Biological Conservation 167 (2013) 137–148

Contents lists available at ScienceDirect

Biological Conservation

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

Fire severity and landscape context effects on arboreal marsupials

D.B. Lindenmayer [a,b,c,d,*], W. Blanchard [a], L. McBurney [a,d], D. Blair [a], S.C. Banks [a,b,c], D. Driscoll [a,b,c], A.L. Smith [a,b,c], A.M. Gill [a]

[a] Fenner School of Environment and Society, The Australian National University, Canberra, ACT 0200, Australia
[b] ARC Centre of Excellence for Environmental Decisions, The Australian National University, Canberra, ACT 0200, Australia
[c] National Environmental Research Program, The Australian National University, Canberra, ACT 0200, Australia
[d] Long-term Ecological Research Network, The Australian National University, Canberra, ACT 0200, Australia

ARTICLE INFO

Article history:
Received 12 December 2012
Received in revised form 8 July 2013
Accepted 23 July 2013

Keywords:
Relative disturbance sensitivity
Forest management
Fire regime
Cavity-dependent arboreal marsupials
South-eastern Australia

ABSTRACT

Although fire is a major form of natural disturbance worldwide, both fire-derived landscape context effects and the impacts of fire severity are poorly known for many species. To address this knowledge gap, we quantified the response of Australian arboreal marsupials to: (1) the spatial effects of fire, (2) fire severity, and (3) fire impacts on the availability of critical nesting resources – hollow-bearing trees.

We identified substantial differences among species in response to fire severity and landscape-scale fire. The Sugar Glider (*Petaurus breviceps*) and the endangered Leadbeater's Possum (*Gymnobelideus leadbeateri*) were extremely rare on burned sites irrespective of fire severity. In addition, these two species declined with the amount of burned forest in the surrounding landscape even when their habitat remained unburnt. The Mountain Brushtail Possum (*Trichosurus cunninghami*) and the Greater Glider (*Petauroides volans*) both occurred on burned and unburned sites. The Greater Glider responded negatively to fire severity at the site level and also negatively to the amount of forest burned in the surrounding landscape. The abundance of the Mountain Brushtail Possum was lowest on sites subject to moderate severity fire.

On unburned sites, the presence and abundance of virtually all species was characterised by a common positive response to the availability of nesting resources in hollow-bearing trees.

Our findings underscore the importance of management practices to better protect species that decline after fire. These include conserving areas of unburned forest, particularly those with hollow-bearing trees which are critical nest sites for arboreal marsupials. These recommendations are currently the opposite of existing management practices.

1. Introduction

Fire is a major form of natural disturbance influencing the diversity and distribution of biota worldwide (Bowman et al., 2009; Nimmo et al., 2013b; Valentine et al., 2012). Understanding relationships between fire and biodiversity is particularly important given the increasing extent and number of fires in many ecosystems (Bowman et al., 2009). Inappropriate fire regimes (including changes in fire–severity) could produce shifts in ecosystem states (Lindenmayer et al., 2011a; Staver et al., 2011) as well as threaten the persistence of many species (Rush et al., 2012; Taylor et al., 1972; Valentine et al., 2012).

A major knowledge gap concerns the quantification of the spatial effects of fire on biota; the vast majority of studies have focused on time since fire and not spatial effects (Clarke, 2008). There is some literature on the spatial mosaics created by fire, including studies of the concept of invisible (historical) mosaics (Bradstock et al., 2005) and the "pyrodiversity begets biodiversity" hypothesis (Parr and Andersen, 2006; Nimmo et al., 2013a; Taylor et al., 2012). However, there are comparatively few landscape context studies in fire-modified landscapes (Bradstock et al., 2012; Clarke, 2008; McKenzie et al., 2011) that document the occurrence of species on unburned sites where the surrounding landscape has been burned. In contrast, the landscape fragmentation literature includes numerous studies of landscape context effects (reviewed by Collinge, 2009; Lindenmayer and Fischer, 2006) showing that patch biota is influenced by the amount and condition of vegetation surrounding those patches (Viveiros de Castro and Fernandez, 2004). The widespread evidence for landscape context effects in fragmented systems suggests that similar effects may occur where variation in fire extent and severity create a heterogeneous

* Corresponding author at: Fenner School of Environment and Society, The Australian National University, Canberra, ACT 0200, Australia. Tel.: +61 2 61250654.
E-mail addresses: david.lindenmayer@anu.edu.au (D.B. Lindenmayer), wade.blanchard@anu.edu.au (W. Blanchard), lachie_mcb@hotmail.com (L. McBurney), davoblair@nex.net.au (D. Blair), sam.banks@anu.edu.au (S.C. Banks), don.driscoll@anu.edu.au (D. Driscoll), annabel.smith@anu.edu.au (A.L. Smith), malcolm.gill@anu.edu.au (A.M. Gill).

0006-3207/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.biocon.2013.07.028

landscape. Quantifying fire-derived landscape context effects is critical for informing the conservation and management of fire-prone areas, such as developing policies and practices to protect unburned refugia (Mackey et al., 2012) and protect burnt areas from additional disturbances like post-fire salvage logging (Lindenmayer et al., 2008).

Another key knowledge gap concerns the effects of fire severity on fauna. Fire severity refers to the extent of loss or consumption of the vegetation and other biomass as a result of fire (Keeley, 2009). While many studies have compared the post-fire recovery of biota on burned sites and unburned sites, few have quantified the effects of variation in fire severity on biodiversity (although see Rush et al., 2012; Smucker et al., 2005). Fire severity is a fundamental component of fire regimes (Gill, 1975) and therefore without a good understanding of its effects, accurate predictions of the response of fauna to fire will remain elusive (Driscoll et al., 2010). It is imperative to remedy this deficiency quickly because fires are predicted to become larger, more frequent and more severe as a result of climate change (Driscoll et al., 2012; Westerling et al., 2006; Cary et al., 2012).

