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Char height on fence posts as a practical proxy of flame length and fire intensity in grass fires

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Abstract

Wildfire behavioural parameters are assessed through metrics that can be expensive to measure with sufficient resolution in real time, such as rate of spread, intensity, and severity. Wildfire researchers and practitioners are thus in need of accurate, cost-effective, and user-friendly methods to estimate these metrics. Flame length is one such established proxy metric widely used to estimate fireline intensity, however direct measurements can be challenging. Char height on tree trunks has been proposed as a cost-effective proxy for flame length, and thus fireline intensity, but its accuracy has not been widely tested.

Based on research by Williams et al. (1998) in Australian eucalypt savannas, this study explores the relationship between char height on fence posts and flame length in a South African grassland fire context. Data were collected at 143 monitoring plots within 7 landscape-scale prescribed fires in Eastern Cape mesic montane grassland. Flame length was recorded in real time using installed wooden fence posts of known height as visual aids, and grouped by fire type (head, back, flank). Char height measurements were later recorded from the soil surface to the maximum height of charring on the fence posts.

Across all fire types, the flame length (y) could be accurately estimated from char height ($y = 1.42x + 0.971$; $R^2 = 0.609$), but there were some differences between fire types. For head fires, char height yielded a strong rank correlation ($r_{s(37)} = 0.807$; $p < 0.001$) with flame length, while char height in flank fires had a moderate rank correlation ($r_{s(25)} = 0.532$; $p < 0.005$). Back fires did not show a significant rank correlation between char height and flame length ($r_{s(15)} < 0.15$; $p > 0.567$). Pragmatically, the simple doubling of *post-hoc* char height serves as a direct estimate of flame length.

This research confirms that in mesic montane grasslands of southern Africa, char height is a reliable *post-hoc* indicator of flame length, particularly for head fires, and could have wide practical application as a rule-of-thumb in these grassland ecosystems.

Introduction

Wildfires are a common occurrence in many landscapes and present significant challenges for fire management in rural or remote areas. Understanding fire behaviour, particularly the intensity of fires, is critical for both prediction and post-fire analysis, which contributes, *inter alia*, to planning suppression efforts, and protecting human and ecological assets.

Wildfire behaviour is typically assessed through various parameters, such as rate of spread, intensity, and severity, however, these metrics can be challenging to measure. Among these, measuring fire intensity directly can be a particularly tedious and time-consuming process, and as a result, empirical evaluations of intensity are not often conducted (Van Wilgen 1986; Schwilk 2003; Scott et al. 2014). There is, therefore, a demand from both researchers and practitioners for accurate, cost-effective, and user-friendly methods for measuring fire intensity in the field.

It has long been established that direct correlations exist between flame length and fireline intensity (Byram 1959; Brown & Davis 1973; Rothermel & Deeming 1980; Van Wilgen et. al. 1985; Van Wilgen 1986; Cochrane & Ryan 2009; Scott et. al. 2014), however, direct measurements of flame length during fire progression can be challenging and impractical due to the dynamic nature of fires.

In response, charring and leaf scorch height on trees have been proposed as useful and practical post-fire proxies of flame length and thus fire intensity (Van Wagner 1973; Williams 1998), offering an accessible alternative for both researchers and land managers (Williams et. al. 2003). Based on data collected from a series of fire experiments conducted between 1990 and 1994 in eucalypt savannas at the Kapalga research site, Australia, Williams et. al. (1998) showed that the height of char and scorch on savanna trees were both associated with fireline intensity. These relationships between flame length, height of char (and scorch), and fireline intensity have been corroborated in literature (Byram 1959; Van Wilgen et. al. 1985; Van Wilgen 1986; Cochrane & Ryan 2009), but their accuracy and applicability have not been widely tested in different systems.

Previous research has explored the relationship between fire intensity and various fuel and weather conditions, however, little attention has been given to the potential for physical markers, like char height, to provide post-fire, accessible data for fire behaviour assessment. This study explores the relationship between char height on fence posts and flame length in mesic montane grasslands of the Eastern Cape, South Africa.

Fence posts are commonly found in many rural and wildland-urban interface areas, where they could provide a simple and immediate reference for fire behaviour. By examining char height in relation to flame length measurements under different fire conditions, we aimed to establish a field-based method for estimating fire intensity that could complement traditional fire behaviour prediction models.

