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A PRESCRIBED BURNING EXPERIMENT IN YOUNG SLASH PINE

I. SITE DESCRIPTION AND ESTABLISHMENT

by A. P. VAN LOON

II. FIRST PROGRESS REPORT

by L. A. LOVE

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A PRESCRIBED BURNING EXPERIMENT IN YOUNG SLASH PINE

SUMMARY

This report describes the establishment of a long term study into the effects of repeated prescribed burning on a young plantation of Slash Pine (*Pinus elliottii*) where two- and four-yearly burning cycles will be tested against unburnt controls in a 4 × 3 randomized block design.

The condition of the stand prior to the first burning treatment is summarized in terms of growing stock, understorey and the fuel complex on an individual plot and block basis.

Descriptions of the behaviour of the 1969 series of burns include information on prevailing meteorological conditions, fuel and soil moisture and time-temperature relationships. Special emphasis is given to fire intensities experienced by individual trees.

Information is then given on growth characteristics following the first burning treatment and on the behaviour of the second series of burning treatments in 1971.

I. SITE DESCRIPTION AND ESTABLISHMENT

1. INTRODUCTION

This is the first report on the progress of a field experiment designed to evaluate the effects of regular prescribed burning on a planted stand of Slash Pine, *Pinus elliottii* Engelmann.

The experiment is a long-term project so that a considerable passage of time will be required before meaningful effects can be expected to become evident. For this reason it is important that the condition of the stand before the first burn, and the nature of each individual burn, are adequately documented and described. This is the main purpose of this report, which in many respects resembles a report on a similar experiment in a stand of Blackbutt, *Eucalyptus pilularis* Sm. (Van Loon, 1969).

It is further hoped that the information presented here will stimulate those concerned with forest fire, to describe fire in a quantitative way, which is meaningful in considering fire effects on vegetation, soil and other resources.

Finally it is not intended that the control burns described in this report should be taken as optimum, since this can only be established by continued experience over a period of time.

2. THE EXPERIMENTAL SITE

The experiment is located in a compartment of 40·4 acres of Whiporie State Forest No. 928. The forest, which has a latitude of 29° 21′ S. and a longitude close to 153° E., is located midway between the towns of Grafton and Casino on the north coast of New South Wales.

The region has a pronounced summer rainfall with January, February, and March each averaging over 600 points. The mean annual rainfall is 5,032 points and the lowest mean monthly rainfall is 156 points for August. The mean temperature of the coldest month, July, is 54·4° F, while January is the hottest month with a mean temperature of 73·5° F.

The topography is very flat and drainage lines are broad and indistinct. The elevation approximates 100 feet above sea level. Soils are principally derived from the Grafton series of Jurassic sandstones and consist of sands or sandy loams over clay. The original forest species which occupied the site were mainly *Angophora floribunda, Tristania suaveolens*, and the eucalypts, *Eucalyptus signata, amplifolia, gummifera, maculata,* and *tereticornis*. In the major understorey, species of *Melaleuca, Casuarina, Acacia, Persoonia,* and *Hakea* were the most common.

The site was prepared for planting in 1960–61 by felling and burning, and planting was carried out in June, 1961, at a spacing of 8 ft × 8 ft (680 stems per acre). In 1967 the stand was uncommercially thinned to 360 stems per acre and low pruned to a height of 8 feet. At the same time coppicing hardwood stems were slashed.

Control burning prior to the first thinning cannot be contemplated due to the small size of the trees and the presence of branches to ground level. It is particularly after the first thinning that fire hazard in these plantations is at its highest. The prunings and thinnings combine with the dense understorey vegetation (not yet hindered in its development through the effects of canopy closure) to create an extremely hazardous fuel complex. As some time must lapse after thinning to allow branches to dry and consolidate it is considered that age 8 is the earliest age at which prescribed burning can be commenced in these stands.

Compartment 138 was selected as the most suitable one in this age class for this experiment due to its homogeneous nature and suitable size. The compartment, roughly 30 × 13·5 chains in size, was divided into twelve plots, each with minimum dimensions of 5 × 6 chains (or 3 acres in area), by means of 12-foot-wide graded firebreaks.

In each of the 3-acre plots a central plot of 0·4 acres was established, and all measurements and observations restricted to these centrally located internal plots. This was considered desirable in order to enable the prescribed fire in the burning treatments to develop a definite pattern of spread before entering the study area and thus 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 study plots, and a sketch of their location in the general layout is shown in figure 1.

3. THE CONDITION OF THE STAND BEFORE BURNING

3.1 The Growing Stock

In each internal plot of 0·4 acres all pines were tagged, painted at breast height, and measured for diameter over bark.

The heights of the twelve tallest trees were obtained in each plot and bark thickness was measured on ten trees immediately adjacent to the western boundary of each central plot by meaning the thickness gauged at the four cardinal points of the compass on each of those trees.

Maps showing the exact location of all trees in each plot were also prepared. Full details of these measurements are given in appendix 1.

Although the growing stock in the compartment is even-aged and of similar provenance, while no obvious topographical or other visual site differences occur in the compartment, there proved to be a marked difference in the mean size between trees of different plots.

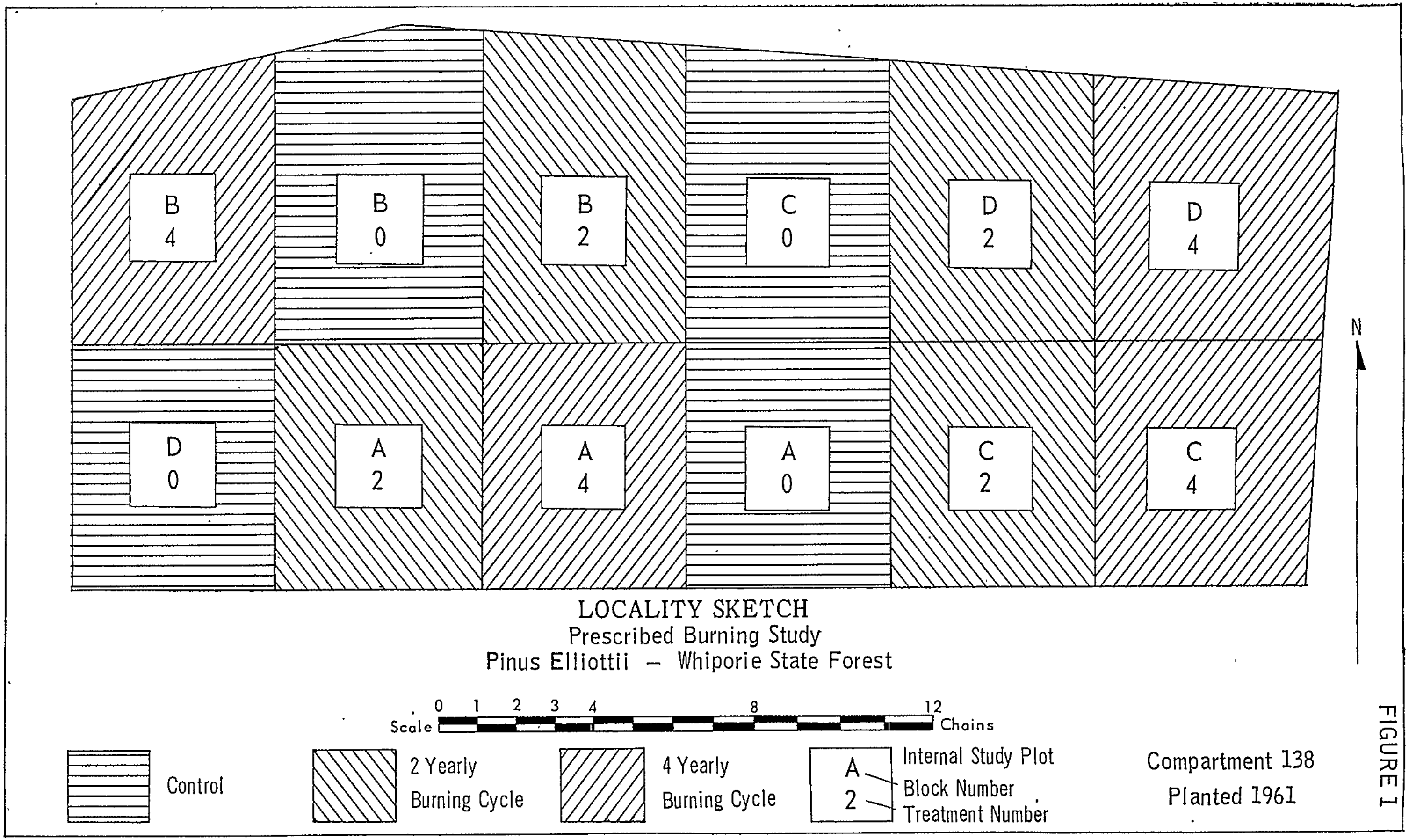
B 4
B 0
B 2
C 0
D 2
D 4
D 0
A 2
A 4
A 0
C 2
C 4
N
LOCALITY SKETCH
Prescribed Burning Study
Pinus Elliottii — Whiporie State Forest
Scale 0 1 2 3 4 8 12 Chains
Control
2 Yearly Burning Cycle
4 Yearly Burning Cycle
A 2 Internal Study Plot
Block Number
Treatment Number
Compartment 138
Planted 1961

FIGURE 1

In order to offset this initial difference in growth, plots were assigned to blocks in order of size. Thus Block A contains the three plots of smallest diameter, basal area, and height, Block B the three plots next biggest in size, etc. Stand parameters on a block basis are given in table 1.

TABLE 1

Stand Parameters of Growing Stocks by Blocks

Block	No. of stems per acre	Mean diameter (inches)	Bark thickness (inches)	Basal area per acre (sq ft)	Mean dominant height (feet)
A	360	3·43	0·51	24·08	21·2
B	371	4·02	0·60	33·55	23·7
C	369	4·39	0·61	39·66	25·4
D	366	4·73	0·64	45·72	27·5

Each of the three treatments, control (0), two-yearly burning (2), four-yearly burning (4), was randomly assigned to plots within each block. Stand parameters on a treatment basis are compared in table 2.

TABLE 2

Stand Parameters of Growing Stock by Treatments

Treatment	No. of stems per acre	Mean diameter (inches)	Bark thickness (inches)	Basal area per acre (sq ft)	Mean dominant height (feet)
Controls	376	4·19	0·59	37·31	24·6
2-yearly burns	365	4·17	0·59	36·01	24·6
4-yearly burns	358	4·07	0·59	33·94	24·2

The similarity of stand parameters between treatments as shown creates confidence that any effects of the burning treatments on subsequent growth of the stand will become evident as the study progresses.

3.2 The Major Understorey

As mentioned earlier, the original vegetation cover of the compartment comprised a mixed hardwood type. After the felling and burning of the original crop to prepare the site for planting, numerous coppice shoots appear, which are then controlled by the applications of herbicides prior to planting. Although coppice control by this means is by and large successful, large numbers of stems survive the treatment.

These persistent stems are slashed at the time when the plantation is first thinned and pruned and although this slashing does not substantially reduce the number of coppicing stems, it controls their development sufficiently to render their competition with the pines negligible.

In order to obtain an estimate of the number of coppicing stems by species, and to test the effects of burning on this stand component, six permanent circular quadrats 0·0125 acres in size were systematically installed in each of the plots. In each quadrat the position of each woody understorey species over 3 feet in height was sketched on a circular plot diagram and its height was measured.

A full summary of this assessment is given in appendix 2, which lists, for each individual plot, the number by species on a per acre basis as well as the mean height for each species. This summary shows that the distribution of these major understorey species is extremely variable. Plot means range from 401 to 5,371 stems per acre.

Table 3 combines these plot means by treatments and it can be seen that considerable variation still occurs. Nevertheless it is anticipated that burning effects on this component will be detected in due course.

TABLE 3

Stocking of Major Understorey Species compared by Treatments

	Controls		2-Yearly burns		4-Yearly burns	
	No. of stems/ acre	Mean height (feet)	No. of stems/ acre	Mean height (feet)	No. of stems/ acre	Mean height (feet)
Angophora sp.	1,403	6·0	305	6·7	657	6·0
Melaleuca sp.	241	4·8	64	5·5	601	4·7
Tristania sp.			64	4·6	417	6·3
Casuarina sp.	225	8·5	96	6·4	120	6·3
Euc. signata			40	11·0	100	8·1
Acacia sp.	80	6·0			40	4·9
Persoonia sp.	80	4·0				
Euc. gummifera	20	5·0	40	5·0		
Hakea sp.	20	3·3			20	3·1
Pomaderris sp.	20	3·5				
Alphitonia sp.	20	5·0				
Jacksonia sp.	20	3·2				
Totals	2,129	5·9	609	6·5	1,955	5·7

3.3 The Minor Understorey

Minor understorey such as grasses, herbaceous vegetation and woody species under 3 feet in height were sampled by means of two permanent 50 ft long transect lines randomly installed in each plot.

