FIRE AND ITS INTERACTION WITH ECOLOGICAL PROCESSES IN BOX-IRONBARK FORESTS

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Box-Ironbark forests extend across a swathe of northern Victoria on the inland side of the Great Dividing Range. Although extensively cleared and modified, they support a distinctive suite of plants and animals. Historical fire regimes in this ecosystem are largely unknown, as are the effects of fire on most of the biota. However, knowledge of the ecological attributes of plant species has been used to determine minimum and maximum tolerable fire intervals for this ecosystem to guide current fire management. Here, we consider the potential effects of planned fire in the context of major ecological drivers of the current box-ironbark forests: namely, the climate and physical environment; historical land clearing and fragmentation; and extractive land uses. We outline an experimental management and research project based on application of planned burns in different seasons (autumn, spring) and at different levels of burn cover (patchy, extensive). A range of ecological attributes will be monitored before and after burns to provide better understanding of the landscape-scale effects of fire in box-ironbark forests. Such integration of management and research is essential to address the many knowledge gaps in fire ecology, particularly in the context of massively increased levels of planned burning currently being implemented in Victoria.

Keywords: planned burn, experimental management, landscape ecology, fire regime

FIRE is a natural disturbance process that influences the structure and function of ecosystems throughout Australia and the world. Fire is also widely used as a management tool for reducing the risk of severe wildfire, and for manipulating ecosystems for conservation purposes (Gill 2009). Vegetation types differ greatly in their natural fire regimes and such differences are reflected in the way in which biota respond to fire (Bradstock et al. 2002). An inappropriate fire regime for a particular ecosystem can have detrimental consequences, including population decline or local extinction of species (Keith 1996). Consequently, the planned use of fire requires knowledge of the ecological effects of fire on plants, animals and their habitats, at spatial and temporal scales relevant to the long-term persistence of their populations.

Box and Ironbark forests primarily occur inland of the Great Dividing Range in south-eastern Australia. In Victoria, they formerly occupied an area of ~1 million ha on gentle slopes and inland hills (ECC 1997). They are dry sclerophyll forests dominated by eucalypts, with a shrubby understorey. Common canopy species include Red Ironbark *Eucalyptus tricarpa*, Mugga Ironbark *E. sideroxylon*, Grey Box *E. microcarpa*, Yellow Gum *E. leucoxylon* and Red Stringybark *E. macrorrhyncha*. Since European settlement, this ecosystem has been highly modified, with clearing of >70% of the former forests. The region has a distinctive flora and fauna, including numerous species of conservation concern at both state and national level (Muir et al. 1995; ECC 1997). Remaining forests have experienced major disturbance associated with gold mining, timber harvesting and other land uses (ECC 1997; Lawrence and Bellette 2010). Management of these and other temperate forests in southern Australia is of national conservation significance (Lindenmayer et al. 2010).

The ecological effects of fire in box-ironbark forests have recently been reviewed by Tolsma et al. (2007a,b, 2010), with a focus on the likely effects of prescribed burning on plant and animal species. Here, we complement their work by considering the role of fire in relation to major ecological drivers that determine the status of box-ironbark forests. We then outline the objectives and design of an experimental management and research project to better understand the effects of planned burning at the landscape scale in box-ironbark forests.

FIRE REGIMES IN BOX-IRONBARK FORESTS

Little information is available on fire regimes in box-ironbark forests prior to European settlement (ECC 1997; Tolsma et al. 2007a). Aboriginal peoples in northern Victoria employed fire as part of food gathering activities (Curr 1883), but their use of fire in dry shrubby forests compared with open grassy woodlands of the plains, is not known. Similarly, there is little detailed knowledge of burning patterns in the early years of European settlement. Some anecdotal reports exist, such as that of a Goldfields Commissioner in 1853, describing 'black charred gullies' when visiting the Rushworth area (Lawrence and Bellette 2010).

The present fire regime is driven by fires caused by humans rather than ignition by natural causes. Data for the period 1983/84 to 2002/03 for the Bendigo Fire District (DSE 2003a) show that only 7% of fires (133/1849) were attributed to lightning, with the remainder being of human origin (deliberate or accidental) (66%), or of unknown cause (27%). The large majority (93%) of these fires were ≤5.0 ha in area, with only five fires >400 ha. The largest was in Jan 1985 at Maryborough, when 50,800 ha of land was burned (DSE 2003a).

