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Review

Optimisation of fuel reduction burning regimes for carbon, water and vegetation outcomes

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ABSTRACT

Fire plays a critical role in biodiversity, carbon balance, soil erosion, and nutrient and hydrological cycles. While empirical evidence shows that fuel reduction burning can reduce the incidence, severity and extent of unplanned fires in Australia and elsewhere, the integration of environmental values into fire management operations is not well-defined and requires further research and development. In practice, the priority for fuel reduction burning is effective mitigation of risk to life and property. Environmental management objectives, including maintenance of high quality water, reduction of CO_2 emissions and conservation of biodiversity can be constrained by this priority. We explore trade-offs between fuel reduction burning and environmental management objectives and propose a framework for optimising fuel reduction burning for environmental outcomes.

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1. Introduction

High-intensity bushfires can result in substantial losses of human life and property, incurring immense social and economic damages to the country (Rittmaster et al., 2006; Attiwill and Adams, 2008; Stephenson, 2010; Moseley et al., 2012). Worldwide, there is increasing recognition of the importance of the application of fuel reduction burning (FRB) in the face of rapidly increasing losses of life and property from bushfires. In Australia, FRB is practiced in a wide diversity of vegetation types and has been shown to significantly reduce the incidence and extent of bushfires (Boer et al., 2009; McCaw, 2009; Burrows and McCaw, 2013;

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McCaw, 2013; Russell-Smith et al., 2013) for up to 15–20 years after the burn (Gould et al., 2011; Attiwill and Adams, 2013). Similarly, studies in the United States have shown that relatively small reductions in fuel load can increase fire resilience (Stephens et al., 2012) and that FRB can reduce wildfire size considerably (Raymond and Peterson, 2005; Moghaddas et al., 2010). Fernandes and Botelho (2003) reviewed the general effectiveness of FRB in a range of forest types and found that fuel-reduced areas limit the spread of fire within the burnt area and result in less homogenous post-burn landscapes.

Australia and parts of the United States have had extensive FRB programs in place since the early 1960s. In Australia, the area treated with FRB is approximately 1.2 million ha (equal to an average 3% of public forests; Adams and Attiwill, 2011; Australian Government Department of Agriculture State of the Forests Report, 2013). In the United States, an area totalling approximately 1 million ha is burned annually as a result of fire management programs (Ryan et al., 2013; Omi, 2015). As the incidence of unplanned fires increases in other areas across the world, particularly in the Mediterranean region of Europe (e.g. Fernandes et al., 2013; Marino et al., 2014), there is an escalating need for FRB and a concomitant requirement for better understanding of the ecological effects of such practices as well as the social and economic impacts.

In recent decades, south eastern Australia has experienced multiple landscape-scale fire events. Between 2003 and 2007, bushfires collectively burnt 10% of the State of Victoria as a result of fuel accumulation and extreme climate and weather conditions, particularly during several weeks of sustained high temperature following years of drought. Australian Federal and State Government inquiries and a Royal Commission concluded that an increase in FRB across the landscape was essential. Following the Royal Commission, the target for FRB in Victoria was increased to around 400,000 ha annually from its previous 130,000 ha. In the past 12 months, the Victorian State Government has decided to reject hectare-based targets for FRB in favour of a “risk-based approach” and other states are beginning to follow this lead (AFAC, 2016a).

Projections of future climate suggest that fire regimes will change (Lucas et al., 2007; Seidl et al., 2014). While application of FRB can mitigate bushfire risks and create fire mosaics for ecological purposes, our understanding of the effects of single and multiple FRB on carbon and water values (e.g. capacity for carbon sequestration, altered water quality and yield) remains meagre (Fernandes and Botelho, 2003; Van Wilgen, 2013). We lack even the most basic ability to contrast the effects of bushfires with cumulative effects of FRB despite the extraordinary costs of landscape-scale bushfires in recent years (Adams and Attiwill, 2011).

