SHORT-TERM RESPONSES FROM CONTROLLED BURNING AND INTENSE FIRES IN THE FORESTS OF WESTERN AUSTRALIA

by

G. B. PEET and J. McCORMICK

W. R. WALLACE
Conservator of Forests

PERTH
1971

75392—(1)

TABLE OF CONTENTS

SUMMARY

This publication sets out short-term results from eleven experiments measuring responses to controlled burning in girth growth of pole-sized trees and crown damage to saplings.

The experimental results were divided into tree species, tree sizes, and intensity of the treatment fires. Fire intensity was described by Byram's formula I = Hwr.

The experiments included four species, jarrah, karri, maritime pine and monterey pine, all of which are subjected to varying amounts of controlled burning in Western Australia.

The fire intensities were within the limits normally used for controlled burning. For pole sizes they ranged from 13 to 27 B.T.U. per second per foot for jarrah, 22 to 29 for karri, 9 to 11 for maritime pine, and 4 to 5 for monterey pine. These fires failed to produce responses in girth growth over two- to four-year measurement periods.

One experiment included treatment with intense fires for jarrah poles. Twenty per cent. of these trees were killed in spring and 27 per cent. in autumn. Most of the remainder developed "dry-sides" and the area of this damage was related to bark thickness.

Damage from the intense fires contrasted with the controlled-burnt poles where only one in 253 trees was killed, and there was little or no evidence of butt damage to the remainder. Subsequent girth growth of trees in the intense fire treatments was similar to the unburnt control trees.

Small jarrah and karri saplings were susceptible to crown damage during controlled burning. Jarrah saplings less than nine feet (2.7m.) high were damaged by 9 to 12 B.T.U. per second per foot, and saplings up to 13 feet (4m.) high were damaged by 25 B.T.U.

Karri saplings less than 19 feet (5.8m.) high were killed by 20 to 30 B.T.U. but saplings 30 feet (9.1m.) high withstood 12 B.T.U. without butt damage or loss in girth growth.

Controlled burning under pole-sized pines failed to produce responses in girth growth, but marked responses developed after intense fires which scorched the crowns. These responses were related to the length of green tip above the scorched crown.

INTRODUCTION*

Early attempts to protect the jarrah (*Euc. marginata* Sm.) forest in Western Australia by excluding fire were not successful (Wallace, 1965). After several years of fuel accumulation this forest was very inflammable during summer, and control of fires on the worst days proved beyond the resources of available men and equipment. Since 1954 large areas of this forest have been controlled burnt to aid fire control in summer, except where small advance growth temporarily precludes the practice.

In the southern forest, which includes karri (*Euc. diversicolor* F. muell.), wide-spread controlled burning was hindered until recently by access, mixed

* Note: Metric equivalents are given in the text but not in accompanying tables or appendices.

fuels and dense scrub. New lighting techniques for aircraft (Packham and Peet, 1967) and improved planning, have reduced these problems to the extent that rotational controlled burning seems practicable; over 800,000 acres (324,000ha.) were burnt over in four years.

Figure 1.
Controlled burning under maritime pine.

A restricted programme of controlled burning has developed in plantations of both maritime pine (*Pinus pinaster* Ait.) and monterey pine (*Pinus radiata* D. Don). Approximately 3,000 acres (1,200ha.) are burnt annually.

Wide-spread controlled burning has proven the most practical solution to damaging summer fires in these forests. The objective for this burning is fuel reduction with negligible forest damage (Harris and Wallace, 1959).

Until recently there was little measured data to support visual evidence that damage to trees was negligible, or to confirm that standards for controlled burning were correct (Peet, 1967).

Since 1963 a number of experiments have measured responses from crown damage and girth growth following controlled burning. While still short-term, these experiments show initial growth response and suggest acceptable fire intensities for controlled burning under saplings.

Three variables were used in designing these experiments: fire intensity, differences in resistance between tree species, and differences between sizes.

Hare (1961) and Van Loon (1967) pointed to differences in fire resistance between tree species. This provided the basis for studying responses to jarrah, karri, monterey pine and maritime pine in separate experiments. Most of the treatments tested the effect of controlled burning, but more intense fires were tried in jarrah, and to a lesser extent, in pines.

75392—(2)

