FIRE RESEARCH BRANCH

REPORT NO 14

FUEL REDUCTION BURNING IN RADIATA PINE PLANTATIONS

M WOODMAN

R RAWSON

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SUMMARY

This report summarises the results of a number of studies related to fuel reduction burning in radiata pine plantations. It discusses plantation fuel properties, the use of low intensity fire for fuel reduction and the effect of such burning on wood quality, fuel quantity and tree growth.

During spring, and under carefully prescribed conditions of fuel moisture and wind speed in particular, fuel reduction burning in both the needle litter layer and elevated fuel from thinning can be conducted with safety. Operations confined to stands aged 11 years or older should cause little or no stem damage and no reduction in stand growth.

After first thinning operations fire can also be used, as an alternative to pruning, to remove much of the dead needle fuel from the lower crown.

INTRODUCTION

At the beginning of 1981 the area of softwood plantations managed by the Forests Commission was approximately 80 000 hectares (FCV 1981), of which 96% was radiata pine (*Pinus radiata*). These plantations produced 29% of the sawlog volume from Victorian State forests in 1980/81 (FCV 1981) and the proportion of wood coming from them will increase in future. For example, by the year 2020 softwoods are expected to supply some 60% of Australia's total wood requirement from less than 5% of the total forest area (Anon. 1980).

The high value per unit area of softwood plantations, the fire sensitive nature of the species used and the increasing dependence of large industries on established plantations means that the economic loss caused by wildfire can be very high. For example, following a 160 hectare fire in the Rennick plantation in 1979 Greig (1979) estimated a loss to the Commission of nearly $540 000.

The extent of loss due to fire depends on the fire intensity and the feasability of salvaging the burnt trees. Both factors are affected by the age of the stands burnt. The worst situations arise at first thinning age and younger when the combination of a very dangerous fuel distribution and small tree diameters means total loss can occur, even under conditions of relatively low fire danger. As at March 1981 78.6% of the total area of radiata pine plantation in Victoria was aged 15 years or less.

Fuel modification is an important component of fire protection strategy in both eucalypt forests and softwood plantations. However, fuel modification in softwood plantations consists mainly of low pruning while in eucalypts low intensity fire is used extensively to reduce fuel quantities. Low pruning is costly and does not have the same potential for reducing fire hazard as does low intensity burning.

Since the early 1970's many aspects relating to fire in softwood plantations have been studied in Victoria and particularly the use of low intensity fire to reduce hazardous fuels. This report is a compilation of research results and is intended to provide staff with a background of information on which to base fuel reduction burning operations in plantations.

1 PLANTATION FUEL PROPERTIES

1.1 Fuel Quantity and Distribution

Native vegetation recovers quickly after plantation establishment. Minko (1974, 1978) measured quantities of 0.9-9.2 t/ha in plantations in north-eastern Victoria two years after clearing and burning. After canopy closure this vegetation gradually declines and Forrest and Ovington (1969) considered 0.4 t/ha to be an average quantity in closed stands at Tumut, NSW.

Forrest and Ovington found the build up in radiata pine foliage to be slow until age 5 years after which a rapid increase occurred until an equilibrium value of 10 t/ha was reached between the ages of 7 and 10 years. Similarly, Williams (1977) estimated a foliage weight of 10 t/ha in a 12 year old stand at Myrtleford, Stewart and Flinn (1981) 10.9 t/ha in a 15 year old stand in South Gippsland and Will (1964, 1966) 9.0 t/ha and 10.6 t/ha for 12 and 18 year old stands respectively in New Zealand. From a fire behaviour viewpoint the most significant feature is the relatively constant weight of foliage in the crowns following canopy closure. Figure 1 summarises the results of these studies including also the weights of bole and branch wood.

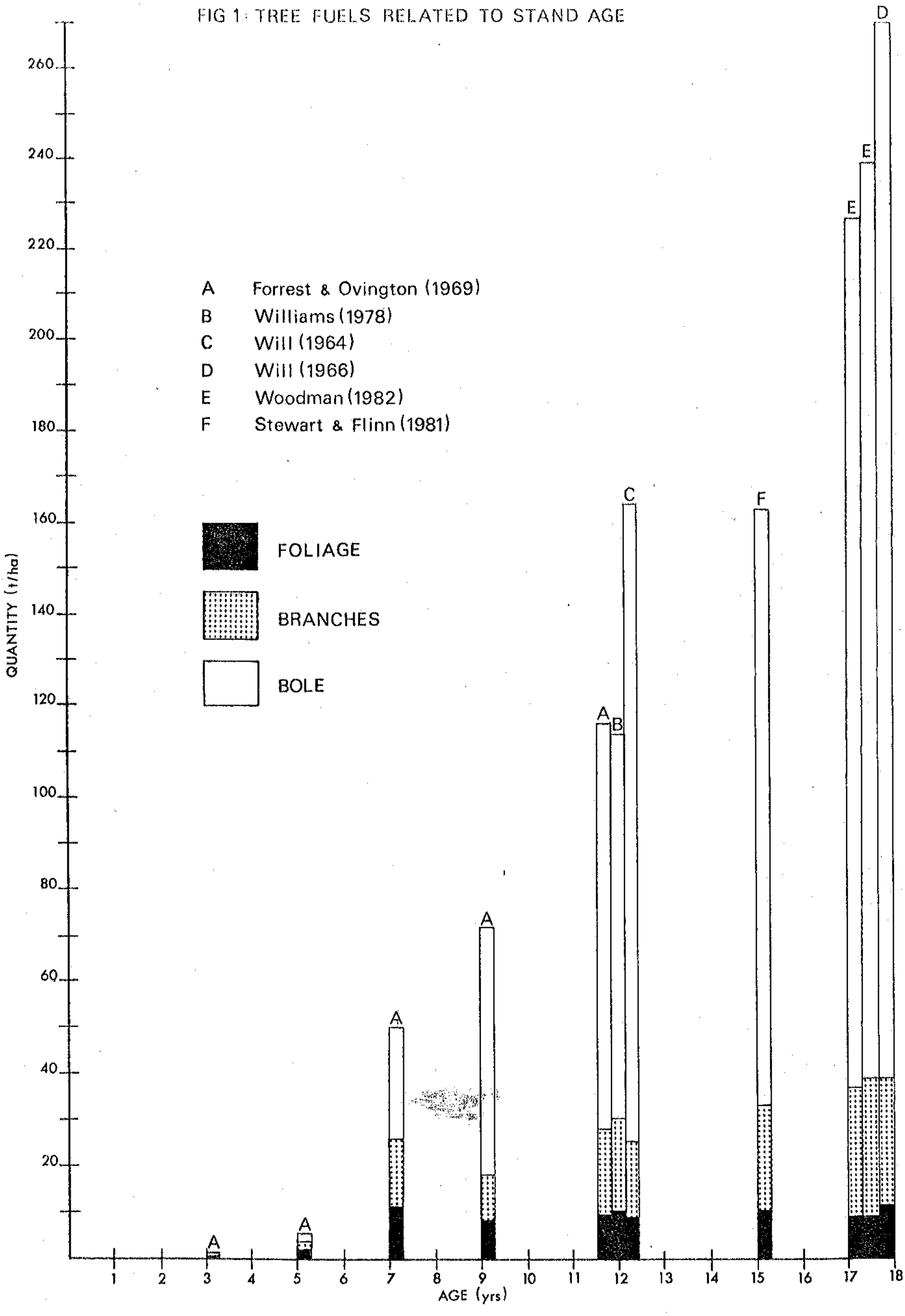
After canopy closure the dead needles lodging on the branches of the lower crown form a highly flammable link between the ground and higher crown fuels, and fuel modification is frequently aimed at removing this link. In the 12 year old stand at Myrtleford Williams estimated this fuel quantity to be 2.4 t/ha and higher quantities are thought to exist in other plantation areas, eg south-west Victoria.

