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The influence of ignition technique on fire behaviour in spinifex open woodland in semiarid northern Australia

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Abstract. Unplanned, unmanaged wildfires are a significant threat to people, infrastructure and ecosystems around the world. Managed, planned burning is widely used for reducing the incidence, extent or intensity of wildfires. Fire weather and the season of burning are recognised as crucial factors influencing fire behaviour but the demonstrated influence of ignition technique on fire behaviour is not as prominently discussed in relation to planned fires. We found wildfires, irrespective of season, burnt the ground layer more completely (i.e. were less patchy) and produced greater crown scorch severity than did planned fires in a spinifex (*Triodia* spp.)-dominated open woodland. Fires ignited with a 50-m line burning with the wind produced significantly higher intensities than did line ignition against the wind, and spot ignitions with or against the wind. These data suggest that the higher severity of wildfires in spinifex-dominated habitats is strongly influenced by long fire fronts, in addition to fire season and weather conditions. This study supports the value of planned burning for reducing fire severity and highlights the value of spot ignitions in ecological burning to create a patchily burnt landscape, with limited canopy severity.

Additional keywords: planned burning, semiarid rangeland, wildfire.

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Introduction

Unplanned and unmanaged wildfires may provide some level of ecological service, such as plant recruitment, but are often highly intense and extensive, sometimes causing human fatalities, as well as infrastructure and ecological damage across the globe (Penman *et al.* 2011; Attiwill and Adams 2013; Le Maitre *et al.* 2014; Waltz *et al.* 2014). Managed, planned fires have been demonstrated to reduce the incidence, severity and extent of wildfires by reducing fuel loads, and because they can be implemented during mild weather conditions and using ignition techniques that minimise fire intensity (Fernandes and Botelho 2003; Boer *et al.* 2009; Cheney 2010; McCaw *et al.* 2012; Burrows and McCaw 2013). Direct comparisons between the severity of wildfires and associated planned burns in forest ecosystems show wildfires to be considerably more severe (Volkova *et al.* 2014).

Fire behaviour is influenced by several factors, especially weather conditions and fuel load characteristics, the latter related to time since last fire (Cheney and Sullivan 2008; Murphy and Russell-Smith 2010; McCaw *et al.* 2012). Wildfires are particularly severe and extensive when they occur in hot, dry conditions. The intensity of fires in tropical savannas with tussock grasses has been shown to have a strong seasonality, with higher intensities in the late dry season compared with early dry season (Williams *et al.* 1999; Williams *et al.* 2003*a*, 2003*b*; Russell-Smith and Edwards 2006). Patchiness of ground layer fuel combustion has also been shown to be less during late dry season fires (Price *et al.* 2003; Williams *et al.* 2003*b*; Russell-Smith *et al.* 2009).

As a result of the clear seasonal effects on fire intensity, significant education and incentive schemes have appropriately been designed around the promotion of early dry season fires in northern Australia; for example, for carbon farming (Commonwealth of Australia 2013).

In comparison to the seasonality of fire, the influence of ignition technique and pattern (i.e. spot *vs.* line ignition) has received less attention, but ignition characteristics are known to have considerable influence on fire intensity (Cheney *et al.* 2001; Cheney and Sullivan 2008).

A large proportion of fire ecology research has focused on tropical savannas (Williams *et al.* 2002; Andersen *et al.* 2005), Mediterranean shrublands (Keeley *et al.* 2012) and temperate forests (Ashton 2000; Vivian *et al.* 2008). Considerably less research has addressed fire behaviour and ecology in arid and semiarid zones of the world.

The arid and semiarid rangelands of Australia are dominated by spinifex (*Triodia* spp.), a group of ~65 taxa growing across more than a quarter of the Australian continent (Lazarides *et al.* 2005). They are typically hummock forming and highly flammable as a result of the well-aerated structure of the fuel and resinous nature of some species (Felderhof 2007). Fires in the spinifex-dominated, arid and semiarid rangelands of Australia can be extensive (sometimes burning areas in excess of 10 000 km^2; Luke and McArthur 1978; Wright and Clarke 2008) and very severe, reaching intensities of up to 14 000 kW m^{-1} (Burrows *et al.* 1991). These intense fires can affect the flora and fauna within the spinifex woodlands themselves and can threaten the less fire-tolerant communities that are dispersed among the spinifex landscape (Nano *et al.* 2012).