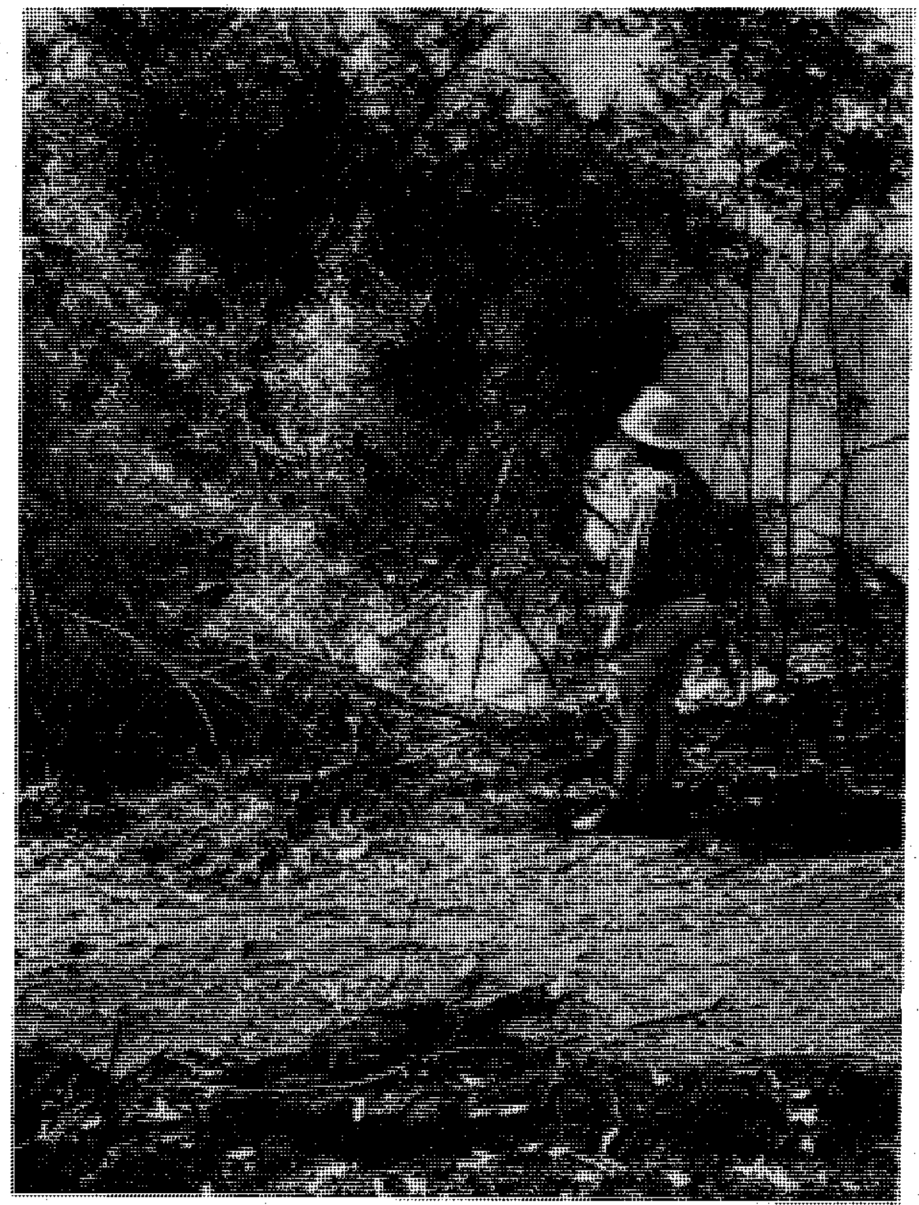

Figure 2.
Controlled burning under karri.

The intensities of these fires are illustrated by Figures 1 and 2 for controlled burning, and by Figure 3 for intense fires. Differences in fire intensity were described by Byram's (1959) formula except for intense fires where the variables were not measured properly. The formula was:

$$I = Hwr.$$

Where I = Fire intensity in B.T.U. (British Thermal Units) per second per foot of fire front.

H = Heat yield of fuel in B.T.U. per pound.

W = Weight of available fuel in pounds per square foot.

r = Rate of forward spread in feet per second.

Figure 3.
Intense fire in jarrah.

A uniform heat yield of 8000 B.T.U. per pound was assumed for these fuels.

Byram's formula was useful for describing differences between fire treatments. The flames in Figures 1 and 2 ranged from 10 to 30 B.T.U. per second per foot, while those in Figure 3 were more than 1000.

The time of burning was similar to normal controlled burning practice. For jarrah and karri, separate treatments were included for spring and autumn. The pine litter was burnt during winter.

In addition, separate spring and autumn treatments made allowance for seasonal effects such as: differences in available fuel after a dry summer, growth effects before and after summer leaf replacement, differences in fire resistance after summer drought, and fire effects on seasonal growth surges. These factors may have different influences on fire response in spring and autumn.

EXPERIMENTAL METHOD

Eleven trials measured girth growth or crown damage from fire. Tree sizes, number of trees in each treatment and the treatments for each trial are listed in Table 1. The trials were generally located in relatively pure stands of jarrah or karri, and in pine plantations.

Tree Sizes and Measurements

The trials included two sizes of tree: poles and saplings. These smaller trees seemed more susceptible to fire damage than larger, mature trees, and represented the stand components most likely to suffer from controlled burning or more intensive fires. Vines (1968) pointed to this difference by showing thicker-barked trees to be more resistant to cambium damage from fire.

Tree sizes were described by basal area for poles (Tables 2 to 5) and by height for saplings.

Girth growth was measured with band dendrometers (Liming, 1957) fitted at breast height. For intense fire treatments the dendrometers were moved to 10.5 feet (3.2m.) above ground to avoid fire scars on the bole.

Bole damage was measured by area of fire scar, called "dry-side". The size of these dry-sides was expressed as a percentage of the surface area for the eight-foot (2.4m.) butt log.

Crown damage to saplings was observed by recording scorch after the fires then recovery one year later. Dead saplings were defined as those whose original crown died, irrespective of new shoot development from the lower stem or lignotuber. Most of the jarrah and karri produced these shoots but the original sapling was either lost or deformed.

The effect of crown scorching to pines was recorded by responses in girth growth. Three severities of crown scorch were measured: 1.5 (0.46m.), 5 (1.5m.) and 10 feet (3.0m.) of green tip remaining above the scorched crown. Trees representing these classes were scorched within one foot (0.3m.) of these limits. The control trees were burnt under at the same time but not scorched.

For the other trials, growth of the burnt trees was compared with an equal number of unburnt controls of similar size and type. The trees selected for measurement were either dominants or codominants in the stand.