Table 1 shows the fuel quantities found at ground level in plantations of different age classes in north-eastern Victoria (Woodman, 1982). Litter comprises the surface layer of whole or partly decomposed fine fuels (ie fuels < 6 mm diameter) and duff the fuel layer beneath which is in an advanced state of decomposition.

TABLE 1: LITTER AND DUFF QUANTITIES

Age Class (years)	No. of samples	Mean 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

FIG 1: TREE FUELS RELATED TO STAND AGE



The high co-efficients of variation show the wide range in fuel quantities measured within each age class. The results do however indicate there is no increase in total fuel weight (litter and duff) after 15 years, which means that there is an equilibrium between the rate of litter input and litter decomposition. Further evidence is provided by Forrest and Ovington (1969) who showed this equilibrium occurred at age 12 years in stands at Tumut.

In north-eastern Victoria Woodman (1980) found the average annual litter fall over a wide range of stand ages to be 3.3 t/ha and fairly evenly distributed throughout the year (Figure 2). This is in general agreement with the estimates of 3 t/ha for Tumut (Forrest and Ovington, 1969), 4 t/ha in New Zealand (Will, 1959) and 3.4 t/ha (Pausey, 1959) and 3.3-4.2 t/ha (Florence and Lamb, 1973) for South Australian plantations.

Thinning causes dramatic changes in the fuel distribution, and while in the long term these may be beneficial in terms of fire behaviour, the short term effects are likely to mean a hazard at least equal to that existing prior to thinning because of increased ground fuel quantities and increased stand exposure.

Changes in the distribution of fuel quantities caused by first thinning operations have been described in some detail by Williams (1978) and are summarised in Table 2. He examined the effects of two first thinning regimes, third row outrow and sixth row outrow with bay thinning, on fuel distribution in a 12 year old stand at Myrtleford. The total fuel quantities added to the forest floor were 19.1 t/ha and 26.0 t/ha, comprising 7.2 t/ha and 7.7 t/ha of fine fuels (< 6mm diameter) and 11.9 t/ha and 18.3 t/ha of heavy fuels (> 6mm diameter) respectively.

When the stand studied by Williams reached 18 years the section previously thinned using the sixth row outrow method was selectively thinned from approximately 730 to 390 stems/ha. This is a normal second thinning regime for the region concerned and Woodman (1982 a) found that, although 17.7 t/ha of fuel was added to the forest floor, the quantity of needle fuel was only 1.9 t/ha and comprised 1.6 t/ha of living needles and 0.3 t/ha of dead needles (Table 2). This is much less than after first thinning and the slash therefore constitutes a lesser fire hazard.

TABLE 2: FUEL QUANTITIES (T/HA) ADDED TO THE FOREST FLOOR AFTER THINNING

FIRST THINNING (WILLIAMS,1978)			SECOND THINNING (WOODMAN,198	
Fuel Component	Third Row Outrow	Sixth Row Outrow with Bay Thinning	Fuel Component	
Heavy			Stemwood	
- dead	1.8	2.5	- dead	1.1
- living	10.1	15.8	- living	7.3
TOTAL	11.9	18.3		
Fine			Branchwood	
branchwood - dead	0.9	1.1	- dead	3.7
- living	1.5	1.7	- living	3.2
needles - dead	2.1	2.1	Needles	
- living	2.7	2.8	- dead	0.3
			- living	1.6
TOTAL	7.2	7.7	TOTAL	17.2

Perhaps even more important than the absolute quantity of fuel added to the forest floor following thinning is the distribution of fuel. The elevated and well aerated distribution that normally results creates conditions under which a fire can spread more rapidly than one burning in a fuel of similar quantity but more compact arrangement. This additional hazard reduces as the fuels age. Woodman (1980 a) studied the

