DEPARTMENT OF CONSERVATION

FORESTRY COMMISSION OF N.S.W.

RESEARCH NOTE No. 23

INVESTIGATIONS INTO THE EFFECTS OF PRESCRIBED BURNING ON YOUNG, EVEN-AGED BLACKBUTT

ESTABLISHMENT AND PRELIMINARY PROGRESS REPORT

1969

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G 6975

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SUMMARY

This report describes the establishment of a long-term study into the effects of repeated prescribed burning on an even-aged Blackbutt stand, and detailed fire behaviour and intensity of the first burning application.

Two- and four-yearly burning cycles are to be tested against unburnt controls in a 4 × 3 randomized block design, and summaries of growing stock, major and minor understorey and the fuel complex are given on individual plot and block basis.

Results of two-year observations of litter fall in the study area are given and these are compared with results in similar stands over the same period.

Meteorological and site condition before and after burning are described, as are time-temperature relationships encountered in the fires.

Special emphasis is given to the fire intensity of the burns, both on a plot and on an individual tree basis.

INVESTIGATIONS INTO THE EFFECTS OF PRESCRIBED BURNING ON YOUNG, EVEN-AGED BLACKBUTT

INTRODUCTION

In recent years there has been a substantial increase in both the knowledge and understanding of most factors which influence fire behaviour.

This development has proved itself not only beneficial in the suppression of wild fires, but has also enabled forest management to develop techniques which aim at keeping the intensity of prescribed fires within certain limits.

However, before the wide application of these improved techniques for prescribed burning can be justified, it is essential that the various effects of prescribed fire in the forest should be properly understood and evaluated.

This is the first of a series of planned reports on the progress of the first field experiment designed to evaluate such effects on a coastal hardwood forest in New South Wales.

The experiment has been planned as a long-term project which will not be concluded until the end of the rotation. The ultimate purpose of the study will be to provide material of known fire history for conversion and defect studies, but information in a number of other fields will become available from time to time. The first of such information is presented in this report.

EXPERIMENTAL AREA

The experiment is concentrated on an area of young, even-aged Blackbutt regrowth in the Lansdowne Section of Manning River National Forest No. 1.

Blackbutt (*Eucalyptus pilularis* Sm.) is one of the most important hardwoods in Australia and is the principal species sawn in coastal New South Wales.

The study area has a latitude of 31° 48′ S. and longitude of 152° 36′ E. and is located 17 miles north of Taree. It has a sub-tropical climate influenced by the proximity of the Pacific Ocean (10 miles to the east). The rainfall, which predominantly falls in summer, averages 57·3 inches per annum, and temperature extremes range from 25°–114° F. The study site is approximately 100 feet above sea level.

The majority of coastal hardwood forests in N.S.W. have been managed in the past under a Group Selection System and are decidedly uneven-aged in structure and heterogeneous in nature, while little is known of the history of the older stand components.

In contrast, the stand selected for the experiment is more or less even-aged, not only to offset the disadvantages inherent in establishing experiments in heterogeneous stands, but foremost because it is felt that the conditions in this stand will be increasingly typical of the conditions found in managed Blackbutt forests throughout coastal N.S.W. Part of the experimental site is known locally as the 70 Acre Block and it is the largest even-aged area, dating back to 1940. Some of this area was previously claimed for experiments in stand dynamics, and series of thinning plots were established there in 1950 and 1956.

After intensive cruising of the remaining area, about 30 acres of comparable site quality were considered suitable for fire effects experimentation. This area was divided into 4 blocks, each approximately 7½ acres in size.

Actually 3 age classes occur in the area; viz. 1940 regeneration, 1943 regeneration and a 1948 plantation area. Two of the four blocks fall in the 1940 regeneration area, which is the only area that has received treatment since its regeneration. These blocks were slashed twice between 1940 and 1949 and in this period received several light control burns. The area was thinned for pit props in 1951, for a reported yield of 10,000 super feet per acre, and it was again control burnt in 1952. Commercial thinnings were carried out between 1962 and 1965 for a yield estimated at 2,800 super feet per acre.

The 1943 regeneration and the 1948 plantation area contain one block each. These have not been slashed or thinned, nor have they ever been subject to fire of any description.

Each of the 4 blocks were divided by means of 10 feet wide fire trails into 3 plots, each 2½ acres in size. The following treatments were randomly allocated to the plots in each block:

(a) Prescribed burning at 2-yearly intervals.

(b) Prescribed burning at 4-yearly intervals.

(c) Control (total exclusion of fire).

It was further determined to restrict all measurements and observations in each of the plots to one 0·4 acre sample plot, located as far as practicable in the centre of the treatment areas, thus according a theoretical buffer of 1½ chains between the sample area and the external plot boundary.

This was considered important in order to enable the prescribed fire in the burning treatments to develop a definite pattern of spread before entering the sample areas. Thus it would more closely resemble the behaviour of routine prescribed fire.

All observations described in the following sections of this report are based on the conditions in the internal 0·4 acre sample plots. A sketch of their location within each block, and of the general lay-out of the experimental site, is shown in figure 1.

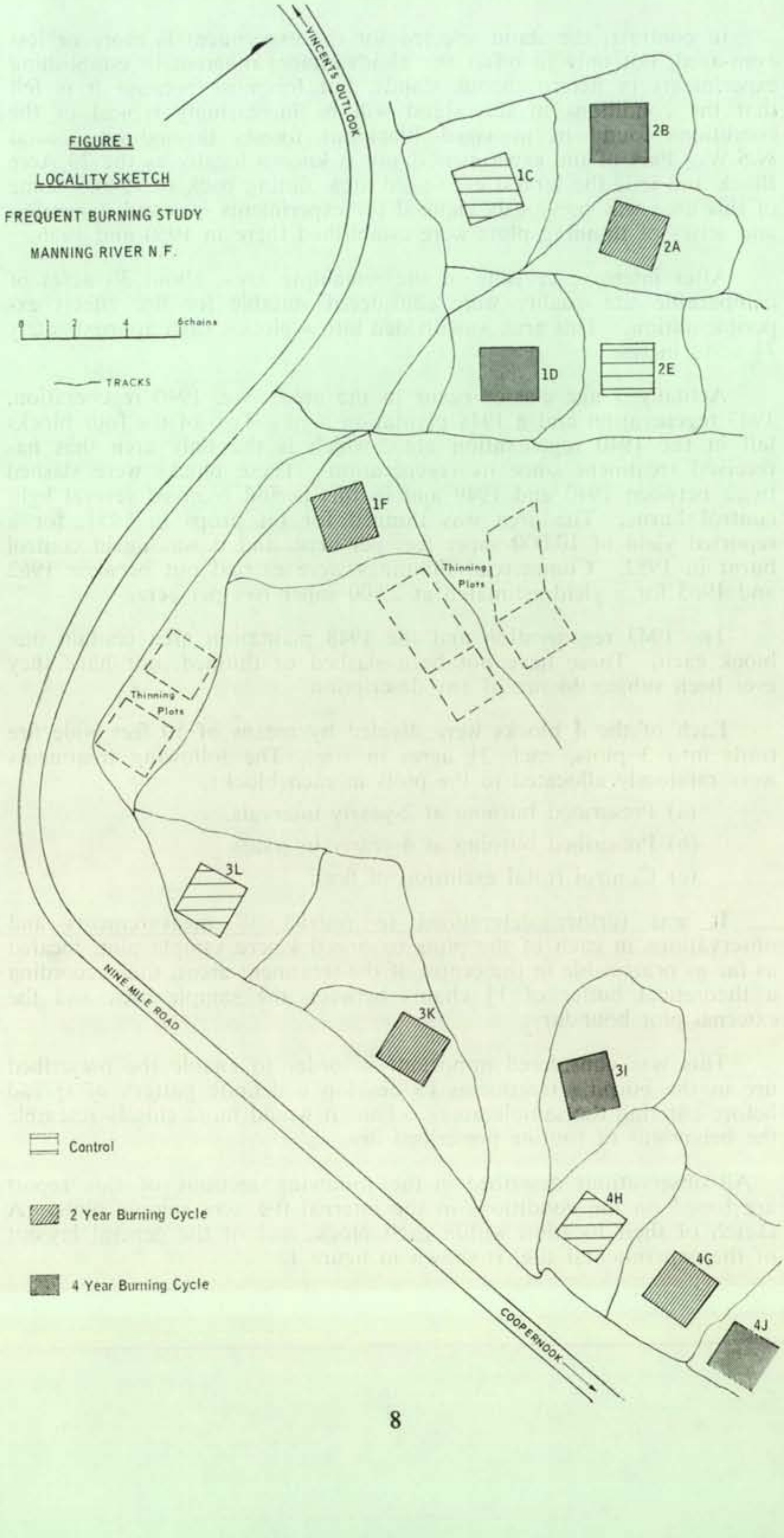


FIGURE 1

LOCALITY SKETCH

FREQUENT BURNING STUDY

MANNING RIVER N.F.

CONDITION OF THE STAND BEFORE BURNING

1. The Growing Stock

In each plot all stems of the merchantable species (e.g. all eucalypts) over 2 in diameter breast height were tagged, painted at breast height, measured for diameter and classified for dominance.

Dominance classes used were:

1. Dominant.
2. Codominant.
3. Subdominant.
4. Suppressed.

Details of these measurements are given in appendix 1. This gives, in 2 categories (for all stems, and for dominant and codominant stems only), the total number of stems per acre, the basal area per acre and the mean diameter, and it also gives the mean dominant height, for each of the 12 plots.

The growing stock in the stand can be more readily pictured by referring to table 1, which tabulates these various stand parameters on a block basis.

TABLE 1

STAND PARAMETERS, GROWING STOCK

	No. of stems per acre		Basal area in feet^2 per acre		Mean diameter in inches		Mean dom. height in ft, 12 trees per plot
	All stems	Dom. 1 + 2	All stems	Dom. 1 + 2	All stems	Dom. 1 + 2	
Block 1 .. .. (1940 regeneration)	257	95	117	88	9·14	13·06	105·2
Block 2 .. .. (1940 regeneration)	329	101	133	98	8·57	13·36	113·9
Mean all 1940 regeneration ..	293	98	125	93	8·82	13·21	109·5
Block 3 .. .. (1943 regeneration)	244	87	106	74	8·87	12·47	102·6
Block 4 .. .. (1948 plantation)	258	101	108	85	8·76	12·44	94·6

From this table it can be seen that dominance classes 1 and 2 (dominants and codominants) contain 35 per cent of the total number of stems in the stand and make up 75 per cent of the basal area.