TABLE 1

Summary of Treatments for Eleven Trials Measuring Responses to Fire

Species	Trial No.	Tree Size	No. of Treatments	No. of trees per Treatment	Controlled Burning			Intense Fire		
					Autumn	Spring	Winter	Autumn	Spring	Winter
Jarrah	1	Poles	4	30	X	X	...	X	X	...
	2	Poles	1	30	...	X	...	...	...	...
	3	Saplings	1	200	...	X	...	...	...	...
Karri	4	Poles	2	40	X	X	...	...	...	...
	5	Poles	2	40	X	X	...	...	...	...
	6	Saplings	1	40	...	X	...	...	...	...
Maritime Pine	7	Poles	1	13	...	...	X	...	...	...
	8	Poles	1	50	...	...	X	...	...	...
	9	Poles	3	10	...	...	...	...	...	X
Monterey Pine	10	Poles	1	50	...	...	X	...	...	...
	11	Poles	3	10	...	...	...	...	...	X

TABLE 2

JARRAH

Girth O.B. Growth of Pole Sizes After Fire Treatments

Trial	Treatment	Fire Intensity B.T.U. per sec/ft.	Average tree B.A.O.B. sq. ft.		Growth Period	Average Girth O.B. Growth inches		Sig. of Variance Ratio
			Burnt	Controls		Burnt	Controls	
No. 1	Spring Control Burn	19.6	0.56	0.58	1 year before burning 1st year after burning 2nd year after burning 3rd year after burning 4th year after burning	0.46 0.50 0.31 0.21 0.23	0.44 0.42 0.31 0.17 0.16	N.S. N.S. N.S. N.S. N.S.
No. 1	Autumn Control Burn	12.7	0.65	0.58	1 year before burning 1st year after burning 2nd year after burning 3rd year after burning	0.42 0.45 0.25 0.22	0.40 0.43 0.22 0.20	N.S. N.S. N.S. N.S.
No. 1	Spring Intense Fire	Described only	0.94	0.95	1 year before burning 1st year after burning 2nd year after burning 3rd year after burning 4th year after burning	0.65 0.59 0.91 0.38 0.39	0.61 0.57 0.65 0.22 0.24	N.S. N.S. N.S. N.S. N.S.
No. 1	Spring Intense Fire	Described only	0.70	0.70	1st year 2nd year 3rd year	0.45 0.26 0.17	0.33 0.26 0.14	N.S. N.S. N.S.
No. 1	Autumn Intense Fire	Described only	0.70	0.71	1st year 2nd year	0.26 0.19	0.13 0.21	N.S. N.S.
No. 2	Spring Control Burn	27.1	0.52	0.58	9 months before burn 1st year after burn 2nd year after burn 3rd year after burn	0.23 0.28 0.26 0.32	0.21 0.22 0.26 0.33	N.S. N.S. N.S. N.S.

Fire Treatments

The fires ranged from mild controlled burning to flames six (1.8m.) to ten feet (3.0m.) high scorching the crowns of pole-sized pines, to intense 20 foot (6.1m.) high flames which defoliated and scarred the boles of pole-sized jarrah (Figure 3).

Averages for weather, fuel and fire behaviour during these fires are shown in Appendices 1 to 4. Unfortunately, this data was not recorded during the fires which caused crown scorching or other intense fires.

Fires for controlled burning were measured with a standard experimental fire technique (Peet, 1965). This involved sampling fuel then recording spread rates and weather during the fire.

The intense fires were created by heaping dry slash around the butt of each tree. These heaps were about three feet (0.9m.) high and wide. Vines (1968) described these fires and this description was apt for both autumn and spring treatments. "The flames were generally 25 (7.6m.) to 30 (9.1m.) feet high initially and after two minutes still 20 feet (6.1m.). The fuel continued to burn fiercely until exhausted. After seven minutes a thick layer of burning embers was left, and these remained hot for some time. Thus the trees were usually bathed in flames for five minutes, and were subject to intense radiation for another five minutes."

The fires which scorched crowns of pines were considerably milder. Flames were six (1.8m.) to ten feet (3.0m.) high but lasted less than a minute. There was very little prolonged glowing of embers around the butts.

EXPERIMENTAL RESULTS

Jarrah and Karri Forest

Poles. Girth growth for jarrah and karri poles was unaffected by controlled burning with fire intensities between 12 and 30 B.T.U. per second per foot (Tables 2 and 3). There was one exception: growth was stimulated the third year after spring burning under small karri poles (Trial 5).

The two jarrah trials had different fire histories. Trial 1 lay in forest controlled burnt for four years previously, and Trial 2 in forest protected from fire for over 30 years. Neither responded to controlled burning, nor was there evidence of prolonged growth losses after treatment by intense fires (Trial 1, Table 2).

Most of the trees treated with intense fires were scarred on the lower bole, so dendrometers were fitted higher up the trunk. Fitting the dendrometers was delayed seven months for the spring plots and for seventeen months in the autumn ones, to allow time for bole damage to develop. After these delays the burnt trees grew at a similar rate to the unburnt controls.

There was no obvious bole damage in any of the controlled burnt plots, except for one karri tree killed by a log burning against the butt.

Saplings. In spring 1965, three plots, each with 200 jarrah saplings, were controlled burnt with fire intensities between 9 and 18 B.T.U. per second per foot (Trial 3). In spring 1968, more data was gathered by burning under 300 saplings with intensities between 12 and 25 B.T.U.

Sapling heights ranged between 3.5 (1.1m.) and 17.5 feet (5.3m.), and averaged eight feet (2.4m.).

Damage to the crowns was influenced by their height and by intensity of the fires.

The effect of rising fire intensity is illustrated in Figure 4. Good correlation was obtained between number of crown deaths and increase in fire intensity.

