

Bird population responses to wildfire and planned burns in foothill forests of Victoria, Australia

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Abstract Fires and people have helped shape forest ecosystems. Planned burns can be used to reduce social or ecological risks from wildfires, but we need a better understanding of the ecological effects of planned burns and wildfire over various temporal and spatial scales. Here, two approaches were used to answer various questions about responses of diurnal birds to fire regimes in mixed eucalypt forests in the foothills of Victoria, Australia: what are the effects of planned burns (at two different frequencies and seasons) when applied systematically over many years, and what are the short-term effects of severe wildfire? A long-term experiment examined planned burns in two seasons and at two frequencies on 25 sites in Wombat State Forest in 1984. An opportunistic study compared bird abundance in 33 burnt and 33 unburnt sites in the year after an extensive severe wildfire in Bunyip State Park in 2009. Brief reference is also made to a retrospective study, which provided a longer-term perspective by examining bird abundances at 113 sites in eastern Victoria that had been subject to different regimes over the past 40+ years, addressing questions about the impacts of different fire frequencies and times since fire. This paper considers data from snapshot surveys in 2009–2012. Data from Wombat

State Forest showed significant effects of fire treatments for just four of the 27 species analysed ($p < 0.05$). In frequently burnt sites, Brown Thornbills *Acanthiza pusilla* (shrub foraging insectivores) and Scarlet Robins *Petroica boodang* (open-ground insectivores) were least common, and Rufous Whistlers *Pachycephala rufiventris* (canopy-foraging insectivores) and Australian Magpies *Cracticus tibicen* (open-ground insectivores) were most common. There was weak evidence that three species were advantaged by burning in autumn rather than spring, and one of them (White-winged Chough *Corcorax melanorhamphos*, an open-ground insectivore) was rarely recorded except in sites burnt in autumn. Data from Bunyip State Park showed that birds were 77 % less numerous on burnt than unburnt sites in the winter after severe bushfire, but some redistribution had occurred by the next spring, along with an unprecedented spring influx of White-browed Woodswallows *Artamus superciliosus* (aerial insectivores) to burnt sites from inland Australia. The study shows that planned burns can be conducted in spring or autumn every 3–10 years with only small effects on common forest birds, at least when they are conducted on small areas in a forest with a history of disturbance. Wildfires can have much more dramatic short-term effects on bird populations. The retrospective study suggested that these effects may be short-lived, as such dramatic contrasts were not found between sites burned at different times beyond 3 years. Multiple approaches will be needed to answer key questions about longer-term effects of planned burns and wildfires in order to help reduce risk and conserve biodiversity.

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Introduction

The ranges of southeastern Australia are among the most fire-prone environments in the world, and can serve as a laboratory for understanding some of the processes that may be occurring globally and the social and ecological issues that need to be addressed in managing them. Studies of bird populations can be particularly helpful in understanding some of the ecological processes involved in this complex issue. Fires and people have helped shape the native eucalypt forests for millennia, but fire regimes are changing in response to climate change and modern human interventions (Gill 1975, 1981, 1996; Bowman et al. 2009; Bradstock et al. 2012; Attiwill and Adams 2013). Occasional severe fires can devastate human communities and can have profound effects on natural ecosystems (Friend 1993; Woinarski and Recher 1997; Spies et al. 2011; Gill et al. 2013). The challenge is to manage fire regimes to minimise impacts while maintaining the natural character and ecological values of the forests.

In Victoria (southeast Australia) the Victorian government has implemented a range of policies and research projects to meet this challenge, both before and after the devastating fires of Black Saturday in 2009. Those fires began on a day of extreme weather (47 °C, hot north winds >100 kph) after a hot dry week and a decade of drought (Teague et al. 2010): some burned for several weeks over 401,073 ha and killed 174 people, mostly on the first day. A Royal Commission inquiry was held to learn from this tragic experience and to work towards new knowledge and practices, with improved outcomes for public safety and biodiversity conservation. The commission's many recommendations included an increased program of planned burns to reduce fuel (5 % of public land per year) and an enhanced program of monitoring and research (Teague et al. 2010).

Planned burns are one of the main tools available to land managers for reducing fuel loads and decreasing the risk of catastrophic wildfire (Gill 1996; Woinarski and Recher 1997; Tolhurst 2003; Teague et al. 2010; Bradstock et al. 2012; Attiwill and Adams 2013). The practice is likely to be increasingly used as human populations expand into forested areas with high fire risk and severe fire weather becomes more frequent with climate change. After the disastrous Black Saturday fires in Victoria in February 2009, the Royal Commission recommended that the public state agency for managing forests and fire (now the Department of Environment, Land, Water and Planning) should double its targets for planned burns such that 5 % of public land was burned each year, with a monitoring program to assess effects (Teague et al. 2010). Policy decisions of this sort can have major implications

for both risk management and biodiversity conservation, and to make informed decisions on these matters, it is clearly necessary to understand the efficacy and effects of different management strategies, including the effects of planned burns and severe wildfire in the short term and over many years.

This paper presents some of the key findings from two studies on birds and fire (and a third more briefly), and uses them to illustrate the range of questions and research approaches needed to improve our understanding and ability to manage fire to minimise human risk and conserve biodiversity. These studies examined the effects of fire regimes or particular fires on birds in foothill forests of Victoria, Australia, and each study addressed different sets of questions. The Wombat Forest study examined the effects of planned burns at two different frequencies (~3 or 10 years vs no burns) and two seasons (spring or autumn vs no burns), based on a long-term series of small replicated sites where specific fire regimes were maintained deliberately over 30+ years for this experiment. The Bunyip State Park study opportunistically examined short-term effects of severe wildfire in three different vegetation types. The retrospective study examined the longer-term effects of planned burns and wildfire over 40+ years in eastern Victoria, and here we focus briefly on its potential and discuss some of the issues involved in each approach and the different questions they address.

