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The effects of topographic variation and the fire regime on coarse woody debris: Insights from a large wildfire

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ABSTRACT

Coarse woody debris (CWD) is a common structural component of terrestrial ecosystems, and provides important habitat for biota. Fires modify the distribution of CWD, both spatially and temporally. Changes in fire regimes, such as those arising from prescribed burning and changing climatic conditions, make it critical to understand the response of this resource to fire. We created a conceptual model of the effects of fire on logs and dead trees in topographically diverse forests in which trees often survive severe fire. We then surveyed paired sites, in a damp gully and adjacent drier slope, ~3.5 years after a large wildfire in south-eastern Australia. Sites were stratified by fire severity (unburnt, understorey burnt and severely burnt), and fire history (burnt ⩽3 years or ⩾20 years prior to the wildfire). Both components of the fire regime influenced CWD availability in gullies. Severe wildfire and fire history ⩽3 years reduced the volume of small logs (10–30 cm diameter) in gullies, while severe wildfire increased the number of large dead trees in gullies. CWD on slopes was not affected by fire severity or history at ~3.5 years post-fire. Log volumes on slopes may recover more quickly after wildfire through rapid collapse of branches and trees. Gullies generally supported more logs than slopes, but longer inter-fire intervals in gullies may allow fuel loads to accumulate and lead to comparatively larger fire impacts. Given that fire severity and fire interval are predicted to change in many fire-prone ecosystems in coming decades, this study highlights the importance of understanding the interacting effects of multiple components of the fire regime with landscape structure. In particular, variation in fire interval and fire severity in relation to topographic position will influence the pattern of accumulation of coarse woody debris across the landscape, and therefore the structure and quality of habitats for biota.

1. Introduction

Fire shapes the composition of ecosystems through its effects on vegetation structure (Bond et al., 2005; Bowman et al., 2009), which in-turn affects the distribution of fauna (Fox, 1982; Friend, 1993). The immediate and longer-term effects of fire on faunal habitat depend on the fire regime: fire severity, fire frequency, time-since-fire, fire interval and the season of fire (Gill and McCarthy, 1998; Smucker et al., 2005; Haslem et al., 2012). Fire regimes can vary within relatively small areas, because even large, intense fires create a mosaic of severities at multiple scales (Turner et al., 1994; Román-Cuesta et al., 2009; Leonard et al., 2014).

Coarse woody debris (CWD: here defined as logs and dead trees) is a common component of many terrestrial ecosystems (Harmon et al., 1986; Jonsson and Kruys, 2001; Lohr et al., 2002). It has an important role in nutrient cycling and carbon storage, and provides habitat for plants and animals (Harmon et al., 1986; Lindenmayer and Franklin, 2002). The dynamics of CWD are driven by the interaction of long-term processes, such as senescence and decay, with shorter-term disturbance processes, such as timber harvesting and fire (Harmon et al., 1986; Haslem et al., 2011).

Fire is integral to the dynamics of CWD, as it both consumes existing debris and generates new material through its influence

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on tree death and collapse (Harmon et al., 1986; Tinker and Knight, 2000). Diverse responses to aspects of the fire regime have been observed. For example, the effects of time-since-fire on the abundance of logs ranges from a post-fire increase (Monsanto and Agee, 2008), to a peak at intermediate fire ages (Roccaforte et al., 2012), or no detectable effect (Pedlar et al., 2002; Eyre et al., 2010). Such diverse relationships suggest that responses to fire vary between, and potentially within, ecosystems. However, such variable effects of time-since fire could also be influenced by failing to account for other aspects of the fire regime, both spatial and temporal. Fire severity (e.g. Smucker et al., 2005) and fire interval (e.g. Haslem et al., 2012) are known to strongly influence habitat structure, but are rarely accounted for in fire ecology studies, including those on CWD (but see Collins et al., 2012b).

Topographic variation influences fire behaviour, as moist gullies often repeatedly escape fire, or burn less severely than the surrounding landscape (Pettit and Naiman, 2007; Bradstock et al., 2010; Leonard et al., 2014). When gully vegetation does burn at high intensity, for example during extreme fire conditions (Leonard et al., 2014), the vegetation may recover more quickly due to the protected aspect and high soil moisture (Romme and Knight, 1981; Segura and Snook, 1992). Thus, topographic variation may interact with fire regimes to determine the dynamics of CWD.

