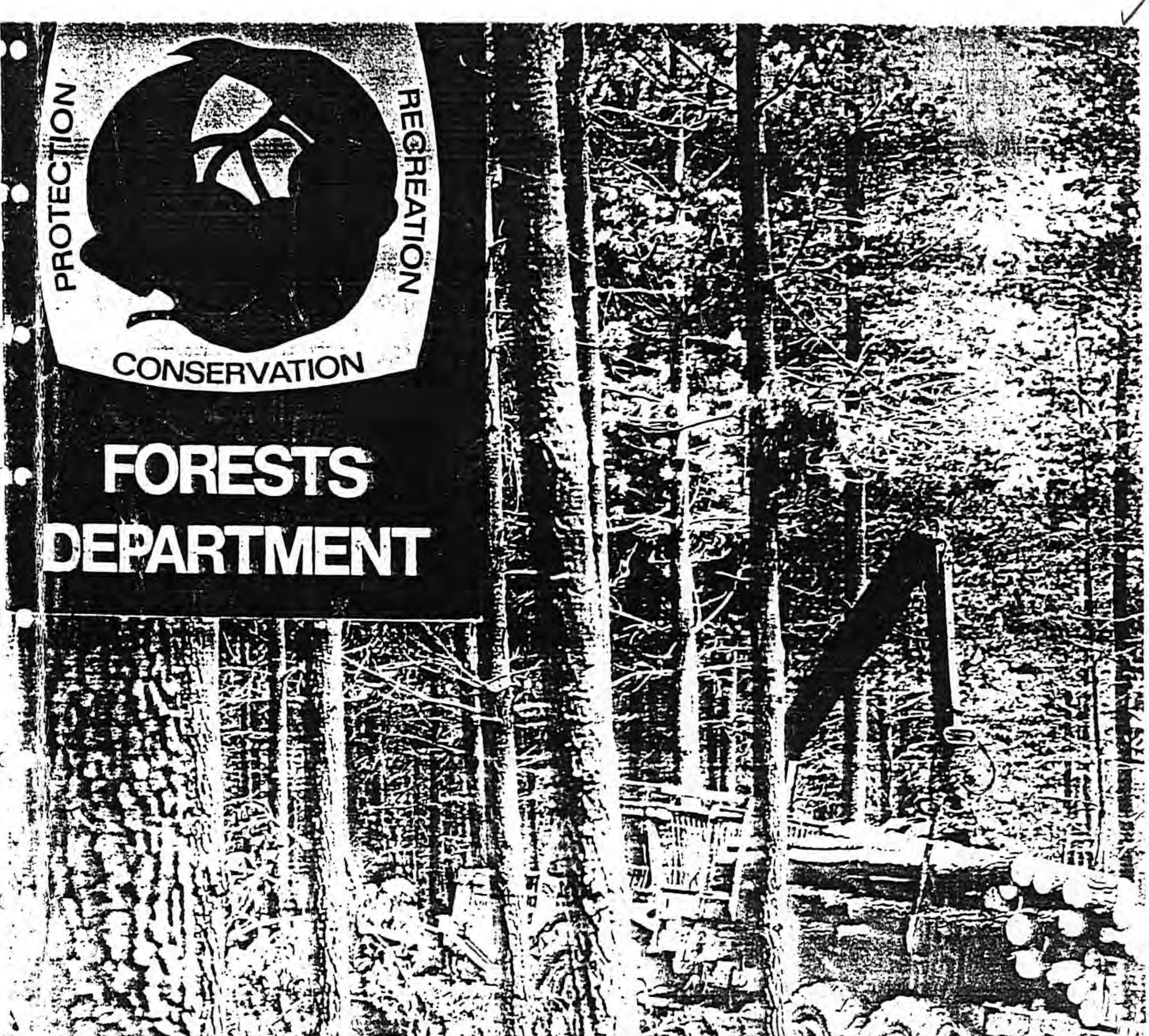

PROTECTION PYROTECHNICS FOR PINE PLANTATION PYROLOGISTS

\- A REVIEW OF RESEARCH INTO FUEL REDUCTION
BURNING UNDER P. RADIATA -

N. BURROWS
1984.

1984
N.D BURROWS

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GUIDES TO SLASH FUEL REDUCTION BURNING IN
P. RADIATA PLANTATIONS IN WESTERN AUSTRALIA

BY

N.D. Burrows

1984

SUMMARY

Thinning and pruning operations considerably re-structure the fuel arrangement in fire sensitive *P. radiata* plantations. The likelihood of crown fires is reduced, but up to 30 t/ha of fuel can be added to the ground fuels. Much of this is aerated, fine flash fuels which exist in a highly flammable state for up to 3 years.

Research in Western Australia and Victoria has shown that the flash fuel component (aerated twigs and needles) can be removed by burning under mild conditions.

Provided the fire intensity is maintained below 200 kW/m, stands older than 12 years will not be adversely affected. Pine burning requires a professional approach and adherence to guidelines if it is to be successful.

This report discusses the results of research and presents burning guidelines for plantation managers.

INTRODUCTION

In the south west of Western Australia, some 27,000 hectares of *Pinus radiata* D. Donn. plantations have been established on land held as State Forest to supplement the production of sawn timber from native hardwood forests (Beggs, 1982). The total standing value of these plantations is in the order of $25 million and current plantation establishment costs are $400 - $450/hectare excluding overheads. The potential exists for large monetary losses directly from wildfires and subsequent discruptions in sawlog supply to the timber industry in Western Australia.

Timber harvesting, - thinning and pruning operations produce large quantities of highly combustible residue slash (Burrows, 1980) which, if left untreated, severely increases the fire hazard and interferes with livestock grazing where this is practised. To assist in the protection of forests and surrounding assets from wildfire, considerable emphasis is placed on fuel reduction by low intensity (<350 kW/m) fire (Underwood & Christensen). In Western Australia, this has been largely confined to eucalypt forests which are far more fire resistant than fire sensitive *P. radiata*.

The re-arrangement of plantation fuels caused by thinning and pruning can have a significant effect on fire behaviour (McArthur, 1962). While thinning and pruning *per se* may decrease the probability of the start and spread of crown fires, the protection benefits of fuel re-arrangement in the crowns will be offset, probably for 3 - 4 years following the operation, by increased quantity of aerated ground fuel (Rawson, pers. comm.). Reducing the amount and arrangement of this fuel will increase the level of protection within a plantation (Burrows, 1980).

Recent research in Victoria has shown that low intensity (< 200 kW/m) fire can be successfully used to reduce such fuel accumulations in *P. radiata* plantations (Bitling et al). A knowledge of fire behaviour is a necessary first step to successfully burn slash fuels. When this is gained, the best conditions and techniques for carrying out such burns can be determined. The study of the behaviour of slash fires in the field and over a range of weather and fuel conditions is constrained by plot preparation costs, potential fire damage to trees and the risk of fire escape.

A recent pine fire near Grimwade highlights our lack of knowledge of pine fire behaviour and pine fuel characteristics for both prescribed fuel reduction burning and in forecasting the spread rate and behaviour of wildfires. Our knowledge of pine fuels and fire behaviour can be extended by a concerted research programe. While there has been considerable research into needlebed prescribed burns, there has been very little research into the disposal of flammable tops and slash by fire. It is the intention of this report to summarise the various aspects of slash pine burning research which has been undertaken in Western Australia since 1977. The report also draws on and discusses the research done by Victorian Foresters, especially Rawson, Billing, Woodman and Bywater. This report is not intended to be a heavy duty scientific document, but is aimed at providing operations staff with information to assist with pine protection. I have endeavoured to get this report out while the Grimwade pine fire, largest in the States history, is fresh on our minds, so apologise for grammatical deficiencies, typing errors etc.

1. P. RADIATA FUEL PROPERTIES

1.1 FUEL QUANTITY AND DISTRIBUTION

On many sites, clearing burns following chaining down of the native vegetation promotes the regeneration of dense native scrub species especially legumes such as *Acacia pulchella*. In many cases, the scrub regrowth competes with and keeps pace with the young pines up to canopy closure, which is usually by about age 5. Native scrub contributes 1.0 - 6.0 tonnes/ha. The scrub dies off with canopy closure and after this, contributes little to the total fuel quantity. Aside from intensive and costly operations such as spraying with herbicide, very little can be done to ameliorate these scrub fuels in young stands. The fire sensitivity of young pines prohibits burning to protect the young stands from fire.

Grasses growing beneath pines planted on reclaimed farmland can be grazed to reduce the fire hazard (Burrows, 1981).

Researchers in the Eastern States and in New Zealand have found that the build up of foliage (canopy) is slow until age 5 years, after which a rapid increase occurs until an equilibrium value of 10 tonnes/ha at age 10 - 12 years. The significant feature here, is that the fuel loading in the canopy does not alter after age 10.

After canopy closure (usually at about age 5 - 7 years) needles are cast. Many needles hang up in the branches and on the stems of the trees and accumulate on the ground. This forms an excellent fire ladder from ground to crown and promotes crown fire. In a 12 y.o. stand in Victoria, Williams (1977) estimated the quantity of dead fuel "hung up" in the trees to be in the order of 2.4 t/ha. In Western Australia, the quantity of dead suspended needles has been measured at between 1.0 - 3.6 tonnes/ha (Burrows, unpublished).

Needlebed fuel accumulation rate studies carried out in pine stands in Western Australia indicate that needle cast commences at age 5 - 7 years and the needlebed fuel steadily accumulates to age 15 - 20 years (Burrows, unpublished). Figure 1 below indicates a wide range of fuel loadings with variation in site and other growth and decomposition affecting factors. The effect of fuel reduction burning is also shown. After 15 - 20 years there is a balance between needle input and needle decomposition. On the most productive sites (such as found in the Blackwood Valley) equilibrium is reached at around age 15 years. This is supported by similar findings in Victoria and New South Wales.

FIGURE 1: Ground fuel accumulation rates with stand age. (P. radiata Nannup, Kirup, Grimwade) (Note the considerable variation).