This sampling method, known as "the three-step method" and devised by Parker and Harris (1959), is specially designed to indicate changes in understorey composition and density at periodic intervals. Vegetation is measured by means of a $\frac{3}{4}$-inch diameter loop at fifty 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. These hits are summed by species and this sum, which is referred to as the loop index of density, is an indication of the frequency of occurrence. Means by species for the study area are included as appendix 3.

A shorter summary, comparing the frequency of occurrence of the main species by treatments, is given in table 4.

TABLE 4

Average Loop Index of Density of Minor Understorey Species by Treatments (per cent)

	Controls		2-Yearly burns		4-Yearly burns	
	Green	Cured	Green	Cured	Green	Cured
Axonopus affinis	27	13	29	13	26	19
Alloteropsis sp.	25	6	36	9	20	1
Entolasia marginata ..	11	6	14	8	19	11
Panicum fulgidum ..	9	6	9	2	5	2
Lepidosperma sp. ..	4	1	7	4	6	1
Cannia aspera	4	1	7	3	4	5
All other species ..	29	13	20	10	17	17
Totals	109	46	122	49	97	55

This table shows that a reasonable similarity exists between treatments for both total density and the main species which contribute to it. Of additional interest is the high ratio between green and cured densities, an indication of active current growth of grasses and other plants in the compartment at the time of this series of burns, February–March, 1969.

Coloured photographs of each transect line were taken before and after each burn.

3.4 The Fuel Complex

In forest fire terminology two types of fuel are recognized, total fuel and available fuel (Byram, 1959). *Total fuel* is the quantity of fuel which would burn under the driest conditions with the highest intensity fire. In prescribed burning as it is understood in Australia, which aims at low intensity burning, total fuel does not assume much importance and it was ignored in this study.

Available fuel is the quantity of fuel that actually burns in a fire and it is recognized as one of the most significant variables affecting the behaviour of fires. Even in a homogeneous forest type it is subject to wide variation. The moisture content of fuel effects its availability to a marked extent, moreover as fire intensity increases more fuel becomes available for combustion. For these reasons it is extremely difficult to forecast or sample with any degree of accuracy prior to burning. However, as available fuel is one of the main factors required to calculate fire intensity its measurement is essential.

In each plot, before and after burning, fine fuels were sampled at six random locations, using McIntyre's "ranked sets" method of sampling in an attempt to increase sampling efficiency. (McIntyre, 1952: Halls and Dell, 1966).

Estimates of available fuel, that is fuel actually consumed in the fires, were obtained by subtracting the post-fire values from those sampled before burning. Each sample consisted of one square foot of the forest floor, but logs and branches over 1-inch diameter were excluded, as it was considered that these would not become available for combustion in light-intensity burning. The pre-fire samples were sorted in the following fractions:

1. twigs and branches under 1-inch diameter,
2. needles,
3. green vegetation,
4. cured vegetation,
5. 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 converted to pounds per acre. The plot means for each of the fine fuel fractions are given in appendix 4, expressed in pounds per acre (top line), and as a percentage of the total fine fuel (bottom line). Table 5 summarizes this information on a treatment basis.

TABLE 5

Pre-Burn Fine Fuel Fractions

Treatments	Fine fuels in lb per acre						Total in tons per acre
	Twigs under 1 inch	Needles	Green Vege-tation	Cured Vege-tation	Misc.	Total	
Controls ..	1,272	2,635	501	2,713	969	8,090	3·6
2-Yearly burns	1,546	1,668	448	2,399	824	6,889	3·1
4-Yearly burns	1,830	2,791	449	1,823	1,660	8,554	3·8
Compartment mean ..	1,549	2,365	466	2,312	1,151	7,844	3·5
Ton equivalent	0·7	1·1	0·2	1·0	0·5	3·5	
% of total ..	19·7	30·1	5·9	29·5	14·7		

Here it can be seen that needles and cured vegetation each contribute 30 per cent of the fine fuels.

Post-fire fine fuel quantities were frequently so small that sorting them in fractions did not prove practicable. Only their total weights were determined by oven-drying, and the results are presented in table 6, which also gives the pre-fire total weights and the fine fuel reduction percentage.

TABLE 6

Total Fine Fuel Weights before and after Burning

Plot No.	Fine fuel weights in lb per acre		Fine fuel reduction per cent
	Before burning	After burning	
A2	8,731	602	91
A4	7,607	3,567	53
B2	6,372	907	86
B4	10,318	924	91
C2	5,353	2,117	61
C4	7,676	1,902	74
D2	7,100	856	87
D4	8,616	2,748	69

Available fuel and the fine fuel reduction per cent will be further referred to in section 4.2, Fire Behaviour and Intensity.

Litterfall studies in the compartment were commenced 6 months prior to the first burning treatment. In each of the twelve plots three 2 ft × 2 ft square littertraps were randomly placed, the contents being collected at 3-monthly intervals and ovendried at 105° C.

Needlefall in the compartment during the 6 months period before burning was uniform, as shown in table 7.

TABLE 7

Six Months Litterfall in lb per acre

Treatment	Litterfall (lb per acre)
Control	994
2-yearly burns	957
4-yearly burns	981
Compartment mean	977

The even distribution of litterfall between treatments is a further indication of the similarity of the growing stock between treatments.

4. THE 1969 BURNING TREATMENTS

4.1 Meteorological Conditions

The first burning treatments of the experiment were carried out in February and March, 1969. Four plots were burned in the first week of February and the remaining four during the second week of March.

The preceding spring had been exceptionally dry and a serious wild fire had damaged over 900 acres of Slash Pine in the adjacent plantation at Banyabba State Forest on the 19th November, 1968.

Rainfall for January, 1969, was close to average, 547 points being recorded on the plantation. February also brought a good rainfall of 639 points, but the March total was low at 114 points.

Rainfall, as recorded in the study area with a Lambrecht "Hellman" type automatic recording raingauge during the first 3 months of 1969, is given in table 8.

TABLE 8

Compartment Rainfall in points by days for the period 1*st January*, 1969, *to* 31*st March*, 1969

(100 points = 1 inch)

January		February		March	
Date	Rainfall	Date	Rainfall	Date	Rainfall
2	188	10	31	5	8
3	43	11	230	6	1
9	186	12	249	10	2
10	75	13	42	12	10
20	55	17	8	16	2
		19	9	17	69
		20	13	18	10
		21	11	21	5
		23	46	29	7
Totals	547		639		114

On each day that burning was carried out temperature and relative humidity were measured continuously by thermohygraphs placed in a Stevenson screen installed in the study area at a height of 3·5 feet above ground level. These instruments were checked daily with an aspirated psychrometer.

During actual burning operations windspeed was measured continuously with a "Casella" sensitive cup anemometer, installed in the stand at a height of 5 feet above ground level, and read at 2-minute intervals.

Meteorological conditions prevailing during the periods that burning was in progress are given in table 9.

TABLE 9

Meteorological Conditions at Time of Burning

Plot No.	Date and month of burn, 1969	Time fire entered study plot	Temp. in °F	Relative humidity per cent	Wind speed mph at 5 ft	Wind direction
A2	4/2	13·05	87	50	2·3	S. then N.
A4	13/3	12·55	83	71	0·6	E.
B2	6/2	8·43	81	70	2·2	S.
B4	5/2	9·10	81	64	2·2	S.
C2	13/3	14·02	86	64	2·3	E.
C4	11/3	14·27	81	56	0·5	E.
D2	7/2	8·07	78	81	2·2	S.
D4	11/3	11·14	81	59	0·1	S.
Mean			82·2	64·4	1·5	

It can be seen that the burns were carried out during periods of high temperatures and high relative humidity. Windspeed was invariably low, the highest speed measured during any 2-minute period was 3·3 mph at 5 ft in the forest, which is roughly equivalent to 12 mph at a height of 33 ft in the open.

4.2 Fire Behaviour and Intensity

The only definite prescription for the application of the burning treatments in this study is that burning will be carried out only in the period between 1st February and 30th June of each odd year. Safety from escape is the overriding cause of this limitation. Analysis of fire problems in the northeastern corner of the State of New South Wales, presented by Luke (1964), shows that for the 8-year period 1956–64, the number of wildfire attendances by forestry staff in the Casino, Coffs Harbour, and Kempsey forestry districts in the period 1st February to 30th June totalled only 3 per cent of the 8-year total. At the same time the acreage of State Forests burnt in these 5 months amounted to less than 1·7 per cent of the total for the period quoted. Although the period 1st February to 30th June includes the last month of summer and the first of winter, (both incidentally the wettest months of their respective seasons), burning at this time of the year is, for convenience, referred to as autumn burning.

In order to compare each burn not only with other burns of this series, but also with subsequent burns foreshadowed in the experimental design, it was considered essential to measure and observe as many fire characteristics as time, manpower, and equipment allowed. Some of these measurements place certain limitations on the type of burning that can be employed in the study. Due to the importance of accurately measuring rate of fire spread grid lightning is not considered feasible, while burning at night also precludes the possibility of adequate documentation.

The obvious aim of burning in this study is to reduce as much fine fuel as possible while keeping the intensity of the fires as low as possible to minimize possible damage to the stand. In order to achieve this aim no definite rule can be laid down as to whether head or backfire will be used. This will depend on meteorological and or site conditions which frequently vary from day to day.

In the 1969 series six of the eight burns were lit as backfires. One of these (plot A2) was subject to a dramatic change in wind direction before the fire reached the study plot, so that the end result of the series was five backfires and three headfires. Because many fire characteristics are known to differ markedly between head and backfires, relevant fire data are grouped separately in succeeding summaries.

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. Both colour and black and white photographs were taken every 5 minutes while in addition a short run of the fire at these intervals was recorded on coloured 8-mm movie film.

If fires and their effects are to be compared some numerical expression of fire intensity is desirable. Byram (1959) first expressed fire intensity as the energy per unit of time per unit of length of fire front. This is calculated as:

Fire Intensity = Heat of combustion × fuel consumed × rate of spread

$$\underset{\text{(Btu/sec/ft)}}{I} = \underset{\text{(Btu/lb)}}{h} \quad \underset{(\text{lb/ft}^2)}{w} \quad \underset{\text{(ft/sec)}}{r}$$

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, and by Hodgson (1967), who 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 realized.

Obviously it will be some time before the numerical expression of fire intensity will become meaningful to the practising forester, nevertheless its adaptation is strongly urged, since its calculation is not difficult. In the equation $I = hwr$, the heat of combustion (h) can for most practical purposes be considered constant. In this study it is taken as 8,000 Btu's per pound of fuel, a value suggested by McArthur (1967). The forward rate of spread (r), in feet per second, is one of the most readily measured fire characteristics.

Estimation of the weight of fuel consumed (*w*, expressed as pounds per square foot) is the most difficult requirement of the fire intensity calculation. It requires estimates of fuel both before and after the fire, but skill in estimating fuel is constantly increasing. In addition data on fuel weights in various fuel types are also becoming more available. The amount of fuel consumed will generally range between 50 and 90 per cent and a value between these extremes can be fairly readily estimated with experience.

An example of fire intensity calculation is given below. In this example all values used are the means of the five backfires in the 1969 series. The average fine fuel before burning was 3·56 tons per acre, of which 0·66 ton remained after the fire. Fuel consumed equalled 2·9 tons per acre or 0·150 pounds per square foot. The average rate of spread was 1·74 feet per minute or 0·029 feet per second. The average fire intensity therefore equalled:

$$8{,}000 \times 0{\cdot}150 \times 0{\cdot}029 = 35 \text{ Btu per second per foot of fire front.}$$

This value, incidentally, is midway in the optimum range described by McArthur (1962) and shown in table 10. This table indicates fire intensity limits for acceptable damage standards in commercial forests.

TABLE 10

Fire Intensity Limits for Acceptable Damage Standards in Commercial Forests

(After McArthur, 1962)

Fire intensity (Btu/sec/ft)	Description of fire behaviour
5–12	Intensity too low, fires generally self-extinguishing.
13–50	Optimum intensity.
51–70	Too severe for some forest types.
71–100	Upper limit for acceptable damage effects.