Methods

The studies examined the effects of fire regimes or particular fires on birds in foothill forests of Victoria, Australia, with a variety of fire-tolerant eucalypt species (e.g. Messmate *Eucalyptus oliqua*, Silvertop *E. sieberi*, Narrow-leaf Peppermint *E. radiata*, Mountain Grey Gum *E. cypellocarpa* and White Stringybark *E. globoidea*) dominating the overstorey. Foothill forests of this sort cover more than 80 % of the forested area in the eastern ranges of the state. These eucalypt species show high survival rates after most fires, with new foliage produced from epicormic shoots even when intense fires have caused total defoliation. Hence, the architecture of the original forest is usually maintained after the fire, while the understorey may be opened up for a short period before a flush of regrowth as shrubs and trees regenerate from new seedlings or vegetative resprouting. This contrasts with the situation in tall wet forests (dominated by Mountain Ash *Eucalyptus regnans* or Alpine Ash *E. delegatensis*), where tree mortality is commonly high, regrowth is mainly from seed (though some trees do produce new epicormic foliage), and intense fires are often considered as stand-

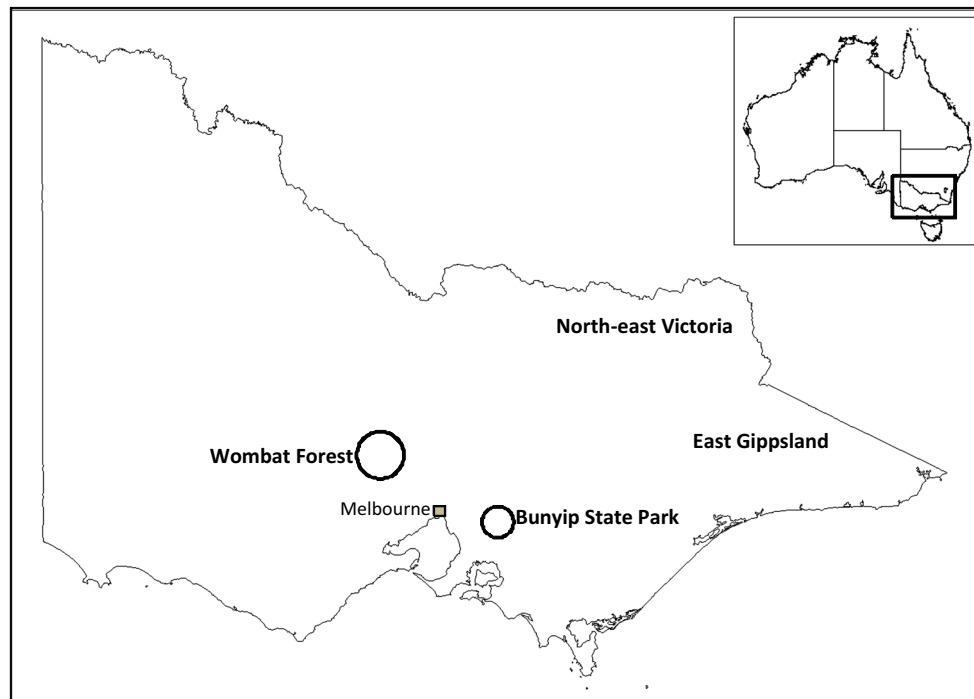


Fig. 1 Locations of the two main study sites in Victoria, southeast Australia (Wombat State Forest and Bunyip State Park) and other regions mentioned

replacing events (albeit with a legacy of large old trees, dead or alive).

One study was a long-term experimental study on the effects of planned fuel reduction burns at two different frequencies (~ 3 or ~ 10 years) and two seasons (spring or autumn); this work was initiated in 1984 and was conducted in Wombat State Forest 80 km northwest of Melbourne (Fig. 1). The second was an opportunistic study on the short-term effects of a very severe fire event, the Black Saturday bushfire of February 2009; this work was initiated in 2009 and was conducted in Bunyip State Park 70 km east of Melbourne (Fig. 1). Brief mention is made of a retrospective study on the effects of previous fire regimes; this work was initiated in 2010–2011, and conducted in East Gippsland and northeast Victoria 250–350 km east or northeast of Melbourne (Fig. 1). The data considered here were all collected during the period 2009–2012, following a decade of drought over much of southeastern Australia. The drought broke in the winter of 2009, with good rains then and subsequently.

Planned fuel reduction burns in Wombat State Forest (experimental study)

Five broad areas were selected for study (up to 130 ha), with five study sites in each broad area (25 sites altogether). All areas were known to have been free of

burning for long periods at the start of the study in 1984 (the last fires being in 1931, 1935, 1944, 1953, and 1974 for each of the five groups of sites). Five experimental treatments were assigned at random to each of the five sites in each of the five areas, giving five replicates for each treatment in a randomised block design. These treatments represented factorial combinations of planned burns in spring or autumn at short (3 years when possible) or medium intervals (~ 10 years), along with an unburnt control treatment. The schedule was maintained from 1984 to the present, with minor adjustments when needed for logistical reasons. At the time of the current assessment in 2011, the frequently burnt sites had each been burnt 4–7 times since 1984 (mostly 6 or 7 times) and the infrequently burnt sites two or three times. The mean time since fire was 3.5 years for the frequently burnt sites (2.6–4.5) and 5.8 years for the infrequently burnt sites (3.7–7.6). All of the planned burns were of low intensity, burning proportions of the understorey vegetation but leaving a green canopy, with only small amounts of leaf scorch and negligible tree mortality. A wildfire impinged on part of one of the 25 sites in ~ 2002 , but other sites were not affected by wildfire over the duration of the period.

