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# Fire modelling and fire weather in an Australian desert

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## ABSTRACT

Hummock grasses form a discrete fuel for landscape fires in the vast arid and semi-arid regions of Australia. For fires to spread in such discrete fuels, the flames need to be long enough to cross gaps, under sufficient wind to have large tilt angles, and impinge on the next hummock long enough to ignite it. Wind speed, discrete-fuel loadings, fuel moisture contents and gap-size distributions are key characteristics for fire-spread modelling in these fuels. Present models derived in the arid region do not have universal application.

Once a model is formed, formal prediction of fire spread requires a three-stage process: (i) a domain analysis for the applicability of the inputs to the fire-spread model; (ii) a likelihood-of-any-spread analysis; and, (iii) application of a spread model to predict rate of spread of the headfire.

That direct inputs, such as fuel moisture, are not available for models on a routine basis creates problems of prediction. For fully cured fuels, fuel moisture may be expected to be a function of fuel temperature, fuel humidity, and wind speed near the ground; these variables are not directly available so they, too, must be predicted. With each extra step in the estimation of inputs, further errors in spread prediction are likely to arise.

At Rudall River National Park in north-western Western Australia, fire weather may reach extremes. Temperatures are often over 40°C, dew points drop to – 37°C; and winds, unattenuated by trees, reach 50-60 km h$^{-1}$ at any time of the year. Fuels may appear completely dead while gaps between plants may extend a metre or more.

Appropriate fire-weather indexes for the arid region need to be determined independently of fuel considerations and should not be tightly linked with fire behaviour because of the great spatial variety found in fuel condition. Any one-step index linked to fire behaviour is likely to fail because several variables need to reach threshold levels before spread will occur.

## INTRODUCTION

Hummock grasses are the main fuel type over thousands of square kilometres of arid Australia. Fire intervals there are thought to be from 5 to 50 years (Walker 1981). However, there have been few studies of fuels, fires or weather. In this paper, we introduce a number of problems, submit some new ideas, and present pertinent data and experiences relating to the spread of fires in hummock grasses. We examine the context of fire spread in and near the 1.6 million hectare Rudall River National Park (Australia's second largest national park) in arid north-western Australia. Because the relief of the landscapes are generally subdued we ignore terrain. We consider only fuels, fire weather (in the broadest sense) and the spread of fires.

## DISCRETE HUMMOCK-GRASS FUELS

Hummock grasses are the predominant fuel of the arid zone; they are a unique Australian growth form in which:

> 'Each plant branches into a great number of culms which intertwine to form a hummock and bear rigid, involute, pungent leaves representing a serried phalanx to the exterior.' (Beard 1981)

Hummock grasses belong to the genera *Triodia*, *Plechtrachne*, *Symplectrodia* and *Monodia* (Jacobs 1992). They occur on rocks, sand and laterite (Beard 1981), usually with bare ground between the plants.

Hummock grasses may be too moist to burn (as in many parts of Rudall River National Park in the winter of 1992) or remain moribund and highly flammable for years (as in the Gibson Desert from 1988-1991); both the cured and green condition may exist in the same region at the same time (as at Rudall River National Park in 1992). The hummock grasslands of our study areas were largely of live material, the only apparently dead material being the immediate subcanopy leaves and the persistent remnants of leaf sheaths on the tillers. Hummocks at suitable moisture contents supported fire even without the growth of ephemerals in the usually bare areas between the plants. After 27 mm of rain overnight in January 1993 at Rudall River National Park, hummock grasses, straw coloured at first, became greener over the next few days (A.M.Gill, P.H.R.Moore and B.Ward, personal communication); a similar observation has been made in the Gibson Desert (N.D.Burrows, personal communication).

The coverage of hummocks over the ground may vary widely from near 100 per cent in some drainage lines to near zero on some rocky hills. Plant size, and shape (see above), may also vary widely. Plants 25-30 cm tall were common in the study area. Hummocks varied widely in density (i.e. number of plants per unit area), degree of aggregation (genets per hummock), aggregate shape and height, and within-plant bulk density (plant weight per unit volume); these attributes, along with moisture content and windspeed, have a major bearing on whether or not a fire will spread.