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

Fire intensities calculated for the 1969 burns are given in table 11, together with other fire behaviour and fuel reduction information.

TABLE 11

Fire Intensity and Fuel Reduction

Plot No.	Fire intensity Btu sec/ft	Rate of fire spread ft/min	Fine fuels tons/acre before burning	Fuel moisture content per cent o.d.w.	Fuel reduction per cent
			A. Backfires		
B4	59	2·0	4·6	26	91
D4	36	2·0	3·8	31	69
D2	32	1·6	3·2	38	87
B2	27	1·6	2·8	34	86
C4	25	1·5	3·4	41	74
Mean of 5 backfires	35·5	1·7	3·6	34	81
			B. Headfires		
A2	181	7·3	3·9	18	91
A4	41	3·3	3·4	55	53
C2	30	2·9	2·4	43	61
Mean of 2 headfires (A4 and C2 only)	35·5	3·1	2·9	49	57

It may be seen that one of the burns (plot A2) exceeded the normally accepted upper intensity limit for prescribed burning. This fire, although lit as a backfire, developed into a headfire before reaching the study plot. In places it burnt as an uncontrolled crown fire and concern for the safety of the plantation and personnel made the taking of some routine measurements impossible. Due to a consequent lack of some information and the atypical behaviour of the fire it is not included in some comparisons.

It is interesting to compare the data from table 11 for means of the headfires and backfires. Although the mean fire intensities are the same at 35·5, the rate of spread of the headfires at 3·1 feet per minute is nearly twice that of the backfires (1·7 ft/min).

The table also shows the reason for using headfire on two occasions. This is the high fuel moisture content of 49 per cent, an increase of 44 per cent on the fuel moisture content of the back burned plots. Of particular interest is the comparison between fuel reduction, where backfires, giving 80 per cent reduction, are shown to be far more efficient than headfires at 57 per cent. Overall, fine fuel was reduced from 3·6 to 0·8 tons per acre.

The fire intensities referred to up to now are means for each of the plots, obtained by using the average rate of spread for each plot. In fact, of course, fires rarely spread at an even rate. By plotting the rate of spread as it was marked at 5-minute intervals while the fire was in progress, and superimposing rate of spread contours on a plan showing the location of the growing stock, it is possible to show how fire intensity varies throughout the plot, and to which intensity each of the trees in the plot has been subjected. The broad assumption is made here that fuel (sampled at six ranked locations in each plot) is evenly distributed through the plots.

An example of this is shown in figure 2 where, for plot D4, fire intensities obtained in this way are sketched on a plan showing the growing stock location. Although the average fire intensity for this plot is 31 Btu per foot per second, it can be seen that in some areas the intensity approached 125 Btu's.

Similar plans were prepared for all plots and a summary showing the number of trees of each plot as they occurred in nine fire intensity classes ranging from 0–400 Btu's per feet per second is included as appendix 5.

A shorter summary showing the percentage of the 1,158 stems under study in the nine intensity classes is given in table 12.

TABLE 12

The Percentage of all Trees by Fire Intensity Classes, as experienced during all 1969 *control burns*

Fire intensity class	Fire intensity range in Btu ft/sec	Number of stems in class	Percentage of all trees
1	0–25	145	12·5
2	25–50	532	45·9
3	50–75	225	19·4
4	75–100	94	8·1
5	100–150	33	2·8
6	150–200	22	1·9
7	200–250	53	4·6
8	250–300	24	2·1
9	300–400	30	2·6
Total ..		1,158	100%

Here it should be pointed out that the 10 per cent of trees which received intensities in excess of 150 Btu's all occur in plot A2 which, as mentioned, was subject to a 180° change in wind direction.

By grouping the trees of all plots in fire intensity classes, it is hoped that any difference in growth caused by differing fire intensities will become evident.

Typical fire intensities of the 1969 series are shown in photographs 1 and 2.

4.3 Fire Temperatures

In seven of the burns in this series temperatures at the outerbark of trees of 1·5 feet above ground level were measured with a portable recording pyrometer. The instrument used (manufactured by Rustrak) is basically a millivolt recorder calibrated for the output of thermocouples, and it records the temperature sensed at the thermocouple at one-second intervals. It is thus possible to obtain a measure of the maximum temperature reached at the observation point as well as the duration at which specific temperatures are maintained.

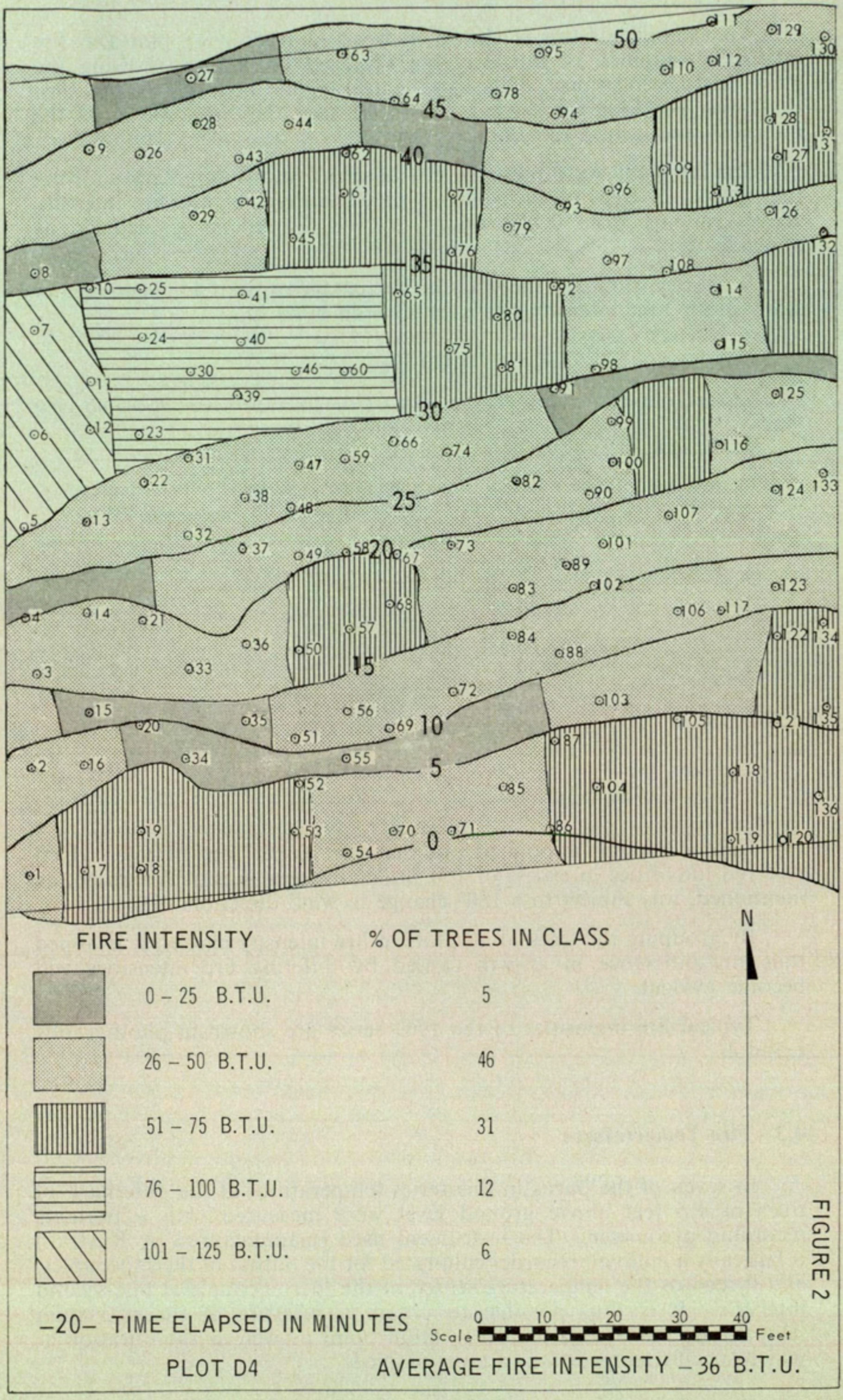
50
45
40
35
30
25
20
15
10
5
0
N
FIRE INTENSITY
% OF TREES IN CLASS
0 – 25 B.T.U. 5
26 – 50 B.T.U. 46
51 – 75 B.T.U. 31
76 – 100 B.T.U. 12
101 – 125 B.T.U. 6
–20– TIME ELAPSED IN MINUTES
Scale 0 10 20 30 40 Feet
PLOT D4
AVERAGE FIRE INTENSITY – 36 B.T.U.

FIGURE 2

Photo 1

Burning in progress in plot B2. Average fire intensity 27 Btu; rate of spread 1·6 feet per minute; fuel reduction 86 per cent

Photo 2

Burning under way in plot D4. Average fire intensity 36 Btu; rate of spread 2·0 feet per minute; fuel reduction 69 per cent

Temperatures were sensed on a total of 56 trees, and a summary of these measurements is given in table 13, which gives the maximum temperatures (in 100° C classes) experienced by the monitored trees, as well as the time in seconds at which a temperature of over 100° C was maintained. It should be noted that no measurements were made in the highest intensity burn (plot A2).

TABLE 13

Distribution of Outerbark Maximum Temperatures

Temperature range in °C	Actual mean of range	No. of trees	Percentage of all observations	Time in seconds over 100° C
0 –100° C	66°	3	5	..
100°–200° C	144°	20	36	60
200°–300° C	219°	9	16	65
300°–400° C	314°	4	7	91
400°–500° C	451°	7	13	104
500°–600° C	534°	6	11	167
600°–700° C	650°	4	7	172
700°–800° C	704°	3	5	188
Mean	297°	56	100	97

It can be seen that temperatures varied considerably. The mean maximum temperature for all observations is 297° C, while above 100° C temperatures were maintained for an average of 97 seconds. Due to the uneven distribution of trees in the arbitrary 100° C temperature classes the mean maximum temperature of 297° can be misleading. In fact 59 per cent of trees experienced temperatures of less than 300° C and the mean maximum temperature of these stems was only 149° C, maintained above 100° C for 62 seconds.

It is interesting to compare temperatures observed in backfires (42 trees), against those in headfires (14 trees). Backfire temperatures averaged 323° C, while this value in headfires was 100° C lower (223° C). Likewise the duration above 100° C for backfires was 109 seconds, against 60 seconds in the headfires.

Kayll (1963), who worked with *Pinus strobus* L. in Canada, compared outerbark temperatures with temperatures at the cambium for a range of bark thicknesses. He found that for bark thicker than 0·4 inches an applied external heat with a temperature of 500° C can be withstood for 5 minutes without raising the cambium temperature to 60° C (the normally accepted lethal limit). Although this study deals with a different species of *Pinus*, the fact that bark thickness in this stand averaged 0·59 inches makes it unlikely that any cambium deaths have been incurred through any of the time-temperature combinations observed in this series.

As mentioned in preceding sections, each of the trees in the burnt plots was assigned to a fire intensity class by means of the rate of spread contour maps prepared for each plot. Thus it is possible to compare the time-temperature relationships established with the pyrometer between trees of different fire intensity classes.

Photo 3:

View of plot D2 taken 30 days after burning treatment, showing leaf scorch and low height of bark scorch.

Photo 4:

Burning under way in plot C2, showing the dramatic change in fire behaviour when dense Bladey Grass dominates the understorey.

This comparison is shown in table 14, where once again observations on backfires are presented separately from those on headfires.

TABLE 14

Time-Temperature Relationships in Fire Intensity Classes

Fire intensity class	No. of trees	Mean max. temp. °C	Time in seconds over 100° C
	A. Backfires (5)		
I (0–25 Btu)	7	144	79
II (26–50 Btu)	28	374	123
III (51–75 Btu)	5	432	98
	B. Headfires (2)		
I (0–25 Btu)	4	383	115
II (26–50 Btu)	4	178	44
III (51–75 Btu)	6	189	32

It can be seen that in the case of backfires results are as one would expect. The lowest intensity class produced the lowest mean maximum temperature for the shortest duration, and the highest intensity class the highest mean maximum temperature for the longest duration.

However in the two headfires the reverse applied. It is suggested that this is a function of the inefficiency of the headfires used in this series in reducing the fuel. It has been shown in table 11 that the headfires reduced only 57 per cent of the fuel, and it appears that the faster these fires travelled the more fuel they left unburnt, resulting in lower maximum temperatures.