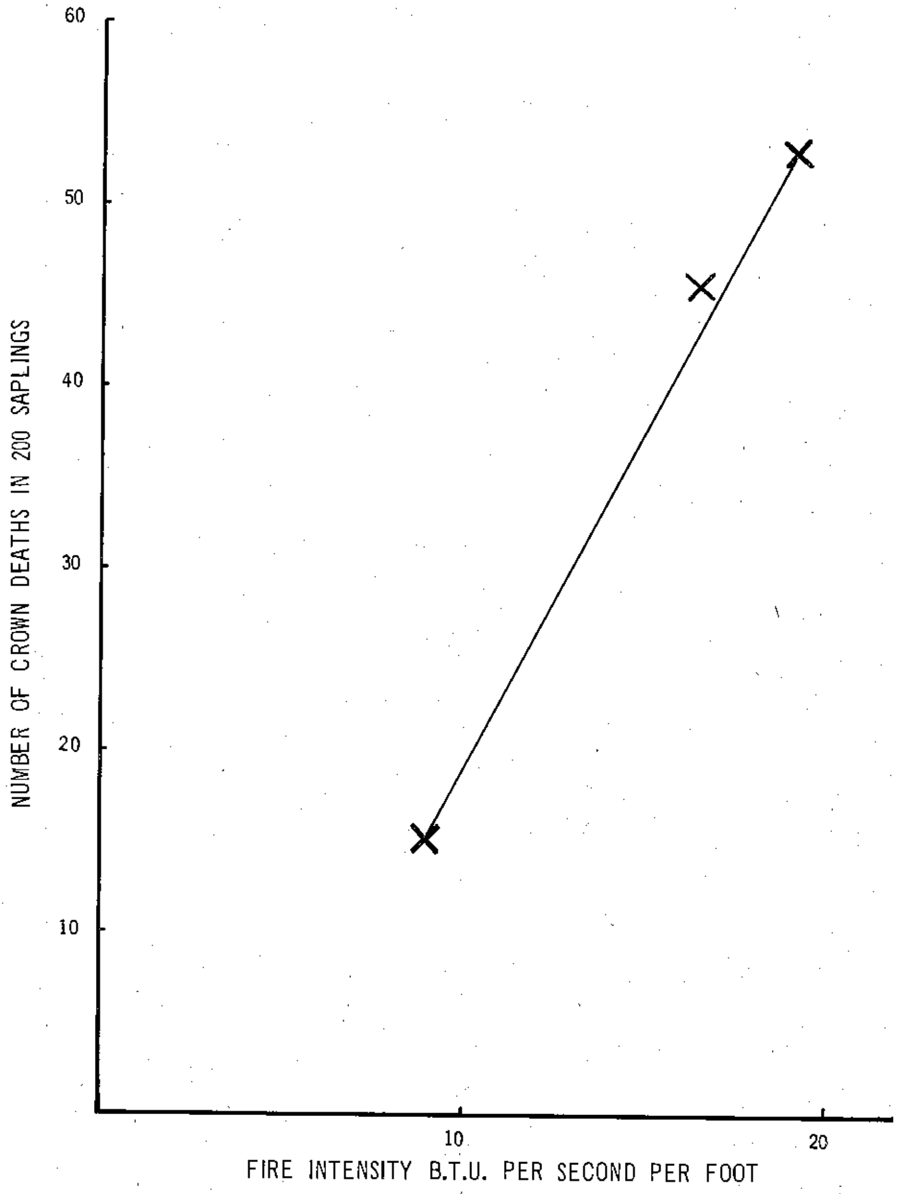

Figure 4.
Relationship between crown damage and fire intensity for jarrah saplings.

TABLE 3

KARRI

Girth O.B. Growth of Pole Sizes after Fire Treatments

Trial	Treatment	Fire Intensity B.T.U. per sec/ft.	Average tree B.A.O.B. sq. ft.		Growth Period	Average Girth O.B. Growth inches		Sig. of Variance Ratio
			Burnt	Controls		Burnt	Controls	
No. 4	Spring Control Burn	21.6	0.58	0.55	7 months before burn 1st year after burn 2nd year after burn 3rd year after burn	0.33 0.55 0.74 0.53	0.37 0.57 0.80 0.59	N.S. N.S. N.S. N.S.
No. 4	Autumn Control Burn	28.8	0.52	0.55	11 months before burn 1st year after burn 2nd year after burn 3rd year after burn	0.36 0.70 0.66 0.44	0.41 0.67 0.74 0.49	N.S. N.S. N.S. N.S.
No. 5	Spring Control Burn	11.9	0.12	0.10	7 months before burn 1st year after burn 2nd year after burn 3rd year after burn	0.72 1.21 1.38 1.29	0.64 1.24 1.24 0.87	N.S. N.S. N.S. 0.01
No. 5	Autumn Control Burn	12.0	0.12	0.10	1 year before burn 1st year after burn 2nd year after burn	1.39 1.00 0.73	1.34 1.18 0.79	N.S. N.S. N.S.

In the 1968-burnt plots there were numerous marri (*Euc. calophylla* R. Br.) saplings of similar size to the jarrah. They suffered similar levels of crown damage.

Despite the mild intensity for these fires most saplings under ten feet (3.0m.) high and all saplings under four feet (1.2m.) high were killed. Replacement of these small saplings was rapid. Fifteen months after the fires, ingrowth into the three (0.9m.) to four feet (1.2m.) height class equalled or exceeded the number before the fires.

Forty karri saplings were controlled burnt in spring 1966, with a fire intensity of 22 B.T.U. per second per foot. Their heights ranged between 8.3 (2.5m.) and 17.6 feet (5.4m.) and averaged 12.7 feet (3.9m.). Three survived, but only one, the tallest, kept a completely normal crown.

