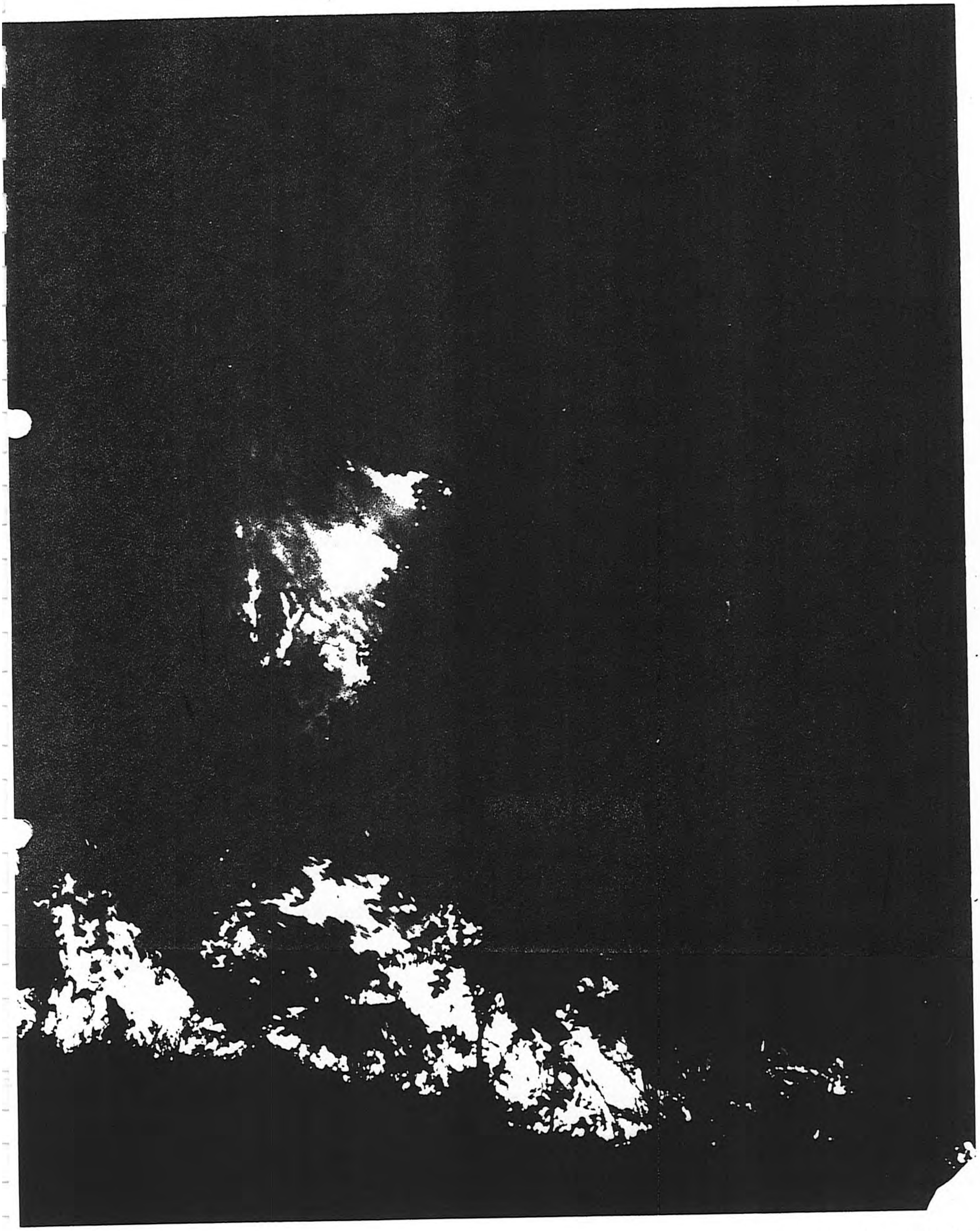
JARRAH FOREST FIRE; IT'S BEHAVIOUR & ACTIONS UNDER DRY FUEL CONDITIONS.
(A SMALL PLOT APPROACH)



FIRE RESEARCH '81

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JARRAH FOREST SMALL FIRE BEHAVIOUR UNDER DRY CONDITIONS

SUMMARY

The behaviour of small (2 ha) jarrah *(E. marginata)* forest fires under dry fuel conditions ($\leq 7\%$) is strongly influenced by wind strength, ambient temperature and relative humidity. Large forest fires under such conditions, have the potential to influence local fire weather (wind, temperature and R.H.), thereby influencing fire behaviour. Fast spreading, intense fires of the type often experienced under extreme conditions take a considerable time, and burn a considerable area, before reaching a steady state. For these reasons, the model presented may not be indicative of large, intense fires.

Single steady state fire behaviour models cannot be used to predict the fire behaviour and intensity of mass ignition, large area fires under dry conditions.

Moderate intensity fires of 1200 kwm^{-1} selected against large, mature individuals of the *Banksia grandis* population. Fire intensity, *per se*, was found to be unrelated to soil temperature which was a function of soil dryness and available litter fuel loading.

After 12 months, healthy jarrah stems of a diameter in excess of 40 cm (D.B.H.O.B.) showed minor fire damage following intensities of 1200 kwm^{-1}. Smaller stems were severely damaged or killed to ground level. Fire damage (drysiding) was visually assessed and accurate predictions as to the nett commercial loss cannot be made.

1. INTRODUCTION

This is the second and final report on a series of small plot studies aimed at;

a) increasing the reliability of predicting jarrah forest fire behaviour under dry fuel conditions.

b) determining the impact of summer fire on the *B. grandis* population.

c) determining fire and other characteristics which favour legume (esp. *Acacia pulchella*) regeneration.

d) determining damage to jarrah as a result of moderate intensity summer fires.

Initially this study was titled "Medium to high intensity jarrah forest fire behaviour", a vague title without some measure of intensity. It was envisaged that high rate of spread fires (500 - 1000 m/hr) under summer conditions would be studied but such fires proved elusive over the 2 year study period. This can be attributed to a) the small size of the experimental plots and b) the rare events of the severe fire weather necessary for a fast running headfire. Small plot fires lit by spot ignition under the rare severe fire weather conditions were accelerating as the fires burnt out of the plot. Time to reach a quasi steady state condition was shortened by lighting the plots using a line of fire rather than a spot. The second shortfall of small plot studies is that large, high intensity fires tend to modify the localised fire environment through spotting and more importantly, by advanced pre-heating and drying of the environment through entrained and ambient winds. Under dry fuel, summer conditions, minor changes in the dryness, temperature and particularly the magnitude of ambient and entrained winds, results in significant changes in fire behaviour, a poorly understood phenomenon characteristic of large summer fires.

2. METHODS

The methods employed were essentially the same as for the Harrington series, with the following modifications.

The fire perimeters of slow burning fires were mapped at 10 minute intervals and mean flame heights, flame lengths and flame depths were determined. The overall low spread rates experienced at Young Block resulted in some 6 plots being lit with two lines of fire. The object of this was to (i) obtain higher intensity fires to examine the response of *B. grandis* and soil temperature and to (ii) observe the fire behaviour of coalescing fires - as might be expected under a mass igntion system. Such fires were dealt with separately in analysis.

Chromel-alumel thermocouples connected to a multi-point data logger were used to measure soil heating in an attempt to determine factors contributing to soil heating for seed heat treatment. Within each plot, a 12m x 10m thermocouple subplot was located some 20 - 30 meters into the plot and 30 probes were inserted about 20 mm into the soil on a 2m x 2m grid (the actual depth was accurately measured). The heavily insulated cables were strung above the fuel bed to a junction point. From here the cable was laid on a mineral earth break to a multi-point recorder. It may have been desirable to trench the cable, ensuring its insulation , but to do so for some 900 m of cable would have been extremely time consuming. Such an exercise would have disrupted the fuel array.

2.1 Analysis of Data

Fire behaviour data from both Young Block and Harrington Block were pooled for analysis. Constantly changing wind velocity over relatively short durations (particularly with the Harrington series) hampered initial quasi steady state analysis, so noisy data ($> \pm 30^{o}$ changes in wind direction) were excluded from further analysis. Data were analysed by a number of computer programmes

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available in the Statistical Package for the Social Sciences (S.P.S.S.). This package provided frequency distributions simple correlations, partial correlations, means and variances for stratified sub populations, scattergrams, canonical correlations and multiple regressions which greatly simplified data handling. Through sub-programme breakdown, the means and variances of selected dependent variables (such as rate of spread, flame height etc.) were provided for various sub-groups from the sample data (such as wind speed, relative humidity etc.). This enabled an examination of the rate of change of dependent variables as one or more independent variables were varied.

PLATE 1: Layout of Harrington Plots

Multiple regression provided a description of the structure of linkages between dependent variables and independent variables in an 'ordered' fashion - with the most 'causal' variables heading the pathway and the less 'causal' variables stepped in later. The results of data analysis are presented, culminating in a working model for predicting the behaviour of fire under the experimental conditions (App. 1).

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3. RESULTS & DISCUSSION

FIGS. 1 - 6 FREQUENCY DISTRIBUTION

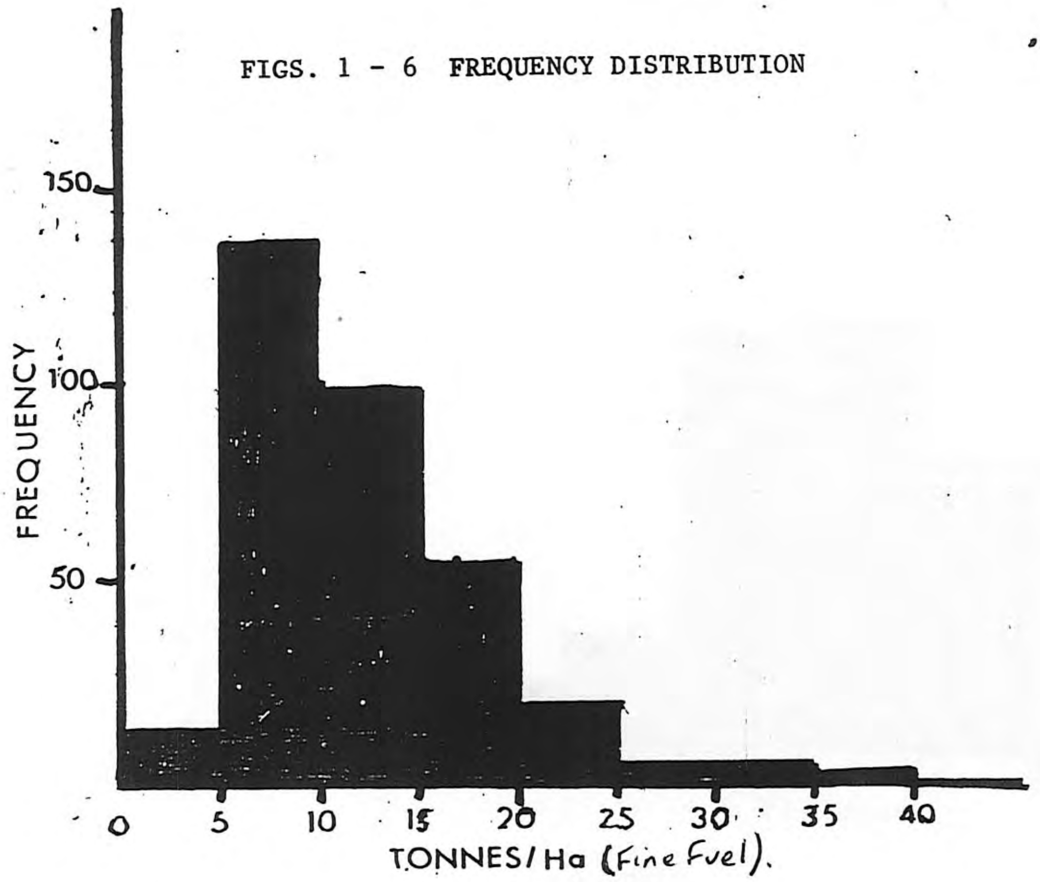

FIGURE 2

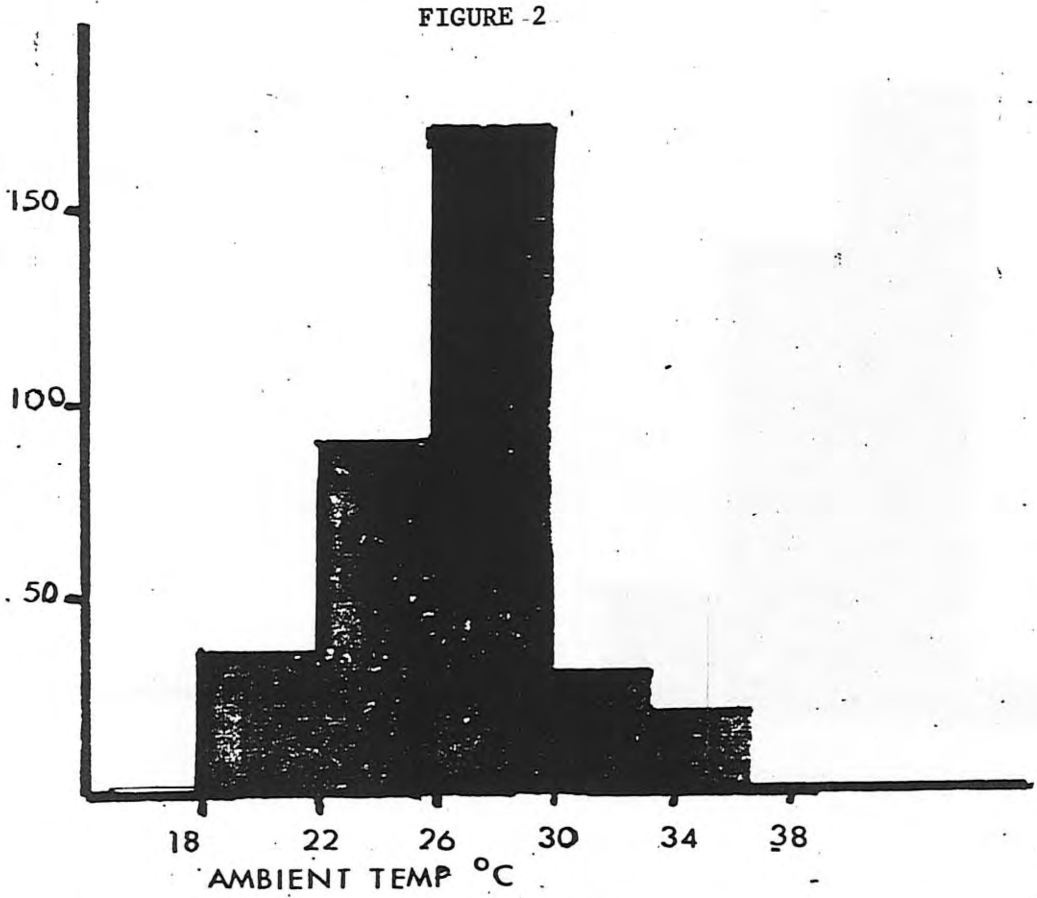

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FIGURE 3

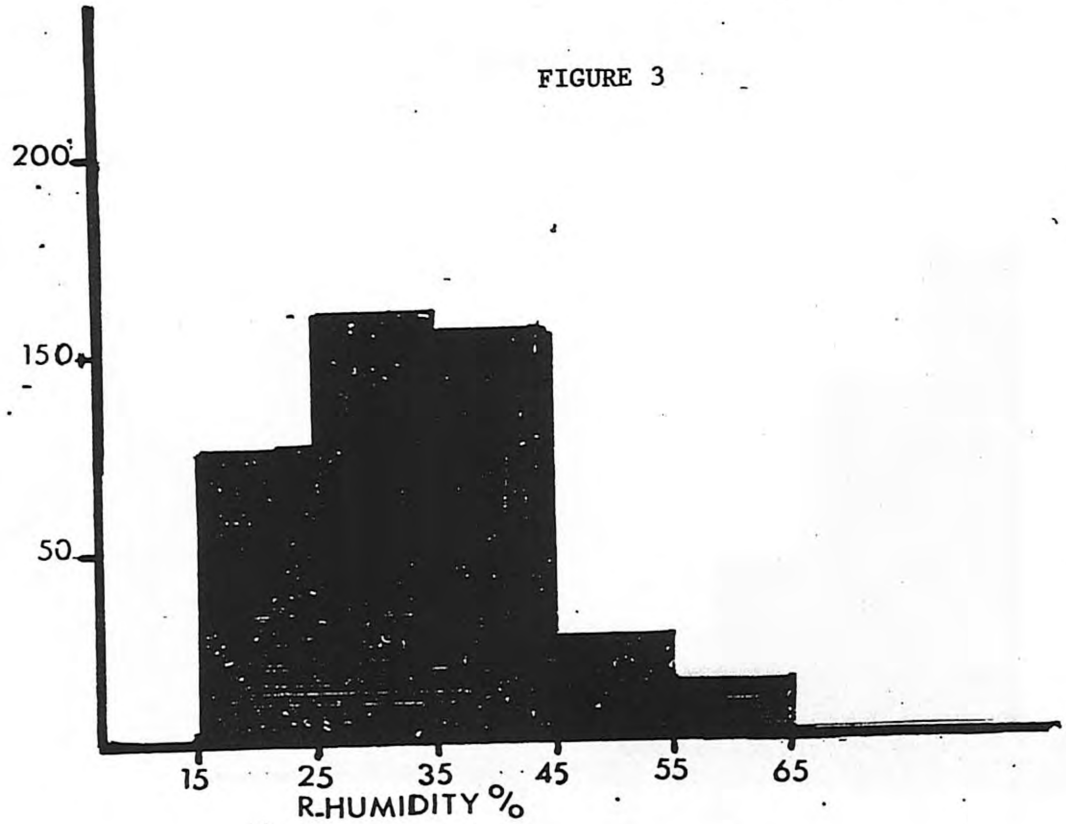

FIGURE 4

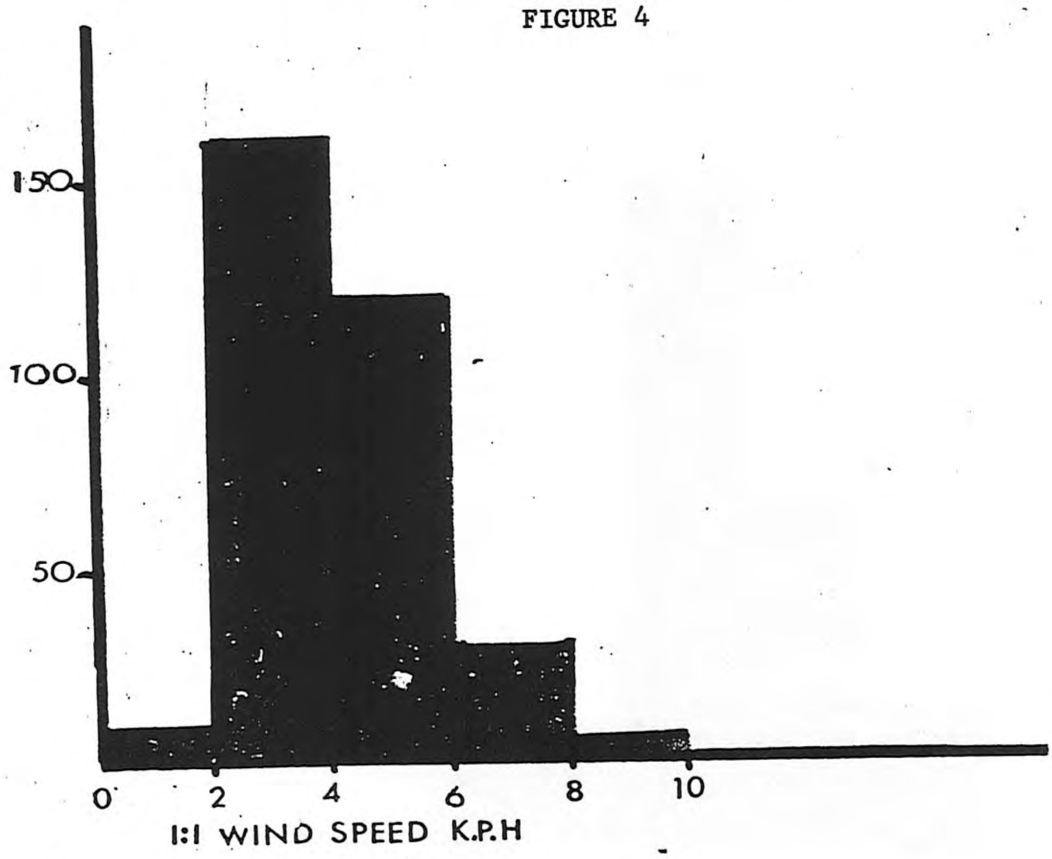

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FIGURE 5

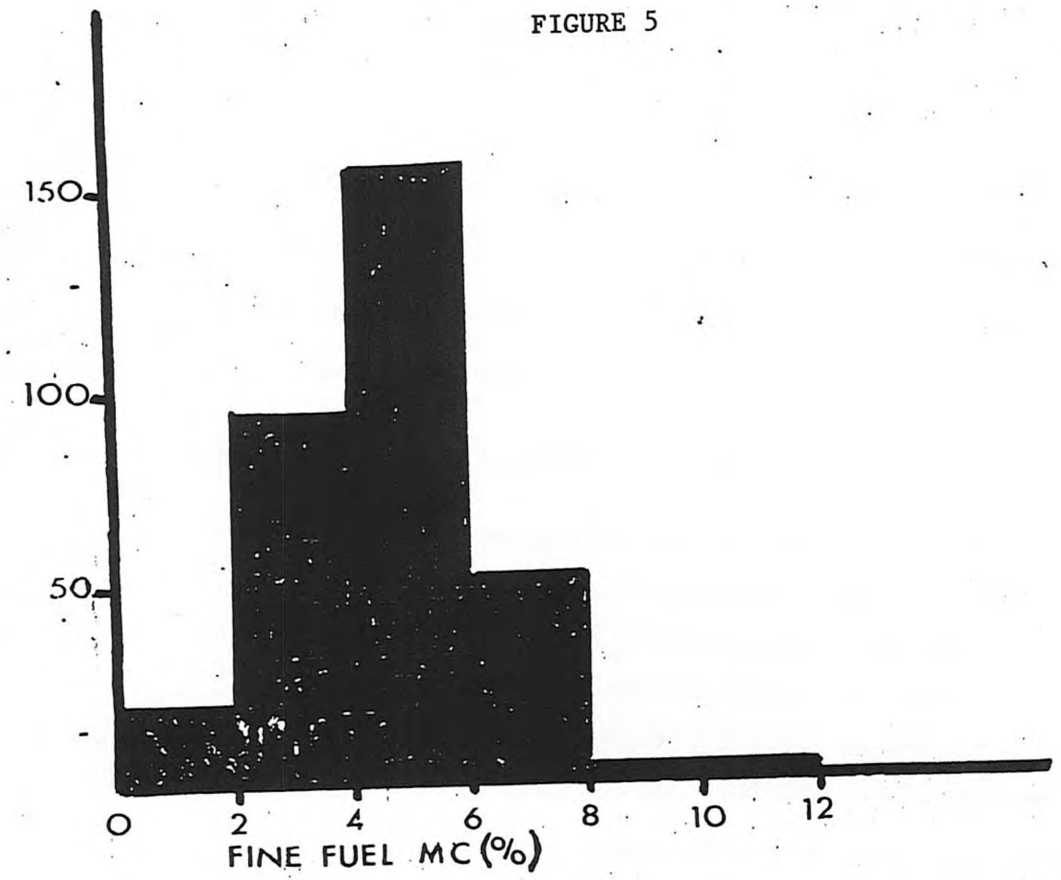
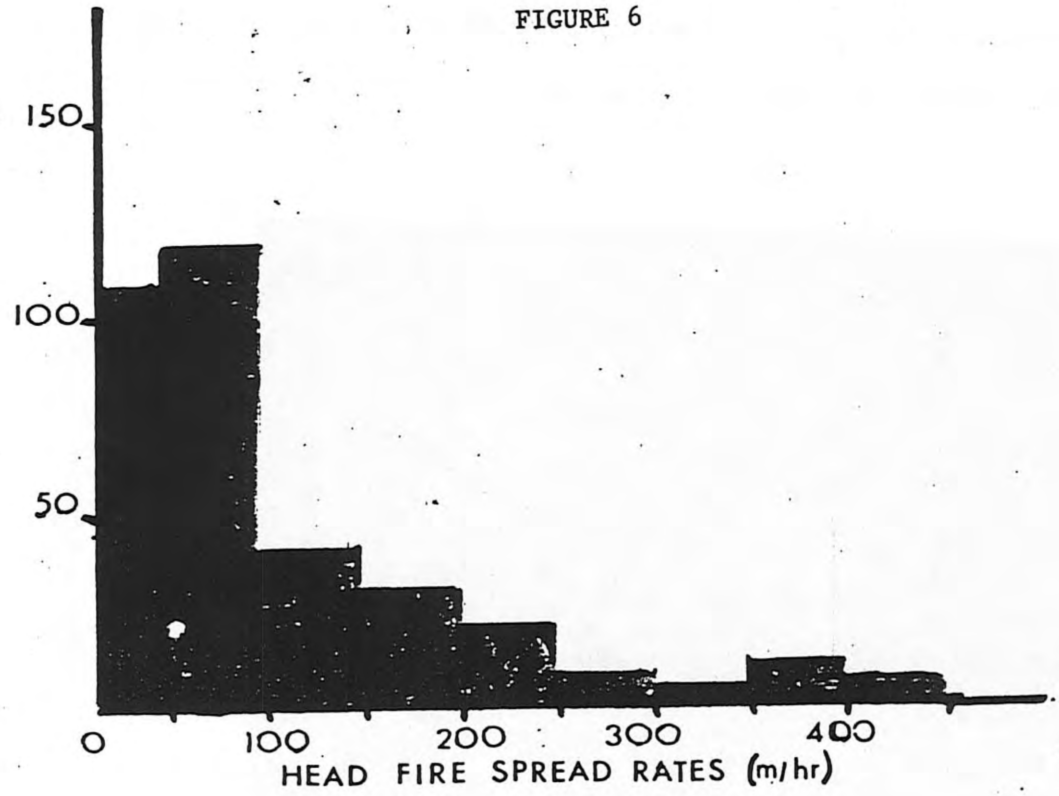


FIGURE 6



3.1 Dependent Variables

3.1.1 Headfire Rate of Spread (H.F.R.O.S.)

The multiple regression technique was used to analyse the relationship between H.F.R.O.S. and a set of independent variables. This technique described the linear dependence of one variable on others and disclosed the best linear prediction equation and its prediction accuracy. Using H.F.R.O.S. as the dependent variable, the best fit line was determined to be;

$$\ln(\text{H.F.R.O.S.} + 1) = .44V5 + .023V3 + 0.018V6 - .002V4 + 1.60 \quad \text{- Equation 1}$$

Where H.F.R.O.S. = headfire rate of spread (m/hr)
V5 = wind speed (km/hr) at 1.5m above ground
V3 = ambient temperature - T (^{o}C)
V6 = fine fuel moisture content (M.C.)
V4 = relative humidity (R.H.)