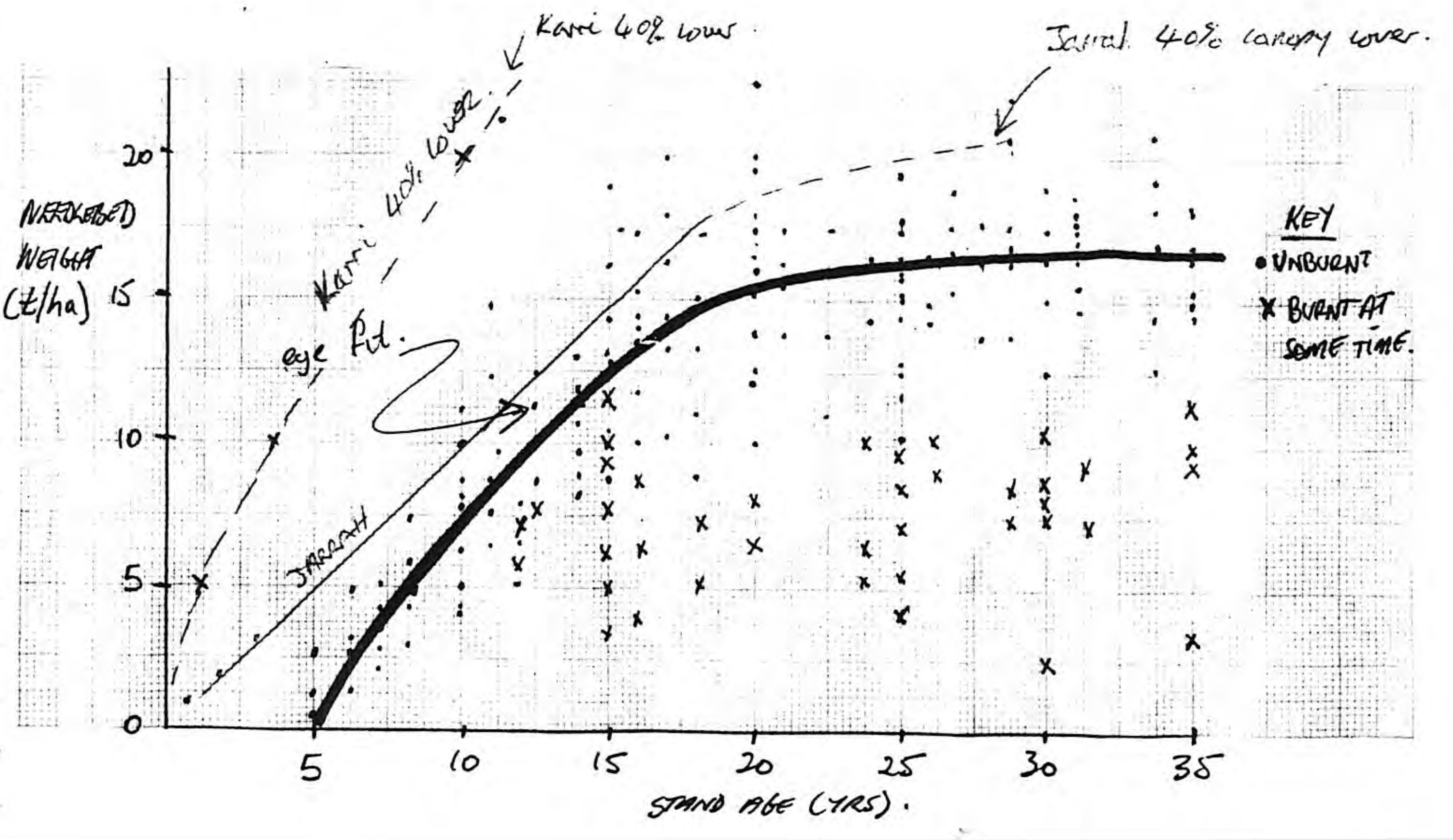


Table 1 shows the fuel quantity found at ground level in plantations of different age classes in North Eastern Victoria (Woodman, 1982). This has not been documented for Western Australian plantations, but is probably similar to the Victorian scene.

TABLE 1: (From Woodman and Rawson, 1982). Litter and duff quantities.

AGE CLASS YEARS	NO. OF SAMPLES	MEAN SURFACE LITTER WEIGHT (t/ha)	CO-EFFICIENT OF VARIATION (%)	MEAN DUFF WEIGHT (t/ha)	CO-EFFICIENT OF VARIATION (%)
10 - 14	134	4.4	39	9.6	53
15 - 19	128	2.4	78	7.3	89
20 - 24	78	3.5	50	9.4	60
25 - 29	38	3.4	44	9.1	42
30 - 34	34	3.1	48	7.7	68

The high co-efficient of variation reflects a wide range of fuel quantities.

Studies in 14 y.o. pine in Western Australia (Burrows, unpublished) have shown that needlebed burns which remove the surface needles (3 - 4 t/ha) are only effective for 18 months - 2 years after burning. After this time, fuel loads are at pre-burn levels.

1.2 FUEL RE-DISTRIBUTION BY THINNING AND PRUNING

Thinning causes major re-distribution of fuels in plantations. In the long term, thinning (and pruning) can be beneficial to fire control by decreasing the likelihood of sustained crown fires, but in the first few years (2 - 3) after thinning, a severe fire hazard exists on the ground.

Changes in the fuel distribution and the added quantity of ground fuels following thinning and pruning have been discussed by Williams (1978) and Burrows (1980). The undesirable ground fuel condition following thinning can be treated either by mechanical reduction (Burrows, 1981) or by using fire. The following reports on slash burning studies carried out in Western Australia and incorporates the results of researchers in the eastern states (esp. Rawson and Bitling).

2. METHOD - W.A. STUDIES

Thirteen small (.25 ha) plots were constructed in a recently thinned 14 year old *P. radiata* stand in a plantation near Grimwade. The compartment was commercially thinned in January 1979 from 750 stems/ha to 200 stems/ha. The operation was a chainsaw/forwarder operation.

The thinning operation deposited an additional 28.4 tonnes/hectare of fuel on top of the 8.0 tonnes/hectare of needlebed. Thinning slash comprised 5.0 t/ha of aerated needles, 6.5 t/ha of light branchwood (< 25 mm dia.) and 16.9 t/ha of heavy stemwood (> 25 mm dia.).

In an attempt to determine the moisture content at which the finer (needles) fuels would just sustain combustion, the moisture content of aerial needles (in tops) suspended needles (hung up in standing trees), ground surface needles (surface of the needlebed) was monitored over the winter months of 1979. At 1500 hrs each day, three samples, (each of ~ 30 grams) were taken from each of the fuel types described for oven dry moisture content determination. At the same time, 10 fusee matches were lit and thrown randomly amongst each fuel type. The number of sustained ignitions in each fuel type was recorded. When conditions were such that more than 80% of these test fires in the aerated fuel types, sustained ignition, and the ground needle surface fuels just carried fire, the plot was lit by a line of fire set at the upwind end of the plot.

Throughout the burn, all fuel moisture contents were monitored and fire behaviour recorded. An on site weather station provided windspeeds and direction, temperature and relative humidity. Table 2 below summarises weather, fire behaviour and fire damage to trees for the 13 plots burnt over a period from early August to early September, 1979. At the time of burning, the slash needles were in a red condition. Two years after burning, trees were inspected for signs of bole damage as a result of the fires.

3. RESULTS AND DISCUSSION

The average level of fuel reduction achieved by these experimental burns is summarised in Table 3. The quantity of fuel removed varied with fuel dryness and weather conditions, but ranged from 5.4 t/ha to 12.8 t/ha. All needle fuel in the thinning slash was removed as well 30 - 40% of the needlebed.

Headfire spread rates in slash fuels ranged from 24 m/hr to 78 m/hr and were generally 2 - 3 times faster than needlebed fires. Even on slow spreading fires, flames flared up to 2 metres when the fire burnt into elevated heaps of tops and debris. On a few occasions,

TABLE 2: Fuel, weather and fire behaviour for experimental fires in 14 y.o. *P. radiata* (slash fuels). Burnt August - September, 1979 (Note, these are mean values).

FIRE NO.	SMC	PMC	AMC	TEMP.	RH	WIND	CLOUD	SLOPE (°)	$\bar{x}$ HFROS TOPS	$\bar{x}$ HFROS N/BED	$\bar{x}$ H.F. FLAME HEIGHT TOPS	$\bar{x}$ H.F. FLAME HEIGHT N/BED	$\bar{x}$ H.F. FLAME LENGTH TOPS	$\bar{x}$ H.F. FLAME LENGTH N/BED	$\bar{x}$ H.F. FLAME LENGTH	$\bar{x}$ SCORCH HEIGHT
1	22	112	20	14	65	2.2	3/8	3	40	22	1.0	.15	1.2	.20	.8	5.3
2	18	148	16	15	58	1.8	3/8	4	60	35	1.4	.10	1.5	.15	1.0	6.5
3	19	125	17	14	64	2.5	4/8	2	44	21	1.3	.10	1.4	.15	.70	3.5
4	18	55	17	15	61	2.9	3/8	4	56	40	1.3	.20	1.4	.25	.9	5.8
5	18	81	16	16	58	3.9	1/8	4	78	39	2.1	.15	2.3	.25	1.3	10.0
6	16	62	16	18	45	2.6	4/8	3	45	23	1.3	.15	1.4	.20	1.0	6.6
7	15	60	14	20	45	3.3	0	2	74	34	1.6	.40	2.0	.50	1.3	10.0
8	18	32	17	19	45	3.1	0	2	34	22	1.0	.13	1.1	.18	.40	3.6
9	17	34	16	19	45	3.0	1/8	4	40	25	1.2	.15	1.4	.20	.50	4.0
10	18	40	17	18	55	3.1	6/8	4	25	15	.8	.08	.9	.09	.35	2.5
11	18	40	17	18	55	3.1	6/8	4	24	15	.8	.08	.9	.09	.35	2.5
12	18	150	17	20	52	3.5	2/8	6	75	30	1.5	.20	1.7	.30	1.2	9.0
13	17	110	16	20	50	3.1	2/8	7	75	30	1.6	.20	1.8	.25	1.2	9.0
MEAN	18	80	16.5	18	53	3.0	4/8	4	51	27	1.3	.16	1.5	.21	.85	6.0

TABLE 3: Fuel loading (t/ha) before and after experimental fires in 14 y.o. *P. radiata*.

	BEFORE				AFTER.				
FIRE NO.	NEEDLEBED	AERATED NEEDLES	WOODY ≤ 25mm	WOODY > 25mm	NEEDLEBED	AERATED NEEDLES	WOODY FUEL ≤ 25mm	TOTAL FUEL REMOVED (%)	INTENSITY
1	8.9	6.5	8.5	15.6	7.2	0	7.8	8.9 (23)	159
2	9.1	7.4	9.6	20.3	7.5	0	8.5	12.3 (24)	258
3	10.1	5.4	8.2	20.8	8.5	0	6.6	10.0 (22)	118
4	6.2	6.3	7.8	21.4	3.9	0	5.8	11.0 (26)	205
5	5.9	6.6	7.1	18.4	3.7	0	4.8	12.2 (32)	455
6	6.3	5.1	7.0	16.3	5.5	0	6.0	8.2 (23)	258
7	7.0	5.3	7.2	18.9	5.8	0	5.4	10.1 (26)	455
8	4.8	3.6	4.4	9.8	3.4	0	4.4	5.4 (24)	35
9	4.9	3.8	4.9	10.4	3.2	0	4.0	7.4 (30)	57
10	5.2	3.4	4.3	10.1	3.5	0	4.0	5.7 (24)	26
11	4.9	3.0	4.1	16.4	3.4	0	3.8	6.0 (21)	26
12	10.7	4.8	6.0	21.0	7.4	0	4.3	12.8 (30)	383
13	14.0	5.2	6.4	21.5	9.8	0	4.8	12.8 (27)	383
MEAN	7.5	5.0	6.5	16.9	5.6	0	5.4	9.4	216

suspended dead fuel ("hung up" needles) within standing tree crowns, flared up, but presented no control problems.

3.1 LIGHTING TECHNIQUE

Under calm and stable conditions, a fire allowed to develop from a single spot ignition will give excellent results in terms of reducing the fuel quantity. However, this technique is very responsive to wind fluctuations. Backfires are tolerant of changes in wind speed and direction. A backfire can only burn very quietly into wind (20 - 25 m/hr) and the wind must swing 180° before the backfire can develop into a fast spreading headfire. Such dramatic wind shifts are unlikely under the mild conditions of these types of burns. Also, coalescence and its associated unpredictable and often severe fire behaviour is avoided using the backfiring technique.

3.2 BURNING GUIDELINES

The lighting pattern recommended for operational use is a line of fire allowed to backburn across the area to be treated. These slow moving fires may be inadequate if large areas are to be treated, but initially small strips or buffers no more than 100 m in depth should be burnt using this system.

TABLE 4: Recommended conditions for burning pine slash (Burrows, unpublished).

