Department of
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Environment

Ecological effects of repeated low-intensity fire on bird abundance of a mixed eucalypt foothill forest in south-eastern Australia

Research report no. 62

Victoria
The Place To Be

Effects of repeated low-intensity fire on bird abundance in a mixed eucalypt foothill forest in south-eastern Australia

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Cover photographs 1. Low-intensity fire in foothill forest, DSE/K.Tolhurst 2. Spotted Pardalote, DSE/I.McCann

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Foreword

The vegetation, topography and climate of south-eastern Australia combine to make the region one of the most wildfire-prone areas on Earth. Over tens of thousands of years, naturally occurring fires have been highly significant in shaping the distribution and composition of much of the region's native flora and fauna. The arrival of humans here is also considered to have had a more recent influence on these evolutionary processes. Paradoxically, it has been estimated that, in the last one hundred years, two-thirds of all human deaths related to bushfires in Australia and more than half of all significant related property losses have occurred in Victoria.

The severity of a bushfire depends on topography, weather and fuel conditions. Fuel is the only factor over which a land manager can exert some control. The strategic use of prescribed fire (under specified environmental and fire behaviour prescriptions), generally in spring or autumn, is the only practical method of reducing fuels over significant areas and has been a key component of park and forest management in Victoria since the late 1950s – early 1960s.

The threat posed by fire to life and property and the relationship between fire regimes and biodiversity are arguably the key on-going issues confronting the managers of Victoria's parks and forests.

In 1984, a multidisciplinary study was established in the Wombat State Forest, 80 km north-west of Melbourne (Victoria), to investigate the effects of repeated low-intensity prescribed burning in mixed eucalypt foothill forest. The study—the Wombat Fire Effects Study—is quantitative and statistically based and includes various aspects of fauna, flora, soils, tree growth, fuel management and fire behaviour.

On the same permanent plots, various methodologies are used to investigate the ecological impacts of fire on understorey flora, invertebrates, birds, bats, reptiles, terrestrial mammals, soil chemistry and the growth, bark thickness and defect development in trees. Local climate and weather, fuel dynamics and fire behaviour are also studied, along with their interactions. Numerous published papers and reports have been produced as a result of the work. Fire Management Research Reports comprising the current (2003) series are:

No. Title

57. Ecological effects of repeated low-intensity fire in a mixed eucalypt foothill forest in south-eastern Australia - Summary report (1984–1999) - Department of Sustainability and Environment
58. Effects of repeated low-intensity fire on the understorey of a mixed eucalypt foothill forest in south-eastern Australia - K.G. Tolhurst
59. Effects of repeated low-intensity fire on fuel dynamics in a mixed eucalypt foothill forest in south-eastern Australia - K.G. Tolhurst & N. Kelly
60. Effects of repeated low-intensity fire on carbon, nitrogen and phosphorus in the soils of a mixed eucalypt foothill forest in south-eastern Australia - P. Hopmans
61. Effects of repeated low-intensity fire on the invertebrates of a mixed eucalypt foothill forest in south-eastern Australia - N. Collett & F. Neumann
62. Effects of repeated low-intensity fire on bird abundance in a mixed eucalypt foothill forest in south-eastern Australia - R. Loyn, R. Cunningham & C. Donnelly
63. Effects of repeated low-intensity fire on terrestrial mammal populations of a mixed eucalypt foothill forest in south-eastern Australia - M. Irvin, M. Westbrooke & M. Gibson
64. Effects of repeated low-intensity fire on insectivorous bat populations of a mixed eucalypt foothill forest in south-eastern Australia - M. Irvin, P. Prevett & M. Westbrooke

65. Effects of repeated low-intensity fire on reptile populations of a mixed eucalypt foothill forest in south-eastern Australia - M. Irvin, M. Westbrooke & M. Gibson
66. Effects of repeated low-intensity fire on tree growth and bark in a mixed eucalypt foothill forest in south-eastern Australia - K. Chatto, T. Bell & J. Kellas

The foreword to the summary report (Fire Management *Research Report* No. 57) sets out more fully the background to the research, the impact it has had on fire management in the State and the future of the program.