These pyrometer measurements were supplemented with sets of chromatic thermocrayons applied to asbestos squares attached, at a height of 1·5 feet above ground level, to ten randomly selected trees in each plot. The crayons are designed to change colour when specific temperatures are reached; ten crayons with temperature limits ranging between 65°–600° C were applied to each asbestos square. The mean maximum temperature reached was shown to fall in the range between 280°–320° C, which agrees completely with the mean maximum pyrometer temperature of 297° C.

In addition to the temperature measurements on standing trees, temperatures were also sensed at and below the soil surface in five of the burns. For this purpose a potentiometer with chromel-alumel thermocouples and a manual switch was used. This method of obtaining fire temperatures does not have much to commend it. Wires connecting the asbestos-covered thermocouple leads to the potentiometer had to be buried in trenches, creating a disturbance to the site, while considerable time lags occurred between readings at any one thermocouple because of the manual balancing of the potentiometer circuit and the recording of the observations. Maximum temperatures were almost certainly missed and results presented here can only be considered approximate. At each of the five measuring stations thermocouples were placed at seven positions. Two were buried ½ inch below the soil surface, two buried at a depth of ¼ inch, 1 at the soil surface and 2 at a height of 1·5 feet on an adjacent tree, one on the leeward and one on the windward side.

Maximum temperatures recorded at each of these points are presented in table 15, while the time–temperature relationships established for average maxima are presented in figure 3.

TABLE 15

Maximum Temperature in °C, as measured by Potentiometer

Plot No.	Tree trunk		Soil Surface	Soil depth ¼ inch		Soil depth ½ inch	
	Windward	Leeward		1	2	1	2
B2	86	155	163	58	50	44	40
B4	109	..	135	46	34	38	34
C2	67	181	230	37	32	28	25
D2	193	89	67	35	30	31	31
D4	76	181	367	171	84	146	34

The only surprising recordings were obtained in plot D4, where maxima measured at ¼ inch and ½ inch below the soil surface were 171° C and 146° C respectively with a corresponding high at the soil surface of 367° C. It has not been possible to explain why temperatures in this plot appear so much higher than those in other plots of this series.

It can also be seen that, in three out of four occasions, temperatures measured on the leeward side of trees were roughly twice as high as those on the windward side, while on one occasion the reverse applied. A faulty connection in one of the channels in plot B4 precluded this comparison in the fifth plot.

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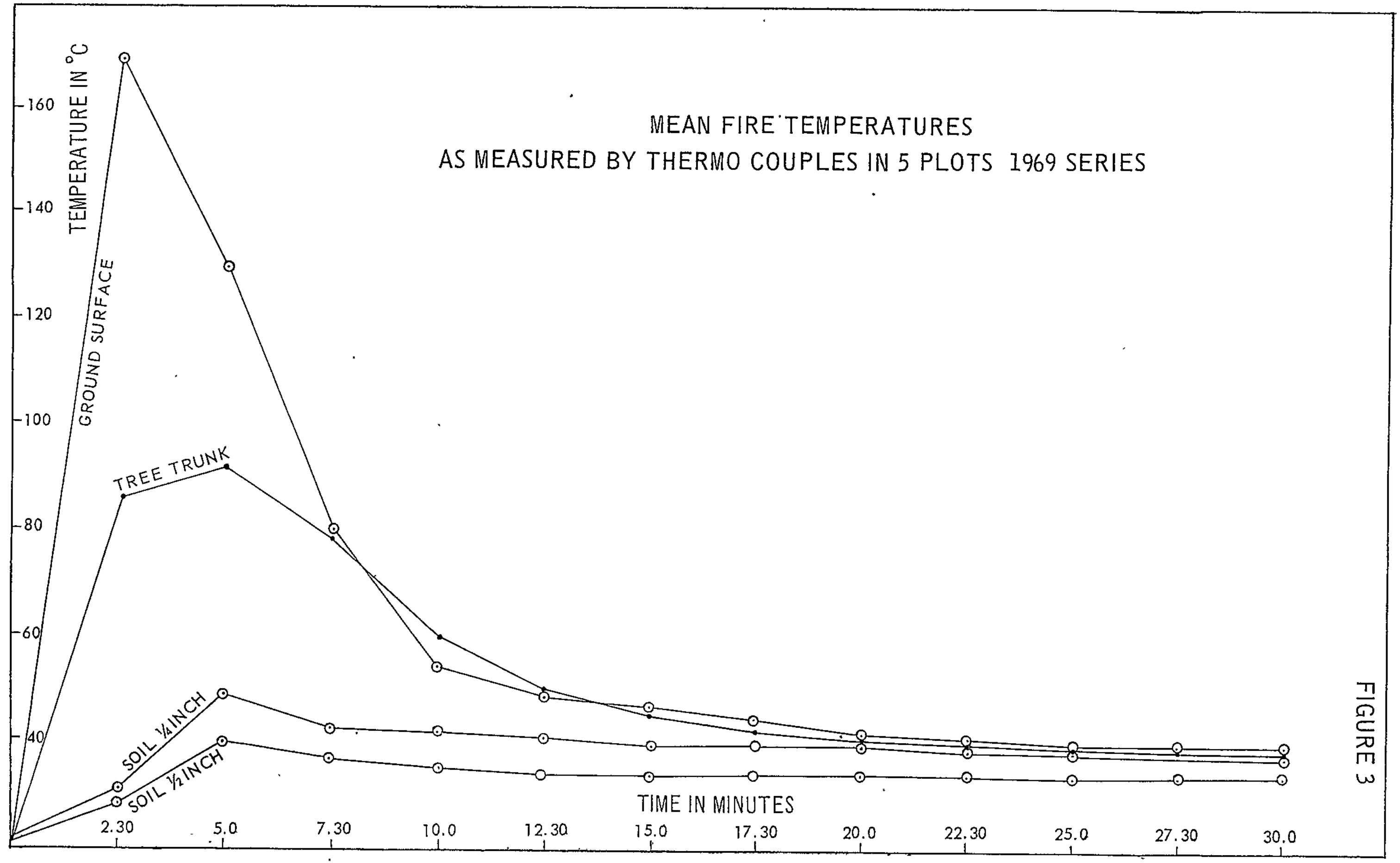

FIGURE 3

4.4 Scorch Height

Due to the young age of the stand and the low pruning height of 8 ft, it was fully expected that some needles on some trees would be scorched during burning. But it was not expected that needle scorching would be as prominent as it turned out to be. No less than 95 per cent of the 1,158 stems in the internal study plots showed evidence of needle scorch and the mean scorch height of these stems was 14·26 feet. This basically means that needles on the two lowest whirls of branches were affected. Photograph No. 3, taken in plot D2, 30 days after burning, gives a visual impression of degree of scorch. In this particular plot 99 per cent of stems showed scorching and the mean scorch height of 15·60 feet was above the average for the series.

There can be little doubt that in low intensity burning the height of scorch is largely a function of the initial vegetation temperature. Byram (1958) states that the quantity of heat required to raise the temperature of living vegetation up to the lethal temperature is directly proportional to the difference between this temperature and the initial vegetation temperatures. Hence fires of equal intensity are more damaging on hot days than on cool days. Graphs presented in his paper indicate that had fires in this series been of equal intensity but burnt on days with a mean maximum temperature of 60° F, instead of 82° F as was the case, the scorch height would have been reduced by more than 60 per cent and would have averaged about 8·5 feet. However the same author points out that "crown scorch is not always a reliable indication of total damage". Moreover, the fuel complex in the stand was such that, to support fire during cool weather, the fuel moisture content would have to be extremely low.

The presence of Bladey Grass (*Imperata cylindrica*), whether in a green or cured state, has a pronounced effect on scorch height. This species, which ranks only tenth in importance as green vegetation and fourth as cured vegetation in the study area (see appendix 3), dramatically increases flame height whenever it is burnt.

Photograph No. 4 shows how a cool controlled fire with an average fire intensity of 27 Btu's and on average rate of forward spread of 2·9 ft (relatively low for a headfire), can crown readily when it encounters an area where Bladey Grass dominates the understorey.

It has not been possible to establish a relationship between the average flame height and the average scorch height for each plot, but indications are that the ratio appears to be in the vicinity of 1 to 6, that is an average flame height of 2 feet would cause scorehing to occur to a height of 12 feet.

Comparing scorch heights of individual trees with their fire intensity ratings described earlier shows a good correlation. Table 16 gives the number of stems in each fire intensity class, the percentage of these scorched and the average scorch height for each class.

TABLE 16

Percentage of Trees scorched, and Average Scorch Height, by Fire Intensity Classes

Fire intensity class	Fire intensity range in Btu/ft/sec	No. of trees in class	Percentage of trees scorched	Average scorch height (in feet)
1	0–25	145	84·1	13·2
2	26–50	532	94·9	13·4
3	51–75	225	97·8	14·7
4	76–100	94	97·9	14·9
5	101–150	33	100	17·7
6	151–200	22	100	19·3
7	201–250	53	100	16·8
8	251–300	24	100	17·1
9	301–400	30	100	17·6

In this series of burns there was no evidence of difference in scorch heights between headfires and backfires. As the average dominant height of trees in the study area is 24 feet and no branches occur below 8 feet, the theoretical crown length is 16 feet. For an average scorch height of 14 feet, 6 feet of the crown length (or 37·5 per cent) has been affected by scorch. The affected portion, however, can be expected to be the least efficient part of the crown.

4.5 Fuel and Soil Moisture Content

The moisture content of forest fuel has long been known to be one of the main factors affecting forest fire behaviour. Much heat is required to raise the temperature of water in the fuel and subsequently to evaporate it, while the resulting water vapour dilutes the oxygen and interferes with the gaseous phase of combustion. Most control burning guides or fire danger rating systems attempt to estimate fuel moisture content either by the use of hazard sticks or by reference to tables of temperature, relative humidity and recent rainfall.

In this study an attempt was made to obtain a measure of the fuel and soil moisture contents as they were at the time of ignition of each fire. Immediately before ignition fine fuel components described in section 3·4 were sampled at a number of random locations. The samples for each component in each plot were bulked and weighed before and after oven-drying at 105° C. To obtain an average fuel moisture content for each plot the moisture contents for branches (under one inch diameter), needles and cured vegetation were weighed in the ratios in which they occurred in each plot, using the data given in the section on the fuel complex. The moisture content of green vegetation, although determined, was not used in calculating the average plot moisture content.

In addition three random soil samples were taken to a depth of 1·5 inches at the time of ignition and the same number at adjacent locations immediately after each fire was out. These data are presented in table 17.

TABLE 17

Fuel and Soil Moisture Contents

Plot No.	Fuel moisture content—per cent					Fuel reduction per cent	Fire intensity in Btu's	Soil moisture content	
	Green veget.	Branches	Needles	Cured veget.	Average plot rating			Before burn	After burn
A2	162·3	9·3	10·2	8·5	9·1	91	181	1·3	1·4
A4	235·2	52·5	27·8	44·9	42·5	53	41	7·9	7·9
B2	218·3	20·9	18·8	15·4	17·6	86	27	1·4	1·1
B4	237·7	16·8	11·5	13·0	12·9	91	59	1·6	1·6
C2	305·6	25·8	15·1	31·9	22·8	61	30	5·3	6·4
C4	272·6	15·4	17·2	15·9	16·3	74	25	1·7	3·5
D2	246·1	21·1	12·6	23·5	18·6	87	32	1·6	1·0
D4	310·0	20·8	18·2	20·1	19·5	69	36	4·4	3·6
means	248·5	22·8	16·4	21·6	19·9	76·5		3·1	3·3

This table again highlights the difficulties in this type of experiment to find meaningful eorrelations between fire behaviour and the many variables which affect it.

Comparing fuel moisture content with the fuel reduction per cent on the one hand, and with fire intensity on the other, one might suggest that moisture contents below 13 per cent result in fire intensities above the optimum, while moisture contents above 20 per cent hinder efficient fuel reduction, at least under such conditions of temperature and relative humidity as prevailed in this series of burns. Obviously similar evidence from a far greater number of burns is needed before valid conclusions can be drawn.

Table 17 also shows the differences in soil moisture content, as it was sampled, before and after each burn. As in the 1968 series of burns under Blackbutt it is not possible to discern a trend caused by burning. Once again some post-burn values were higher than the pre-burn ones, in other cases the reverse applied.

5. OTHER ASPECTS UNDER STUDY

5.1 Chemical properties of the soil

In order to observe if the burning regimes will alter the chemical properties of the soil, a chemical analysis of soils of the study plots will be carried out annually.