The moderately slow regrowth and patchy, discontinuous cover of spinifex across most communities means that flames must preheat unburnt hummocks across gaps, which can form a barrier to the spread of fire when fuel loads are low. The percentage cover, or connectivity of spinifex clumps, has been demonstrated to influence fire spread, requiring a certain wind speed for fire to carry (Burrows *et al.* 2009). In contrast to the biennial fires that can occur in the tussock grasses of wetter areas across northern Australia, spinifex fires can have a return interval of more than 5 years (Allan and Southgate 2002; Felderhof and Gillieson 2006).

The aim of this study was two-fold. First, we evaluated whether the severity rating (Russell-Smith and Edwards 2006), assessed in terms of proportion of grass layer combustion and crown scorch, differed between wildfires and planned fires. Second, we tested the influence of different ignition techniques, specifically spot and line ignition, both with and against the wind, on fire behaviour in spinifex woodlands in the semiarid Mt Isa district.

Materials and methods

Site selection

The study was undertaken in the vicinity of the town of Mt Isa (20°38′24″S, 139°29′35″E), in north-western Queensland. Average annual rainfall at Mt Isa is 471 mm, though annual rainfall was below average between 2011 and 2014. Sites used to evaluate unmanaged wildfires and managed fires were located within a radius of 25 km of Mt Isa. The site used for documenting fire behaviour with different ignition technique was located ~9 km north of the centre of Mt Isa.

The fire behaviour trial using different ignition techniques was implemented in a site that contains a low open woodland on flat terrain dominated by *Eucalyptus leucophloia* (taxonomy follows Bostock and Holland 2013), with a canopy height of 4–7 m and projected foliage cover of 3–10%. *Acacia* spp., especially *A. chisholmii*, form a scattered to patchy 1–3-m shrub layer. The ground layer is dominated by spinifex, primarily *Triodia brizoides*, averaging 67% cover. The vegetation equates to Regional Ecosystem 1.5.3, which is widespread across the district (Queensland Herbarium 2014). Minor gullies dominated by *E. camaldulensis* are present in the landscape but were not burnt in the trial. Based on Landsat imagery, the ignition technique trial site appears to have been last burnt in 2001, 13 years before the study.

Patchiness and crown scorch between wildfires and managed fires

Assessments were made of the patchiness of fires (in terms of the proportion of ground layer consumed) and their severity (in terms of proportion of tree crown combustion) within areas burnt in 14 separate fires between February 2012 and April 2014. Wildfires occurred from February through to December. Managed fires were all implemented in the late wet–early dry season, between February and April, as part of a landscape fire program (Fig. 1). Field assessments were undertaken in May annually, inside areas burnt within the previous 12 months.

Of the 14 different fires, five were wildfires, two were aerially ignited (i.e. planned burns implemented by spot ignition from a helicopter) and seven were on-ground managed fires (i.e. planned burns implemented from the ground). A total of 38,100 pace-long evaluation transects were walked across the 14 distinct fire events, comparing wildfires (11 transects across five different fire events), aerially ignited fires (eight transects across two different fire events) and on-ground managed fires (19 transects across seven different fire events). Each transect was separated by at least 200 m from another transect, but most transects were several kilometres apart.

The methodology used in the field assessment transects generally followed that for the carbon assessments in Australian tropical savannas (Russell-Smith *et al.* 2009). The percentage ground layer burnt was calculated as the proportion of 100 walked paces that stepped on burnt ground. The crown scorch was assessed for trees covering a hectare surrounding the 100-m transect and was calculated as the average height of scorched canopy leaves multiplied by the proportion of trees that displayed crown scorch. For example, if the average scorch height was 4 m on 8 m tall trees (i.e. 50% of the height) and half of the trees were scorched, the recorded crown scorch was 25%.

Ignition technique and fire behaviour

On 9 and 10 April 2014, a comparison was made between different ignition techniques. Ten areas were burnt comparing four ignition types:

(1) a single spot ignition burning against the wind direction (‘Spot against wind’) across two replicate areas
(2) a single spot ignition burning with the direction of the wind (‘Spot with wind’) across three replicate areas
(3) a 50-m long line ignition burning against the wind direction (‘Line against wind’) across two replicate areas
(4) a 50-m long line ignition burning with the direction of the wind (‘Line with wind’) across three replicate areas.