Research on the post-fire dynamics of CWD has been conducted largely in forests that experience stand-replacing fires, such as the boreal forests of North America and Europe (Harmon et al., 1986; Tinker and Knight, 2000; Pedlar et al., 2002; Monsanto and Agee, 2008), and tall wet eucalypt forests of south-eastern Australia (Lindenmayer et al., 1999). In other forests, such as the mixed *Eucalyptus* species foothill forests that cover some 7.9 million ha of south-eastern Australia, trees often survive severe fires through epicormic sprouting. Despite the complex role of fire in structuring these ecosystems (Gill, 2012), and the key role that CWD plays within them (Lindenmayer et al., 2006), understanding of the drivers of CWD is limited, particularly in relation to fire regimes.

Here, we explore the role of multiple components of the fire regime and topographic variation on the dynamics of CWD in a foothill forest ecosystem following the 2009 'Black Saturday' wildfires in central Victoria, Australia, which burnt 228,000 ha of forest. We had four primary objectives: (1) to develop a conceptual model of the effects of wildfire on CWD over time; (2) to determine the effects of fire severity and fire history on the relative abundance of CWD (logs and dead standing trees); (3) to examine whether the effects of the fire regime are modified by topographic position (i.e. damp gullies vs. drier slopes); and (4) to determine whether the size of logs and dead trees influences how they are affected by the fire regime.

1.1. Conceptual model and predictions

We developed a conceptual model of the post-fire dynamics of logs in forest ecosystems in which trees often survive severe fire (Fig. 1). There are four main sources of logs following fire. First, at least part of the existing log resource is likely to remain post-fire. Second, trees not killed by fire may drop branches, resulting in a pulse of smaller logs. Third, some trees are damaged at the stem base and are killed by fire, and either fall shortly after the fire or remain as standing dead trees for many years before collapsing. Finally, trees that regenerate in gaps created by fire will contribute to the log resource in the longer term.

The magnitude and rate of log consumption, tree death, tree collapse and tree regeneration will depend on several aspects of the fire regime, including fire severity and fire history. More severe fires will result in the consumption of more logs and kill more trees, but may obscure the effects of previous fire on CWD. Characteristics of logs, including their size, moisture content and level of decay, will affect their flammability; while the death and collapse of trees will be influenced by the composition of tree species, tree health and the (non-fire) disturbance history of the forest. Moisture differentials associated with topographic position will

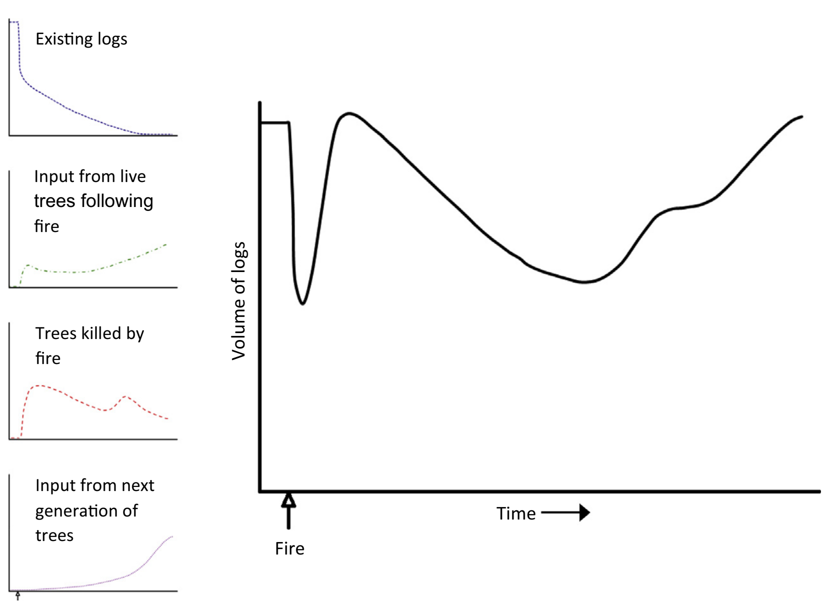

Fig. 1. Conceptual model of log volume over time following a wildfire in a forest in which trees often survive severe fire. The side panels show the trajectories of logs from four sources: (1) existing logs at the time of the fire (some of which are consumed by fire and those not consumed continue to decay); (2) input from live trees following fire (branches are lost immediately following the fire, and after time these trees continue to drop branches, die and collapse); (3) trees killed by fire (a number of trees die and collapse immediately following the fire, while some trees are killed but remain standing, and collapse as a cohort many years later); and (4) input from the next generation of trees (seedlings that grow following the fire, reach maturity and begin to drop branches). The main plot shows the cumulative volume of logs from these sources. The specific pattern of each log source will depend on the severity of the fire and topographic location (i.e. damp gullies or dry slopes). Trajectories may be affected by fire interval, with a likely overall decline in log volume over time if short fire intervals do not allow regenerating trees to mature.