The prediction equation above displays the variables in order of importance or in the order in which they account for variance - the first mentioned variable (V5) accounting for the greatest amount of variance in H.F.R.O.S. etc. The variable which explains the greatest amount of variance in conjunction with the first, is entered second etc. Equation 1 accounted for 74% of the variation in H.F.R.O.S.

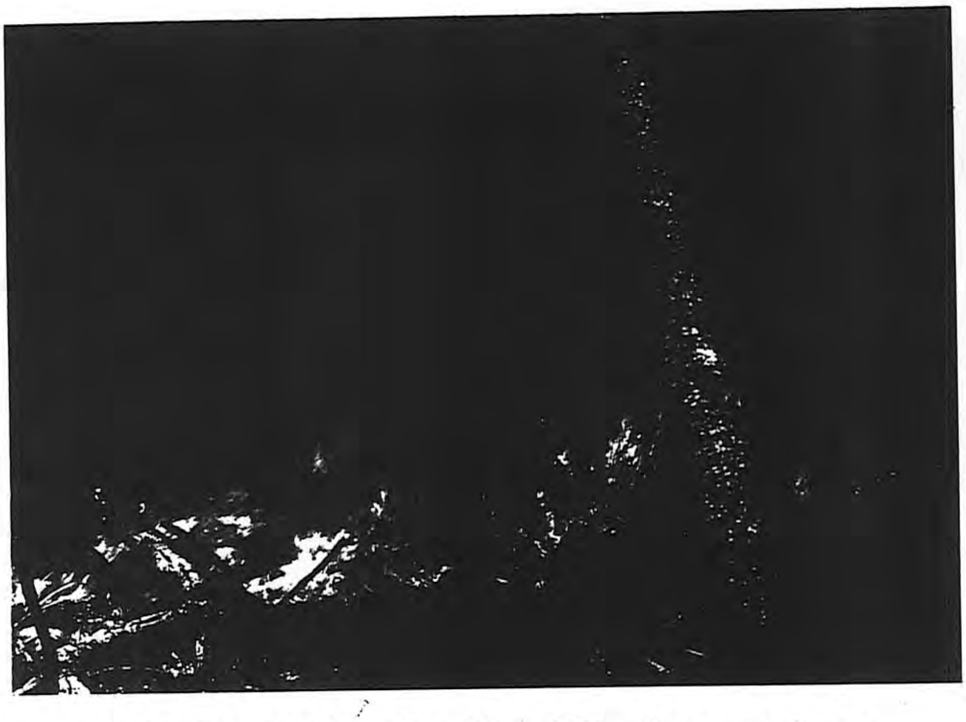


PLATE 2: Accelerating fire following a wind gust

As might be expected, V5 wind speed accounted for most variation in H.F.R.O.S. V3, ambient temperature explains the greatest amount of variance in conjunction with wind speed. Unexpectedly, V6 - M.C. has a positive correlation. This is unexpected in that temperature is negatively correlated to relative humidity which is in turn, positively correlated to fuel moisture content. It is remotely possible that this multi-collinearity is sufficiently strong to prevent the unique determination of the coefficients involved. If this is so, then using only one of the variables (Temperature) would be sufficient to represent the common underlying dimension. Another possibility for the positive coefficient of M.C. is that a high proportion of the 329 samples were burnt under conditions of mild temperatures - see fig. 2 and low dew points (low R.H.) which resulted in dry fuels. A significant positive correlation was identified between temperature and wind speed which, together with low ambient temperatures resulted in low rates of spread, thereby underestimating the importance of fuel moisture content. A third explanation is, *ceteris paribus*, moisture content and H.F.R.O.S. are positively related. There is overwhelming evidence (Rothermel, Anderson, etc., 1966) to refute this.

Rate of spread may then be expressed by;

$$\ln(\text{H.F.R.O.S.} + 1) = .45W + .022T + 1.64 \quad \text{- Equation 2}$$

where; $R^2 = .74$

SEE (standard error) for;

$W = .016$

$T = .006$

$C = .16$

Ambient temperature is the common underlying dimension of fuel surface temperature, fuel dryness and relative humidity.

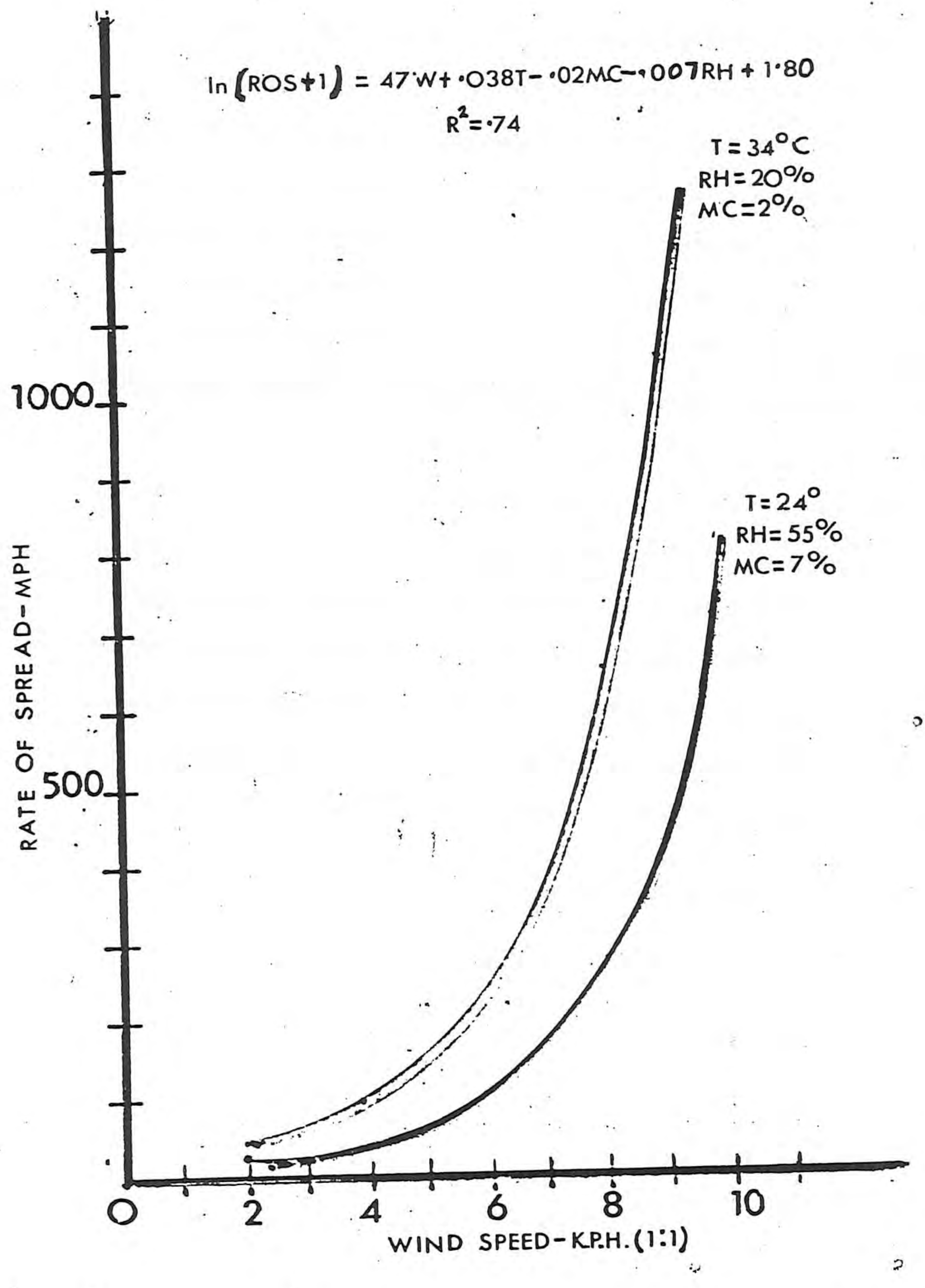


FIGURE 7 R.O.S. & its relationship with Temperature, M.C., R.H. & Wind

PLATE 3: Low intensity fire typical of low wind conditions

It may be helpful to consider the process of fire spread at this stage. From Rothermel (1972), heat is supplied from the flaming zone to the fuel. The fuel surface is dehydrated and further heating raises the surface temperature of the fuel until the fuel begins to pyrolyze, releasing combustible gases. When the gas - air ratio can support combustion, flames ignite the gas and the fire advances. This results in a constant rate of spread where the fire advances at a rate which is the average of all the constituent rates.

In the low wind situation the flame height/length ratio is near unity (Plate 3). The spread rate is low. The flame direction (vertical) indicates the direction of the convection, so fuel bed pre-heating is essentially as a result of radiant heat only. This supports Rothermel, who found that fuel temperatures rose slowly in the no or <u>low</u> wind situation (see fig. 8). Rothermel also states that while fuel particles are being heated by radiation they are also being cooled by convective indraughts. Fuel ignition (through the ignition of pyrolyzed gases) only occurs when the flame is within a few centimetres.

This explains the 'threshold' effect of fires burning under no wind or low wind conditions (see Plate 3).

Considering the process further, from fig. 8 it can be seen that as the wind speed increases (and flame length / flame height is > 1) the temperature of the fuel bed rises sharply, well in advance of the headfire. This results in exponential spread rates (fig. 7). Wind in excess of the threshold, reduces the angle of the flame to the fuel bed, increasing the propagating heat flux by exposing the fuel to increased radiant heating. Smoke and flame direction indicate that convective heating also adds to the heat flux. Thorough mixing of the pyrolyzed gases with warm air from convective turbulence may also contribute to more rapid combustion.

The fire spread process is, therefore, very dependent on the total heat flux. From equations 1 & 2, ambient temperature is important in determining spread rate. For a given heat flux, the nett spread rate is deterimined by ambient (temperature, relative humidity and wind) and fuel conditions (bulk density, packing ratio, moisture content). Moist fuels require a longer duration of heating (to drive off moisture) before pyrolyzing and finally igniting. However, equation 1 indicates that for the fuel moisture content ranges experienced in this study, fuel moisture content alone does not account for much variation in rate of spread (see fig. 10). That is, at low fuel moisture contents (3 - 7%) it is possible that ambient conditions associated with low moisture contents are more important than fuel moisture content changes between 3 & 7%. The propagating heat flux is likely to raise the temperature of the fuel bed at greater rate when ambient temperature conditions are high, there being a reduced heat differential. Relative humidity may also impede radiant heating. It is also possible that relative humidity inversely effects the ignition time and combustion rate (through the presence of moisture) of the pyrolyzed gases. An inability to instrument this precludes presenting conclusive data.

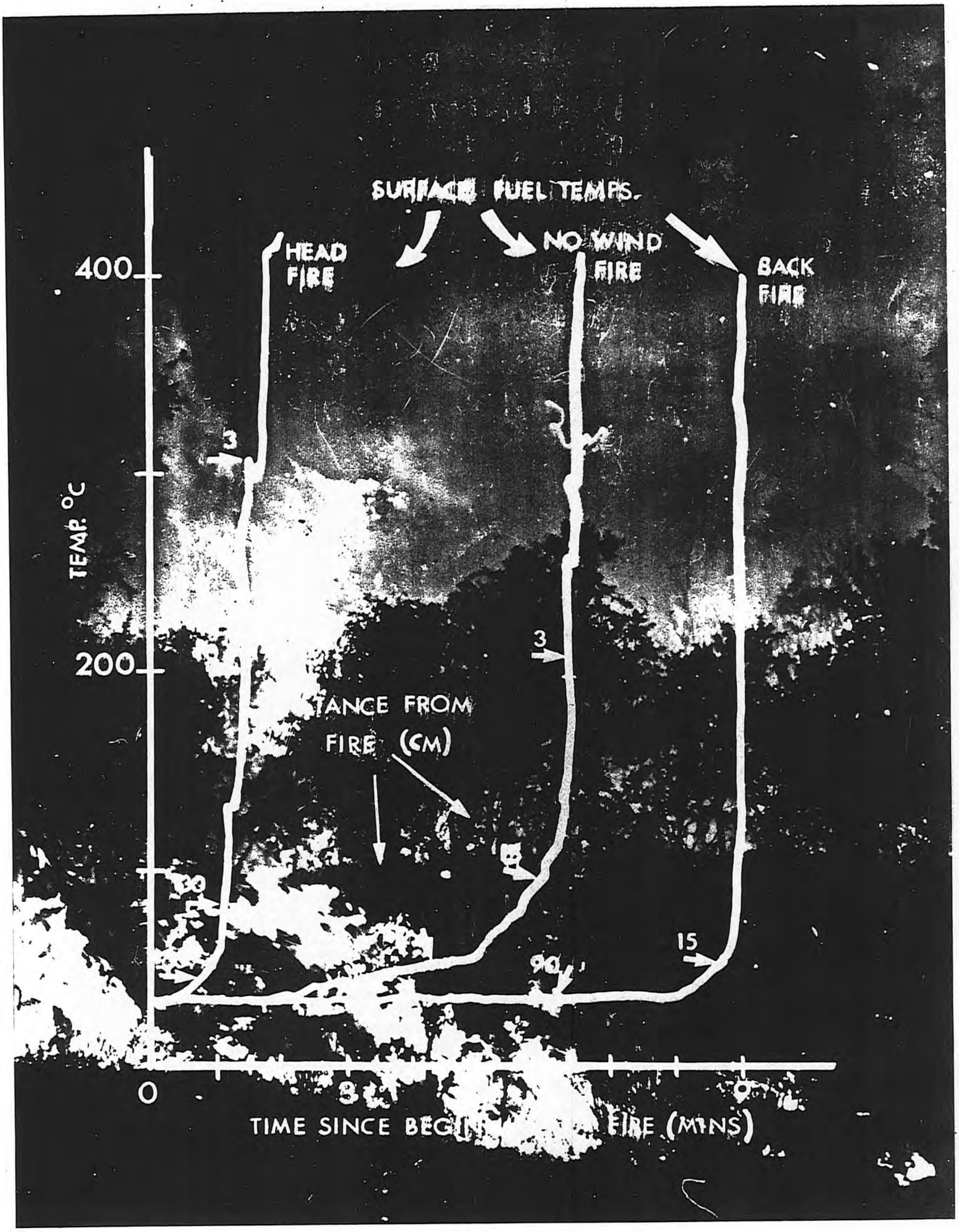


FIGURE 8: Time vs Surface fuel temperatures for various fires

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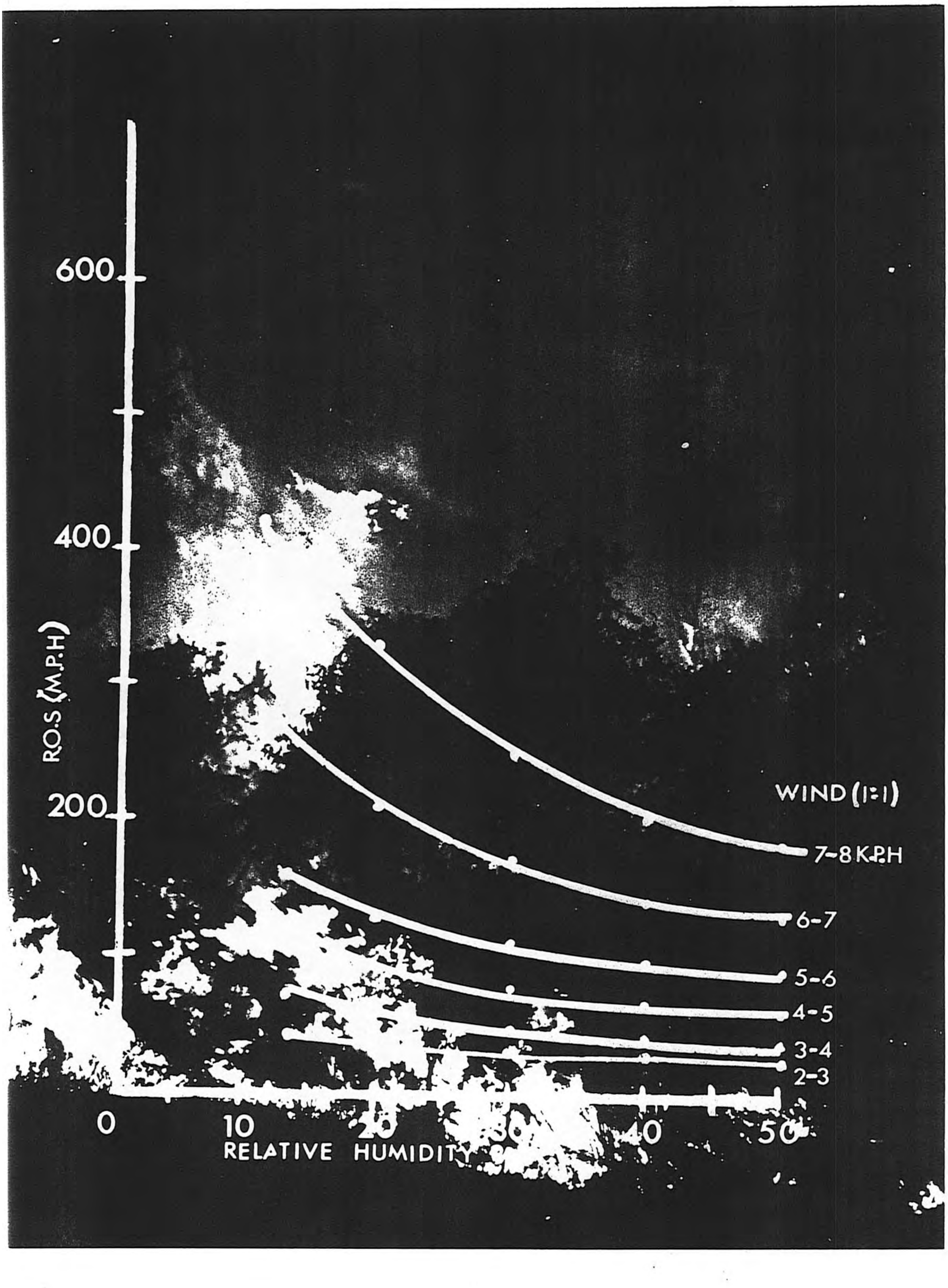

FIGURE 9: R.H. vs R.O.S. & wind speed

The standard errors of the estimated coefficients in equation 1, are statistically insignificant. The 95% Confidence Limits (C.L.) illustrated in Fig. 10 present an unacceptable range of spread rate estimates. If 95% confidence limits for each coefficient are examined to produce the upper 95% C.L. for H.F.R.O.S., then equation 1 becomes;

$\ln(\text{H.F.R.O.S.} + 1) = .476W + .038T - .02\text{M.C.} - .007\text{R.H.} + 1.80$ - Equation 3

From equation 3, fine fuel moisture content is, conventionally, inversely related to headfire rate of spread albeit minutely. However, the combined effect of temperature, moisture content and relative humidity substantially effects headfire rate of spread, *ceteris paribus*.

Equation 3 above, has been used to develop the rate of spread index (App. 1). Wind and temperature midpoints were used to generate the spread rates for each class. It is considered a safeguard to use the upper 95% confidence limits of coefficients determining H.F.R.O.S. To facilitate the ease of using the table, fuel moisture content is expressed by an underlying dimension, relative humidity. For the given temperatures, the effects of moisture content and relative humidity have been united and are expressed under the relevant dew point classes with relative humidity and fine fuel moisture content being generated from the lower class range. For example, for an expected maximum temperature (T) of 31°C and a calculated dew point of 10°C; minimum relative humidity = 25%. We found that;

Fine fuel $\text{M.C.} \approx \dfrac{\text{R.H.} - 15.9}{3.5}$ (for the conditions of this study) - Equation 4

$\therefore \text{M.C.} \approx 3\%$

These values (R.H. & M.C.) have then been entered into equation 3 to generate a spread index of 75 metres per hour for a forest wind of 3.8 km/hr at 1.5m above ground (1:1).

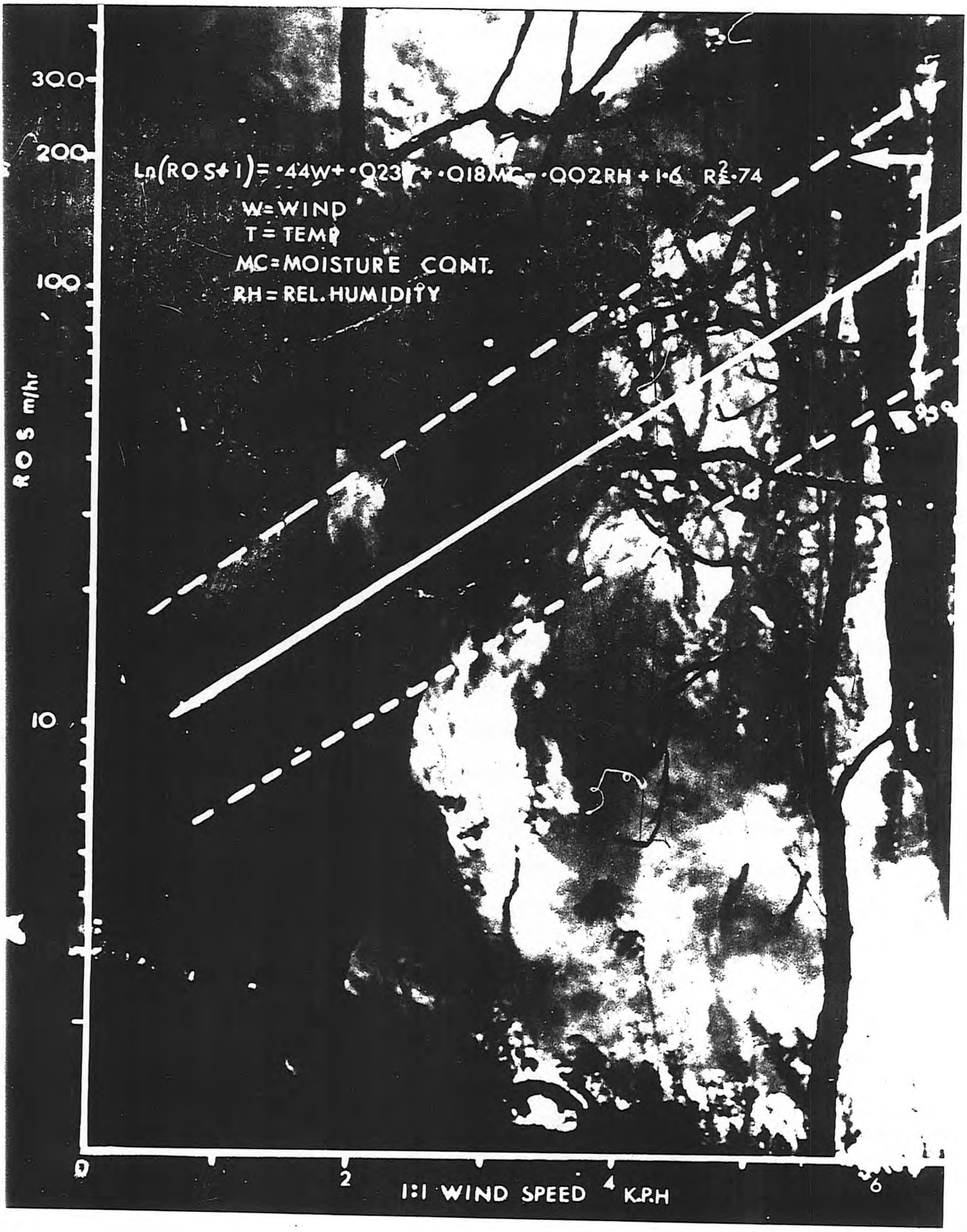

FIGURE 10: 95% C.L. R.O.S. function

As mentioned, for conditions of this study, combinations of temperature, relative humidity and fine fuel moisture content are important in determining spread rates. Therefore, these equations and tables should not be used when conditions of temperature, relative humidity and particularly fuel moisture, are external to this study. For such conditions, the Forest Fire Behaviour Tables for Western Australia should be used. As there were only 11 cases out of 329 where the fine fuel moisture content exceeded 7%, it is recommended that these tables are used only when; 3% $\leq$ fine fuel moisture content $\leq$ 7%. For cooler, moister conditions, the Forest Fire Behaviour Tables should be used.