Efforts to optimise management operations for a given set of environmental variables are not new. For decades, forestry industries have sought such optimisation in many parts of the world (e.g. Hauer et al., 2010; Diaz-Balteiro et al., 2014). In Australia, land and fire management agencies have long recognised the need for ecological sustainability in fire management frameworks (Driscoll et al., 2010), albeit with a clear emphasis on conservation of biodiversity ahead of other values. Perhaps the most well-known Australian example of an attempt to optimise fire regimes is the determination of minimum and maximum fire intervals for plant communities according to life spans of particular species, including their seed bank (Keith et al., 2002). In the United States, the intersection of ecological sustainability and delivery of goods and services from forests through good management practices was articulated in the 1990s (Christensen et al., 1996) and brought to the attention of fire managers in the “Rainbow Series” of publications (Brown, 2000). Indeed, evidence-based adaptive approaches for optimising management outcomes and reducing undesirable impacts are often called for but have not been fully developed. One notable exception is the optimisation of fire regimes for soil carbon storage and greenhouse gas emissions in northern Australia (Richards et al., 2011).

Above and beyond the protection of life and property, optimisation of fire regimes, including FRB, should be able to encompass more facets than economics and resources and maintaining plant and animal diversity. As our knowledge and understanding of the environment improves, planning and conduct of FRB should also be able to promote ecosystem services such as clean air, carbon stores and delivery of high quality water to cities and towns. Linking fire management practices with ecosystem services requires monitoring of a set of carefully chosen ecosystem components (McIver et al., 2013).

Implementation of FRB is largely influenced by stark contrasts in public perception of risk and the level of understanding of ecological benefits of fire (Halliday et al., 2012; Altangerel and Kull, 2013). But to what level is FRB a trade-off between protection of property, biodiversity conservation, air quality and clean water supply? Given this complexity, here we attempt to reconcile environmental objectives related to FRB and propose a framework that informs optimisation of FRB for both risk mitigation and ecologically sustainable outcomes. Even though the discourse that follows is largely set in an Australia context, the basic premises we describe and the framework we provide are applicable to fire-prone areas worldwide.

2. Impact of fuel reduction burning on environmental variables

While the full effects of FRB on ecosystems, the atmosphere and climate are not known, all available evidence points to its utility for managing the far more severe risks associated with high intensity bushfires. Fuel reduction burning consumes biomass and, in the process, multiple environmental variables are modified. Carbon, one of the most important elements for living organisms, is stored in vegetation, soil, the atmosphere and oceans. The amount of carbon stored in each of these pools are referred to as ‘carbon stocks’ and movements of carbon between these pools contribute strongly to climate regulation. Similarly, knowledge of the effects of FRB on ‘nutrient stocks’, including nitrogen and phosphorus, is important for optimising FRB as availability of nitrogen and phosphorus is fundamental to determining primary productivity, and ultimately fuel loads in ecosystems.

Water from forested catchments is globally critical to cities and industries. In south eastern Australia, Ash-type forests supply water to at least 25% of Australia's population, as well as for use by nationally significant industries including agriculture (Langford, 1976). These same catchments are at high risk of high intensity bushfires (Adams and Attiwill, 2011), as amply demonstrated in both 1939 and 2009 when large-scale bushfires compromised the water supply for towns and cities in Victoria. While Ash-type forests cannot themselves be managed with FRB, the surrounding forests can. Other forested catchments (i.e. non-Ash-type) can also be protected with judicious FRB. An understanding of the role of vegetation, including ground cover, understorey shrubs and overstorey trees, before and after FRB, is fundamental for provision of high quality water from forested catchments (Emmerich and Cox, 1992; Buckley et al., 2012; Gharun et al., 2013; Heath et al., 2014; Flerchinger et al., 2016).

Long-term quantitative, multidisciplinary and statistically-sound studies of fire effects are essential for optimisation of FRB. In Australia, ecological effects of FRB have been investigated regularly for the past few decades (see Table 1). This includes a small number of long-term studies in Victoria (Department of