One replicate of all four burning treatments was implemented in the afternoon of 9 April 2014. These were allowed to burn

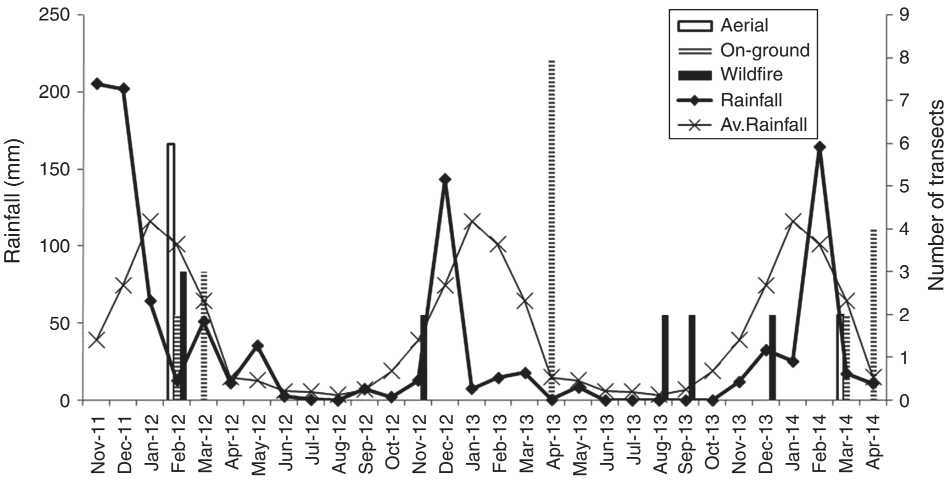

Fig. 1. Monthly average rainfall, and rainfall measured during the study by the Bureau of Meteorology at the Mt Isa airport; the timing of fires assessed and number of transects used for aerial, on-ground ignited and unmanaged wildfires.

out overnight against a gully and burnt areas from a few to 8 ha in size. On the following day, two more examples each of line and spot ignitions with the wind were implemented, as was one further example each of line and spot against the wind. Due to time constraints, these burns on 10 April were allowed to burn across small areas, from around half to a few hectares and were then extinguished.

The dominant spinifex at the site is *Triodia brizoides*, though some *T. longiceps* and *T. pungens* are also present in the area. Immediately before burning, fuel loads were measured in each of the 10 areas by dropping a calibrated disk 25 times along a 50-m transect, using previous relationships between spinifex height with measured fuel loads (Felderhof 2007). The connectivity of spinifex clumps was also measured along a 50-m measuring tape, where the total cover of spinifex was calculated as a percentage of the entire 50-m transect.

Soil and spinifex moisture samples were collected from three points and dried in an oven at 80°C for 48 h. The percentage moisture for soil and spinifex was calculated as initial fresh weight: dry weight/dry weight $\times$ 100. Weather details (wind speed, relative humidity and air temperature) were recorded using hand-held Kestrel® weather instruments at the site.

The rate of spread of the fire front in each of the 10 burning areas was timed across 5–20-m lengths, at two or three locations during each fire. Average fire speeds within each fire were combined with fuel loads for the particular burn area to calculate Byram's fireline intensity (Byram 1959).

Statistical analyses

A one-factor ANOVA was used to assess the significance of differences in ground layer combustion and crown scorch between the three fire types: wildfire, planned aerial ignition and planned on-ground ignition. As managed fires were only implemented during the late wet–early dry season and wildfires burnt in all seasons, a one-factor ANOVA was used to assess whether there was any significant seasonal effect on ground layer combustion and crown scorch between early (January–July) and late dry season (August–December) wildfires. Fire season categories follow Felderhof and Gillieson (2006), and Russell-Smith and Edwards (2006).

A one-factor ANOVA was also used to assess the significance of differences in fuel load, spinifex connectivity and fire intensity between the four ignition treatments. A Cochran's test detected significant variance among the raw intensity data, which was log-transformed before analyses (Underwood 1997). A Duncan's multiple range *post hoc* test was used to determine significant differences among treatments.

Pearson *r* correlations were determined between weather details (wind speed, relative humidity and air temperature) and fire intensity calculations.