I would like to acknowledge the very considerable efforts of the scientists and technical officers who have contributed to this specific report and more generally to this most significant project.

Gary Morgan AFSM

CHIEF FIRE OFFICER
Department of Sustainability and Environment

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Contents

List of tables and figures

Summary

Bird communities were assessed in 1992–94 in the Wombat State Forest on 25 areas that had been subject to one of five experimental low-intensity burning treatments (frequent or infrequent burning in spring or autumn, or no burning—control), as part of a multidisciplinary study established in 1984. The 1992–94 assessments were made at least a year after the most recent burn. The frequently burnt areas had all been burned at least twice since experiments began in 1985 and the infrequently burnt areas just once, six to eight years previously. Data on bird abundance and species per count were analysed with respect to burning treatment by analysis of variance. Time, habitat data and pre-treatment data were also considered in supplementary analyses.

Insectivorous birds that forage from open ground increased in abundance on burnt areas compared with controls, especially on areas burned frequently in autumn. Nectarivores showed complex patterns, apparently responding to fire positively or negatively at different times. Other changes were subtle, but birds that feed in shrub layers tended to be less common on burnt areas than controls, especially on areas burned frequently in spring. Overall, burning season had no significant effect on any group except as an interaction with frequency. Frequent burns served to maintain early successional stages that benefited some species and may have disfavoured others.

Habitat variables added little to this picture, except that hollow-nesting birds responded strongly and positively to hollow density indices for each area. Inclusion of pre-treatment data as covariates did not improve the models produced, though the data were helpful in describing qualitative changes and stability in bird communities.

Fuel reduction burning in patches of less than 40 ha appears to have minor effects on bird communities in this forest (compared with not burning), and may benefit some species that forage from open ground. Autumn burns are marginally preferable to spring burns. Greater effects would be expected in forests with different shrub structures. Effects of broadscale burning would depend on the mosaic of burnt and unburnt areas produced. Long-term vegetation changes should be avoided. All effects should be evaluated with regard to effects of wildfire and any influence of fuel reduction burning on wildlife behaviour.

Introduction

Fire is one of the major agents of successional disturbance in many forests, and especially so in the highly flammable eucalypt forests that grow in Mediterranean climates of temperate southern Australia (Gill 1981 et al. 1981; Attiwill 1994; Woinarski & Recher 1997). Occasional severe wildfires can cause immense damage to human property and compromise safety (e.g. Cheney 1976; Noble 1977; Rawson et al. 1983), and have earned a fearsome reputation in the psyche of recent human settlers. Much effort is expended to reduce the extent and severity of wildfires and to protect public and private property and the natural resources of eucalypt forests (timber, flora and fauna, water supply, etc.). One of the main tools used is fuel reduction burning, in which fires are deliberately lit when weather conditions are mild, and the fires burn within control lines at relatively low intensities, to reduce fuel (litter, understorey and external bark) with minimal damage to trees or adjacent property. However, increasing attention is now being paid to the role that such fuel may play in the ecological processes of the forests.

In Victoria, south-eastern Australia, fuel reduction burning is practiced annually on up to 477 000 ha of the 7.2 million ha public forest estate, with an average of 136 000 ha having been treated each year from 1982 to 2001 (Department of Natural Resources and Environment annual reports). No other type of active land management affects such a broad area of the State each year. The practice is governed by a *Code of Practice for Fire Management* (CNR 1995), which sets objectives and standards for a range of associated activities, including environmental care. Ecological effects are not well known in Victoria or elsewhere, however, and the need for more information is widely acknowledged (Ealey 1984; Woinarski & Recher 1997). Whereas effects of wildfire can only be studied opportunistically or retrospectively (Loyn 1997), a more systematic experimental approach is possible for fuel reduction burning. Several specific management questions need to be addressed, including the relative costs and benefits of burning at different frequencies or seasons. Fuel reduction burning in central Victoria is normally conducted in spring or autumn, when vegetation is dry enough to burn and weather is mild enough for control to be maintained. Spring burns tend to be patchy because more rain falls in spring and the vegetation contains more residual moisture than it does in autumn after a hot dry summer. Spring burns coincide with the main breeding season for many forest birds and small mammals (Blakers et al. 1984; Loyn 1985; Menkhorst 1995).

