Forest Ecology and Management 400 (2017) 568–577

Contents lists available at ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

Fuel moisture in Mountain Ash forests with contrasting fire histories

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ARTICLE INFO

Article history:
Received 16 May 2017
Received in revised form 19 June 2017
Accepted 20 June 2017
Available online 29 June 2017

Keywords:
Canopy cover
Fire severity
Flammability
Fuel availability
Microclimate
Plant area index
Regime shift
Time since fire
Wildfire

ABSTRACT

Fuel moisture is a key driver of forest flammability as it influences ignition likelihood, fire intensity and resultant fire severity. Changes to forest canopy cover following disturbances like wildfire or logging may alter forest flammability by changing the microclimatic conditions that influence fine fuel moisture. Wet forests dominated by Mountain Ash (*Eucalyptus regnans*) are highly valued for their flora and fauna, timber, carbon and water. Wildfires are an important part of the lifecycle of these forests, but too frequent fire can threaten post-fire regeneration. With large tracts of Mountain Ash forest recovering from recent wildfires (in 2009 and 1983) there is a need to understand the mechanisms driving flammability in these forests, particularly as the forest structure changes following fire. This study sought to understand the effects of fire history on the flammability of Mountain Ash forests by specifically considering fuel moisture for different times since fire and fire severities. We measured canopy cover (plant area index) and fuel moisture within 8 forest sites last burnt between 7 and 200 years ago by wildfires of low or high severity. Fuel moisture and fuel availability (i.e. number of days when fine fuels are dry enough to ignite and sustain spreading fire) were strongly associated with canopy cover; with denser canopied forests having higher fuel moisture. The largest differences in canopy cover occurred between the recently burnt high and low severity forests. For the longer-unburnt forests there were no systematic differences evident in canopy cover with time since fire or fire severity. The fuel moisture was higher and fuels only available to burn on one day in the forest recently burnt by high severity fire (in association with a dense canopy). In contrast, fuels were drier and available to burn on 238 days in the forest recently burnt by low severity fire (in association with a sparser canopy). For the longer-unburnt forests (33 or more years since fire) there were no clear trends between fuel moisture and time since fire and fire severity suggesting that fires do not have a lasting impact on fuel moisture within these wet forests. Overall, this study shows that wildfires have immediate impacts on fuel moisture in Mountain Ash forests but as the time since fire increases, moisture appears to be more a function of canopy properties than fire history.

1. Introduction

Fire is important to many ecosystems globally, influencing the distribution, abundance and structural form of particular plant species and vegetation communities (Ryan, 2002; Bond and Keeley, 2005). Whilst being ecologically beneficial in many situations, extreme fire behaviour can also threaten human lives and property (Keeley et al., 2009; Koutsias et al., 2012; Blanchi et al., 2014) and altered fire regimes may pose risks to the ecosystems themselves (Bond and Keeley, 2005; Meyn et al., 2007). Flammability – the ability of vegetation to burn (Gill and Zylstra, 2005; Pausas et al., 2017) – is important to fire behaviour and fire regimes. To successfully manage fire, we need to understand the factors driving forest flammability and how they vary spatially and temporally across the landscape.

Fine fuel moisture is a key driver of flammability (Gill and Zylstra, 2005). Fine fuel is defined here as being the fuel (live and dead vegetation) burning in the flaming zone of a fire, typically dead fuel less than 6 mm thick and live fuel less than 2 mm thick (Tolhurst and Cheney, 1999). Fine fuel moisture contents influence the amount of fuel available to burn (n.b. in this study *fuel availability* is measured by the number of days when the fine fuels are dry enough to ignite and sustain a spreading fire) and this has implications for ignition likelihood, rate of spread, intensity and resultant severity of the fire (e.g. Rothermel, 1972; Fosberg et al., 1981; Forestry Canada Fire Danger Group, 1992; Burrows, 1999). For lower fine fuel moisture contents there is a higher likelihood of successful ignition, higher rates of spread and more intense fire behaviour. For Australian eucalypt forests, the upper

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http://dx.doi.org/10.1016/j.foreco.2017.06.046
0378-1127/

moisture threshold for ignition of dead fine fuel is likely to be 22%, while most prescribed burns occur up to a threshold of 16% and erratic fire behaviour occurs below 7% (McArthur, 1968; Sneeuwjagt and Peet, 1985; Sullivan et al., 2012). Over longer time scales, fuel moisture contents influence the frequency (or recurrence interval) of fire, with drier forests available to burn more often if there is sufficient biomass (Meyn et al., 2007; Bradstock, 2010). The level of moisture in the landscape also influences the total biomass or fuel load (Meyn et al., 2007; Bradstock, 2010). Wetter forests tend to have higher fuel loads (Thomas et al., 2014), resulting in intense fire behaviour when the fuel is dry enough to burn.