Results

Patchiness and crown scorch between wildfires and managed fires

Planned fires, both aerial and on-ground ignition, produced significantly less percentage ground layer combustion (i.e. greater patchiness within burnt areas; $F_{2,35} = 9.05$, $P < 0.001$) and lower crown scorch severity ($F_{2,35} = 7.28$, $P < 0.01$; Fig. 2) compared with wildfires. The wildfires also tended to completely combust the canopy leaves, whereas the crowns of trees after planned fires tended to be scorched but retained.

There was no relationship between the season of the wildfire and the resulting percentage ground layer combustion ($F_{1,9} = 0.03$, $P > 0.8$) or crown scorch ($F_{1,9} = 0.03$, $P > 0.8$).

Ignition technique and fire behaviour

The soil was dry at the time of the ignition trial in April 2014, with mean moisture content of 0.35%, and the moisture content of spinifex clumps averaged 15%.

There was no significant difference in fuel loads among the fire treatments, with a mean of 10.4 t ha^{-1} ($F_{3,6} = 1.33$, $P >$ 0.34). There was also no significant difference in connectivity (i.e. cover) of spinifex across the fire treatments, with a mean of 64.2% cover ($F_{3,6} = 2.31$, $P > 0.17$).

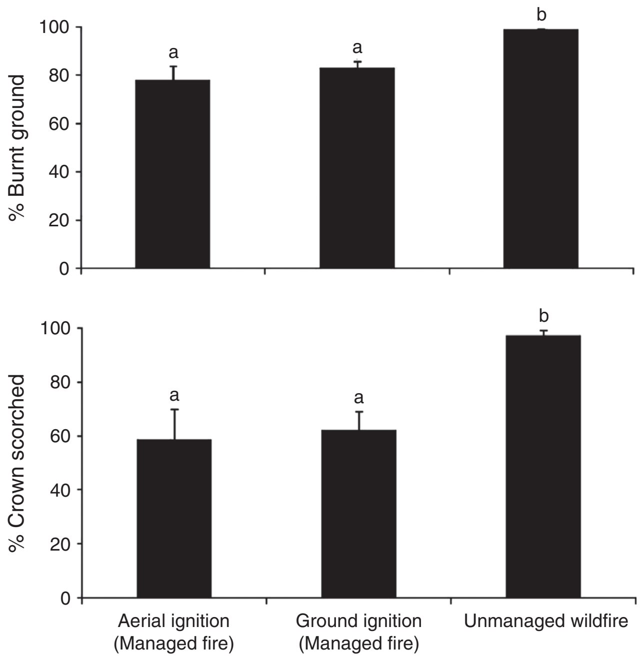

Fig. 2. The average percentage burnt ground layer and crown scorch with ignition type (error bars are 1 standard error of the mean). Columns with different subscripts are statistically significant ($P < 0.001$).

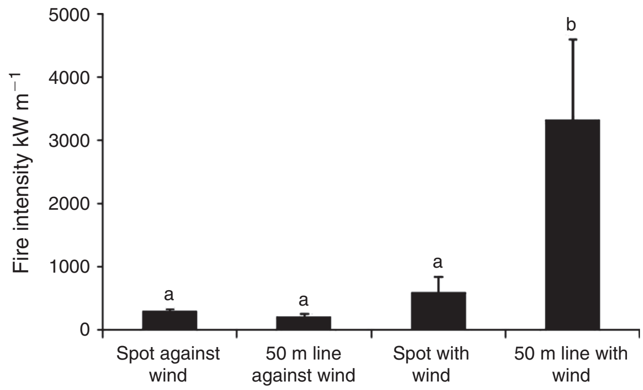

Fig. 3. The average fire intensity with ignition type (error bars are 1 standard error of the mean). Columns with different subscripts are statistically significant ($P < 0.02$).

The mean wind speed during the fires was 2.5 km h^{-1} (SE = 0.61 km h^{-1}), mean relative humidity was 31.9% and mean air temperature, 36.6°C. There was no significant correlation between weather conditions during the fires and fire intensity (wind speed $P > 0.8$; relative humidity $P > 0.9$; air temperature $P > 0.6$).

The 50-m long, continuous line ignition burning with the wind produced significantly greater fire intensity than all of the other treatments ($F_{3,6} = 9.537$, $P < 0.011$; Fig. 3).

Discussion

Wildfires in the Mt Isa district over the last few years have been less patchy and exhibited more severe canopy scorch than planned fires that have combined spot and slowly ignited fire lines (P. R. Williams, unpubl. data). This supports the results of a broad range of studies that highlight the effect of wildfires compared with planned burns (Cheney 2010; Burrows and McCaw 2013; Volkova *et al.* 2014).

