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Fuel and fire behaviour in semi-arid mallee-heath shrublands

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Abstract
An experimental burning program was set up in South Australia aimed at characterizing fuel dynamics and fire behaviour in mallee-heath woodlands.
Fuel complexes in the experimental area comprised mallee and heath vegetation with ages (time since fire) ranging from 7 to 50 years old. Dominant overstorey mallee vegetation comprised *Eucalyptus calycogona*, *E. diversifolia*, *E. incrassate* and *E. leptophylla*. A total of 66 fires were completed. The range of fire environment conditions within the experimental fire dataset were: air temperature 15 to 39°C; relative humidity 7 to 80%; mean 10-m open wind speed 3.6 to 31.5 km/h; Forest Fire Danger Index 1.7 to 46. Total fuel load ranged from 0.38 kg/m^2 in young (7-year old) mallee to 1.0 kg/m^2 in mature stands. Fire behaviour measurements included rate of spread, flame geometry, residence time and fuel consumption. Measured rate of spread ranged between 0.8 and 55 m/min with fireline intensity between 144 and 11,000 kW/m.
The dataset provided insight into the threshold environment conditions necessary for the development of a coherent flame front able to overcome the fine scale fuel discontinuities that characterise the semi-arid mallee-heath fuel types and support self-sustained fire propagation. The data also provided a better understanding of the variables determining the behaviour of self-sustained fires, including rate of fire spread, flame dimensions, crowning and spotting activity.

Keywords: fuel accumulation, fire dynamics, Eucalyptus shrublands, rate of fire spread, crowning, spotting

1. Introduction

Mallee woodlands occupy extensive areas in southern Australia. Key values associated with mallee woodlands are biodiversity and maintenance of remnant populations of a wide range of vertebrate and invertebrate species. Fire is a determinant component of these ecosystems. The occurrence of large fires associated with periods of extreme fire potential can lead to local extinguishment of certain species (McCaw 1997). The application of prescribed burning to create a diverse mosaic of fuel ages has been proposed as a method to reduce landscape level fuel continuity and reduce the likelihood of large fire occurrence. Nonetheless, the use of prescribed burning in managing the potential of large fire development has been hindered by the complex nature of fire spread in these fuel types and the difficulty in predicting it.
Mallee-heath vegetation occurring in semi-arid climates develops a vertically non-uniform and spatially discontinuous fuel complex. As a broad description, the fuel complex has a mallee overstorey ranging from 2 to 10 m high depending on time since fire, bioclimatic conditions and soil type. Long strands of bark suspended along the stems and an intermediate canopy layer of tall shrub species (e.g., *Callitris ssp.*) constitute ladder fuels that facilitate the transition from a surface to a crown fire. The understorey elevated fuel component (0.5 to 2 m tall) comprising a large range of species, namely sclerophyll and semi-succulent shrubs, develops in the understorey. The extent of this heath understorey

varies from dense to moderately dense. A lower layer of tussock and hummock grasses, ephemeral herbs, low sedges, low shrubs and dead suspended material comprises the near-surface layer with heights ranging between 0.1 and 0.3 m. The presence of the overstorey and elevated layers suppress the development of the near-surface layer, resulting in a sparse and discontinuous layer. Although not determining fire spread per se, the high dead/live ratios of this layer constitute an important fuel to sustain fire propagation in the elevated layer. Fluxes of ephemeral grasses can follow periods of above average rainfall, increasing the cover of the near-surface layer to a level where it becomes the main fuel layer carrying the fire. The litter layer in mallee heath fuel types vary from a well developed layer under the mallee clumps to a very sparse cover under the shrubs, where the fine dead leaves tend to mix and be partially buried by sand (Bradstock and Gill 1993).

