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Fire planning for multispecies conservation: Integrating growth stage and fire severity

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ABSTRACT

Setting suitable conservation targets is an important part of ecological fire planning. Growth-stage optimisation (GSO) determines the relative proportions of post-fire growth stages (categorical representations of time since fire) that maximise species diversity, and is a useful method for determining such targets. Optimisation methods can accommodate various predictor variables, but to date have only been applied using post-fire growth stages as the primary landscape variable. However, other aspects of fire regimes such as severity may influence species diversity but have not yet been considered in determining conservation targets in fire planning. Here we use a space-for-time substitution to address two objectives, 1. To determine the effects of growth stage and fire severity on plant and vertebrate species' occurrence, and 2. To determine the optimal mix of growth stages and fire severities for sustaining the diversity of these groups. We used the tall wet forests of southeast Australia as the focal system because fire severity is expected to create distinct successional pathways and influence species' responses. We found that growth stage predicted the occurrence of many species, and severity of the most recent fire was an important factor over and above growth stage for a small subset of species. The optimal distribution of growth stages for both plants and animals included a substantial proportion of young forest, however when fire severity was considered, areas burned at low severity were most important in driving the diversity of both groups. Growth stage is a good surrogate for developing conservation targets in tall wet forests, however growth stage alone does not capture the full range of species' fire responses. More complex versions of growth stage optimisation that accommodate multiple fire-regime variables need to be explored to yield ecologically meaningful conservation goals.

1. Introduction

Fire is an important natural process that influences ecosystem structure and function (Bowman et al., 2009). It is also used as a forest management tool globally, both for ecological objectives and to reduce wildfire risk (Penman et al., 2011; Fernandes et al., 2013). Managing fire for biodiversity conservation is challenging because of the competing needs of multiple species, stochasticity associated with fire regimes and uncertainty about species' fire responses (Bowman et al., 2016). Varying the properties of fire regimes across space and time has been advocated as a way of accommodating the needs of multiple species, in various guises (e.g. patch mosaic burning, pyrodiversity begets biodiversity Martin and Sapsis, 1992; Parr and Andersen, 2006). However; there is uncertainty about appropriate levels of pyrodiversity and which properties of fire regimes should be varied (Parr and Andersen, 2006; Bowman et al., 2016; Kelly et al., 2017).

Growth-stage optimisation (GSO) is a recent approach to biodiversity conservation in fire-prone landscapes that provides a strategy to manage fire in a way that maximises biodiversity values based on the requirements of multiple species (Di Stefano et al., 2013). GSO determines the relative proportions of post-fire growth stages that maximise a species diversity index, where growth stages are categorical representations of a successional pathway as determined by time since fire (Cheal, 2010). GSO provides tangible operational goals linked to ecosystem resilience, which can be achieved through planned burning, fire suppression or other management interventions (DELWP, 2015). GSO has been incorporated into fire management policy in south eastern Australia because it has a strong theoretical basis, input data can be obtained using standard ecological survey techniques, and it provides a unified framework for addressing conservation goals associated with multiple species (DELWP, 2015).

To date, optimisation methods in fire management have only been

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applied using growth stage as the primary landscape property. This method, however, can be applied in any context where there is a landscape attribute of interest that may influence multiple species and can potentially be influenced by management. For example, fire regime elements such as severity, frequency, interval and season (Gill, 1975) have the potential to be strong drivers of community organisation but have not yet been used in GSO (Kelly et al., 2015). Developing a better understanding of the role of such factors in driving community composition in addition to growth stage will be important for determining ecologically meaningful conservation targets.

Fire severity, related to fire intensity, is a measure of the loss of above- and below-ground organic matter caused by fire (Keeley, 2009). Indicators of fire severity are typically associated with vegetation or soils. Vegetation-related indicators include the amount of unburnt, scorched and burnt vegetation in each vegetation stratum and the scorch height. A range of organisms respond to fire severity; for plants, severity is directly related to mortality and has important implications for mechanisms of persistence (e.g. seeding vs resprouting) and the subsequent availability of resources such as light and nutrients (Wang and Kemball, 2005; Kuenzi et al., 2008). For animals, severity has important implications for a species' capacity to survive fire, and for forest structure which in turn affects resources used as shelter and forage in the post-fire environment (Smucker et al., 2005; Bassett et al., 2017). Recent work has shown that fire severity influences species' occurrence and abundance (Chia et al., 2016; Lindenmayer et al., 2016; Gordon et al., 2017) and spatiallyheterogeneous fire severities can benefit species diversity at a landscape scale (Tingley et al., 2016).

Here we investigate the influence of growth stage and fire severity on flora and fauna using the tall wet forests of south eastern Australia as a case study system. These forests are highly valued for biodiversity, timber, water and carbon storage (Burns et al., 2015). Furthermore, they exhibit large differences in successional response between high and low severity fire (McCarthy and Lindenmayer, 1998; Benyon and Lane, 2013). A recent wildfire in 2009 has provided an opportunity to examine the role of fire severity. We use a space-for-time substitution to address two objectives, 1. to determine the effects of growth stage and fire severity on plant and vertebrate species' occurrence, and 2. to determine the optimal mix of growth stages and fire severities for sustaining the diversity of these groups.