3.2 Independent Variables

3.2.1 Fuel

3.2.1.1 Litter Fuels

A spreading fire is a series of particle-to-particle ignitions where the energy necessary for propagation has its source within the combustion zone (Fons, 1946).

Although fire spread is attributed to particle-to-particle ignition, the intervals between ignitions for a continuous fuel bed are averaged over time to obtain a rate of spread representative of that fuel array. This average rate of spread can then be related to the average fuel bed properties. A quasi steady state exists if a constant spread rate is achieved. This was rarely perfectly achieved except at low rates of spread, mainly as a result of continually fluctuating wind velocity at the high spread rates. However, over time, all components were averaged, including rate of spread, and a quasi steady state was assumed to exist.

The rate of fire spread through a fuel array depends on static fuel parameters β, ρ_p, Q_{ig}; and the dynamic source function, I_R, (Rothermel, 1972, Frandsen, 1973 & others).

Such that; $R_o = \dfrac{\xi I_R}{\varepsilon \rho_b Q_{ig}}$ where R_o = spread rate - no wind situation.

Where ξ is the efficiency of converting total reaction intensity, I_R, to propagating intensity, I_ρ - the proportion of intensity driving the fire (Rothermel, 1972) and where;

ε = effective heating number
β = $\frac{\rho_b}{\rho_p}$ = packing ratio (ρ_p - bulk density of fuel particle)
ρ_b = oven dry bulk density of fuel array
Q_{ig} = heat of pre-ignition

For the litter bed fuels in this study, β was assumed to be constant for fuel beds composed of litter from similar plant species. On this basis, the following classes of litter fuels were recognized.

			ABSOLUTE FREQUENCY (Harrington series only)
Uniform	1.	Jarrah-marri	392
	2.	Casuarina	73
	3.	Banksia grandis	17
	4.	Hibbertia hypercoides	1
	5.	Ti-tree	1
Non-uniform	6.	Tops	2
		TOTAL	487

For analysis, litter beds were coded according to the above. Oven dry particle densities, heat of ignition and packing ratio within each coded type were assumed to be constant. Total fuel quantity and moisture content were the other litter fuel parameters measured.

The 20m x 4m belt transects from which fire behaviour was also sampled and averaged, did not always fall clearly into one of the litter types. *Casuarina* litter types and *B. grandis* litter types tended to occur as pockets or islands within the jarrah-marri dominated types. In Dwellingup however, it was not unusual for *B. grandis* types to occupy considerable areas sufficient to influence fire behaviour.

Visually, both *Casuarina fraseriana* and *B. grandis* litter types burned more ferociously than the jarrah-marri litter fuels. Both flame heights and rates of spread were increased. This was due to the high fuel loading (tonnes/ha) and to the greater surface area-to-volume ratios accompanying these fuel types. On drying to low moisture contents ($\leq 7\%$) the leaf components of the *B. grandis* fuel bed tend to curl and twist, considerably increasing the volume (surface area) of the fuel bed. In short, forests containing dense stands of *B. grandis* present a more severe fire hazard than a jarrah forest on a similar site but with a reduced *B. grandis* population.

Analysis to this stage has not allowed conclusions to be drawn as to the precise nature of influence of different litter types on fire behaviour. There are many reasons for this, including the subjectivity of typing litter beds, which for the most part, do not show clear cut offs. At the commencement of this study, litter typing was not emphasized so the criterion for such was left to each assessor to type according to what he felt made up the bulk of the litter. The physical and chemical constitution of the litter bed is a reflection of the vegetation from which it was derived. An attempt at delineating vegetation types proved more successful in absorbing fire behaviour variation than simply typing the litter bed. This will be discussed further under a separate heading.

A multiple linear regression with H.F.R.O.S. being the criterion variable, attributed a small amount of variation in H.F.R.O.S. to litter depth (which was converted to tonnes/ha using litter depth - weight relationship). The variation in H.F.R.O.S. attributable to litter depth was lost when the regression was transformed using ln (H.F.R.O.S. + 1). The upper 95% confidence level for the coefficients of the linear regression are;

$$\text{H.F.R.O.S.} = 50W - 1.33\text{R.H.} - 1.1\text{M.C.} + 1.0T - 86 \text{ - Equation 5}$$

Litter quantity did not reveal itself to be accountable for much variation in spread rate, probably because of its continuous nature and an inadequate sampling intensity within the subplots. Conversely, it might be argued that there was very little (in terms of spread rate) variation in fuel loadings in the plots examined (see fig. 1). The very small size of the subplots would also mask the contribution of litter weight to spread rate. A fast spreading fire, on running into a subplot (20 m long) with a reduced litter loading showed no appreciable reduction in spread rate. The retarding effect (if in existance) was not detected over the short distance. Unless plots are uniform in fuel loading, and a quasi steady state is quickly reached, it would be difficult to measure and attribute spread rate variation as a result of changing fuel loads, unless such changes were dramatic, which is rarely the case. The spread index (App. 1) is that calculated for litter fuels between 8 - 10 tonnes/ha. Fuel correction factors used in Table 2 are based on both the Forest Fire Behaviour Tables and observations made during this study. Controlled environment studies should confirm these factors.

The effect of fuel loading on spread rate revealed itself further when a second analysis controlling for temperature, selecting low spreading fires (≤100 m/hr) and pooling the behaviour data for various fuel loading classes was initiated.

The various fuel loadings apparently have little effect on low spread rates. This is not the case when functions are extrapolated to higher spread rates.

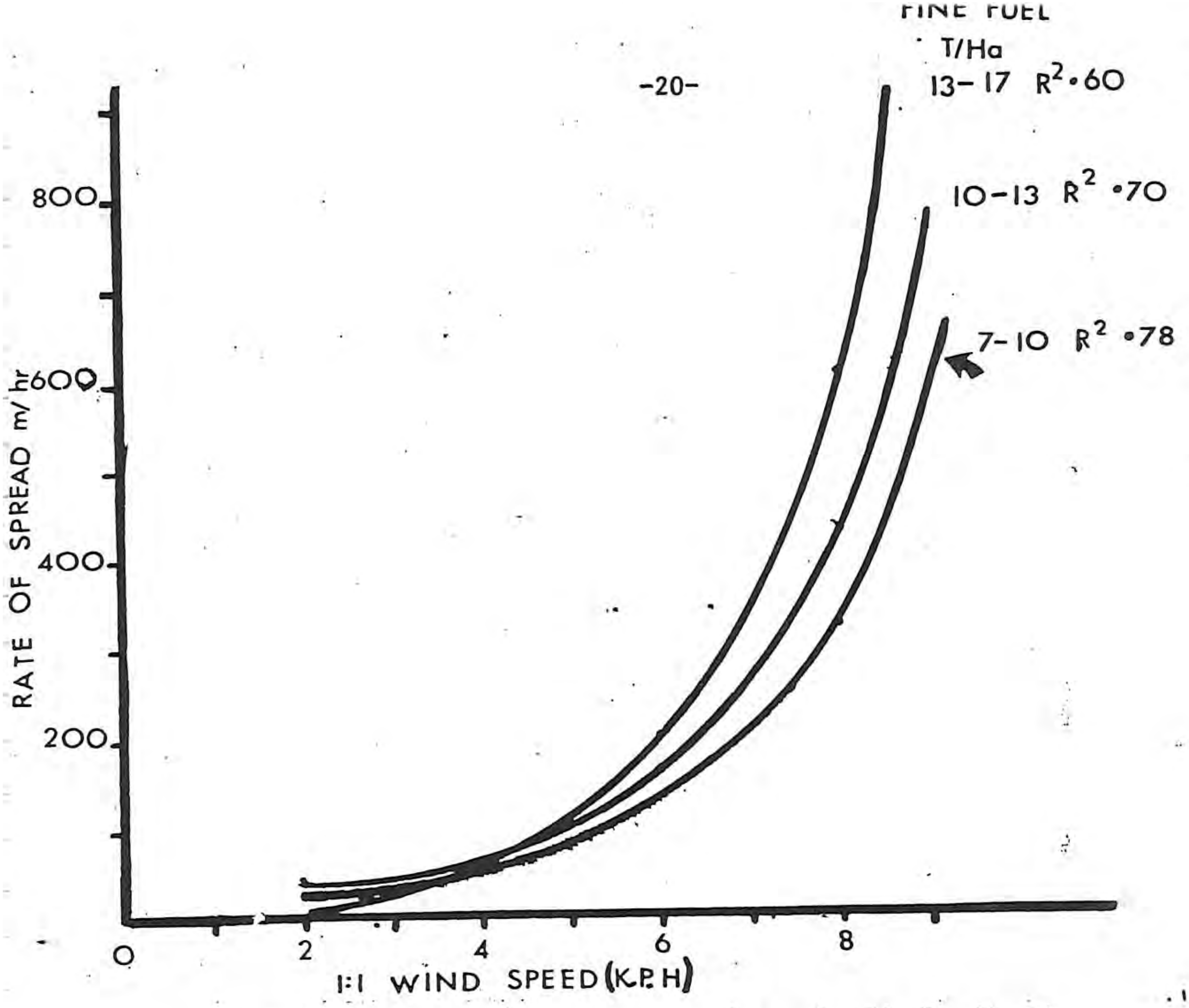

FIGURE 11: Influence of fine fuel loadings on R.O.S.

During experimentation, every effort was made to allow fires to approach a quasi steady state. In many instances, plots were ignited by a line of fire and allowed to burn freely for up to 50 metres before being monitored. The gustiness and directional variability of wind made it difficult to identify a quasi steady state, particularly at high spread rates (>200 m/hr). The consistent spread rates determined for very slow moving fires (<50 m/hr) was a sure sign of a quasi steady state having been reaching. Cheney (1979) states that fast travelling headfires could take up to two hours to reach a steady state. This would require experimental plots to be up to 1 km. This 'pulsating' effect, highly noticeable on faster moving fires, may prohibit the explanation of any more than about 74% of the variation in headfire rates of spread under small plot experimentation. This should be borne in mind throughout the remainder of this discussion. As stated in an earlier report, the results of this study show fire behaviour to be slightly lower than estimated for by the "Red Book" at low wind speeds and higher than the "Red Book" estimates at high ind speeds. Large scale (≈100 ha) studies are required to confirm large fire ehaviour under dry fuel conditions.

.2.1.2 Vegetation (Scrub)

The litter bed contributed most (by weight) to fueling forest fires (in hese experiments). Its position in the fuel ladder (base), dryness, quantity nd, very importantly, its continuity combine to make this fuel the cornertone. Vegetation is an extension of the litter bed fuel and is, in the lemental state, the most variable. Vegetation types in the jarrah forest tudied here, contributed between 0.5 - 5 tonnes/ha of available fuel, with the ost common fuel loading being near 1.5 tonnes/ha. It was beyond the resources f this study to measure the pyro-characteristics displayed by the vegetation ithin each of the 329 plots. Unlike a uniform litter bed, packing ratio, urface area-to-volume ratios, bulk density, total biomass and spatial istribution (in all dimensions) and chemical constitution are highly variable n the vegetation fuel array. A pilot test to assess the suitability of neeuwjagt's (1976) levy rod technique resulted in the technique being unfavourble because of the extremely high sample intensity necessary to obtain a onfident representation (if in fact, one exists). Attempting to describe the yro-botanical features of a 80 m^2 subplot is not an easy task. It is probably ore difficult than attempting to classify or describe the standard botanical eatures in that other important features of pyro-botany include quantity and ontinuity or spacial distribution. Havel (1975) discusses the difficulties of electing methods for classifying vegetation. Havel states that if vegetation s continuous and therefore cannot be classified, then the only alternative is rdination on environmental ordinates or on ordinates generated from an analysis f vegetation. The greater the degree of discontinuity of the vegetation fuel rray, the less influence it will have on quasi steady fire behaviour. A eduction in continuity usually results in a reduction of other pyro-botanical eatures (over an area) such as quantity of available fuel. It follows then, that highly discontinuous and sparse vegetation has a diminishing yet increasingly difficult to measure effect on fire behaviour and intensity.

Where vegetation spacial distribution (horizontal plane) was greater than subplot size (80 m^2) then its effect on fire behaviour was likely to be minimal. Being aware of the pitfalls of classifying vegetation into discrete types, the vegetation within the subplots was classed on the basis of the presence or absence of indicator species (McCutcheon & Havel) and with added features such as topographical location and soil type. No provision was made for transitions or mixed types. Where these were encountered a subjective assessment was made as to its 'class', aided by a subjective assessment of pyro-botanical features. As the fire behaviour plots were clumped together within the two locations, rapid, macro vegetation changes were not obvious. There was a degree of variability of a) species association b) fuel continuity and c) fuel quantity (vegetation fuel) between the subplots of given vegetation types. Of the 720 subplots (of which not all were used for fire behaviour analysis - only 329) which were concentrated in an area of about 90 ha, 2 vegetation types emerged, a third category being created for the many subplots in Young Block which contained <10% ground cover of vegetation (high spacial distribution therefore, declared of no significance in terms of a fuel). A visual assessment, supported by a small number of biomass samples, suggested that there existed a greater 'between type' variation of pyro-botanical features than 'within' types. It was beyond the scope of this study to measure and compare the pyro-botanical continuum either at the ordination or classification level. It is envisaged that this will be attempted at a later date.

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PLATE 4: An example of Vegetation Type CD (DC)

PLATE 5: Typical Vegetation Type G

Vegetation type 0 (coded 0) existed where there was a complete break down of (scrub) vegetation fuel continuity (subjectively placed at <10% cover). As mentioned, the continuity of a fuel can only be in relation to the condition of the fire determined by other factors - something akin to a bend in the higway - taken at a slow speed, it is a harmless and easily negotiable bend - taken at high speed it becomes dangerous. For the purpose of the study, vegetation type 0 was solely a litter bed fuel complex. Vegetation classed as type G (Plate 5) (coded 3), was often found on upper slopes and gravelly soils. Species present (or absent) varied, but subplots containing sufficient abundances of species such as *Adenanthos barbigera, Hibbertia montana, Tetratheca setigera, Isopogon sphaerocephalus* and *Leucopogon capitellatus* were placed into this category. Generally, this fuel type was further typified by being moderately continuous, (40 - 60% ground cover) moderately uniform in bulk density, was generally about 0.4 m high and added 2.10 ($\bar{x}$) tonnes per hectare of available fuel - available over all range of fire intensities under summer, dry fuel conditions. This type contained pockets of *Casuarina fraseriana* and thickets of *Banksia grandis* (Plate 5), which contributed greatly to the litter bed fuels. Where such pockets were isolated and small, the effect on the behaviour of the running fire was isolated and short-lived, although very often, spectacular. While such vegetation types contributed little to fire behaviour, they were often associated with heavier eucalypt litter bed loadings. This tended to reduce further, the proportional contribution to combustion of the understorey vegetation. *Ceteris paribus*, the greatest impact of this vegetation type was probably its slight stiffling of ambient winds. It should be pointed out that all experimental plots had been burnt under typical, mild spring conditions some 6 years prior to this study. It is highly unlikely that there would have been any consequential species changes or that the vegetation was undergoing dynamic vegetation association changes but it is not known to what degree the post burn biomatter productivity rate had stabilized following the post fire growth burst. Biomass samples taken some <u>21 months</u> after burning yielded the following;

TABLE 1

VEGETATION TYPE & BIOMASS (TOTAL)

	VEGETATION TYPE			
	G		CD (DC)	
	CONTROL	TREATMENT	CONTROL	TREATMENT
No. Samples ($1m^2$)	15.0	37.0	15.0	24.0
$\bar{x}$ Biomass (T/ha)	2.40	1.84	5.6	3.01
S. Error	.18	.16	.31	.24

Control = 8 years since burning

Treatment = 21 months since burning

Vegetation classified as CD (Plate 4) contained abundances of *Adenanthos obovata, Agonis parviceps, Dasypogon bromeliaefolius, Agonis linearifolia, Pultenaea reticulata, Adenanthos meissneri, Leptospermum crassipes* and *Xanthorrhoea preissii*. Generally, this vegetation was more continuous than type G and had an average height of 1 m - ranging up to 2 m in dense thickets of *A. parviceps*. The average scrub loading prior to burning was 5.2 T/ha. These associations were frequently located on the lower lying, poorer drained sites of the study. Associated with this vegetation was a considerably lower litter bed accumulation, which became very sparse and consisted of only scrub species litter in some patches.

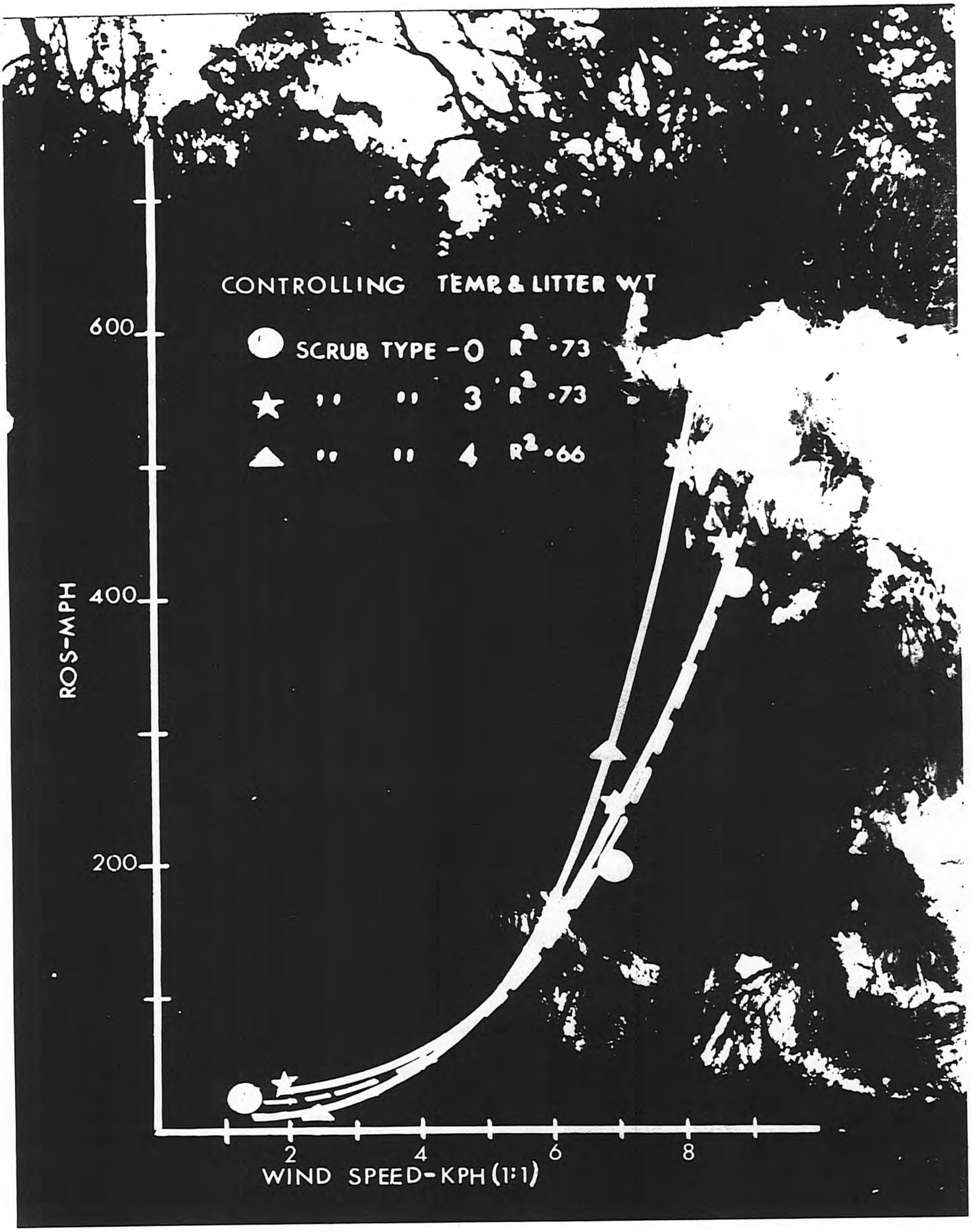

FIGURE 12: R.O.S. for various scrub types where 3 = type G & 4 = type CD(DC)

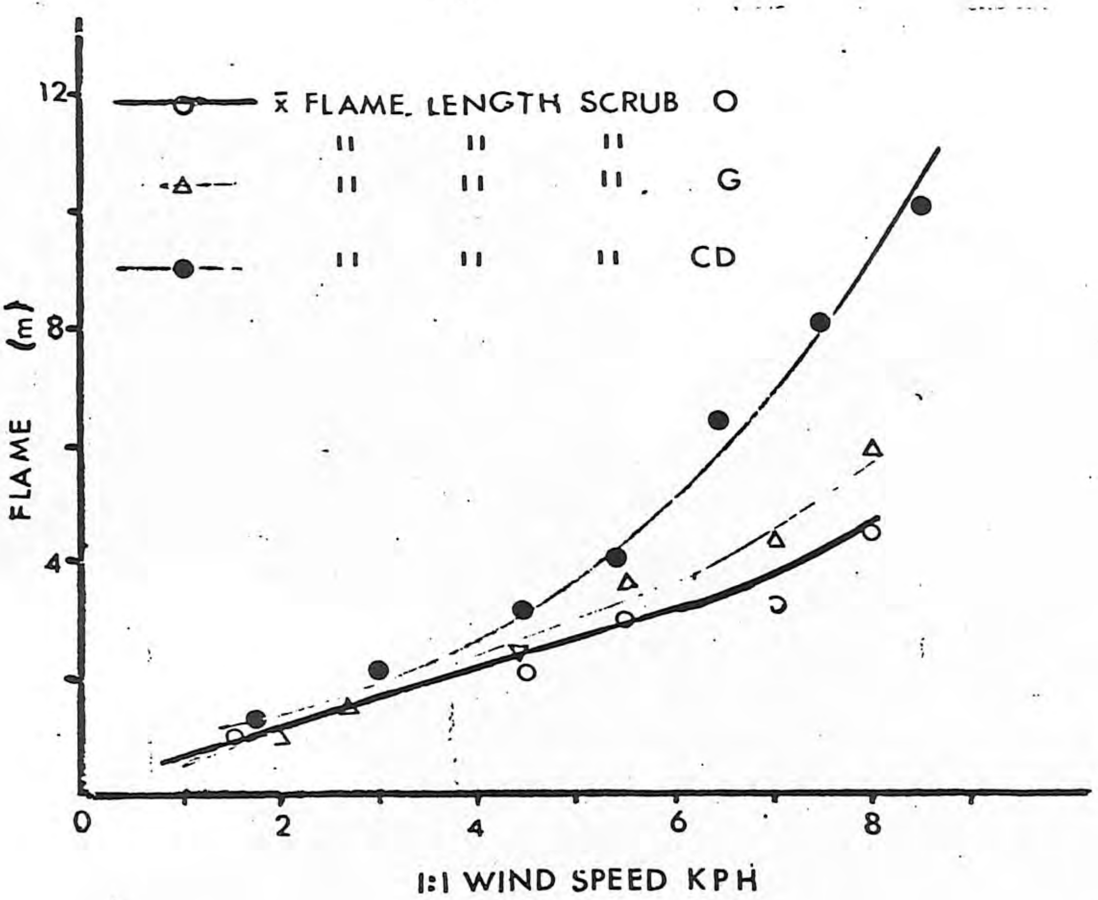

FIGURE 13: Wind vs Flame length for scrub type

Controlling for litter fuel loading, exponential regressions above (fig. 12) indicate a minor effect of scrub type on H.F.R.O.S. at low wind speeds. This effect increases as indicated by the exponential nature of the regressions, and at high wind speeds, considerable differences in H.F.R.O.S. develop. Fuels without a scrub component show slightly depressed rates of spread However, the functions relating H.F.R.O.S. and LOWIND for fuels containing a scrub loading, fall within the 95% confidence limits of the O scrub function at lower wind speeds. It is also noticeable that with scrub type DC, the H.F.R.O.S. is lower than the type G scrub for wind conditions <5.8 K.P.H. This is probably as a result of the higher level of wind interception by this scrub type. The vegetation fuel correction factors presented in Appendix 1 are a rationalized expression of the expected effect of scrub type (6 years old) on spread rates. From fig. 13 above, it can be seen that the flame height/length increases markedly for scrub types DC when wind is in excess of 5.8 km/hr.