This study was part of a multidisciplinary project (Tolhurst et al. 1992) that was designed to address some of these questions in a systematic experimental fashion for a region of central Victoria where fuel reduction burning is practised widely in the mixed eucalypt foothill forests on the Great Dividing Range. Other studies in the project have dealt with vegetation, fuel loads, soil chemistry, invertebrates, mammals and reptiles (e.g. Neumann & Tolhurst 1991; Tomkins et al. 1991; Tolhurst et al. 1992; Collett et al. 1993; Humphries 1994; Neumann et al. 1995; Tolhurst 1996a, b, c; Collett 1998). The present study deals with diurnal birds. Birds are often an instructive subject for study because they include a wide range of species that respond in different ways to environmental change. They are conspicuous (especially by call) and more easily studied than other groups of vertebrate or invertebrate animals.

Study area

The study was conducted in the Wombat State Forest, 80 km north-west of Melbourne. The forest straddles the south-western end of the Great Dividing Range, at altitudes of 500 to 800 m above sea level. Climate is temperate, with warm to hot summers (daily temperatures may exceed 40 ºC) and cool to cold winters (daily temperatures sometimes falling to –6 ºC). Most rain falls in winter and spring (70%), with about 160 wet days each year (Tolhurst et al. 1992). Snow falls in many years but rarely settles.

The forest contains a mixture of eucalypt species, usually growing as uneven-aged stands. The dominant species are Messmate Stringybark (*Eucalyptus obliqua*), Narrow-leaved Peppermint (*E. radiata*) and Candlebark (*E. rubida*). The understorey comprises a range of mostly sclerophyllous species with scattered shrubs and a dense ground layer including Austral Bracken (*Pteridium esculentum*) and a wide range of forbs and grasses. Forest Wire-grass *(Tetrarrhena juncea*) is common but less dominant than in the wetter forests further east. Orchids are common, often growing in areas of bare ground with dry litter from the tree canopy. Gullies contain a different range of understorey plants, including Tall Sword-sedge (*Gahnia clarkei*) and Prickly Tea-tree (*Leptospermum juniperinum*) (Tolhurst et al. 1992). The vegetation is currently classified as Shrubby Dry Forest or Herb-rich Foothill Forest with Damp Forest in the gullies, using the current Victorian system of Ecological Vegetation Classes (Woodgate et al. 1994).

Bird populations are typical of many of the drier foothill forests of Victoria (Loyn 1985; Emison et al. 1987). Small numbers of species characteristic of drier box–ironbark forests occur locally, and a few species typical of the wet forests of eastern Victoria occur in the wetter gullies. However, these two groups form a small component of the bird fauna, and some species are notable by their absence (e.g. Superb Lyrebird, *Menura novaehollandiae*).

Five broad Fire Effects Study Areas (FESAs) were selected in 1984, in parts of the forest that had not been burned for long periods of time. One was on the northern slopes of the Divide and the other four were on the generally wetter southern slopes. Details are shown in Table 1.

Table 1 Details of the Fire Effects Study Areas in the Wombat State Forest

Fire Effects Study Area	Location (latitude / longitude)	Mean elevation (m asl)	North or south of Great Divide	Annual rainfall 1986–90 (mm/year)	Hollow density index
Barkstead	37° 29′ S 144° 05′ E	640	South	926	4.0
Blakeville	37° 31′ S 144° 10′ E	600	South	898	46.4
Burnt Bridge	37° 25′ S 144° 20′ E	730	South	895	10.6
Kangaroo Creek	37° 19′ S 144° 18′ E	660	North	779	113.4
Musk Creek	37° 28′ S 144° 10′ E	645	South	920	98.6

Methods

The five FESAs were each divided into five areas, and a treatment assigned to each area at random. The five fire treatments are:

- frequent fires (approximately every three years) in spring—short-rotation spring, S3
- frequent fires (approximately every three years) in autumn—short-rotation autumn, A3
- infrequent fires (approximately every 10 years) in spring—long-rotation spring, S10
- infrequent fires (approximately every 10 years) in autumn—long-rotation autumn, A10
- fire exclusion (unburnt for more that 20 years)—long-unburnt control, C.