Soil is sampled at two levels, 0–3 inches and 12–15 inches. The 0–3 inch level is considered the most important sample, not only because it is thought to be the best indication of nutrient status, but also because it is the layer which will be affected by the fire. A total of six random samples are collected and bulked per plot. Only one sample is collected from the 12–15 inch level.

The first sampling was carried out before the first burning treatment in February, 1969, with a subsequent sampling in June, 1969, and future samplings will be annually in June thereafter. In conjunction with the June soil sampling each year, samples of foliage will be collected and assessed for foliage nutrient level.

5.2 Physical properties of the soil

As repeated burning can also effect physical properties of the soil, the top 2½ inches of soil was sampled in each plot for the determination of bulk density.

Bulk density is a measure of the compaction of the soil and is expressed as the oven-dry weight in grams of one cubic centimeter of soil in an undisturbed condition.

Six cores, each 150 cubic centimetres in size were randomly collected in each plot. The plot, block and treatment means are presented in table 18.

TABLE 18

Soil Bulk Density, January, 1969

(grams per cubic centimetre)

Plot No.		Bulk density	
	A0	1·26	
	A2	1·24	
	A4	1·23	
Mean block	A		1·24
	B0	1·22	
	B2	1·25	
	B4	1·27	
Mean block	B		1·25
	C0	1·37	
	C2	1·25	
	C4	1·29	
Mean block	C		1·30
	D0	1·33	
	D2	1·29	
	D4	1·24	
Mean block	D		1·29
All controls		1·29	
All 2-yearly burns		1·26	
All 4-yearly burns		1·26	

Bulk density will be resampled in January of each year scheduled for burning.

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II. FIRST PROGRESS REPORT

7. INTRODUCTION

This section presents progress of the study outlined in the previous section up until August, 1971, and gives emphasis to the effects of the first burning treatments on the growing stock, litterfall, fuel weights and understorey vegetation.

It also describes the fire behaviour of the second series of burns, carried out in May, 1971, on the 2-year treatment plots. The experimental prescription requires these blocks to be burnt every 2 years and that burning is carried out between February 1st and June 30th. Due to light fuel weights and unfavourable weather conditions some difficulty was experienced in effecting these burns.

8. SITE CONDITIONS

8.1 Growing Stock

Three measurements of the growing stock occurring in each 0·4 acre internal study plot have been made over a 2-year period. To detect if any growth differences existed between plots before burning, the first measurement period covered 6 months before the first burns. The second period measured growth for a period of 18 months following burning. Table 19 summarizes stand parameters and basal area increments during these periods and shows the effect of burning on the growing stock.

TABLE 19

Stand Parameters, Diameter Increment and Basal Area Increment of the Growing Stock by Treatments

Treatment	No. of stems per acre	Mean dia. (inches)	Mean dia. increment (inches)	Basal area (sq ft/acre)	Basal area increment (sq ft/acre)	Mean dominant height (feet)
Controls:						
9/68	376	4·19		37·31		24·6
			0·46		8·37	
4/69	376	4·65		45·68		27·5
			0·80		16·65	
10/70	375	5·45		62·33		32·4
2-yr burn:						
9/68	365	4·17		36·01		24·6
			0·42		7·39	
4/69	365	4·59		43·40		27·4
			0·58		11·26	
10/70	359	5·17		54·66		31·4
4-yr burn:						
9/68	358	4·07		33·94		24·2
			0·45		7·44	
4/69	358	4·52		41·38		26·9
			0·63		11·62	
10/70	354	5·15		53·02		31·6

From the table it can be seen that there was similarity in diameter and basal area increments between treatments in the period prior to the first burning treatments.

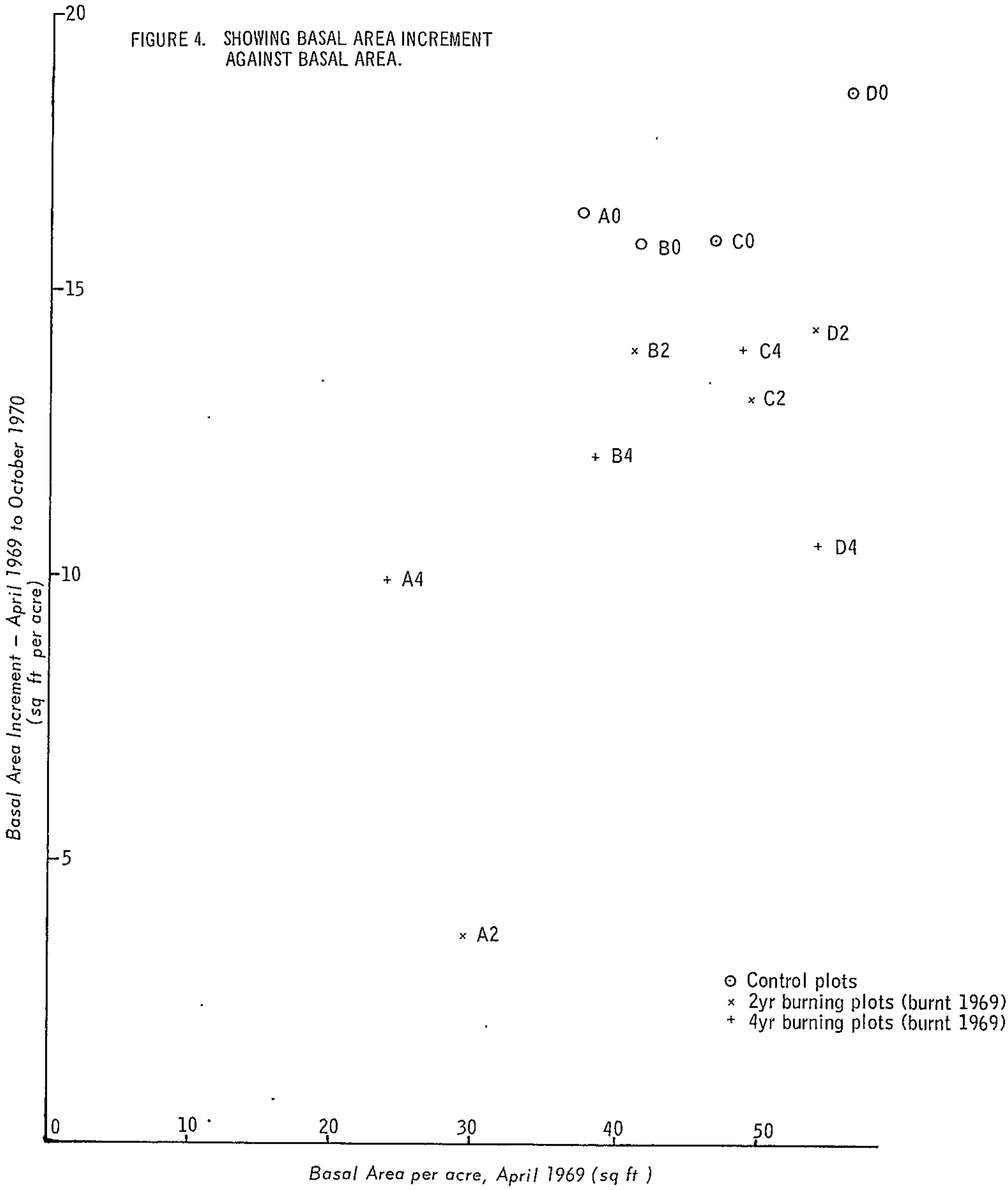


FIGURE 4. SHOWING BASAL AREA INCREMENT
AGAINST BASAL AREA.
20
15
10
5
0
10
20
30
40
50
D0
A0
B0
C0
D2
B2
C4
C2
B4
D4
A4
A2
Control plots
2yr burning plots (burnt 1969)
4yr burning plots (burnt 1969)
Basal Area Increment – April 1969 to October 1970 (sq ft per acre)
Basal Area per acre, April 1969 (sq ft)

In the 18-month period following burning the basal area increment which occurred in the burnt plots was only 69 per cent of that which occurred in the control plots.

Figure 4 shows a graph of basal area increment against basal area by plots for the post burn period. Highest basal area increment occurred in the four control plots.

An analysis of basal area increments between treatment plots over this period showed, however, that these growth differences were not significant ($F_{2, 6} = 4{\cdot}2$). Covariance analysis, using initial basal area as the dependant variable reduced the variance to $F_{2, 6} = 2{\cdot}5$. The analysis is given in appendix 6.

If similar growth reductions to those apparent after the initial burn occur after each successive burn, the growth differences should become statistically significant after two or three burning treatments.

8.1.1 *Effect on Growth by Fire Intensity Classes*

Part I shows that the average fire intensity of the initial burns varied between plots from 25 to 181 Btu/ft/sec. It also describes the measurement of fire intensity variation within each plot and the subsequent allocation of each burnt tree to a fire intensity class.

Table 20 below, lists the mean sectional area increment of the burnt trees by fire intensity classes and also shows the number of trees and mortality in each class.

TABLE 20

The Effect on Growth by Intensity Classes, for Trees burnt in 1969 (*including controls*). *Period April,* 1969, *to October,* 1970

Fire intensity class	Intensity range (Btu/ft/sec)	Number of trees in each class	Mortality after burning	Mean d.b.h. at time of burning (inches)	S.A.I. per tree (sq ft) period 4/69 to 10/70
Control	0	602	1	4·66	0·044
1	0–25	145	2	4·83	0·037
2	25–50	532	3	4·67	0·037
3	50–75	225	1	4·59	0·033
4	75–100	94	2	4·46	0·027
5	100–150	33	0	4·20	0·024
6	150–200	22	0	4·20	0·008
7	200–250	53	3	3·64	0·006
8	250–300	24	1	3·81	0·008
9	300–400	30	1	3·91	0·010
		1,760	14	4·59	0·036

There was a decrease in the mean diameter of trees subjected to higher fire intensity as represented by the intensity classes. This could be explained as an effect of the size of individual trees on the state of the fuel surrounding them.

There was a decrease in the mean sectional area increment of trees subjected to all classes of fire intensity. This was most pronounced in trees subjected to fire intensity of greater than 150 Btu/ft/sec². Part I shows that these trees (n = 129) had a mean scorch height of 17·5 feet. The stand dominant height was 24 feet, indicating that over half the crown depth of these trees was scorched.

It appears that to minimise growth losses caused by burning in stands of this type fire intensity should be kept low and aimed not to exceed 50 Btu/ft/sec.

8.1.2 *Bark Thickness*

Most reports on the effect of prescribed burning on tree growth have involved the interpretation of overbark measurements and the effect of bark thickness changes may be critical in view of the small growth differences reported.

The design of this experiment precludes the use of destructive or damaging bark sampling techniques on the growing stock.

Bark thickness was measured on the row of trees immediately adjacent to the western boundary of each central study plot by meaning the thickness gauged at the four cardinal points of the compass on each tree. Measurements were made in January, 1969, before burning and again 2 years later. (Table 21).