SOIL DRYNESS INDEX	SURFACE MOISTURE CONTENT (%)	PROFILE MOISTURE CONTENT (%)	AERIAL NEEDLE (SLASH) M.C. %	AIR TEMP. (°C)	R.H. (%)	WIND IN THE FOREST (K.P.H.)
<250	17 - 24	≥45	16 - 24	≤22	≥50	2 - 4

The conditions specified above should give a fire with a very low spread rate in the needlebed fuels (10 - 20 m/hr) and low spread rate in aerated slash fuels (20 - 40 m/hr). Aerated fuels are more responsive to humidity changes than the surface needlebed fuels and are usually 2 - 3% drier. Before lighting, a test fire should be lit in the needlebed fuels to ensure that the needlebed will sustain a very low intensity fire with flame heights <20 cm. Surface and aerated needles respond faster to humidity changes than do eucalypt litter fuels, so it is very important that, throughout the light-up phase and during burning, fuel moisture conditions are closely monitored with a marconi moisture meter and that wind, temperatuer and relative humidity are likewise monitored. The most stable conditions for these burns are usually in August and September and in the afternoon. Light-up times of between 1200 and 1400 hrs have been most successful as this usually gives 2 - 4 hours of burning time. It is crucial that the profile moisture content be ≥45% and that logs and woody fuels are wet (i.e. S.D.I. <250). A low S.D.I. is indicative of a high profile moisture content. The moisture content can be determined by using speedy or marconi moisture meters or by the oven drying technique. If the profile is too dry, stem damage and control problems will be experienced.

The temperature and relative humidity ranges in the above table indicate the mild conditions and will also affect the moisture content of surface and aerated needles. Air temperature will also influence scorch height. Close attention must be paid to the weather conditions on days preceeding the burn and on the day of the burn. The conditions described in Table 4 are most likely to occur in late winter or early spring and will only occur on a very few days (6 - 10 days). Changes in weather conditions during the day will further limit burning time. A good local knowledge of changes in temperature, relative humidity and wind are important in establishing ignition and burnout times. Further aids to burning are presented later.

Slope has been left out of the burning guidelines because it will not promote fire behaviour using the backfiring technique. In fact slope may cause backfires to be milder than prescribed. Difficulty may be experienced when slope and wind interact, especially when wind is blowing down or across the slope. No clear prescription can be given on lighting technique, but steepness of the slope and wind strength must be considered and a judgement made in the field. If in doubt, don't light up. Steep ($> 10^{\circ}$) slopes can be burnt by backfires when the wind strength is very low ($<$ 3 k.p.h.).

4. FIRE DAMAGE

Maximum scorch heights should be kept below 6 m for stands older than 12 years. Of the experimental fires reported here, fires 5 and 7 caused unacceptable scorch and stem damage. Fire intensity must be kept below 200 kW/m to avoid excessive scorch. (flames generally $<$ 1m. Flash flames to 2m acceptable. "Thick", (needlebed or compacted) fuel flames must not exceed 20 cm.)

Studies carried out in Victoria (Woodman & Bitling, 1979) showed that fires with <u>maximum</u> intensities less than 200 kW/m in stands aged 11 and 16, did not show any reduction in height or diameter increment for 18 months after burning. They also found that stem damage was minor and was strongly related to bark thickness - thinned barked trees were more susceptible. (More on tree damage later).

Figures 2 and 3 below show flame heights likely from burning slash (for given mild conditions) and likely scorch heights. (Burrows, unpub.).

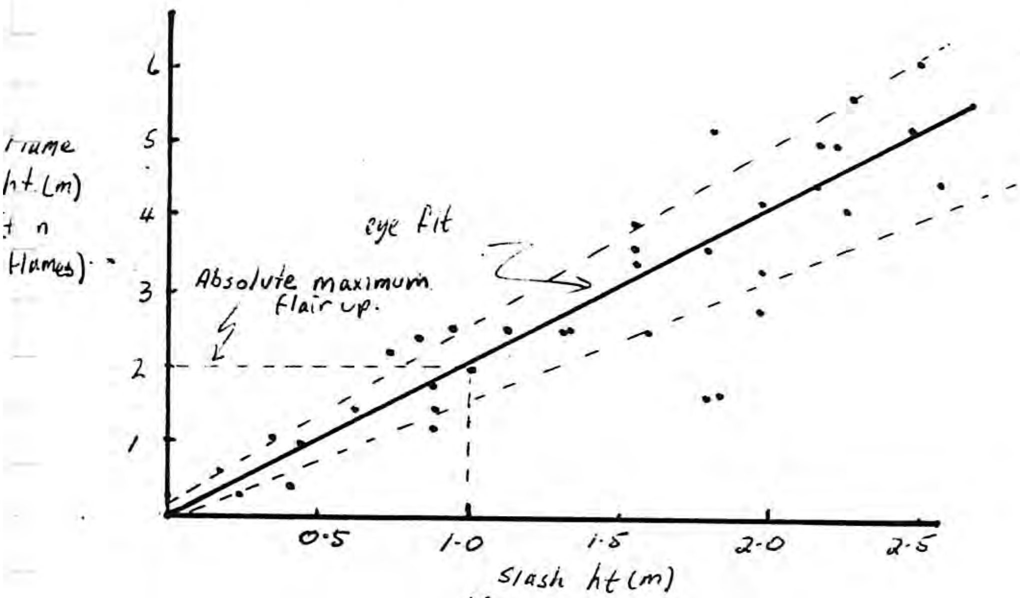


FIG. 2

Flame ht vs slash ht - non compacted slash (ie: well aerated) - for conditions in table 4.

N.B. "Thin" flames or those from burning flashy fuels as opposed to "thick" flames from compacted or needlebed fuels.

- - - - - = upper & lower limits.

"Thick", needlebed flame must be < 20cm.

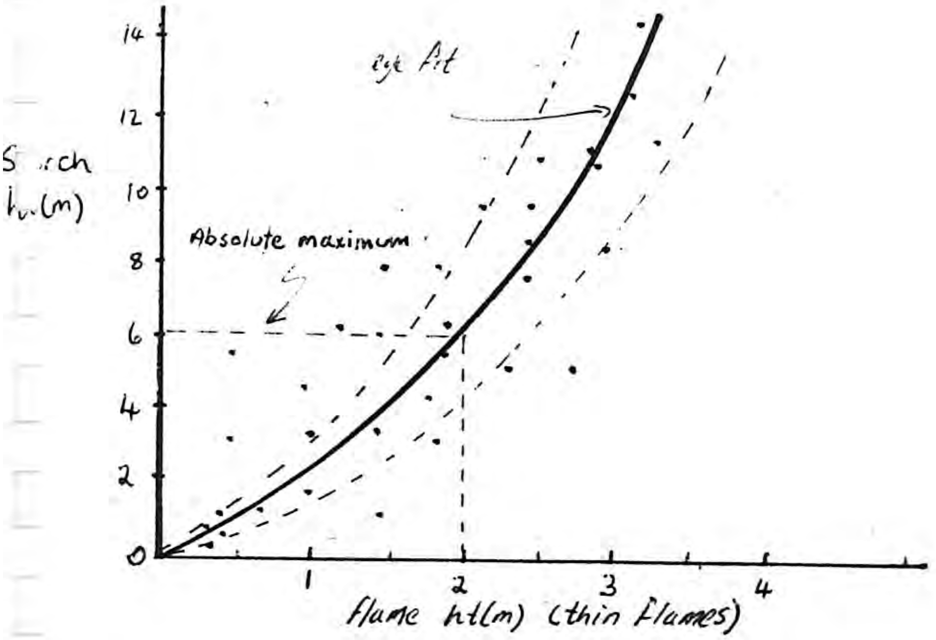


FIG 3:

Flame ht vs Scorch ht. for "thin" flames & cool conditions (Table 4). Scorch will be higher for warmer, drier conditions or if trees are under drought stress.

- - - - upper & lower limits.

A NOTE ON FIRE INTENSITY

Byram's Fire Intensity is determined by:

$I = HWR$

where:

I = fire intensity (kilowatts per meter kW/m)

H = heat yield of the fuel and ~18,600 kilojoules per kilogram (may be a little less for pine fuels)

R = headfire rate of spread in meters per sec.

A quick way of calculating I is:-

$$I = \frac{\text{fuel consumed (t/ha)} \times \text{headfire rate of spread (m/hr)}}{2}$$

or: from flame length

where $I = 258\ (Fl)^{2.17}$. The problem with this is that flame length is variable and difficult to measure accurately, so I prefer to use the first formula.

As a guide to determining available fuel in slash burning, use (i) litter depthing from Red Book, (ii) slash fuel estimates from Res. Note No. 60, 1980. For the conditions described in table 4 (p. 12); assume the following availability:

- needlebed (see p. 23 - Red Book)
- aerated slash (needles) - complete removal
- woody fuel < 25 mm dia - 20% of total (1/5)
- stemwood > 25 mm - 0

e.g.

Needlebed

(i) surface fuel moisture content = 19%

(ii) profile fuel moisture content = 55%

(iii) average litter bed depth = 20 mm = 9.0 t/ha.

from Red Book, table 7.2.1, available fuel factor = .6 = .6 x 9.0 = 5.4 t/ha. This will be a maximum, as under these cool conditions, available factor will be more like 0.4 = 3.6 t/ha (PMC up to 150%).

∴ available fuel - needlebed ~ 4.5 t/ha (average).

Slash

(i) 550 stems/ha have been commercially thinned (not machine harvested)

(ii) ∴ ~ 5.1 tonnes/ha of aerated needles

(iii) ~ 5.9 tonnes/ha of light branchwood (< 25 mm dia)

(iv) ~ 13.9 tonnes/ha of large stemwood

(from Res. Paper No. 60).

All aerated needles will be burnt	~ 5.1 t/ha
*20% (.2) of branchwood be burnt	~ 1.2
No stemwood (to speak of) burnt	0
total slash burnt =	6.3 t/ha
total fuel burnt =	+ 4.5 (needlebed)
	= 10.8 t/ha

* For conditions described in table 4, p.12.

Now

$$\text{Max. I} = 200 = \frac{\text{fuel burnt (t/ha) x R.O.S. (m/hr)}}{2}$$

$$\therefore \text{ Max. R.O.S.} = \frac{2 \text{ x } 200}{10.8} = 37 \text{ m/hr}$$

5. CONCLUSION

Low intensity (< 200 kW/m) fire can be used to remove the flash fuels following thinning/pruning in *P. radiata* stands older than 12 years. No significant stem damage or loss of growth has been observed where fire intensity is < 200 kW/m.

Fire managers must carefully monitor fuel moisture and weather conditions prior to and during the burning operation. If the guidelines are not strictly adhered to, success is not guaranteed. As these guidelines are based on only 13 experimental fires, they may not cover the range of suitable burning conditions, but until further work is done, they should be adhered to.

6. OPERATIONAL GUIDES FOR BURNING SLASH FUELS

1. Aerated (flash or slash) fuels will exist in a flammable state for 2 - 3 years. It is recommended that where stands are older than 12 years, slash fuels be reduced by burning or crushing.

2. Slash heaps should be less than 1 m in height and should be away from the base of trees. This can be controlled during thinning/pruning operations or heaps can be re-arranged prior to burning.

3. Slash should be burnt while it is in the "red" stage. Trying to burn earlier may not be successful and any further delay in burning prolongs the hazard. It may not be efficient to burn grey needles as these are highly weathered and will soon fall to the ground.

4. Slash burns should be carried out in winter - spring and on an S.D.I. < 250. Some autumn burning may be possible, but planning should be for the former conditions.

5. The moisture content of fine fuels is particularly important for the successful implementation of slash burning. Accurate measurement of moisture content is essential, using moisture meters or the oven drying technique. (See later section)

The Table below (Williams, 1977) relates the moisture content of radiata pine needles to fire behaviour.

TABLE 5: Fuel moisture content and fire behaviour.