Burning treatments were first applied in spring 1985, and continued according to the schedule shown in Table 2.

Table 2 Dates of pre-treatment fires and experimental fuel reduction burns in each Fire Effects Study Area in the Wombat State Forest

Fire Effects Study Area	Burn treat't	Location grid ref.[1]	Elevation (m asl)	Area (ha)	Last fire pre-treat't	Dates of treatment burns
Barkstead	C	423471	630	4.4	1931	
	A3	421469	625	3.3	1931	27/4/87, 11/4/91
	A10	423470	630	4.2	1931	27/4/87
	S3	421471	625	3.8	1931	13/11/85, 28/10/88, 15/10/91
	S10	422472	635	3.0	1931	13/11/85
Blakeville	C	503448	605	15.3	1935	
	A3	508448	610	18.2	1935	8/4/87, 24/3/92
	A10	509446	615	14.8	1935	8/4/87
	S3	502451	610	16.0	1935	15/10/85, 3/11/88, 23/10/91
	S10	512444	610	16.2	1935	15/10/85
Burnt Bridge	C	644545	715	17.3	1953	
	A3	641552	725	11.5	1953	27/3/87, 10/4/91
	A10	644547	710	9.9	1953	27/3/87
	S3	646541	710	15.1	1953	30/9/86, 11/11/88, 18/11/91
	S10	641548	720	7.8	1953	30/9/86
Kangaroo Ck	C	602673	595	17.8	1944	
	A3	603658	600	24.2	1944	24/3/87, 20/3/92
	A10	606658	625	30.5	1944	24/3/87
	S3	604669	585	35.0	1944	1/10/85, 10/11/88, 14/11/91
	S10	606658	625	20.2	1944	1/10/85
Musk Creek	C	498503	640	15.0	1974	
	A3	496507	650	13.8	1974	26/3/87, 7/5/91
	A10	499504	670	17.8	1974	26/3/87
	S3	494506	640	10.3	1974	10/11/86, 3/11/88, 23/10/91
	S10	496505	655	20.6	1974	10/11/86

1. Locations are six-figure map references from the Australian Map Grid, 1;100,000 mapsheet 7722 (Blakeville) and 7723 (other FESAs).

Birds were studied on the 25 treatment areas in autumn 1985 (before burning) and at intervals subsequently (Loyn et al. 1992). Data were collected from all 25 treatment areas in four periods during 1992–94 (spring and autumn 1992–93 and 1993–94); these data sets are the main subject of this paper. When the 1992–94 assessments were made, each of the A3/S3 areas had been burned two or three times and the A10/S10 areas had been burned once, less recently.

Bird abundance was assessed by an area-search technique (Loyn 1986) in which areas of 3 ha were searched on foot for 20 minutes. Smaller areas (2 ha) were used at one of the five FESAs (Barkstead) to fit smaller treatment areas. All birds seen or heard were identified and numbers recorded. Any significant observations of feeding or breeding behaviour were noted. Birds observed outside the FESA were recorded separately and not included in further analysis. Raptors and aerial insectivores were only included as on-site if they were seen hunting or foraging directly in or over the respective area. Swifts (White-throated Needletail, *Hirundapus caudacutus*) were excluded from analysis because flocks fly rapidly over large distances and were rarely associated with specific study areas.