Methods

The study was conducted on seven landscape-scale controlled burn sites across the Eastern Cape province of South Africa from early September to mid November 2019. These burn sites were comprised mostly of mesic montane grassland and occasional savanna vegetation. The prescribed burns were conducted as planned management burns to remove moribund and unpalatable material, as well as control woody encroachment (Figure 1).

Figure 1. Example of prescribed management burn, conducted for the purposes of removing cured, unpalatable material.

Dry, untreated wooden fence posts (>3m) were planted prior to burn treatments, at 143 monitoring plots situated within the seven landscape-scale burn sites.

Flame length and fire spread type (head, back, or flank) were recorded observationally at each monitoring plot (n = 143). Objects of known height (planted fence posts) in the fire's path, were used as visual aids when measuring flame length (Van Wilgen 1986). Weather conditions (wind speed and direction, relative humidity, and temperature) were recorded at one-minute intervals, in the vicinity of the fire, using a portable weather station (Campbell Scientific; R.M. Young Company). Fuel load and degree of curing were also recorded.

Where charring occurred, it was recorded on the planted fence posts. Height of char was measured in centimetres, from the base of the post, at the soil surface, to the maximum height of charring, following the methods proposed by Williams et. al. (1998) (Figure 2).

The entire dataset met the assumptions for normality, so linear regression analysis was used to test the relationship between char height and double (2x) char height (dependent variables) and real-time flame length (independent variable). For the individual fire types, non-parametric tests were required, so Spearman's rank correlation was performed to validate associations between char height and flame length.

Results

The approximate mean weather conditions prevailing for the duration of each prescribed burn are summarised in Table 1. In terms of the formal Fire Danger Rating System (Lowveld) for the Republic of South Africa (Government Gazette Notice 1099 of 2013), weather conditions recorded for each monitoring plot, translate to Fire Danger Indices (FDIs) ranging between 30 and 72, in the mid "Green" and upper "Orange" zones, respectively. The total mean FDI for all monitoring plots was 43.44 ± 6.69. The total mean fuel load and curing percentage for all monitoring plots were 6.76 ± 1.72 ton/ha and 72.6% ± 6.97%, respectively.

Figure 2. Example of charring on pre-planted fence post. Charring occurred higher on the leeward side of the pole.

Table 3: Summary of approximate mean weather conditions and Lowveld Fire Danger Index (FDI) scores with standard deviations (SD), for duration of prescribed burns at each site in the Eastern Cape, South Africa. Lowveld FDI scores were calculated according to the methods stipulated in Government Gazette Notice 1099 of 2013 for the Republic of South Africa.

Site	Date	Air Temperature ± SD (ºC)	Wind Speed (km/h)	Relative Humidity ± SD (%)	Lowveld FDI Score ± SD
1	11 Sept 2019	24 ± 0.78	4–14	60 ± 0.47	39 ± 2.7
2	17 Sept 2019	23 ± 0.71	7–14	57 ± 0.23	46 ± 3.5
3	15 Oct 2019	17 ± 1.34	2–15	55 ± 0.41	37 ± 2.7
4	16 Oct 2019	26 ± 1.2	5–14	55 ± 0.3	44 ± 3.4
5	4 Nov 2019	19 ± 0.39	8–16	49 ± 0.21	42 ± 1.1
6	8 Nov 2019	18 ± 0.54	7–21	49 ± 0.54	40 ± 2.5
7	12 Nov 2019	24 ± 0.89	13–42	51 ± 0.25	54 ± 7.2

Charring occurred on 83 of the 143 planted fence posts (~58%). Across all fire types, the flame length (y) could be accurately predicted from char height ($y = 1.42x + 0.971$; adjusted $R^2 = 0.609$), but there were differences between fire types (Figure 3). In head fires, char height showed a strong positive correlation ($r_{s(37)} = 0.807$; $P < 0.001$) with flame length. Char height in flank fires had a moderate correlation ($r_{s(25)} = 0.532$; $p < 0.005$). In contrast, char height from back fires did not show significant correlation with flame length ($r_{s(15)} < 0.15$; $p > 0.567$).