The mean annual increments for dominants and codominants in the 1940 and 1943 regeneration areas are very similar: in diameter growth these are 0·49 in and 0·52 in respectively, in height growth 4·1 ft and 4·3 ft. These increments for the 1948 plantation area are 0·66 in and 5·0 ft, but it is believed that a large proportion of dominant growing stock in this stand does not in fact originate from 1948 plantings but was present at the time of planting from scattered 1943 regeneration.

The similarity found to exist in both the stocking and past growth of the active growing stock components in the study area creates confidence that any effects of the prescribed burning treatments on growth will become evident as the study progresses.

As mentioned in the Introduction, the ultimate purpose of the experiment is to provide material of known fire history for conversion and defect studies. It was therefore considered essential to obtain an estimate of defects occurring in the stand prior to the application of the first burning treatment. This was attempted in two ways. Firstly, the bottom 10 ft section of each of the 1,364 stems in the study plots was closely inspected for externally visible defects. Secondly, in each plot 12 randomly selected trees in dominance classes 1 and 2 were subjected to a detailed external defect measurement over the full tree length.

Full summaries of external defects encountered in these assessments are not presented here but are deferred for inclusion in later reports, when the effects of a number of burns may be expected to alter the extent and nature of defects in the stand.

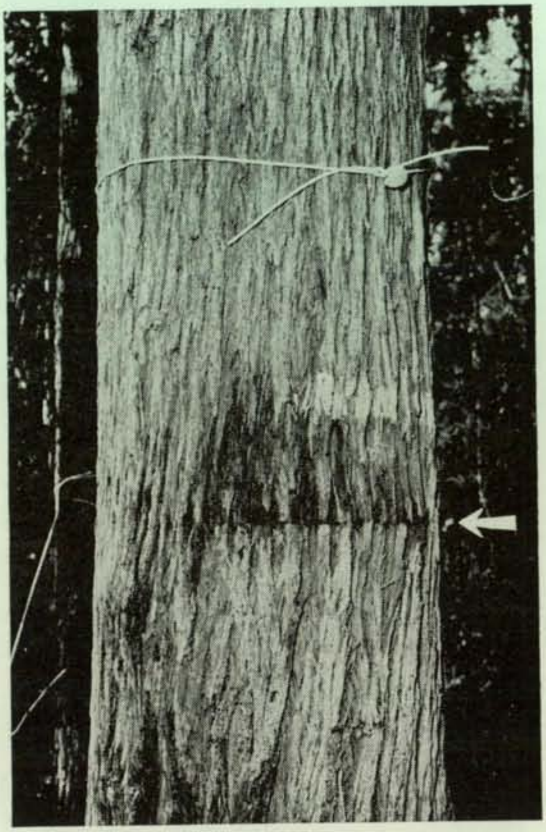
Photograph No. 1

Tree defects: Stem originating from old stump

There appear to be some significant differences in the nature and frequency of defects between the blocks. In blocks 1 and 2 which, as mentioned, have been slashed, thinned and logged, 35 per cent of stems are associated with stumps as shown in photograph 1, while in the untreated blocks 3 and 4 only 8 per cent of stems are thus affected. On the other hand, the younger, untreated, fire-excluded blocks 3 and 4 show greater evidence of bark damage and/or insect attack than blocks 1 and 2. This interesting incidence is shown in table 2.

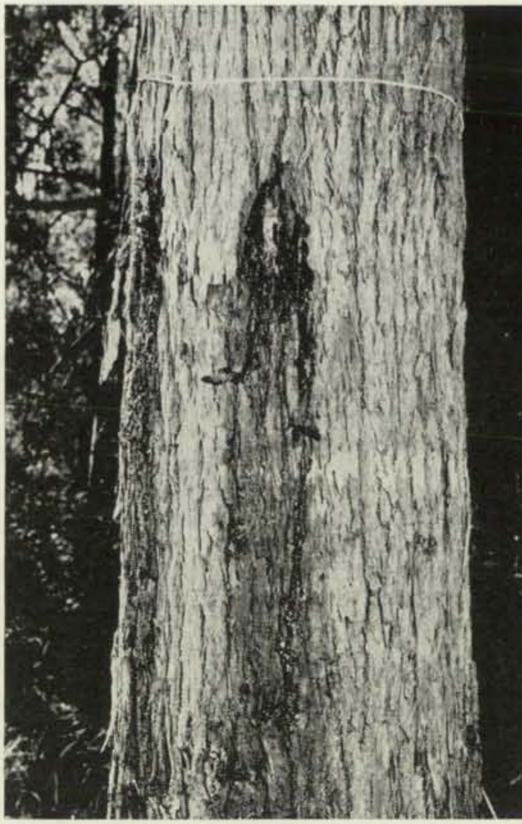
Photograph No. 2

Tree defects: Vertical bark split



Photograph No. 3

Tree defects: Evidence of insect (longicorn) attack



Photograph No. 4

Tree defects: Kino exudation

TABLE 2

SOME DEFECT COMPARISONS BETWEEN TREATED/BURNT AND UNTREATED/UNBURNT BLOCKS

Type of defect and percentage of stems	Mean of Blocks 1 + 2: slashed, thinned, logged, burnt	Mean of Blocks 3 + 4: untreated, unburnt
Associated with Stumps (Photograph 1)	35	8
Vertical Bark Splits (Photograph 2)	20	27
Evidence of Insect Attack (Photograph 3)	23	41
Evidence of Kino Exudation (Photograph 4)	15	28

The more detailed defect observations on the full height of sample stems were made with the aid of a Barr and Stroud dendrometer. For each of the 144 sample stems three 10 in × 1 in rectangles were drawn on squared paper, thus representing three faces of the bole, spaced 120° apart. Various features of the crown and bole and visible defects were indicated by arrows at their appropriate height. Additional measurements obtained during this exercise were: total height, the bole length, the natural log length, the diameter at approximately 10 ft intervals along the bole, and the crown width of all sample trees.

2. The Major Understorey

Although the overstorey throughout the experimental area is reasonably homogeneous, marked differences in understorey composition and density are readily apparent between some of the blocks.

To ascertain the extent of this variation, and to enable testing of the effects of fire on the various understorey components, 2 sampling schemes were adopted. All major understorey plants, comprising shrubs, woody unmerchantable species and stems of merchantable species under 2 in diameter breast height (d.b.h.) but over 1·5 ft tall, were counted in 6 systematically placed 5-milliacre circular quadrats in each of the sample plots.

In each quadrat the position of each stem was plotted on a circular plot diagram, while stems over 1 in d.b.h. were measured for diameter. A full list of major understorey species encountered, showing also the number per acre in which they occur throughout the study area, is presented in appendix 3.

Appendix 2 lists their frequency on an individual plot basis and gives the total number of stems per acre, the number of stems under 1 in d.b.h., the number of stems over 1 in d.b.h. and their mean diameter, and finally the basal area per acre. In order to calculate the latter all stems under 1 in d.b.h. were assumed to have a breast height diameter of 0·25 in.

Table 3 highlights the differences between blocks in both species composition and stocking per acre.

Perhaps the most striking difference between the blocks is the total number of understorey stems per acre: these closely follow the ratio 10 : 5 : 2. Species composition is also markedly different. *Casuarina*, the most common species in blocks 1 and 2 (37 per cent) is virtually absent in blocks 3 and 4, as are *Glochidion* (17 per cent) and *Sambucus* and *Helichrysum* (together 13 per cent). In contrast *Lantana*, present as only 2 per cent in blocks 1 and 2, forms 55 per cent and 47 per cent respectively of the understorey in blocks 3 and 4.

Whether these differences can be attributed to past treatment (e.g. slashing and burning in blocks 1 and 2) is not known. It is certainly not intended to imply here that the variation is more than strictly a site difference.

Fortunately differences within blocks are small and the effects of the burning treatments on this understorey will be closely observed.

TABLE 3

COMPARING STOCKING OF MAJOR UNDERSTOREY SPECIES BETWEEN BLOCKS 1 AND 2, 3 AND 4 ON A PER ACRE BASIS

Species	Blocks 1 + 2 (1940 origin)		Block 3 (1943 origin)		Block 4 (1948 origin)	
	No. of stems	Basal area sq ft	No. of stems	Basal area sq ft	No. of stems	Basal area sq ft
Casuarina torulosa ..	1,355	10·12	11	1·58		
Glochidion ferdinandii ..	628	2·50				
Eucalyptus spp. (under 2 in d.b.h.)	559	3·00	22	0·17	44	0·31
Helichrysum diosmifolium	244					
Sambucus australasica ..	238	0·07	11			
Lantana camara ..	83	0·11	1,000	0·92	344	0·10
Acacia spp.	33	0·2	145	16·6	11	
Breynia oblongifolia ..	216		378		178	
All other species ..	244		255		245	
Total per acre	3,600	16	1,822	19	722	0·7

3. The Minor Understorey

Minor understorey such as grasses, low herbaceous vegetation and woody species under 1·5 ft in height was sampled by means of two permanent 50-ft long transect lines randomly installed in each plot.

The sampling method followed, known as "the three-step method" devised by Parker and Harris (1959), is especially designed to indicate changes in understorey composition and density at periodic intervals.

Vegetation is measured by means of a ¾-in diameter wire loop at 50 randomly selected sample points along each line. The loop can be regarded as a minute quadrat, and at each sample point the decision is made whether the loop is occupied, either above or below, by green or cured vegetation. The frequency of occurrence is expressed as a loop index of density per cent, and means by species for the study area are included as appendix 4, while appendix 2 gives these means on a plot basis for both green and cured occurrence.

Table 4 presents a shorter summary.

TABLE 4

COMPARING DENSITY OF MINOR UNDERSTOREY SPECIES BETWEEN BLOCKS 1 AND 2, 3 AND 4, EXPRESSED AS AVERAGE LOOP INDEX OF DENSITY PER CENT FOR MAIN SPECIES

Species	Blocks 1 and 2 (1940 origin)		Block 3 (1943 origin)		Block 4 (1948 origin)	
	Green	Cured	Green	Cured	Green	Cured
Imperata cylindrica (Blady Grass)	4·7	12·3	10·0	20·0	44·3	74·0
Pteridium esculentum (Bracken)	11·7	11·0	5·0	10·0	12·7	16·3
Entolasia marginata (Bordered Panic Grass)	7·8	2·3	10·0	1·0	6·0	0·3
Lantana camara (Lantana)	0·5		8·3	3·0	4·3	1·6
Desmodium varians (Variable Tic-Trefoil)	1·6		0·6		10·0	
Helichrysum diosmifolium (Sago Bush) ..	7·0	0·3				
Other Species	17·7	11·1	18·1	2·0	8·7	0·8
Total	51·0	37·0	52·0	36·0	86·0	93·0

Of interest are the similarities in total density between blocks 1 and 2, and 3, despite small fluctuation in relative importance between the individual species. Block 4 shows a much higher density than the other blocks and this is mainly caused by the higher stocking of *Imperata*. It is believed that this is largely a reflection of the low basal area of major understorey species in this block: at 0·7 sq ft per acre this is only about 4 per cent of that found in the other blocks.