Data on individual birds per count and species per count were used as measures of total bird abundance and diversity respectively. Bird species were also grouped for statistical analysis according to their usual feeding behaviour, requirements for small or large nest-hollows, migratory pattern or abundance in Victoria (Table 3). Grouping data ensures that distributional assumptions underlying statistical analysis are more likely to be met than if data were analysed by species. Groups were only analysed formally if there were zero counts at fewer than ten of the 25 treatment areas.

Table 3 Bird species and their groupings (nesting, feeding, migration and Victorian status), Wombat State Forest, 1992–94

Common name	Scientific name	Nest	Feed	Mgrtn	Status	% all birds
Brown Goshawk	*Accipiter fasciatus*		Ve			0.02
Wedge-tailed Eagle	*Aquila audax*		Ve			0.02
Square-tailed Kite	*Lophoictinia isura*		Ve		U	0.02
Yellow-tailed Black-Cockatoo	*Calyptorhynchus funereus*	LH	SE			0.03
Gang-gang Cockatoo	*Callocephalon fimbriatum*	LH	SE			0.23
Sulphur-crested Cockatoo	*Cacatua galerita*	LH	SE			1.14
Crimson Rosella	*Platycercus elegans*	LH	SE			3.94
Blue-winged Parrot	*Neophema chrysostoma*	LH	SG		U	0.01
Laughing Kookaburra	*Dacelo novaeguineae*	LH	Ve			1.43
Sacred Kingfisher	*Todiramphus sanctus*	SH	Ve	S		0.20
Fan-tailed Cuckoo	*Cacomantis flabelliformis*	BP	Sb	S		0.22
Shining Bronze-Cuckoo	*Chrysococcyx lucidus*	BP	Ca	S		0.31
Welcome Swallow	*Hirundo neoxena*		A			0.08
Tree Martin	*Hirundo nigricans*	SH	A	S		0.58
Grey Fantail	*Rhipidura fuliginosa*		Ca			7.54
Rufous Fantail	*Rhipidura rufifrons*		Sb	S		0.09
Satin Flycatcher	*Myiagra cyanoleuca*		Ca			0.75
Scarlet Robin	*Petroica multicolor*		OG			0.98
Flame Robin	*Petroica phoenicea*		OG	S		0.46
Eastern Yellow Robin	*Eopsaltria australis*		DG			1.37
Golden Whistler	*Pachycephala pectoralis*		Sb			1.93
Rufous Whistler	*Pachycephala rufiventris*		Ca	S		2.93
Olive Whistler	*Pachycephala olivacea*		LU		U	0.02
Grey Shrike-thrush	*Colluricincla harmonica*		Ca			4.44
Crested Shrike-tit	*Falcunculus frontatus*		Ba			0.18
Black-faced Cuckoo-shrike	*Coracina novaehollandiae*		Ca	S		0.57
Spotted Quail-thrush	*Cinclosoma punctatum*		OG		U	0.04
Striated Thornbill	*Acanthiza lineata*		Ca			11.32
Brown Thornbill	*Acanthiza pusilla*		Sb			8.13
Buff-rumped Thornbill	*Acanthiza reguloides*		OG			1.19
White-browed Scrubwren	*Sericornis frontalis*		LU			6.62
Superb Fairy-wren	*Malurus cyaneus*		OG			5.14
Dusky Woodswallow	*Artamus cyanopterus*		A	S		0.13
Varied Sittella	*Daphoenositta chrysoptera*		Ba			0.93
White-throated Treecreeper	*Cormobates leucophaeus*	SH	Ba			7.65
Red-browed Treecreeper	*Climacteris erythrops*	SH	Ba		U	1.27
Mistletoebird	*Dicaeum hirundinaceum*		Fr			0.02
Spotted Pardalote	*Pardalotus punctatus*		Ca			7.66
Striated Pardalote	*Pardalotus striatus*	SH	Ca			4.42
Silvereye	*Zosterops lateralis*		Fr			0.08
White-naped Honeyeater	*Melithreptus lunatus*		Ne			8.61
Brown-headed Honeyeater	*Melithreptus brevirostris*		Ne/Ba			0.44
Eastern Spinebill	*Acanthorhynchus tenuirostris*		Ne			0.33
Yellow-faced Honeyeater	*Lichenostomus chrysops*		Ne			1.77
White-eared Honeyeater	*Lichenostomus leucotis*		Ne/Ba			0.99
Yellow-tufted Honeyeater	*Lichenostomus melanops*		Ne			0.02
Red Wattlebird	*Anthochaera carunculata*		Ne			0.25
Red-browed Finch	*Neochmia temporalis*		SG			0.03
White-winged Chough	*Corcorax melanorhamphos*		OG			1.52