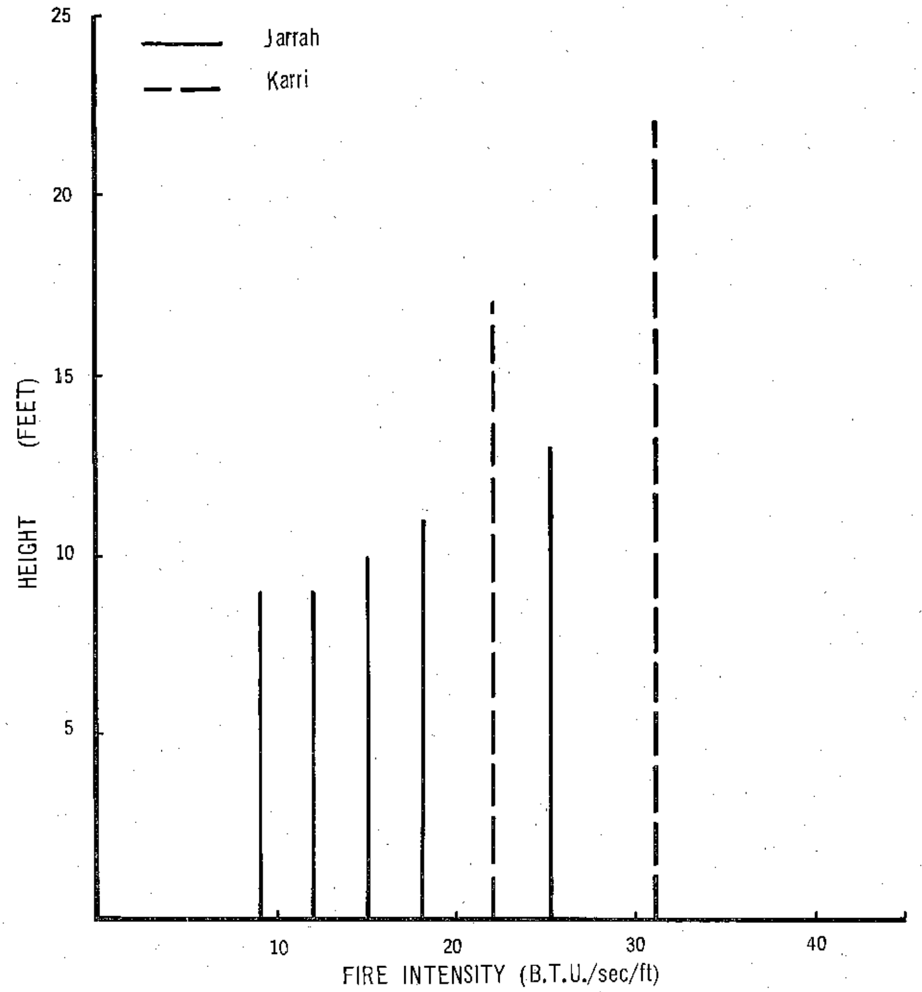

Figure 5.
Relationship between the top-height of jarrah and karri saplings which suffered crown deaths and fire intensity.

In spring 1969 another forty karri saplings were burnt under with a fire intensity approximately 31 B.T.U per second per foot. These were taller, ranging between 14 (4.3m.) and 29 feet (8.8m.), and averaging 19.5 feet (5.9m.). Twenty-six retained a normal crown.

These results demonstrated the importance of height in regulating crown damage. Figure 5 depicts the top-height of jarrah and karri saplings suffering crown deaths, and the fire intensities which caused these deaths.

Seasonal Effects. The fires for treating these plots burnt in periods of rapid growth, in autumn and spring.

The girth growth of controlled burnt poles was unaffected by season, probably because the fire intensities were low and boles and crowns were apparently undamaged, except for one karri tree.

During the intense fire treatments the rough outer bark of jarrah proved drier in autumn and this produced a higher level of charring on the boles. All these trees were either defoliated or fully scorched; there seemed to be little difference between seasons. Subsequently, more of the autumn trees died, and there was a larger area of dry-sides on the boles than in spring.

For the 30 trees treated in spring, six were killed, six apparently undamaged and the remainder dry-sided. These scars ranged in size between 12 and 52 per cent. of the surface area for the eight-foot (2.4m.) butt-log.

For the 30 trees treated in autumn, eight were killed and the remainder dry-sided. The areas of dry-side were larger than in spring, extending up to 80 per cent. of the butt-log surface.

In both seasons the trees killed were the smaller ones in the plots. There were significant correlations between area of dry-side with bark thickness and girth.

Maritime Pine Plantation

Three experiments measured responses to fire in pole-sized maritime pine. Two recorded effects of controlled burning on girth growth (Trials 7 and 8, Table 4) and the third measured the effect of scorching to tree crowns (Trial 9, Table 4).

The controlled burnt stands were pruned, unthinned and had not been burnt under previously. Mild controlled burning (9 to 11 B.T.U. per second per foot) failed to produce responses in girth growth (Table 4).

Unfortunately, dendrometers were not fitted to the trees in Trial 9 until six months after scorching and initial responses were lost. Subsequent losses in girth growth were related to length of green tip. Significant decreases were recorded for the 1.5 (.46m.) and five feet (1.5m.) classes, but not for the 10-foot class (3.0m.). These differences were illustrated by expressing the growth of the scorched trees as a percentage of that for the control trees (Figure 6).

Monterey Pine Plantation

Two experiments were established in pole-sized monterey pine; the first measuring girth growth after controlled burning (Trial 10, Table 5) and the second measuring responses to scorching of tree crowns. Neither trial area had been burnt previously.