The discontinuous nature of this fuel complex constrains fire propagation under low to moderate burning conditions, the environment normally sought for prescribed burning operations. Determining the fire weather conditions that will allow the development of a flame front that provides the propagating flux necessary for a fire to self sustain is key to planing and conducting prescribed burning operations in mallee woodlands. A flame front ignited below these threshold conditions will fragment into discrete units that will fail to breach fuel gaps and eventually lead to its extinguishment. The prediction of fire spread in these discontinuous fuel complexes is seen as a two-step process (Gill et al. 1995; Burrows et al. 2009). The first component requires determining the conditions for sustained fire propagation. The second component of the process applies after sustained fire propagation occurs and deals with predicting the fire behaviour quantities that can be used to support decision making, e.g., rate of spread, flame geometry, residence time, fireline intensity and spotting characteristics.

This study aimed to characterizing fuel dynamics and fire behaviour in mallee-heath woodlands of South Australia. The project was developed with the aim of conducting a sufficient number of experimental fires under a range of weather conditions and fuel complex structures to understand the effect of fire environment variables on fire behaviour and the interdependencies between fire behaviour characteristics.

2. Methods

The study was conducted from 2006 to 2008. The experimental area (35° 45’ S, 140° 51’ E) located within the Ngarkat Conservation Park, South Australia, is a characteristic dune and swale system comprising large flat areas with relatively small dunes intermixed. Elevation was approximately 130 m above sea level. Soils in the area are Aeolian sands of varying depth, overlying deep alluvial soils of the old River Murray delta (Specht and Rayson 1957).

The area fire history and local landform variations resulted in a mosaic of fuel complexes that allowed the study of fuel structure on fire behaviour. The area had three fuel age classes resulting from wildfires occurring in 1958, 1986 and 1999 and two fuel types: mallee dominated shrubland (mallee-heath) and heath. Heath vegetation from the 1958 wildfire could not be located at the site and this age of heath is relatively rare in this landscape. The Mallee-heath fuel type is characterized as open woodland with *Eucalyptus calycogona*, *E. diversifolia*, *E. incrassata* and *E. leptophylla* as dominant overstorey species and an understorey of *Astroloma conostephioides*, *Adenanthos terminalis*, *Babingtonia behrii*, *Calytrix involucrata*, *C. tetragona*, *Daviesia benthamii*, *Dillwynia hispida*, *Leptospermum coriaceum*, *L. myrsinoides* and *Phyllota pleurandroides*. A ground layer of mixed grasses and sedges was also present. In the experimental area this fuel type tended to be absent from deep sandy soils and dune crests, being often found in areas where soils tended to be more loamy with a higher clay content. By contrast the heath fuel type tended to be associated with large flat inter-dunal swales and areas with deeper sands. Dominant vegetation in this fuel type was *Banksia ornata*, *Leptospermum myrsinoides* and *Babingtonia behrii*. Mallee clumps were almost absent (typically cover < 5 %) in the heath-classified areas.

Fuel characterization

Fuel complex characterisation involved a variety of sampling methods aimed at quantifying the physical properties of each fuel stratum and surrogate variables. We defined the fuel complex as being an aggregate of two strata, the surface stratum encompassing litter, near-surface and elevated fuel layers, and the canopy stratum, encompassing the intermediate and overstorey canopy layers (Fig. 1). Fuel assessment was based on the point intersect method in conjunction with destructive sampling. A systematic sampling grid was established within each experimental plot. Transect lines were established within a sub-set of experimental plots to determine gap size and distribution, fuel layer/stratum cover and height through the point intersect method (Canfield 1941). Three transects were systematically established paralell to the expected fire spread direction in 13 experimental plots. Transect length varied with plot size, from 200 m in the smaller plots to 400 m in the larger plots. Fuels were sample every 1-m along the transect line. At each point, intercept of bare ground, litter, near-surface, elevated and overstorey canopy fuels along with the dominant fuel layer height were recorded.

