Effects of head fire shape and size on forest fire rate of spread

J. S. Gould, [1] N.P. Cheney, [1] L. McCaw, [2] S. Cheney [1]

[1] CSIRO Forestry and Forests Product, Canberra ACT, Australia

[2] Dept of Conservation and Land Management, Manjimup, Western Australia

Abstract

Importance of head fire width and shape is significant in influencing the fire spread in forest fuels. Forest fires where the head fire width is narrow are not spreading at their full potential and with a small change in wind strength and/or direction will have a sudden change in the behaviour and spread of the fire. Prescribed burning ignition pattern and spacing can influence the effectiveness of prescribed burning operations. If the ignition points are too close fire coalesce early into wide fire fronts increasing the behaviour of the fire beyond the prescribed prescriptions. Cases studies are used to illustrate the effects of head fire width and shape from a series of line fires and point ignition. Grid point ignition fires within a 100 hectare plots burn at different rates of spread and all below their potential fire spread until they coalesce into a wide fire front. The effect in the shape and width forest fire head is has important implication to fire fighter safety and planning effective prescribe burning prescriptions.

Introduction

The growth of fires from a point ignition to a quasi-steady state rate of spread where the forward spread reached an equilibrium with the available fuel, dead fuel moisture content and the mean wind speed was well recognised as a basic characteristic of all fires in all fuel types. Once the fire had reached the quasi-steady sate variation around the mean rate of spread was attributed to variation of wind speed alone. Scientists conducting field experiments to compile prescribed burning guides and fire behaviour tables recognised that this build up period needed to be exceeded before reliable correlations could be established between fuel moisture, wind speed and rate of spread (ROS) for a particular fuel type.

The time for a point-source fire to reach the quasi–steady ROS was generally considered to be short if it was not influenced by diurnal changes in weather variables. From mid-morning to mid-afternoon Luke and Mc Arthur (1978), McArthur (1967) considered that a steady rate of spread was achieved after 20 to 30 minutes. McRae (1999) found that point source fires in jack pine slash (*Pinus banksiana*) reached an equilibrium conditions in 22.3 minutes under a steady wind direction and supported the findings of Van Wagner (1985). Weber (1989) McAlpine and Wakimoto (1991) who predicted or found that the elapsed time from ignition to steady state was independent of fire weather and fuel type.

However, Cheney (1981) considered that fire growth patterns were extremely variable and fires reached a steady state after a few minutes under mild conditions and the more severe the burning conditions the longer the growth phase will take. Others reported that the time for a point-source fire to reach equilibrium ranged from 5 to 10 minutes in grassy fuels to more than 60 minutes in heavy logging slash (Chandler et al. 1983).

Effect of Fire width on forest fire spread

The rate of spread of experimental grassfires spreading from a line source was found to depend on the effective ignition line length and the head fire shape (Cheney et al. 1993). A grassfire starting from a point source can establish several periods of quasi-steady spread during the growth phase even though the fuel and weather variables remained unchanged (Cheney and Gould 1995). The potential rate of spread will only be realised when the fire has developed a broad head

The Project Aquarius fire behaviour experiments carried out in 1983 were designed to determine the ignition requirements to produce the fire behaviour equivalent to that of the head of a 10 ha fire to evaluate the limits of effectiveness of different suppression techniques. Simultaneous fires were lit from point and line sources up to 200 m wide and burnt in 100 ha blocks of tall jarrah/marri forest. The fuels were 8 years old and had in places well-developed understorey shrubs up to 2.5 m high. The pattern of fire development was measured by periodic mapping with an infrared line scanner at roughly 7-minute intervals (Gould et al 1996.)

Four experimental fires burnt simultaneously in a 100 ha experimental block of jarrah/marri forests were examined for the effect of ignition line length on rate of spread. One fire was started as a point ignition and the others from lines of 50, 100 and 200 m in length. The 200 m line-ignition fire spread on average was 16 percent faster than the 100 m line-ignition and 2.8 times faster than the 50 m line-ignition fire. The peak rate of spread just before the 100 m and 200 m line-ignition fires coalesced into one large fire front were 2.0 and 2.5 times faster than the average rate of spread before and after coalesced. This increase in rate of spread was probably a local wind and convective interaction effects between the two fires. After the fires coalesced, the rate of spread settled down at near or below the average rate of spread before the coalesced, even though the head-fire width was around 550 m wide (Gould et al 1996).