Fire management agencies (Department of Sustainability and Environment, Parks Victoria) use planned fire to reduce fuel loads and the risk of wildfire in forests close to regional cities and towns (e.g. Bendigo, Castlemaine, Rushworth, St Arnaud) and to create strategic breaks through public land blocks. Typically, approx. 2000 ha has been burned annually in the Bendigo Fire Management Area. However, current governmental policy is to greatly increase this extent (to more than 11000 ha per annum) to implement the recommendation of the Bushfire Royal Commission that prescribed burning be increased to an annual rolling target of 5% minimum of public land in the state (Recommendation 56; Teague et al. 2010).

KNOWLEDGE REQUIRED FOR FIRE MANAGEMENT

Driscoll et al. (2010) highlighted three areas of knowledge required to underpin the management of fire for ecological purposes: 1) a mechanistic understanding of species' responses to fire regimes; 2) understanding of how the spatial and temporal patterns of fire influence the biota; and 3) knowledge of the interaction of fire regimes with other processes.

Few ecological studies of fire have been conducted in box-ironbark ecosystems (but see Meers and Adams 2003; Orscheg 2006). Accordingly, Tolsma et al. (2007a) concluded that little is known regarding the response of plants and animals to fire regimes in box-ironbark forests. To summarise the likely effects of fire on box-ironbark biota (understorey plants, canopy trees, invertebrates, birds, mammals, and reptiles and frogs), Tolsma et al. (2007a, 2010) drew on ecological knowledge of species from other studies, including studies of the effects of fire in other ecosystems (e.g. the long-term study in the more-mesic Wombat State Forest (DSE 2003b)).

Knowledge of the vital attributes of plant species, including their mode of establishment and persistence, time to reach reproductive maturity and longevity, can be used to identify 'key fire response species'. Such species have been used to propose 'tolerable fire intervals' for different vegetation types in Victoria (Cheal 2010). For box-ironbark forests, Tolsma et al. (2007a) identified 40 species of vascular plants as key fire response species, the most suitable being the Grey Grass-tree *Xanthorrhoea glauca* and Daphne Heath *Brachyloma daphnoides*. The minimum tolerable fire interval recommended for 'Ironbark/Box Ecological Vegetation Division' is 12 years for a low severity (patchy) fire and 30 years for a wildfire; and the maximum tolerable fire interval is 150 years (Cheal 2010). Tolsma et al. (2010) recommended a conservative approach to the use of prescribed burning, with minimum fire intervals of 20-25 years. While recognising that box-ironbark forest vegetation is likely to be relatively robust to fire, they noted that there is little evidence that fire is necessary for the vegetation and that a fire regime that will enhance biodiversity in box-ironbark forests (rather than simply maintain it) has yet to be identified (Tolsma et al. 2010).

Tolerable fire intervals are based primarily on knowledge of the response of plant species to fire. However, the requirements of animals must also be considered and may differ from those of plants (Clarke 2008). A fire management regime based on minimum tolerable fire intervals for plants is likely to be inconsistent with that required for the provision and maintenance of structural habitat components on which many animal species depend.

In addition to limited knowledge of species' responses to fire, little is known for box-ironbark forests of how the spatial and temporal patterns of fire influence the biota, or of the interaction of fire regimes with other processes. We address some of these issues below.

FIRE IN THE CONTEXT OF MAJOR ENVIRONMENTAL PROCESSES

Present-day box-ironbark forests and their biota have been shaped by a combination of natural and anthropogenic processes. The effects of fire in these forests must be considered in light of such processes.

Climate and the physical environment

The climate and physical environment are primary determinants of the structure and composition of the vegetation (Muir et al. 1995; ECC 1997), which in turn influences habitats for fauna. The topography is one of low hills with gentle slopes, with elevation generally between 150–350 m. Soils across much of the region are derived from Paleozoic sedimentary strata and typically are shallow and stony with low fertility and poor water-holding capacity (Muir et al. 1995; ECC 1997). Mean annual rainfall ranges from 450 mm in the north-west to 650 mm in the south-east (ECC 1997). Temperatures are warm in summer, with mean daily maxima of ~28–29^{0}C, although days above 35^{0}C are common (ECC 1997).

A consequence of nutrient-poor soils and low moisture availability is that primary productivity in these forests is low compared with other sclerophyll forests (Kellas 1991). Tree growth rates are slow, the forest structure and shrub layers are relatively open (Muir et al. 1995), and litter volume is less than in other dry sclerophyll forests (Chatto 1996; Tolsma et al. 2007a). These attributes have implications for fuel hazard, and the potential reduction in risk available through fuel reduction burning. In Chiltern Box-Ironbark National Park, the overall fuel hazard was assessed to be below critical levels, even after decades without fire, except where stringybarks were present, contributing to bark hazard (Chatto 1996). Fuel-hazard assessment (Hines et al. 2010) in 22 areas in Rushworth Forest (by DSE staff 2010, unpublished), all unburnt for >25 years, found that all were low or moderate (i.e. none were high, very high, or extreme).