The wildfires produced low ground layer patchiness and high crown severity, irrespective of the time of year they occurred. This suggests that the wildfire behaviours documented in this study were responding to factors in addition to fuel load curing or seasonality in weather conditions.

The ignition trial burns demonstrated that a 50-m line ignition with the wind produced a higher fire intensity than line ignition against the wind, and spot ignitions with or against the wind. Weather at the time of ignition (i.e. temperature, relative humidity and wind speed) did not have a clear association with fire intensity.

The average fire intensity observed for line ignition with the wind (3320 kW m^{-1}) is high for early dry season (i.e. April–July) fires in northern Australia. In comparison, early dry season fires in tussock grass-fuelled tropical eucalypt woodlands in sub-coastal northern and coastal north-eastern Australia typically range from 804 to 2100 kW m^{-1} (Williams *et al.* 1999; Russell-Smith *et al.* 2003; Williams *et al.* 2003*a*). Late season fires are typically of higher intensity than early season fires, averaging >5500 kW m^{-1} (e.g. Williams *et al.* 1999; Russell-Smith *et al.* 2003; Williams *et al.* 2003*a*), and can be of very high intensity under some conditions (e.g. 7700 kW m^{-1} Williams *et al.* 1999).

The intensity of these early dry season spinifex fires is lower than most late dry season (i.e. August–December) fires in tussock grass-fuelled tropical eucalypt woodlands, which average 5511–7700 kW m^{-1} (Williams *et al.* 1999; Williams *et al.* 2003*a*), although some annual late dry season fires in tussock grass woodlands average 2739 kW m^{-1} (Russell-Smith *et al.* 2003;).

Cheney *et al.* (2001) demonstrated that a 120-m ignition line approaches its maximum potential intensity within 3 min. The data from this study illustrate that even an initial 50-m ignition line burning with a low wind speed creates a significantly more intense fire than does a single ignition point, at least over the distance of several hundred metres.

The large difference in intensity between the line ignition with the wind compared with against the wind, given the low wind speed averaging <7 km h^{-1}, is noteworthy because many managed fires are implemented against the wind. Although sections of wildfires can burn against the wind, the data from this study suggest large sections of wildfires in the Mt Isa district tend to travel as lines with the wind, and therefore at high intensity.

The connectivity of spinifex fuel at Mt Isa 13 years after fire was greater than that of spinifex in the more arid Gibson and Great Sandy Deserts of Western Australia (WA), 33 years after fire (Burrows *et al.* 2009). Above average rainfall in each of 2009 to 2011 will have helped spinifex growth around Mt Isa. This probably explains the greater ability of spinifex fires at Mt Isa to carry under low wind conditions averaging <7 km h^{-1}, and against the wind, compared with those recorded in WA, which tended to require wind speeds of >10 km h^{-1}.

Although the ignition trial burns were carried out across relatively small areas, some cautious extrapolation into the broader landscape can be proposed, especially for burning small areas, such as around fire sensitive vegetation and adjacent to infrastructure. The combined data comparing wildfires with planned fires, and spot with line ignition, suggest that the lower patchiness and higher crown severity of wildfires in spinifex is strongly influenced by fire front length, perhaps more than the season of fire. These wildfire fronts are likely to be primarily driven by the wind, and therefore provide expanses of long, forward-burning fire lines. Although fuel loads, weather conditions and seasonality of fire are crucial factors influencing fire behaviour, this study highlights the importance of ignition technique on fire behaviour.

The predominance of spot fires rather than long fire lines should be considered a crucial aspect of ecological burning, in addition to appropriate timing and weather conditions. Spot ignitions can most easily be implemented from a helicopter, including at distances from access tracks. However, aerial ignition is often not an option for land managers, so particular effort should be given to implementing spot ignitions when on-ground burning, to increase fire patchiness and reduce severity.

Although this study was undertaken in semiarid spinifex fuels of the Mt Isa district, we propose that the effect of ignition technique applies to other grass-fuelled vegetation. Further assessment is required to evaluate this issue in higher rainfall, tussock grass-fuelled woodlands. Further trials should investigate the interactions between fire season and ignition type. Larger burn areas can evaluate the scale at which spot ignitions may ultimately produce fire lines with the same intensity as line ignitions.

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