Surveys of birds were conducted at all 25 sites at various times beginning in 1984. Data from November to December 2011 (spring-summer) are presented here.

Effects of extensive severe fire in Bunyip State Park (opportunistic study)

A total of 68 sites were selected for study, coinciding with sites where owls and arboreal mammals had been studied in 2001 (McNabb and McNabb 2002). Two were excluded from further analysis here because they were the only representatives of a localised vegetation type (Swampy Riparian Woodland), and both sites burned in 2009. Half the remaining sites (33/66) burned in the fires of February 2009, which burned ~55 % of the park (Fig. 2). The sites were in various vegetation communities across all sections of the park and the adjacent Kurth Kiln Regional Park. For the present analysis, sites were grouped into three vegetation communities, termed heathy woodland, tall shrubby forest, and wetter forest, with roughly equal numbers of burnt and unburnt sites in each (Table 1). Fire intensity (“soil burn severity”) was mapped over the area within the burn perimeter (anon 2009), and classed as high over 11 % of that area, moderate over 36 %, low over 31 %, and unburnt over 22 %, at the scale of 16-ha polygons, based

on a combination of aerial and ground surveys (Table 1). The high category involved >50 % canopy consumption (black canopy) and the moderate category >50 % canopy scorch (mainly brown canopy). In the low category, the fire burned mainly in the understorey, leaving a green canopy.

Bird surveys were conducted on these sites in winter (May–July) and spring (Oct–Dec) 2009 3–5 and 8–10 months after the fire, respectively

Field methods

Birds were surveyed using timed area searches, in which an observer moves through an area recording species and numbers of all birds seen or heard on the site (Loyn 1986). Birds observed offsite were recorded but not considered further in the analysis. At Wombat State Forest, 20-min searches of 2 ha were used, and 10-min searches of 1 ha were used in Bunyip State Park, where vegetation communities sometimes changed on fine spatial scales. Two searches were usually made on each site, and mean values were used for analysis.

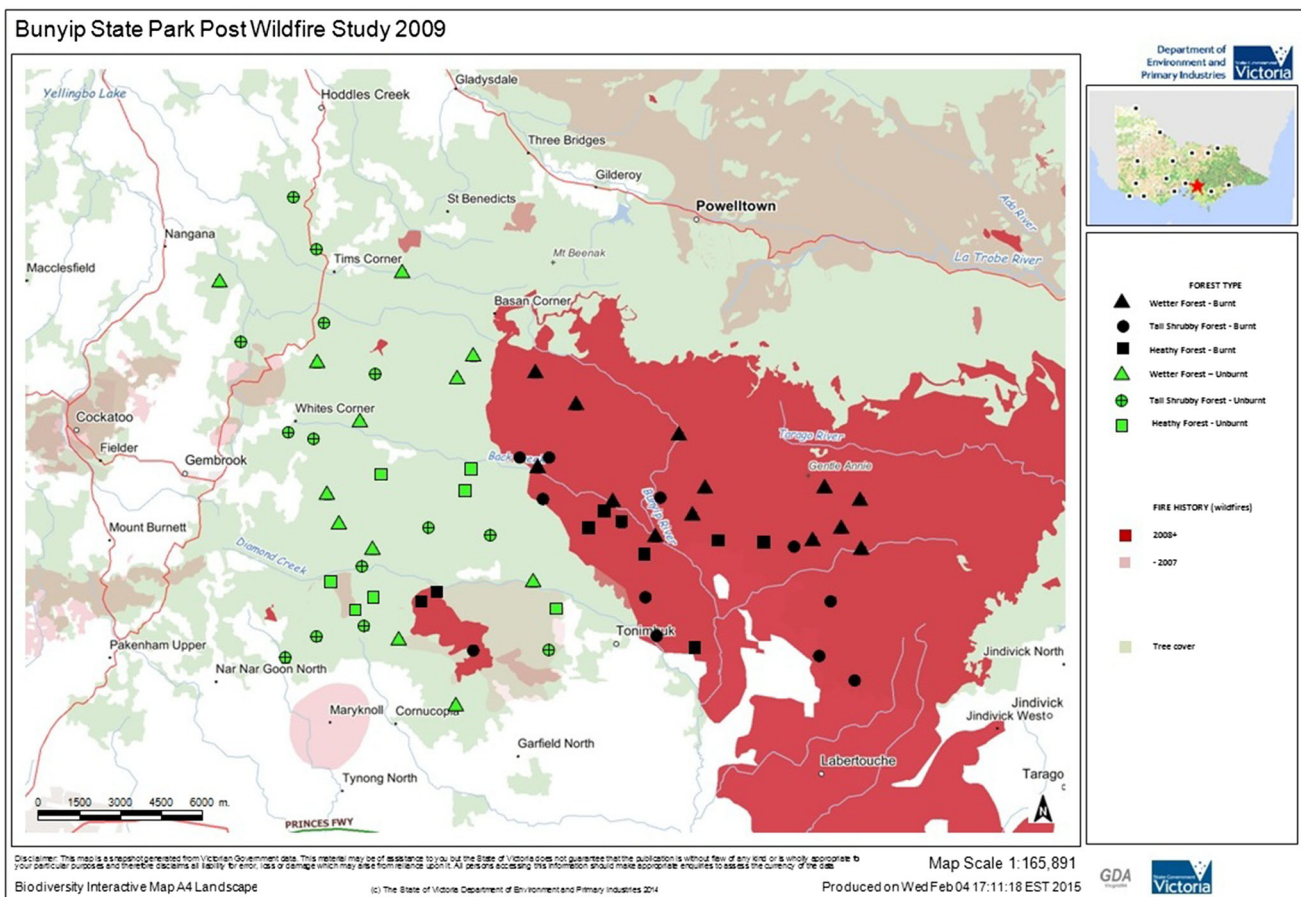


Fig. 2 Area burnt by wildfire in Bunyip State Park 2009 (dark red shading) and distribution of study sites (black burnt, green unburnt). Squares represent heathy forest (Damp Heathy Woodland EVC); circles denote tall shrubby forest (Lowland Forest or Shrubby Foothill