FUEL MOISTURE (%)	FIRE BEHAVIOUR
25 - 30	* Elevated needles will just ignite and will carry fire only with the assistance of wind. **Surface needles will not ignite.
20 - 25	Elevated needles will ignite and just carry fire (e.g. ROS <15 m/hr). Surface needles will ignite and only carry fire with the assistance of wind.
15 - 20	Elevated dead needles easily ignite and carry fire of low spread rate (e.g. ROS up to 45 m/hr). Surface needles ignite and carry slow moving fire (20 m/hr).
10 - 15	Elevated needles carry fire of moderate spread rate (e.g. 60+ m/hr). Surface needles easily ignited and carry fire of moderate spread rate. (50 m/h)

P.T.O.

FUEL MOISTURE (%)	FIRE BEHAVIOUR
7 - 10	Elevated needles carry fire of high spread rate (e.g. 200+ m/hr), possibly crown fire, difficult to control. Surface needles carry fire of moderate to high rates of spread (100+).
< 7	Very intense (> 2,000 kW/m) possible with spread rates > 500 m/hr, crowning and control of headfire likely to fail. * Elevated needles = dead pine needles lodged in branches, in logging slash etc. so that they are well aerated and above the ground. **Surface needles refer to the top layer of dead pine needles on the plantation floor.

Work done by Woodman (1982) on fuel moisture changes is summarised:

- Variations in moisture content are likely to be more pronounced in thinned stands, i.e. those exposed to greater fluctuations in temperature, relative humidity and air movement.

- A fuel moisture differential commonly exists between elevated fuels and ground litter fuels.

- The moisture content of the needle fuels (especially elevated and surface) can change in a couple of hours from levels where burning is difficult to sustain to levels where moderate to severe fire behaviour can occur.

Woodman (1982) derived a model to predict litter fuel moisture changes under drying conditions. This model (discussed below) has application in planning fuel reduction burning operations (Woodman & Rawson, 1982) as it can help to indicate:-

(a) the time of day when litter fuel moisture content will decrease to a level where successful burning is possible

(b) the time over which suitable burning conditions will hold before moisture levels become too low.

To predict changes in litter fuel moisture content under drying conditions, adopt the following procedure:-

(a) measure the actual fuel moisture content and relative humidity. e.g. MC = 22%, RH = 50%

(b) determine the appropriate equilibrium moisture content (EMC) (13.5%) from fig. 4(a)

(c) use the difference between the actual MC and the EMC (8.5%) to determine the likely moisture loss in the next one hour (5.5%) and the next 2 hours (7%) from fig. 4(b)

(d) the actual MC in one hour (16.5%) and two hours (15%) can then be calculated.

FIG 4(a) : EQUILIBRIUM MOISTURE CONTENT – P. taeda (after Woodman)

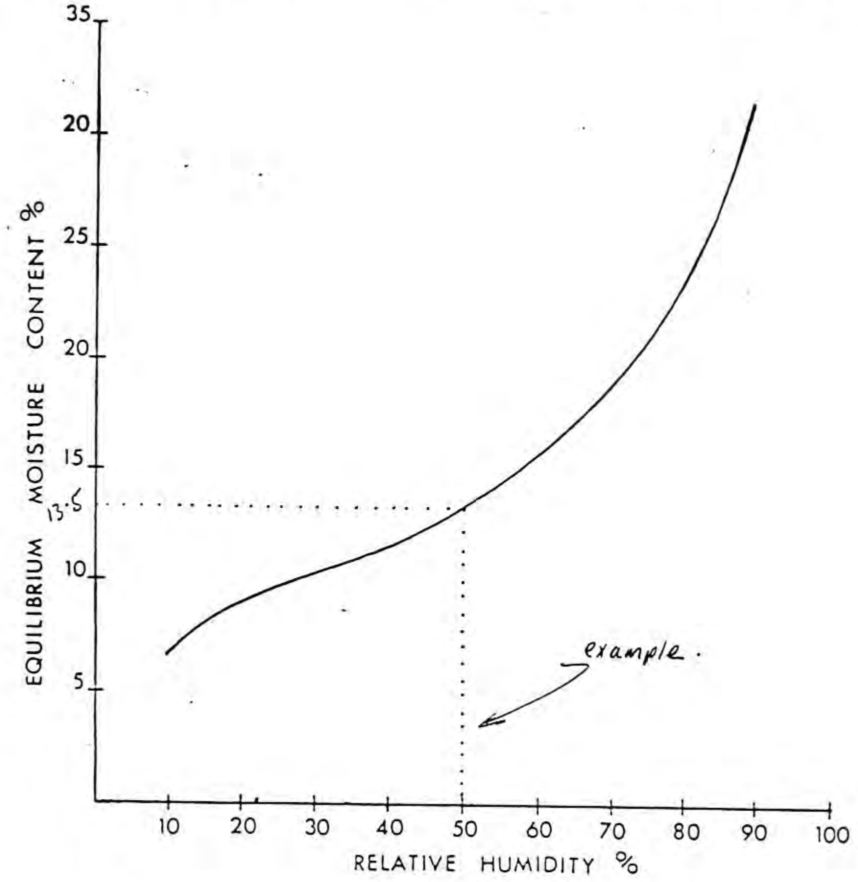
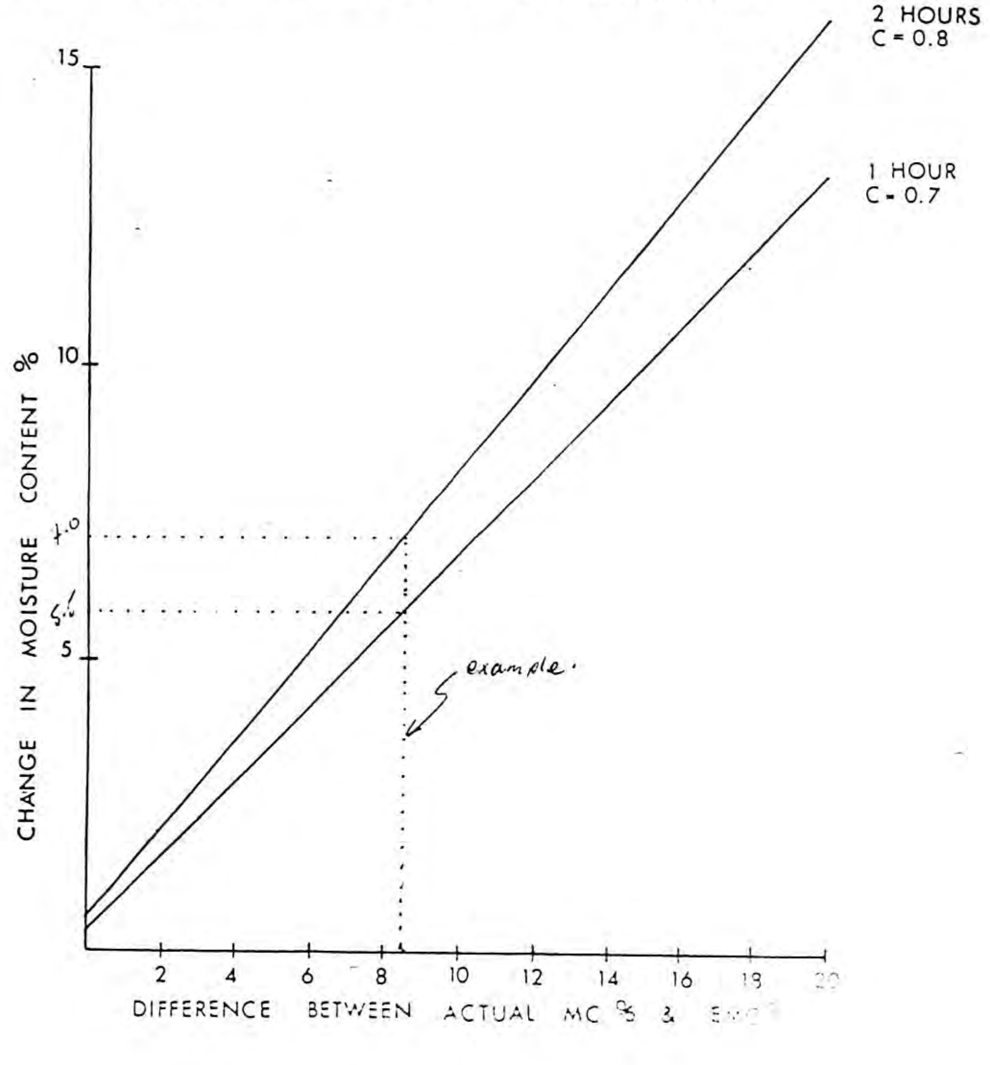


FIG 4(b) : CHANGE IN LITTER MOISTURE CONTENT



ADDITIONAL AIDS FOR FUEL REDUCTION BURNING UNDER P. RADIATA

1. GENERAL

1.1 In contrast to fuel reduction burning in eucalypt forest, burning in P. radiata should be confined to small areas. Pinus radiata is fire sensitive and variations in fuels, slope, aspect and weather can produce undesirable fire intensities. Burning on small areas simplifies the burning operation and allows maximum control of fire behaviour. On a small area, it is possible to fully evaluate the likely effects of topography, fuel and weather on fire behaviour. Lighting pattern and rate of ignition and burnout are more readily controlled. The actual size of the burn is best determined by the officer planning the burn, taking into consideration the factors mentioned above as well as man power, value of the area, risk rating, burning time, location in relation to rest of plantation and adjacent land.

1.2 Areas selected for burning should have a vertical fuel break of 2 - 3 m between ground level and dead suspended fuels in the lower section of tree crowns. This is usually achieved by pruning or vertical fuel removal burns (see separate section).

1.3 The lighting pattern recommended as a starting point is a line of fire allowed to back burn into wind or downhill. If this is too slow (moisture contents at top end of the range) it may be necessary to set a line of spots about 20 - 30 downhill/ downwind and about 10 - 15 m apart. These distances may have to be varied and is best judged on site and at the time.

Whatever - proceed with caution and ensure fire intensity remains low (i.e. backfires should spread at 10 - 25 m/hr and headfires ≤ 45 m/hr).

1.4 Fuel moisture content and wind speed are the two most important factors determining the success of the burn (see guides). The appropriate fuel M.C. will depend to some degree on the nature of the fuel bed. More compact fuels (such as from machine harvesting) will require slightly lower moisture contents to burn (probably 1% lower than recommended in guide). Experience and increased confidence will probably allow the guides to be extended a little, but they provide a start point.

1.5 The moisture content of aerated and suspended needles will be highly responsive to changes in cloud cover and relative humidity/temperature. You must continuously monitor temperature, RH, fuel moisture and wind speed so you can obtain an early indication of deteriorating burning conditions (see below).

1.6 The moisture content requirements for slash burning are more likely to occur in spring. Less damage to crowns and boles is likely at this time.

2. MEASURING FUEL AND WEATHER FOR PRESCRIBED BURNING IN PINES

2.1 FUEL MOISTURE

You will be very much aware of the importance of fuel moisture on fire behaviour.

Methods for measuring fuel moisture:-

- prediction systems based on the relationships between fuel moisture and weather as described in the Red Book. These are O.K. as a lead-up to burning conditions - i.e. these systems will enable you to predict days on which burning is likely and no more.

- direct measurement including instruments such as marconi moisture meter, speedy moisture meter, oven drying using micro-wave ovens or infra-red lamps and weighing machines. The marconi moisture meter works well for fuel moisture contents between 8 - 25%. Oven drying techniques are the most precise, but can be time consuming.