This may be interpreted as the point at which there is total defoliation and consumption of the scrub fuel, thereby reducing the impedence of low level winds. This further results in accelerated spread rates. Although spread is not greatly increased by either scrub type G or DC, recorded flame height/lengths are higher than for O scrub, especially in scrub type DC. Flame height was taken as an average over the 80 m^2 fire sample plots and with the occasional flare up in scrub type DC resulted in an inflated mean. Flame resulting from the burning of high surface area-to-volume and low quantity fuels such as scrub type DC are flashy and broken in contrast to the more solid, structural flame generated from the combustion of more dense and high quantity fuels such as litter beds. The measuring system did not cater for this differential in flame types ($\approx$ propagating intensity) as a result of burning different fuels. Flame was recorded simply in terms of its $\bar{x}$ height and length and short duration flare ups unwittingly biased estimates. The added fuels by way of vegetation types does increase H.F.R.O.S. above a certain wind speed, so these fuels and flare ups must contribute to the fire spread action - probably by increased pre-heating of fuels and an enriched (gaseous) burning medium ahead of the flaming zone. Short distance (1 - 2m) multiple spotting was very noticeable in scrub type DC when wind speeds increased. This may have contributed to fire spread, although the headfire appeared to over-run most spots. An important influence of scrub, especially of the type DC, is its potential to lift flame into the crowns of lower tree species and ultimately, to the upper canopy. This occurred in a few isolated incidences where a fuel ladder existed, resulting in the defoliation of the upper canopy. Mostly, this process is prevented from reaching upper canopy defoliation, but often results in full scorch to the upper canopy and defoliation of the low tree canopy (where such exists). Extrapolating the derived function for scrub type DC (see fig. 12), differences in H.F.R.O.S. develop between scrub and no scrub fuels.

PLATE 6: The contribution of vegetation to fire intensity

Appendix 1, table 3 gives vegetation fuel correction factors. It is very likely that these correction factors decrease with increasing litter bed fuel accumulation.

3.3 Scorch Height & Defoliation Height

A multiple regression analysis determined scorch height to be a function of:

$$\text{Scorch Ht.} = .29T + .93W - .36M.C. - 0.034R.H. + 6.82 \quad \text{- Equation 6}$$

where;

	STANDARD ERROR Coefficient
T = ambient temperature	.14
W = ambient wind (G.L.)	.31
M.C. = moisture content	.19
R.H. = relative humidity	.04

multiple R = .41 $R^2 = .17$

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The poor amount of variation in scorch height explained by equation 6 expresses the high degree of variation in scorch height measured in the field. In many subplots there was no indicator of Maximum <u>possible</u> scorch height. This was particularly so in subplots not containing high level forest. When scrub or low level forest had to be used as a measure of scorch height, full scorch (to the height of the vegetation) was achieved over a wide range of conditions. The poor correlation coefficient for equation 6 is also as a result of the 'self scorch' effect of jarrah under dry conditions. In many instances (especially on days of low R.H.) the bark of jarrah trees ignited. This bark ignition would not be restricted to the first few metres of the bole, but would extend to all primary, secondary etc. branches. This would often result in full scorch to the tree. The problem of variation in canopy heights was partially overcome by selecting cases within a base canopy height > 2 m and an upper canopy height > 4m. The independent variables occurring in equation 6 also occur in equation 1 so H.F.R.O.S. was selected as the only 'independent' variable. The following was generated (expressed is the upper 68% C.L.).

$$\text{Scorch ht. (m)} = .37\ (\text{R.O.S.}) - 0.9 \quad \text{- Equation 7}$$

$$\text{where } R^2 = .46$$

this can be expressed as;

$$\text{Scorch ht. (m)} = .37\ \text{R.O.S. (for} \leq 7\%\ \text{M.C. conditions)}$$

Therefore, under these (summer) conditions, full scorch is achieved by a R.O.S. of near 55 m/hr for most jarrah forest types.

Defoliation height expressed flame height, which in turn is expressed by; (upper 95% C.L.).

$$\text{Headfire flame ht.} = 1.1W + .04T - .02R.H. + 0.3T/ha + .65 \quad \text{- Equation 8}$$

$$\text{where multiple } R^2 = .44$$

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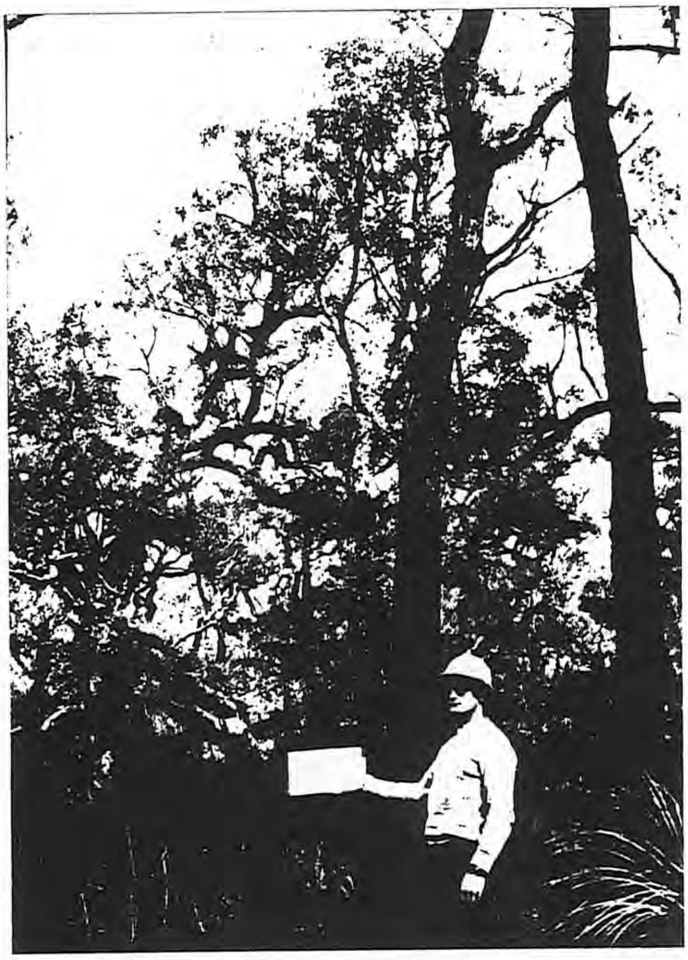

PLATE 7: High scorch levels from low intensity fire under dry conditions.

PLATE 8: Complete defoliation of scrub following a fire of $\approx$ 800 kw/m.

$$\text{Flame ht.} = \text{defoliation ht.} = 0.035\,(\text{R.O.S.}) - 1.20$$

$$R^2 = .56$$ (For ROS > 35 m/h)

flame height and flame length are strongly related by;

$$\text{Flame ht.} = .08 + .58\ \text{flame length} \quad \text{- Equation 9}$$

$$R^2 = .82$$

From observations of a small number of fires where flame height exceeded 10 m, the relationship between flame height and flame length could be better expressed as a sigmoid.

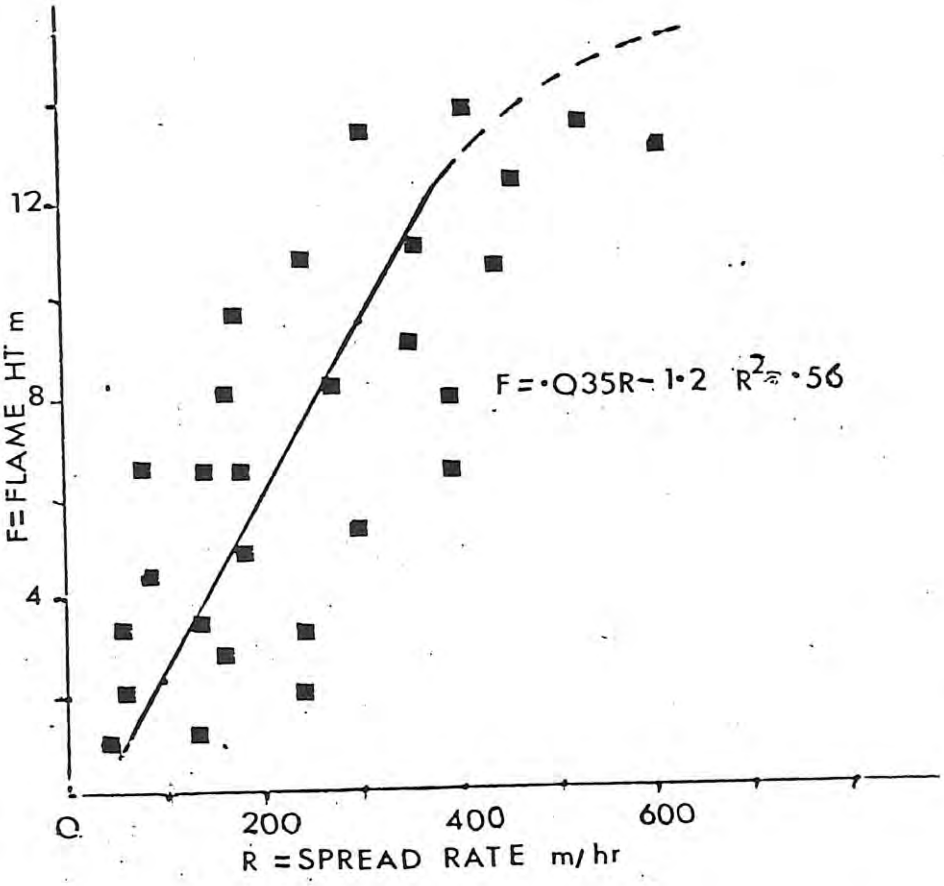

FIGURE 14: Flame height vs R.O.S.

However, equation 9 can be used confidently for flame heights up to 10 m (Rates of spread up to 230 m/hr). Beyond this, flame height will possibly be over-estimated, and the relationship shown in fig. 14 above should be used. There was evidence suggesting a change in the linear relationship between flame length and spread rate up to the spread rates experienced in this study.

$$\text{flame length} = .02\bar{x} - 1.52 \quad R^2 = .44 \text{ - Equation 10}$$

It is also highly likely that this linear relationship becomes sigmoidal with large rates of spread.

Up to a flame length of 6 m, flame depth and flame length were found to be related by;

$$\text{flame length} = .246 + 1.0 \text{ flame depth - Equation 11}$$

$$\text{where } R^2 = .59$$

Beyond 6 m flame length, observations became highly scattered corresponding to the severe and erratic fire behaviour and difficulties in observing and determining the parameters (this applies to flame height measurements). From this and rate of spread, flame dwell time can be calculated.

Scorch height was found to be related to fire intensity (I = H.W.R.) by;

$$\text{Maximum scorch ht. (m)} = 0.07\ (I) - 1.1 \text{ - Equation 12}$$

$$\text{where } R^2 = .41 \ \& \ \text{S.M.C.} \leq 7\%$$

$$I = \text{intensity } (\text{kwm}^{-1})$$

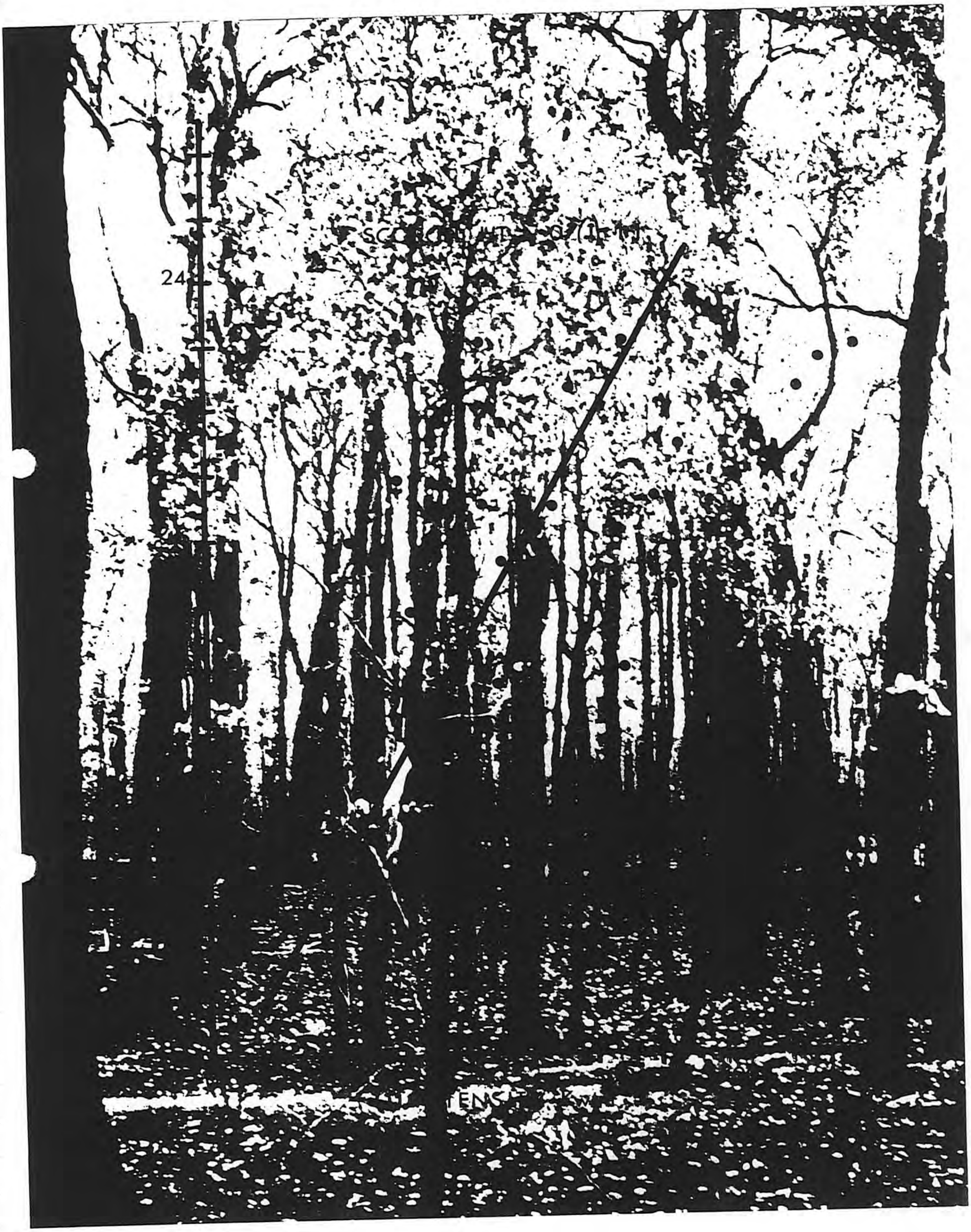

FIGURE 15: Scorch height vs Fire intensity - dry conditions

3.4 Spotting Distance

Tafia, Countrymen, Albini and others have drawn attention to the role that firebrands can play in the spread rate of large fires. There is little information on the detailed trajectories of firebrands for Australian forest fires. Small plot studies of the type undertaken here are highly inadequate for long range spotting studies as the occurrence of such is peculiar to large fires. However, short range spotting (up to 50 m) was observed in this study. The distance of short range spotting, was dependent on wind, litter quantity, moisture content, relative humidity and temperature - i.e. - was proportional to rate of spread.

$$\text{Expected Maximum Spotting Distance} = 1.62W + 0.07T/ha - 3M.C. - .14R.H. + .30T + 2.0 \quad \text{- Equation 13}$$

$$R^2 = .32$$

where

W = low level wind speed (at 1.5m)
T/ha = weight of litter fuels
$M.C.$ = moisture content
T = temperature

The above equation accounts for a small (32%) percentage of variability in spotting distance and may be treated as a guide to spotting only. From a visual assessment, it was apparent that spotting, at any one instant, was irregular both in distance and intensity of firebrands. Short distance spotting under small plot studies had little effect on spread rates as main headfires quickly overan the spots before they had developed to an influential size. Where wind speed was variable, short distance spotting did enchance spread rates. On a number of occasions, a short duration (30 seconds) wind gust up to 10 km.hr (at 1.5 m A.G.L.) would result in accelerated fire behaviour and multiple spotting up to 40 metres in advance of the headfire. Following a wind lull and a return to a very slow main fire spread rate, the many spot fires developed to a size sufficient to exert a noticeable influence on the main headfire spread rate.

3.5 Coalescing Fire Behaviour

A small number of plots lit by double line ignition enabled the observation of coalescing fires and resultant erratic fire behaviour. A recent pilot study also allowed the observation of mass ignition fire behaviour, an example of which is illustrated in figure 16 below.

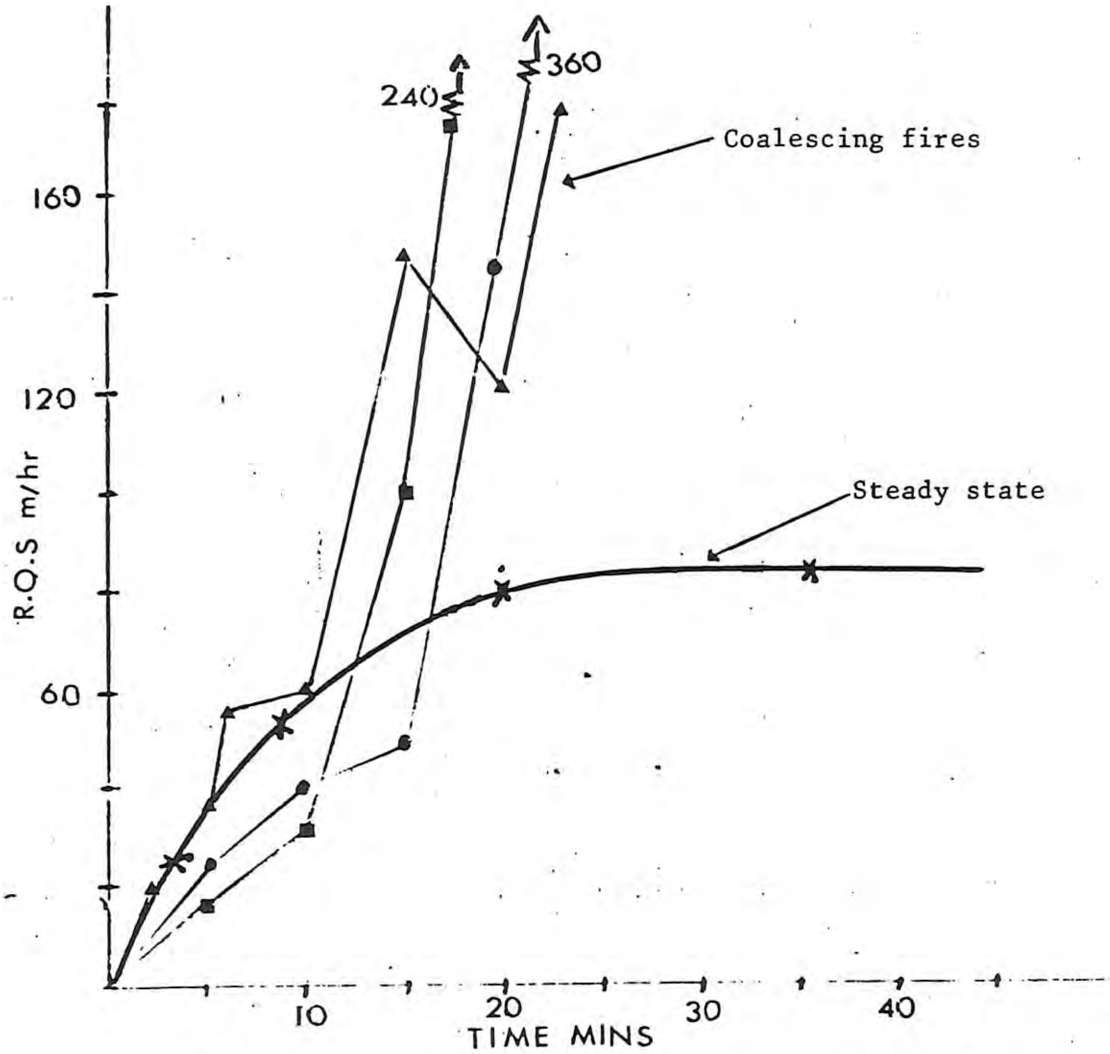

FIGURE 16: Coalescing & steady state fire behaviour

The violent increase in fire behaviour of merging fires is not unique to dry fuel conditions but appears to be amplified under such conditions. This is in keeping with the observation that comparatively slight changes in ambient conditions dramatically changes fire behaviour under dry fuel conditions. Such changes are imposed on a local scale by the fire (s) itself, resulting in the apparent unification of convective winds and the observed increases in fire behaviour and intensity. This phenomenon will not be dealt with at length here but forms part of the topic of a pilot study completed recently in anticipation of further studies. Such a phenomena can be considered highly advantageous as it may allow the controlled prescription of higher intensity fires under dry fuel conditions. This is a widely practised technique in regeneration burns where a considerable margin of error in resulting intensities is allowed. This negates the requirements for a sound prediction model. Regeneration burns present a completely different fuel array and fuel loading so techniques used in such burns cannot be readily adapted for forest fire prescriptions.

3.6 Summer Fire & Damage to Jarrah

It is a difficult task to develop a precise relationship between commercial loss through fire damage and a fire characteristic. Byrams (1969) measure of fire intensity has long been used to characterize fires and appears to be an acceptable measure of both the energy released and the above ground vegetation responses to this energy release. Byram expressed fire line intensity as;

$$I = H.W.R.$$

where I = intensity (kwm^{-1})
H = heat yield (18,600 kj/kg for euc. fuels)
W = total consumed fuel ($\mathrm{kg/m}^2$)
R = linear spread rate (m./s.)

Intensity is expressed as a mean of a sample of burning forest. By definition, intensity changes by the metre as forest fuels change. Fuel loadings and fire behaviour at the base of trees will vary. Intensities expressed here are calculated from mean fuel quantity consumed and the mean spread rate through 80 m^2 sample plots (4m x 20m). All trees within these plots were examined for i) drysiding to the bole and ii) crown damage. It should be borne in mind that the following are results visually obvious only 12 months after burning.

3.6.1 Drysiding

Drysiding results when the cambium is killed, occlusion is incomplete and bark is shed from the un-occluded area, exposing drywood.

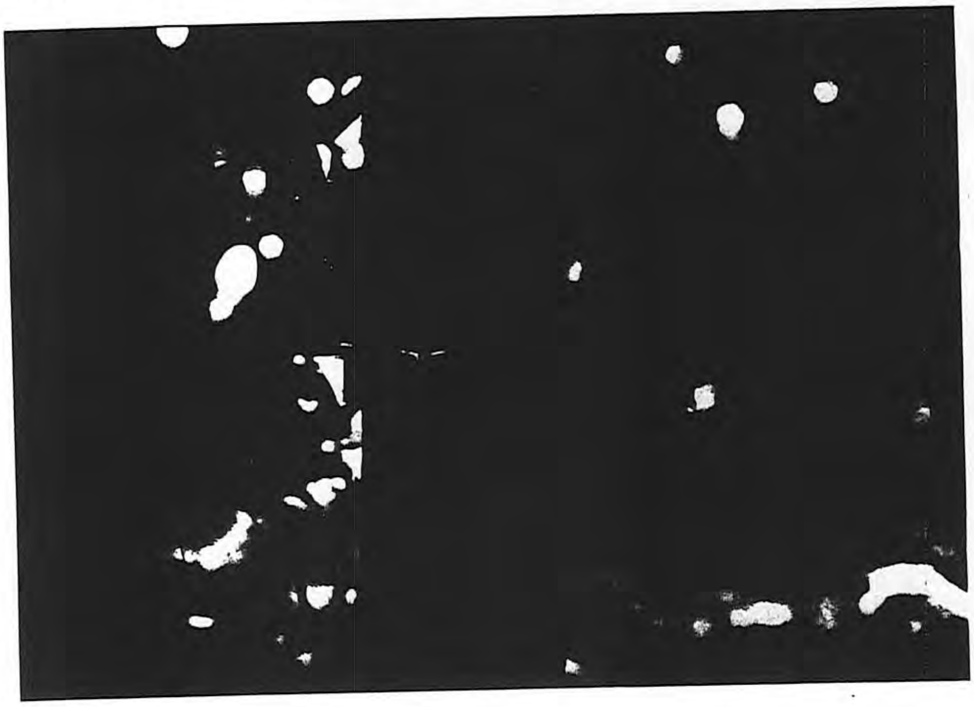

PLATE 9: Primary damage to small jarrah following a 300 kw/m fire.

PLATE 10: Tertiary damage to marri following a 1500 kw/m fire.