TABLE 4

MARITIME PINE

Girth Growth O.B. after Fire Treatments

Trial	Treatment	Fire Intensity B.T.U. per sec/ft.	Average tree B.A.O.B. sq. ft.		Growth Period	Average Girth O.B. Growth inches		Sig. of Variance Ratio
			Burnt	Controls		Burnt	Controls	
No. 7	Winter Control Burn	9.3	0.30	0.30	1st year after burn	0.70	0.59	N.S.
					2nd year after burn	0.62	0.59	N.S.
No. 8	Winter Control Burn	11.2	0.31	0.30	1st year after burn	0.67	0.45	N.S.
					2nd year after burn	0.78	0.73	N.S.
No. 9	Crown Scorch to 1.5 feet	Unknown	0.40	0.40	1st year after burn	0.12	0.70	0.01
					2nd year after burn	0.51	1.36	0.01
No. 9	Crown Scorch to 5 feet	Unknown	0.41	0.41	1st year after burn	0.38	0.73	0.05
					2nd year after burn	0.92	1.37	0.05
No. 9	Crown Scorch to 10 feet	Unknown	0.47	0.47	1st year after burn	0.75	1.00	N.S.
					2nd year after burn	1.45	1.48	N.S.

The controlled burnt stand was pruned but unthinned when the trial was established. It was burnt twice before thinning and twice afterwards. Three of these treatments were very mild (4 to 5 B.T.U. per second per foot), and no growth response developed (Table 5).

Recently, this trial was re-burnt with higher fire intensities (10 to 150 B.T.U. per second per foot). Some bole damage developed on 5 to 13 per cent. of the trees in plots burnt at intensities greater than 60 B.T.U. These dry-sides cover as much as 40 per cent. of the surface area for the eight-foot (2.4m.) butt-log and average 16 per cent.

There was no visible butt damage in plots burnt at intensities less than 12 B.T.U.

Scorching of tree crowns only affected the girth growth of trees in the 1.5 (.46m.) feet-of-green-tip class (Table 5). Growth of the scorched trees, expressed as a percentage of growth for control trees, is shown in Figure 6.

DISCUSSION

The definition of acceptable fire intensities for different tree species and sizes must be an important aspect of research into controlled burning. Without such information the achievement of negligible forest damage depends on personal judgment, which may or may not be an adequate control; and in either case there is no measured data to show the objective is achieved.

The use of Byram's formula to describe fire intensity seemed successful and sensible correlations were obtained between rising fire intensity and damage to jarrah saplings.

In normal controlled burning practice jarrah saplings are protected until they reach 15 (4.6m.) to 20 feet (6.1m.) in height. The success of this specification will depend on keeping the intensity of the first burn below 20 B.T.U. per second per foot.

Karri saplings, averaging 13 feet (4.0m.) high, were almost completely killed by 22 B.T.U. and half the 19-foot (5.8m.) saplings were damaged by 31 B.T.U. Saplings averaging 30 feet (9.1m.) withstood 12 B.T.U. without apparent damage or losses in girth growth.

Karri saplings appear to be less fire-resistant than jarrah (Figure 6) and it is probable that they need protection until at least 30 feet (9.1m.) high. The first burn should approximate 12 B.T.U. but this degree of control will be difficult to achieve in these dense fuels (Figure 2). Until further information is forthcoming it is advisable to protect karri until it reaches pole-size.

The controlled burning treatments for pole-sizes were comparable with normal West Australian practice. None of the mild-fire treatments made any difference to girth growth of jarrah, karri, monterey pine or maritime pine for two to four years of measurement. Season of burning for jarrah and karri was not a significant factor in growth response. One karri pole was killed by a log burning next to the butt and some bole damage occurred in monterey pine when fire intensity exceeded 60 B.T.U. The remaining 252 controlled burnt trees were apparently undamaged.

TABLE 5

MONTEREY PINE

Girth Growth O.B. after Fire Treatment

Trial	Treatment	Fire Intensity B.T.U. per sec/ft.	Average tree B.A.O.B. sq. ft.		Growth Period	Average Girth O.B. Growth inches		Sig. of Variance Ratio
			Burnt	Controls		Burnt	Controls	
No. 10	Winter Control Burn	4 to 5	0.43	0.43	10 months before 1st burn	0.77	0.81	N.S.
					6 months between 1st and 2nd burn	0.35	0.39	N.S.
					16 months after 2nd burn	1.37	1.35	N.S.
					12 months after 3rd burn	1.07	0.93	N.S.
					13 to 18 months after 3rd burn	0.72	0.58	N.S.
					18 to 30 months after 3rd burn	1.17	1.00	N.S.
No. 11	Scorched to 1.5 ft	Unknown	0.24	0.24	1st year after scorch	0.18	0.60	0.01
					2nd year after scorch	0.13	0.33	0.05
No. 11	Scorched to 5 ft.	Unknown	0.29	0.29	1st year after scorch	0.49	0.53	N.S.
					2nd year after scorch	0.35	0.31	N.S.
No. 11	Scorched to 10 ft.	Unknown	0.36	0.36	1st year after scorch	0.71	0.80	N.S.
					2nd year after scorch (7 months only)	0.52	0.46	N.S.