The appropriate manner in which to record the sizes and patterning of spinifex hummocks for prediction of fire spread needs further research. The only method reported so far has been the wheel-point (point quadrat) method (Griffin and Allan 1984; Burrows *et al.* 1991) which records plant presence or absence every 1 m along a transect. This method gives an estimate of cover and an index of pattern based on the number of consecutive wheel-point contacts made on plants, or on bare ground. On the basis that the fire spreads when the gap between plants is breached by a flame of a suitable length developed from a hummock of an appropriate size (Bradstock and Gill 1993), we need to know the length of flame developed from any hummock and the distance that flame will have to breach to ignite another. Bradstock and Gill (1993) found flame length to be correlated with hummock height and diameter for circular hummocks. For irregularly shaped hummocks, we have been exploring the idea of randomly selecting a hummock, selecting a random compass direction, measuring the longest intercept across the hummock in the chosen compass direction and aligned with the nearest neighbour, measuring the shortest distance from the edge of the hummock to the nearest neighbour along the same compass orientation ('gap width'), and measuring hummock height, width and length. Our results for gap widths (Fig. 1) show various frequency distributions (for 50 measurements per site) with gaps up to 2 m or more on some occasions; in our three study sites at Rudall River National Park, the frequency of gaps less than 60 cm wide was 70 per cent, 66 per cent and 46 per cent. While this idea for fuel measurement in discrete hummock-grass fuels needs to be tested in the light of experimental fires, it has potential in that it directs attention to the obstacles in the way of fire spread in discontinuous fuels. We do not know what the consequences to fire spread of the different frequency distributions of gap and hummock sizes may be but these could be predicted if isosceles triangles can be used as templates for spread, the template shapes and sizes representing flame shapes and dimensions in plan view.

Prediction of hummock sizes, and the widths of gaps between them, as a function of time since fire is a challenge waiting to be met. Plant cover, and therefore fuel loading (Griffin and Allan 1984), is a function of accumulated rainfall since the previous fire (Griffin 1992) but the way the pattern changes with time needs to be investigated.

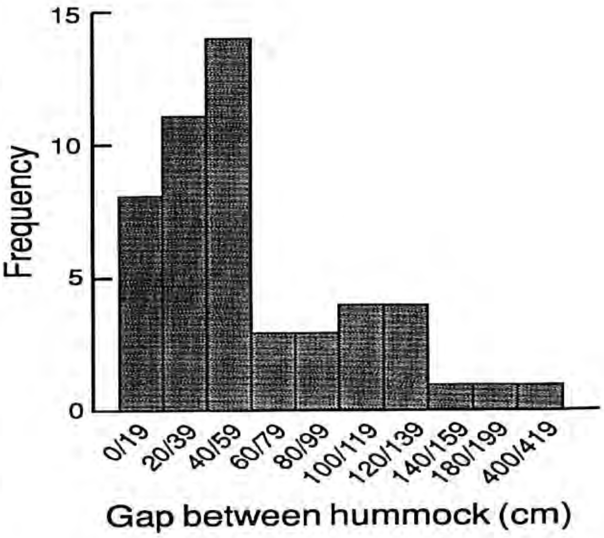

*Figure 1. Frequency distribution of gap widths in a spinifex grassland fuel at the Rudall River site.*

## FIRE WEATHER

Fire weather indices provide a guide as to the effect of weather on fire behaviour. McArthur's (1967) 'fire danger meter' for eucalypt forests, asserts that the weather index given by the meter is 'directly related to the chances of a fire starting, its rate of spread, intensity and difficulty of suppression ...'. The index is based on windspeed together with factors contributing to fuel moisture. The index reflects the effects of weather on fire behaviour. The equivalent McArthur (1966) index for grasslands uses a different formula (Noble *et al.* 1980).