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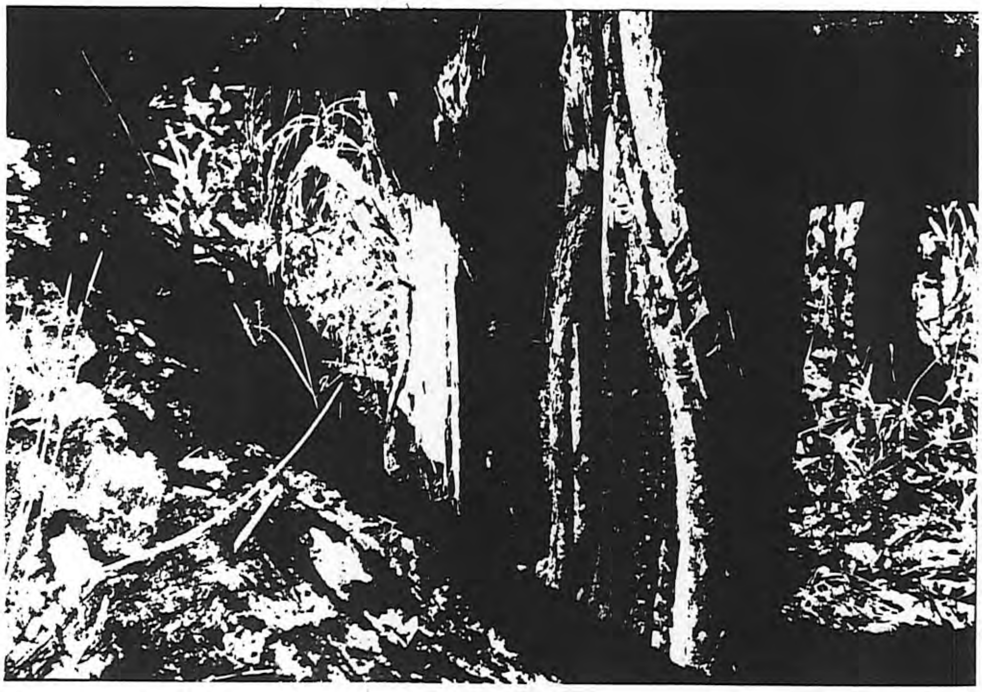

PLATE 11: Tertiary damage from adjacent burning log

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Although the causes of tree cambial damage are fairly well understood, the healing processes aren't. The persistence of dryside for a given species appears to be a function of 1) extent of cambium killed (especially in the radial axis) 2) stem diameter 3) stem vigour 4) frequency and intensity of subsequent fires. While it is known that some cases of fire killed cambium completely occlude over and become packed into the dense heartwood while others don't occlude and ultimately become hollowbutts, accurately predicting events in between these extremities is impossible at the very least, difficult. Further long term and detailed studies may result in a better understanding of the processes and allow better prediction of commercial timber loss as a result of fire. Cambial damage was visually assessed (see description of methods in Working Plan 28/78 and Progress Report on W.P. 28/78 - Harrington series). The following data (see fig. 17) & table 2. are the extent of the Young Block damage visually discernable some 12 months after burning. Subsequent measurements will determine whether the expression of damage is increasing or declining. It requires 1 - 2 years for most bole damage to be visible by way of splitting bark. Jarrah only was examined.

From Fig. 17 it can be seen that there exists a surprisingly high level of background fire damage as a result of wildfires and/or hazard reduction burns. Although hazard reduction burns are low intensity (50 - 300 kwm^{-1}) there are occasional 'hot spots' and trees near hot spots or heavy fuels (such as tops, logs etc.) may suffer cambial damage. This is particularly so for the second instance - heavy fuels. Logging activity has resulted in increased heavy fuel loadings (tops, uncommercial log lengths) which do not burn away under cool, moist conditions, but do burn for significantly long periods to damage nearby stems. These same logs are re-ignited in 5 - 7 years time and the same tree is exposed at the same location, to heat damage. Under such conditions, drysides rarely occlude and the tree ultimately becomes a hollowbutt. It is also likely that frequent burning reduces the bole bark thickness at

TABLE 2

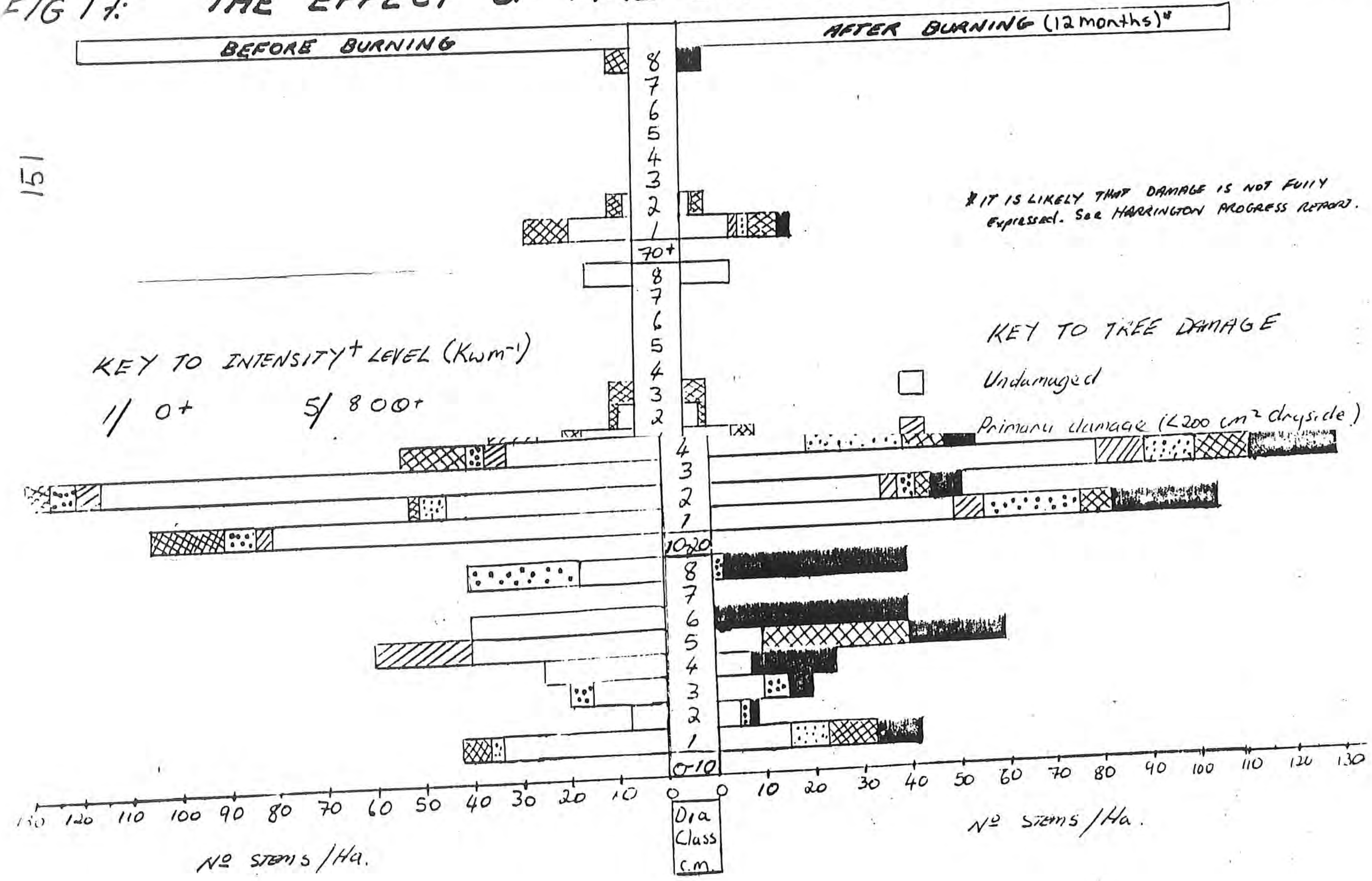
% DAMAGE TO JARRAH, BY DIAMETER & INTENSITY CLASS, FOLLOWING SUMMER FIRES - YOUNG BLOCK

(NOTE - THIS REPRESENTS DAMAGE VISIBLE AFTER 12 MONTHS)

	MEAN FIRE INTENSITY (KW/M)																															
	40+				200+				400+				600+				800+				1000+				1200+				1600 - 2000			
DIA. CLASS (CM)	P	S	T	K	P	S	T	K	P	S	T	K	P	S	T	K	P	S	T	K	P	S	T	K	P	S	T	K	P	S	T	K
0 - 10	0	2	14	0	0	0	0	0	0	19	0	0	0	0	0	0	28	0	0	0	0	0	0	0	-	-	-	-	0	30	0	0
	0	16	23	22	0	22	0	27	0	22	0	25	0	0	0	68	0	0	50	30	0	0	0	100	-	-	-	-	0	6	0	94
10.1 - 20	2	6	14	0	0	11	4	0	4	4	3	0	7	5	24	0	25	0	0	0	0	0	40	0	0	0	0	0	0	7	7	0
	5	16	8	19	5	6	6	13	8	8	9	13	0	36	12	12	31	54	0	15	0	0	11	20	0	40	0	60	0	0	8	74
20.1 - 30	10	2	20	0	6	6	10	0	11	9	18	0	0	15	0	0	12	10	0	0	25	15	0	0	0	0	0	0	0	0	0	0
	10	15	16	4	7	8	8	3	23	15	19	0	0	18	0	0	0	36	0	6	0	0	27	21	0	0	0	4	0	3	0	97
30.1 - 40	16	8	0	0	0	0	0	0	0	0	0	0	-	-	-	-	24	0	0	0	-	-	-	-	0	0	0	0	-	-	-	-
	16	10	4	0	15	0	0	0	17	16	18	0	-	-	-	-	24	22	0	0	-	-	-	-	0	0	0	0	-	-	-	-
40.1 - 50	0	0	10	0	8	0	8	0	0	0	0	0	0	0	0	0	-	-	-	-	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	10	0	8	0	9	0	0	0	0	0	0	0	0	0	-	-	-	-	0	0	0	0	6	0	0	0	6	0	0	0
50.1 - 60	15	15	0	0	0	30	0	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0
	15	15	0	0	0	30	0	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0
60.1 - 70	0	0	20	0	0	0	25	0	0	0	100	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0
	0	0	20	0	0	0	25	0	0	0	100	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0
70.1 - 100	0	0	20+	0	0	0	50	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	100+	0
	6	6	12	8*	0	0	50	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	100*

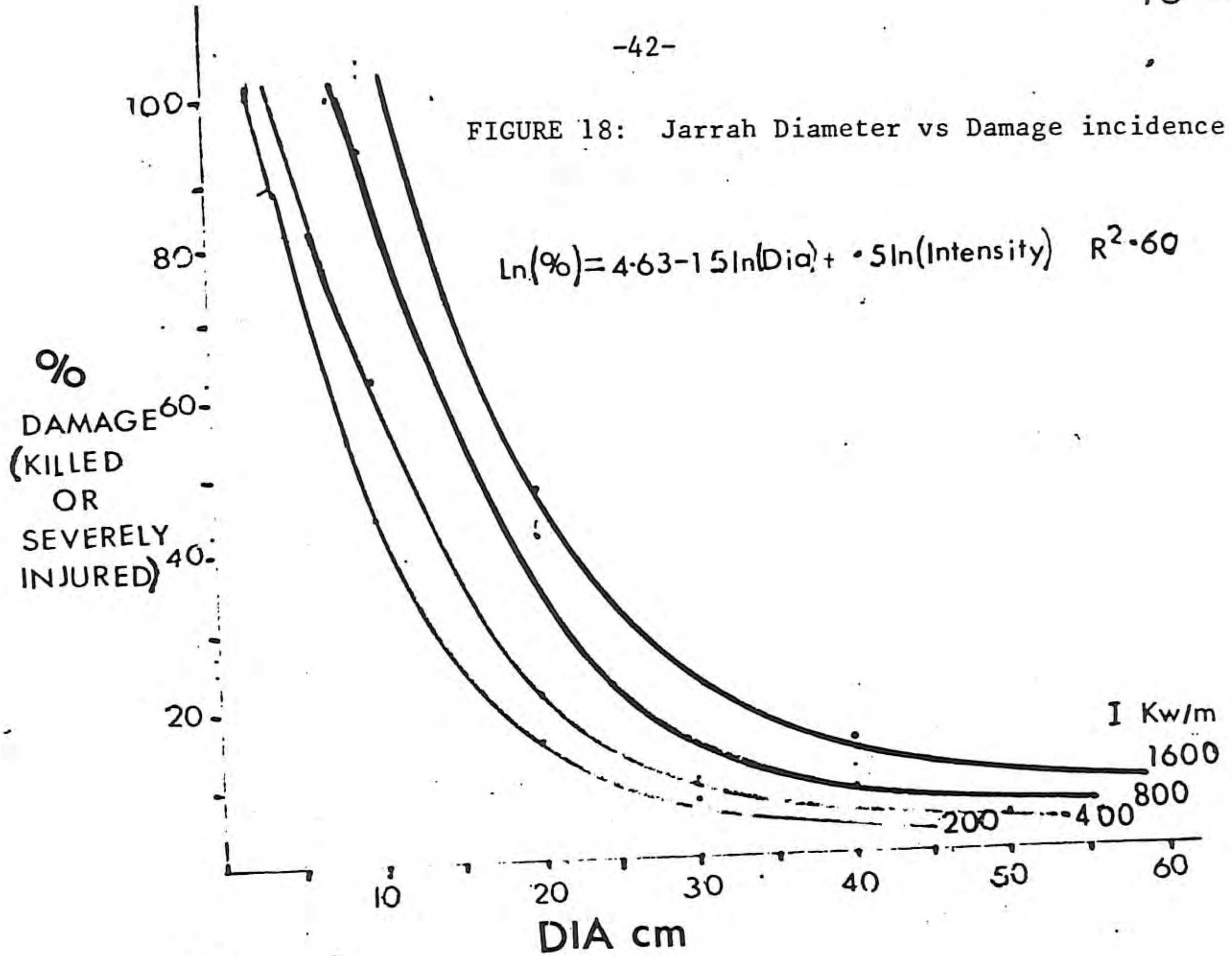
DAMAGE LEVELS
P = primary damage (dryside totaling <200 cm^2)
S = secondary damage (dryside totaling 200 - 600 cm^2)
T = tertiary damage (dryside totaling >600 cm^2) - + includes hollowbutts
K = kill to ground level * = Burnt down

FIG 17: THE EFFECT OF FIRE INTENSITY ON JARRAH. ([illegible] BK)



* IT IS LIKELY THAT DAMAGE IS NOT FULLY Expressed. See HARRINGTON PROGRESS REPORT.

FIGURE 18: Jarrah Diameter vs Damage incidence



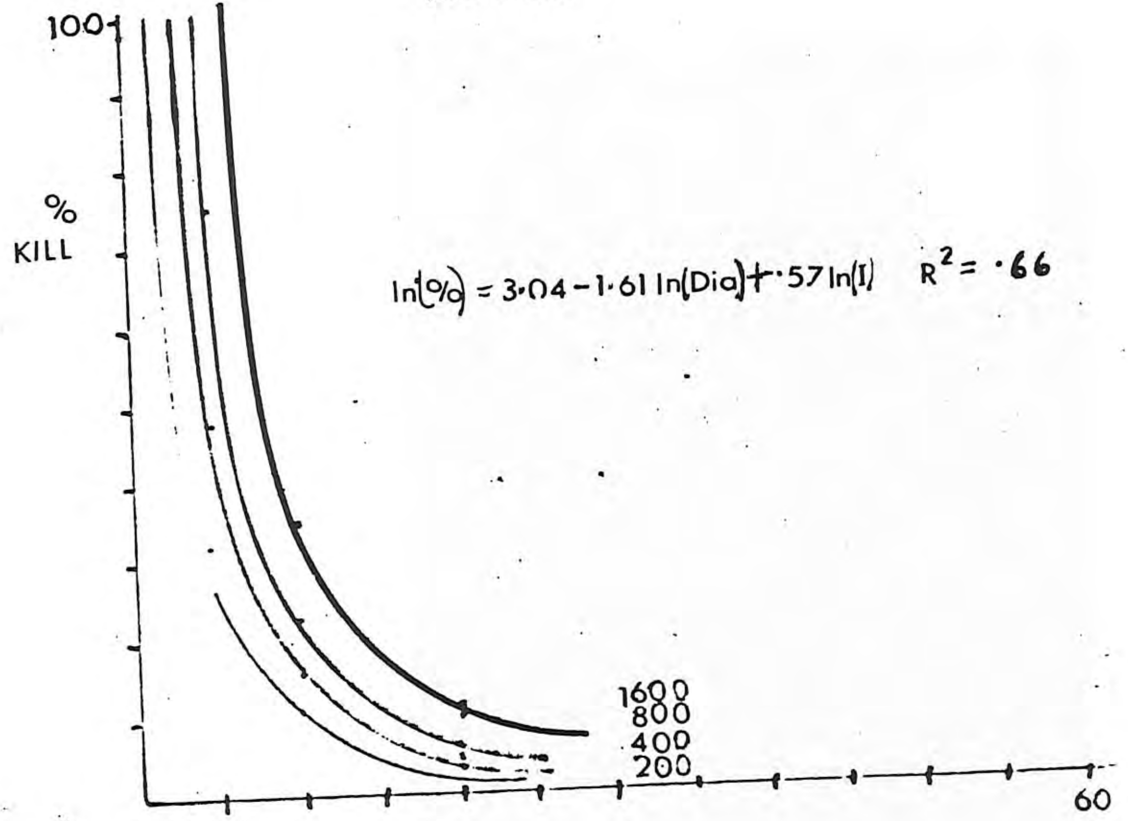


FIGURE 19: Jarrah Diameter vs Kill incidence

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lower levels (up to 3m), further reducing the trees resistance to cambial damage through heating. As can be seen from figs. 17, 18 and 19 and has been reported in the literature, larger stems with thicker bark are more resistant to death and/or damage by fire. The variability of fire intensity and varying background damage levels prevented the setting of definite damage levels for fire intensity. At best, kill (to ground level) and damage are expressed as percentages likely for various mean intensities (fig. 18). This percentage kill/damage reflects the variability of intensity and background damage for the conditions studied and can be approximated by;

$$\ln(\text{percent kill}) = 3.04 - 1.61 \ln(\text{diameter}) + .57 \ln(\bar{x} \text{ intensity}) \quad \text{- Equation 14}$$

$$R^2 = .68$$

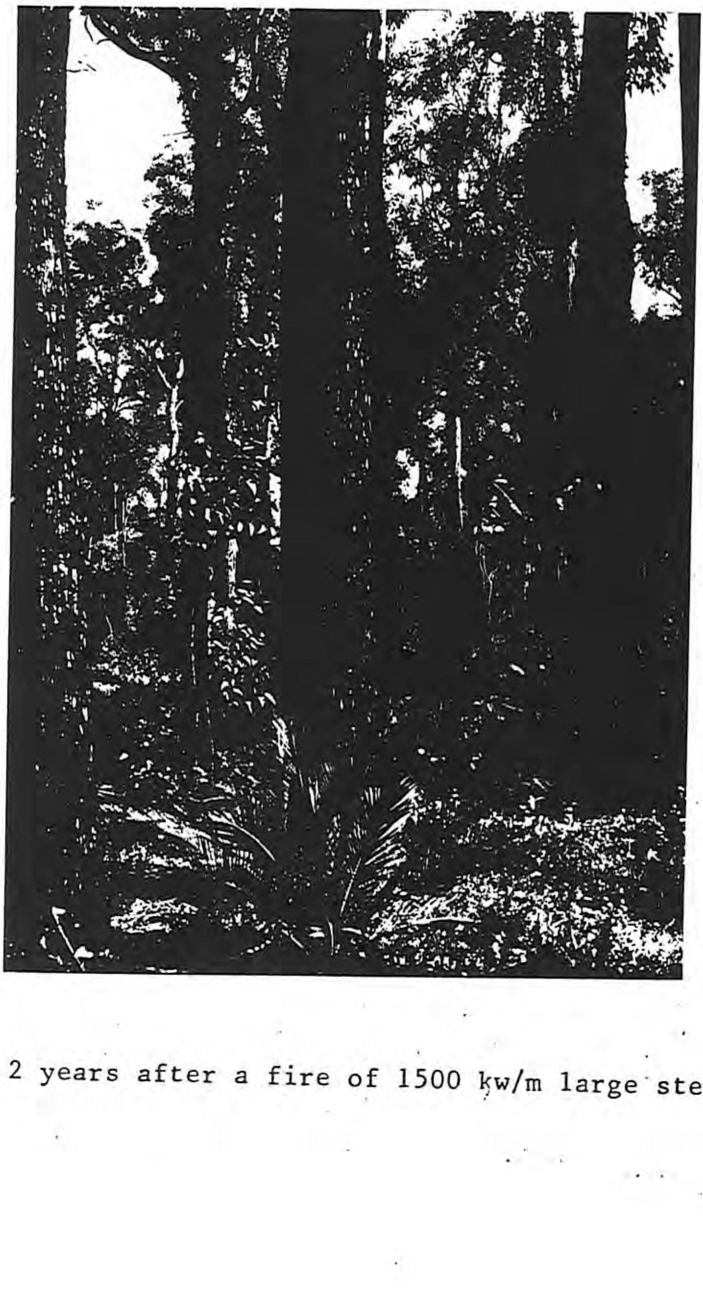

PLATE 12: 2 years after a fire of 1500 kw/m large stems undamaged

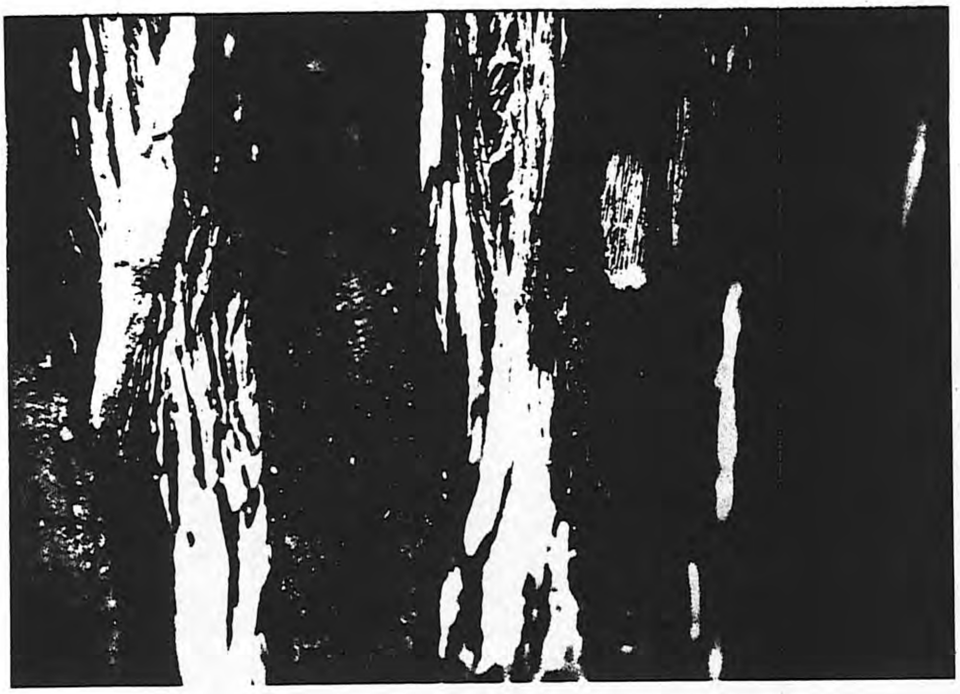

PLATE 13: Thick protective jarrah bark

Tertiary damage is also dependent on the extent to which pre-burn primary/secondary damage develops further following fire. No weighting could be given to this factor. From Fig. 17 it can be seen that there is an increase in stem damage (primary [illegible] tertiary damage) with increasing intensity and decreasing diameter. Stems with little or no "old" scars and which were in excess of 40 cm D.B.H.O.B., showed no signs of stem damage even up to mean intensities of 2000 kwm^{-1}. Very large stems (70+cm D.B.H.O.B.) with severe "old" tertiary damage (hollowbutts) were burned down or killed by fires of 1600 - 2000 kwm^{-1}. Generally, the increase in number of stems >30 cm exhibiting tertiary damage, is small following fires up to 2000 kwm^{-1}. A followup assessment in the second year after burning may reveal further damage, as was the case with the Harrington plots.

The percentage of trees severely damaged and/or killed following fires up to 2000 kwm^{-1} can be expected to be related by;

$$\ln(\%\text{ trees killed and/or severely damaged}) = 4.63 - 1.5\ln(\text{diameter}) + .50\ln(I) \quad \text{- Equation 15}$$

$$R^2 = .60$$

PLATE 14: Severely damaged & killed jarrah following a 4000 kw/m fire (Note dead banksias).

This assumes a background damage level (i.e. pre-burn damage) similar to that shown in fig. 17. Using Equation 15 above in conjunction with Equation (14) should provide a guideline to secondary and tertiary damage levels following summer fires up to 2000 kwm^{-1}, This relationship may not apply beyond this intensity. It should also be pointed out that headfire intensities will be greater than flank and backfire intensities and the area exposed to a steady state headfire is probably up to ½ total area burnt. In many instances in the small diameter classes more stems were killed to ground level than were left with tertiary damage. The raw data in fig. 17 clearly indicates the extent of combined (kill, tertiary, secondary and primary) damage following summer fires up to 2000 kwm^{-1}. A large proportion ($>$ 50%) of stems $\leq$ 10 cm incur some form of visual damage (temporary as it may be) from all intensity classes; stems in the 10 - 20 cm diameter class incur damage following intensities in excess of 600 kwm^{-1}; stems in the 20 - 30 diameter class prove to be resistent up to 1200 kwm^{-1}.

It should again be stressed that these observations were made only 12 months after burning. More damage may be evident on a second evaluation 2 years after burning.

3.6.2 Basal Area

Within each subplot, all jarrah basal areas were calculated before and 12 months after burning to determine the impact of various summer fire intensities (up to 4000 kwm^{-1}) on basal area. Subplots were grouped according to the mean intensity (treatments) experienced. Intensity classes were 200 kwm^{-1} in size, commencing from 0 - 199 up to 1000 kwm^{-1}, from where larger classes, 1000 - 2000 and 2000 - 4000 were formed (to increase the data pool at these intensities).