Photograph 5 (colour) shows the appearance of one of the transect lines in block 3 prior to the first burn. The preponderance of *Lantana* in the understorey of this block can be clearly seen.

4. Litterfall

As part of a major study on rates of fuel accumulation (project F8/8), litterfall in the study area has been under observation since April, 1966. A total of sixteen 2 ft × 2 ft trays are randomly placed in the 1943 regeneration area and their contents are collected at 3-monthly intervals.

Upon collection the contents are sorted in the following fractions:

1. Leaves.
2. Bark.
3. Miscellaneous fine litter.
4. Twigs below $\frac{1}{4}$ in diameter.
5. Twigs $\frac{1}{4}$-$\frac{1}{2}$ in diameter.
6. Twigs $\frac{1}{2}$-1 in diameter.
7. Twigs over 1 in diameter.

These fractions are then ovendried at 105° C until no further loss in weight occurs, and ovendry weights are converted to pounds per acre. The results are presented in table 5 which gives the totals of each fraction for each 3-monthly collection period, for each 12 month period, and a mean annual total for the 2 year period April, 1966–April, 1968. The totals of individual fractions are also expressed as a percentage of the mean annual total litterfall.

TABLE 5

LITTERFALL IN STUDY AREA, DURING THE PERIOD APRIL, 1966—APRIL, 1968 IN POUNDS PER ACRE (O.D.W.)

Means of 16 *Trays*, 2 *ft* x 2 *ft*

3-month period preceding	Leaves	Bark	Misc. fine litter	Twigs					Total litter fall
				0–¼ in	¼–½ in	½–1 in	Over 1 in	Total	
July, 1966	632·5	29·8	68·8	98·7	7·4	3·6	513·2	622·9	1,354·0
October, 1966	731·7	15·5	Nil	133·7	9·7	Nil	233·3	376·7	1,123·9
January, 1967	564·7	152·8	28·7	137·0	17·9	92·7	Nil	247·6	1,053·8
April, 1967	211·0	103·0	37·9	23·2	Nil	30·3	Nil	53·5	405·4
Annual Total 1966–67	2,139·9	301·1	195·4	392·6	35·0	126·6	746·5	1,300·7	3,937·1
July, 1967	236·3	7·9	32·8	93·5	8·1	Nil	Nil	101·6	378·6
October, 1967	451·5	54·2	44·4	93·4	58·4	Nil	Nil	151·8	702·3
January, 1968	908·5	464·3	93·1	168·8	117·4	58·5	Nil	344·7	1,810·4
April, 1968	577·1	74·0	47·6	120·9	63·0	Nil	Nil	183·9	882·6
Annual Total 1967–68	2,173·6	600·4	217·9	476·6	247·0	58·5	Nil	782·1	3,773·9
Annual Mean 1966–68	2,156·7	450·7	206·6	434·6	141·0	92·5	373·2	1,041·3	3,855·5
	0·96 ton	0·20 ton	0·09 ton					0·46 ton	1·72 ton
Percentage of total litterfall ..	56	12	5	11	4	2	10	27	100

It can be seen that the recorded mean annual litterfall averages $1\frac{3}{4}$ tons per acre, of which 1 ton consists of leaves and $\frac{1}{2}$ ton of twigs. Litterfall occurs throughout the year and in the short 2 years' observation period no definite peaks are apparent.

The litterfall as sampled in the study area is light when compared with that in 2 other even-aged Blackbutt stands which have been sampled during the same period. Table 6 shows this comparison.

TABLE 6

COMPARISON OF MEAN ANNUAL LITTERFALL (LB/ACRE) BETWEEN 3 EVEN-AGED BLACKBUTT STANDS, FOR THE PERIOD APRIL, 1966—APRIL, 1968

Stand	No. of traps	Age (yrs)	Mean basal area (sq ft/ac.)	Leaves	Bark	Twigs	Misc. fine litter	Total litter fall	Equivalent in tons per acre
Study Area (Manning River N.F.)	16	25	104	2,156	450	1,041	206	3,855	1·72
Bellangry M.A.	32	24	133	3,532	756	1,663	367	6,318	2·82
Middle Brother S.F.	16	39	151	2,435	873	1,383	295	4,986	2·22
Mean all stands	64			2,708	693	1,362	289	5,053	2·25
Percentage of total litterfall ..				54	13	27	6	100	

No explanation is offered why the litterfall in the Manning River stand should only be 60 per cent of that at Bellangry and 80 per cent of that at Middle Brother S.F. As these litterfall studies are scheduled to continue for another 3 years it is hoped that, with the passage of time, the picture will become clearer.

5. The Fuel Complex

a. Available Fuel

"All studies of fire behaviour in eucalypt fuels have indicated that the amount of available fuel on the floor of the forest is one of the most significant variables affecting the behaviour of fires" (McArthur, 1962).

Some knowledge of available fuel is therefore essential to a full understanding of fire behaviour, and this requirement assumes special importance when prescriptions are made for the controlled use of fire.

Available fuel is the quantity of fuel that actually burns in a forest fire. Even in a homogeneous forest type it is subject to wide variation. Fuel moisture conditions affect the availability to a marked extent. Moreover, as the fire intensity increases, more fuel becomes available for combustion. It is therefore extremely difficult to forecast or sample with any degree of accuracy prior to burning.

In this study an attempt was made to estimate the quantity of available fuel by removing samples of the forest floor and excluding logs and branches over 1 in diameter.

In each of the 12 plots six 1 sq ft samples were taken, using McIntyre's "ranked sets" method of sampling (see McIntyre, 1952; Halls and Dell, 1966).

Upon collection the samples were sorted in the following fractions:

1. Twigs under 1 in diameter.
2. Bark.
3. Leaves.
4. Live vegetation.
5. Dead vegetation.
6. Miscellaneous decomposing matter.

After sorting, the fractions were ovendried at 105° C until no further loss in weight occurred, and the weights of each fraction were converted to pounds per acre.

The plot means for each of the fractions are given in appendix 5 expressed in pounds per acre (top line) and as a percentage of the total fuel for each plot (bottom line).

Table 7 summarizes the information on a block basis.

TABLE 7

AVAILABLE FUEL IN BLOCKS PRIOR TO BURNING, IN LB PER ACRE

	Twigs under 1 in diam.	Bark	Leaves	Live vegetation	Dead vegetation	Miscell-aneous	Total in lb	Total in tons
Block 1—1940 regeneration ..	4,969	974	2,868	177	541	2,359	11,889	5·3
Block 2—1940 regeneration ..	6,081	1,587	2,750	161	447	2,417	13,443	6·0
Block 3—1943 regeneration ..	4,831	840	4,002	112	1,177	2,725	13,689	6·1
Block 4—1948 plantation	6,324	1,061	2,882	135	1,195	2,114	13,710	6·1
Mean all blocks	5,551	1,116	3,126	146	840	2,404	13,183	5·9
Ton equivalent	2·5	0·5	1·4	0·1	0·4	1·0	5·9	
Percentage of total	42	9	24	1	6	18	100	

The similarity in the totals of available fuel, especially between blocks 2, 3, and 4, is striking. Even more encouraging is the similarity of the mean obtained in this sampling to that derived from sampling in the study area at 3-monthly intervals for the fuel accumulation studies referred to previously. The mean of 108 random samples collected in the study area between June, 1966, and March, 1968, is 13,077 lb per acre, or 5·84 tons, against 13,183 lb or 5·88 tons, obtained for 72 samples in the current study.

It is interesting to compare the ratio of litter components as they occur in the available fuel complex with the ratio in which they succeed to the forest floor as litterfall. From table 5 it can be seen that twigs under 1 in diameter constitute 17 per cent of the mean annual litterfall, while they occur as 42 per cent of the available fuel; leaves, 56 per cent of the litterfall, occur as 24 per cent of the available fuel; and corresponding percentages for bark are 12 per cent and 9 per cent.

b. Total Fuel

Total fuel is defined as "the quantity of fuel which would burn under the driest conditions with the highest-intensity fire" (Byram, 1959).

In prescribed burning, as it is understood in Australia, where the aim is for low intensity burning, total fuel does not assume much importance. In fact, a large amount of fuel, in large size classes, will generally adversely affect the rate of spread of a low intensity fire.

As mentioned earlier the boundary between available and non-available fuel in this study was set at twigs of 1 in diameter. Litterfall studies in the area over the last 2 years have given an indication of the size class distribution of twigs falling on the forest floor, and this is as follows:

	Per cent
Twigs 0–¼ in diam.	41 (by weight)
Twigs ¼–½ in diam.	15
Twigs ½–1 in diam.	7
Total twigs under 1 in diam.	63
Twigs over 1 in diam.	37

It should be possible to alter the "available fuel" classification at a later stage, should this be considered desirable.

An estimate of non-available fuel in each plot was obtained from the transect lines installed for understorey sampling. The length of all logs and branches over 1 in diameter, occurring in a foot strip on either side of the transect lines, was recorded in inch diameter classes. Thus, in each plot, 2 random strips each 50 feet long and 2 feet wide were measured, enabling a determination of volume on a per acre basis. The volumes thus obtained were converted to weights using the basic density of Blackbutt (44·9 lb ovendry weight per cu ft) as the conversion factor. The plot totals and block means in 3 in size classes are given in appendix 6.

Table 8 shows the block means in 3 in size classes, and the totals of non-available fuel, for easy references.

TABLE 8

WEIGHTS OF NON-AVAILABLE FUEL IN LB PER ACRE

Block No.	Weights in lb/acre in 3 in size classes					Total in tons/acre
	1 in–3 in	4 in–6 in	7 in–9 in	10 in–12 in	Over 13 in	
1	5,789	4,266	1,743	20,522	2,747	15·9
2	6,596	15,397	15,582	16,213	18,597	32·3
3	450	2,613				1·3
4	463	849				0·6

This summary clearly shows that, in the treated blocks 1 and 2 (slashed once, thinned twice), a quite substantial quantity of non-available fuel is present (16–32 tons), while in the untreated blocks 3 and 4 the non-available fuel does not assume much importance (0·6–1·3 tons per acre).

The total fuel quantities in the untreated blocks of 7·4 tons and 6·7 tons seem remarkably light for stands which have not been subject to any method of fuel reductions for periods of 25 and 20 years respectively. They represent less than 4 years total litterfall.

c. Fuel remaining after Burning

After the 1968 burning had been carried out, the fuel not consumed in the fires was sampled in identical fashion to the pre-burn assessment. The plot means for each of the fractions are given in appendix 7, expressed in pounds per acre (top line) and as a percentage of the remaining available fuel for each plot (bottom line).