FIG 2 : LITTER FALL

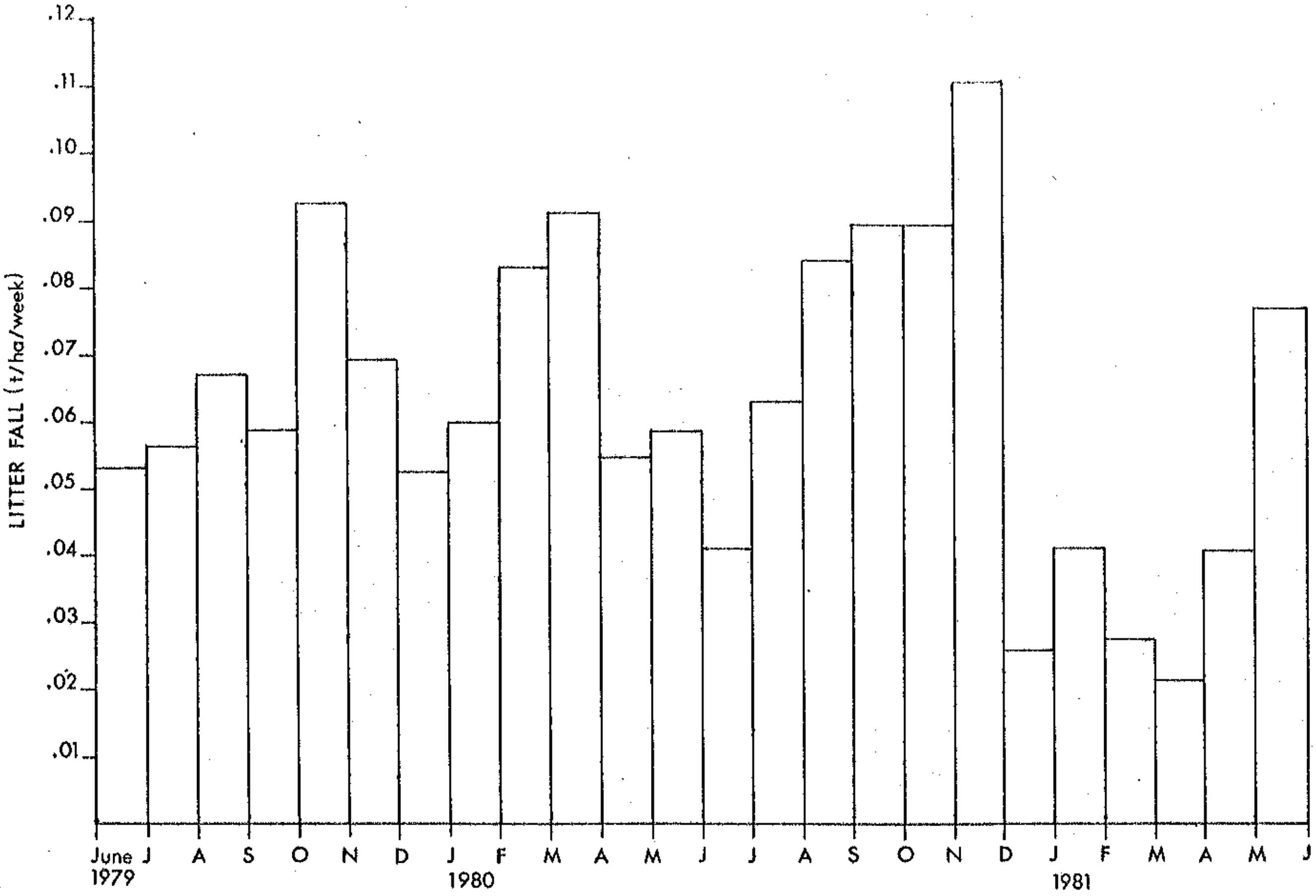
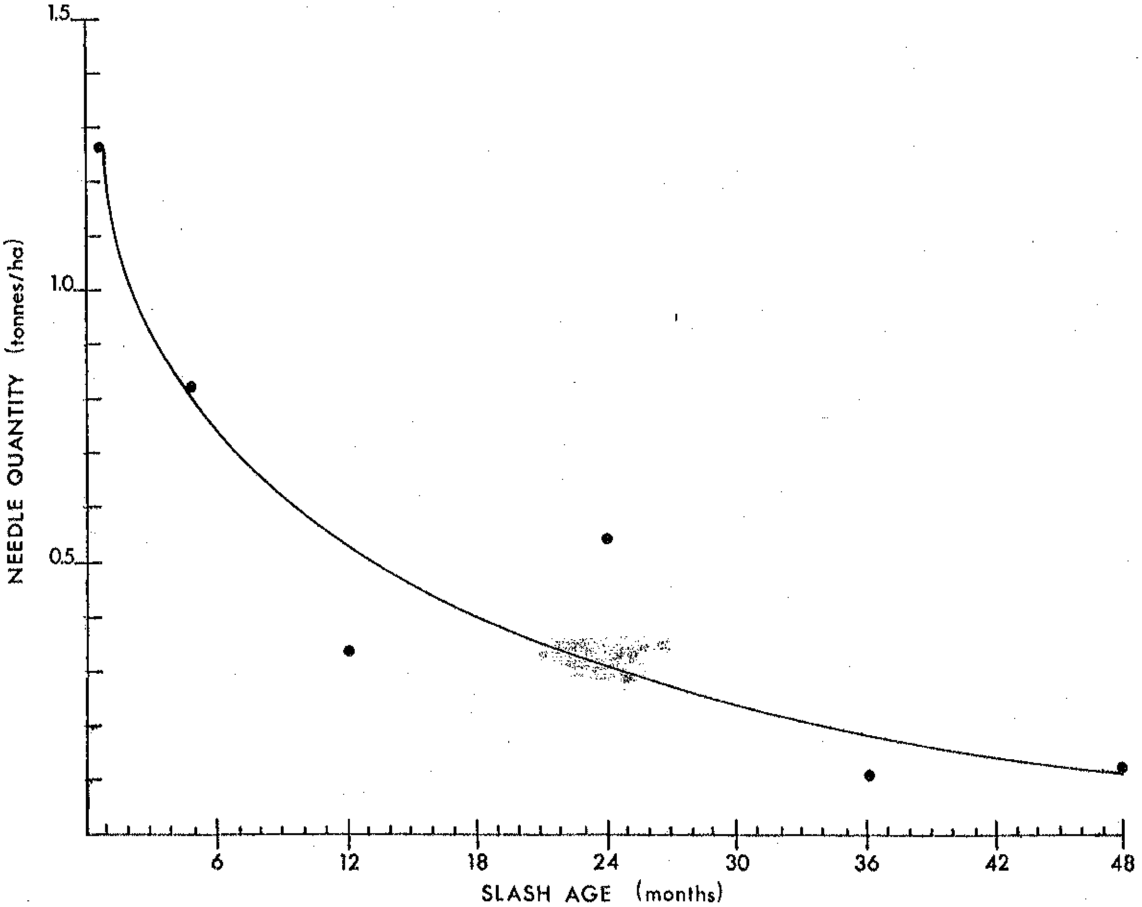