2.1.1 FINE (NEEDLE) FUEL MOISTURE CONTENT

2.1.2 LOCATION

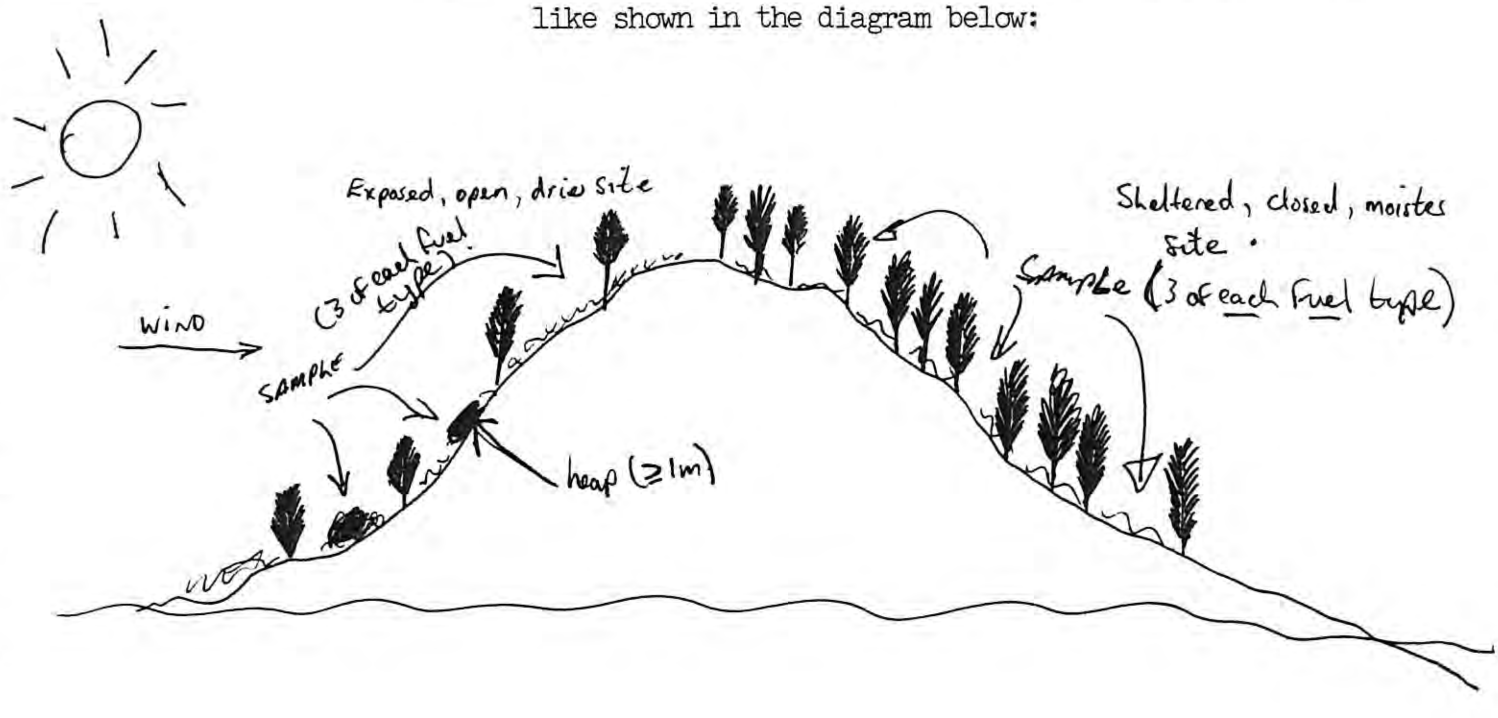
The aim is to attempt to not only establish an average fuel moisture content but also to determine the extremes of moisture content. Locate the drier aspects - i.e. north facing, exposed to wind (lower canopy cover) on ridges etc. and compare those moisture content values with the wetter aspects found on southern slopes, under dense canopies, gullies and generally sheltered and shady areas.

With slash heaps, take 3 separate moisture content readings - one from the top (exposed needles), one in the middle of the slash heap and one from the bottom. You may have to take 2 or 3 readings from these 3 locations. If the reading from the bottom is lower than recommended, burning is not advised if slash heaps contribute significantly to the fuel type. It is desirable to spread heaps before burning and to keep slash below about 1 m in height.

2.1.3 SELECTING THE SAMPLE

Select dead but not decomposed needles (i.e. red or grey needles) from a variety of sun/shade situations for aerial and surface fuels. Keep aerial and surface fuel samples separate. Surface fuels are the same as described in the "Red Book". Bearing in mind the site difference and the effects of heaps (discussed above) initially take 3 separate samples each of about 40 - 50 grams (a good handfull) from each location. Note from which location the samples were taken and place samples in an air tight container.

e.g. Assume the area you are about to burn is something like shown in the diagram below:



2.1.4 How you would initially sample.

- 3 surface needle samples (top 10 mm of needlebed) each 50 g, from representative (sun/shade or mottled shade) locations from each side of the hill. i.e. a total of 6 surface fuel moisture samples. Keep each sample separate and label tins as "exposed" or "dry" or "moist" etc. to differentiate the sites from which they came.

- 3 profile moisture samples (see "Red Book") same as surface above, from each site.

- 3 aerial (aerated, suspended - slash) samples - same procedure as above, from each site.

- 3 samples from heaps (as discussed) and from each site.

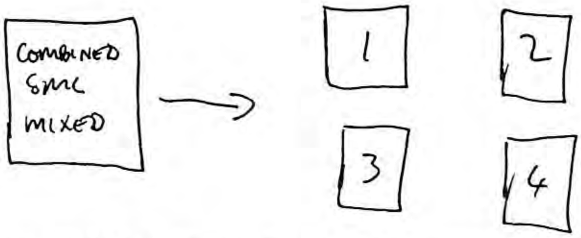
While this is a lot of sampling, it is unlikely that you would find this amount of variation in a small burn. More often than not, 3 samples of each of surface profile and aerial fuels will be adequate. It is largely for you to judge the site.

2.2 PREPARING THE SAMPLES FOR MOISTURE CONTENT DETERMINATION

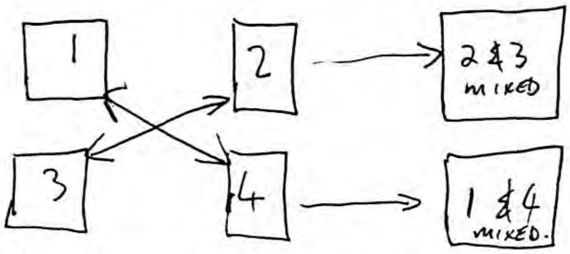
- Separate tins according to the site from which samples were gathered.

- Select the 3 surface moisture samples from one of the sites, mix and spread contents on a flat, ~~then~~ clean surface.

. Divide this combined sample into 4 quarters.



. Combine the diagonally opposite quarters and mix well.



Having done this, one of the halves can be used for the Marconi moisture meter and the other either discarded or used for an oven drying check.

For fuel moisture determination using the marconi, check the "users" manual and follow instructions carefully.

Repeat this procedure for aerial and profile samples, remembering to record the moisture contents from each fuel type and from each site (where applicable). Profile moisture may be beyond the range of the Marconi. If you are not confident that the profile and the duff are wet enough, you may have to oven dry the sample to confirm.

If using a portable system of oven drying, mince up samples using a spong. Record the air dry weight of the sample and continue drying the sample until no further weight loss is observed. If using a micro-wave oven, samples should be weighed every 2 minutes initially (the duration depends on how wet the sample is) and as the sample dries, every 30 seconds. Fuel will ignite in the microwave if left too long. If you are contemplating the use of infra-red lamps or microwave, contact Fire Research, Manjimup for advice on procedure.

Having determined the range of fuel moisture contents on the block to be burnt, you are now in a position to judge whether you should light up and if so, how. Remember to sample aerial and surface fuels each hour or so after light up. An officer should be set aside specifically to maintain a check of fuel moisture and weather conditions. After the initial sample prior to ignition, it will not be necessary to sample all sites and locations thereafter. It will be adequate to maintain a check on fuel moisture conditions on your driest site/location. In the event that fuels are drying out, ignition may have to be stopped. It is recommended that ignition commence after the peak period of the day (usually 14 - 1500 hours).

Fuel moisture content sampling should be commenced several days prior to the day on which you expect to burn <u>or</u> the day after the last shower of rain in excess of 5 - 10 mm and when the S.D.I. $<$ 250. Sampling prior to burning should be done at the peak hour of the day, around 1500 hours. There is no substitute for local knowledge in deciding when a pine burn should be contemplated and when pre-burn sampling should be commenced. "Red Book" SMC/PMC predictions are a very useful guide to when you should be sampling in the field. Remember to record all sample results and file away.

3. MONITORING FIRE WEATHER

We are all very much aware of the effect weather has on fire behaviour. Fire in slash fuels and especially needles, is more sensitive to changes in weather than even in eucalypt fuels. It is somewhere between eucalypt fuels and grass fuels.

3.1 RAINFALL

Weather leading up to the burn is usually recorded at the office. Very often, weather experienced at the office is not the same as might be experienced at the burn site. Rainfall is particularly variable and important, so it is advisable to set up a rain gauge near the burn and preferable in a clearing. This should be checked daily prior to burning and observations used for SMC and PMC calculations.

3.2 TEMPERATURE AND HUMIDITY

On the day of the burn and during burning, both temperature and relative humidity should be closely monitored. Thermohydrographs are not robust enough for field use, so an aspirated or whirling phsychrometer should be used. Readings should be taken under the canopy, in the shade and every hour or so.

3.3 WIND

Wind, with fuel moisture, dominates fire behaviour. It is essential that the wind speed and direction is measured prior to ignition and measured each 10 - 30 minutes during burning. Longer range forecasts (hourly or two hourly) are available and should be incorporated, together with a local knowledge of wind behaviour, in executing the burn.

On site, wind speed can be measured under the canopy using a variety of sensitive cup type anemometers, including hand held versions. Observations from further afield, such as nearby Divisional officers are useful in anticipating changes. For example, Nannup Division should keep in contact with the Margaret River office for advance warnings on the arrival and strength of a sea breeze.

All weather, fuel and fire behaviour observations made prior to and during the burn, should be documented and filed. Documentation will enable a review of the success of the operation, the validity of the burning guides and can provide valuable information for the next burn. An officer should be nominated to observe and record this information which should be fed to the fire boss. Recording information at a fire is done for similar reasons that bomb disposal experts communicate their defusing process step by step - so that others may learn what NOT to do! Remember, you may not always be in a Pine Division and your replacement, who may have spent all his time at Walpole, will be grateful for your documentation of pine burns.

A necessary and final step in burning is to assess the success of the burn. This can be done by taking 20 - 30 needlebed depth measurements before and after burning and noting the quantity of aerial (flash) fuel removed by the fire. Again, the quality of the burn, including scorch height and butt damage, should be measured and documented.

6.1 LIGHTING TECHNIQUES

Careful consideration must be given to the method of ignition to ensure a controlled and low (<200 kW/m) intensity fire. Drip torches should be used and as mentioned earlier it is safest to start with a line of backfire. If this is burning too slowly, then a line or a line of spots can be lit 10 - 20 metres downwind or downslope of the original backfire. Burning is part science and part art. Ignition pattern and timing is the artistic part and can best be judged at the time, but PROCEED WITH CAUTION and always keep a check on weather and fuel moisture conditions. Pine burning, unlike hardwood burning, is far more sensitive to changes and far less forgiving of "hot spots" - it kills the trees outright! Ensure that junction zones do not coincide with planting lines! Do not try to simultaneously light up and burn out large areas, as is the custom in hardwood forest. Concentrate on strategic strips, high risk areas etc. first.

6.2 MOP UP

If the prescription is successful, there should be little mop-up. A feature of pine burning is that resin in stumps and stems may burn after the main fire. This is easily extinguished and cooled. Under these mild conditions, spotting and hop-overs should almost be non existent unless there are hardwoods (marri esp.) growing among the pines.