Table 9 summarizes the information on a block basis.

The average fuel reduction achieved was 4·1 tons per acre, or 70 per cent of the available fuel as sampled before the burning.

It is interesting to compare the reduction between the individual fractions. These* were:

	Per cent
1. Twigs under 1 in diam.	55
2. Bark	64
3. Leaves	84
4. Live vegetation	100
5. Dead vegetation	84
6. Miscellaneous	70

The dead vegetation component in the post-burn assessment is 136 lb per acre, almost identical to the 146 lb per acre of live vegetation in the pre-burn sample. In essence the dead vegetation was fully consumed in the fires, and the material classified as dead vegetation after the fire was in fact the live vegetation before burning.

* These reduction percentages are based on the post-burn sampling of the 2 *burnt* plots in each block, and on the pre-burn sampling of the *same* 2 plots in each block. Table 7 is based on the pre-burn sampling of all 3 plots in each block, and consequently the reduction percentages given above are more accurate than, and do not quite coincide with, percentages calculated from the figures given in tables 7 and 9.

TABLE 9

UNBURNT "AVAILABLE" FUEL IN BLOCKS AFTER BURNING (LB PER ACRE)

	Twigs under 1 in diam.	Bark	Leaves	Live vegetation	Dead vegetation	Miscell-aneous	Total in lb/acre	Total in tons/acre
Block 1—1940 regeneration ..	2,402	565	753		200	612	4,532	2·0
Block 2—1940 regeneration ..	2,531	238	366		85	736	3,956	1·8
Block 3—1948 regeneration ..	1,692	368	410		106	521	3,097	1·4
Block 4—1948 plantation	2,893	271	461		153	778	4,556	2·0
Mean all blocks	2,379	361	498		136	662	4,036	1·8
Ton equivalent	1·1	·1	·2		·1	·3	1·8	
Percentage of total	59	9	12	0	3	16	100	

Due to the differences in reduction between the fractions, fuel remaining after the fire occurs in different proportions to those existing before burning, for example:

	Twigs under 1 in	Bark	Leaves	Live vege-tation	Dead vege-tation	Miscell-aneous
Percentage of fuel before burning ..	42	9	24	1	6	18
Percentage of fuel after burning ..	59	9	12	0	3	16

In no case did the burning reduce the quantity of non-available fuel in any significant way. Even in the highest intensity burn the reduction in branches and logs over 1 in diameter was less than 2 per cent of the total weight.

METEOROLOGICAL CONDITIONS BEFORE AND DURING BURNING

The first burning treatments of the experiment were carried out in February, 1968. Three plots were burned on the 6th and 7th days of February and 5 more 2 weeks later on the 19th, 20th, and 21st days of the month.

The preceding year (1967) had been exceptionally wet, 81 inches of rain being recorded 1 mile from the study area against an annual average for that station of 57 in. In the month of January, 1968, over 15 in of rain fell against a January average of 7 in. Rainfall figures for January and February, 1968, are tabulated in table 10.

TABLE 10

RAINFALL FOR JANUARY AND FEBRUARY, 1968

(100 points = 1 inch)

January 1—January 14, 1968	777 points
January 15	467 points
16	182 points
17	10 points
18	22 points
22	23 points
26	27 points
30	4 points
February 4	28 points
5	2 points
8	84 points
9	35 points
12	12 points
14	2 points
15	4 points
16	18 points
27	5 points
28	9 points

In each day that burning was carried out, temperature and relative humidity were measured continuously on a thermohygrograph placed in a Stevenson screen installed in the study area at a height of 3·5 ft above ground level. This instrument was checked with a sling psychrometer before and after each burn. Rainfall was measured with a Lambrecht "Hellman"-type rainfall recorder.

During actual burning operations wind speed was measured continuously with a "Casella" sensitive cup anemometer, installed at 5 ft above ground level in the stand and read at intervals not exceeding 5 minutes.

Just before ignition 2 random samples were obtained in each plot for moisture content determination of:

1. the top litter layer;
2. the bottom litter layer;
3. tree bark at 2·5 ft above ground level;
4. soil at 0–1 in level;
5. soil at 1–2 in level;
6. soil at 2–3 in level;
7. soil at 3–4 in level.

The meteorological and physical site conditions prevalent at the time of ignition of each plot are summarised in the table 11.

It can be seen that the temperature ranged between 84° and 91° (mean 87·5° F) and relative humidity between 42 per cent and 56 per cent (mean 50 per cent).

The minimum wind speed measured was 1·5 miles per hour and the maximum 3·1 mph at 5 ft in the forest. Equivalent wind velocities at 33 ft in the open approximate 3 and 12 mph respectively, and the mean averaged about 7 mph.

The mean moisture content of the bottom litter layer at 55 per cent was about 3 times the value of the top litter layer. Moisture content of the soil decreased with depth in all cases, the main decrease occurring between the 0–1 in and 1–2 in layers.

FIRE BEHAVIOUR AND INTENSITY

In planning the experiment the only limitation placed on the application of the burning treatments was that burning should be carried out between January and July of each year requiring treatment. For convenience, burning at this time of the year is referred to as *autumn burning.*

In the past, control burning on the North Coast of New South Wales has predominantly been carried out in the spring. At this time of the year, however, strong northwesterly winds of continental origin (hot and dry) are common, and spring burning frequently takes place on a rising hazard so that difficulties in escape prevention are a common and inevitable consequence. Because of this a swing in favour of autumn burning has become apparent in recent years.

TABLE 11

METEOROLOGICAL AND PHYSICAL SITE CONDITION AT TIME OF BURNING

Block No.	Plot No.	Date and month of burn, 1968	Time of ignition	Temp. °F	Rel. hum. per cent	Av. wind speed mph, 5 ft a.g.l.	Moisture content, percentage O.D.W.						
							Top litter layer	Bottom litter layer	Bark 2·5 ft a.g.l.	Soil depth			
										0–1 in	1–2 in	2–3 in	3–4 in
1	F	6/2	11·40	85	50	1·5	25	64	21	30	24	24	24
	D	6/2	15·20	91	48	1·5				34	21	19	19
2	A	20/2	11·30	84	47	3·0	15	64	37	35	24	23	23
	B	7/2	13·40	91	56	2·5				25	20	20	18
3	K	21/2	11·30	87	55	1·5	16	40	30	40	35	32	29
	I	20/2	14·50	85	55	2·7	15	48	47	51	40	35	31
4	G	19/2	12·50	89	42	1·6	18	29	67	52	41	38	36
	J	19/2	14·45	88	50	3·1	23	84	55	39	36	33	32
Mean all plots	..	..	.. ..	87·5	50	2·2	19	55	43	38	30	28	27

Photograph No. 5

View of transect line before burning, *Block* 3, Plot K

Photograph No. 6
View of same transect line after burning,
Block 3, Plot K

Photograph No. 7

Prescribed burn in progress, *Block* 1, Plot F

Average forward rate of spread 0·9 feet per minute; average flame height 1·6 feet; average bark scorch height 5·7 feet

Fuel reduction 65·5 per cent

Fire intensity 24 Btu/ft/sec

Photograph No. 8

Prescribed burn in progress, *Block* 2, Plot 14

Average forward rate of spread 4·9 feet per minute; average flame height 5·4 feet; average bark scorch height 15·2 feet

Fuel reduction 82·3 per cent

Fire intensity 197 Btu/ft/sec

In an average year the number of days suitable for autumn burning may be limited. However, it is especially at this time of the year that conditions of soil moisture and bark moisture content are such as to suggest that minimum fire damage will occur.

Apart from the limitation on time of year, no definite prescription is laid down for the type of burning to be employed in the study. The meteorological and fuel moisture conditions prevailing at the time will dictate whether the burning will be with or against the wind; up, down or across the slope; etc. However, due to the importance of accurately measuring rate of fire spread, grid lighting is not considered feasible, while a number of other measurements essential for fire documentation preclude the use of night burning.

Due to the comparatively high moisture contents of available fuel and the low wind speed prevailing, all fires of the 1968 series were lit as head fires, that is with the wind and upslope.

In addition to the meteorological observations described in the previous section, flame height, flame depth and angle of flame were recorded for each of the fires at intervals not exceeding 5 minutes.

At similar intervals the progress of each fire was marked by placing metal markers at the fire front. Each metal marker was identified by a number designating the time in minutes at which it was placed, enabling subsequent plotting of the perimeter of each fire in the internal sample plots at the time intervals used. The number of markers used in each plot varied with the rate of spread, but an average of 120 markers was used in each 0·4 acre plot.

Both colour and black and white photographs were taken of the fire front at the same time intervals as used for marking the rate of spread. As mentioned previously, after each fire had passed the amount of "available fuel" remaining on the forest floor was sampled in identical fashion to the sampling before the fire, and upon collection each sample was treated in the same way as the pre-burn samples.

Likewise soil moisture content was sampled immediately after each fire as it was done just prior to burning. Fire temperatures were measured at a number of sites in 4 of the burns both by means of chromel-alumel thermocouples connected to a potentiometer and switch, and by chromatic thermometer crayons.

In short, in this study it was deliberately attempted to measure and observe as many fire, fuel, weather and site characteristics as time, manpower and equipment made possible.

This was considered desirable so as to create the possibility of comparing each fire not only with the other fires in the 1968 series, but also with subsequent fires foreshadowed in the experimental design.

If fires, and especially their effects, are to be compared some numerical expression of fire intensity is desirable. Byram (1959) first described how to express a forest fire's energy per unit of time per unit length of fire front. He called it *fire intensity* and calculated it:

Fire intensity	=	Heat of combustion	× fuel consumed	× rate of spread
(Btu/sec/ft)		(Btu/lb)	(lb/ft^2)	(ft/sec)
I	=	hwr		

This expression gives the rate of energy output of each foot of the fire front.

In Australia it has been used by McArthur (1962), who gives fire intensity limits for acceptable damage standards in commercial forests, while Hodgson (1967) refers to it as "an excellent description of a fire because it is so obviously related to how difficult the fire is to control and how much damage the fire causes".

In Canada, Van Wagner (1965) stated that it is the best quantitative measure of fire behaviour and claimed that a wider use of the energy output concept will probably be necessary if the full benefits of advances in fire control technology are to be realised.

Obviously it will be some time before the numerical expression of fire intensity will become meaningful to the practising forester, nevertheless its adoption is strongly urged, since its calculation is not difficult.

In the equation, I = hwr, the combustion rate (h) can for most practical purposes be considered constant. (In this study it is taken at 8,000 Btu per pound of fuel.) The forward rate of spread (r, in feet per second) is one of the most readily measured fire characteristics.