A series of "t" tests (for paired observations) established, at the 95% significance level, no difference in basal areas before burning and 12 months after burning for all intensity classes. However, there was a very slightly significant difference of the basal areas of the control plots over the 12 month period (calculated t = 3.08, table $t^{0.05}_{DF27}$ = 2.05) i.e. there was a significant increase in the basal area of the control (unburnt) plots over the 12 months.

There was no significant difference (95% level) in basal area between fire treatments and no significant increase (95% level) in basal area over the 12 month duration. There was a slight reduction in basal area in all instances (except the unburnt control) which is indicative of i) zero growth through

TABLE 3

JARRAH BASAL AREA (M^2/HA)

FOLLOWING A RANGE OF INTENSITIES

	INTENSITY (TREATMENTS) Kwm^{-1}															
	T1 0-199		T2 200-399		T3 400-599		T4 600-799		T5 800-999		T6 1000-2000		T7 2000-4000		T8 *C	
	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER
N	86	86	39	39	20	20	6	6	7	7	7	7	2	2	28	28
$\bar{x}$	39	34	28	23	31	28	13	12.7	12	10	52	18	10	2.2	23	24
S.D.	50	38	27	23	32	30	9.4	9.1	13	11	51	13.3	8	1.3	29	30
S.E. of $\bar{x}$	5.4	4.1	4.3	3.7	7.3	6.8	3.8	3.8	4.9	4.2	19	5.0	5.6	1.8	5.6	5.7

*T8 = Control = Unburnt

N = Number of subplots

$\bar{x}$ = Mean of subplots

S.E. = Standard error

TABLE 3a

2 WAY ANOVA (B/A m²/ha)

	T1	T2	T3	T4	T5	T6	T7	T8
Before	39	28	31	13	12	52	10	23
After	34	23	28	13	10	18	3	24

Mean = 22.6

(Var.) S^2 = 150

Total Sum Square = 2413

Column " " = 1779

Row " " = 189

Table F = 4.21

F - value column = 4.0

d.f.V_1 = 7

d.f.V_2 = 7

F - value row = 3.0

d.f.V_1 = 1

d.f.V_2 = 7

Table F = 5.65

loss of caopy (full scorch), ii) bark reduction, iii) possible slight reduction in diameter as food stored in individual cells is utilized. The reduction in individual stem diameters also supports this. Kill to ground level of small stems (< 10 cm D.B.H.O.B.) also accounts for slight reductions in basal area. Further monitoring of diameter basal area increment will reveal the length of the post burn growth lapse. With the rapid regeneration from rootstock of smaller stems killed by fire, it is unlikely that the jarrah population will be greatly re-structured. A very high frequency of such fires may result in re-structuring as stored nutrients are depleted and rootstock vitality reduced. This has been shown to occur in understorey hardwoods in the south east U.S.A. where repeated annual burning eliminated sprouting in 85% of rootstocks (Grano, 1970).

3.6.3 Crown Damage

Crown damage (scorch and defoliation) has been discussed. Scorched canopies were mostly replaced by epicormic foliage when measured 12 months after burning. The first signs of epicormic shooting were evident as early as four weeks after the fire. Stem epicormics reflected fire intensity, stem diameter and virility, with the surviving smaller stems (20 - 30 cm diameter) being heavily clad in stem epicormics following fires in excess of 1000 kwm^{-1}. Larger stems (50+cm diameter) rarely produced a significant quantity of stem epicormics at the intensities experienced in this study. The real effect of stem epicormics on wood quality is difficult to assess. On smaller diameter stems, it is likely to be negligable.

Crown recovery is being monitored on an annual basis. The greatest impact of crown damage is probably the accompanying decline in increment.

PLATE 15: Epicormic development 2 years after a defoliating fire

3.7 *Banksia grandis* Response (12 months after summer fire)

The response of *B. grandis* to summer fires (< 4000 kwm^{-1}) was examined in a manner similar to that outlined in an earlier report, the main difference being that the diameter class distribution of the 3 categories (A, B & C) was examined before and after burning. Lack of time and resources prohibited the diameter measurement of every *B. grandis* in the subplots (some 163 subplots containing up to 30 individuals each!). A sample from within each height size class (A, B & C) was selected and a highly representative population diameter class structure determined.

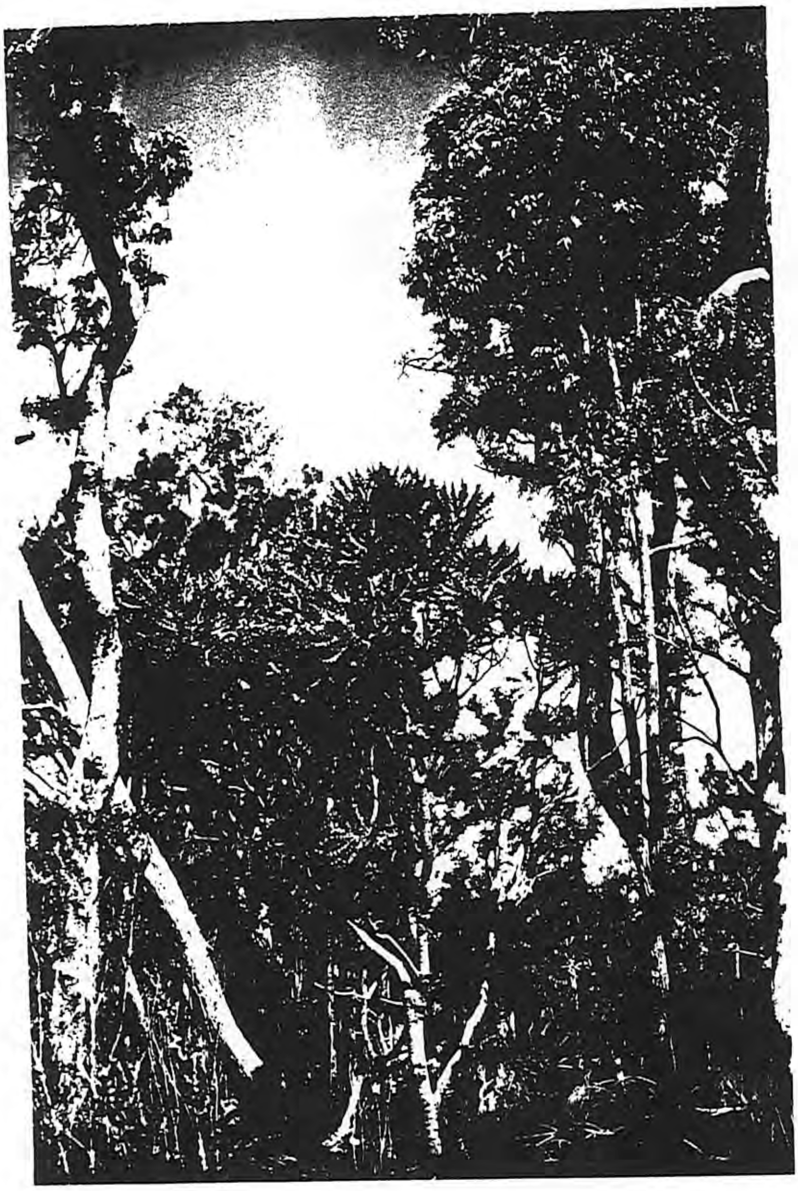

PLATE 16: Typical "C" class *B. grandis* - Harrington Block.

The diameter class structure for stands in Young Block differed from those found in Harrington Block (figs. 20 & 21).

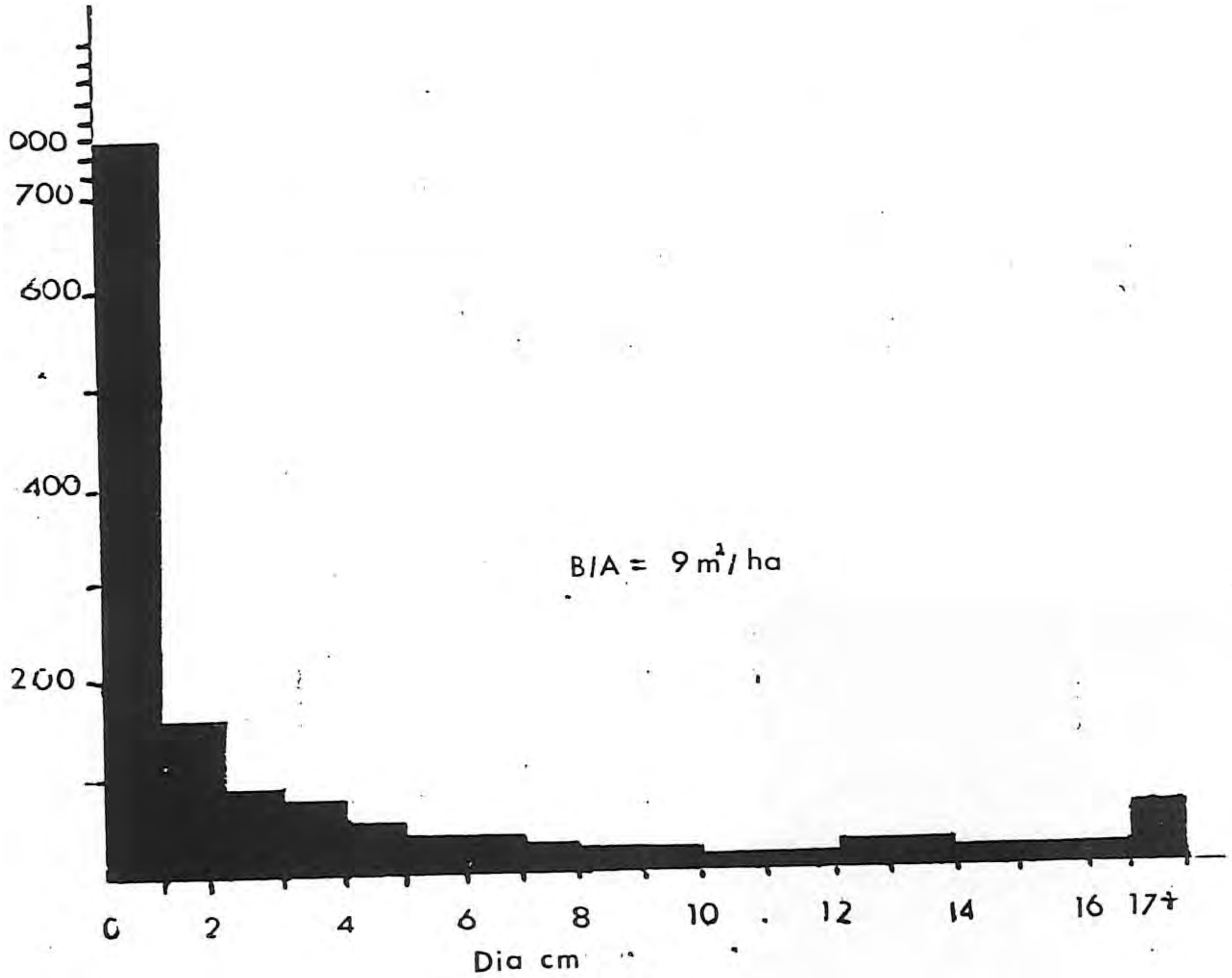

FIGURE 20: *B. grandis* diameter class structure - Harrington Block

The lower basal area and lower number of mid diameter range (5 - 10 cm) individuals probably reflects the lighter cutting history in Harrington Block. *Banksia grandis*, being a pioneer species, quickly establishes in clearings left by heavy cutting (personal observation). The physical appearance of these stands (such as in Young Block) is one of heavily stocked, spindly, co-dominant individuals (C class) underlain by a few straggly suppressed stems (B class) on a carpet of seedlings and moribund advanced growth (A class). The fire effect on Banksias at Young Block was similar to that on the Harrington Banksias but results were achieved with slightly lower intensity fires.

Banksia grandis has four basic traits which enable it to survive fires, these being a caudex, epicormic shoots, thick protective bark and soft seeds encased in a hard cone which remains affixed to the plant. However, not all

FIGURE 21a

FIGURES 21 a, b, c, d, e, f show the before & 12 months after fire population structure of *B. grandis* at Young Block "B" class individuals where killed to ground level only.

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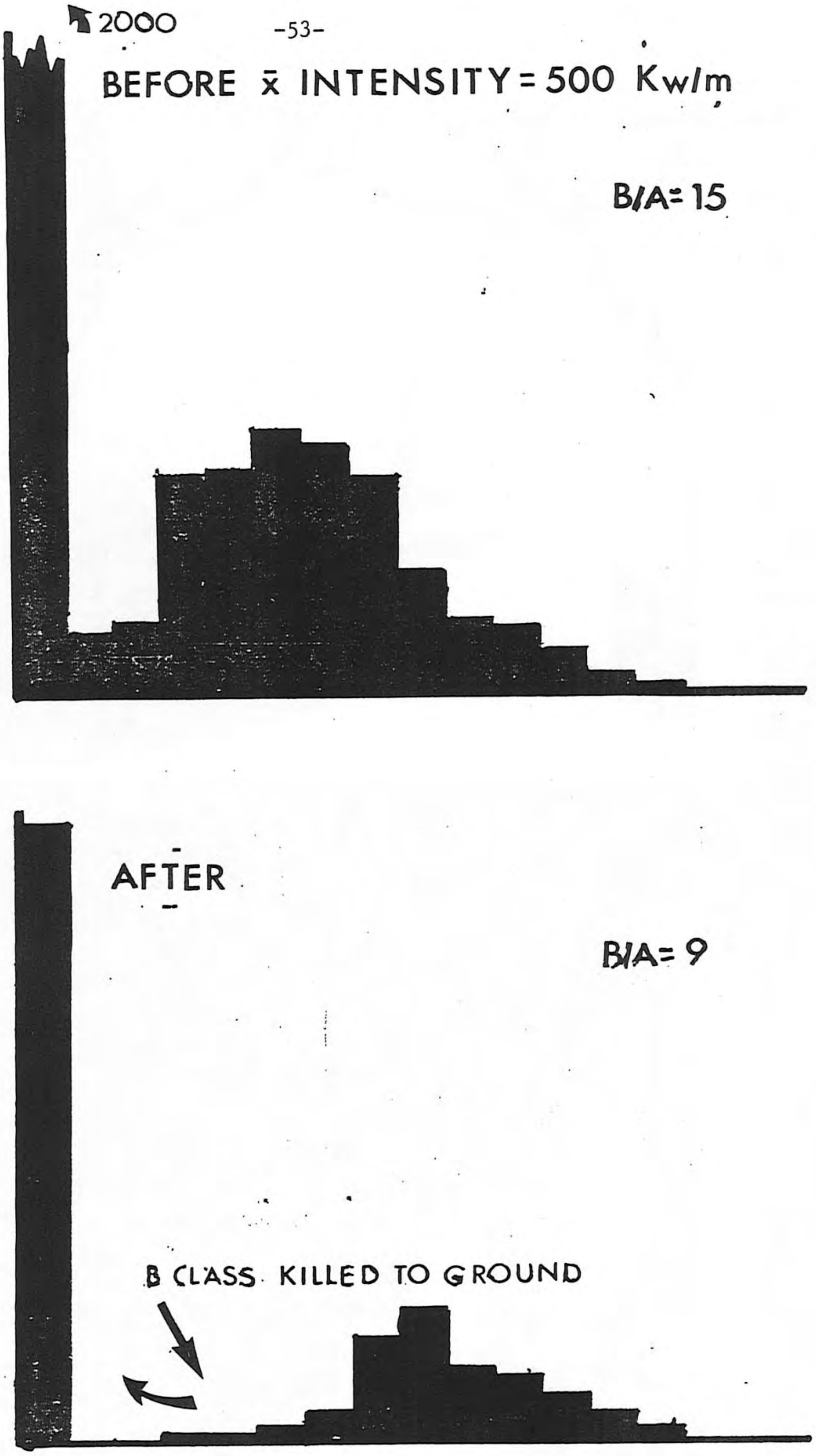

FIGURE ~~12b~~ 21b

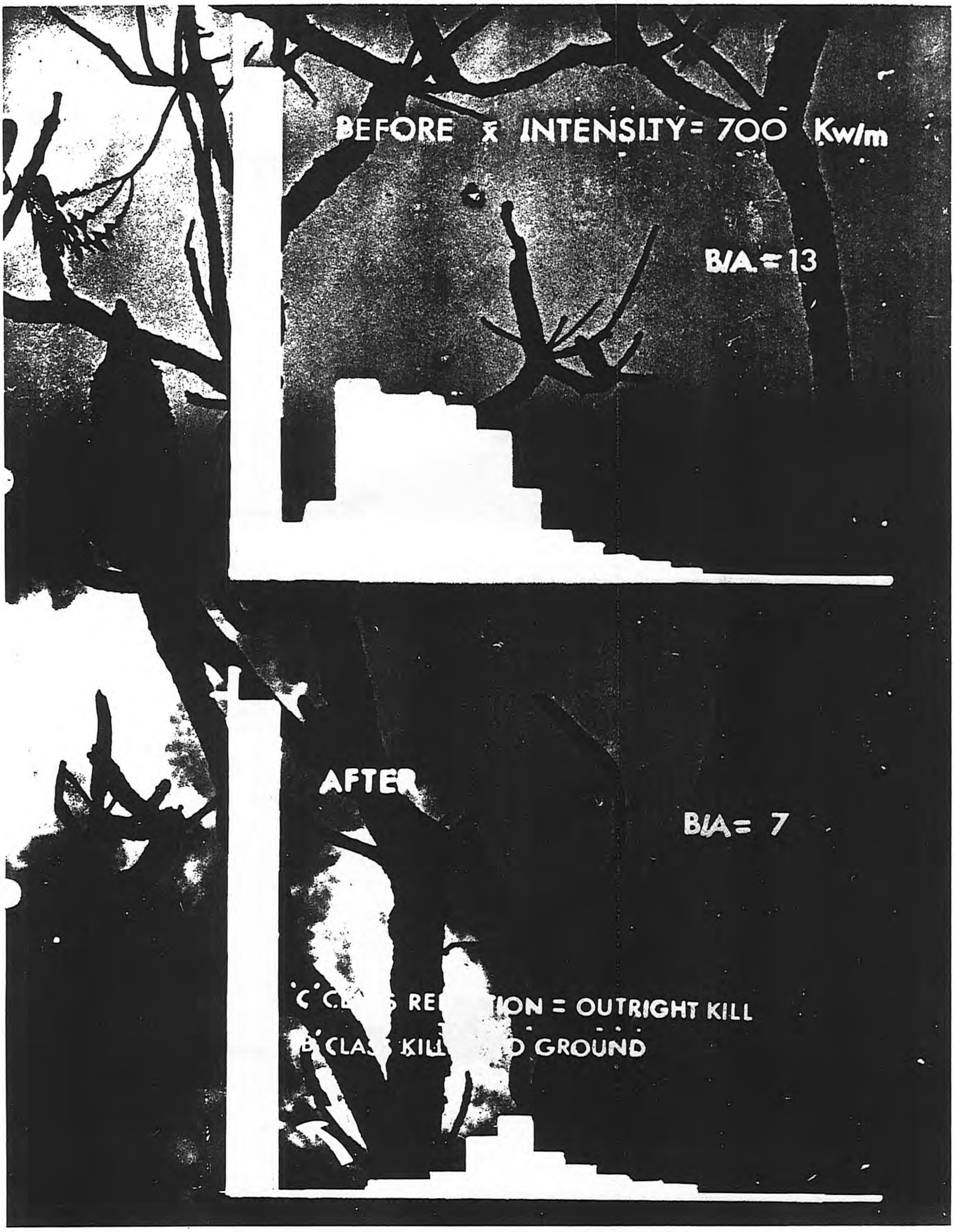
BEFORE x̄ INTENSITY= 700 Kw/m
B/A.= 13
AFTER
B/A= 7
'C' C[illegible] RE[illegible]ION = OUTRIGHT KILL
'B' CLA[illegible] KILL[illegible]O GROUND

FIGURE 21c.