An important consideration in relation to fine fuel moisture is how it varies spatially and temporally across landscapes. Fine fuel moisture contents are primarily controlled by microclimatic conditions – surface temperatures, relative humidity, precipitation and solar radiation (Countryman, 1977; Viney, 1991; Matthews, 2014). Mountain topography and forest cover create spatially variable microclimatic conditions over short distances (e.g. 100 m to 1 km) (Chen et al., 1999; Aussenac, 2000; Beniston, 2006). Several studies have measured fine fuel moisture contents in contrasting topographic positions and vegetation types (Matthews, 2014; Nyman et al., 2015). Those studies demonstrated substantial spatial variation in moisture content with typically higher moisture contents on polar-facing slopes, in gullies and beneath denser canopies compared with equatorial-facing slopes, ridges and sparser canopies. The spatial connectivity of available fuels within a catchment varies at a range of timescales. At hourly to daily timescales, this is likely to contribute to spatially heterogeneous fire behaviour and fire severity (e.g. Bradstock et al., 2010; Leonard et al., 2014). Drought conditions can cause landscapes to become highly connected as polar-facing slopes, gullies and denser canopied forests dry out, increasing the risk of major conflagrations (Miller and Urban, 2000; Caccamo et al., 2012; Sullivan and Matthews, 2013).

Forest canopy cover often varies concurrently with topography, but can also vary independently in response to disturbances such a wildfire and logging. Canopies typically have a moderating effect on the climate by intercepting a portion of solar radiation and precipitation, reducing wind speeds and buffering against the extremes of temperature and potential evapotranspiration (Chen et al., 1999; Aussenac, 2000). In tropical forests selective logging and fire can reduce the density of the canopy, resulting in lower fuel moistures (Fetcher et al., 1985; Uhl and Kauffman, 1990; Holdsworth and Uhl, 1997; Balch et al., 2008). When coupled with changes to the fuel load and structure, the lower fuel moisture contents can make the forest more fire prone, leading to a fire regime shift with more frequent fires (Uhl and Kauffman, 1990; Balch et al., 2015). In the eucalypt forests of southern Australia it is common practice for harvested stands to be burnt adjacent to unharvested forest, relying on the differential in fuel moisture content between the closed standing forest and the open, harvested forest to prevent the fire from igniting the unharvested forest (Department of Conservation and Environment, 1990).

Mountain Ash (*Eucalyptus regnans*) dominated wet forests are valued for their unique flora and fauna, timber, carbon and water, as well as being the tallest hardwood forests globally. Infrequent and intense wildfires are part of their lifecycle; the trees are killed and regenerate from seed, resulting in even-aged stands (Ashton, 1976). Lower intensity, understorey fires may also occur, but are less common (Ashton, 2000; Lindenmayer et al., 2000; Lindenmayer, 2009). Mountain Ash are obligate seeders requiring 25–30 years to reach maturity, as a result they are vulnerable to frequent fire, which can eliminate them from a site (Lindenmayer et al., 2011; Bowman et al., 2014). This has occurred in recent years in the higher elevation Alpine ash forests (*E. delegatensis*) (Bowman et al., 2014; Bassett et al., 2015). Little is known about how the flammability of these wet forests changes as a result of fire. It has been suggested that fires and logging make the forest more fire prone and flammability declines with time since fire (Lindenmayer et al., 2009, 2011). However, the mechanisms driving this have not been studied in wet eucalypt forests. A number of factors could be important to consider, including fuel structure, fuel load, species composition and fuel moisture.

Our study sought to better understand the effects of fire history on fuel moisture contents and fuel availability in Mountain Ash forests. We considered the effect of time since fire and past fire severity using automated fuel moisture sensors installed in forests with different fire histories. Our key research questions were:

- To what extent does canopy cover drive differences in fine fuel moisture?
- To what extent does fire history determine canopy cover?
- Is there an association between fire history and fine fuel moisture?
- What are the implications for forest flammability?

2. Methods

2.1. Site description

Eight forested study sites were located in Mountain Ash forest (*Eucalyptus regnans*) in the Central Highlands region of Victoria, Australia (Fig. 1, Table 1). These forests occur in areas with high, relatively reliable rainfall (1000–1500 mm yr^{-1}) and deep, fertile soils (Ashton and Attiwill, 1994). An additional two sites on flat clearings in close proximity to the forested sites were used for equivalent open weather observations. The forest sites spanned a range of major wildfire years (2009, 1983, 1939 and long unburnt) and fire severities. It is likely that the long unburnt 'rainforest' site had not been burnt by a high severity fire for >200 years (though a low severity fire may have occurred). It contained a dense midstorey of mature rainforest species (e.g. *Nothofagus cuninghamii* and *Atherosperma moschatum*) beneath an overstorey of mature and senescing Mountain Ash trees. The four Mountain Ash trees within the plot had diameters of 79, 186, 229 and 317 cm. Based on those diameters the estimated ages of the trees was 72, 168, 206, and 283 years old, respectively (Ashton, 1976).

Sites were selected to be as similar as possible in all physical attributes except fire history, but some variation was unavoidable due to the geographic configuration of the past fires. All sites were approximately south-facing, in mid-hillslope positions with slopes between 11 and 23 and elevations between 373 and 740 m. The vegetation overstorey consisted of Mountain Ash, however structure and understorey species composition varied markedly between the sites. Our sites captured the broad vegetation successional stages described in ecological studies for Mountain Ash forests (Ashton, 2000). The Rainforest site occurred in a narrow strip along a subsurface drainage line in close proximity to the 1939High and 1939Low sites (same elevation and aspect as the 1939 sites). It is likely that the drainage line within the Rainforest site and the southerly aspect provided enough moisture and protection from fire to enable the rainforest to establish in this location (Wood et al., 2011).

2.2. Field data collection

Fuel moisture contents were monitored for 16 months from November 2015 to March 2017, spanning two fire seasons. The fire season for Mountain Ash forests typically occurs in January and February (Murphy et al., 2013), though conditions are infrequently dry enough for the forests to burn even at this time of year. Fuel