Estimating the weight of fuel consumed (w, expressed as pounds per square foot) is the most difficult requirement of fire intensity calculation. It requires estimates of fuel both before and after the fire, but skill in estimating available fuel is constantly increasing. In addition, data on the weights of available fuel in various fuel types are also becoming more readily available. An analysis of over 1,000 fuel samples, taken in Blackbutt stands of varying ages on the North Coast of New South Wales in recent years, indicates that, regardless of stand history, available fuel quantities range around 6 tons per acre. The amount of fuel consumed will generally range between 50 and 90 per cent and a value between these extremes can be fairly readily guessed. An example of fire intensity calculation is given below. In this example all values used are the means of the 8 prescribed burns of the 1968 series.

Average available fuel before burning was 5·7 tons, of which 1·8 tons remained after the fire. Fuel consumed equalled 3·9 tons per acre or 0·20 pounds per square foot. Average rate of forward spread equalled 2·14 ft per minute or 0·0357 ft per second. Fire intensity equalled 8,000 × ·20 × ·0357 = 57 Btu per second per foot of fire front.

McArthur (1962), who worked in Jarrah fuel types in Western Australia and in dry and wet sclerophyll forests in N.S.W. and the Australian Capital Territory, indicated the following fire intensity limits for acceptable damage standards in commercial forests:

Fire Intensity Btu/sec/ft	
5–12	Intensity too low (fires generally self extinguishing)
13–50	Optimum intensity
51–70	Too severe for some forest types
71–100	Upper limits for acceptable damage effects

Byram (1959) quotes an intensity of about 160 Btu as probably near the upper limit that could be used in prescribed burning work.

TABLE 12

FIRE BEHAVIOUR AND INTENSITY

Block No.	Plot No.	Av. slope of plot	Av. wind speed, mph at 33 ft in open	Av. forward rate spread, ft/min	Av. flame height, ft	Av. flame depth, ft	Av. max. height of bark scorch, ft	Av. bark scorch, percentage	Reduction percentage of available fuel	Fire inten. Btu/ft/sec
1	F	7°	2·2	0·9	1·6	1·5	5·7	28	65	24
	D	12° 45′	2·2	2·0	2·1	2·4	6·7	35	53	29
2	A	8° 45′	10·8	4·9	5·4	3·0	15·2	80	82	197
	B	8° 45′	8·0	1·1	2·7	3·5	7·0	36	56	22
3	K	8° 30′	2·2	2·2	1·8	1·6	8·3	38	83	77
	I	8° 15′	9·1	1·6	1·9	1·7	8·0	37	66	38
4	G	7° 30′	2·8	1·7	2·3	2·0	4·7	23	68	47
	J	7° 15′	11·4	2·6	3·1	2·8	6·3	34	62	62

Fire intensities calculated for the 1968 burns are given in table 12, together with other fire behaviour information.

It may be seen that only one of the burns (plot A) exceeded the normally accepted upper limit for prescribed burning, a fact which was obvious as the fire was in progress. The average forward rate of spread in this plot was 4·9 feet per minute (about 4½ chains per hour), and the average flame height 5·4 feet. Of 186 aluminium tags attached at a height of 5 feet above ground level to the growing stock in the study plot, 39 (or 21 per cent) melted in the fire. As aluminium melts at about 660° C (1,200° F), it is believed that temperatures at 5 ft exceeded that figure on at least 20 per cent of the area.

Unfortunately it has not yet been possible to determine why the intensity of the fire in plot A was up to 8 times as high as that in other plots in the series. Perusal of weather, fuel and site conditions has so far failed to give a satisfactory explanation. Multiple regression analysis is planned when more data is available.

Of the other 7 burns, 5 registered ratings in McArthur's optimum range (13–50 Btu), while 2 burns, although of slightly higher intensity (62 and 77 Btu), were still considered to be well within the acceptable low intensity range.

Table 12 also presents some information on bark scorch sustained in the burning. Firstly an average maximum bark scorch height is quoted, obtained by summing the top height at which bark scorch was visible on each of the stems in the internal plots and dividing by the number of stems.

Secondly a bark scorch per cent is given, obtained by estimating the percentage of the circumference of the bottom 10 ft of bark, blackened by the fire for all stems in each plot.

For those burns of which the fire intensity was less than 70 Btu (6), the average reduction per cent of available fuel was 62 per cent; for those over 70 Btu intensity (2 only), the average reduction was 82 per cent.

Photographs 7, 8, 9, and 10 show examples of fire behaviour and intensity for 4 of the burns of the 1968 series (plots A and F, coloured, plots B and K, black and white).

The fire behaviour and intensity data presented in table 12 are based on averages obtained by meaning the observations of each parameter as measured at the 3- or 5-minute intervals used. In fact large variations occur in most of the parameters over the period that the fire traversed the study plots. An example of the variation encountered in rate of spread is given in figure 2.

Photograph No. 9

Prescribed burn in progress, Block 2, Plot B

Average forward rate of spread 1·1 feet per minute; average flame height 2·7 feet; average bark scorch height 7·0 feet

Fuel reduction 55·9 per cent

Fire intensity 22 Btu/ft/sec

Note thermocrayons installed at height of 2·5 feet on tree at left of photograph

Photograph No. 10

Prescribed burn in progress, Block 3, Plot K: fire in Lantana

Average forward rate of spread 3·3 feet per minute; average flame height 1·8 feet; average bark scorch height 8·3 feet

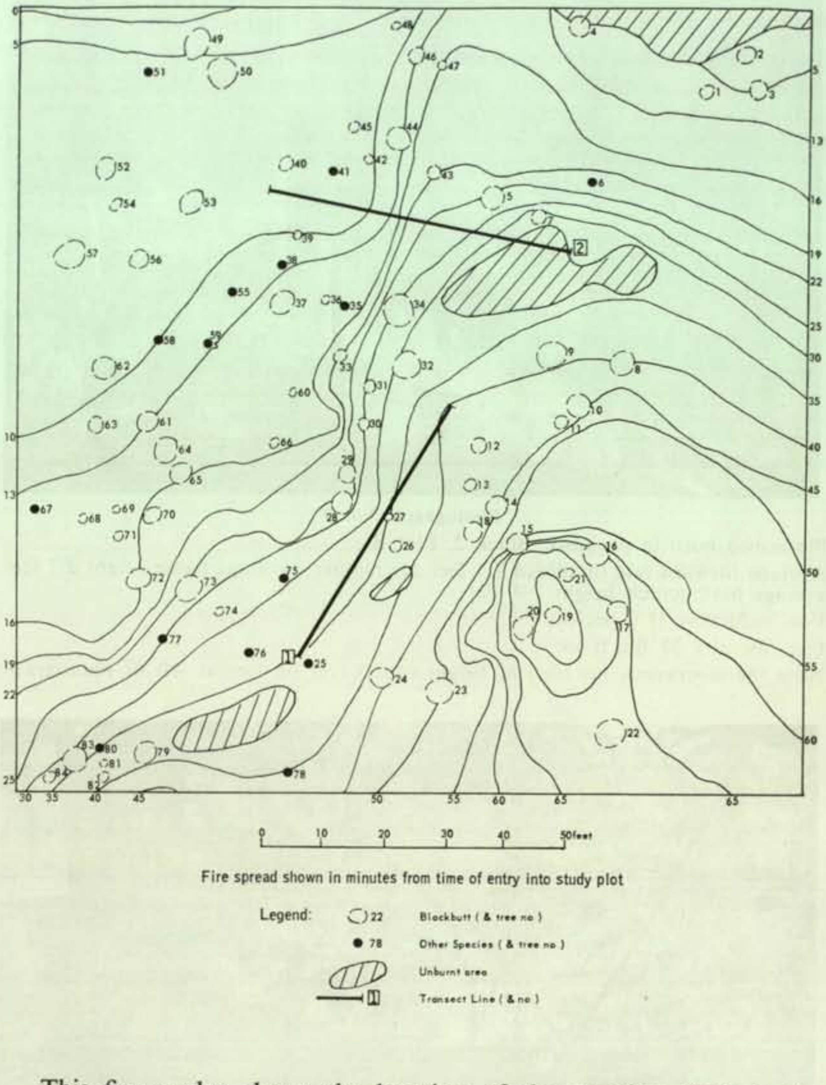
Fuel reduction 83·5 per cent

Fire intensity 77 Btu/ft/sec

FIGURE 2

RATE OF FIRE SPREAD – PLOT K

February 1968, Showing also location of growing stock.



Fire spread shown in minutes from time of entry into study plot

Legend:
- Blackbutt (& tree no)
- Other Species (& tree no)
- Unburnt area
- Transect Line (& no)

This figure also shows the location of the growing stock in the plot, the placement of the 2 random transect lines for minor understorey sampling, and some small unburnt areas. It can be seen that, for instance, the rate of spread between 5 and 10 minutes far exceeded that between 60 and 65 minutes.

After the rate of fire spread had been plotted on sketches showing the location of the growing stock, it was possible to delineate areas of specific fire intensity for each of the plots and subsequently each tree could be assigned to a fire intensity class.

An example of this is shown in figure 3, where for plot B areas of 4 different fire intensities are sketched in on a plan showing the growing stock location. The average fire intensity of this plot, calculated on the average rate of fire spread, is 22 Btu per foot per second, but it can be seen that in large sections of the plot area this intensity was exceeded.

A comparison between the areas of 4 intensity classes, the percentage of stems in the plot in each class, the average maximum bark scorch height and the percentage of bark scorched in the bottom 10 ft of the stems in each class is given in table 13.