2. Methods

2.1. Study area

We conducted this study in the Central Highlands region of Victoria, Australia (Fig. 1). We focussed on tall wet forests, specifically those dominated by mountain ash (*Eucalyptus regnans*). This vegetation community occurs in high rainfall areas at altitudes of between 200 and 1100 m. The fire regime in tall wet forests is characterised by infrequent, high intensity fire during drought, when fuel becomes available to burn (Attiwill, 1994). Mean intervals between stand-replacing fires have been estimated at between 75 and 150 years (McCarthy et al., 1999). High-severity fires are often stand-replacing events, with new tree cohorts regenerating from canopy-stored seed (Ashton, 1976). However, there is evidence from both Victoria and Tasmania that many individual trees can survive fire events and form part of multi-aged cohorts (McCarthy et al., 1999; Turner et al., 2009). In recent wildfires, large areas were burnt at low or moderate intensity and many ash-type eucalypts survived (Smith and Woodgate, 1985; Benyon and Lane, 2013), including in areas that were backburned by management agencies as part of fire suppression operations. Large wildfires have occurred throughout the study area over the last 100 years, most prominently in 1939, 1983, and 2009 (Teague et al., 2010).

2.2. Study design and site selection

We used a space-for-time approach to investigate mammal, bird and plant species' responses to growth stage and severity. We designed our study around the three dominant growth stages present across the landscape. Areas regenerating from wildfires in 1939, 1983 and 2009 correspond to three growth stages; juvenile (3–9 years), adolescent (7–35 years) and mature (35–250 years), respectively, which represent developmental stages in key fire response species (Cheal, 2010).

We obtained fire-severity maps for the 2009 fire which were based on the change in vegetation from pre- and post-fire satellite imagery (DELWP, 2009). Fire severity was scaled into six classes based on the extent of canopy scorch: 1 (crown burn: 70–100% of overstorey tree crowns completely burnt), 2 (crown scorch: 60–100% of overstorey tree crowns completely scorched, some burnt), 3 (moderate crown scorch: 30–60% of overstorey tree crowns completely scorched), 4 (light or no crown scorch: 1–30% of overstorey tree crowns scorched, understorey burnt), 5a (no crown scorch: < 1% of overstorey crowns scorched, > 1% of understorey burnt or scorched) and 5b (no crown scorch: < 1% of overstorey crowns scorched, 100% of understorey unburnt and unscorched). For the purposes of this study we used two fire-severity categories, high severity, which corresponded to categories 1 and 2 and low severity which corresponded to categories 3 and 4. Our high-severity category represents sites where the overstorey has mostly been killed and new recruits are growing underneath. Our low-severity category represents sites where the overstorey has mostly survived but the understorey has been affected by fire. These categorisations are consistent with other studies from tall wet forests (Lindenmayer et al., 2014) and on-ground observations of the effects of the different fire severity categories on vegetation (Benyon and Lane, 2013). We groundtruthed fire severity using evidence of canopy scorch and understorey condition. For low severity sites, we also verified that the sites had been burnt using high resolution aerial photographs taken immediately after the fires supplied by the Victorian government.

We used a restricted random protocol to select sites within the adolescent and mature growth stages and the two fire-severity categories for the juvenile growth stage. Sites were between 50 m and 150 m from vehicle tracks and a minimum of 300 m from each other. We avoided sites that were logged since the 1970s according to the Victorian Government's last-logged spatial layer. It is possible that sites were salvage logged in the decade following the 1939 and 1983 fires as these activities were poorly documented (Taylor et al., 2014). Sites within each category were spatially interspersed with those of other categories where possible (Fig. 1) and we used an index of aridity (Nyman et al., 2014) to ensure that sites in the different categories represented a range of environmental conditions. Each site consisted of a 50-m transect oriented at random such that it did not extend back towards a vehicle track. We surveyed a total of 42 sites for ground-dwelling mammals and birds plus an additional 42 sites for plants (Table 1).

2.3. Data collection

We surveyed ground-dwelling mammals from April to May 2015 using camera traps. Two Reconyx cameras were deployed at each transect, one at the start and one at the end. We used both HC500 and HC600 cameras, and as there may be slight differences in species' responses to the flashing systems on these models, we assigned them to sites haphazardly. We mounted each camera on a tree approximately 50 cm off the ground with a bait station 1.5 m from the camera. The bait station consisted of five tea infusers suspended 30 cm off the ground on a wooden stake containing bait of rolled oats, peanut butter, golden syrup and pistachio essence which is a good generalist bait for detecting multiple ground-dwelling mammal species (Paull et al., 2011). Cameras were left in place for 21 days on their highest sensitivity setting, and set to rapid fire with five images taken per trigger and no delay between