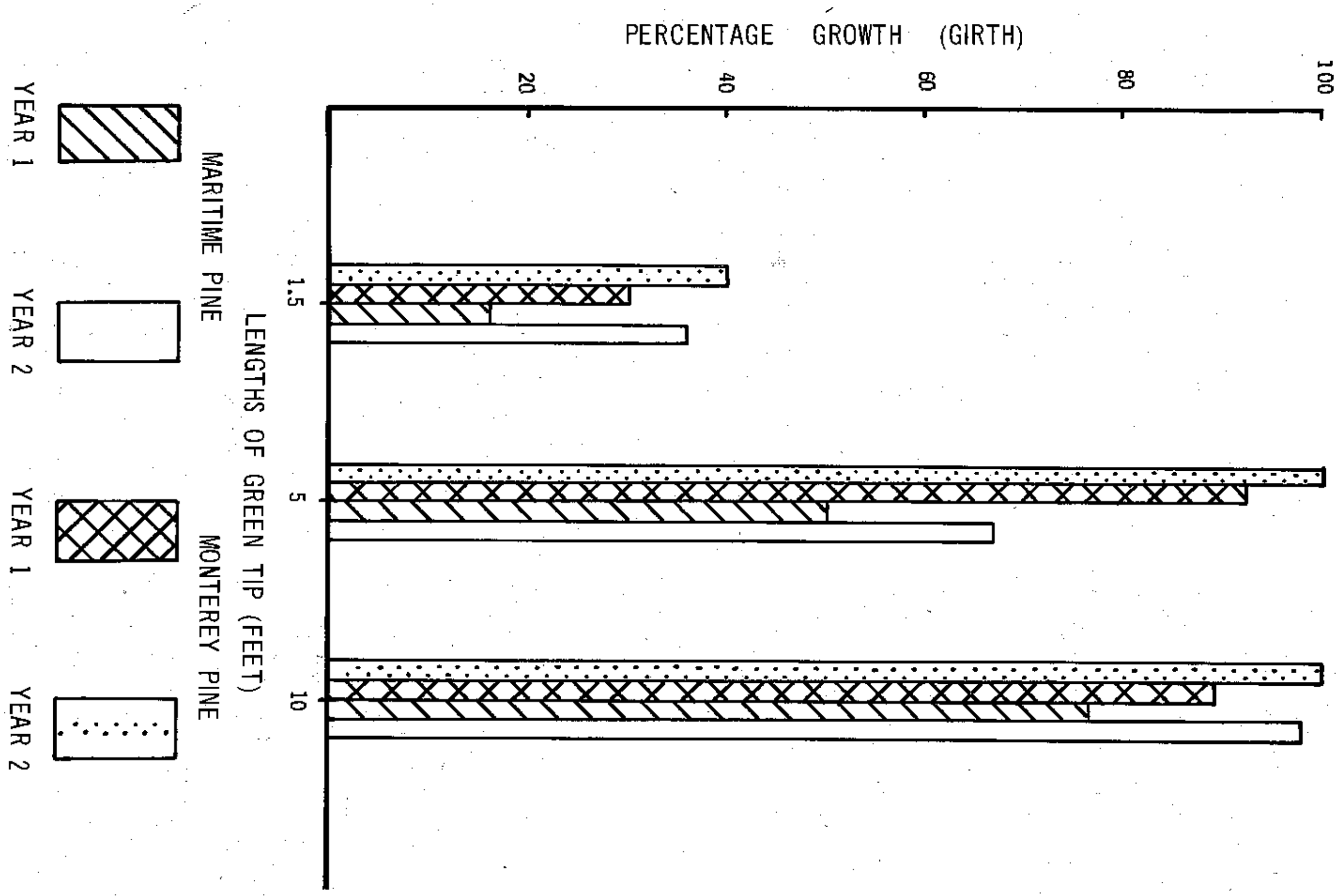

Figure 6.
Growth of scorched pine trees expressed as a percentage of growth of unscorched, control trees. Data are grouped into three classes of length of unscorched crown.

These results contrasted with the intense fire treatments for jarrah where 20 per cent. were killed in spring and 27 per cent. were killed in autumn. Of the remainder, 87 per cent. were dry-sided, and the eight-foot (2.4m.) butt-log may be useless for future sawmilling. The amount of dry-siding was related to bark thickness. More trees were damaged in autumn than in spring.

Scorching to within 1.5 feet (.46m.) of the crown tips produced marked growth losses in both maritime and monterey pines. However, ten feet (3.0m.) of green tip seemed sufficient to prevent significant losses in girth growth. Losses decreased in the second year of measurement for both species, indicating recovery.

TABLE 6

Suggested Fire Intensities for Controlled Burning in B.T.U. per second per foot.

Species	Size Class	Acceptable Fire Intensity
Karri	Mature	Less than 50
	Poles	Less than 30
	Saplings	Protected
Jarrah	Mature	Less than 50
	Poles	Less than 30
	15 to 20 feet Saplings	Less than 20
	13 to 15 feet Saplings	Less than 12
	Less than 13 feet	Protected
Maritime Pine	Poles	Less than 15
	Saplings	Protected
Monterey Pine	Poles	Less than 15
	Saplings	Protected

The intensities for controlled burning under pines were low but sufficient to remove flash fuels such as aerated surface needles and dead bracken. Experience with wildfires in summer suggests removal of these fuels will reduce rates of forward spread and throw distances for spot fires, even if a thick duff is left.

To summarize these results a table of acceptable fire intensities for controlled burning was compiled. This table needs revision from time to time as more results come to hand. For maritime pine trees, intensity was extrapolated (Table 6).

ACKNOWLEDGMENTS

The authors are indebted to Messrs. G. W. van Didden, M. N. Rowell, and W. Freeman, for their assistance with establishment of the experiments and with the collection of data.

REFERENCES

Byram, G. M. 1959. Combustion of forest fuels. Forest control and use. McGraw Hill, pp. 77-84.