Common name	Scientific name	Nest	Feed	Mgrtn	Status	% all birds
Pied Currawong	*Strepera graculina*		Ve			0.51
Grey Currawong	*Strepera versicolor*		Ve/DG			0.79
Australian Magpie	*Gymnorhina tibicen*		OG			0.49
Australian Raven	*Corvus coronoides*		Ve			0.05
Bassian Thrush	*Zoothera lunulata*		DG			0.05
Common Blackbird	*Turdus merula*		DG/Fr		I	0.07
Bird abundance (birds/count)						100.00

Groups		
Brood parasites	BP (cuckoos, laying eggs in active nests of other species)	0.54
Large hollow-nesters	LH (mainly parrots and Laughing Kookaburra)	6.81
Small hollow-nesters	SH (mainly treecreepers and Striated Pardalote)	14.11
All hollow-nesters	AH (sum of LH and SH, nesting in tree hollows)	20.98
Bark foragers	Ba (treecreepers, sittellas, shriketit and two honeyeaters)	11.45
Low seed-eaters	SG (taking seeds from ground or low vegetation)	0.04
Large seed-eaters	SE (mainly parrots, taking seeds, galls, etc. from all levels)	5.35
Frugivores	Fr (taking soft berries or mistletoe drupes)	0.17
Aerial insectivores	A (taking insects, often above the canopy)	0.49
Open-ground foragers	OG (taking invertebrates mainly from dry open ground)	9.82
Damp-ground foragers	DG (taking invertebrates mainly from damp leaf litter below trees or shrubs)	2.31
Low-understorey foragers	LU (taking invertebrates from dense understorey or damp ground below)	6.64
Shrub foragers	Sb (taking invertebrates from shrubs and wattle trees)	10.41
Canopy foragers	Ca (taking invertebrates from eucalypt canopy)	39.94
Nectarivores	Ne (taking nectar mainly from eucalypts, also invertebrates)	12.43
Carnivores	Ve (taking vertebrates, sometimes also large invertebrates)	3.02
Summer migrants	S (absent from forests or rare for period each winter)	6.30
Uncommon species	U (fewer than 850 records in Emison et al. 1987)	1.35
Introduced species	I (introduced to Australia)	0.04

Notes:

1. Some of these groups were represented on these assessments by few or single species (e.g. introduced birds, low seed-eaters and low-understorey foragers): compare percentages of total records for each group and its constituent species.
2. Species assigned to two feeding groups were scored as half in each.
3. Birds classed as 'foragers' have diets consisting mainly of insects and other invertebrates.

For the main analysis, the five FESAs and four assessment periods over 1992–94 were considered as contributing random effects. Planned comparisons were made between birds on controls versus burning treatments; birds on areas burned in spring versus autumn; and birds on areas burned frequently versus infrequently (but recognising that frequently burned areas had been burned more recently than others). The interaction between season and frequency of burning was also examined. Another level of analysis examined the effects of assessment period and their interactions with treatments and FESAs.