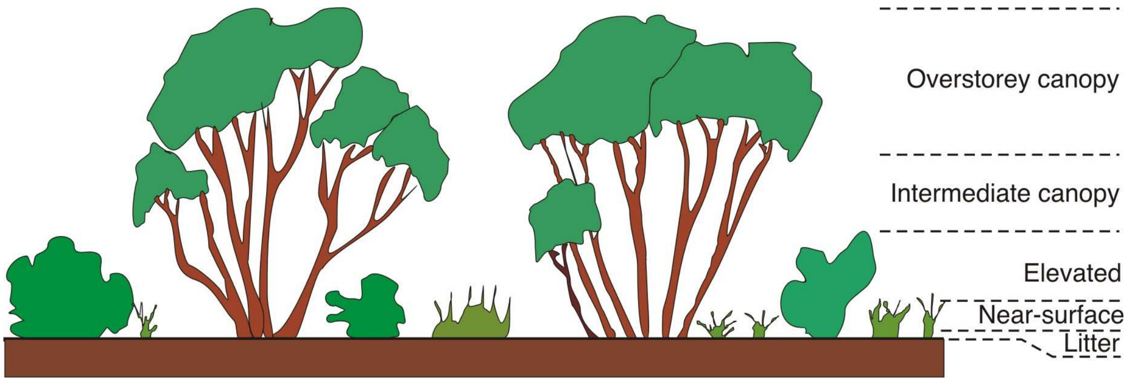

Figure 1. Idealized profile of mallee-heath fuel complex

Measurements of fuel quantity per fuel layer (litter, near-surface and elevated), state (live and dead) and size class (live: diameter (d) < 3 mm, dead: $d < 6$ mm, 6 mm < d < 25 mm, d > 25 mm) were conducted in a 2-m^2 sampling quadrat randomly located along a sampling transect. Total number of destructive fuel sample plots varied with the size of the burn plot and resources available. Prior to fuel destructive sampling, fuel layer height and cover were visually estimated within the quadrat. The harvested fuels were sorted and weighted in situ ensuring no particle loss. After weighting, a subsample of each fuel category was taken and place in a sealed container for fuel moisture determination. Fuel moisture samples were oven dried at nominally 100°C for 24 hours to determine their dry weight.

Overstorey mallee canopy biomass (foliage, live twigs (d<0.3 mm) and dead twigs (d < 6 mm, 6 mm < d < 25 mm)) was destructively sampled. Within each fuel age, nine plants were randomly selected to cover the observed height range. Prior to felling, measurements of canopy dimensions (width, length and depth) and height were recorded for each mallee clump (comprising several stems). The stems were felled into a large polyethylene sheet and fuel particles were partitioned by category and weighted in situ. As per the shrub component, a subsample of each fuel category was collected into a sealed container for fuel moisture determination. Live fuel moisture content samples were oven dried at nominally 100°C until a constant weight was reached.

Fire experiments

To quantify the effect of weather and fuel variables in determining sustained fire propagation and fire behaviour characteristics, two types of experimental fires were conducted: (a) fire sustainability and (b) fire behaviour experiments. Fire sustainability (go / no-go) experiments aimed to quantify the conditions that allow sustainable fire propagation. Fire behaviour experiments aimed to measure fire characteristics in well-developed flame fronts. The sustainability experiments were smaller in scale than the fire behaviour experiments. This was a compromise to gather a sufficiently large dataset on fire sustainability given constraints derived from the size of the experimental area and the distribution of plots by fuel type/age. The size of the fire sustainability plots allowed fire to develop into a pseudo-steady state propagation stage but would not provide information on the transient nature of fire propagation and short range spotting characteristics, features that were measured on the fire behaviour plots.

Ignition and plot dimensions

Ignition line length depended on plot size, fuel type and prevalent weather conditions. Initial trials indicated that an ignition line length less than 75 m produce less than pseudo quasi-steady rate of spread with an ever-decreasing flame front width. It was found in these trials that ignition line lengths of 100 - 110 m would sustain pseudo quasi-steady fire spread throughout the length of the experimental plots. Given the predefined plot layout it was established that a fire sustainability experiment would have a 110 - 120 m long ignition length and an approximate run of 100 m. Plots 250 x 250 (≈6.2 ha) were divided into 4 subplots of equal size (≈1.5 ha). Fire sustainability experiments were ignited along the windward side of the subplot. If the flame front failed to propagate the burn was considered a no-go and subsequent ignition was planned for when weather conditions would sustained fire spread.