Hare, R. C. 1961. Heat effects on living plants. Occ. Paper 183. U.S. For. Ser.

Harris, A. C. and Wallace, W. R. 1959. Controlled burning in West Australian forest practice. Paper to A.N.A.A.A.S., 1959.

Liming, F. G. 1957. Homemade dendrometer. Jour. of For., Vol. 55, No. 8.

Packham, D. R. and Peet G. B. 1967. Developments in controlled burning from aircraft. C.S.I.R.O. Chem. Res. Labs.

Peet, G. B. 1965. A fire danger rating and controlled burning guide for the northern jarrah forests of Western Australia. W.A. Forests Dept. Bull. No. 74.

Peet, G.B. 1967. Controlled burning in the forests of Western Australia. Paper to 9th Br. For. Conf. India.

Van Loon A. P. 1967. Some effects of wildfire on a southern pine plantation. N.S.W. For. Comm. Res. Note 21.

Vines, R. G. 1968. Heat transfer through bark and resistance of trees to fire. Aust. Journ. of Botany 16. 499.

Wallace, W. R. 1965. Fire in the jarrah forest environment. Jour. of Royal Soc. of W.A. Vol. 49 p. 2

APPENDIX 1

JARRAH TRIALS

Weather, Fuel and Fire Behaviour during Controlled Burning Treatments

Variable	Pole Sizes			Sapling Sizes				
	Trial 1		Trial 2	Trial 3 (Spring 1965)			Trial 3 (Spring 1967)	
	Spring	Autumn	Spring	Plot 6	Plot 7	Plot 8	Plot 9	Plot 10
1. Air temperature degrees F.	69	70	68	67	67	67	71	68
2. Relative humidity per cent.	53	44	63	63	63	63	63	72
3. Wind velocity at 4 feet, m.p.h.	2.5	1.9	1.6	2.9	2.8	2.8	2.6	2.8
4. Total litter quantity tons per acre e.o.d.w.	3.2	2.7	6.9	1.9	3.4	2.3	4.1	3.7
5. Available litter tons per acre e.o.d.w.	3.2	2.7	4.2	1.4	2.9	2.1	2.3	2.6
6. Litter profile moisture content per cent.	16.0	16.0	50.0	20.6	20.6	16.1	22.6	16.0
7. Headfire flame height, feet.	1.7	2.1	1.0	1.0	1.2	1.8	1.5	1.9
8. Average rate of forward spread of headfire ft. per min.	1.0	0.8	1.1	1.0	1.0	1.2	0.9	1.6
9. Fire Intensity B.T.U. per sec. per ft.	19.6	12.7	27.2	8.6	17.7	15.2	12.4	25.0

APPENDIX 2

KARRI TRIALS

Weather, Fuel and Fire Behaviour during Controlled Burning Treatments

Variable	Pole Sizes				Saplings	
	Trial 4		Trial 5		Trial 6 (12.7 ft)	Trial 6 (19.5 ft)
	Spring	Autumn	Spring	Autumn	Spring	Spring
1. Air temperature degrees F.	72	64	77	68	71	78
2. Relative humidity per cent.	54	66	53	69	49	54
3. Wind velocity at 4 feet m.p.h.	2.6	2.6	1.9	0.8	1.9	1.6
4. Total litter tons per acre e.o.d.w.	4.6	13.3	4.4	8.3	5.5	8.5
5. Available litter tons per acre e.o.d.w.	3.0	4.0	2.2	4.0	4.1	5.2
6. Litter profile moisture content per cent.	25	81	41	40	15	30
7. Headfire flame height, feet.	1.7	3.0	1.3	1.0	1.5	3.0
8. Average rate of forward spread feet per minute	1.2	1.2	0.9	0.5	0.9	1.0
9. Fire intensity B.T.U. per sec. per ft.	21.6	28.8	11.9	12.0	22.1	31

APPENDIX 3

MARITIME PINE

Weather, Fuel and Fire Behaviour during Controlled Burning Treatments

Variable	Trial 7	Trial 8
1. Air temperature, degrees F.	68	68
2. Relative humidity, per cent.	55	47
3. Wind velocity at 4 feet, m.p.h.	1.6	1.8
4. Total litter tons/acre e.o.d.w.	4.0	4.6
5. Available litter, tons/acre e.o.d.w.	1.3	2.4
6. Litter profile moisture content, per cent.	121.0	88.5
7. Average rate of forward spread, ft/min.	1.2	0.8
8. Fire intensity, B.T.U. per sec. per ft.	9.3	11.2

APPENDIX 4

MONTEREY PINE

Weather, Fuel and Fire Behaviour during Controlled Burning Treatments

Variable	Trial 10			
	1st Burn October 1965	2nd Burn April 1966	3rd Burn September 1967	4th Burn September 1969
1. Air temperature degrees F.	68	65	59	65
2. Relative humidity per cent.	57	55	77	81
3. Wind velocity at 4 feet m.p.h.	1.5	2.5	0.7	1.8
4. Total litter tons per acre equal oven dry weight	3.6	3.8	6.0	8 to 12
5. Available litter tons per acre e.o.d.w.	1.0	1.0	2.0	3 to 10
6. Litter profile moisture content per cent.	168	172	120	35 to 90
7. Headfire flame height, feet	1.0	0.7	0.5 to 2.0	1 to 6
8. Rate of forward spread, feet per minute	0.6	0.5	0.4	0.6 to 2.6
9. Fire intensity B.T.U. per sec. per ft.	3.6	3.6	5.0	10 to 156

75392/7/71—450

WILLIAM C. BROWN, Government Printer, Western Australia