Minor variation in elevation, topography and moisture availability result in differences in forest composition and structure, and create a heterogeneous landscape mosaic that supports a diverse assemblage of plants and animals (ECC 1997). There are marked differences, for example, in the richness and composition of bird communities between gullies and adjacent slopes in box-ironbark forests (Mac Nally et al. 2000). Different combinations of eucalypts occur in different topographic positions and, as different species flower at different times of the year (Wilson 2002), the topographic heterogeneity enhances the local availability of nectar sources through the year.

Fire also contributes to heterogeneity in box-ironbark forests by its influence on plant regeneration processes and forest structure. Spatial variation in structural complexity (e.g. shrub height and density, litter depth, abundance of dead trees) in forest stands of different post-fire seral stages, influence patterns of habitat quality for animal populations across the forest landscape. Different species respond to such heterogeneity in different ways, although no studies have yet quantified the influence of fire-mosaic patterns in dry eucalypt forests. A first step is to understand how the occurrence and abundance of species change in relation to post-fire successional stages, and then, how spatial patterns of successional stages arising from different burn treatments affect the biota at the landscape scale.

Land use, forest clearing and fragmentation

Massive transformation has occurred in the box-ironbark region over the last 150 years, with >70% of tree cover removed and the remaining forests being fragmented into numerous remnant blocks of various sizes (ECC 1997). Remnant forests typically are separated by land cleared for agriculture, with clearing disproportionately greater for vegetation types associated with better soils. The combination of reduced size, increased isolation and altered land uses in these fragments results in changes to plant and animal communities (e.g. Mac Nally et al. 2000; Mac Nally and Brown 2001). The potential use of planned fire in such remnants has been considered in detail by Tolsma et al. (2007b). We note two ways in which fire regimes interact with such land-use change.

In the event of fire (wildfire or planned burning), smaller blocks have a greater risk of most, or all, of the block being burned in one fire event. Transformation of the vegetation to a single, early-seral age-class is potentially detrimental for populations of any species closely associated with later seral stages. If populations are extirpated locally, the potential for recolonisation when habitat becomes suitable depends on the dispersal ability of the species and the types of surrounding land use.

Small remnants have a greater proportion exposed to other land uses (farmland, urban) than larger remnants. Changes to ecological processes at, or close to, such edges may influence the effects of fire on the biota. For example, grazing pressure on plants after fire by herbivores (native or introduced), or predation on native fauna by introduced predators, may be greater close to edges where populations of such herbivores and predators are sustained by food in adjacent farmland. In Reef Hills State Park, where a high density of the Eastern Grey Kangaroo *Macropus giganteus* is sustained by adjacent farmland, Meers and Adams (2003) reported a significant reduction in shrub diversity on grazed compared with ungrazed plots in burned areas. They suggested that kangaroos may shift their grazing from farmland to burnt areas within forest where new growth occurs.

Land use within forests

A long history of exploiting natural resources within box-ironbark forests has caused major changes to forest structure. Lawrence and Bellette (2010) documented land uses within the Rushworth forest block since the 1850s, including gold mining, indiscriminate tree felling, charcoal production, logging and silvicultural management over many decades, firewood harvesting, grazing by stock, eucalyptus oil production, removal of 'pest' plants (mistletoe, dodder laurel, *Cassinia*), gravel extraction and, more recently, conservation.

Today, evidence of the intensive modification of these forests is the scarcity of large trees (e.g. >80 cm diameter), high densities of small stems (<30 cm diameter), limited fallen timber (particularly large logs), eroded drainage lines, mullock heaps from gold mining, and a stony ground layer with sparse topsoil. These structural aspects affect the fauna: larger trees, for example, are a better source of tree hollows (Soderquist 1999), they are more likely to flower heavily and to provide nectar (Wilson and Bennett 1999), and they are a primary source of large logs and other fallen timber for ground-foraging birds (Laven and MacNally 1998).

Fire, whether a planned burn or wildfire, further modifies forest structure and the availability of habitat components used by fauna. Fallen timber, stumps, litter and dead trees are flammable components and may be disproportionately consumed in fires. Alternatively, burning may result in further dead stems and the collapse of trees to add logs and debris to the ground layer. The extent of such structural changes and their implications for habitat quality for plants and animals are largely unknown, particularly with regard to variation in fire severity and patchiness across the landscape.

The pattern of burning influences fine-scale heterogeneity on the ground layer. In this water-limited, nutrient-poor system, fine-scale patchiness created by logs, litter piles, shrubs, stumps and large trees may have an important influence on landscape function (Ludwig et al. 1997). By slowing the surface flow of water and enhancing soil infiltration, and by trapping fine soil and litter particles and retaining nutrients, such patchy structures may be critical to the maintenance of local productivity. Investigation is needed into the effects of different burning regimes on such soil surface dynamics and micro-landscape function.