TABLE 21

Bark Thickness of Sample Trees before, and 2 years after, Burning

	No. of trees	Bark thickness, inches		Increase	Percentage increase over 2 years
		1969	1971		
Unburnt ..	36	0·59	0·77	0·18	31
Burnt ..	75	0·59	0·72	0·13	22

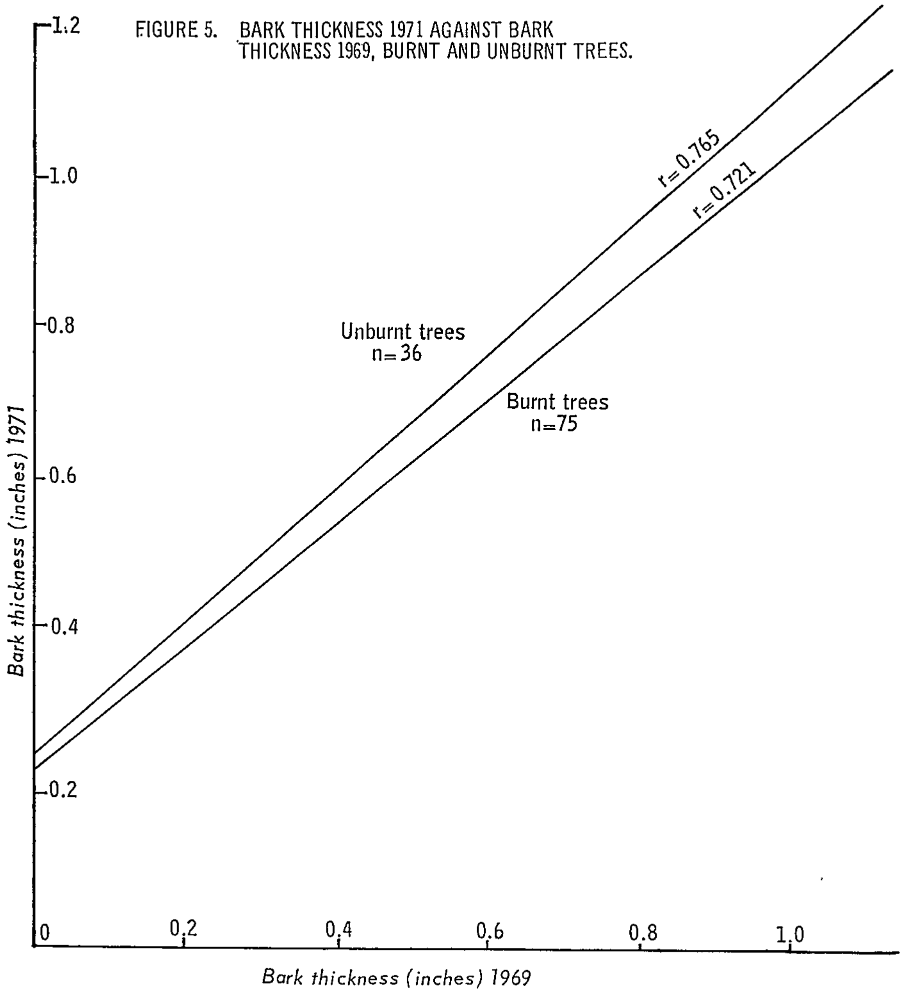
The increase in bark thickness of the burnt trees was only 70 per cent of the increase which occurred in the unburnt trees over the two-year period.

The reduction in bark thickness increment of the burnt trees can be attributed to two possible causes: consumption of bark during burning and to a reduction in bark thickness increment proportional to an apparent reduction in growth which occurred in the burnt trees.

In this study it appears that most of the loss in bark thickness increment could be attributed to growth losses. Testing of a bark thickness increment on diameter increment for burnt and unburnt trees would substantiate this and will be carried out at the next measurement.

Figure 5 shows regressions of bark thickness 2 years after burning against bark thickness before burning, using individual tree measurements. Both regressions were significant and covariance analysis showed a significant difference between the elevation of the two regressions. The analysis is given in appendix 7.

FIGURE 5. BARK THICKNESS 1971 AGAINST BARK THICKNESS 1969, BURNT AND UNBURNT TREES.



8.2 Major Understorey

In section 3.2 it was shown that the stocking and composition of the major understorey species varied considerably between plots and treatments.

Table 22 compares the per acre stocking and mean height of the most common major understorey species for the control plots (4) and the plots burnt in 1969 (8), as measured just prior to the 1969 series of burns and again 2 years later.

TABLE 22

Stocking of Major Understorey Species on Burnt and Unburnt Plots as at January, 1969 and January, 1971

	Controls (4 plots)				Burnt (8 plots)			
	1969		1971		1969		1971	
	No. of stems /acre	Mean height (feet)	No. of stems /acre	Mean height (feet)	No. of stems /acre	Mean height (feet)	No. of stems /acre	Mean height (feet)
Angophora floribunda ..	1,363	6·0	1,563	7·1	482	6·2	572	5·0
Melaleuca nodasa ..	241	4·8	261	6·6	330	4·8	530	3·7
Tristania suaveolens ..					240	6·1	340	4·9
Casuarina sp.	225	8·5	225	8·1	110	6·3		
Eucalyptus signata ..			20	7·0	70	9·4	110	5·5
Acacia sp.	80	6·0	60	11·3	20	4·9	10	3·2
Persoonia sp.	80	4·0	20	4·7				
Eucalyptus gummifera	60	5·0	120	7·2	30	5·0	110	4·4
Hakea dactyloides ..	20	3·3	20	3·3	10	3·1	40	4·2
Pomaderis sp.	20	3·5	40	4·5				
Alphitonia excelsa ..	20	5·0	20	6·8			20	4·0
Jacksonia scoparia ..	20	5·2						
Lomatia sp.			20	3·2				
Totals	2,129	5·9	2,369	7·1	1,292	5·9	1,732	4·5

There was in increase in the per acre stocking of major understorey species in both the control and burnt plots. The increase of 34 per cent in the burnt plots was higher than the increase of 11 per cent in the controls.

Table 23 shows the mortality and ingrowth of understorey species which occurred during the 2-year period following burning.

TABLE 23

Mortality and Ingrowth of Major Understorey Species after Burning

	Understorey species recorded before burning 1969 measurement		Survival recorded 2 years after burning		Mortality recorded 2 years after burning	Ingrowth recorded 2 years after burning	
	No. of stems per acre	Mean height (feet)	No. per acre	Mean height	No. per acre	No. per acre	Mean height
Controls (4 plots) ..	2,129	5·9	2,029	7·5	100	340	5·1
Burnt (8 plots) ..	1,292	5·9	1,052	4·6	240	670	4·3

The initial stocking of major understorey species was reduced in both the burnt and control plots. In the burnt plots the stocking was reduced by 19 per cent during this period and in the control plots by 5 per cent.

Ingrowth during the 2-year period increased the total per acre stocking of the burnt plots by 51 per cent and the per acre stocking of the control plots by 16 per cent.

The net effect of the first burning treatment was to increase the stocking of major understorey species. This occurred mainly by the stimulation of lignotuberous and coppice growth from stumps and root bases already occurring in the study area.

8.3 Minor Understorey

The sampling method used to sample the minor understorey of grasses, herbaceous vegetation and woody species less than 3 feet in height was described in section 3.3. It lists the loop index of density of the main species as they occur by treatments and a list of all species for the study area is given in appendix 3.

Before the burning treatments the total loop index density of the minor understorey species was comparable between treatments. As shown in table 24, 2 years later the total loop index of density for both burnt and control plots had increased by approximately 20 per cent.

Table 24 shows the frequency of occurrence of the main species before and 2 years after burning.

TABLE 24

Average Loop Index of Density—Minor Understorey Species

Species	Controls (4 plots)		Burnt (8 plots)	
	Jan., 1969	Jan., 1971	Before burning Jan., 1969	After burning Jan., 1971
Axonopus affinis	27	21	28	26
Alloteropsis sp.	25	37	28	24
Entolasia marginata	11	37	17	36
Panicum fulgidum	9	1	7	7
Lepidosperma sp.	4	2	7	4
Gahnia aspera	4	5	7	8
Pratia purpurascens	2	11	1	5
All other species	27	17	15	24
Total loop index of density ..	109	131	110	134

There is a similarity between treatments for total loop index of density, though there has been some change in the main species which contribute to it. The loop index of density of cured vegetation decreased in both treatments, as shown in table 25.

TABLE 25

Total Loop Index of Density for Green and Cured Minor Understorey Vegetation

	Controls (4 plots)		Burnt (8 plots)	
	Jan., 1969	Jan., 1971	Jan., 1969	Jan., 1971
Green vegetation	109	131	110	134
Cured vegetation	46	23	52	35

The increase in the ratio of green to cured vegetation which occurred in both treatments is probably indicative of the effect of above average rainfall which occurred during this period. (Rainfall data is listed in the section on meteorological conditions.)

8.4 Litterfall

Litterfall studies, outlined in section 3.4, have been conducted for 3 years. During this period the mean annual needle litterfall occurring in the study site has been 2204 lb per acre. This is considerably less than the annual litterfall recorded in similar studies in Blackbutt forests, of 5,800 lb per acre. Table 26 gives the mean annual litterfall by treatments for three years.

TABLE 26

Mean Annual Litterfall—lb per acre

	Plantation age—years			Mean over 3 years
	8	9	10	
Controls (12 trays) ..	1,597	1,817	3,206	2,207
Burnt (24 trays)	2,192	1,610	2,805	2,202
Mean	1,994	1,679	2,939	2,204

The total litterfall occurring in the burnt and control plots over the 3-year period was very similar. The litterfall study was commenced 6 months before application of the first burning treatments and table 27 illustrates the effect these burns had on litterfall.

TABLE 27

Litterfall before and after the First Burns

Period	Controls 12 trays	Burnt 24 trays
8/68 to 2/69 (6 months before burning)	986	969
2/69 to 8/69 (6 months after burning)	611	1,223
2/69 to 2/71 (2 years after burning)	3,554	3,776
2/71 to 8/71 (including 3 months after 2nd burns) ..	2,081	1,861
Total over 3 years	6,614	6,605

A marked increase in needlefall occurred in the burnt plots in the 6 months following burning. This effect from burning was only temporary and in the 2-year period following the burns the total litterfall in the control and burnt plots was fairly similar.

The seasonal distribution of litterfall is shown in figure 6. A marked seasonal variation occurred, with litterfall during the period from November to May being two and a half times greater than that in the other 6 months.

As outlined in part I there was a marked difference in the mean size between trees of different plots at the commencement of the study. The basal area of individual plots varied from 18 to 47 square feet per acre. Figure 7 shows mean annual litterfall over 3 years against initial basal area of the twelve study plots. It shows a significant relationship existed between basal area increment and litterfall. Details of the analysis are given in appendix 8.

The litterfall occurring in each of the 36 littertrays was compared with the basal area and basal area increment of the growing stock occurring within a 16-feet radius of each tray. No definite relationships could be established and it appeared that the litterfall occurring in an individual tray was more dependent on the proximity of the nearest tree than on the surrounding growing stock.

8.5 Fuel Complex

Section 3.4 gives full details of the fine fuel weights as sampled prior to and immediately after the first series of burns. The average prior to burning was equivalent to 3·5 tons of fine fuels per acre. The mean weights of the four plots chosen as controls were 3·6 tons per acre, and of the eight plots allocated for burning, 3·5 tons per acre. Fuel reduction during burning varied from 53 to 91 per cent, reducing the mean fuel weight of the burnt plots to 0·8 tons per acre.

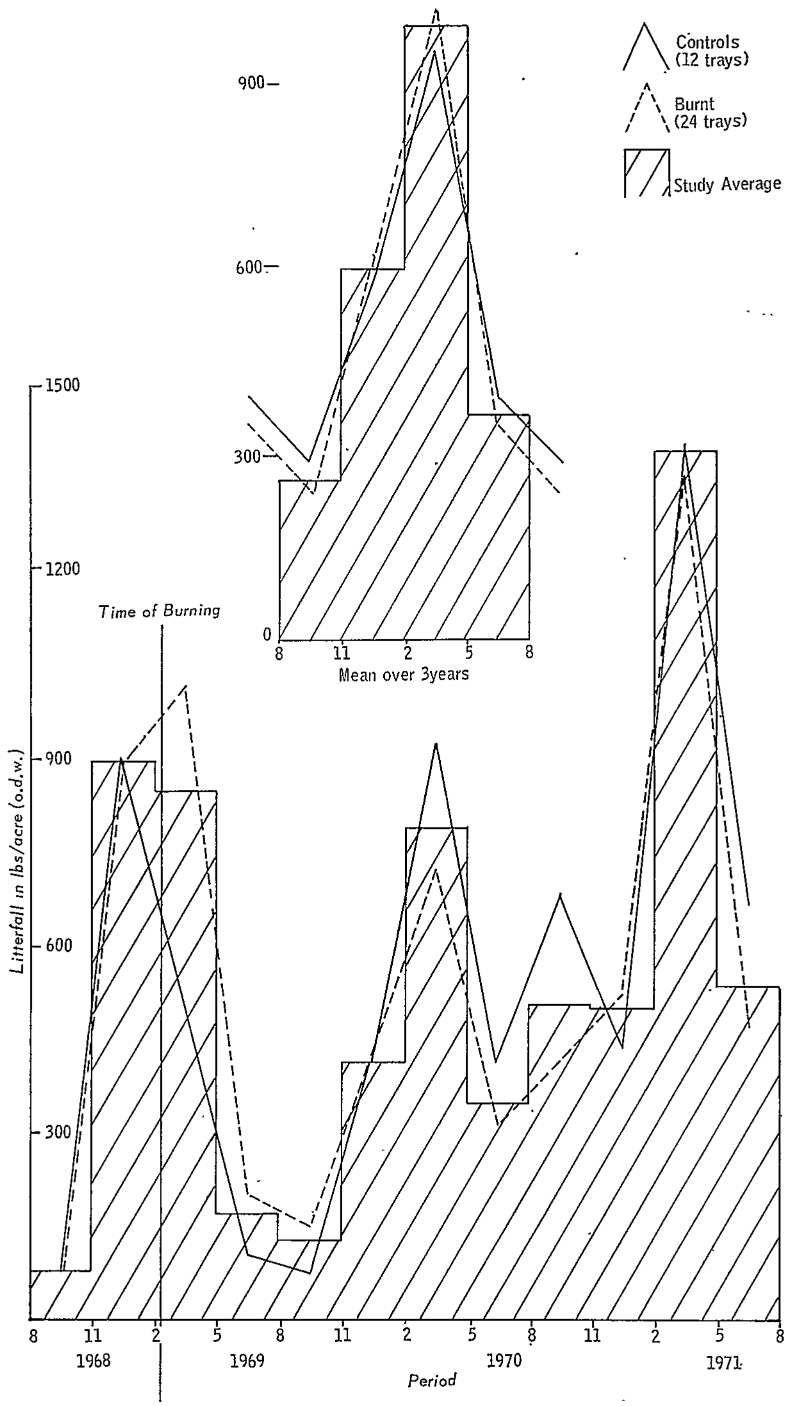
Fine fuel weights were sampled in identical fashion prior to the 1971 burns. Table 28 gives the fine fuel weights of the control and burnt plots before and after burning in 1969 and before burning in 1971.