FIGURE 3

VARIATION IN FIRE INTENSITY — PLOT B

February, 1968 Showing also location of Growing Stock

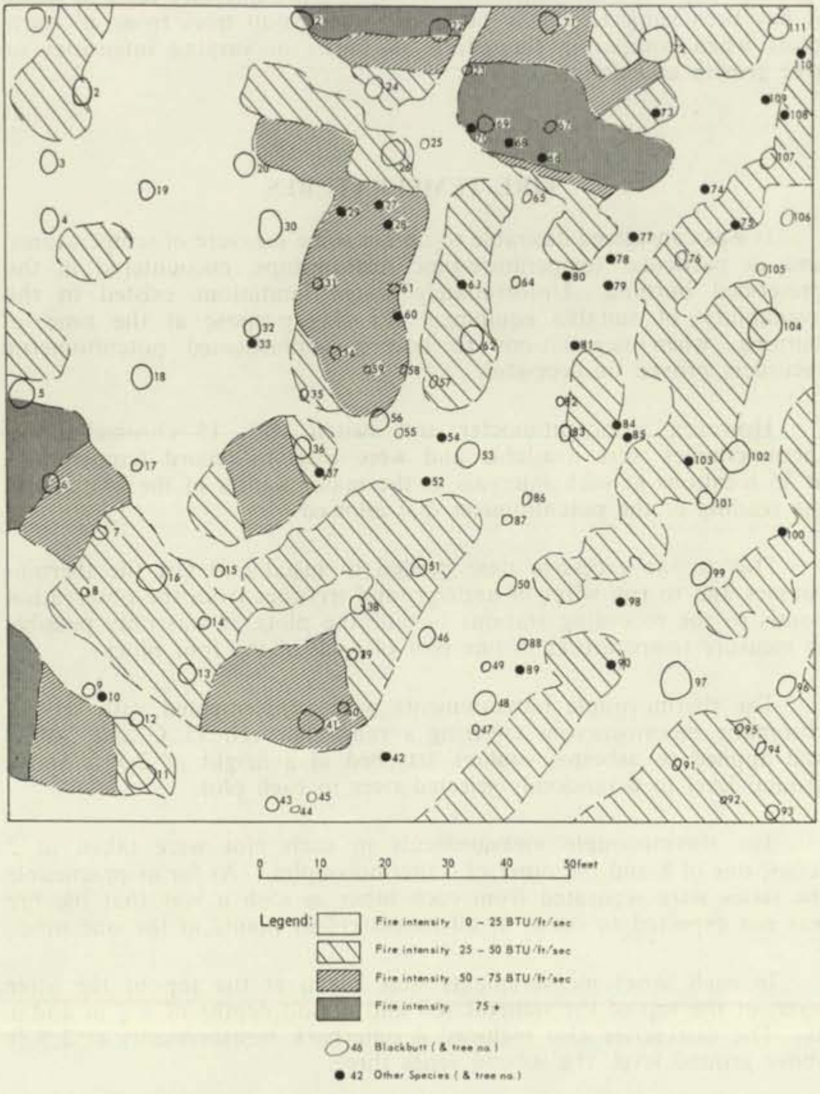


TABLE 13

FIRE INTENSITY CLASSES IN PLOT B

Fire intensity (Btu/ft/sec)	Percentage of plot area	Percentage of stems	Av. max. bark scorch height in ft	Av. bark scorch percentage
0–25	53	39	5·2	27
25–50	29	40	7·1	36
50–75	13	13	8·4	36
75–100	5	9	12·1	63

By assigning each individual tree to the fire intensity class to which it has been subject, it may be possible to group trees from all burnt plots when comparing the effects of burns of varying intensities on tree growth and defect.

FIRE TEMPERATURES

It was considered desirable to obtain some measure of temperatures and in particular temperature-time relationships, encountered in the prescribed burning. Unfortunately severe limitations existed in the availability of suitable equipment for this purpose at the time of burning, when negotiations to borrow sophisticated potentiometric recorders proved unsuccessful.

However, a potentiometer and switch with 15 chromel-alumel thermocouples were available and were used to record temperatures at 15 locations at such intervals as the manipulation of the switch and the reading of the potentiometer dial allowed.

Due to the excessive time needed to instal and test the thermocouples and to run wires in underground trenches from the observation points to the recording stations outside the plots, it was only possible to measure temperatures in one plot of each of the four blocks.

The thermocouple measurements were supplemented with sets of chromatic thermocrayons covering a range between 75° C and 280° C and applied to asbestos squares attached at a height of 2·5 ft above ground level to 6 randomly selected trees in each plot.

The thermocouple measurements in each plot were taken in 2 series, one of 8 and the other of 7 thermocouples. As far as practicable the series were separated from each other in such a way that the fire was not expected to occur at all measurement points at the one time.

In each series measurements were taken at the top of the litter layer, at the top of the mineral soil and at soil depths of a ¼ in and 1 in. The first series also included 4 outerbark measurements at 2·5 ft above ground level, the second series three.

TABLE 14

MAXIMUM FIRE TEMPERATURES RECORDED

Maximum Temperature in °C as measured by Chromel-Alumel Thermocouples

Block No.	Plot No.	Series	Leeward side			Windward tree 3	Top of litter	Top of soil	Soil $\frac{1}{4}$ in	Soil 1 in
			Tree 1	Tree 2	Tree 3					
1	F	1	227	44	244	N.D.	137	237	39	35
		2	489	105	91	170	104	109	50	50
2	B	1	N.D.	128	117	76	390	35	29	27
		2	229	120	77	95	35 (not burnt)	33	25	24
3	I	1	541	501	271	N.D.	313	343	50	25
		2	143	93	98	232	250	45	27	24
4	G	1	251	169	286	N.D.	319	36	32	35
		2	136	70	67	209	72	41	50	24

The temperature measurements were handicapped throughout. Trenches dug to bury wires, and adjacent tracks caused by repeated walking between observation points during the process of thermocouple installation, interfered with the natural spread of the fire, despite efforts to cover the tracks up with natural dry fuel from adjacent areas. In one case (plot B, series 2) the site disturbance caused the fire to go out before reaching the litter and soil sensors. On other occasions the fire enveloped all 15 thermocouples at the same time and large time intervals between readings for each point could not be avoided. Due to the rapidly fluctuating nature of heat in forest fires, maximum temperatures were almost certainly missed and information on the duration of specific heat application is scanty.

The maximum temperatures recorded are given in table 14.

This table shows how extremely variable the temperatures as measured at the outerbark of trees at a height of 2·5 ft above ground level are. The measurements ranged from 44° to 541° C. Unexpectedly, in a majority of cases (4 out of 5) higher temperatures were recorded on the windward side than on the leeward side of the same tree.

Temperatures measured at the top of the litter layer and at the top of the soil also showed large variations (41° to 390° C). The highest temperature recorded at a $\frac{1}{4}$ in below the soil surface did not exceed 50° C, and temperature rises at 1 in below the surface were generally even smaller.

Far more meaningful than the maximum temperature reached is the period of time over which significant increases in temperature are maintained. As mentioned previously, it proved impossible to adequately monitor the majority of thermocouples, to establish meaningful time-temperature relationships. Nevertheless in some cases a sufficient number of readings of a particular thermocouple were obtained over a short period of time to give an indication of what time-temperature relationships occurred during the fires.

An example concerning the temperatures as measured at the outer-bark of a tree at a height of 2·5 ft above ground level is given in figure 4. This figure shows that in this instance temperatures exceeding 400° C (752° F) were maintained for up to 1 min 12 sec, and temperatures over 200° C for 3 min 12 sec.

Figure 5 illustrates the duration of increases recorded at and below the soil surface. The temperature at 1 in below the soil surface reached a maximum of 50° C, but temperatures above 46° C (115° F) were maintained for 10 min. About 30 min after the fire had passed the soil temperatures were still about 8° C higher than before the burn.

The sets of chromatic thermocrayons placed in 7 of the 8 burns did not reveal as much information as had been hoped. The crayons are designed to change colour when specific temperatures are reached, but unfortunately the top temperature range used in the sampling was 280° C and this temperture was exceeded in 52 per cent of the 42 samples used. Indications are that, if a wider range of temperatures is used and the sampling intensity increased, the crayons may give a reasonable estimate of fire intensity.

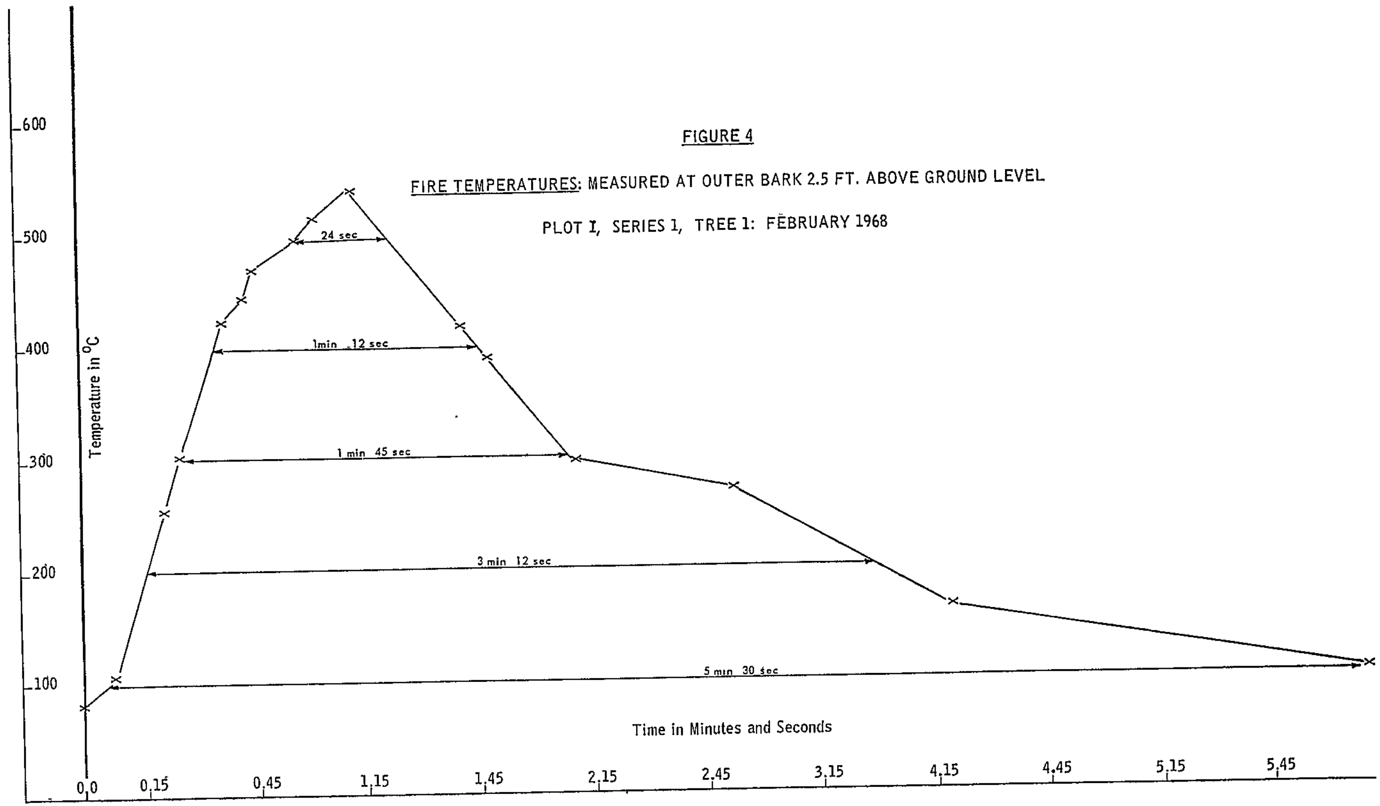


FIGURE 4
FIRE TEMPERATURES: MEASURED AT OUTER BARK 2.5 FT. ABOVE GROUND LEVEL
PLOT I, SERIES 1, TREE 1: FEBRUARY 1968
Temperature in °C
600
500
400
300
200
100
24 sec
1min 12 sec
1 min 45 sec
3 min 12 sec
5 min 30 sec
Time in Minutes and Seconds
0,0
0,15
0,45
1,15
1,45
2,15
2,45
3,15
4,15
4,45
5,15
5,45