Finally, carefully document all attempts at hazard reduction in pines. Records of fuels, weather and techniques can be used to improve our performance, so on this basis alone, no fire is unsuccessful.

- PINE PROTECTION WORKSHOP - APRIL 1984

SOME EFFECTS OF LOW INTENSITY BURNING ON RADIATA PINE

N.D. Burrows

SUMMARY

Results from studies carried out in Western Australia and in Victoria show that trees older than 11 years can withstand fires of up to 200 kW/m. After these fires, no loss in growth or mortality was observed. In one instance in Western Australia, droughting was responsible for deaths and loss of growth. Often, trees with scorch (more than 2 m of green crown) were better able to survive drought.

Stem damage to trees was non-existent or very minor for fires < 200 kW/m. Trees which were fully scorched by fires of up to 750 kW/m were killed and severely infested by Ips grandis. The level of stem damage is also a function of bark thickness, with younger, smaller trees being most susceptible.

When carrying out slash (or tops) burns it is essential that tops be more than 1 m from the base of trees. Trees injured by thinning or trees with considerable resin discharge were prone to extended stem damage by fire, but this was observed in only a few cases.

Summary of the Results of Several Studies

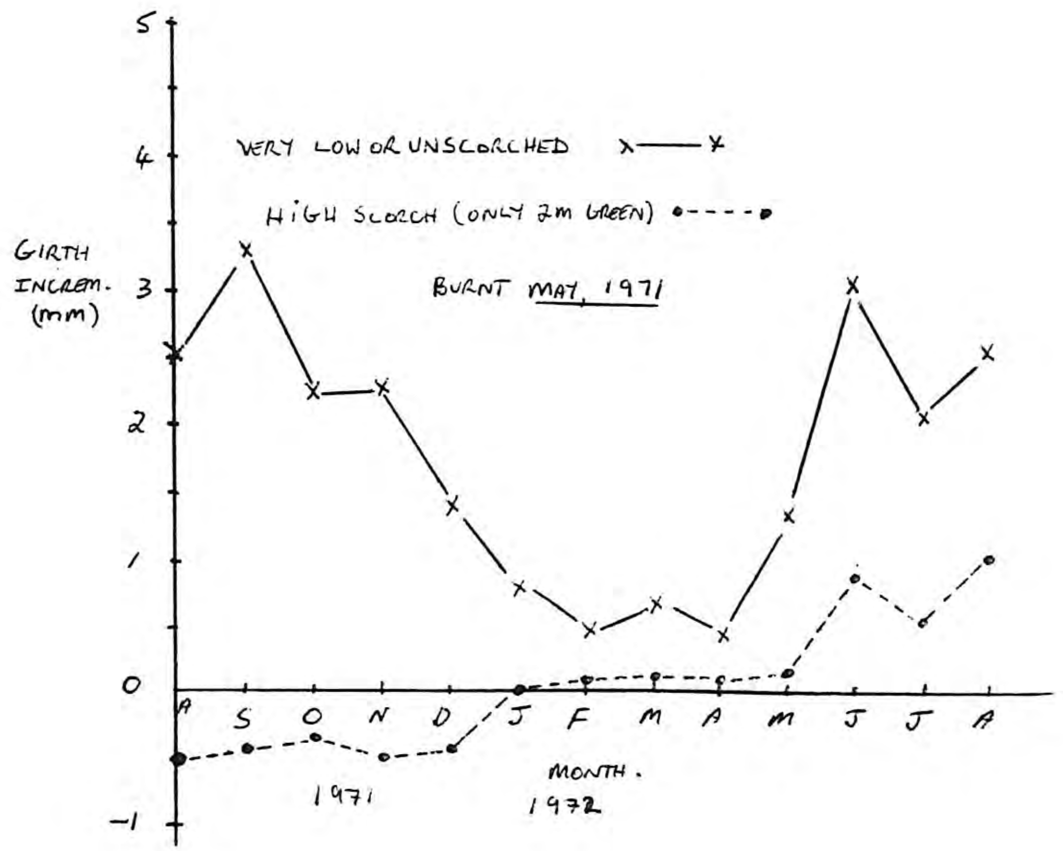
TABLE 1: *P. radiata* growth for burnt (<200 kW/m) and unburnt stands (From Woodman, 1979) Victoria.

STAND AGE (YEARS)	INCREASE IN STAND HEIGHT (18 MONTHS)		MEAN DIAMETER (CM) INCREMENT (18 MONTHS)		% OF TREES DEAD	
	BURNT	UNBURNT	BURNT	UNBURNT	BURNT	UNBURNT
11	1.6m	1.9m	0.8	0.8	2.1	2.6
16	0.9m	1.5m	0.7	0.8	0.9	0

TABLE 2: Mortality of 13 y.o. P. *radiata*, scorched but with at least 2m of green tip. (Sneeuwjagt, 1973)

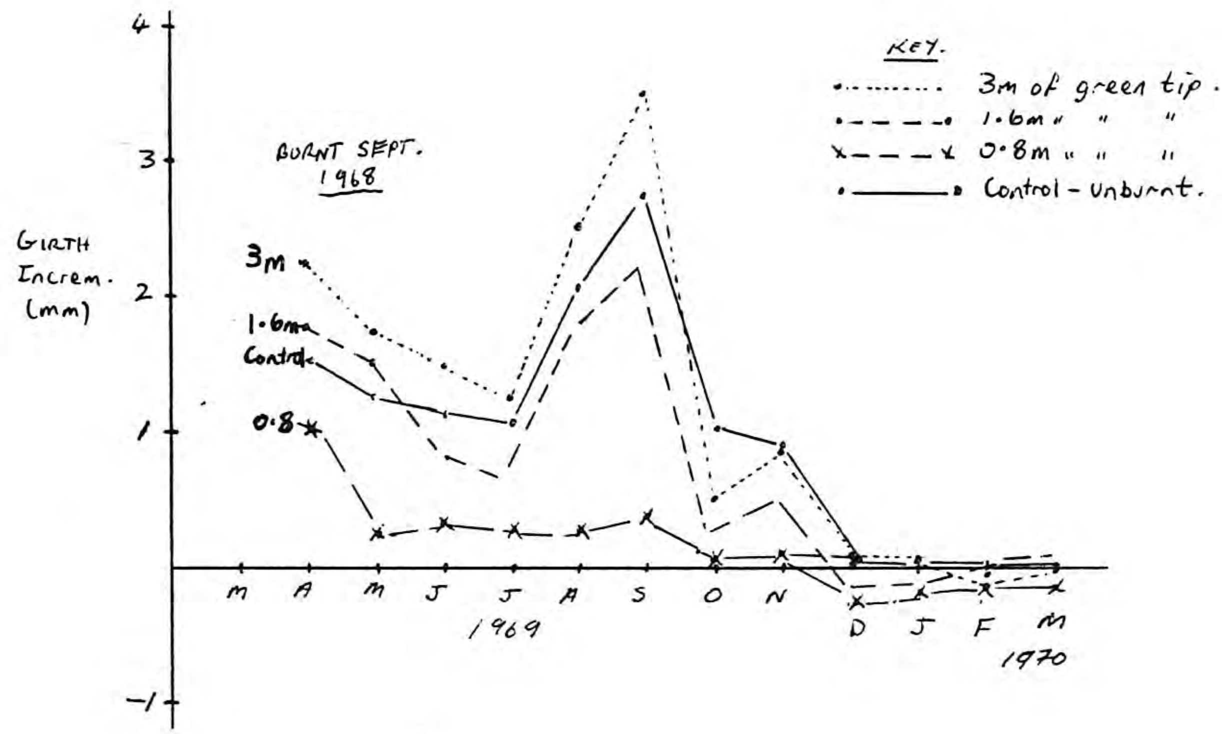
DOMINANCE STATUS	TOTAL NUMBER OF TREES SCORCHED	% OF SCORCHED TREES WHICH SURVIVED	% OF SCORCHED TREES WHICH DIED
Dominant	92	76	24
Co-dominant	205	64	36
Suppressed	57	21	79
TOTAL	354	% OF TOTAL = 59%	% OF TOTAL = 41%

FIGURE 1: Mean monthly girth increment of unscorched trees (intensity < 200 kW/m, *flames < .8m) and living, scorched trees (intensity > 200 kW/m, *flames up to 2m). (Sneeuwjagt '73).



* "Thick" flames – ie. long duration such as needlebed flames or compacted fuels. as opposed to "thin" flames from flashy, aerated fine fuels.

FIGURE 3: The effect of different levels of scorch on the growth rate of P. *radiata* (Nannup) 11 year old trees.(Sneeuwjagt?)



CROWN DAMAGE - DISCUSSION OF RESULTS

The 11 year old trees which were scorched by spring fire, (Fig. 3) and survived, were able to maintain diameter growth rates equivalent to trees without scorch, providing scorched trees had at least 2 m of green tip. However, not all trees survived due to combinations of drought and scorch.

Thirteen year old trees which survived a burn in May, but which were scorched to within 2 m of their tips, showed no positive growth increment even after 12 months. Many trees died. (Fig.1)

CROWN DAMAGE - CONCLUSIONS

Fires of intensity < 200 kW/m (mean flame height < .80 m) are harmless to the crowns of *P. radiata*, older than 11 years and at least 21 m in height. No losses in growth should occur. Trees should retain at least 4 m of green growing tips. Spring burning produces less damage to crowns than autumn burning. When scorch is such that less than 2 m of green tip is left, high mortality (> 50%) can be expected. Trees under drought strees (such as in autumn) are more susceptible to death resulting from scorch than trees burnt on a low S.D.I. or preceeded by favourable moisture conditions (such as in spring). The size (height/diameter), hence fire resistance of trees, varies with site.

BOLE DAMAGE

Fig 4: BARK THICKNESS (MAX) VS. DBHOB - *P. radiata*

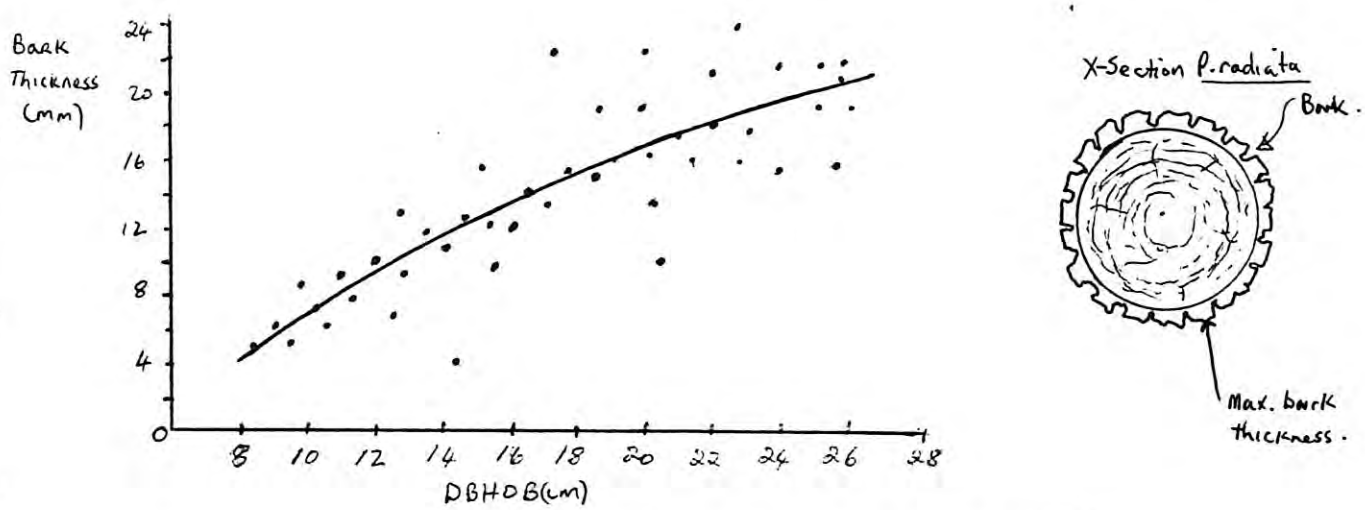


Fig 5: Scorch Ht. vs Stem Charring (AUTUMN).