There were insufficient fires to attempt a complete analysis of the data but selection of simultaneous sets of fires established that the relationship describing the effect of head fire width and wind speed on rate of spread was similar to that established for grass fire. At low wind speeds (5-15 kmh^{-1}) the potential quasi-steady rate of spread is established when the head fire width exceeds 100 m and at high wind speeds the rate of spread increased with increasing head fire width up to 300 m. High rates of spread were associated with coalescing fires but after joining there was no further increase in spread at head fire widths of 450 m.

Discussion

The capacity of fires to maintain different quasi-steady rates of spread under the same weather conditions makes interpretation and observation of fire behaviour difficult.

Fires in open grasslands burn mostly in fine fuels of less than 5 t ha^{-1}. The convective energy flux is low, the residence time is often less than 10 seconds and the fine fuels ignite easily allowing the fire to be highly responsive to fluctuations in wind speed and direction. In unstable conditions when there are rapid changes of wind direction, a grass fire developed the quasi-steady rate of spread associated with a headfire width of 150 m in 12 minutes. Yet under stable conditions when changes in wind direction were less frequent, a fire driven by the same wind speed of 2 m s^{-1} developed 4 periods of quasi-steady spread and took 45 minutes to develop a headfire width of 150 m and was close to its potential rate of spread (Cheney and Gould 1995).

Cheney and Gould (1995) suggested that head fire width of more than 75 m in grasslands and 200 m in woodlands are required to get spread rates within 10 percent of the potential rate with wind condition in the open at 10 around 20 km h^{-1}. The data from the selected experimental fires in dry eucalypt forest shows that the head fire width must exceed 300 m before the fires are spreading at their potential rate of spread in wind speed of 20 km h^{-1} at 10 m in the open. These results suggest that fires must be wide or allowed to develop to considerable dimension in order to validate fire spread models designed to predict the fire spread of wildland fires at high wind speeds.

Fires burning in heavy forest fuels require a stronger wind to overcome the effect of convection drawing the fire front back towards the burnt area (Burrows 1994) and are less responsive to changes in wind direction. There are many factors affecting forest fires that might restrict the development of a wide head fire and thereby produce quasi-steady rates of spread that are well below the potential rate of spread. These include the presence of logs, rocky areas and old logging trails which can restrict the development of a wide headfire, particularly in heavy fuels. Variation of the in-forest wind speed due to differences in overstorey and understorey density may mean that not all the fuel layers are burnt at low wind speeds. This may restrict the development of fires that may burn much more rapidly when wide head fires involve all the available fuel layers.

Small fires burning on slopes aligned with the wind tend to remain narrow because the upslope convection of the fire entrains the prevailing wind and the lateral spread of the fire is restricted. These fires often produce very narrow pointed heads and although they can develop more rapidly than fires on level ground they can maintain a quasi-steady rate of spread that is less than the potential rate of spread of fires on level ground and much less than the potential rate of spread of a wide head fire burning up slope. On the other hand a fire burning on level ground can respond to changes in the wind direction and progressively develop wider and wider headfire until it reaches a width that reflects the potential rate of spread for the prevailing wind speed.

Practical Application

Fire experiments: empirical fire experiments need to allow the fire to develop sufficiently to establish the dynamic balance between the convection and the wind speed. Where the aim is to predict the potential rate of spread for the prevailing conditions then the head fire has to be wide enough to ensure that the maximum quasi- steady rate of spread will be established for the mean wind speed before correlations can be drawn between fuel and weather variables. Experimental blocks have to be large enough to establish wide headfire that can burn freely for the duration of the experiment without being constrained by the edges of the block.

Field Validation: Likewise any test fire that is used to validate the predicted burning conditions must be wide enough to reflect the quasi-steady rate of spread that was established by the burning guide. In most conditions, a single test fire at a point source and allowed to burn for 20 minutes will seriously underestimate the potential rate of spread.