In this study, we aimed to help close knowledge gaps about landscape context and fire severity effects on biota. We report new findings from a detailed study of arboreal marsupials in the montane ash forests of Victoria, south-eastern Australia. Work on arboreal marsupials in this system over the past three decades has indicated that these animals are highly sensitive to human-generated disturbances, particularly clearcut logging at both site and landscape scales (Lindenmayer et al., 1991a, 1999). Among the eight species of arboreal marsupials in montane ash forests, Leadbeater's Possum (*Gymnobelideus leadbeateri*) is listed as nationally endangered (Department of Sustainability, Environment, Water, Population and Communities, 2012). Montane ash forests are fire-regime dependent ecosystems, with the regeneration of key overstory tree species dictated by infrequent, high severity conflagrations (Ashton, 1981; Lindenmayer, 2009; McCarthy et al., 1999). However, the impacts of fire on arboreal marsupials remain virtually unknown.

In late-summer 2009, widespread fires burned over 72,000 ha of montane ash forests. These were the most damaging fires in Australian history in terms of loss of human life and property (Gibbons et al., 2012). The severity of these fires varied substantially, with some areas remaining unburned, others subject to moderate severity fire, and some fire-affected areas reputed to have experienced among the most intense fires ever recorded, reaching 88,000 kW/m (Cruz et al., 2012). In addition, the effects of the fires varied spatially, with some landscapes almost completely burned, whereas others experienced either patchy fire or no fire (Price and Bradstock, 2012). The 2009 fires therefore provided a unique opportunity to explicitly test hypotheses about the impacts of fire severity and landscape context on arboreal marsupials. The array of 108 field sites used in our investigation also varied in vegetation structure, topographic position and stand age, allowing us to construct novel composite models that integrated data on site- and landscape-level disturbance, stand structure, and environmental conditions.

We posed three key questions in our investigation:

- *Are there landscape context effects of fire on the occurrence of arboreal marsupials*? Some species of arboreal marsupials are sensitive to changes in landscape-level forest cover resulting from clearcutting of the landscape surrounding otherwise intact sites (Lindenmayer et al., 1993, 1999). Given these earlier findings and with the extensive evidence for landscape context effects from the habitat fragmentation literature (Collinge, 2009), we postulated that unburned sites surrounded by extensive areas of burned forest would be less likely to support animals than sites where the surrounding forest remained unburned. Under this hypothesis, even if species can survive in unburned refuges during wildfire, they may still be sensitive to fire in the surrounding landscape.
- *What are the impacts of fire severity on the occurrence of arboreal marsupials*? We predicted that animals would be negatively affected by high-severity fire more than by moderate severity fire. This was because of the increased effects of high severity fire on: (i) animal mortality (Hewish, 1983; Keith et al., 2002), and (ii) indirect impacts of severe fire on habitat suitability – particularly the increased levels of destruction of severe fire of large old trees (Banks et al., 2011b; Lindenmayer et al., 2012) which arboreal marsupials use as nest and den sites (Lindenmayer et al., 1991a).
- *Will an abrupt change in the abundance of key nesting resources influence the presence/abundance of arboreal marsupials?* Repeated past statistical modeling has demonstrated that a key habitat attribute for arboreal marsupials is the occurrence of hollow-bearing trees which are denning sites for these animals. All species are significantly more likely to occur on sites where such trees are abundant, and do not occur in the absence of hollow-bearing trees (Lindenmayer et al., 1991b, 1994). However, the condition and abundance of key vegetation attributes can change over time (Swanson et al., 2011) and this can in turn influence the temporal suitability of a site as habitat for a particular species (Haila et al., 1996; Monamy and Fox, 2000). Recent work in montane ash forests has shown that fire has marked negative effects on populations of hollow-bearing trees, with their numbers significantly reduced in burned areas (Lindenmayer et al., 2012). Given that virtually all species of arboreal marsupials are obligate hollow-users in montane ash forests (Lindenmayer et al., 1991a), we postulated that previously established hollow-tree/animal occurrence relationships would persist over time on sites that continue to support hollow-bearing trees, including on sites that had been burned.

The insights from our empirical study are critical for understanding the impacts of fire (including very high fire severity) on biodiversity at both a site level and a landscape level. They are also valuable for highlighting which kinds of species within an assemblage may be sensitive to fire severity. Our work provides a valuable model for illustrating the conservation management and ecological learning that can arise from the early initiation of studies that follow major natural disturbances such as unplanned fires.

2. Methods

2.1. Study area

Our study took place in the montane ash forests of the Central Highlands of Victoria, south-eastern Australia. The dominant tree species in these forests were Mountain Ash (*Eucalyptus regnans*), and Alpine Ash (*Eucalyptus delegatensis*). These two tree species are obligate seeders and intensive stand-replacing fire is a common natural disturbance pathway (Ashton, 1981; Lindenmayer, 2009).

The Central Highlands region lies about 120 km north-east of the city of Melbourne and covers approximately ½° of latitude and 1° of longitude (37°20′–37°55′S and 145°30′–146°20′E) (Fig. 1). Further information on the study area including climate, land use and other features are given in Lindenmayer et al. (2011a).

2.2. The arboreal marsupial fauna of montane ash forests

In addition to Leadbeater's Possum, three other species of arboreal marsupials are relatively common in montane ash forests – the