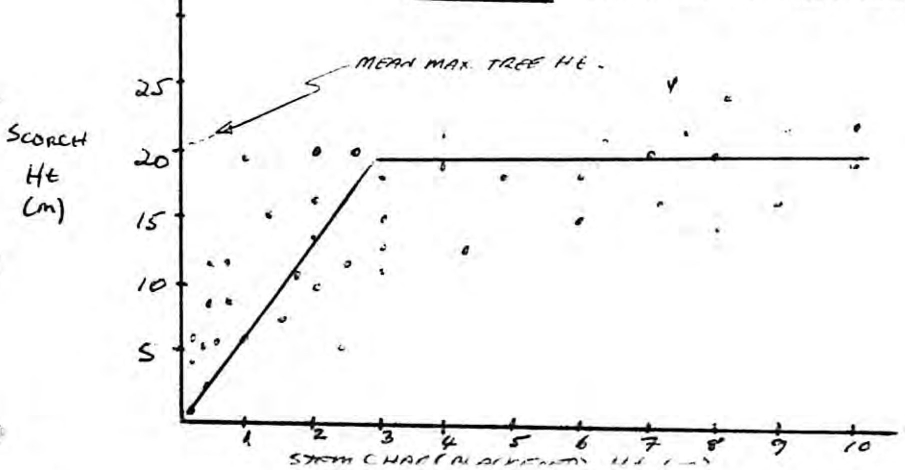


TABLE 3: ESTIMATE OF BOLE DAMAGE (CAMBIAL KILL) FROM STEM CHARRING.
(AFTER BILLING & WOODMAN, 1974)

Stand Age (yrs)	Tree No	DBHOB (cm)	Char or Blackening Height (m)	No of faces Charred.	* Damage Height (cm)	Max. Damage Height (cm)	Circum. Damaged (%)	Minimum Bark Thickness (mm)	$\bar{X}$ Bark Thickness (mm)
11	1	12.5	0.4	4	30	30	20	1.0	12
	2	17.2	0.4	2	-	-	-	3.0	17
	3	21.6	1.4	4	-	-	-	2.0	18
	4	16.2	1.8	3	30	120	3	2.0	13
	5	18.8	1.7	4	-	-	-	3.0	28
	6	14.0	1.8	4	15	15	4	2.5	7
	7	15.3	1.0	2	-	-	-	3.0	12
	8	14.3	1.2	4	-	-	-	NA	12
	9	8.0	0.8	3	70	70	6	2.0	9
	10	14.4	1.6	4	15	60	18	2.0	18
	11	18.9	1.2	4	-	-	-	2.5	14
	12	16.6	0.7	3	30	30	5	1.5	17
	13	9.1	0.6	4	110	110	8	1.0	7
	14	15.4	1.3	3	70	40	40	2.0	12
	15	20.6	2.2	4	30	205	25	2.0	15
Mean		15.5	1.2		27	47		2.1	13.4
16	16	25.9	0.4	4	-	-	-	3.5	26
	17	9.5	0.1	1	-	-	-	2.0	16
	18	17.0	1.0	4	30	30	18	2.0	15
	19	16.3	1.2	2	-	60	-	2.0	21
	20	23.5	0.6	2	-	-	-	3.0	22
	21	21.0	1.0	3	-	60	-	2.0	20
	22	14.8	0.5	2	-	-	-	NA	17
	23	19.6	0.3	4	-	-	-	NA	19
	24	22.9	0.5	2	-	-	-	2.5	16
	25	17.2	1.0	2	-	-	-	2.0	21
	26	22.2	1.2	2	-	-	-	3.0	15
	27	24.7	0.7	2	-	-	-	2.5	16
	28	12.4	0.5	2	70	70	9	1.5	12
	29	20.6	3.0	3	-	275	-	2.0	20
	30	18.7	1.8	4	-	-	-	NA	17
	31	16.7	1.0	2	-	-	-	2.5	17
Mean		18.9	0.9		6	31		[illegible]	[illegible]

* Damage = Cambial kill.

BOLE DAMAGE - DISCUSSION OF RESULTS

(From Woodman & Bitling, 1979 - unpublished)

Bark thickness is very important in determining the level of protection from fire. The relationship between bark thickness and tree diameter (B.H.) is shown (from Western Australian experiments) but may vary with site. Older stands generally have thicker bark for a greater distance up the bole.

In Victoria, it was estimated that the loss in merchantable volume from slash fuel reduction burns in 11 year old pines is less than 4.5%. For older stands, damage was found to be negligible. Trees with a diameter in excess of 17 cm are likely to be undamaged by the peaks of fire intensity associated with slash burning.

FEEDER ROOTS

In some schools, it is believed that pine needlebed should not be burnt down to mineral earth because the feeder roots are killed. Studies (Burrows, unpublished) have shown this is not necessarily the case. Deaths associated with needlebed burning down to mineral earth result from (i) the higher intensity of the fire (greater fuel consumed), (ii) the fire residence time around the stem, (iii) early droughting due to the removal of the duff layer and combinations of the above.

CONCLUSION

Any damage (which is usually negligible) caused by low intensity (< 200 kW/m) fuel reduction burning should be considered in relation to the increased potential loss in a wildfire that is associated with a lack of protective burning. A fire of only 750 kW/m is sufficient to kill or seriously damage a 13 year old pine stand. Such a fire is only classed as moderate intensity.

LOGGING SCARS

If there is an occlusion of new wood associated with a logging scar, then the heat generated by the burning sheath of resin is sufficient to kill the cambium associated with the occlusion and so extend the logging damage (Thompson, 1977). Where logging damage is slight, the effect of burning is likely to be insignificant.

FUEL ACCUMULATION AFTER FIRE - NEEDLEBED

In 11 year old stands, the effect of low intensity needlebed fuel reduction burns was lost after 18 months (Woodman & Billing, Burrows, unpublished). Studies by Woodman & Billing showed that fuel accumulation rates after burning remained unchanged. In older stands (20+ years) needlebed burns can be of a higher intensity and hence consume more of the needlebed. This reduction is effective for up to 3 years.

Fuel removal is only one aspect of increased protection from burning. The re-structuring of fuels following thinning, pruning and burning the slash offers greatly enhanced protection. I believe slash burning is a must, if not broadscale, then strategic strips. I believe it is important to burn under old stands (20+) when wilding regrowth commences and to repeat burning to prevent wildings developing. Wildings provide considerable fuel (up to an additional 20 tonnes/ha in some cases) and provide a fuel ladder for crowning in older stands. Low intensity fires ($<$200 kW/m) will kill wildings.

ASPECTS OF WILDFIRE BEHAVIOUR IN P. RADIATA THINNING/PRUNING SLASH FUELS

INTRODUCTION

Most wildfires in *P. radiata* plantations have been quickly controlled and the losses have been generally small. But there are exceptions to this, and South Australia recently lost 25% of its wood resource in about 2 - 3 days. Weather patterns, fuel loadings and ignition sources in Western Australia ensure that we too, could be confronted with a massive,devastating and costly pine fire.

Even prior to the events of Ash Wednesday, the Caroline fire (South Australia) destroyed 3,500 ha of plantation and the loss was conservatively estimated at $2 million. Yield regulation and regional stability will be disrupted for many years.

FIRE BEHAVIOUR

A survey of our knowledge of fire behaviour *P. radiata* plantations was carried out by Dawson (1983) and is summarised in the table below.

TABLE 1: Pine fire behaviour under extreme fire behaviour (after Dawson, 1983). (see over)

TABLE 1 HIGH INTENSITY FIRES IN *PINUS RADIATA* (DAWSON 1982, unpub)

	Date	Age (yr)	Area (ha)	Stocking (stems/ha)	HT (m)	T (°C)	RH (%)	FMC	ROS (m/h)	FLAME HT (m)	CROWNING	SPOTTING (m)	WIND SPEED (km/h)	OTHER
VICTORIA														
reswick	25/ 1/61	sapling mature	200			35	21						30	
reswick	12/ 2/77	mature	258			34	25						30	+nigra
yrtleford	10/ 3/78	45	22						4600					
aroline	2/ 2/79	13	163											
ongford	17/11/62	10-11	111		9-15	27	30		600	9-15	almost cont.	300	19	no T/P
lanket Hill	3/ 3/65		324			38	9				in places		80	T1
eeralang	14/ 3/65		5											
aryvale	17/10/68	13	54	975		29			360		Yes	240-600	48 80	T June, no P
lynn Crk	13/10/71		16			26						Yes	19	+pinaster
ongford	13/12/77	4-13	8			28								
ongford	25/ 9/80	3-4	17			22							strong	
N.S.W.														
oodburn	28/10/68	1-36	139			32	8						>60	+elliotii, taeda
oodburn	25/ 9/80	18	130			33	12				near road	50	15	+elliotii, taeda, P, no T
owra	30/ 9/80	16-18	777	1600		34	6		50	12	immediate	400-500		no T,P
elanglo	30/ 4/77	21	2			15				1.5		nil		P, some high P
ewnes	27/ 9/71		21			12				3-4		40	56	
unny Corner	27/ 9/71		63							3		200		
unny Corner	19/ 2/78	11	8			30	30		125		when exposed	10	light	no P
ondi	21/ 3/80	47-48	9			32	18			3			56	+laricio
urraguldrie	26/ 2/63	mature	3											
ochinvar	24/12/77	2	20	1333		25	15		367				14	no P/T
ondobolas	14/ 1/78	8-9	15	1600	10	30	35			severe		35		no T, some P
ombala	2/ 4/81	mature	8							3				
otal NSW FC	1954-1981	1900												+laricio

TABLE 1 HIGH INTENSITY FIRES IN *PINUS RADIATA* (Dawson, 1982 unpub).

	Date	Age (yr)	Area (ha)	Stocking (stems/ha)	HT (m)	T (°C)	RH (%)	FMC	ROS (m/h)	FLAME HT (m)	CROWNING	SPOTTING (m)	WIND SPEED (km/h)	OTHER
A.C.T.														
Stromlo	5/ 2/52	26-27	270			38	13						40 64	
		1-11	46			38	13						40 64	
Jervis Bay	23/12/72		122			39	39						30	
Fairbairn	7/ 1/75	15	31	750		29	18		1044		immed.		16	T 6months 5° slope
Stromlo	18/12/81	31	6	200		30	13		300		yes-individual trees		20 70	
Uriarra	9/ 8/82		21											
S.A.														
Wandilo	5/ 4/58		320		5-30	33	29		600-1600		yes	400-2000	40	
Glencoe	2/ 4/66	8-12	40		6-10	33	20		600-1200		full	400-600	43	no P
Nangwarry	17/ 3/67	35	5	400	37-39	34	18		280-440	1.5-2.0	1 tree		40 56	p, low fuel
Kongorong	29/ 3/71	29	328	200		33	23		70-80		not in old stands	100-800	35	heavy slash
Mt Burr	19/ 1/73	21	1		21	35	30					240		no T
Penola	18/ 1/73		2		30	38	17				2 trees	400	20 40	
Glencoe	30/ 1/74		370			34	31		600-1200		in poor stands	800	50 65	
Mt Bold South	7/ 1/77	19	50			39	37		160	10	on upslope		23	+canariensis
Caroline	2/ 2/79	8-19	3344		15-18	38	16		3000-4000	70	Yes	multiple short dist.	43 69	
N.Z.														
Balmoral	25/11/55		2400				33		1400		Yes	Yes		
Average	1955-1980	330/yr												

TABLE 1 HIGH INTENSITY FIRES IN *PINUS RADIATA*

	Date	Age (yr)	Area (ha)	Stocking (stems/ha)	HT (m)	T (°C)	RH (%)	FMC	ROS (m/h)	FLAME HT (m)	CROWNING	SPOTTING (m)	WIND SPEED (km/h)	OTHER
6. W.A.	many <5 ha, mostly >10 yrs ago, no worthwhile records of fire behaviour.													
	14/ 4/78 Forests Dep. 284 ha													
	Cyclon Alby Private 830 ha													
7. TAS.	1935-81	494	av. size 15 ha, 18 internal ignition (= most of the recent fires), 15 external, 1-6% plantation estab.											
Mt Helen	7/ 1/64	8	67	1240	5	20	18		400-1096	5	Yes	40	40-50	only fire >5 ha since 1960

TABLE 2. FIRE BEHAVIOUR UNDER EXTREME FIRE DANGER (Dawson, 1982 unpubl.).