Forest EVCs), and triangles represent wetter forest (Damp Forest, Riparian Forest, or Wet Forest EVCs). EVCs refer to Ecological Vegetation Classes, used for classifying vegetation in Victoria (color figure online)

Table 1 Vegetation types of the 66 sites studied in Bunyip State Park, winter (May–July) and spring (October–December) 2009, 3–10 months after severe wildfire

Vegetation type	Ecological Vegetation Classes (EVCs)	Total sites	Burnt sites	Unburnt sites
Heathy woodland	Damp Heathy Woodland	15	8	7
Tall shrubby forest	Lowland or Shrubby Foothill Forest	25	12	13
Wetter forest	Damp Forest, Riparian Forest and Wet Forest	28	15	13

Analysis

Each bird species was assigned to guilds for feeding and nesting (as in Loyn et al. 2007), but here we focus mainly on analysis at the species level.

General linear modelling was used to determine the effects of the main categorical variables of interest in each case (aspects of fire regimes, and vegetation type expressed as EVD or combinations of EVDs).

For the study of planned burns in Wombat State Forest, burn season and frequency were considered as fixed factors (each with three levels, including no burns), and the five broad areas were considered as a random factor.

For the study of severe wildfire in Bunyip State Park, mean values were taken for each site from surveys in winter and spring 2009 and were analysed with respect to two categorical variables (whether they had burnt in the recent fires, and the three vegetation types) (Table 2). Separate analyses were also conducted for each of the two seasons (spring and winter) and were used for species that were mainly summer or winter visitors, respectively.

Results

Planned fuel reduction burns in Wombat State Forest (experimental study)

The fire treatments had no significant effect when all birds were considered as a whole ($p = 0.198$ for season; $p = 0.462$ for frequency; $p = 0.949$ for the interaction). Mean values suggested that birds were 95 % as abundant on burnt sites as on the unburnt control sites (Fig. 3) (i.e. they may have declined by 5 %). Most species showed little difference between burnt and unburnt sites (Table 2).

No species was significantly affected by burn season ($p < 0.05$), but three species showed evidence of such an effect at lower levels of significance ($p < 0.1$). Grey Fantails *Rhipidura fuliginosa* and Superb Fairy-wrens *Malurus cyaneus* were least common in sites burnt in spring (Table 2). White-winged Choughs *Corcorax melanorhamphos* were mainly found on sites burnt in autumn (Table 2). Choughs were the only species that had not been present on the sites on initial surveys when the experimental regime began in 1984.

Four species showed significant responses to burn frequency (two negative and two positive). Brown Thornbills *Acanthiza pusilla* (a shrub-foraging insectivore) were least common in frequently burnt sites ($p = 0.029$) (Table 2). Scarlet Robins *Petroica boodang* (an insectivore that feeds from open ground among trees) were absent from frequently burnt sites on this occasion ($p = 0.009$) (Table 2). In contrast, Rufous Whistlers *Pachycephala rufiventris* (a canopy-feeding insectivore) were most common in frequently burnt sites ($p = 0.030$) (Table 2), but this was not typical of the guild in general. One of the insectivores that feed from open ground, Australian Magpie *Cracticus tibicen*, responded positively to fire frequency ($p = 0.038$) and was absent from unburnt sites (Table 2). This species is mainly found in open country. Another bird that forages from open ground, the Flame Robin *Petroica phoenicea*, also appeared most common in frequently burnt sites, but at a lower level of significance ($p = 0.092$) (Table 2).

No other species responded significantly to the fire regime variables, even at $p < 0.1$. No interactions were found between burn season and frequency.

Effects of severe wildfire in Bunyip State Park (opportunistic study)

Taking all species together, birds were 23 % as numerous in burnt sites as in unburnt sites (i.e. 77 % less common) in winter 2009. Most of the 85 species recorded during the study were substantially less common in burnt than unburnt sites. Almost all of these birds were forest birds, with open-country species constituting <1 % of the bird community in burnt or unburnt sites in the first winter after the fire. Forest birds decreased in unburnt sites between then and spring, and increased in burnt sites, so the contrast was then less marked, with forest birds then 58 % as numerous in burnt sites as in unburnt sites (Fig. 4). Two species in the guild of insectivores that feed from damp shady ground (Superb Lyrebird *Menura novaehollandiae* and Eastern Yellow Robin *Eopsaltria australis*) showed the reverse trend, foraging extensively in burnt sites during the winter but retreating to unburnt forest in spring.

In spring there was an extraordinary influx of aerial insectivores to burnt sites 9 months after the fire. One of them (White-browed Woodswallow *Artamus superciliosus*) became the most numerous species across all sites, with

Table 2 Estimated mean abundance (birds per 20-min search of 2 ha) of all birds and the 27 most numerous bird species in Wombat State Forest in relation to season (autumn or spring) and frequency (3 or 10 years) of planned burns over a 27-year period from 1984 onward, based on a snapshot survey in November–December 2011, with unburnt controls for comparison (total = 25 sites)