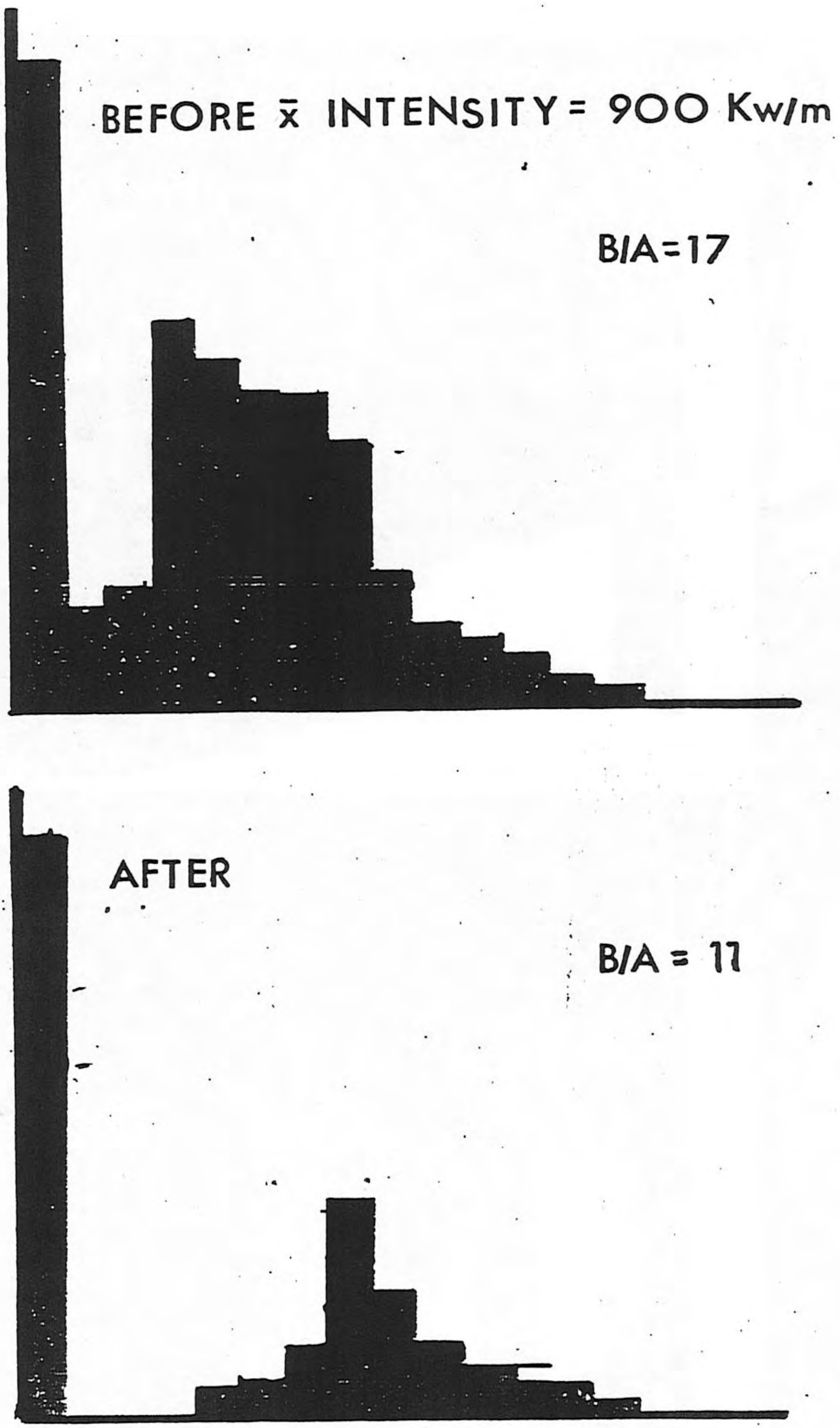

FIGURE 21d

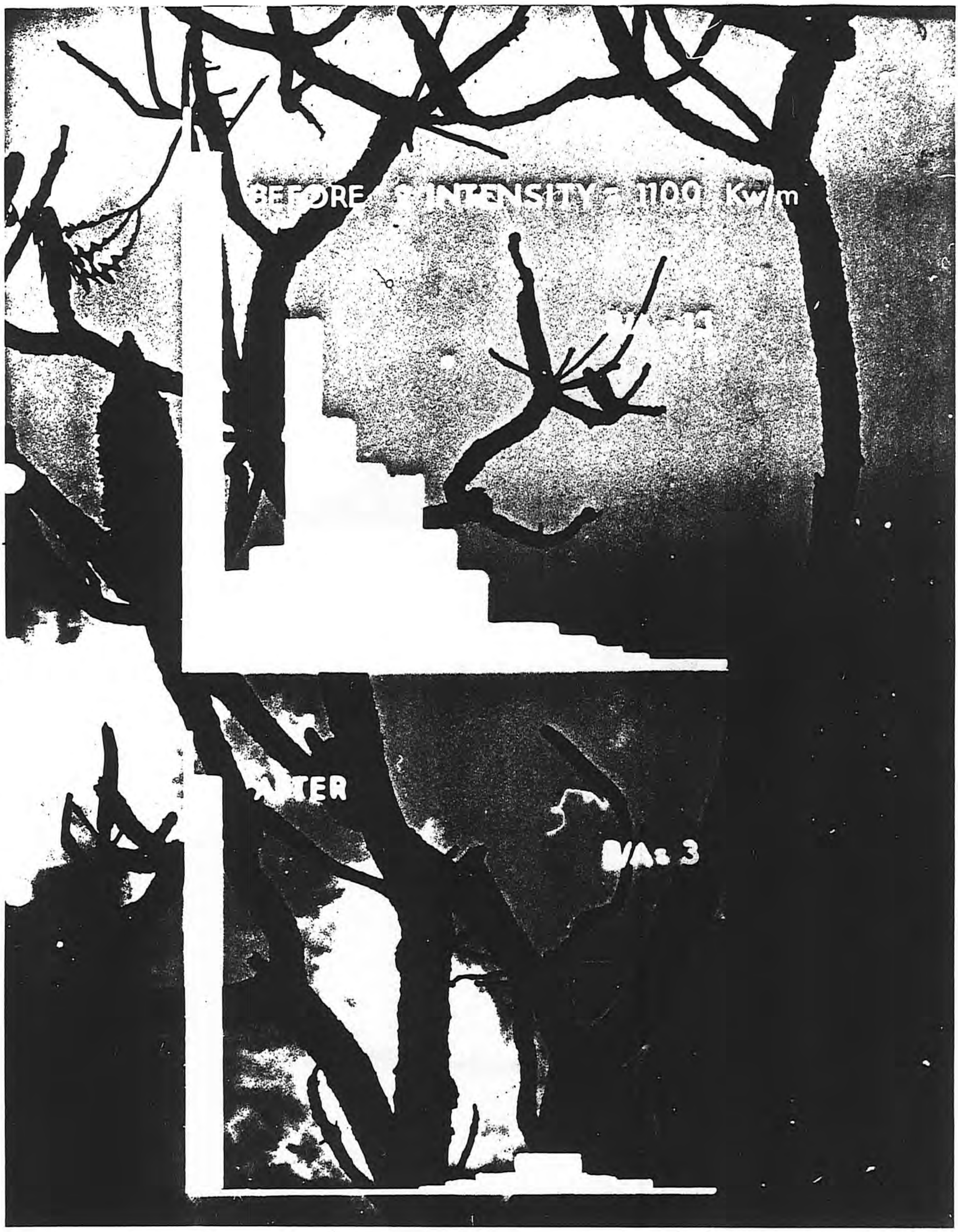

FIGURE 6

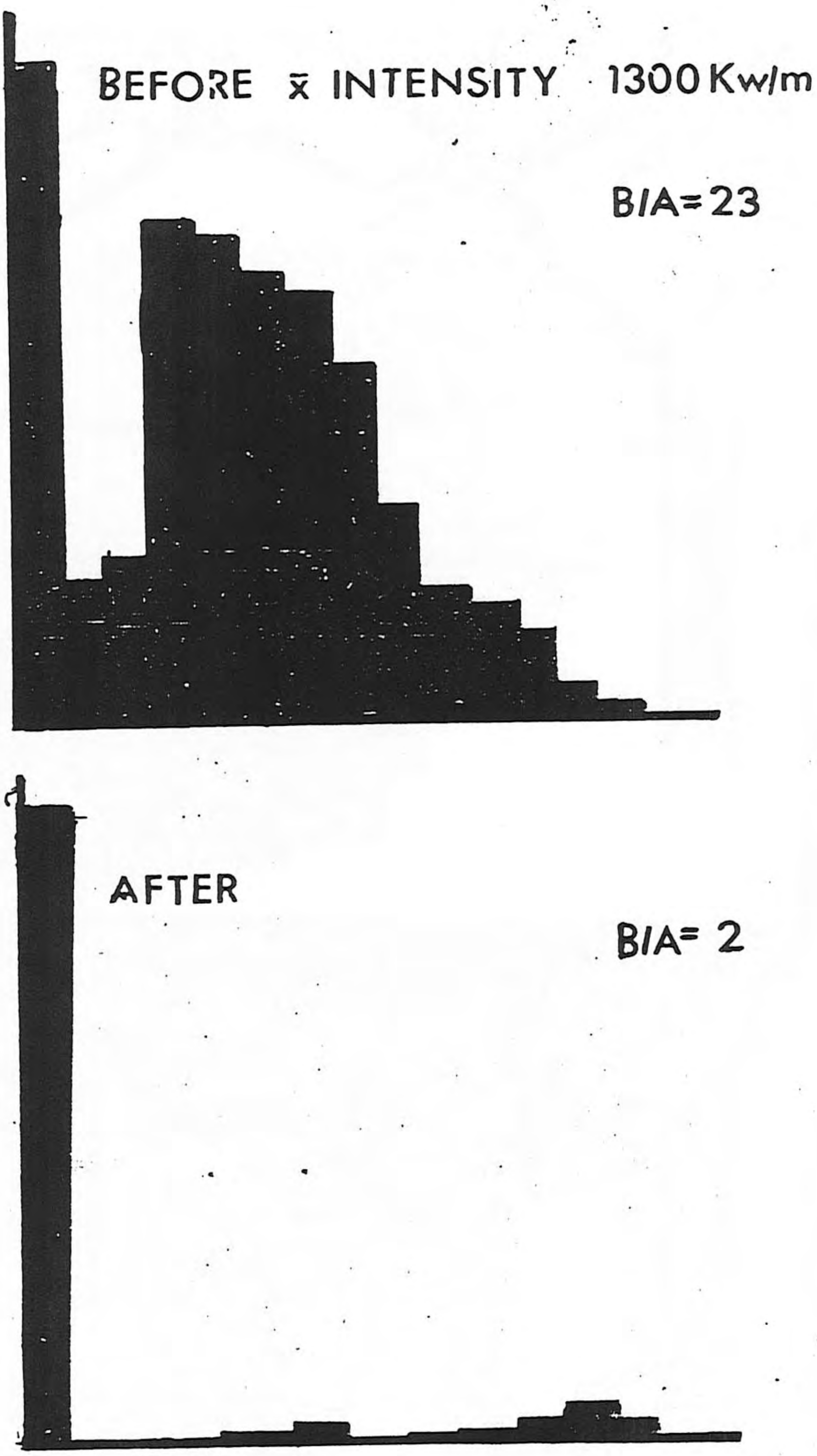

FIGURE 21~~e~~f

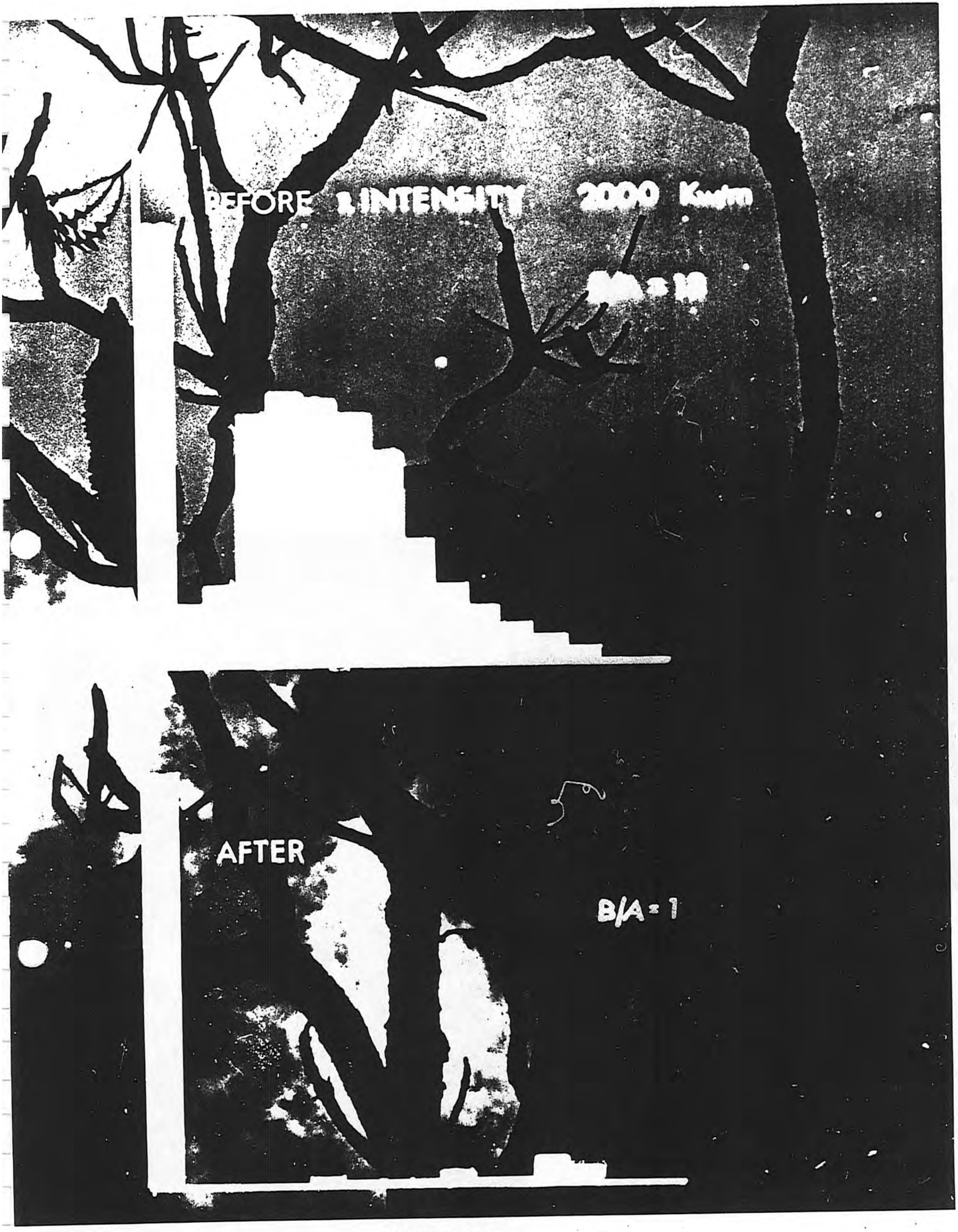

FIGURE 21g

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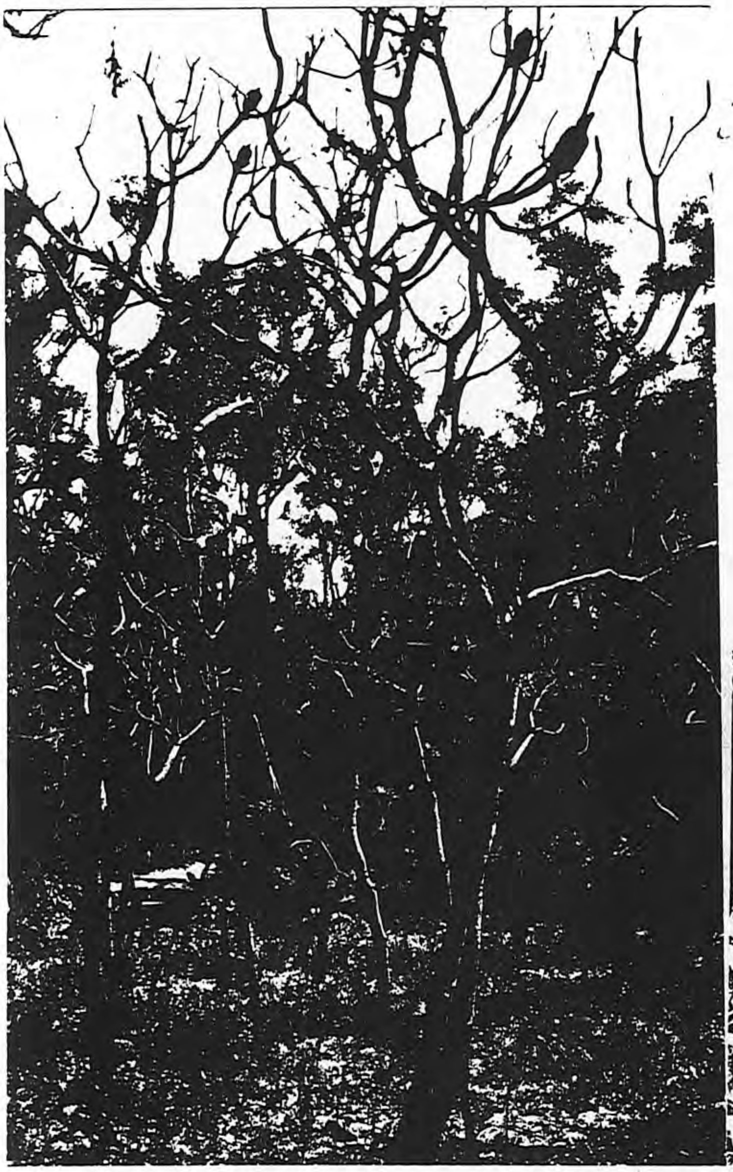

PLATE 17: Outright kill of a clump of "C" class *B. grandis* 2 years after a fire of 1500 kw/m.

PLATE 18: Outright kill of mature "C" class *B. grandis* following a fire of 1200 kw/m. There has been no damage to stems in background (2 years after fire).

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PLATE 10: Outright kill of "C" class *B. grandis*. (Note opened seed capsules)

individuals in the population have all four properties at any one phase in their life cycle. The forest floor dwelling Banksias (A class seedlings and advanced growth < 1 m) rely on a vital caudex insulated in the soil for surviving fires. The caudex is probably the product of years of selection and, providing the chance events of fire fall within the probability limits established throughout the evolution of the caudex, it will survive fire (i.e. the caudex has burn frequency/intensity limits based on the probability of such events occurring). Seedlings and small advanced growth are sexually immature and do not have a thick protective bark. The above ground parts are readily killed by fire. It would appear that its purpose is to build up energy reserves (caudex) to occupy any space that is created. The second category of Banksias (B class) are the suppressed individuals of the current co-dominants possibly with a few struggling advanced growth individuals. In this class, are found exceptions to the statement above concerning the fire adaptive features. A number of these individuals show all four traits, but are usually i) very poor flowerers (having only 1 to 3 cones), ii) have a thin protection of bark and iii) varying degrees of caudex vitality, although most individuals (~ 85%) have a viable caudex. The third class (C class) of Banksias are the co-dominants. These are heavy flowerers, and, providing their bark is able to insulate the cambium from killing heat, will successfully replace a scorched or defoliated crown from epicormic meristems. However, many of these individuals do not have a vital caudex. It would appear that as the ability to produce hormones which initiate flowering, increases, the greater is the inhibitation of caudex regeneration. Flowering ability appears to be linked with dominance status (crown/root development).

PLATE 20: Regeneration from caudex of "A" class *B. grandis* (~~breaks~~ 6 weeks after fire)

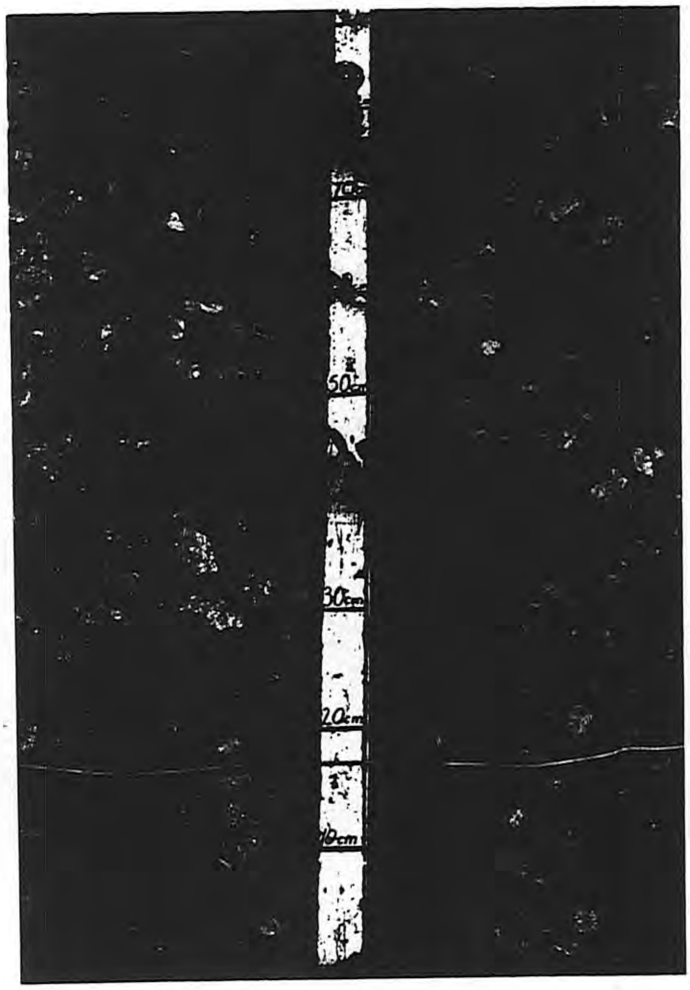
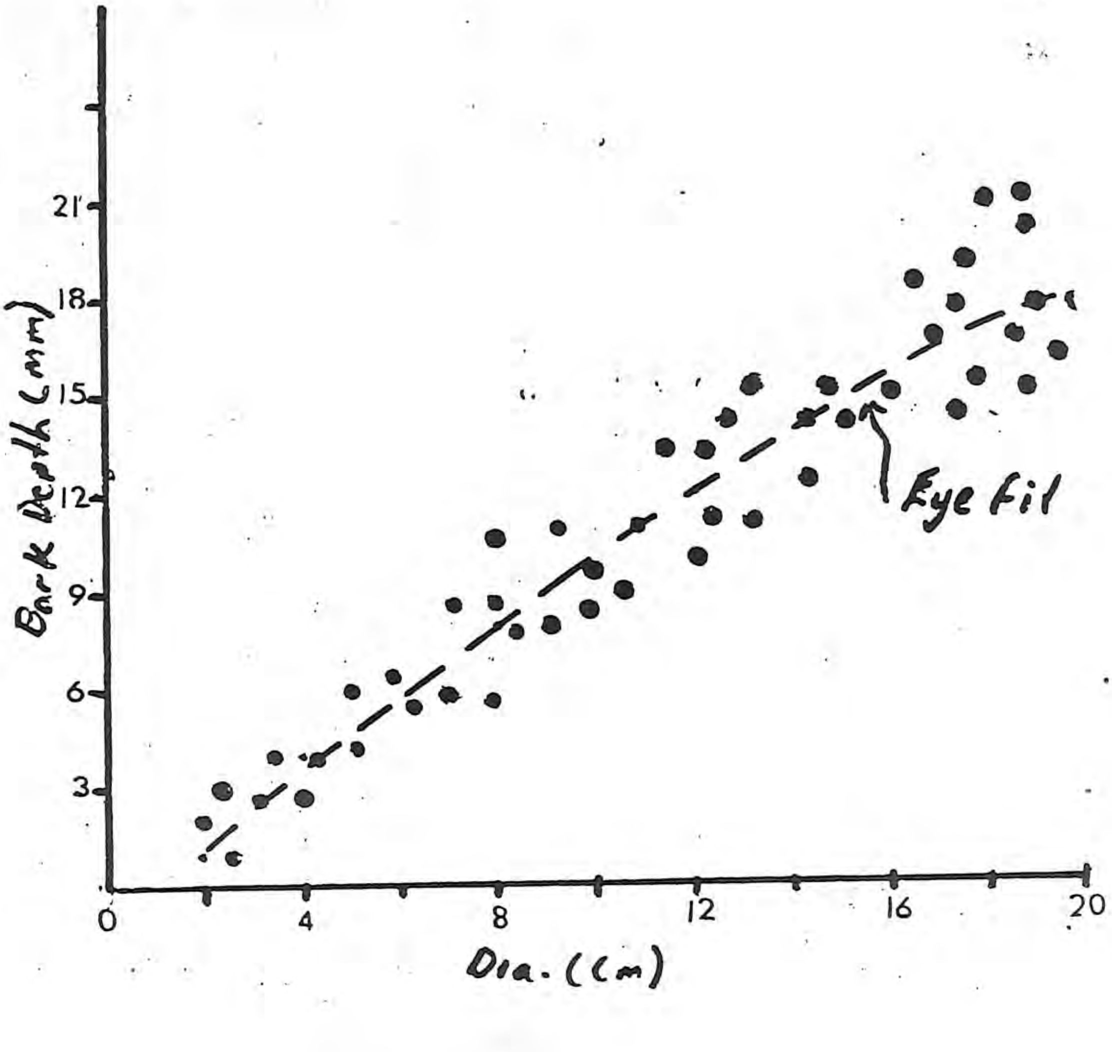


PLATE 21: Viable rootstock of "B" class *B. grandis*

PLATE 22: Typical *B. grandis* structure - Harrington Block (Note A, B, & C class individuals)

PLATE 23: Complete dominance by *B. grandis* - Young Block

FIGURE 22: *B. grandis* bark thickness vs diameter (B.H.)



Figures 21a - d suggest a substantial reduction in the "B" size class range following low intensity fires. This is somewhat misleading as, with very few exceptions, all stems have been killed back to ground level and have re-sprouted from the caudex. Consequently all such stems appear in the "A" size class (0 - 1 cm diameter). If one assumes that all such stems will survive to regain their formudimensions in a few years, the low intensity burn will have had an insignificant effect on the *B. grandis* population (~~as indicated by the red line~~). Even following recruitment from larger size classes, there is an apparent reduction in numbers of the 0 - 1 cm diameter class following all fires. Although the post burn number is still very high, losses in this diameter class are probably due to i) heavy grazing of the new shoots, thereby obscuring them from assessment, ii) operator error or bias in assessment, iii) a decline as a result of death by fire of young seedlings without a caudex or other natural causes. A similar decline in numbers in the control plot is assumed natural (other than fire) mortality. Low intensity fire (200 - 400) has killed outright, a small number of smaller diameter C class stems. The number and diameter class killed increases with intensity. All that is required to kill outright the larger C class stems is a fire of sufficient intensity to girdle the stem. Resistance to fire then becomes a factor of intensity and bark thickness, (see fig. 22 - Bark thickness) with intensities of around 1000 - 1200 kwm^{-1} killing a substantial number of larger diameter stems. The Harrington Banksia population is slightly more resistant to fire than the Young Block population as it is composed of more stems of larger diameter (bark depth) than the Young Block stands. Young Block contains a high number of individuals lacking a vital caudex and which are vulnerable to girdling (small diameter).

A more detailed statistical analysis will be carried out on the Dwellingup Banksia data when a second year post burn assessment has been undertaken. By this time, survivors will be readily identifiable. In essence then, it appears as though the initial impact of summer fire on *B. grandis* population depends on

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i) fire intensity, ii) physiological structure of the stand, iii) diameter class structure of the stand and, speculatively, iv) fire frequency (seedlings need a limited time to develop viable caudexes).

3.8 *Acacia pulchella* Regeneration

It is far to early to accurately assess successful *A. pulchella* regeneration. A second assessment in March - April 1982 should reveal the extent of regeneration. A visual inspection of the subplots indicated a high level of germination in those subplots in which the species was present before burning.

The following is a discussion of soil temperatures during fires, which should relate to the density of regeneration of *A. pulchella*, and in extreme cases, to the survival of caudexes.

PLATE 24: Exclusion (grazers) plot to examine legume regrowth (10 months after fire).

Soil temperature data collected from within each thermocouple sample plot were variable. It is not known how much variation can be attributed to the measuring technique and soil structure variation but there was considerable variation as a result of fuel loading, probe depth and soil moisture content.

The gravelly upland jarrah soils (like most) are very good heat insulators. It can also be seen that moister soils are a better insulator than dry soils (figs. 24 & 25). The third factor to which much variation can be attributed is available fuel loading (litter fuels).

The rapid decline in soil temperature with soil depth following a forest fire partially explains the survival of caudexes following intense summer fire. Figure 23 illustrates that, for given fuel/soil conditions, soil temperature is almost at ambient conditions at a depth of some 30 mm. For given conditions then, the success of regenerating legume seed requiring heat treatment depends on the location of the seed in the soil profile and its heat treatement requirements - both temperature and duration.

Fire characteristics such as spread rate, flame depth or dwell time could not account for any variation in soil temperature at 20 mm. For a given soil at a given moisture content, available ground fuel loading accounted for most variation in soil temperatures at 20 mm (figs. 24 & 25). Soil temperatures near high bulk density fuels (such as woody fuels (logs etc.)) were extremely high and stayed this way for the duration of recording (see fig. 24). There were also indications that the composition of the leaf litter fuel bed influenced soil temperature. However, this needs to be substantiated under controlled environment conditions.