STAGE OF STAND DEVELOPMENT	FLAME HEIGHT	SPOTTING POTENTIAL	RATE OF SPREAD (ROS)
JUVENILE LIGHT GROUND FUELS *FIRE FIGHTING COST TO AGE 8 $107-136/HA	≥ TOTAL TREE HEIGHT	LOW-INCREASING TOWARDS CANOPY CLOSURE	DEPENDS ON FUEL QUANTITY LOW-HIGH DEPENDIN ON ASSOCIATED VEGETATION AFTER 2ND SPRING ROS 4-5 KM/HR
DEVELOPING - SIGNIFICANT AERIAL COMPONENT - FIRST THIN HEAVY GROUND FUELS *FIRE FIGHTING COST AGE 9-15 $146-190/HA	≥TREE HEIGHT PRUNED: I ∝ DEGREE OF COMPACTION AND BREAKDOWN OF SLASH UNPRUNED; FIRE CROWNS IF NEEDLES SUSPENDED	MOD-HIGH	REDUCED WIND, ROS LOW 400-800M/HR HIGHER IF CROWNS AND SPOTS UP TO 1600 M/HR
MIDDLE A) THINNED/PRUNED GROUND FUELS LESS INCREASED ACCESSIBILITY GREATER POSSIBILITY FOR DIRECT ATTACK *FIRE FIGHTING COST 15 $240-470/HA	GROUND FIRE FLAMES 3-6 M IF SLASH WELL COMPACTED. OTHERWISE MUCH HIGHER.	LOW SHORT DISTANCE SPOTTING FROM GROUND FIRES	400-800 M/HR
B) THINNED/UNPRUNED	CROWN FIRE FREQUENT	HIGH	800-1200 M/HR
SLASH	VARIES GREATLY WITH QUANTITY AND CONDITION OF SLASH	VERY HIGH TENDENCY FOR WHIRLWINDS	≥1600-2400 M/HR

*NZ FOREST SERVICE DATA - 1980

The tables above suggest that a knowledge of wildfire behaviour is poor and unfortunately, so to are records and documentation of such fires which means we can't learn a great deal from wildfires.

The general data available provide a basis for plantation design, coupe layout, location and standards of fuel reduced buffers and silvicultural regimes but plantations are still being destroyed by fire. This begs the questions:

- are existing protection strategies adequate?
- is existing knowledge of fire behaviour adequate?
- what research is needed to refine our understanding of fire behaviour, hence plan better protection systems?
- should research priority and effort be commensurate with the cost of plantation losses?

WHAT ELSE DOES THE SURVEY TELL US?

These general comments can be made:

1. The mean spread rate of plantation wildfires is 1,062 m/hr - maximum recorded 4,600 m/hr. Flames 4 m - 160 m in height.

2. Crowning is common place in young, well stocked stands, and can occur under fire danger conditions greater than or equal to MODERATE. Under severe conditions, a full crown fire with flames up to 160 m were recorded in a 43 year old *P. radiata* plantation which burnt near Bright in Victoria. The trees were 40 m tall and thinned to 200 s/ha. Lack of fuel management beneath the canopy was the primary cause for the sustained crown fire (dense wildings, scrub and heavy needlebed).

3. Spotting in radiata pine is not usually an important component of fire rate of spread (average maximum spot distance = 350 m). Long distance spotting from pine fires is usually from hardwood pockets. However, reports from Victoria (the Bright plantation fire, 1982) reveal that under severe conditions (T = 38°C, RH = 15%, WIND N.W. @ 40 - 60 K.P.H.) spotting from a plantation fire was

severe (mass spotting up to 400 m - maximum spot 2 km) and complicated suppression activity.

WILDFIRE BEHAVIOUR

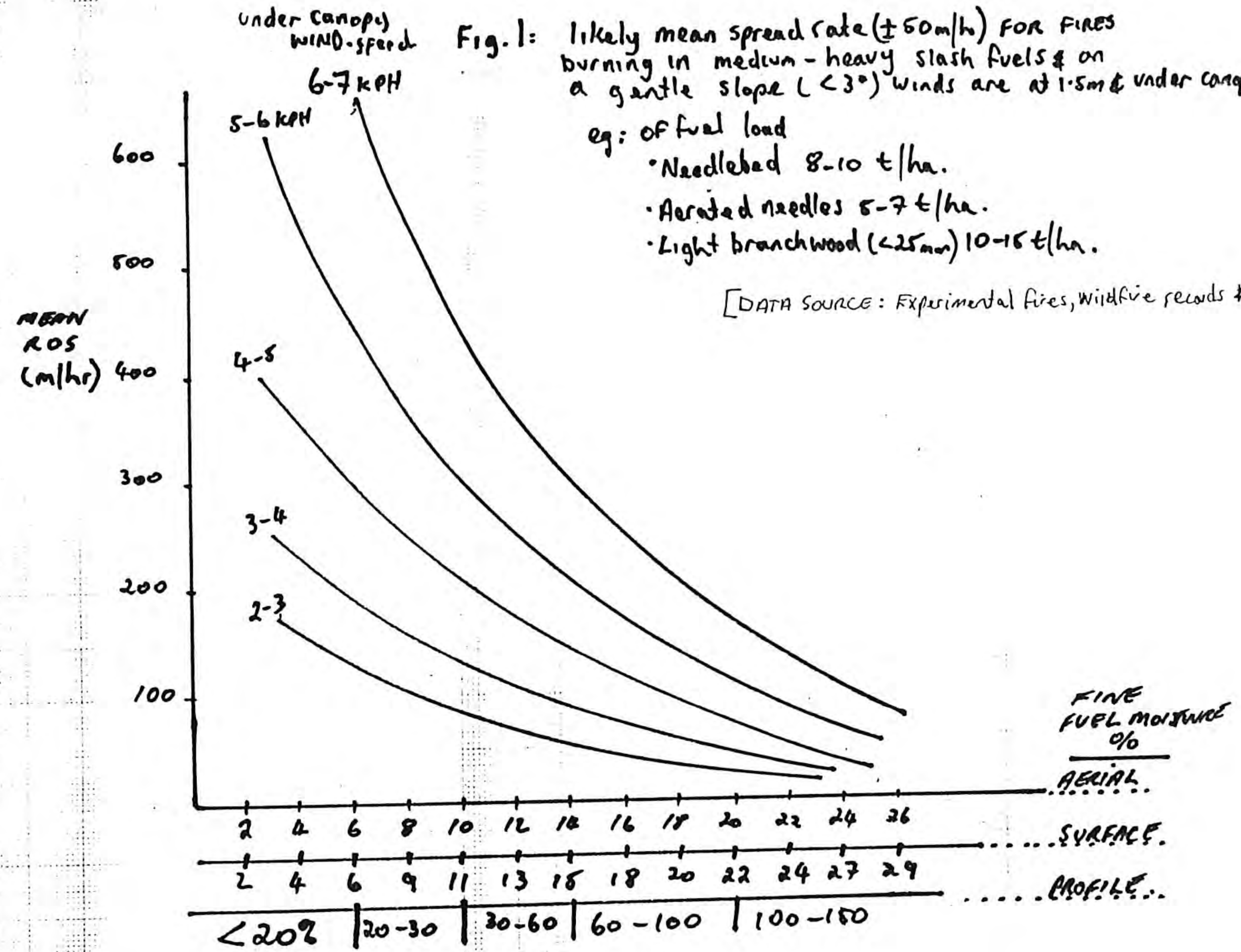
The figure 1 below can be used as a rough guide to predicting fire rate of spread in moderate to heavy thinning slash fuels. The figures are for fires burning on a 3° slope and can be doubled for a 6° slope etc. Unfortunately we are unable to describe the transition from ground to crown fire and the resulting crown fire behaviour. These guides do not take spotting into account. An example of the severity of plantation fires is provided at the end of this section to remind Pine Divisions of what can and will happen without adequate protection measures. Even then, there is no guarantee, but the chances are vastly improved.

(SEE Fig. OVER)

Fig. 1: likely mean spread rate (± 50m/h) FOR FIRES burning in medium - heavy slash fuels & on a gentle slope (< 3°) winds are at 1·5m & under canopy.

eg: of fuel load
- Needlebed 8-10 t/ha.
- Aerated needles 5-7 t/ha.
- Light branchwood (<25mm) 10-15 t/ha.

[DATA SOURCE: Experimental fires, wildfire records & Rothermels model]



REFERENCES

BILLING, P.R. (1979)

Using fire to reduce fuel accumulations after first thinning in radiata pine plantations. For. Comm. Vic. Report No. 4 (unpublished).

BILLING, P.R. (1980)

A low intensity burning operation in a thinned radiata pine plantation. For. Comm. Vic. Report No. 6 (unpublished).

BURROWS, N.D. (1980)

Quantifying Pinus radiata slash fuels. Res. Pap. No. 60, Forests Dept. W.A.

BURROWS, N.D. (1980)

Crushing the thinning slash problem. Res. Pap. No. 62, Forests Dept. W.A.

BURROWS, N.D. (1981)

Fire hazard reduction by grazing cattle in Pinus radiata plantations in the Blackwood Valley. Res. Pap. No. 6 (unpublished).

JONES, P. (1974)

P. radiata scorch trials. In Fire Res. News. R.W.G. No. 6. Bushfire Res. No. 5.

SNEEUWJAGT, R.J. (1973?)

Effects of high scorch on Pinus radiata at Grimwade plantation. Intended Res. Pap., For. Dept. W.A.

SNEEUWJAGT, R.J. & PEET, G.B. (1978)

Forest Fire Behaviour Tables for Western Australia. For. Dept. W.A.

THOMPSON, P.S. (1978)

Low intensity prescribed burning in the <u>Pinus radiata</u> stand types. For. Comm. Vic. Report 2, (unpublished).

WILLIAMS, D.F. (1977)

Effects of thinning on forest fuels in young <u>Pinus radiata</u> plantations. Thesis - Master of Science. Melb. Uni.

WOODMAN, M. & RAWSON, R. (1982)

Fuel reduction burning in radiata pine plantations. For. Comm. Vic. Report No. 14 (unpublished).

WOODMAN, M. & BILLING, P.A. (1979)

Some effects of low intensity burning in Radiata pine. Report No. 5. Vic. For. Comm. (unpublished).

DAWSON, M. (1982).

A REVIEW OF <u>P. radiata</u> WILDFIRES IN AUSTRALIA. PRESENTED TO 7th MEETING OF R.W.G. 6. FIRE MANAGEMENT, BUNBURY.