FIG 3 : ELEVATED NEEDLE QUANTITY vs SLASH AGE



relationships between slash age and the retention of elevated needle fuel as a guide to the reduction in hazard with time since thinning. The results, summarised in Figure 3, indicate that more than half the elevated needle fuel can be expected to fall within one year of thinning and 80% within three years by which time the slash is no longer a substantial hazard.

1.2 Fuel Moisture

Moisture in fuels decreases both the rate of combustion and radiation efficiency and therefore has a marked effect on the rate of fire spread. The moisture content of the fine fuels is particularly important and the successful implementation of fuel reduction burning under the guidelines of Thomson (1978) and Billing (1979) depends to a large extent on accurate measurement of moisture content.

Williams (1977 a) produced a guide relating the moisture content of radiata pine needle fuels to fire behaviour (Table 3). The moisture contents in Table 3 and elsewhere in this report are expressed as a percentage of weight after oven-drying at 105°C.

Woodman (1982) studied fuel moisture changes in an unthinned 17 year old stand and a 28 year old stand thinned to 204 stems/ha. Figure 4 shows the fuel moisture recorded in each stand throughout one 24 hour sampling period and it illustrates:-

(a) variations in moisture content are likely to be more pronounced in thinned stands, ie those exposed to greater fluctuations in temperature, relative humidity and air movement.

(b) the fuel moisture differential which commonly exists between elevated fuels and litter fuels.

(c) significant moisture loss from the duff layer can occur in a few hours if the initial moisture content is high.

(d) the moisture content of the needle fuels can change rapidly from levels where burning is difficult to sustain to levels where moderate to severe fire intensities can occur.