Increases in soil moisture content reduced heat penetration (fig. 25). This may also have been partially due to increased fine fuel moisture content, resulting in a nett reduction of total heat flux as energy is lost as latent heat. There is much literature dedicated to the heat treatment requirements

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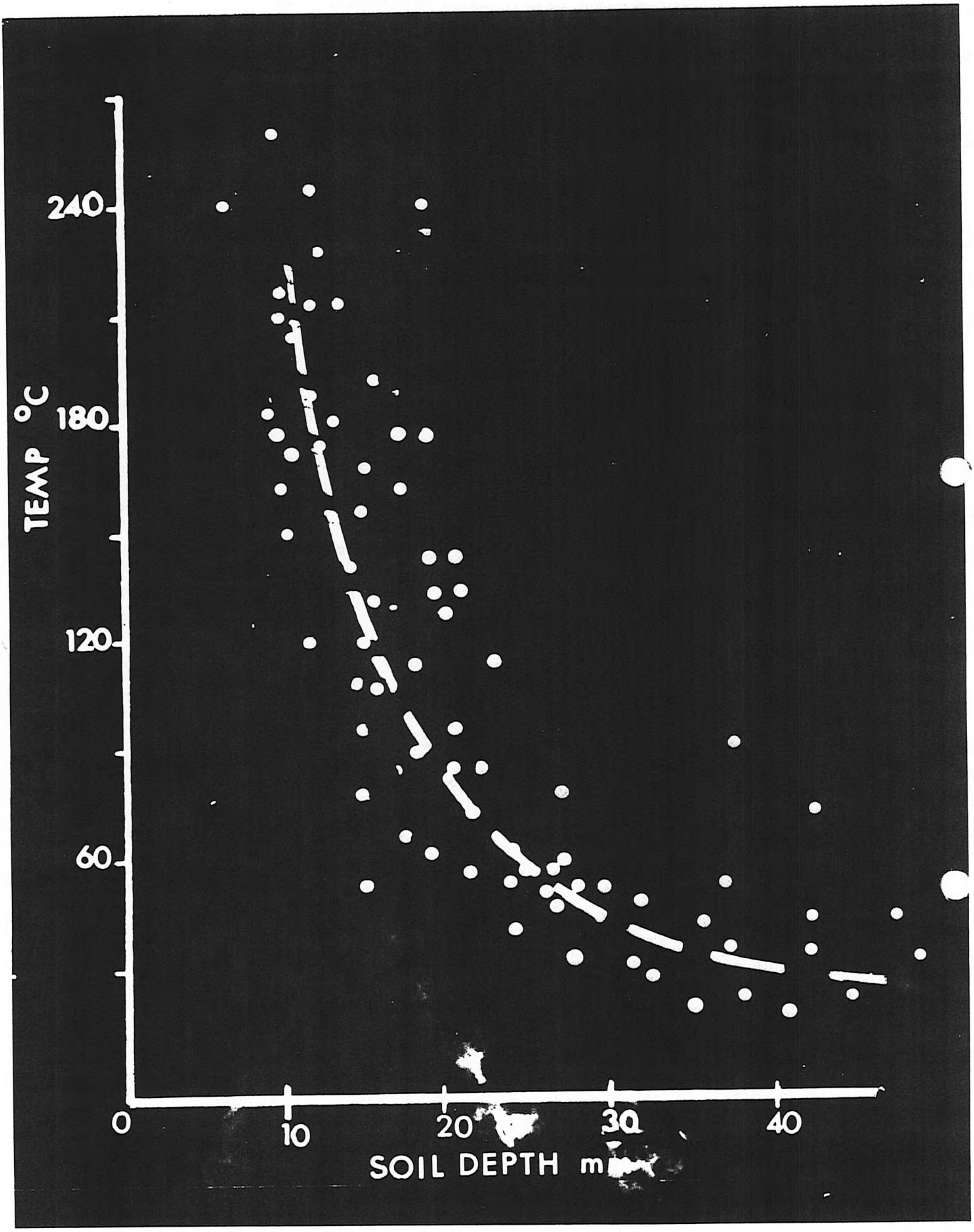
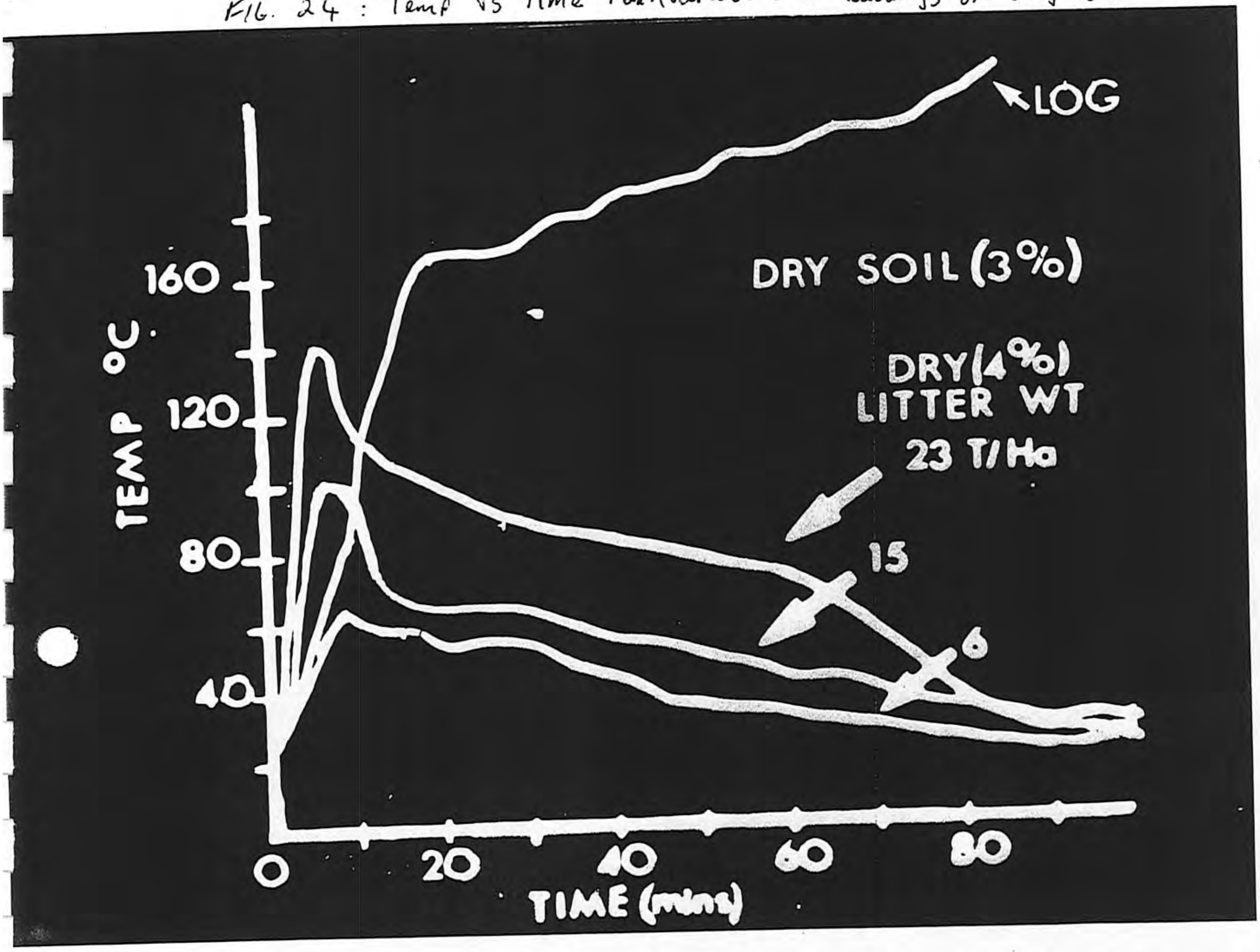


FIGURE 23: Temperature vs Soil depth following a fire on dry soil which consumed ~10 T/ha of dry litter.

FIG. 24 : Temp vs Time ~~For~~ Following the burning of various fuel loadings on dry soil.



of hard seeded species. For some species, moist heat is preferable to dry heat etc., but if in fact *A. pulchella* seed is buried deep in the soil (10 - 30 mm) then the available fuel loadings required for heat to penetrate to these depths on moist soils would be extremely high. Seed germination is no guarantee of the successful establishment of a legume stand. There is some evidence which indicates that fires which consume all ground fuels and scrub and which burn under dry summer - autumn conditions enhance the successful establishment of legumes.

Many workers have shown that different soil types have often vastly different thermal properties. Fuel types differ in their heat yield and it may be postulated that fuel beds from different vegetation species (including tree species) will have significantly different heat yields, *ceteris paribus*. This

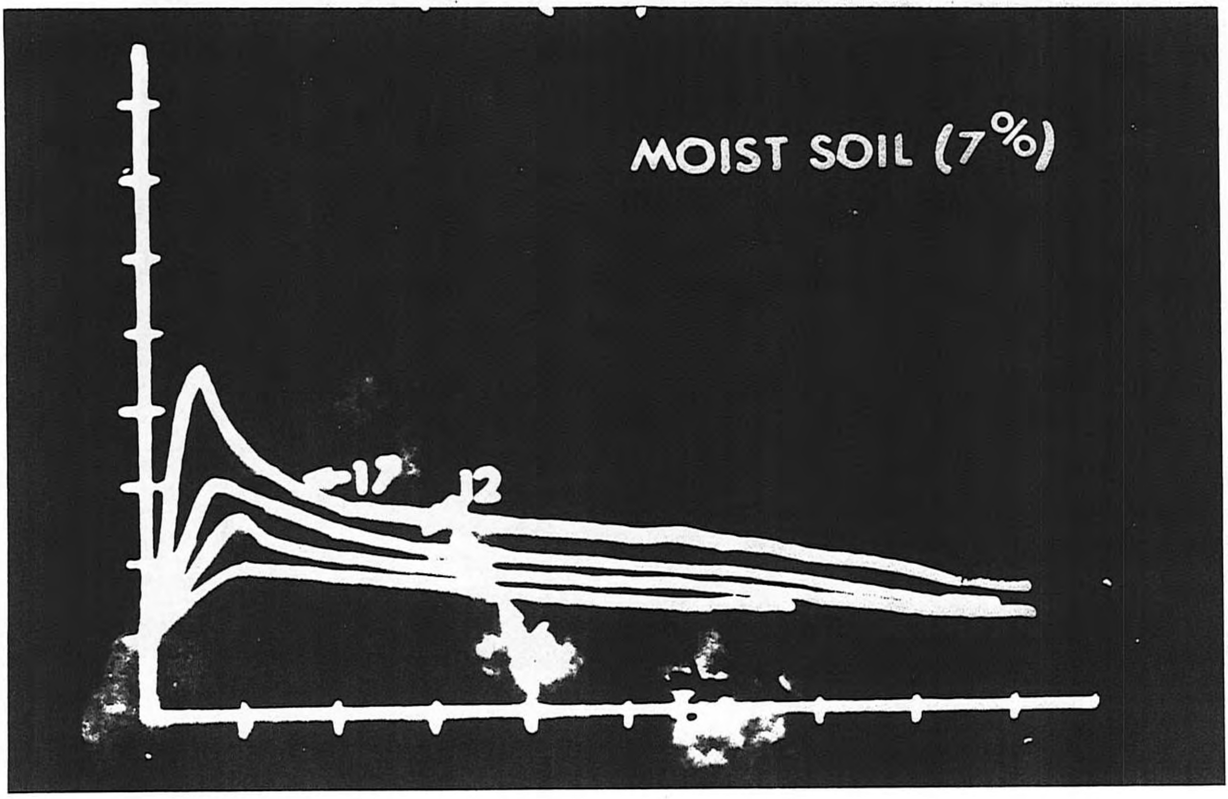


FIGURE 25: Temperature vs Time for various fuel loadings on moist soil (Scale as for Figure 24).

study has also indicated that the rate of fuel bed accumulation is linked with site productivity (although disturbed by logging, fire and disease). Within the jarrah forest, soils vary from grey sands over pale yellow sands to lateritic gravels. Associated with these soil changes are changes in topography, vegetation species and biomass productivity (Havel) including litter accumulation and composition. Given this, it could be postulated that fire behaviour and intensity above ground and the soil time/temperature curves may be vastly different for different sites burning under similar ambient conditions. If this is so, then it may be inaccurate to examine the effect of fire and fire regimes in the jarrah forest collectively, but more accurate to examine the prediction of fire behaviour and the prescription of fire regimes and their effects in relation to site characteristics.

4. CONCLUSIONS

The Young Block fire series generally supports the results and conclusions of the Harrington Block series. Forest fire behaviour for small plots under dry summer - autumn conditions has been studied and is presented in a useable format in Appendix 1. It must be stressed that large fires under summer conditions can change the fire environment within which they are burning. Slight changes in wind, temperature and relative humidity can lead to significant and seemingly unexplainable changes in fire behaviour. Intended fire behaviour studies in conjunction with C.S.I.R.O. should provide the necessary information on the behaviour of large (100 ha) summer fires. The small plot studies in Harrington and Young Block suggest that under most summer - autumn conditions, steady state fires will burn at a low - medium intensity (250 - 800 kwm^{-1}), providing winds are low (10 - 20 K.P.H. tower). Wind strength is the most dominating component of fire behaviour under dry fuel conditions. Tower wind readings and forecast wind strengths should be within ± 5 km/hr if accurate forest fire spread rates are to be predicted. This requires a detailed knowledge of the wind interception ratios in each forest type and local influences on wind strength and direction. Managers using the prediction tables should, ideally, ensure that i) accurate tower wind readings are available from a number of representative sites throughout the Division, ii) know the wind interception ratio of the various forest and scrub types, iii) know the local changes in wind conditions, iv) know the changes in temperature and relative humidity throughout the Division and v) know the fuel - both litter and vegetation - changes and types.

The fire behaviour model developed from this study generates lower spread rates for low wind readings than the Forest Fire Behaviour Tables but estimates higher spread rates for higher wind readings than indicated by the "Red Book". The small number of trials at Young Block also indicated an amplified fire behaviour of mass fires (multi-ignition) under summer conditions. This is further dealt with in a Pilot study report, which highlights the need for an understanding of the mass fire situation if prescribed burning under dry conditions to achieve a higher intensity fire is to be successful and controlled.

Fire damage to commercial timber species (jarrah) has only been assessed by the post burn, visual extent of drysiding. The far reaching significance, in terms of a reduction in available timber, can only be guessed at. There is a real need for detailed research including a mill study, to determine the real loss of timber (if any) as a result of fire damage. A stand fully scorched following summer fire, quickly replaces its crown in 2 years during which time there is no significant increase in basal area. Small trees ($<$10 cm) are readily killed to ground level by fire in excess of 500 kwm^{-1}.

The resistance of the *B. grandis* population to fire is influenced not only by the fires intensity, but also by the size and physiological age (vitality) structure of the stand. Fires of an intensity near 1200 kwm^{-1}, immediately reduce the basal area of most *B. grandis* populations. However, most smaller stems re-sprout with permanent mortality being only recorded in most stems in excess of 6 cm D.B.H.O.B. (or the sexually active individuals). Probably the greatest fire protection of the Banksia population in a large area of forest, is the extreme variability in fire intensity experienced by a burnt forest. In a forest of 6 year old fuels, there is, at most, 10 - 15 tonnes/ha of litter fuels (which, in itself is variable). To achieve an intensity of 1200 kwm^{-1} would mean a spread rate of near 200 m/hr. If the headfire spreads at this rate, then at most only 1/3 of the total area is treated at the required intensity, as back and flank fires will be much slower - therefore *B. grandis* would survive and probably re-populate the headfire treated zones. The perimeter (∴ area treated) of headfire could be increased considerably by manipulating multiple ignition patterns to yield optimum treatment of area at a desired intensity. This would reduce the area burnt by low intensity back and flank fires. In all cases, there will be a percentage of the forest burnt at a very low intensity as ignition spots develop. An understanding of mass ignition fire behaviour would enable close estimates of the area treated by intensity classes. A greater degree of coverage of *B. grandis* eradication type burns could be achieved by allowing a greater build up of fuels (up to 20 tonnes/ha). This means a risk of high intensity occurrences in a burn prescribed to give mean head and flank fire spread rates of 100 m/hr. There is also the risk of loss or severe damage of the timber resources by wildfire. If this becomes of secondary importance, then allowing a heavier build up of fuels would be the most desirable approach for the initial fire treatment of *B. grandis* populations.

Two ambient conditions favouring fire spread (i.e. high temperatures and low relative humidity) would also enhance Banksia kill as pre-heating by radiant energy appears to be enhanced under warm, dry conditions.

Following fire, legume regeneration was readily achieved on dry soils containing seed. Depth of heat penetration was found to be a factor of soil dryness and quantity of available litter bed fuels. Soil type and fuel type are likely to influence soil temperature but rate of spread and intensity, *per se*, had no influence on soil temperatures at 20 mm below soil surface.

Appendixed is a condensed and simplified working table of the Fire Behaviour results of this study. It is not expected that this model will be accurate if used outside the conditions of this study. Further work, particularly on the behaviour of large steady state fires and mass ignition fires is required if fire management is to be at a high level of expertise.

ACKNOWLEDGEMENTS

Thanks are due to the Busselton Research gang, Kirup machine operators and Dwellingup gangs and officers who so ably assisted with the construction, control and mop-up of plots. Thanks are also due to Dave Ward for his help with data computation and to Fiona Styles who patiently typed this report and Tom Leftwich for plate figures.

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SITE VEGETATION MAPPING IN THE NORTHERN JARRAH FOREST (DARLING RANGE)

1. DEFINITION OF SITE VEGETATION TYPES.

BULLETIN No 86; F.D. of W.A.

TABLE 1a

JARRAH FOREST HEADFIRE RATE OF SPREAD INDEX FOR WIND, TEMPERATURE & RELATIVE HUMIDITY CONDITIONS

Wind Ratio		Tower wind velocity (km/hr)											
1:1		1.0 - 2.0			2.1 - 2.5			2.6 - 3.0			3.1 - 3.5		
1:2		2.0 - 4.0			4.1 - 5.0			5.1 - 6.0			6.1 - 7.0		
1:3		3.0 - 6.0			6.1 - 7.5			7.6 - 9.0			9.1 - 10.5		
1:4		4.0 - 8.0			8.1 - 10.0			10.1 - 12.0			12.1 - 14.0		
1:5		5.0 - 10.0			10.1 - 12.5			12.6 - 15.0			15.1 - 17.5		
1:6		6.0 - 12.0			12.1 - 15.0			15.1 - 18.0			18.1 - 21.0		
DEW POINT (°C)		6+	10+	14+	6+	10+	14+	6+	10+	14+	6+	10+	14+
AMBIENT TEMPERATURE (°C)	20+	18	16	13	22	20	17	28	25	20	35	32	26
	22+	20	18	15	25	23	19	31	28	24	40	36	30
	24+	22	20	18	28	26	23	35	32	28	45	41	36
	26+	25	22	20	32	28	25	41	36	32	52	45	40
	28+	28	26	23	35	33	29	44	41	36	56	52	46
	30+	31	29	25	40	37	32	50	46	40	63	59	51
	32+	35	32	29	45	40	36	56	51	46	71	65	58
	34+	38	35	32	49	44	41	62	56	51	78	71	66
	36+	41	38	35	53	48	43	66	62	55	85	79	71
	38+	46	42	38	58	53	48	73	67	61	93	85	78

TABLE 1a

JARRAH FOREST HEADFIRE RATE OF SPREAD INDEX FOR WIND, TEMPERATURE & RELATIVE HUMIDITY CONDITIONS

Wind Ratio		Tower wind velocity (km/hr)											
1:1		3.6 - 4.0			4.1 - 4.5			4.6 - 5.0			5.1 - 5.5		
1:2		7.1 - 8.0			8.1 - 9.0			9.1 - 10.0			10.1 - 11.0		
1:3		10.6 - 12.0			12.1 - 13.5			13.6 - 15.0			15.1 - 16.5		
1:4		14.1 - 16.0			16.1 - 18.0			18.1 - 20.0			20.1 - 22.0		
1:5		17.6 - 20.0			20.1 - 22.5			22.6 - 25.0			25.1 - 27.5		
1:6		21.1 - 24.0			24.1 - 27.0			27.1 - 30.0			30.1 - 33.0		
DEW POINT (°C)		6+	10+	14+	6+	10+	14+	6+	10+	14+	6+	10+	14+
AMBIENT TEMPERATURE (°C)	20+	44	40	33	57	51	42	71	64	54	91	82	68
	22+	51	45	38	64	58	48	81	73	61	103	93	77
	24+	57	52	46	73	66	58	92	83	73	118	105	93
	26+	65	58	51	83	73	65	105	93	82	133	118	104
	28+	72	67	58	91	84	74	115	107	93	147	136	118
	30+	80	75	64	102	94	81	129	120	103	164	152	130
	32+	90	82	75	114	104	93	144	132	118	183	146	153
	34+	99	71	81	125	114	103	159	145	130	202	184	166
	36+	107	99	89	136	126	113	172	160	144	219	203	182
	38+	118	108	98	150	137	125	190	173	158	241	220	201

APPENDIX 1 (ii)

JARRAH FOREST HEADFIRE RATE OF SPREAD INDEX FOR WIND, TEMPERATURE & RELATIVE HUMIDITY CONDITIONS

Wind Ratio		Tower wind velocity (km/hr)											
1:1		5.6 - 6.0			6.1 - 6.5			6.6 - 7.0			7.1 - 7.5		
1:2		11.1 - 12.0			12.1 - 13.0			13.1 - 14.0			14.1 - 15.0		
1:3		16.6 - 18.0			18.1 - 19.5			19.6 - 21.0			21.1 - 22.5		
1:4		22.1 - 24.0			24.1 - 26.0			26.1 - 28.0			28.1 - 30.0		
1:5		27.6 - 30.0			30.1 - 32.5			32.6 - 35.0			35.1 - 37.5		
1:6		33.1 - 36.0			36.1 - 39.0			39.1 - 42.0			42.1 - 45.0		
DEW POINT (°C)		6+	10+	14+	6+	10+	14+	6+	10+	14+	6+	10+	14+
AMBIENT TEMPERATURE (°C)	20+	115	104	86	146	132	110	186	167	139	236	212	176
	22+	131	118	98	166	150	124	211	190	124	267	240	200
	24+	149	134	118	189	170	150	239	216	191	303	273	242
	26+	169	150	132	201	109	168	272	241	213	344	305	270
	28+	186	172	150	236	218	191	300	277	242	379	352	307
	30+	208	193	166	236	244	210	334	310	266	424	393	338
	32+	232	212	191	295	269	242	374	341	307	474	433	389
	34+	256	234	214	325	296	266	412	376	338	522	477	429
	36+	277	257	231	352	326	293	447	414	372	566	525	472
	38+	306	279	255	388	354	323	492	450	410	633	569	520

TABLE 1a

N.B. 1 For use under summer - autumn conditions ie. when S.M.C. = P.M.C. ≤ 7%.

JARRAH FOREST HEADFIRE RATE OF SPREAD INDEX FOR WIND, TEMPERATURE & RELATIVE HUMIDITY CONDITIONS

N.B. 2 Dew point calculations <6, Use 6t.

Wind Ratio		Tower wind velocity (km/hr)											
1:1		7.6 - 8.0			8.1 - 8.5			8.6 - 9.0			9.1 - 9.5		
1:2		15.1 - 16.0			16.1 - 17.			17.1 - 18.0			18.1 - 19.0		
1:3		22.6 - 24.0			24.1 - 25.5			25.6 - 27.0			27.1 - 28.5		
1:4		30.1 - 32.0			32.1 - 34.0			34.1 - 36.0			36.1 - 38.0		
1:5		37.6 - 40.0			40.1 - 42.5			42.6 - 45.0			45.1 - 47.5		
1:6		45.1 - 48.0			48.1 - 51.0			51.1 - 54.0			54.1 - 57.0		
DEW POINT (°C)		6+	10+	14+	6+	10+	14+	6+	10+	14+	6+	10+	14+
AMBIENT TEMPERATURE (°C)	20+	299	269	224	379	341	285	481	432	360	610	548	457
	22+	339	305	239	430	387	322	546	491	409	692	622	519
	24+	385	346	307	488	439	389	619	557	493	785	705	626
	26+	437	387	343	554	491	435	703	623	552	892	790	700
	28+	481	446	389	610	566	494	774	718	626	982	910	794
	30+	538	499	429	682	633	544	865	802	690	1097	1017	874
	32+	601	549	494	763	697	626	968	883	794	1227	1120	1108
	34+	662	605	544	840	767	696	1065	973	875	1351	1234	1109
	36+	718	666	600	911	845	760	1155	1071	963	1465	1358	1222
	38+	791	722	660	1003	916	836	1272	1162	1061	1613	1473	1345

APPENDIX 1 (iv)

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TABLE 2a

JARRAH LITTER BED FUEL QUANTITY CORRECTION FACTORS

AVAILABLE FINE FUELS (T/HA)	SURFACE MOISTURE CONTENT
	3 - 7%
4.1 - 6.0	0.9
6.1 - 8.0	0.9
8.1 - 10.0	1.0
10.1 - 12.0	1.2
12.1 - 14.0	1.4
14.1 - 16.0	1.6
16.0 - 20.0	1.8

N.B. This table requires refinement under controlled environment conditions.

TABLE 3a

JARRAH VEGETATION FUEL TYPE
CORRECTION FACTORS

LITTER FUEL CORRECTED SPREAD RATE	VEGETATION TYPE (6 y.o)		
	0	3	4
0 - 100	0.9	1.0	1.0
101 - 300	0.9	1.0	1.2
300 +	0.9	1.0	1.3

where;

Vegetation Type 0 = <10% ground cover of scrub

Vegetation Type 3 = Vegetation on upland sites, gravelly soils, often containing;

Adenanthos barbigera
Hibbertia montana
Tetratheca setigera
Ispogon sphaerocephalus
Leucopogon capitellatus
Persoonia longifolia
Bossiaea ornata

Vegetation Type 4 = Vegetation on lower lying, poorly drained sites, often contains;

Xanthorrhoea preissii
Agonis parviceps
Adenanthos meissneri
Leptospermum crassipes
Adenanthos obovata

N.B. 1) A more detailed investigation of other scrub types and age since burn is required.

2) Slope corrections etc. as per "Red Book".