For the fire behaviour experiments the ignition line lengths varied depending on the FFDI and the experimental objectives. Under High or lower Fire Danger conditions (FFDI[1] < 24.9) simultaneous ignitions in distinct fuel types (mallee vs. heath; 9- vs. 20- vs. 50-year old fuels) had 110-120 m long ignition length. Above the Very High Fire Danger class lower threshold (FFDI = 25) fire behaviour experiments were conducted in a full 250x250 m plot with an ignition line of 220 m, and no simultaneous ignitions took place. This scaling up of the fire experiment allowed measurement of fire behaviour characteristics that are relevant for the fire propagation process under severe burning conditions, namely spotting and crowning behaviour. Ignition lines were established with two operators using handheld drip torches. Ignitions started at the centre of a pre-marked ignition line, with the lighters moving outward at a fixed pace to ensure development of a solid flame front in less than 2 minutes.

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[1] Forest Fire Danger Index (McArthur 1967)

Weather

Three automatic weather stations (AWS) were placed at fixed locations during the experimental burning program. At these locations air temperature, relative humidity, wind speed and direction (measured at 10-m in the open) were averaged and logged at 10 min intervals.

For each experimental fire, detailed wind measurements were conducted at two locations in the vicinity of the burn. A 10-m tower with two 2-D sonic wind sensors (WindSonic 1, Gill Instruments Ltd; located at 2 and 10-m heights) was placed 50 to 75 m along the side of the burn plot. A smaller tower with a sole 2-D sonic wind sensor at 2-m was placed 50 to 75 m on the windward side of the ignition line centre. Both towers were located in areas of fuel structure representative of the experimental fire. The 10-m tower with two anemometers provided a rough characterization of the vertical wind profile close to the vegetation. Wind direction and speed measurements were made at a frequency of 1 Hz, with 5-sec averages being recorded before, during and after each experimental fire. The relatively short time interval at which wind was sampled aimed to characterise the gust and lull structure prior and during each experimental burn.

Fuel moisture

Moisture content of dead fine fuels was measured by destructive sampling. Two types of samples were collected from both mallee and heath vegetation. Surface litter was collected from the top 10 mm of the litter layer. At locations where the litter layer was less than 10 mm deep, the entire layer was sampled. Suspended dead fuel samples were taken from between 0.1 and 1.0 m height, depending on the vertical distribution of fuel at each sampling location. Fifteen minutes prior to each experimental fire five samples each (10 – 20 g) of litter and suspended fuel dead material of diameter < 6 mm were taken and placed in a sealed tin. Dead fuel moisture samples were also collected after the completion of experimental fires if it was perceived that fuel moisture content changed between the pre-fire samples and the end of the experiment.

The large number of understorey and overstorey species made it impractical to sample live fuel moisture from specific species. Live fuel moisture data was collected while conducting destructive fuel sampling in the days preceding each experimental burn. Six to twelve samples (number varying with plots size) of live fuel (foliage and live twigs diameter < 3 mm) were systematically collected along three transects. Each sample (40 to 60 g) was placed in a sealed tin. The sample tins were returned to a field laboratory where they were weighed, dried for 24 hours at a nominal temperature of 100 °C in a fan forced oven, and then reweighed. Fuel moisture content was calculated as a percentage of oven-dry weight.