TABLE 28

Fine Fuel Weights—lb/acre

Component	Controls		Burnt		
	1969	1971	1969	After burning (total only)	1971
Twigs under 1 inch	1,272	361	1,688		247
Needles	2,635	2,580	2,230		1,264
Green veg. ..	501	1,070	448		1,028
Cured veg. ..	2,713	2,183	2,111		886
Miscellaneous ..	969	386	1,242		200
Total	8,090	6,580	7,720	1,702	3,625

FIGURE 6. SEASONAL DISTRIBUTION OF LITTERFALL OVER 3 YEARS



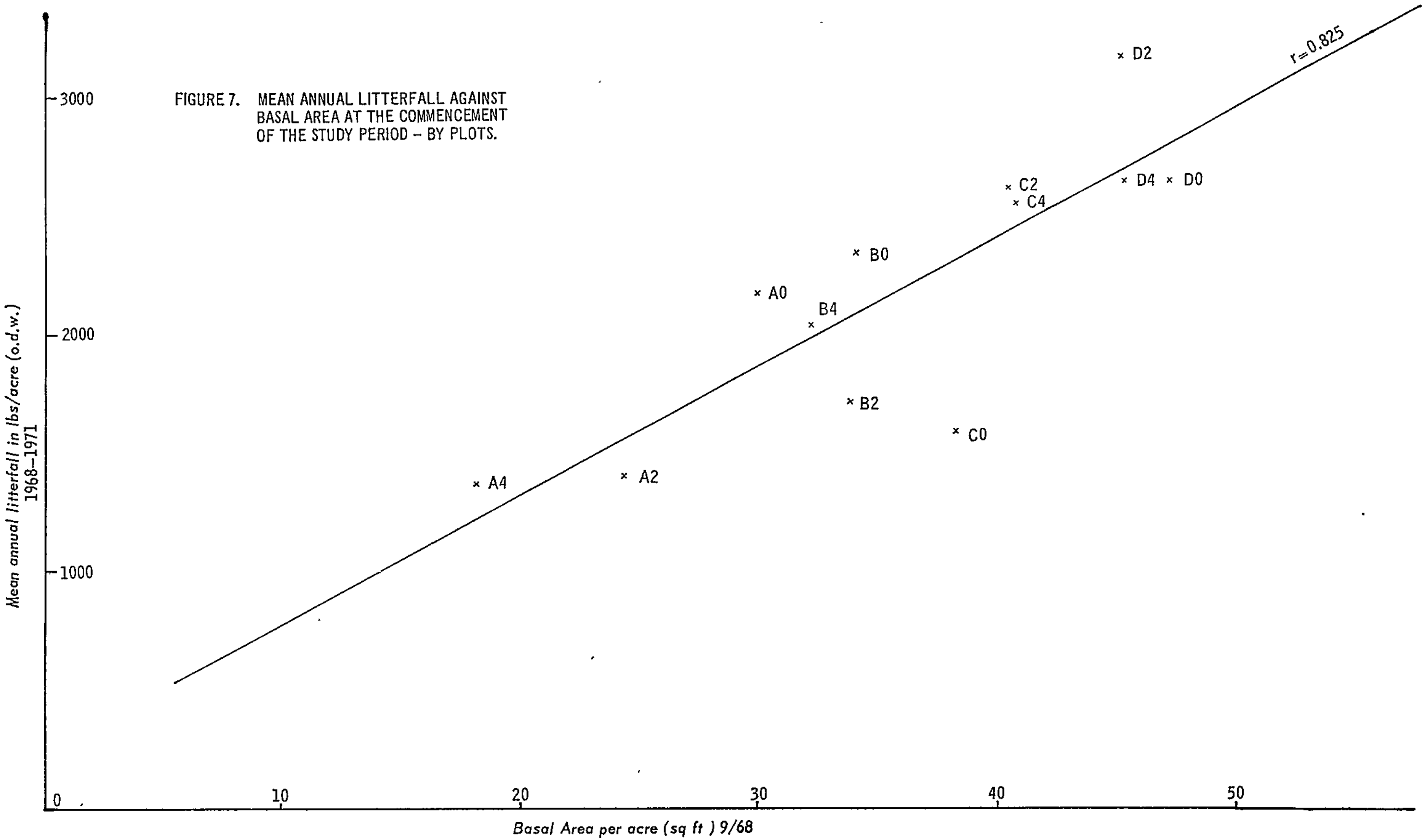


FIGURE 7. MEAN ANNUAL LITTERFALL AGAINST BASAL AREA AT THE COMMENCEMENT OF THE STUDY PERIOD – BY PLOTS.

Two years after burning the fuel weight of the burnt plots was less than half of the pre-burn fuel weight, illustrating a relatively slow rate of fuel build up after burning. This contrasts with the results of studies in Blackbutt forests where, 2 years after the initial burn, the fuel weight had returned to the pre-burn level. The short period of increased needle-fall which occurred after burning does not appear to have accelerated the post-burn fuel build up.

A reduction occurred in the fuel weight of the control plots during the 2-year period. The main reduction occurred in the twig component which now only comprises a small fraction of the total fuel. The study area was thinned to 360 stems per acre and low pruned to a height of 8 feet in 1967. The composition of the fine fuels in 1971 indicate that most of the fine slash from these treatments has apparently decomposed during this period.

Table 29 lists the fine fuel weight of the four 2-year burning treatment plots prior to and after the second series of burns conducted in May, 1971.

TABLE 29

Fine Fuel Weights in 2-year Burning Plots, prior to and after the second burns

Plot No.	1971		Reduction per cent
	Before burning	After burning	
A2	2,688	1,384	49
B2	3,615	1,346	63
C2	3,788	2,265	40
D2	4,412	3,114	30
Mean ..	3,625	2,055	43

Available fuel and fuel reduction is further referred to in section 9.2 on fire behaviour and intensity.

9. 1971 BURNING TREATMENTS

9.1 Meteorological Conditions

Burning of plots scheduled for 1971 was carried out on the 11th and 12th May.

The preceding summer was characterized by above average rainfall with a high frequency of days on which rainfall was recorded. Rainfall figures for February, March and April, 1971, are given in table 30.

TABLE 30

Rainfall (in points) by Days for the Period 1st February, 1971, to 30th April, 1971

(100 points = 1 inch)

February		March		April	
Date	Points	Date	Points	Date	Points
1	48	3	94	1	10
7	170	4	10	2	63
17	365	5	115	3	43
18	35	6	85	4	18
19	5	10	10	5	5
21	44	13	8	6	3
22	76	14	12	13	15
23	10	21	10	14	6
24	5	22	5	15	13
25	40	23	15	18	10
26	15	28	103	25	10
		29	60	26	13
	813	30	90		
		31	23		209
			640		

No rainfall occurred between the 26th April and 11th and 12th May. The prevailing fuel and soil moisture contents at the time of burning are listed in table 31. Moisture contents of individual fuel fractions were measured and a total fuel moisture content estimate derived by weighing the percentage moisture content of each fraction by the proportion it contributed to the total fuel weight.

TABLE 31

Fuel and Soil Moisture Contents at Time of Burning

Plot No.	Fuel moisture content per cent o.d.w.						Soil moisture content	
	Vegetation					Mean of cured fuel	Before burning	After burning
	Twigs	Needles	Green	Cured	Mean			
A2	14·4	25·8	138·7	22·0	93·6	22·0	8·4	8·9
B2	24·1	25·2	151·5	33·9	70·9	28·3	8·9	7·1
C2	24·1	22·3	115·6	27·0	41·3	24·1	7·1	7·0
D2	23·2	26·8	152·9	35·4	48·3	28·9	7·6	7·7
Means ..	21·5	25·0	140·0	29·6	63·5	25·8	8·0	7·7
February, 1969 Means ..	22·8	16·4	248·5	21·6	38·3	19·9	3·1	3·3

Though the moisture content of the green vegetation was less in 1971 its effect on the total fuel moisture content was greater as it comprised a much higher proportion of the total fuel. Cured fuel and soil moisture contents were also higher than those occurring in 1969.

The conditions at the time of burning were more moderate than those under which the first series of burns were carried out (table 32). The temperatures averaged 10° F less and the humidity up to 20 per cent more than was experienced during the first burns. The wind direction on both days was variable, the average windspeed of 2·3 miles per hour being roughly equivalent to a windspeed of 8 mph at 33 feet in the open.

TABLE 32

Meteorological Conditions at Time of Burning

Plot No.	Date	Time of ignition	Temp (°F)	Relative humidity per cent	Av. windspeed at 5 ft (mph)
D2	11/5	11.30 a.m.	70	53	1·9
C2	11/5	1.30 p.m.	70	40	2·1
B2	12/5	11.30 a.m.	72	44	2·4
A2	12/5	1.30 p.m.	74	39	2·6
Means ..			71·5	44	2·3

9.2 Fire Behaviour and Intensity

The main methods and controlling factors in burning in this study have been outlined in section 4.2. Due to the prevailing meteorological conditions all the fires were lit as headfires to burn with the prevailing or anticipated direction of the wind.

As outlined previously the mean fuel weight of the four burning plots was only 1·6 tons per acre, of which only 1·1 tons per acre consisted of cured fuel components. The cured fuel layer consisted mainly of a discontinuous needle bed with a moisture content of 25 per cent. This, together with the impedence by areas of green vegetation prevented uniform combustion along a continuous flame front.

As this became evident during the burns the lighting method was changed in an attempt to obtain a complete burn within the study areas. Strip lighting was used on a 16-feet spacing and this method achieved an effective burn over 90 per cent of the area.

Table 33 summarizes fuel conditions fire behaviour and fuel reduction for the series of burns. Fire intensity did not exceed 25 Btu/ft/sec^2 in any of the burns.

TABLE 33

Fire Behaviour—1971 Series

Plot No.	Fuel weight (lb/acre)	Temp. (°F)	Relative humidity per cent	Fuel M.C.	Fuel reduction per cent	Fire intensity (Btu/ft/sec²)
A2	2,688	74	39	22·0	49	<25
B2	3,615	72	44	28·3	63	<25
C2	3,788	70	40	24·1	40	<25
D2	4,412	70	53	28·9	30	<25
Means	3,625	71·5	44	25·8	43	<25

9.3 The Fire Temperatures

Malfunctioning of the recording equipment prevented the accurate monitoring of fire temperatures during this series of burns.

9.4 The Scorch Height

As a result of the low flame heights experienced in these burns no needle scorch occurred on any of the trees in the study area.

10. OTHER ASPECTS UNDER STUDY

The sampling and analysis of soil and foliage nutrient levels continues to be carried in June of each year. No significant changes in nutrient levels were detected after the first series of burns.