FIG 4 FUEL MOISTURE CHANGES OVER 24 HOURS

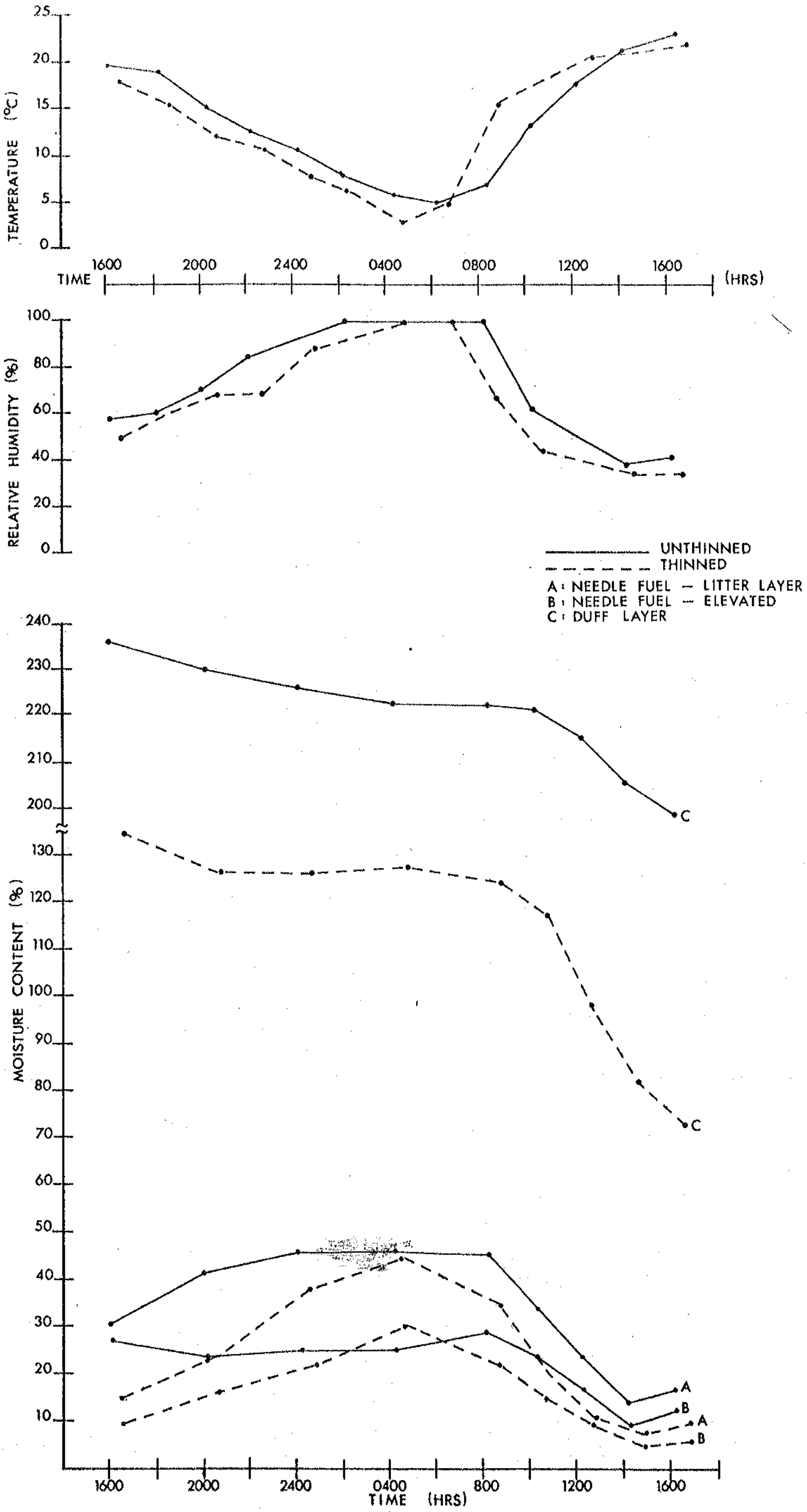


TABLE 3: FUEL MOISTURE CONTENT AND FIRE BEHAVIOUR

Fuel Moisture Content (%)	Fire Behaviour
25-30	* Elevated dead needles will just ignite and will carry fire only with assistance of wind. ** Surface needles will not ignite.
20-25	Elevated dead needles will ignite and just carry a fire (eg ROS < 0.2m/min). Surface needles will just ignite and only carry fire with the assistance of wind.
15-20	Elevated dead needles easily ignited and carry fire of low intensity (eg ROS up to 1m/min). Surface needles ignite and carry slow moving fire (eg ROS < 0.5m/min).
10-15	Elevated dead needles carry fire of moderate intensity (eg ROS > 1m/min). Surface needles easily ignited and carry fire of moderate intensity.
7-10	Elevated dead needles carry fire of high intensity which is difficult to control. Surface needles carry fire of moderate to high intensity.
< 7	Very intense wildfire possible.

* Elevated dead needles refer to dead pine needles lodged on branches, vegetation or debris on the forest floor 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. They are more compacted than elevated dead needles but better aerated than the duff layer.

He derived a model to predict litter fuel moisture changes under drying conditions. The model, which is discussed below, has application in planning fuel reduction burning operations as it can help to indicate:-

(a) the time of day when the 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.

The rate of change of fuel moisture content is affected by the difference between the existing fuel moisture content and the equilibrium moisture content (EMC) (Schroeder and Buck 1970). The EMC is the moisture content which is finally attained uniformly through materials exposed in an atmosphere of fixed temperature and humidity and without external heating and cooling.

Blackmarr (1971) produced EMC curves at an atmospheric temperature of 27°C for the needle fuels of several pine species. Although radiata pine was not studied a curve was developed for loblolly pine (*Pinus taeda*) (Fig. 5 (a)) which is a similar species. Woodman derived linear regressions relating the differences between observed moisture content and the EMC predicted by this curve to recorded changes in moisture content over both the following one and two hour periods (Fig. 5(b)).

To predict changes in litter fuel moisture content under drying conditions the following procedure should be used:-

(a) Measure the existing fuel moisture content and relative humidity, eg MC = 22%, RH = 50%.

(b) Determine the appropriate EMC (13.5%) from Fig. 5 (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 two hours (7%), from Fig. 5 (b).

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

FIG 5(a) : EQUILIBRIUM MOISTURE CONTENT – P. taeda

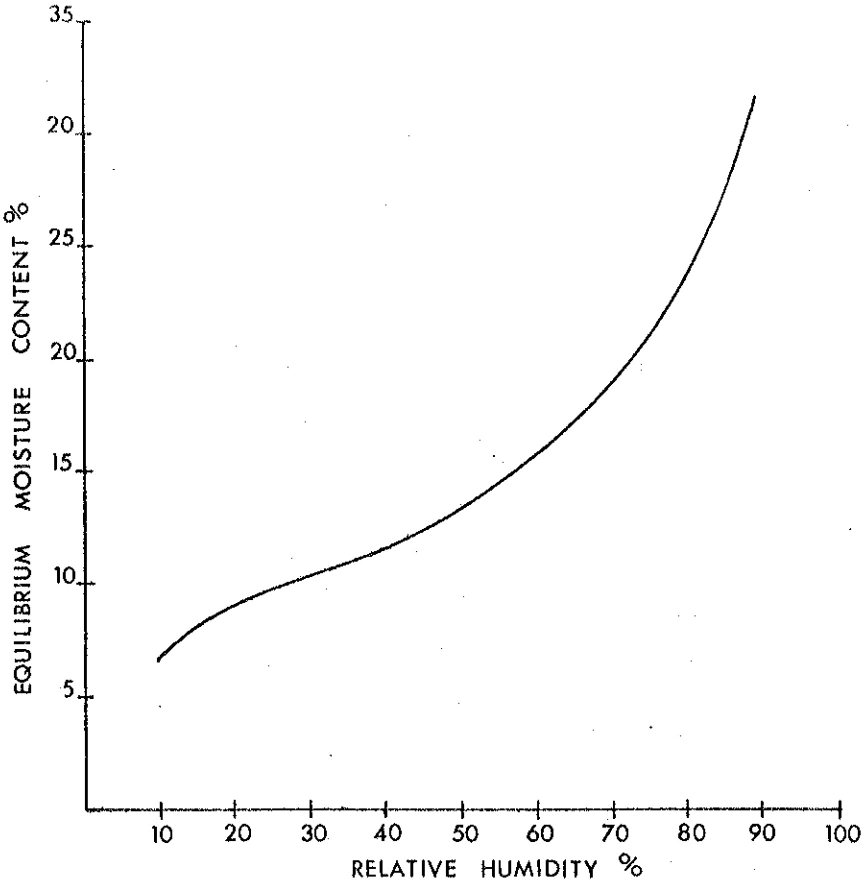
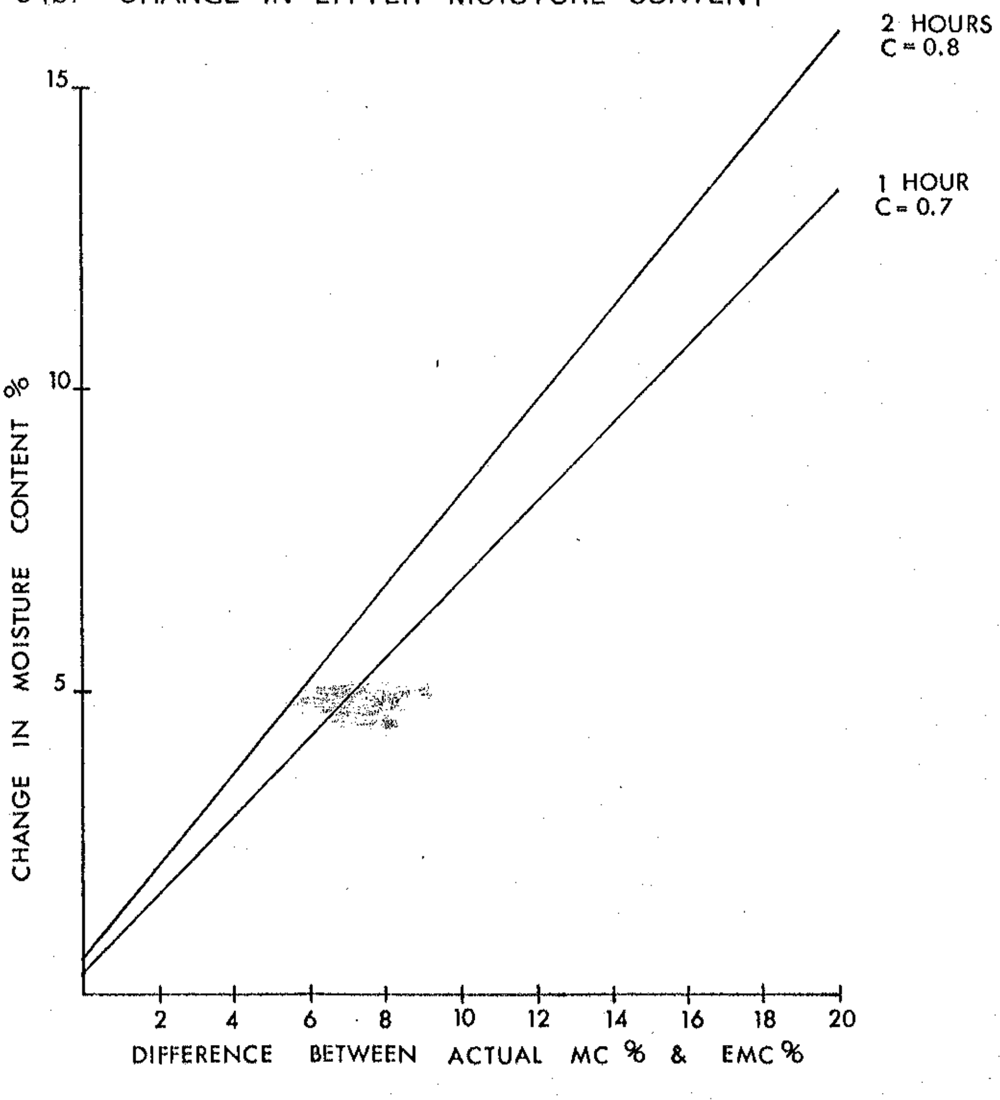