Treatment	Scientific name	No burns	Autumn	Spring	Frequency	10 years	SE
Total birds		30.48	30.42	27.30	29.73	27.98	1.64
Mean species per count		13.03	13.13	13.07	13.57	12.63	0.77
Sulphur-crested Cockatoo	<i>Cacatua galerita</i>	0.30	1.33	0.85	1.83	0.35	0.70
Crimson Rosella	<i>Platycercus elegans</i>	1.45	1.87	1.38	1.45	1.80	0.33
Shining Bronze-Cuckoo	<i>Chrysococcyx lucidus</i>	0.58	0.22	0.33	0.25	0.30	0.12
Fan-tailed Cuckoo	<i>Cacomantis flabelliformis</i>	0.28	0.20	0.17	0.15	0.22	0.11
Laughing Kookaburra	<i>Dacelo novaeguineae</i>	0.47	0.50	0.55	0.60	0.45	0.12
White-throated Treecreeper	<i>Cormobates leucophaeus</i>	2.43	2.28	1.92	2.03	2.17	0.25
Red-browed Treecreeper	<i>Climacteris erythroptis</i>	0.35	0.20	0.05	0.05	0.20	0.13
Superb Fairy-wren	<i>Malurus cyaneus</i>	2.32	2.13	1.27	1.47	1.93	0.31
White-browed Scrubwren	<i>Sericornis frontalis</i>	1.13	0.25	0.30	0.25	0.30	0.18
Striated Thornbill	<i>Acanthiza lineata</i>	1.25	0.75	1.07	1.08	0.73	0.29
Brown Thornbill	<i>Acanthiza pusilla</i>	1.68	1.60	1.60	1.17	2.03	0.25
Spotted Pardalote	<i>Pardalotus punctatus</i>	4.20	3.63	3.73	3.37	4.00	0.34
Striated Pardalote	<i>Pardalotus striatus</i>	1.70	1.88	1.68	2.05	1.52	0.31
Yellow-faced Honeyeater	<i>Lichenostomus chrysops</i>	1.90	1.73	1.15	1.38	1.50	0.31
Red Wattlebird	<i>Anthochaera carunculata</i>	0.80	0.32	0.42	0.50	0.23	0.13
Brown-headed Honeyeater	<i>Melithreptus brevirostris</i>	0.67	0.48	0.33	0.50	0.32	0.20
White-naped Honeyeater	<i>Melithreptus lunatus</i>	3.00	2.47	3.17	2.58	3.05	0.47
Black-faced Cuckoo-shrike	<i>Coracina novaehollandiae</i>	0.17	0.25	0.28	0.25	0.28	0.14
Golden Whistler	<i>Pachycephala pectoralis</i>	0.65	0.50	0.47	0.33	0.63	0.17
Rufous Whistler	<i>Pachycephala rufiventris</i>	0.90	1.25	1.62	1.85	1.02	0.25
Grey Shrike-thrush	<i>Colluricincla harmonica</i>	0.88	1.03	1.42	1.30	1.15	0.23
Australian Magpie	<i>Gymnorhina tibicen</i>	0.00	0.42	0.48	0.75	0.15	0.10
Pied Currawong	<i>Strepera graculina</i>	0.12	0.18	0.08	0.18	0.08	0.08
Grey Currawong	<i>Strepera versicolor</i>	0.23	0.03	0.18	0.13	0.08	0.09
Grey Fantail	<i>Rhipidura fuliginosa</i>	1.52	1.70	1.25	1.60	1.35	0.17
Satin Flycatcher	<i>Myiagra cyanoleuca</i>	0.20	0.25	0.25	0.25	0.25	0.11
White-winged Chough	<i>Corcorax melanorhamphos</i>	0.00	1.30	0.00	1.10	0.20	0.50
Scarlet Robin	<i>Petroica boodang</i>	0.23	0.18	0.13	0.00	0.32	0.08
Flame Robin	<i>Petroica phoenicea</i>	0.10	0.05	0.10	0.15	0.00	0.07
Eastern Yellow Robin	<i>Eopsaltria australis</i>	0.43	0.50	0.50	0.55	0.45	0.15

Notable differences ($p < 0.1$) are shown in bold (see text). Effects of burn frequency were significant for Brown Thornbill ($p = 0.028$), Rufous Whistler ($p = .030$), Australian Magpie ($p = 0.001$) and Scarlet Robin ($p = 0.009$), and less so for Flame Robin ($p = 0.092$). Effects of burn season were less clear but worth noting for Superb Fairy-wren, Grey Fantail and White-winged Chough ($p < 0.1$). No species showed a significant interaction between burn season and frequency. Most species showed no significant effects of burn treatment. Open-country birds and introduced birds constituted $< 0.5\%$ of the total

flocks of many hundreds taking up residence from mid-October to February, mainly in burnt heathy woodland where they bred, along with smaller numbers of a companion species, the Masked Woodswallow *A. personatus*. They did not occur again in subsequent years (personal observation). These species normally inhabit open plains of inland Australia, and had not previously been recorded breeding in this forest; indeed, they had rarely been recorded at all, apart from wandering flocks flying

overhead nearby. Several other open-country species were recorded in burnt sites in spring 2009, but mostly in small numbers. Open-country birds constituted 68 % of the bird community on burnt sites and 1.7 % on unburnt sites in spring, with arid-zone woodswallows accounting for the difference (Fig. 4). Locally resident open-country birds showed little change.