These results suggest that experimental fires must be wide or allowed to develop to a considerable dimension in order to validate fire spread models designed to predict the behaviour of wildland firs at high wind speeds. It is apparent that spread data from small plots or narrow fires may be misleading, even though fires may appear to be spreading at a steady rate. Experimental data from narrow plots can under-estimate potential fire spread under windy conditions because the orientation of the plot may constrain spread in the direction of the wind and the plot may not be wide enough to allow the potential quasi-steady rate of spread to develop.

Prescribed burning: Most prescribed burning guides (e.g. McArthur 1962) for fuel reduction aim have been compiled from experimental fires that have burnt at a quasi-steady rate of spread that is well below the potential rate of spread at any but the mildest of conditions. When the aim of the burn is to achieve fuel reduction with low intensity fire, individual fires are lit at a wide enough spacing so that they maintain this reduced rate of spread until the burning conditions become milder. When carried out correctly prescribed fires can burn at quasi-steady rates of spread over much of the area that are one third or less intense than the potential rate of spread during the peak of the day. When they do join together the burning condition and the intermediate quasi-steady spread is reduced so that the increase in spread resulting from the development of a wide headfire or from the junction zone effect is also reduced and mostly remains within the prescription.

Prescribed fires that are lit too close will join together during the peak of the daily burning conditions and are likely to burn at or above the potential rate of spread which will be well above the intensity prescribed to minimise injury to the vegetation. The potential rate of spread of a single fire can be exceeded when multiple fires join together and the convective interaction induces higher wind speeds in the forest.

Fire Suppression: Wild fires generally start at a point source but a maintain a quasi-steady rate of spread that is well below the potential rate of spread for the prevailing conditions (Cheney - this conference) for several hours. Fire fighters must assume that all initiating fires in dry summer conditions will be spreading below their initial rate of spread and while it is imperative to take advantage of this reduced fire behaviour during initial attack they must always adopt a safe work practice that ensures safe egress to a safe area should the fire develop a wide head.

A major shift in wind direction is the most common reason for fires increasing the head fire width but there are other ways that are subtler and can occur without a major change in the weather. These include the onset of spotting and the coalescence of spot fires or more importantly when spot fires are drawn into the head of the main fire by local in draft winds at right angles to the prevailing wind; a change in fuel type or topography that allows the fire to be more responsive to local fluctuations in wind direction. For example the Mount Muirhead fire South Australia 16.2.1983 started from a shorting powerline in a grassy fuel along the road side verge running through the pine plantation. The grassfire rapidly spread along the narrow verge between the road and the perimeter firebreak at right angles to the prevailing wind because the fire in the fine fuel could respond to gusts in the wind. The fire blew from the verge into the plantation forming a wide front that burnt at its potential rate of spread of 12 kmh^{-1} almost immediately.

Lighting lines of fire during burning-out operations is another common way of increasing the fire intensity unnecessarily. This can create obvious problems if the fire burns up to the fireline that is being secured. The problems may be less obvious when the fire burns away from the fireline. However lighting lines of fire, while rapidly securing the upwind edge of the fire, has often caused problems downwind by threatening firefighters on other sections of line, increasing the overall width of the fire and dramatically increasing spotting from the fire sometimes across control lines established several kilometres down wind.

Conclusion

The relationship describing the effect of head fire width and wind speed on rate of spread in forest fires were similar to that established for grass fires. The headfire width required to realise the potential rate of spread increases with increasing wind speed. At wind speeds in excess of 20 kmh^{-1} the head fire width to achieve the potential rate of spread of forest fires is likely to be greater than that required for fire in open grasslands or grassy woodlands and is probably in excess of 300m.

Forest fires during their build up period can maintain quasi-steady rates of spread that are well below their potential rates of spread for several hours and during severe burning conditions always have the potential to suddenly and dramatically increase in intensity as a result of small changes in conditions that lead to the development of a wide headfire.

The role of headfire width in fire behaviour is a critical factor that has to be taken into consideration when undertaking prescribed burning or fire suppression.

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