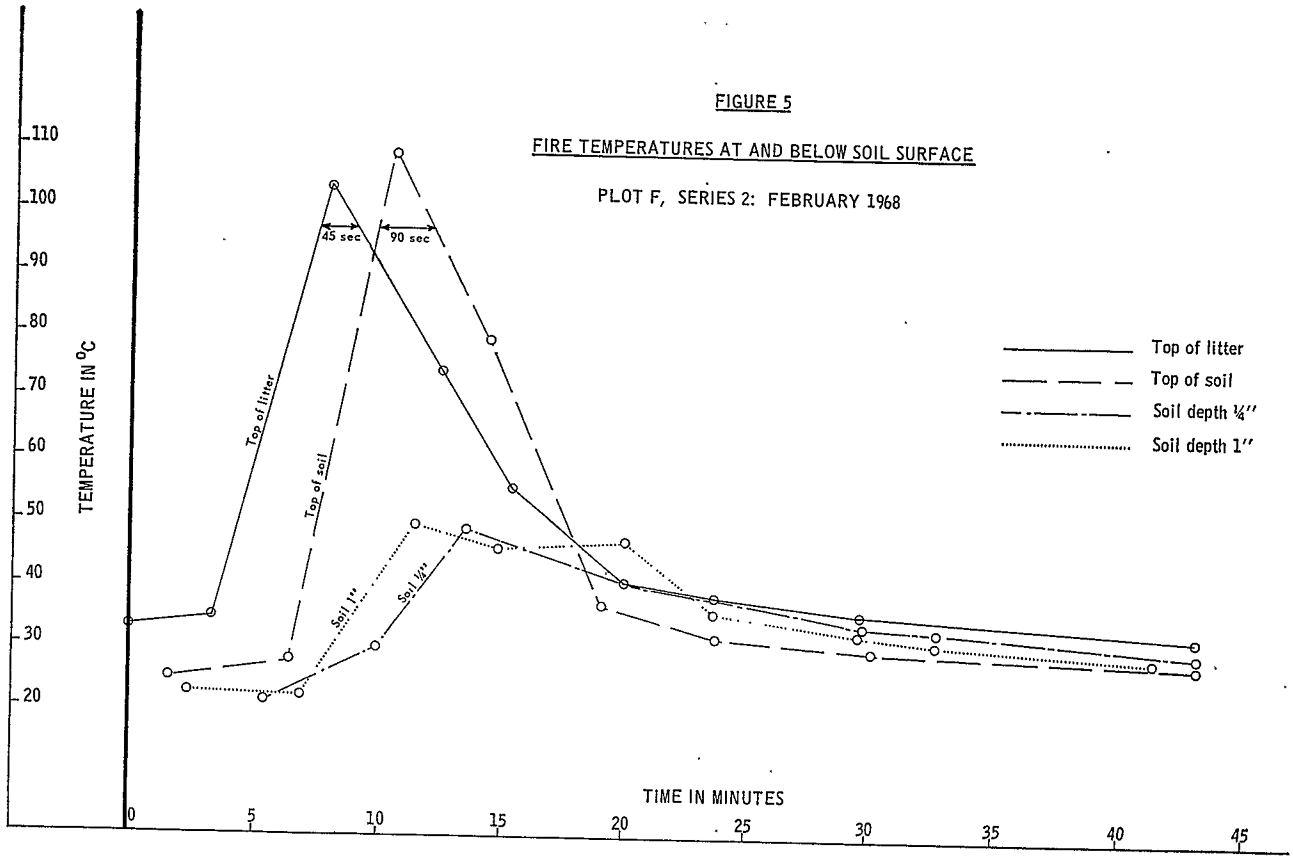


FIGURE 5

FIRE TEMPERATURES AT AND BELOW SOIL SURFACE

PLOT F, SERIES 2: FEBRUARY 1968

OTHER ASPECTS UNDER STUDY

(a) Soil Moisture

The results of soil moisture determinations before and after each fire were disappointing. It was not possible to discern a trend caused by the burning. In some cases post-burn values were higher than the pre-burn ones, in other cases the reverse applied.

(b) Chemical Properties of the Soil

The Chemistry Section of the Forestry Commission Division of Wood Technology will carry out periodic chemical analysis of soils of the study plots to observe if the burning regimes alter the nutrient status of the soil.

Soil is sampled at 2 levels, 0–3 in and 12–15 in. The 0–3 in level is considered the most important sample, not only because it is considered the best indicator of nutrient status, but also because it is the layer which will be affected by the fire: a total of 6 random samples will be collected and bulked per plot. Only 1 sample will be collected from the 12–15 in level. The first set of samples was collected in February, 1967, and subsequent samples will be collected in June of each year.

(c) Foliage Nutrient Level

In each of the study plots samples of foliage will be assessed for foliage nutrient level. As these levels are subject to large month-to-month variations, sampling which commenced in June, 1967, will be repeated in June of each year.

A sample of 12 leaves is collected from the active section of the crown of a codominant tree in each of the plots, and the same tree will be used for subsequent samples. Only mature, well-formed leaves, not younger than the fourth from the tip, will constitute the sample.

(d) Nitrogen Losses

In order to obtain an estimate of nitrogen losses, which might be incurred through volatilization in the burning of litter, a representative square foot sample was collected from each of the study plots. The samples were separated into similar fractions to those used in the available fuel determination. After drying at 70° C the nitrogen content is determined. This procedure will be repeated before each subsequent burn.

(e) Soil Microbial Activity

It was hoped to study a possible shift of soil microbial population following the control burns, and in fact trial runs for this study were conducted in February, 1967. Unfortunately, a serious fire in the Sydney laboratories of the Commission's Division of Wood Technology just before the 1968 burns prevented this study from being carried out on this occasion. It is hoped that in later burns investigations of this nature can be incorporated.

Meanwhile Mr R. Greaves of the Forest Research Institute, Canberra, A.C.T., has sampled all plots shortly before and after burning to obtain estimates of the microfauna present on both occasions.

ACKNOWLEDGEMENTS

The help and co-operation I received throughout the establishment and first treatment of the experiment has been so generous, and the people involved in it so numerous, that I refrain reluctantly from specifying and naming them.

However I gladly make an exception for the technical assistance of Mr T. A. O'Toole, who has been responsible for the bulk of field work, litter sorting and oven drying, as well as assisting in the preparation of figures and plans.

To him and all others I offer my sincere thanks.

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APPENDIX 1

CONDITION OF STAND PRIOR TO BURNING

THE GROWING STOCK

Block No.	Plot No.	No. of stems/acre		Basal area/acre (sq ft)		Mean diameter (in)		Mean dom. height 12 trees (ft)
		Total	Dom. 1 + 2	Total	Dom. 1 + 2	All stems	Dom. 1 + 2	
1. 1940 Natural Regen.	F D C	268 202 300	75 100 110	119 113 119	76 94 94	9·06 10·13 8·54	13·67 13·14 12·57	105·8 106·6 103·3
Mean Block 1		257	95	117	88	9·14	13·06	105·2
2. 1940 Natural Regen.	A B E	470 235 282	105 90 108	150 134 116	101 102 91	7·66 10·23 8·70	13·32 14·43 12·51	112·8 119·7 109·3
Mean Block 2		329	101	133	98	8·57	13·36	113·9
All 1940		293	98	125	93	8·82	13·21	109·5
3. 1943 Natural Regen.	K I L	188 235 310	90 80 92	114 107 97	87 77 59	10·58 9·15 7·61	13·35 13·35 10·83	110·7 108·1 89·1
Mean Block 3		244	87	106	74	8·87	12·47	102·6
4. 1948 Plant. area	G J H	285 220 270	90 112 102	100 106 118	75 89 92	8·03 9·44 8·98	12·41 12·08 12·87	87·4 100·0 96·4
Mean Block 4		258	101	108	85	8·76	12·44	94·6

APPENDIX 2

CONDITION OF STAND PRIOR TO BURNING THE UNDERSTOREY

Block No.	Plot No.	Major Understorey					Minor Understorey	
							Average Loop Index of Density, %	
		Total No. of Stems/acre	No. of Stems under 1 in diameter/acre	No. of Stems over 1 in diameter/acre	Mean diameter of Stems over 1 in	Basal area sq ft/acre	Live Spec.	Dead Spec.
1. 1940 Natural Regen.	F	2,167	1,767	400	2·32	12	49	70
	D	5,433	4,467	967	1·66	16	59	26
	C	2,700	1,567	1,133	1·75	19	42	41
Mean Block 1		3,433	2,600	833	1·81	16	50	49
2. 1940 Natural Regen.	A	3,733	2,333	1,400	1·55	19	53	23
	B	4,667	3,700	967	1·56	14	54	20
	E	2,900	2,000	900	1·57	13	48	21
Mean Block 2		3,767	2,678	1,089	1·56	15	52	21
All 1940		3,600	2,639	961	1·67	16	51	37
3. 1943 Natural Regen.	K	1,333	1,200	133	4·31	14	48	10
	I	2,967	2,633	333	4·47	37	47	22
	L	1,167	1,100	67	4·21	7	62	76
Mean Block 3		1,822	1,644	178	4·40	19	52	36
4. 1948 Plant. Area	G	467	438	33	1·80	0·7	104	83
	J	1,167	1,133	33	1·30	0·7	79	104
	H	533	500	33	1·46	0·6	72	91
Mean Block 4		722	689	33	1·52	0·7	85	93

APPENDIX 3

LIST OF MAJOR UNDERSTOREY SPECIES

(Species occurring in study area, based on six 0·005 acre quadrats in each of the 12 study plots. Frequency expressed as mean number of stems per acre)