One other species was found in the forest for the first time, but in unburnt sites. This was the Scarlet Honeyeater

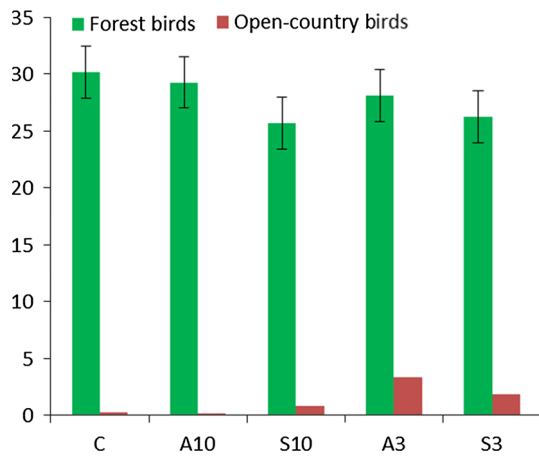


Fig. 3 Estimated mean abundance of forest birds and open-country birds in each of five burn treatments in Wombat State Forest in spring-summer (November–December) 2011 (birds observed per 20-min search of 2 ha). C control (no burns since 1984), A3 burnt frequently in autumn (every 3 years when possible), A10 burnt infrequently in autumn (approximately every 10 years), S3 and S10 likewise, but in spring. All treatments maintained since 1984

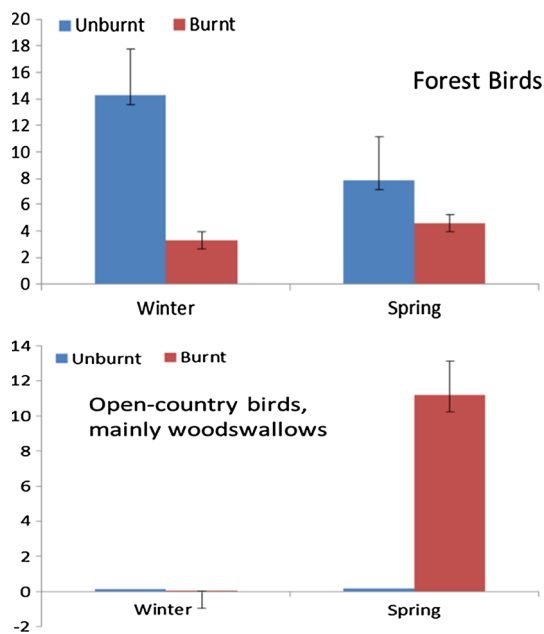


Fig. 4 Estimated mean abundances of forest birds and open-country birds in unburnt and burnt sites in Bunyip State Park in winter 2009 (May–July) and spring 2009 (October–December) after severe fires in summer (February 2009) (birds observed per 10-min search of 1 ha). Nomadic woodswallows from inland Australia constituted 97 % of the open-country birds observed on burnt sites in spring 2009, whereas local open-country birds entered the forest only in very small numbers

Myzomela sanguinolenta, and it was found foraging from flowers of Box Mistletoe *Amyema miquelii* in several forest areas near Melbourne, where the species is generally regarded as a rare vagrant (Emison et al. 1987).

Most bird species were more common in unburnt than burnt forest (Table 3). Several species showed significant interactions between vegetation type and effects of recent fire (Table 3), but which generally related to the magnitude of the effect and not its direction. Of the 27 forest species analysed, nine species were significantly more common in unburnt than burnt sites ($p < 0.05$), and a further three species showed the same trend at lower levels of significance ($p < 0.1$) (Table 3).

Four species showed the reverse effect, becoming significantly more common in burnt than unburnt forest, and one (White-winged Triller *Lalage sueurii*) showed the same trend at lower levels of significance ($p < 0.1$) (Table 2). They included White-browed Woodswallow (an aerial insectivore as discussed above) and three species of insectivore that feed from open ground (Australian Magpie, Flame Robin, and Scarlet Robin *Petroica boodang*). A canopy-foraging insectivore, Spotted Pardalote *Pardalotus punctatus*, also became more common in burnt sites, taking psyllid insects from the developing epicormic foliage. Several other species that are usually found in more open forest were recorded only in recently burnt sites, but their numbers were generally too low for useful statistical analysis.

Discussion

The study of planned burns in Wombat State Forest showed that these planned burns generally have small effects on bird populations, as was apparent with earlier snapshots (e.g. Loyn et al. 2003). The results of the current snapshot suggest that spring burns may mildly disadvantage two common species (Grey Fantail and Superb Fairy-wren) and that autumn burns may favour one less common species (White-winged Chough, which was rarely found in sites that had not been burnt in autumn) and the broader guild of birds that feed from open ground. Autumn is the drier season, and autumn burns were marginally more intense than spring burns, producing more open ground. Autumn burns also avoid the main spring nesting season for most forest bird species. Frequent burns appear to disadvantage two species (Brown Thornbill and Scarlet Robin) and advantage three species (Rufous Whistler, Flame Robin and Australian Magpie). The response of the Rufous Whistler had not been observed on previous snapshots, and the reverse response was found for the Scarlet Robin (Loyn et al. 2003), which has been found to favour recently burnt stands after wildfire (Loyn 1997). Flame Robins and Scarlet Robins compete for territories, and Flame Robins favour early successional stages (Loyn 1980; Robinson 1992); this interspecific competition may have

Table 3 Estimated mean abundances of the 27 most numerous bird species (birds per 10-min search of 1 ha) in Bunyip State Park in winter and spring 2009 (combined), using data from 33 sites that burned and 33 sites that did not burn in February 2009, across three vegetation types (heathy woodland, tall shrubby forest and wetter forest, here combined)