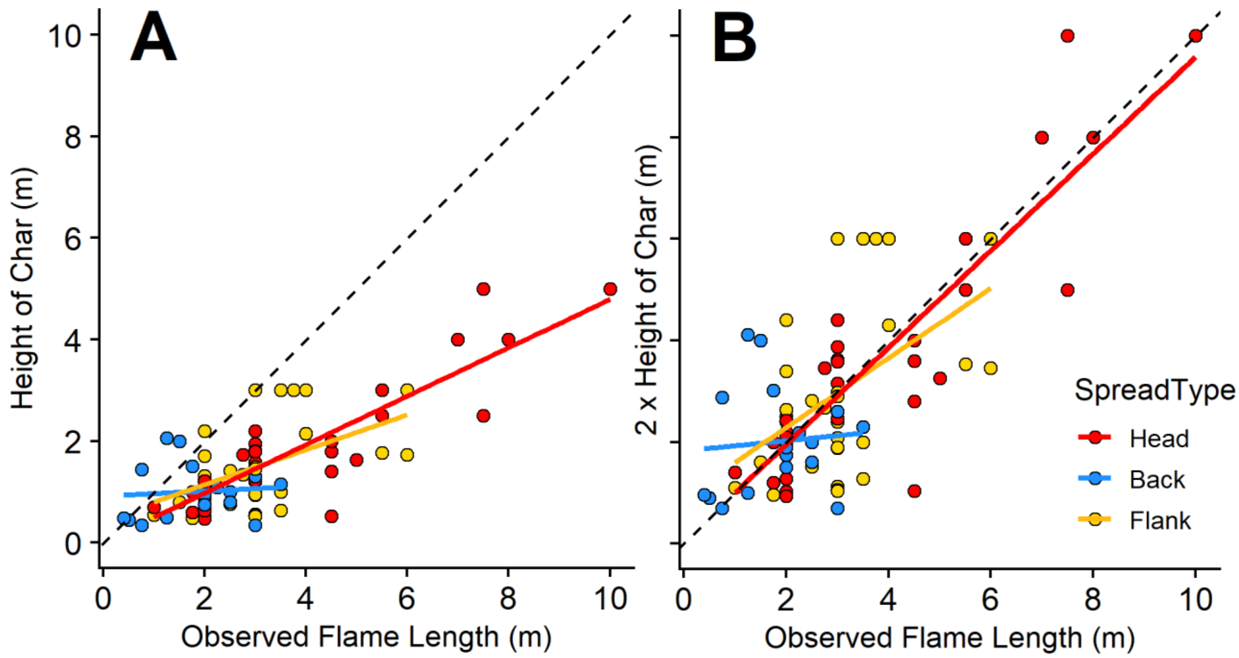

Figure 3. Observed flame lengths versus height of charring (A) & double (2x) the height of charring (B) measured on pre-planted fence posts, separated by fire spread type (head, back, or flank), for 83 monitoring plots in 7 landscape-scale fires in mesic montane grassland. Dashed lines indicate perfect agreement between observed flame lengths and char height values. Solid lines are linear regressions for each fire spread type (head, back, or flank). The regression for 2x height of charring is presented, given the pragmatic potential of this simple proxy. Linear regression for all observations in scatterplot B: $y = 0.71x + 0.971$; adjusted $R^2 = 0.609$, where y is double (2x) char height and x is the observed flame length.

Discussion and Conclusion

The results reveal a significant correlation between char height and flame length, suggesting that char height can serve as a reliable field-based indicator of fire intensity. Serendipitously, for the pragmatic application of this proxy, doubling the charring height provides a simple direct estimate of flame length in head and flank fires. The repeatability of the proxy across multiple sites and varied weather conditions suggests that the proxy may be applicable across a broad range of grassland wildfire conditions.

Williams et al. (1998) previously identified char height on pole-type fuels as a useful *post-hoc* indicator of flame length in eucalypt savannas at the Kapalga research site in Australia. Our study extends this finding to mesic montane grasslands in the Eastern Cape, South Africa, demonstrating a similar relationship (Figure 3).

It is important to note that approximately 40% of fence posts were not charred, which can be attributed to the absence of fuel within the immediate vicinity of the posts, low fire intensities, or short residence times. When applying char height as a post-fire indicator of flame length or fireline intensity, one should be cognizant of the likelihood of the absence of charring and, where possible, identify the fire type in the area.

Despite this limitation, this simple relationship has wide practical applications in southern Africa and other subtropical grassland and savanna systems. Char height provides a useful rule of thumb as a field-based method for estimating fire intensity without the need for specialized equipment. We conclude that char height on fence posts can serve as an effective *post-hoc* measure of fire behaviour, especially in areas where other fire behaviour metrics are expensive and challenging to obtain.

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