Fire behaviour measurements

Fire behaviour was monitored through instrumentation set prior to the burn and direct observation by researchers. Thermologgers were buried or placed within insulated containers through a grid pattern within each burn plot. The grid sampling of fire spread characteristics yielded information on its variability. A thermologger consisted of a small datalogger (HOBO® U12, Onset, Massachusetts, USA) with a 200 mm long, 1.5-mm diameter, type K metal-sheathed thermocouple (Pyrosales, NSW, Australia). Thermocouple size and characteristics was a compromise between response time and durability. Loggers sample temperatures at 1 Hz, Grid spacing varied between 25 and 50 m, depending on the expected rate of fire spread and number of plots being burned simultaneously. The thermologger registered the time the flame front arrived at each grid point. The time of fire arrival, assumed to coincide with a temperature of 320ºC (Albini 1985) was used to determine the rate and direction of fire spread through a triangulation method (Simard et al. 1984, McCaw 1997). Flame time-temperature profile, flame residence time and an estimate of flame depth were derived for each grid point. The grid was set up with compass and hip-chain, and griped points georeferenced with GPS (Trimble GeoXT).

Two groups of two fire behaviour observers in close proximity to the flame front monitored fire characteristics throughout each experiment. Fire behaviour observations recorded at 2-minutes intervals were: fuel layers supporting fire spread, flame geometry (depth, height and angle), spotting activity (distance, quantity and density), overstorey canopy consumption and in-draughts. In low intensity fires the observers mapped the fire perimeters at 2-minute intervals through the use of numbered metal tags and surveyed their locations after the experiment.

3. Preliminary results and discussion

Fuel

The mallee-heath and heath fuel types are an aggregate of discrete fuel layers with distinct dynamics (Table 1), with the development of each particular fuel layer dependent on weather/climate factors and competitive influences of other layers (Bradstock 1989). We did not sample fuel structure for stand ages younger then 7-years (fuel age is time since fire). Between age 7 and 21-years fuel dynamics in the heath fuel type was characterized by an increase in height and maintenance of load at a steady level for the near-surface and elevated fuel layers (Table 1). For the mallee-heath fuel type, changes in the near-surface fuel layer were not significant, whereas all other layers showed a significant increase in cover, height and load (with the exception of the overstorey canopy cover) (Table 2).

Table 1: Changes in fuel structure characteristics with age in heath fuel type.
∇ denotes significant increase (p< 0.1); © denotes significant decrease (p<0.1); = denotes no significant change (p>0.1).

Fuel property	7 – 21 years			
	Litter	NS	Elev.	OS
Height	=	∇	∇	∇
Load	∇	=	=	=

Table 2: Changes in fuel structure characteristics with age in mallee-heath fuel type
∇ denotes significant increase (p< 0.1); © denotes significant decrease (p<0.1); = denotes no significant change (p>0.1).

Fuel property	7 – 21 years				21 – 50 years			
	Litter	NS	Elev.	OS	Litter	NS	Elev	OS
Cover	∇	=	∇	=	=	=	©	∇
Height	∇	=	∇	∇	=	=	∇	∇
Load	∇	=	∇	∇	∇	=	©	∇

Changes in the mallee-heath fuel complex structure between age 21 and 50 years were complex, highlighting the competitive interactions between the various strata, where the expansion of upper strata restricts the development of the understorey fuel layers. There were significant increases in all overstorey canopy fuel metrics, while the elevated fuel layer (likely the single most important fuel layer in this fuel type) increased in height, but had a significant reduction in cover and load. The near-surface layer characteristics remain unchanged during this period.

The results in Table 1 and 2 follow Walker (1981) and Bradstock (1989) speculative reasoning on fuel complex dynamics in mallee-heath vegetation. Distinct fuel layers evolve with time since fire disturbance as a function of competition stresses. Both the near-surface and elevated fuel layers increase in relevance with time after fire, peaking before competition limits development and induces a regressive condition. When considering both fuel load and cover evolution with time, the distinct growth habits of the plants that constitute each fuel layer will determine particular dynamics of development.

Fire behaviour

A total of 66 fires were burned in the period 2006-2008 (May 2006, April 2007, March 2008). Fig. 2 shows the full dataset divided into sustained and self-extinguished fires plotted against the fuel moisture content and 10-m open wind speed. Forest Fire Danger Index (FFDI) classes are displayed on the background. The dataset provides an adequate cover of the range of conditions under which prescribed fires in mallee-heath are likely to occur (Noble 1986; Sandell et al. 2006), and extends into drier ranges of dead fuel moisture (below 5%) typical of summer time conditions.