Species Scientific name	Burnt		Unburnt		Significance (p)			
	Mean	SE	Mean	SE	Fire	Veg	Fire × Veg	
Yellow-tailed Black-Cockatoo	<i>Calyptorhynchus funereus</i>	0.000	1.025	3.340	1.145	0.034	0.029	0.029
Crimson Rosella	<i>Platycercus elegans</i>	0.179	0.055	0.086	0.062	0.266	0.745	0.773
Eastern Rosella	<i>Platycercus eximius</i>	0.056	0.042	0.081	0.046	0.693	0.453	0.655
White-throated Treecreeper	<i>Cormobates leucophaeus</i>	0.163	0.063	0.395	0.070	0.017	0.010	0.351
Superb Fairy-wren	<i>Malurus cyaneus</i>	0.121	0.087	0.247	0.097	0.334	0.209	0.684
Spotted Pardalote	<i>Pardalotus punctatus</i>	0.295	0.041	0.141	0.046	0.017	0.072	0.151
Striated Pardalote	<i>Pardalotus striatus</i>	0.060	0.033	0.163	0.037	0.041	0.007	0.054
White-browed Scrubwren	<i>Sericornis frontalis</i>	0.043	0.065	0.238	0.073	0.051	0.109	0.127
Brown Thornbill	<i>Acanthiza pusilla</i>	0.265	0.116	0.858	0.129	0.001	0.005	0.064
Striated Thornbill	<i>Acanthiza lineata</i>	0.130	0.076	0.265	0.084	0.236	0.022	0.333
Red Wattlebird	<i>Anthochaera carunculata</i>	0.788	0.709	0.853	0.792	0.951	0.218	0.994
Yellow-faced Honeyeater	<i>Lichenostomus chrysops</i>	0.214	0.062	0.371	0.069	0.098	0.285	0.378
White-eared Honeyeater	<i>Lichenostomus leucotis</i>	0.034	0.031	0.120	0.035	0.071	0.096	0.347
White-naped Honeyeater	<i>Melithreptus lunatus</i>	0.000	0.768	1.027	0.858	0.376	0.469	0.469
Crescent Honeyeater	<i>Phylidonyris pyrrhoptera</i>	0.056	0.085	0.523	0.095	0.001	0.088	0.213
Eastern Spinebill	<i>Acanthorhynchus tenuirostris</i>	0.052	0.074	0.551	0.083	0.000	0.327	0.530
Scarlet Robin	<i>Petroica multicolor</i>	0.171	0.040	0.033	0.044	0.024	0.025	0.356
Flame Robin	<i>Petroica phoenicea</i>	0.120	0.037	0.000	0.042	0.038	0.685	0.685
Eastern Yellow Robin	<i>Eopsaltria australis</i>	0.059	0.041	0.176	0.046	0.064	0.330	0.984
Golden Whistler	<i>Pachycephala pectoralis</i>	0.026	0.042	0.234	0.047	0.002	0.000	0.002
Rufous Whistler	<i>Pachycephala rufiventris</i>	0.157	0.049	0.212	0.055	0.459	0.087	0.924
Grey Shrike-thrush	<i>Colluricincla harmonica</i>	0.179	0.045	0.218	0.050	0.567	0.031	0.066
Grey Fantail	<i>Rhipidura fuliginosa</i>	0.156	0.053	0.511	0.059	0.000	0.030	0.243
Black-faced Cuckoo-shrike	<i>Coracina novaehollandiae</i>	0.053	0.031	0.067	0.035	0.771	0.158	0.016
White-winged Triller	<i>Lalage tricolor</i>	0.083	0.026	0.017	0.029	0.093	0.244	0.642
White-browed Woodswallow	<i>Artamus superciliosus</i>	5.337	0.935	0.000	1.045	0.000	0.080	0.080
Silvereye	<i>Zosterops lateralis</i>	0.052	0.111	0.266	0.125	0.206	0.146	0.240

Winter data were not used for woodswallows, as they were absent in that season

contributed to the pattern observed on this occasion. Some of these conclusions must be regarded as tentative, as significant differences can be expected by chance for any species when multiple comparisons are made.

Increases or decreases in particular species are not necessarily good or bad: the challenge is to maintain a set of fire regimes in the forest landscape that maintain habitats for all species over time. Our results suggest that frequent spring burning may be the least desirable of the five options tested, but even that may have its place if used judiciously in combination with other approaches. It would be useful to know details of the “natural” fire regimes, including the influence of Aboriginal people over many thousands of years, but such information remains much debated and sketchily known (Gill 1975; Cheal 2010; Hateley 2010; Gammage 2011; Low 2014).

For most species there was little or no evidence that any of the four burn treatments or the no-burn control would cause major problems, even when the treatments were applied over a 30-years period as they were in this experiment. This conclusion applies only to small-scale burns (a few hectares) in one forest type, and collection of similar data from a wider range of forest types and geographical locations would be valuable. Wombat State Forest has been subject to much disturbance since the gold rush of the 1960s (Hateley 2010), and it could be argued that the current fauna represents a resilient subset of what was originally there. Hence similar studies in less disturbed landscapes would be of value, though few areas of foothill forest have escaped some degree of disturbance in this state or globally (e.g. Gott 2005; McCaw et al. 2011; Spies et al. 2011). Nevertheless, our study does provide some

reassurance that any of the four burn treatments could be applied strategically in the forest landscape without causing major disruption to bird communities as long as care was taken not to overuse the frequent spring burning option. As different species have different needs and responses, the crucial need is to set policies that maintain a mix of fire regimes in the broad forest landscape, allowing some areas to remain unburnt for long periods while burning others more often in order to reduce the impact of wildfires on key natural or human assets.

The study of extensive severe wildfire in Bunyip State Park demonstrated the massive change to bird populations that may occur after wildfire (77 % inferred reduction in forest birds) in a range of vegetation types. A similar but slightly lesser reduction was observed after severe wildfire in East Gippsland (eastern Victoria) during drought conditions in 1983 (Loyn 1997). Many species had fully recovered within 3 years of those East Gippsland fires. The Bunyip State Park study also showed that redistribution occurred between winter and spring a few months after the fire which would help lead to recovery in subsequent years.