A range of habitat data were available for each area and they were included as covariates in subsequent analysis to help determine factors that may have influenced bird abundance or contributed to treatment effects. The habitat data included annual measurements of cover for mineral earth and key plant species or groups, made along transects at each treatment area (Tolhurst & Kelly 2003). Plant species and groups considered in this analysis were all understorey plants (total cover), Austral Bracken, Forest Wire-grass, herbs, legumes, rushes, small shrubs and all shrubs. Habitat data also included estimates of the distribution of hollow-bearing trees, assessed before treatment in 1985. Forest on each treatment area was assessed as having one of four density classes of hollow-bearing trees (0 = none to 3 = many), and the area of each class was estimated for each of the 25 treatment areas. For the present analysis, a hollow density index was calculated for each area by multiplying the area of each class by its class value (0–3), summing across classes, dividing by the area assessed and multiplying by 100. The range of variation between FESAs is indicated by the mean values (each of five areas) as shown in Table 1.

Models were constructed using appropriate variables for each group of birds. Hollow density indices were considered in modelling for small and large hollow-nesters (and a combined group of all hollow-nesters) and for bark foragers (which are dominated by two species of hollow-nesting treecreepers). The other variables were considered in modelling for open-ground foragers, low-understorey foragers and shrub foragers. No variables were considered suitable for other groups of bird species.

An argument could be made for considering assessment period as a fixed effect, in view of known seasonal changes (Loyn et al. 1992) and likely changes in bird abundance over time since fire. This approach was used as a supplementary analysis, to distinguish effects of year of assessment on bird abundance and treatment effects, for each season of assessment separately. It was thought that this could give some indication of whether any apparent effects of burning frequency were in fact due to time since fire rather than frequency per se.

A further analysis was conducted, including corresponding pre-treatment data from 1985 as covariables. This involved unbalanced mixed model analysis (REML) for the spring assessments, as data from spring 1985 were collected at only 16 of the 25 treatment areas and complete pre-treatment data were only obtained in autumn 1985.

In these analyses, main effects and first- or second-order interactions were considered worthy of discussion when p values were up to about 0.12, though they were only described as significant if $p < 0.05$. This approach reduces the chances of type 2 errors (failing to report an effect when there is one) compared with the traditional use of $p < 0.05$. This was considered appropriate as effects were expected to be small, and even small effects can be important biologically. However, the chances of type 1 errors (reporting effects when there are none) are correspondingly high when p values exceed 0.05.

Results

Mean values for total bird abundance were slightly higher in controls and A3 treatments than in the other burning treatments (Table 4): they ranged from 29.5 in A10 to 34.2 in A3. Species per count were slightly higher in the control areas than in any of the burning treatments (Table 4): mean values ranged from 12.0 in A10 to 13.6 in C. Hence there were no large effects of treatment at this level of analysis. Most common species were widespread across treatment areas (Table 4) and FESAs (Table 5). Mean values for total bird abundance ranged from 25.9 at the Barkstead FESA to 39.2 at Kangaroo Creek (a greater range than for burning treatments), and species per count followed the same pattern (Table 5).

Table 4 Mean bird abundances (birds per count) for each burning treatment, Wombat State Forest, 1992–94 (averaged across the five Fire Effects Study Areas and four assessment periods). C=control, A3=frequent autumn burns, A10=infrequent autumn burns, S3=frequent spring burns, S10=infrequent spring burns