APPENDIX 1

CONDITION OF STAND PRIOR TO BURNING—THE GROWING STOCK (SLASH PINE)

Plot number	No. of stems/acre	Mean diameter	Bark thickness	Basal area per acre	Mean dom. ht, 12 trees
A0	360	3·85	0·51	29·81	22·6
A2	360	3·47	0·49	24·31	21·3
A4	360	2·99	0·52	18·12	19·8
Mean Block A ..	360	3·43	0·51	24·08	21·2
B0	372	4·06	0·61	34·17	23·4
B2	365	4·09	0·65	34·12	24·8
B4	375	3·93	0·54	32·36	23·1
Mean Block B ..	371	4·02	0·60	33·55	23·7
C0	388	4·21	0·61	38·23	24·3
C2	365	4·44	0·62	40·34	26·1
C4	365	4·54	0·60	40·42	26·0
Mean Block C ..	369	4·39	0·61	39·66	25·4
D0	385	4·67	0·63	47·04	28·2
D2	372	4·68	0·59	45·26	26·3
D4	342	4·85	0·71	44·85	28·0
Mean Block D	366	4·73	0·64	45·72	27·5
All Controls (0) ..	376	4·19	0·59	37·31	24·6
All 2-yearly burns (2) ..	365	4·17	0·59	36·01	24·6
All 4-yearly burns (4) ..	358	4·07	0·59	33·94	24·2

APPENDIX 2

MAJOR UNDERSTOREY PRIOR TO BURNING

	Angophora floribunda (Sm.) sweet	*Melaleuca nodosa* Sm.	*Tristania suaveolens* Sm.	*Casuarina* sp.	*Eucalyptus signata* F. Muell.	*Acacia* sp.	*Persoonia* sp.	*Eucalyptus gummifera* (Gaertn.) Hochr.	*Hakea dactyloides* (Gaertn.) Cav.	*Pomaderris* sp.	*Alphitonia excelsa* Reiss ex Endl	*Jacksonia scoparia* R.Br.	Totals
A0 No. of shoots	80	561										80	721
Mean height	8·0	4·6										3·2	
A2	80	80		241				80					481
	3·5	5·7		5·0				4·5					
A4	160	2,405		80	80	80							2,805
	6·4	4·6		4·6	4·0	4·8							
Block A No. stem	107	1,015		107	27	27		27				27	1,337
Mean height	6·1	4·6		4·9	4·0	4·8		4·5				3·2	
B0	882	241		401		160	160						1,844
	6·8	4·8		6·6		4·6	3·9						
B2	160	160		160	80								560
	3·8	5·4		8·4	7·0								
B4	1,042		481	160	160				80				1,923
	4·1		4·7	4·6	10·7				3·1				
Block B..	695	134	160	240	80	53	53		27				1,442
Mean	5·2	5·0	4·7	6·6	9·5	4·6	3·9		3·1				

C0	321	160							80				561
	4·6	5·4							3·3				
C2	321		80										401
	7·2		4·0										
C4	1,283		561		80	80							2,004
	7·1		6·0		7·0	7·0							
Block C	642	53	214		27	27			27				990
Mean	6·7	5·4	5·8		7·0	7·0			3·3				
D0	4,330			481		160	160	80		80	80		5,371
	5·9			5·4		7·4	4·0	5·0		3·5	5·0		
D2	641		160		80			80					961
	7·6		5·0		15·1			5·5					
D4	160		641	241	80								1,122
	9·5		8·0	8·0	8·0								
Block D	1,710		276	241	53	53	53	53		27	27		2,484
Mean	6·2		7·4	6·3	11·6	7·4	4·0			3·5	5·0		
Treatment Means 0	1,403	240		220	0	80	80	20	20	20	20	20	2,123
	6·0	4·8	0	5·9	0	6·0	4·0	5·0	3·3	3·5	5·0	3·2	
2	300	60	60	100	40	0	0	40	0	0	0	0	600
	6·7	5·5	4·7	6·4	11·0	0	0	5·0	0	0	0	0	
4	661	601	421	120	100	40	0	0	20	0	0	0	1,964
	6·0	4·6	6·4	6·3	8·1	5·9	0	0	3·1	0	0	0	

APPENDIX 3

MINOR UNDERSTOREY PRIOR TO BURNING

Minor understorey occurring in the study area, based on 12 plots × 2 transects × 50 random observations. Frequency of occurrence for both green and cured state is expressed by average loop index of density per cent.

Species/Family	Common name.	Green	Cured
Axonopus affinis A. Chase Gramineae	Narrowleaved Carpet Grass	27·3.	15·2
Alloteropsis semialata (R.Br.) Hitchc, Gramineae	Cockatoo Grass	27·2	7·5
Entolasia marginata R.Br. Gramineae	Bordered Panic Grass	14·7	8·5
Panicum fulgidum Hughes Gramineae	Two-colour Panic	7·7	3·5
Lepidosperma sp. Cyperaceae		5·6	2·2
Gahnia aspera Spreng. Cyperaceae		5·1	2·9
Themeda australis (R.Br.) Stapf. Gramineae	Kangaroo Grass	5·0	2·3
Andropogon virginieus Gramineae	Broomsedge	4·3	0·6
Poa caespitosa G. Forst Gramineae	Tussocky Poa	3·9	3·1
Imperata cylindrica (L.) Beauv. Gramineae	Bladey Grass	2·7	4·1
Angophora floribunda (Sm.) Sweet Myrtaceae	Rough barked Apple	1·3	..
Helichrysum sp. Compositae		1·2	..
Pratia purpurascens (R.Br.) Benth. Lobeliaceae	White Root	1·1	..
Cymbopogon refractus A. Camus Gramineae	Barbwire Grass	1·1	0·5
Grevillea montana R.Br. Proterceae		0·7	0·3
Dianella caerulea Sims Liliaceae		0·6	0·7
Lomandra longifolia Labill. Xanthorrhoeaceae		0·6	0·1
Melaleuca nodosa Sm. Myrtaceae		0·6	..
Various unidentified species		2·4	1·5
Compartment Total		113·1	53·0

APPENDIX 4

THE FUEL COMPLEX

Pre-burn fine fuels in lb per acre

Plot No.	Twigs	Needles	Green vege-tation	Cured vege-tation	Misc.	Total	Total in tons/acre
A0	616	2,421	658	3,465	912	8,073	3·6
%	7·6	30·0	8·1	42·9	11·3		
A2	3,388	938	477	3,243	685	8,731	3·9
%	38·8	10·7	5·5	37·1	7·8		
A4	1,677	1,533	403	2,532	1,461	7,607	3·4
%	22·0	20·1	5·3	33·3	19·2		
B0	1,171	1,972	659	2,005	1,280	7,088	3·2
%	16·5	27·8	9·3	28·3	18·1		
B2	1,154	1,290	432	2,463	10,32	6,372	2·8
%	18·1	20·2	6·8	38·6	16·2		
B4	1,460	4,268	477	2,159	1,954	10,318	4·6
%	14·2	41·4	4·6	20·9	18·9		
C0	824	1,868	386	3,012	562	6,652	3·0
%	12·4	28·1	5·8	45·3	8·4		
C2	643	2,117	338	1,570	684	5,353	2·4
%	12·0	39·5	6·3	29·3	12·8		
C4	1,938	2,543	637	1,346	1,211	7,676	3·4
%	25·2	33·1	8·3	17·5	15·8		
D0	2,478	4,281	299	2,369	1,120	10,547	4·7
%	23·5	40·6	2·8	22·5	10·6		
D2	1,000	2,325	542	2,319	912	7,100	3·2
%	14·1	32·7	7·6	32·7	12·8		
D4	2,246	2,818	280	1,257	2,015	8,616	3·8
%	26·1	32·7	3·2	14·6	23·4		
Compartment Mean	1,549	2,365	466	2,312	1,151	7,844	3·5
%	19·7	30·1	5·9	29·5	14·7	100	

APPENDIX 5

NUMBER OF TREES FOR EACH PLOT IN FIRE INTENSITY CLASSES

Plot No.	Fire intensity class (Btu's)									Total No. of trees
	1 0–25	2 26–50	3 51–75	4 76–100	5 101–150	6 151–200	7 201–250	8 251–300	9 301–400	
A2		4	6	10	4	13	53	24	30	144
A4	18	68	42	14	2					144
B2	37	100	4	5						146
B4		44	59	34	13					150
C2	38	55	29	9	6	9				146
C4	22	100	17	3						142
D2	23	98	26	2						149
D4	7	63	42	17	8					137
Total No. of trees	145	532	225	94	33	22	53	24	30	1,158
%	12·5	45·9	19·4	8·1	2·8	1·9	4·6	2·1	2·6	100

APPENDIX 6

BASAL AREA IMMEDIATELY AFTER BURNING (APRIL, 1969) AND BASAL AREA INCREMENT FROM APRIL, 1969 TO OCTOBER, 1970

(sq ft per acre)

	Blocks							
	A		B		C		D	
	BA	BAI	BA	BAI	BA	BAI	BA	BAI
Controls ..	37·46	16·34	41·69	15·89	46·96	15·79	56·60	18·58
2-year burn ..	29·61	3·66	41·04	13·96	49·13	13·09	53·82	14·33
4-year burn ..	24·13	9·92	38·45	12·11	48·68	13·99	54·24	10·56

COVARIANCE ANALYSIS FOR BASAL AREA INCREMENT (y) ON INITIAL BASAL AREA (x)

	f	Σx^2	Σxy	Σy^2	Deviations from regression		
					f	S.S.	M.S.
Overall	11	1,103·60	242·11	165·07			
Blocks	3	999·82	179·05	41·57			
Treatments	2	37·07	43·98	72·25			
Error	6	66·71	19·08	51·25	5	45·79	9·16
Treatment and error	8	103·78	63·06	123·50	7	85·18	
For testing adjusted means					2	39·39	19·70

Analysis of y separately:

	f	M.S.	
Treatments	2	36·13	f = 4·23 N.S.
Error	6	8·54	

Analysis of adjusted y:

	f	M.S.	
Adjusted treatments ..	2	9·16	f = 2·15 N.S.
Error	5	19·70	

Conclusion

There is no significant difference in basal area increment between the burnt and control plots for the 18 months following burning.

APPENDIX 7

COVARIANCE ANALYSIS OF BARK THICKNESS, 1971, ON BARK THICKNESS, 1969, FOR BURNT AND UNBURNT TREES

Class	f	a	b	Σx^2	Σxy	Σy^2	Deviations from regression		
							f	S.S.	M.S.
Unburnt	35	0·2427	0·8817	0·3659	0·3226	0·4782	34	0·1938	0·0057
Burnt	74	0·2296	0·8820	0·7024	0·5774	0·9560	73	0·4814	0·0066
							107	0·6752	0·0063
Within regression coefficients							1	0·0008	0·0008 N. S.
Combined	109			1·0683	0·9000	1·4342	108	0·6760	0·0063
Intercepts							1	0·0594	0·0594++
Overall	110	0·2329	0·8470	1·0696	0·9059	1·5055	109	0·7354	

Test of Regressions

(1) Unburnt trees:

Source	D.F.	S.S.	M.S.	F
Linear regression	1	0·2284	0·2284	31·2++
Error	34	0·2498	0·0074	
Total	35	0·4782		

(2) Burnt trees:

Source	D.F.	S.S.	M.S.	F
Linear regression	1	0·4745	0·4745	72·0++
Error	73	0·4815	0·0066	
Total	74	0·9560		

Conclusions

There is a significant difference in bark thickness increment between the sample of burnt trees (n = 75) and the sample of unburnt trees (n = 36).

APPENDIX 8

ANALYSIS OF VARIANCE FOR REGRESSIONS OF LITTERFALL AGAINST INITIAL BASAL AREA AND BASAL AREA INCREMENT, COMBINING BURNT AND UNBURNT PLOTS.

	n	$\overline{BA}$	$\overline{BAI}$	$\overline{L}$	a	b	r	Deviations from regression				
								df	S.S.	M.S.	F	Sig
1	12	35·781		21·920	2·414	0·545	0·825					
	Regression							1	251·54	251·54	21·067	**
	Deviations from regression							10	119·36	11·94		
	Deviations from mean							11	370·90			
2	12		20·890	21·920	7·670	0·682	0·576					
	Regression							1	123·05	123·05	4·964	*
	Deviations from regression							10	247·86	24·79		
	Deviations from mean							11	370·91			

BA = Basal Area, sq ft/acre at 9/68.

BAI = Basal Area Increment, sq ft/acre from 9/68 to 10/70.

L = Mean Annual Litterfall, × 100 lb/acre period 8/68 to 8/71.

Conclusion:

1. There is a significant relationship at the 1 per cent level between mean annual litterfall over 3 years and initial basal area.

2. There is a relationship just significant at the 5 per cent level between mean annual litterfall over 3 years and basal area increment measured over 2 years of that period.

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