MOSAIC BURNING IN BOX-IRONBARK FORESTS: AN EXPERIMENTAL APPROACH

The State of Victoria has recently committed to an annual target of planned burning of an area equivalent to 5% of public land in the state, to reduce the risk of wildfires to human life and property. To meet this target, large 'landscape mosaic burns' are being undertaken with the goal of achieving ecological benefits and reduction of wildfire risk. Given the lack of knowledge of the effects of fire in box-ironbark ecosystems, an experimental project was initiated in 2010 involving fire managers in the Department of Sustainability and Environment and Parks Victoria, and scientists from Deakin and La Trobe Universities, to investigate the ecological effects of fire at the landscape scale.

The study design incorporates two main aspects of planned burning:

a) The extent and pattern of burn (and hence the type of fire mosaic created). Two treatments were selected: a patchy mosaic burn in which ~40–60% of the landscape is burned, and an extensive burn of ~70–90%. The latter is typical of fuel reduction burns in the district, whereas a patchy mosaic burn may be more suitable as an ecological burn.

b) The season of the burn, namely autumn or spring burns.

Twenty-two study landscapes were selected within the Rushworth–Heathcote–Graytown forest block,

Burn cover:	~ 40-60% burn		~ 70-90% burn		reference
	I		I		I
Season:	autumn	spring	autumn	spring	not burned
	I	I	I	I	I
Replicates:	4	4	4	4	6

Fig. 1. Study design for the Box-Ironbark Experimental Burning Project showing the stratification of 22 study landscapes among treatments.

encompassing both state forest and national park. Each landscape is ~100 ha, bounded by roads or tracks, and dominated by vegetation typical of the box-ironbark Ecological Vegetation Class (Muir et al. 1995). Study landscapes are separated by >0.5 km (typically much greater) and are >200 m from the nearest forest–farmland boundary. Areas recently logged or burned were avoided. Forests mapped as ecologically important due to a higher density of large old trees were avoided.

The study design (Fig. 1) is based on eight landscapes being burned in autumn, eight in spring, and six left as unburned 'reference' areas. In each season (autumn and spring), four of the eight landscapes are assigned as low-cover burns (40-60%) and four as high-cover burns (70-90%). Treatments (season, burn cover, reference) were assigned randomly to sets of landscapes, with the exception of three reference landscapes which were assigned a priori due to a lack of suitably sized blocks bounded on all sides by roads/tracks.

Burning is carried out by operational staff of the Department of Sustainability and Environment and Parks Victoria, based on 'normal' procedures for planned burns. The burns were conducted in autumn (Feb-April) and spring (Oct-Dec) 2011 in the designated landscapes (Fig. 2).

Fig. 2. A planned burn in one of the study landscapes, Nov 2011.

Monitoring of the effects of these planned burns was designed to investigate a range of ecological processes and attributes within the forest. Within each study landscape, 12 plots (each 20 x 20 m) were systematically located to assess and monitor vegetation and habitat features. The effects of burning can be evaluated at both the site level (i.e. individual plots) and at the landscape scale by collating data across all plots in a study landscape. Comparisons will be made of vegetation and habitat measures taken before vs after burning, following autumn or spring burning, and of reference vs burned areas. The range of attributes being investigated includes:

a) plant species composition

b) tree species composition, regeneration and stem density

c) dynamics of coarse woody debris (logs)

d) litter, ground cover and vegetation structure

e) composition and abundance of woodland bird communities

f) ecology of selected faunal species (Yellow-footed Antechinus *Antechinus flavipes* and Scarlet Robin *Petroica multicolor*), that depend on the ground layer

g) interaction between the effects of herbivore browsing and fire on vegetation.

This project will greatly improve understanding of the ecological effects of fire in box-ironbark forests. The opportunity for learning created by experimental management actions will allow specific questions to be investigated relating to the response of plants and animals to planned burning. For example:

• what is the relative influence of the extent and pattern of mosaic burning (% of landscape burned vs unburned) on plant and animal populations?

• what kinds of differences occur in the responses of plant and animal species to autumn vs spring burning?

• will burning result in the re-establishment of additional plant species from the soil seed store?

• do individual animals (Yellow-footed Antechinus, Scarlet Robin) survive planned burns? If so, do they respond by shifting their home range (partly or wholly), enlarging their home range, or by remaining in the same home range?

The project findings will help refine future fire management practices for the benefit of biodiversity. Such work is critical given the massively increased levels of planned burning being implemented in Victoria.

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