FIG 5(b) : CHANGE IN LITTER MOISTURE CONTENT



2 BURNING GUIDELINES

2.1 Litter Layer

Thomson (1978) undertook the first comprehensive study of fuel reduction burning in Victorian plantations. He examined low intensity fire behaviour during spring in three stands, with characteristics as shown in Table 4, and developed the burning prescriptions in Table 5.

TABLE 4: STAND CHARACTERISTICS

Stand Age	Site Index*	Top Ht. (m)	Stem No Per Ha	Fuel Quantities (t/ha) Fine	Duff	Heavy
11	25.8	16.0	1633	6.9	2.7	112.0
16	24.0	20.5	1131	6.9	7.2	20.7
26	30.8	36.3	396	5.7	2.8	107.4

* Projected stand height (m) at age 20

TABLE 5: BURNING PRESCRIPTIONS

Stand Age	BKDI[1]	Needle Fuel Moisture (%) Surface Needles	Elevated	Wind Speed[2] (km/hr) Mean	Maximum
11	< 50		15-22[3] 12-22[4]	0-4	7
16	< 100	14-20[3] 12-20[4]		0-4	7
26	< 30	16-20[3] 12-20[4]		0-4	4

1 *The Byram-Keetch drought index measured in points.*

2 *Wind speed recorded at 1-2 m within the stand.*

3 *Moisture limits for a lighting pattern which relies on headfire, ie fires allowed to spread with the wind, or upslope.*

4 *Moisture limits for a lighting pattern which relies on backfire, ie fires spreading into the wind or downslope.*

The 11 year old stand was unthinned and had recently been low pruned to 3 m. There was therefore more elevated fuel near the ground than in the 16 year old stand which was also unthinned but low pruned to 3 m two years before burning. The 26 year old stand had been thinned twice and this, together with low pruning at an early age, meant there was a substantial gap between the ground fuels and crown fuels. The two youngest stands were on gently sloping ground. The 26 year old stand was on a slope of approximately 15° and Thomson allowed for this in his prescription by specifying a higher minimum moisture content for burning with a headfire, by limiting the length of headfire run to 6 m and setting a maximum wind speed within the stand of only 4 km/hr.

Although designed for specific areas these prescriptions can be used as a guide to operations in any stand 11 years or older where surface needle fuels, or small quantities of elevated fuels, are to be burnt. Under the conditions shown in Table 5 the rate of spread should generally be less than 60 m/hr and the intensity less than 200 kW/m.

2.2 Thinning Slash

A prescription (Table 6) for burning first thinning slash was developed by Billing (1979) after study in a 15 year old stand in south-west Victoria. The stand was on gently sloping ground, low pruned and had been first thinned 14 months before the study commenced. Fuels from thinning extended up to 1 m above ground level.

TABLE 6: BURNING PRESCRIPTIONS - 14 MONTH OLD SLASH

BKDI	Moisture Content (%)		Wind	Temp	RH
	Duff	Elevated Needles	(km/hr)	($^{\circ}$C)	(%)
< 70	>40	17-21	< 5	<20	>50

Fire spread on level ground, under the conditions defined in Table 6, should be less than 40 m/hr provided proper attention is paid to lighting technique. The prescription is similar to that shown in Table 5 except that maximum temperature and minimum relative humidity have been specified. This has been done to emphasise the importance of selecting mild conditions if stem damage and crown scorch are to be minimised. Although not included in his prescriptions Thomson's results indicated similar temperature and relative humidity limits were desirable.