Relating weather data to the moisture content of fuels like *Triodia* - which may be green and live, or grey and dead - is difficult. Dead fuel moisture may be estimated from equations such as those of Byram and Jemison (1943) but a number of steps are involved (Fig. 2). Predicting live-fuel moisture may be even more difficult and involve inputs of soil moisture and vapour pressure deficit of the air (Fig. 2). However, the nature of moisture content changes with desiccation of the environment in these plants is unknown. Stems of hummock grasses (*ca* 2 mm diameter) were a significant proportion of the fuel that may be moist while leaves were drier. Here, we present an overview only, of the weather in the vicinity of Rudall River National Park.

The climate of the region may be characterized (using unpublished Bureau of Meteorology data from Telfer, 70 km to the north) as one with a low rainfall most of which falls in summer, high temperatures (*average* daily maxima in summer are near 40°C), low humidities (*average* relative humidity at 3.00 p.m. at Telfer for October is 11 per cent) and high evaporation rates. Telfer had an average annual rainfall of 291 mm over the period 1974-1991 with a marked summer incidence. The maximum average monthly rainfall was 84 mm in February. Average evaporation rate peaked in November at 15.0 mm day$^{-1}$ and fell to a minimum in June when the value was 5.6 mm day$^{-1}$. Our experience was that, in summer, rainfall tended to occur as local storms so that the weather station record is not always a true reflection of the weather over the region.

Wind is a most important variable in determining whether or not a fire will spread in discrete fuels and, if the fire does spread, how fast it will travel. Wind may also affect temperatures of dead fuels (Byram and Jemison 1943) and of live fuels through transpiration. Average monthly 3.00 p.m. windspeeds at Telfer varied from 14-17 km h$^{-1}$ with little variation throughout the year. Frequencies of winds were greatest in the 0-10 km h$^{-1}$ class, the frequency then declining with each higher windspeed class. Wind speed within any one month may range up to about 60 km h$^{-1}$. In January 1993, at Rudall River National Park, we found that strong winds were associated with the presence of nearby storms (dry in our case) which were shortlived. Longer lasting cyclonic winds may be important at some times in some years.

To summarize: fire weather in the Rudall River area can involve frequent high temperatures, low humidities and low soil moistures, and occasional high winds.

## THREE-STAGE FIRE MODELLING

Fire managers sometimes talk of fuels which either carry fire extremely well or not at all - 'stop-go' behaviour; such fuels are usually discrete. In discrete fuels, even dry ones, fires will not spread unless the wind is relatively strong. Fires in similar, but continuous, fuels will spread even without wind. When the wind is above the threshold for spread, the fire may spread at the same rate as in a continuous fuel. If so, the apparent 'stop-go' behaviour is explained (Fig. 3); the more discrete the fuel, the sharper the contrast in the 'stop-go' behaviour.