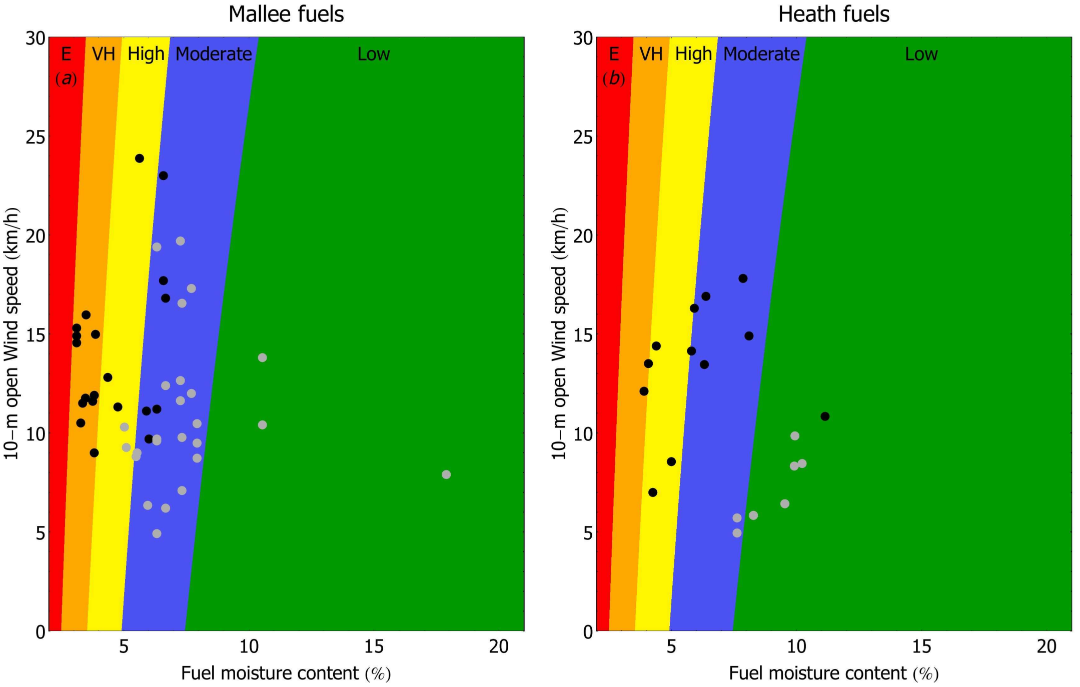

Figure 2. Fine dead fuel moisture and 10-m open wind speed plotted in relation to FFDI classes (McArthur 1967) for the mallee and heath fuel types. Black and grey dots identify sustained and self-extinguished fires respectively.

Table 3 and 4 presents the experimental range of weather and fire behaviour variables partitioned by fuel type and age. Within the mallee-heath vegetation type, the fires with highest FFDI were conducted in the younger ages (Table 3). No experimental fires were conducted under Very High Fire Danger Index conditions in the older fuels due to the high risk of fire escape from the experimental area associated with higher long range spotting potential present in these fuels.

Table 3. Range in weather and fire behaviour variables associated with mallee-heath experimental fires.