The hazard created by thinning slash decreases as weathering reduces the elevated fuel component and flammability is reduced by the leaching of volatile materials. In fuels younger than those burnt by Billing there was concern that different burning conditions may have to be specified to obtain acceptable fire behaviour. In a limited study Woodman (1980 b) found one to two month old slash to be more flammable, as expected, but that alterations to the burning prescription to accommodate this change were only slight. He suggested a minimum elevated needle moisture content of 19%, and a maximum wind speed within the stand of 2 km/hr. There is no doubt that fire can be successfully used to reduce the quantity of these fresher fuels.

2.3 Aerial Fuels

As they can provide a means by which ground fires can readily burn into tree crowns, dead needles in the lower crown levels frequently form an important component of the total fuels. Low pruning is one method of breaking the continuous vertical distribution of fuel although it has the disadvantages of being expensive, adding to the hazard associated with the ground level fuels and being limited in the depth of fuel removal.

Billing (1979) has shown there are some circumstances where fire can be used to safely and cheaply remove this fuel. The method is most applicable after first thinning operations, prior to burning the thinning slash, and it relies upon the presence of a substantial moisture differential between the aerial fuels and ground fuels as well as the inherent difference in flammability due to fuel arrangement.

Because they are extremely well aerated the aerial fuels can sustain burning at moisture contents up to 45%, and the range 25-35% is most suitable for this type of operation. Under these conditions during winter and spring the moisture contents of the elevated slash fuels and litter and duff layers should be too high to sustain significant fire spread. Temperatures less than 15°C, relative humidities greater than 70% and wind speeds within the stand of less than 5 km/hr are desirable. A very slight breeze can in fact assist the operation by breaking up convection into tree crowns and therefore helping to minimise scorch.

Lighting trees in alternate rows or alternate trees within rows is desirable to ensure that the overall fire intensity remains low.

2.4 Special Considerations

While the moisture content of the fine fuels greatly affects the rate of fire spread the moisture content of the heavy fuels and the duff layer plays a critical role in determining the fire intensity. Burning when the duff and heavy fuels are dry enough to ignite and continue to burn will cause an unacceptable fire intensity and result in crown scorch and stem damage. The BKDI is related to the moisture content of these fuels and the importance of this relationship to the quantity of available fuel, and hence fire intensity, is shown in Table 7, taken from McArthur and Cheney (1966) and McArthur (1966 a). The results were obtained from a series of experimental fires in a 23 year old radiata pine stand. At indices greater than 100 substantial quantities of heavy fuels were burnt and fire intensities increased dramatically.

TABLE 7: BKDI AND FIRE INTENSITY

BKDI	Fire Intensity kW/m	Fuel Consumed (t/ha)	Fuel Components Consumed (%)			
			Duff	<0.6 cm	0.6-2.4cm	2.5-7.6cm
48	231	7.0	30	66	0	0
54	290	6.5	14	88	0	0
120	1868	23.6	17	100	53	13
268	3875	34.7	83	100	87	67

The burning prescriptions which have been developed apply only to spring. If there are exceptional circumstances which necessitate autumn burning considerable care should be taken because the BKDI limits defined may not be satisfactory. After the summer drought heavy but short term rainfall can quickly reduce the index to what would appear to be acceptable burning levels without substantial wetting of the heavy fuels.

The varying BKDI limits shown in Table 5 reflect the differences in the quantity of heavy fuel between each stand and its susceptibility to ignition. The higher limit in the 16 year old stand, for example, is an indication of the low quantity of heavy fuel. The index should be less than 100 when burning and as low as practicable when there is a substantial quantity of heavy fuel within the stand. At the prescribed indices the duff layer moisture content should be greater than 40% and therefore at a level at which it will not burn. However, the BKDI is a guide only and an examination to ensure that the duff layer is moist is desirable.

Before a fuel reduction burn is conducted there must be a gap of at least 2 m between the ground and crown fuels. In some stands the lower crown may hold so little dead needle fuel that an effective fuel break already exists, or the break may be created by thinning disturbance. In other instances low pruning or burning of aerial fuels (see Section 2.3) will be required.

The wind speeds prescribed in Tables 5 and 6 need to be strictly observed. While a maximum wind speed as well as a mean wind speed has been specified in Table 5, the maximum may be tolerated for only a few seconds before fire spread becomes too rapid. All wind speeds refer to measurements taken at 1-2 m above ground level within the plantation.

Slope has not been included as a separate variable in the prescriptions although Thomson (1978) did allow for its effect in the 26 year old stand as discussed earlier. Application of the prescriptions to different plantation areas must include provision for the dramatic effect of slope on fire behaviour as defined by Luke and McArthur (1978). eg. an upslope of 10° can double the rate of fire spread compared with spread on level ground.

2.5 Lighting Techniques

To ensure the overall fire intensity remains low careful consideration must be given to the lighting method. Both the lighting pattern and rate of ignition can have a marked effect on fire behaviour.

The method recommended to start an operation is to light a line of fire and allow it to back into the wind or downslope. This technique is relatively insensitive to changes in wind speed and direction and also avoids the sudden increases in intensity that occur in the junction zones when fires join. If the rate of spread is not satisfactory lines of fire, or spot fires spread along a line and allowed to run short distances with the wind or upslope, will give better results. But proceed cautiously and until the fire behaviour is well established do not light a number of such lines simultaneously. Remember the impact of slope on fire behaviour and light higher areas first whenever possible.