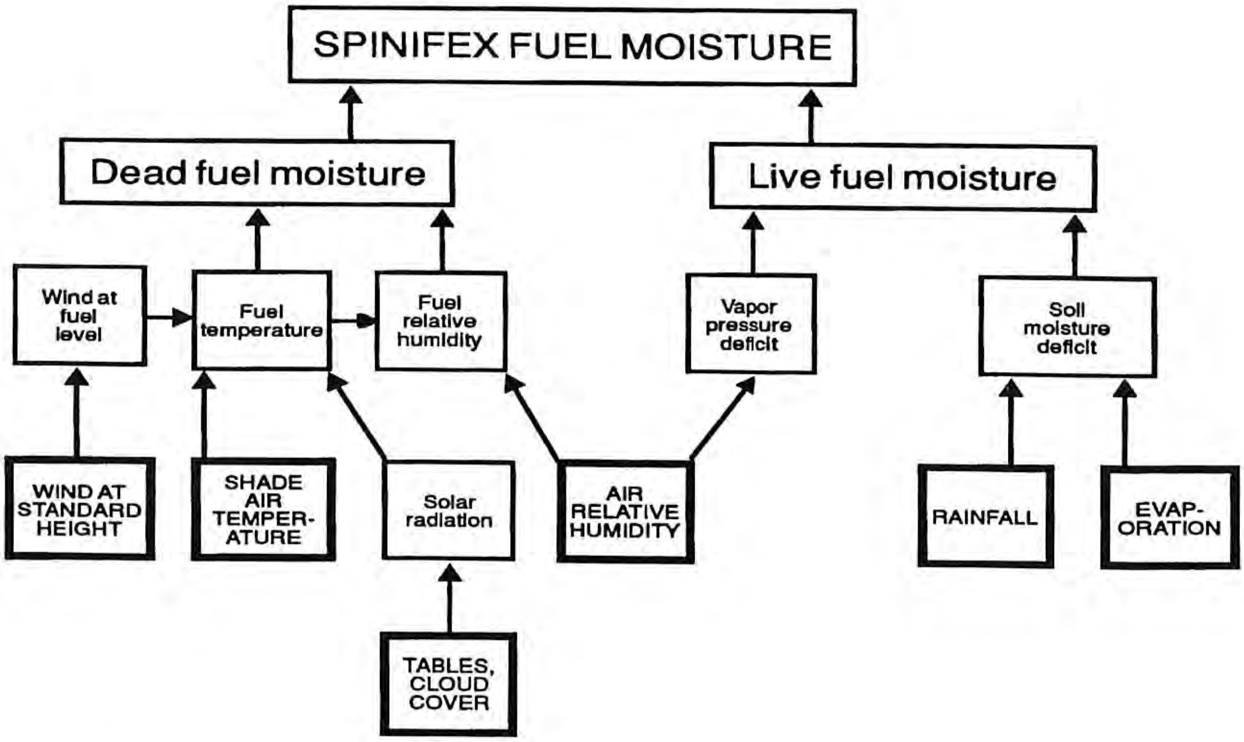

*Figure 2. Simplified chart suggesting variables that may need to be considered for the prediction of fuel moisture from standard weather variables in order to predict sunlit dead-fuel (after Byram and Jemison 1943) and live-fuel moisture. Variables in double boxes are input variables.*

For fires to spread in discrete hummock grass fuels, flames generated in the hummocks need to be long enough, winds need to be strong enough to angle the flames enough, gaps need to be narrow enough for the flames to breach them, and ignition delay time needs to be short enough for the 'receiver' hummock to ignite. We can imagine a number of factors limiting spread despite individual hummocks being ignitable. For example: if winds are too light, flame tilt may be inadequate for spread; with strong winds, flames may be horizontal, but the fire will not spread to the next hummock unless the reach of the flame at least equals the gap size; and, the fire will not spread if the flames do not impinge long enough on the hummock to cause ignition. To predict when fires would start to spread, therefore, requires that certain (multiple) threshold conditions need to be met. The same could be argued for continuous fuels although rate-of-spread models for continuous fuels are not usually designed to predict threshold conditions of spread - or when fires will go out. For example, the equations for the rate-of-spread meter of McArthur for forests (Noble *et al.* 1980) never zero in relation to moisture content (through its surrogates, air temperature and relative humidity), and, mathematically at least, a moisture content too high for combustion can be compensated for by a strong wind. In Rothermel's (1972) formulation, the problem is handled, in part only (Wilson 1985), by the use of a minimum moisture content for fire extinction.

Following Gill and Bradstock (personal communication), it is suggested that the scientific use of rate-of-spread models be *formalized* into three stages:

(i) a domain analysis to determine whether or not the data to be put into the rate of spread equations are within the limits of those used in equation formulation;