	Fuel age (years)		
Variable	8	21	49
Fire weather			
Air temperature (ºC)	18.5 – 39	18.5 – 37.2	16 – 36
Relative humidity (%)	12 – 50	7.2 – 50	15 – 80
10-m open wind speed (km/h)	4.9 – 14.9	9 – 19.7	6.2 – 23.9
2-m wind speed (km/h)	3 – 9.1	3.4 – 10.5	2.2 – 9.4
FFDI	5.8 – 44.1	5.7 – 46.1	1.7 – 34.4
Litter layer moisture content (%)	3.4 – 13.2	1.9 – 19.9	4.2 – 13.4
Suspended dead fuels moisture content (%)	5.2 – 15.3	4.2 – 17.6	6.6 – 17.1
Live fuel moisture content(%)	63 - 76	51 - 93	58 - 89
Fire behaviour *			
n (sustained spread fires)	7 (2)	14 (8)	22 (8)
Rate of fire spread (m/min)	28.7	5.91 – 46.6	1.2 – 55.1
Fireline intensity (kW/m)	6450	1591 – 6931	735 – 10956
Flame height (m)	4	1.5 – 3.8	0.8 - 6

* Fire behaviour data is relative to sustained fires.

Table 4. Range in weather and fire behaviour variables associated with heath experimental fires.

	Fuel age (years)	
Variable	8	21
Fire weather		
Air temperature (ºC)	17.5 – 32	14.5 – 33.6
Relative humidity (%)	26.3 – 55	20.2 – 60
10-m open wind speed (km/h)	4.9 – 14.4	5.7 – 17.8
2-m wind speed (km/h)	4.2 – 10	4 – 13.7
FFDI	3.9 – 20.9	3.5 – 25.8
Litter layer moisture content (%)	3.4 – 14.4	4.0 – 20.4
Suspended dead fuels moisture content (%)	7.4 – 16.1	6.5 – 15.0
Live fuel moisture content (%)	63 - 84	67 – 93
Fire behaviour *		
n (sustained spread fires)	5 (2)	18 (12)
Rate of fire spread (m/min)	11.2 – 43.9	9.1 – 38.5
Fireline intensity (kW/m)	1153 – 6328	1866 – 7302
Flame height (m)	2.3 - 3	1.3 – 2.8

* Fire behaviour data is relative to sustained fires.

Fires in the heath fuel type were conducted under milder fire weather conditions than in the mallee fuels. The range in rates of fire spread and fireline intensities in Table 3 and 4 are relative to plot averages. Higher rates of spread and intensities were observed over small time intervals as a response to wind gusts. The average rate of fire spread is a weighted mean taking into account the length of several runs within an experimental fire. The initial run (first 25-50 meters depending on burning severity) of each fire, in which the flame front was not yet in equilibrium with the environmental conditions, was not considered in the calculation of average rate of spread. Flame height measurements were restricted to a number of fires (n=33). This dataset comprises sustained and self extinguished fires that spread for more than 10 minutes. Not all sustained fires yielded flame dimension data. Smoke and safety constrains limited the estimation of flame dimensions in some of the experimental fires carried out in the mature mallee-heath fuels.

The results from this study of fires in mallee-heath fuels can be categorised into three different states of propagation potentials.

1. Sustain fire propagation- Dead fuel moisture content was found to be the dominant fire environment variable determining fire sustainability. The moisture content of dead suspended fuels was found to better explain fire sustainability than the moisture content of litter fuels. The threshold fuel moisture content for sustainable fire propagation was observed to be strongly dependent on fuel structure. Live fuel moisture was independent on the effect on fire sustainability. Other variables, such as wind speed and fuel cover, have a measurable effect on fire sustainability and will allow fire to spread under higher, or require lower, fuel moistures contents depending on the ambient wind speed and fuel cover. Wind speed had a significant effect on the likelihood of sustained propagation. Overall, 2-m wind speed, a proxy of midflame wind speed, was a better discriminator than 10-m open wind speed. The presence of wind is necessary to aid the process of fire propagation.