The requirement for strict control of fire behaviour, and therefore rate of lighting, means that the areas which can be treated in one day of operation will generally be small in comparison with the areas which can be burnt in eucalypt forest using ground ignition techniques. Billing (1980) recorded an operation in a 16 year old stand when 22.4 ha of 12-19 month old slash was burnt by a 5 man crew (3 lighting) in 4 hours. In burning a 20 m deep protective strip along a boundary of a 17 year old stand Burt [1] recorded a work rate of 110 m of burnt strip per man hour, including the time taken to construct by hand a control line inside the plantation.

3 RESULTS OF FUEL REDUCTION BURNING

3.1 Reduction in Fuel Quantities

Thomson (1978) found that on average his experimental fires reduced the quantity of litter by 85%. Eighteen months after burning litter weights in the two younger stands (11 and 16 years) had almost returned to pre-burn levels, while in the 26 year old stand litter weights were less than half those before burning (Woodman and Billing, 1979). Based on these figures the duration of protection afforded by a single burn in the litter layer of young stands appears to be quite short. However, in many instances alterations to the fuel distribution will also occur and result in a much longer term reduction in hazard. With some applications, such as burning buffers around areas scheduled for slash burning, short term protection only is required and the fairly rapid return to pre-burn fuel levels is of little consequence.

Woodman (1982 c) reburnt many of the plots established by Thomson in the 11 and 16 year old stands. The litter weights on plots burnt twice were significantly less ($p = 0.05$) than those on plots burnt once or remaining unburnt (Table 8). This reduction is expected to persist for some time and indicates that successive burns in areas of strategic importance could be of substantial long-term value.

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[1] Burt, T Forester, Tallangatta Forest District

TABLE 8: FUEL WEIGHTS (t/ha) - 1981

Stand Age (1976)	11 years			16 years		
	Litter	Duff	Total	Litter	Duff	Total
Unburnt	3.3	4.9	8.3	3.5	11.1	14.4
Burnt 1976	3.9	4.1	7.9	3.1	9.7	12.8
Burnt 1979	3.1	5.0	8.2	3.9	8.5	12.4
Burnt 1976, 1979	1.2	3.5	4.7	4.0	5.3	9.3

In thinned stands the reduction in fuel quantity achieved is not as important as the dramatic alteration to fuel distribution through the removal of the elevated needle fuels.

3.2 Effects on Growth

In a trial established in the 11 and 16 year old stands used by Thomson (1978), Woodman (1981) found that 4 years after burning there were no significant differences ($p = 0.05$) between diameter increment and stem mortality on burnt and unburnt plots, even though most of the plots had by then been burnt twice and in some instances three times. Similarly, Billing (1980 b) found no significant difference ($p = 0.05$) two years after burning between the mean diameter increment of trees on areas where first thinning slash was burnt and trees on adjacent unburnt areas. Even trees visually classified as severely burnt showed no loss of increment.

Billing (1980) described a fuel reduction burning operation in first thinning slash in which some areas of crown scorch occurred. Approximately one year after burning, both dominant and co-dominant trees which had more than 50% of their green crown depth scorched had a mean diameter increment significantly less ($p = 0.05$) than trees which were not scorched (Billing, 1981). The mean diameter increments were 59% and 38% of the increments of unscorched dominants and co-dominants respectively. There was no difference between trees with less than 50% scorch and those without scorch.

Fuel reduction burning operations that maintain the low fire intensities described earlier should not scorch tree crowns and therefore are unlikely to have any impact on tree growth.

3.3 Stem Damage

The factors which will determine the extent of damage caused by burning include the intensity of the flame front, the residence or burn out time of the fire close to the tree stem, which will be related to the moisture content of the heavy fuels and duff layer, and the bark thickness and moisture content. All the evidence indicates that provided the prescriptions described earlier are adhered to there will be very little effect on wood quality, and that any damage is most likely in younger stands where bark thicknesses are relatively low.

Nicholls and Cheney (1974) studied sawn timber losses in a 28 year old stand subjected to fire intensities which were generally higher than those recommended for fuel reduction burning. They found that a 0.4% reduction in the total possible sawn timber volume was due to fire damage.

From the 11 and 16 year old stands studied by Thomson (1978) Woodman and Billing (1979) examined 31 of the more severely burnt trees. Most damage was found in the younger stand where bark thicknesses were lower and, because of the fuel distribution, fires were generally slightly higher in intensity. The damage usually consisted of small sections of dead cambium and was only found in trees which were less than 21cm dbhob or had a minimum bark thickness of less than 2.5 mm. In the 11 year old stand Woodman (1982b) felled a further 35 trees, giving a total sample of 50 trees in this younger stand. Assuming complete loss up to the height at which the damage ceased the loss of merchantable volume due to the fuel reduction burning was 1.2% of the total volume. However, the actual loss would be much less because the sample was biased towards the smaller trees. The damaged sections would also still be suitable for pulpwood and, as on average only 20% of the circumference was affected, most would still be suitable for sawn timber production. There is no reason to believe the damage encountered will have any significant impact on future merchantable volumes.

These conclusions are supported by the results of a study in a stand where first thinning slash was burnt 4 years earlier (Billing, 1982). It was estimated that fewer than 10% of trees had stem damage caused by fire and on 50% of these the damage was overgrown by the time of study. Most damage was confined below 0.6 m above ground level and maximum damage, in terms of the percentage of circumference affected, occurred at 0.2 m. Any long-term impact on wood production is most unlikely as at the stage of second thinning, 4 years after burning, no problems were encountered with conversion of thinnings into sawn timber.

The importance of factors other than bark thickness and the intensity of the flame front in minimising damage is shown by the results of clear felling during 1980 of a section of the Mt Franklin plantation (Billing 1980). The stand was 18 years old when burnt by low intensity wildfire, with flame heights generally less than one metre, in January 1969. During felling extensive damage became apparent, including fire scars to heights of 5-7 m and extending on average, depending on tree size, around 22% to 46% of the circumference at stump height. It is probable that increased fire residence time, caused by dry heavy fuels, and the lower moisture content of the inner bark likely during summer were contributing factors.

ACKNOWLEDGEMENTS

Peter Billing provided valuable assistance, particularly with Section 2.3, and Bryan Rees prepared the figures used throughout the report.

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