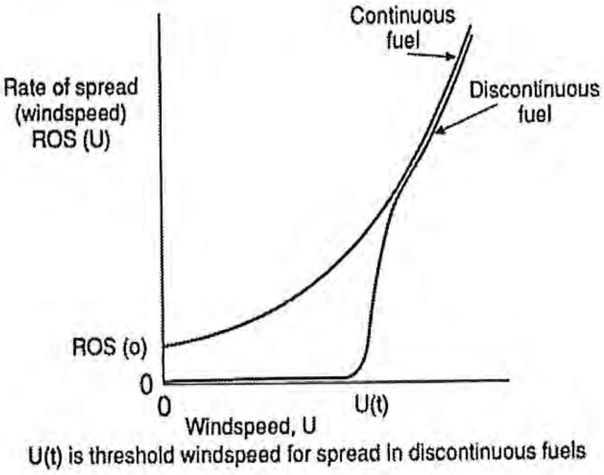

*Figure 3. Graph illustrating the likely relationship between fire spread in continuous versus discrete fuels. In discrete fuels, fires will only spread after certain thresholds have been overcome; when this happens, fire spread may be quite rapid.*

(ii) an initiation-of-spread analysis to predict the probability of spread, which, in its simplest form, would predict whether or not the fire would spread at all; and,

(iii) a rate-of-spread prediction.

For hummock grasslands, Griffin and Allan (1984) have given the domains to which their equations for predicting rates of spread apply; the conditions include a maximum windspeed of 3 m s$^{-1}$ (*c.* 11 km h$^{-1}$) at 2 m height, air temperatures of 23 to 35°C and relative humidities from 12 to 40 per cent. For the Rudall River area, even average weather conditions are often outside these domains. In experimental Gibson Desert fires, the environmental variables under which fires were measured spanned a much wider range than those used in Central Australia by Griffin and Allan (1984), *viz.* windspeeds to 36 km h$^{-1}$, air temperatures to 50°C, and relative humidities from 14 to 48 per cent (Burrows *et al.* 1991), yet the same formulations used by Griffin and Allan could be used to predict fire rates of spread. Thus, Burrows *et al.* (1991) effectively expanded the domains of Griffin and Allan's (1984) equations as far as weather was concerned.

For fuel, a simplistic example shows the importance of keeping within domains. If Griffin and Allan's (1984) 'fuel factor' (inversely proportional to the square root of fuel moisture content) is extended beyond stated domains to include zero moisture content, its value becomes infinite, as does the predicted fire rate of spread.

Threshold conditions for spread have rarely been stated for any fuel type but various values have been suggested for windspeed in hummock grasses, *viz:*

- 16-24 km h$^{-1}$ (McArthur 1972);
- 12-17 km h$^{-1}$ (Burrows *et al.* 1991); and,
- <11 km h$^{-1}$ (Griffin and Allan 1984).

At Rudall River in January 1993, it was found that winds gusting up to 50 km h$^{-1}$ at 2 m height were insufficient to carry flames between hummocks, presumably because fuels were too moist, at 24 per cent, and flames too short to bridge the gaps between the hummocks (A.M.Gill, P.H.R.Moore and B.Ward, personal observation). All limits - gap width, wind strength, flame length, discrete-fuel loading, fuel moisture - not just any one, need to be overcome if fires are to spread.

The third stage in the prediction of the rate of spread of the fire is the use of models, usually in the form of mathematical equations. Griffin and Allan's (1984) model was the first for fires in spinifex grasslands. For fires in the same type of grassland, but in the Gibson Desert, Burrows *et al.* (1991) found that spread rates, using the same formulae as Griffin and Allan (1984), were less than half those predicted. The main reason for this wide discrepancy may involve the way in which fuels were evaluated (see above). Similarly, the successful use of the square of windspeed to predict fire spread in the Gibson Desert (Burrows *et al.* 1991) may not have general application; some modification of equations would appear to be necessary for their application to areas with different fuel conditions.

## CONCLUSION

Despite the considerable advances made in our knowledge of fires in spinifex grasslands in the last decade we still have much to learn if we are going to be able to predict when discrete hummock-grass fuels will ignite, whether or not fires in hummocks will spread, and how fast they will travel once they do spread. We need to know: how to predict the moisture contents of hummock grasses; how to characterize and predict fuel distributions as a function of time since fire or cumulative rainfall since fire; how to depict fire weather in arid lands; and how to parameterize the factors limiting fire spread in hummock-grass fuels.

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