2. Surface fire propagation - After self-sustained propagation and a continuous flame front is established, wind speed was the environmental variable with the largest influence on the rate of fire spread. The strong effect of wind speed can be attributed to two fuel complex features: the absence or open nature of the overstorey component and low fuel loads. The open nature of the mallee woodland induces limited mechanical reduction in wind speed with height. None of the dead fuel moisture content measures were significantly correlated with rate of fire spread. This can be partially accounted for the fire dependent mechanisms determining overall fire spread and the heat transfer efficiency associated with vertically oriented fuel beds. Analogous results were obtained by McCaw (1997) in Western Australia mallee-heath. The effect of dead fuel moisture in other shrub fuel complexes has been shown to be limited (e.g., Catchpole et al. 1998). Of all the fuel descriptors analysed only fuel load was found significant correlated with rate of fire spread ($p<0.05$). The relationship between fuel load and rate of spread was negative, i.e., the lower the fuel load, the higher the rate of spread. At first this relationship seems to be at odds with accepted fire behaviour theory (e.g., McArthur 1967). However, this inverse relationship emerges because a large proportion of the fast spreading fires were in young mallee and heath fuels. Some form of crown fire activity was found to be an ever-present feature of sustained fire propagation in mallee stands. The flame structure required to provide the necessary propagating heat fluxes that sustain surface fire propagation in-between mallee clumps would flare up and induce crown combustion, i.e., torching, upon reaching the litter and hanging bark ribbons that accumulate under the mallee canopy. Under moderate burning conditions it was found that isolated crowning would not cause an increase in the

overall fire spread rate but it would produce a number of spot fires that would assist in breaching areas devoid of fuel

3. Crowing propagation - Intermittent and active crown fire propagation was observed in a number of experimental fires. These higher intensity fires were characterised by high rates of spread and prolific spotting activity. These three fire behaviour features, crowning activity – high rate of spread – spotting activity, seem to be interdependent and occur simultaneously. As fire environment characteristics such as wind speed and fuel dryness increase, fire behaviour intensity escalate with the outcomes of each of these fire behaviour characteristics self-reinforcing the other two. The relationship between wind and rate of fire spread was observed to be discontinuous, or stepped, as described by Cheney (1981). The large effect of wind speed and the feed-back fire mechanisms were found to be the main factors driving crowning activity. Fuel structure and fuel moisture content were not found to have a significant effect on crown fire activity.

4. Conclusions

Mallee-heath fuel complexes are comprised of discrete fuel layers with distinct dynamics. A succession of fuel layer dominance with time was identified. The prevalence of near-surface fuels in the first years since fire is followed by a dominance of the elevated fuel layer at an approximate age of 10-years. As the mallee stand matures, the overstorey fuel strata reach an asymptotic cover and fuel quantity value, and the elevated layer decline in relevance. This dynamic is approximate and dependent on edaphoclimatic conditions and relative short-scale climatic cycles. Low fuel coverage and load were identified as the main fuel characteristics limiting fire propagation in mallee-heath. Average fuel loads were typically low varying between 0.5 and 0.7 kg/m^2.

Fire behaviour in mallee-heath fuel types is characterised as being discontinuous. We identified three states of fire propagation potential. A lower state where a fire if ignited will self-extinguish, a middle state where high intensity surface fire propagation will occur with the passive involvement of the overstorey crown fuel layer, and a third state where a high intensity, fast spreading crown fire develops. Surges between fire propagation states can be caused by small variations in the environment conditions but lead to sudden and significant changes in rate of fire spread and intensity. Drops between states have the opposite effect.

Fire behaviour in the two lower states was observed as being largely dependent on fuel moisture content (largely determining fire sustainability) and wind speed (main control of fire rate of spread). The extent that higher wind speeds can offset the effect of higher fuel moistures is limited to fuel moisture contents up to 15%. For higher fuel moistures, although the increase in heat transfer efficiency associated with higher winds allow a recently ignited flame front to propagate forward, the lack of flank propagation and fuel discontinuity lead to a rapid fragmentation of the flame front into ever increasing smaller segments, followed by flame extinguishment.

The transition from the second state (high intensity surface fire / intermittent crown fire) to an active crown fire required mature mallee fuels and moderate to high wind speeds (10-m open wind speeds >15 km/h). As the fire transitions into this higher state the fire attains a pseudo steady-state rate of fire spread that depends not only on weather conditions, but also on the interdependence of high fireline intensity, crowning and spotting behaviour.

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