Species and Family	*Common Name*	*Stems per acre*
Casuarina torulosa Ait. (Casuarinaceae)	Forest Oak	680
Lantana camara L. (Verbenaceae)	Lantana (naturalized)	377
Glochidion ferdinandii J. Muell. (Euphorbiaceae)	Cheese Tree	317
Breynia oblongifolia J. Muell. (Euphorbiaceae)		247
Helichrysum diosmifolium (Vent.) Sweet (Compositae)	Sago Bush	122
Sambucus australasica (Lindl.) Fritsch (Caprifoliaceae)	Native Elder	122
Eucalyptus acmenioides Schau. (Myrtaceae)	White Mahogany	119
Eucalyptus pilularis Sm. (Myrtaceae)	Blackbutt	97
Persoonia linearis Andr. (Proteaceae)	Geebung	70
Acacia sp. (Mimosaceae)	Wattle	55
Solanum densevestitum F. Muell. ex. Benth. (Solanaceae)		53
Eucalyptus gummifera Gaertn.-Hochr. (Myrtaceae)	Bloodwood	41
Eucalyptus microcorys F. Muell. (Mystaceae)	Tallowwood	30
Lomatia silaifolia (Sm.) R. Br. (Proteaceae)	Crinkle Bush	17
Cassia schultesii Colla (Caesalpineaceae)		14
Synoum glandulosum (Sm.) A. Juss. (Meliaceae)	Scentless Rosewood	11
Cissus antarctica Vent. (Vitaceae)	Native Grape	5
Cinnamonum camphora (L.) Nees (Lauraceae)	Camphor Laurel (naturalized)	5
Archontophoenix cunninghamiana H. Wendl. et Drude (Palmaceae)	Bangalow Palm	5
Eucalyptus resinifera Sm. (Myrtaceae)	Red Mahogany	3
Eucalyptus grandis (Hill) Maiden (Myrtaceae)	Flooded Gum	3
Eucalyptus paniculata Sm. (Myrtaceae)	Grey Ironbark	3
Tristania conferta R. Br. (Myrtaceae)	Brush Box	3
Trema aspera Blume (Ulmaceae)	Peachleaved Poison Bush	3
Duboisia myoporoides R. Br. (Solanaceae)	Corkwood	3
Rhodamnia trinervia (Sm.) Blume (Myrtaceae)	Brush Turpentine	3
Various unidentified species		67
	Total per acre	2,475

APPENDIX 4

LIST OF MINOR UNDERSTOREY SPECIES

(Species occurring in study area, based on two 50-feet transect lines in each of the 12 study plots. Frequency of occurrence for both green and cured state is expressed by average loop index of density per cent (Parker and Harris, 1959)).

Species and Family	*Common Name*	*Green* per cent	*Cured* per cent
Imperata cylindrica (L.) Beauv. var. *major* (Nees) C. E. Hubbard. (Graminaceae)	Blady Grass	21·1	35·4
Pteridium esculentum (Forst. f.) Nakai (Dicksoniaceae)	Bracken	10·2	12·1
Entolasia marginata R. Br. (Graminaceae)	Bordered Panic Grass	7·9	1·5
Desmodium varians Endl. (Papilionaceae)	Variable Tic Trefoil	3·4	
Lantana camara L. (Verbenaceae)	Lantana	3·4	1·4
Eustrephus latifolius R. Br. (Philesiaceae)		1·8	
Helichrysum diosmifolium (Vent.) Sweet (Compositae)	Sago Bush	1·7	
Oplismenus imbecillis (R. Br.) Roem et Schult. (Graminaceae)	Creeping Beard Grass	1·6	
Rubus moorei F. Muell. (Rosaceae)	Bush Lawyer	1·6	
Desmodium rhytidophyllum F. Muell. (Papilionaceae)		1·3	0·8
Dianella caerulea Sims. (Liliaceae)		1·0	0·3
Lomandra longifolia Labill. (Xanthorrhoeaceae)		0·8	0·4
Glycine clandestina Wendl. (Papilionaceae)		0·8	
Pratia purpurascens (R. Br.) Benth. (Lobeliaceae)	White Root	0·3	
Lomatia silaifolia (Sm.) R. Br. (Proteaceae)	Crinkle Bush	0·3	0·1
Pandorea pandorana (Andr.) Steen (Bignoniaceae)	Wonga Wonga Vine	0·2	
Casuarina torulosa Ait. (Casuarinaceae)	Forest Oak	0·2	
Hardenbergia violacea (Scheen.) Stearn (Papilionaceae)		0·1	
Smilax australis R. Br. (Smilacaceae)		0·1	
Breynia oblongifolia J. Muell. (Euphorbiaceae)		0·1	
Synoum glandulosum (Sm.) A. Juss. (Meliaceae)	Scentless Rosewood	0·1	
Cryptocarya rigida C. Meissner (Lauraceae)	Rose Maple	0·1	
Culcita dubia (R. Br.) Maxon (Dicksoniaceae)	Rainbow Fern	0·2	

APPENDIX 4—*continued*

Species and Family	*Common Name*	*Green*	*Cured*
		per cent	per cent
Cissus antarctica Vent. (Vitaceae)	Native Grape	0·1	
Cassia schultesii Colla (Caesalpineaceae)		0·1	
Eucalyptus gummifera (Gaertn.) - Hochr. (Myrtaceae)	Bloodwood	0·1	
Eucalyptus acmenioides Schau. (Myrtaceae)	White Mahogany	0·1	
Unidentified Species		4·6	2·2
	Totals	63·3	54·2
Ovendry weight equivalent in pounds per acre		146	840

APPENDIX 5

FUEL COMPLEX PRIOR TO BURNING

(AVAILABLE FUEL)

(Top line of each entry gives weight in pounds per acre; bottom line, the percentage of the total available fuel for each plot)

Block No.	Plot No.	Available fuel in lb per acre							
		Twigs under 1 in diam.	Bark	Leaves	Live vegetation	Dead vegetation	Misc.	Total	Total in tons/acre
1	F	5,583	882	2,935	200	1,072	2,238	13,180	5·9
	Per cent	44·4	6·7	22·3	1·5	8·1	17·0	100	
	D	3,560	1,079	2,833	118	198	1,944	9,733	4·3
	Per cent	36·6	11·1	29·1	1·2	2·0	20·0	100	
	C	5,493	962	2,836	214	354	2,895	12,754	5·7
	Per cent	43·1	7·5	22·2	1·7	2·8	22·7	100	
Mean		4,969	974	2,868	177	541	2,359	11,889	5·3
2	A	7,164	1,218	3,988	72	434	3,038	15,914	7·1
	Per cent	45·0	7·7	25·1	0·5	2·7	19·1	100	
	B	5,565	1,490	1,855	149	430	2,094	11,583	5·2
	Per cent	48·0	12·9	16·0	1·3	3·7	18·1	100	
	E	5,514	2,052	2,407	262	478	2,119	12,833	5·7
	Per cent	43·0	16·0	18·8	2·0	3·7	16·5	100	
Mean		6,081	1,587	2,750	161	447	2,417	13,443	6·0

3	K	4,915	925	3,529	82	1,221	3,055	13,728	6·1
	Per cent	35·8	6·7	25·7	0·6	8·9	22·3	100	
	I	4,102	572	4,651	58	874	1,442	11,698	5·2
	Per cent	35·1	4·9	39·8	0·5	7·5	12·3	100	
	L	5,477	1,024	3,827	197	1,437	3,678	15,640	7·0
	Per cent	35·0	6·5	24·5	1·3	9·2	23·5	100	
Mean		4,831	840	4,002	112	1,177	2,725	13,689	6·1
4	G	6,359	787	3,222	162	1,188	1,474	13,191	5·9
	Per cent	48·2	6·0	24·4	1·2	9·0	11·2	100	
	J	5,237	1,002	2,913	102	1,231	2,265	12,749	5·7
	Per cent	41·1	7·9	22·8	0·8	9·7	17·8	100	
	H	7,375	1,394	2,510	141	1,165	2,604	15,189	6·8
	Per cent	48·6	9·2	16·5	0·9	7·7	17·1	100	
Mean		6,324	1,061	2,882	135	1,195	2,114	13,710	6·1
Mean All plots		5,551	1,116	3,126	146	840	2,404	13,183	5·9
per cent		42·1	8·5	23·7	1·1	6·4	18·2	100	

APPENDIX 6

FUEL COMPLEX PRIOR TO BURNING

(Non-available Fuel)

Block No.	Plot No.	Non-available fuel in lb per acre: Branches and logs over 1 in diam.					
		Size class					Total tons/ acre
		1 in–3 in	4 in–6 in	7 in–9 in	10 in-12 in	13 in+	
1	F	8,248	3,246		30,734	8,242	22·5
	D	5,287	3,843				4·8
	C	3,842	5,710	5,230	30,832		20·4
Mean		5,789	4,266	1,743	20,522	2,747	15·9
2	A	5,926	3,381	8,643	10,668		12·8
	B	3,861	24,762	24,231		26,971	35·6
	E	10,002	18,048	13,873	37,971	28,821	48·5
Mean		6,596	15,397	15,582	16,213	18,597	32·3
3	K	870	848				0·8
	I	323					0·1
	L	157	6,990				3·2
Mean		450	2,613				1·3
4	G	695					0·3
	J	157					0·1
	H	538	2,548				1·4
Mean		463	849				0·6

APPENDIX 7

FUEL COMPLEX AFTER BURNING

"Available" fuel not burnt in the 1968 fires, in lb/acre (top line), and as a percentage of the remaining available fuel (bottom line)

Block No.	Plot No.	Twigs under 1 in	Bark	Leaves	Live vegetation	Dead vegetation	Misc.	Total in lb	Total in tons
1	F	2,654	550	523	0	234	582	4,544	2·0
	Per cent	58·4	12·1	11·5		5·1	12·8	100	
	D	2,150	580	984	0	166	642	4,521	2·0
	Per cent	47·6	12·8	21·8		3·7	14·2	100	
Mean Block 1		2,402	565	753		200	612	4,532	2·0
2	A	1,599	128	348	0	0	734	2,809	1·3
	Per cent	56·9	4·6	12·4			26·1	100	
	B	3,463	349	384	0	170	738	5,104	2·3
	Per cent	67·8	6·8	7·5		3·3	14·5	100	
Mean Block 2		2,531	238	366		85	736	3,956	1·8
3	K	1,648	56	211	0	26	323	2,265	1·0
	Per cent	72·8	2·5	9·3		1·1	14·3	100	
	I	1,736	680	610	0	186	720	3,933	1·7
	Per cent	44·1	17·3	15·5		4·7	18·3	100	
Mean Block 3		1,692	368	410		106	521	3,097	1·4
4	G	2,967	243	293	0	194	530	4,227	1·9
	Per cent	70·2	5·7	6·9		4·6	12·5	100	
	J	2,820	299	629	0	112	1,026	4,886	2·2
	Per cent	57·7	6·1	12·9		2·3	21·0	100	
Mean Block 4		2,893	271	461		153	778	4,556	2·0
Mean all Blocks		2,379	361	498		136	662	4,036	1·8
	Per cent	59	9	12	0	3	16	100	
Ton Equivalent		1·1	0·1	0·2	0	0·1	0·3	1·8	

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