The spring influx of woodswallows to burnt sites in Bunyip State Park highlights the continental mobility of these birds. White-browed and Masked Woodswallows are classic nomads following ephemeral pulses of food around mostly inland Australia (Higgins et al. 2006). These food sources include nectar, flying insects, leaf-sucking psyllid insects and lerps, and plague locusts. In burnt sites near Melbourne, they were seen taking insects from epicormic foliage as well as from the air, tree bark and the ground. While it cannot be said that these woodswallows depend on severe forest fires in the temperate zone, it seems clear that they do depend on successive blooms of varied food resources throughout Australia (mainly the interior). Globally, birds with similar strategies have had mixed fortunes as their environments are “tamed” by human settlement: in central Asia, Pallas’s Sandgrouse *Syrhaptes paradoxus* no longer make periodic irruptions, while in North America the Passenger Pigeon *Ectopistes migratorius* has famously gone from super-abundance to extinction (del Hoyo et al. 1997).

The retrospective study in East Gippsland aimed to provide a longer-term perspective, answering questions about the effects of time since fire and fire frequency over many decades (Muir et al. 2015). Results suggest that differences between fire regimes are fairly subtle in terms of effects on bird communities: the stark contrasts between burnt and unburnt sites a few months after wildfire in Bunyip State Park were not apparent in the longer time series available for study in eastern Victoria. Further analysis is planned to assess the effects of fire type and other variables on bird species and guilds over time, and to do more to tease apart the related effects of fire frequency (as

a fire regime variable) and time since fire (a more proximal driver of habitat change, which may influence bird abundance directly). The two variables are reciprocally related, as frequent fires inevitably reduce the mean level of time since fire in the landscape.

Some authors have questioned the value of relating successional change to time since fire (Di Stefano et al. 2011; Sitters et al. 2014), as biota respond to habitat elements that may change in variable ways over time, depending on many factors other than fire (e.g. Woinarski and Recher 1997; Catling et al. 2001; Kavanagh et al. 2004; MacHunter et al. 2009; Loyn and Kennedy 2009): birds don’t measure numbers of years since fire. However, we contend that the fauna concerned are much more capable of assessing the nature and value of those habitat elements than are we. It is not currently realistic for people to make habitat assessments across the landscape of the sophistication necessary to manage habitat for the whole suite of species according to the structure or other habitat features that the fauna actually need. We should try to improve our ability to identify key habitats, but we should also look for relationships with variables that we know we can manage, and time since fire is the most obvious and simple of all. It has been used effectively with respect to fire in the mallee (Haslem et al. 2011, 2012; Watson et al. 2012; Avitabile et al. 2013) and both logging and fire in the forests of southeastern Australia (e.g. Loyn 1980, 1997, 2004; Kavanagh et al. 2004; Robinson et al. 2014). Thus it remains important to look for such relationships, while recognising that this represents a simplification and a first step to better understanding. Concepts such as “tolerable fire intervals” have been developed to guide the frequency of planned burns in different vegetation types (Cheal 2010), although they may not yet cater to the diverse structural needs of birds and other wildlife (Clarke 2008; MacHunter et al. 2009).

In terms of fire planning, the results thus far show that planned burns can be conducted in foothill forests at frequencies of between 3 and 10 years with little negative impact on birds, at least as long as burn areas are kept small, whereas wildfires can have a much greater short-term impact. Hence, when strategic planned burns reduce the incidence, extent or severity of wildfire, the risks to birds and humans are also reduced. The effects on birds may be slightly greater when planned burns are conducted in spring than autumn, which is to be expected, as spring is the main breeding season for most species. However, that seasonal effect is subtle and not clearly established; it appears quite reasonable to conduct planned burns in both seasons, but to favour autumn when possible. Many species appear to recover quite quickly after wildfire (within 3 years in some cases) (Loyn 1997; Muir et al. 2015), but much more needs to

be known about the details of such recovery and the conditions necessary for it occur. Some habitat elements take many decades to develop after disturbance (especially after stand-replacing events), and it is important to provide conditions in which those habitats can be conserved and created at the right places within the forest landscape. We need to know more about effects of different types of fire over long time spans and the effects of fire regime variables (especially frequency) so that we can model their effects in complex landscapes (Friend 1993; Woinarski and Recher 1997; Driscoll et al. 2010; Spies et al. 2011; Gill et al. 2013). This will enable us to make informed decisions about how to reduce human risk while conserving biodiversity and maintaining the resilience of the ecosystem.

It is widely accepted that a more sophisticated risk-based approach to fire management is needed to deliver improved safety and biodiversity conservation outcomes in Australia (Clarke 2008; Driscoll et al. 2010) and internationally (Franklin et al. 2002; Bowman et al. 2009; Flannigan et al. 2009; Spies et al. 2011). A mix of management approaches will be needed, and a mix of research and monitoring approaches will be needed to inform these choices and evaluate their effects. Our ideal mix of approaches would include an array of planned experiments, a system of surveillance sites that could be monitored opportunistically after planned burns or unexpected wildfires, as currently implemented with the Hawkeye system in Victoria or the Forestcheck system in Western Australia (McCaw et al. 2011), and a program of retrospective research focusing on key questions about the spatial and temporal changes that occur under various fire regimes.

This paper illustrates two research approaches (long-term experiment with snapshot monitoring, and opportunistic monitoring of a single event) and also discusses a third approach (broad-scale retrospective research). All contribute in different ways to answering different questions. There are challenges in obtaining resources for long-term experiments, unless they can be woven into operational plans as in the Wombat State Forest example. A local champion is a key ingredient for success, and snapshot monitoring can be useful, as shown here. Opportunistic studies are greatly facilitated by the presence of established but flexible research programs, preferably with staff based near the event, as in our Bunyip State Park example. Retrospective studies offer the only practical way of obtaining data on long-term processes in short time frames. There are many challenges in design and analysis, but the main need is for high levels of replication (multiple sites) and a flexible approach to understanding the data and their limitations and to communicating the practical implications.

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