Scientific name	Common name	Treatment				
		C	A3	A10	S3	S10
Brown Goshawk	*Accipiter fasciatus*	0.00	0.00	0.00	0.03	0.00
Wedge-tailed Eagle	*Aquila audax*	0.03	0.00	0.00	0.00	0.00
Square-tailed Kite	*Lophoictinia isura*	0.03	0.00	0.00	0.00	0.00
Yellow-tailed Black-Cockatoo	*Calyptorhynchus funereus*	0.00	0.00	0.00	0.05	0.00
Gang-gang Cockatoo	*Callocephalon fimbriatum*	0.05	0.07	0.14	0.03	0.08
Sulphur-crested Cockatoo	*Cacatua galerita*	0.46	0.35	0.33	0.48	0.23
Crimson Rosella	*Platycercus elegans*	1.38	1.78	0.95	1.23	1.01
Blue-winged Parrot	*Neophema chrysostoma*	0.00	0.02	0.00	0.00	0.00
Laughing Kookaburra	*Dacelo novaeguineae*	0.37	0.54	0.51	0.48	0.40
Sacred Kingfisher	*Todiramphus sanctus*	0.07	0.13	0.03	0.07	0.03
Fan-tailed Cuckoo	*Cacomantis flabelliformis*	0.03	0.08	0.08	0.11	0.07
Shining Bronze-Cuckoo	*Chrysococcyx lucidus*	0.18	0.08	0.13	0.07	0.05
Welcome Swallow	*Hirundo neoxena*	0.03	0.00	0.10	0.00	0.00
Tree Martin	*Hirundo nigricans*	0.35	0.04	0.18	0.22	0.15
Grey Fantail	*Rhipidura fuliginosa*	2.56	2.14	2.55	2.44	2.43
Rufous Fantail	*Rhipidura rufifrons*	0.05	0.08	0.00	0.03	0.00
Satin Flycatcher	*Myiagra cyanoleuca*	0.18	0.38	0.00	0.48	0.18
Scarlet Robin	*Petroica multicolor*	0.18	0.48	0.23	0.30	0.38
Flame Robin	*Petroica phoenicea*	0.02	0.15	0.19	0.13	0.27
Eastern Yellow Robin	*Eopsaltria australis*	0.48	0.60	0.34	0.35	0.44
Golden Whistler	*Pachycephala pectoralis*	0.78	0.57	0.60	0.67	0.49
Rufous Whistler	*Pachycephala rufiventris*	0.91	1.06	1.00	0.62	1.12
Olive Whistler	*Pachycephala olivacea*	0.00	0.00	0.00	0.00	0.03
Grey Shrike-thrush	*Colluricincla harmonica*	1.38	1.66	1.59	1.39	1.13
Crested Shrike-tit	*Falcunculus frontatus*	0.05	0.03	0.03	0.14	0.05
Black-faced Cuckoo-shrike	*Coracina novaehollandiae*	0.12	0.38	0.13	0.19	0.10
Spotted Quail-thrush	*Cinclosoma punctatum*	0.00	0.03	0.00	0.02	0.03
Striated Thornbill	*Acanthiza lineata*	4.03	3.69	3.35	2.93	4.18
Brown Thornbill	*Acanthiza pusilla*	2.81	2.38	2.84	1.89	3.15
Buff-rumped Thornbill	*Acanthiza reguloides*	0.48	0.61	0.16	0.33	0.33
White-browed Scrubwren	*Sericornis frontalis*	2.08	2.41	2.17	1.63	2.35
Superb Fairy-wren	*Malurus cyaneus*	1.47	2.07	1.61	1.59	1.53
Dusky Woodswallow	*Artamus cyanopterus*	0.05	0.06	0.01	0.03	0.06
Varied Sittella	*Daphoenositta chrysoptera*	0.10	0.32	0.67	0.31	0.10

Scientific name	Common name	Treatment				
		C	**A3**	**A10**	**S3**	**S10**
White-throated Treecreeper	*Cormobates leucophaeus*	2.61	2.38	2.44	2.21	2.66
Red-browed Treecreeper	*Climacteris erythrops*	0.62	0.34	0.18	0.57	0.35
Mistletoebird	*Dicaeum hirundinaceum*	0.03	0.00	0.00	0.00	0.00
Spotted Pardalote	*Pardalotus punctatus*	2.94	2.28	2.16	2.38	2.57
Striated Pardalote	*Pardalotus striatus*	1.31	1.34	1.28	1.84	1.34
Silvereye	*Zosterops lateralis*	0.08	0.03	0.00	0.00	0.03
White-naped Honeyeater	*Melithreptus lunatus*	3.23	2.56	2.29	3.62	2.15
Brown-headed Honeyeater	*Melithreptus brevirostris*	0.13	0.15	0.18	0.13	0.13
Eastern Spinebill	*Acanthorhynchus tenuirostris*	0.14	0.00	0.10	0.10	0.18
Yellow-faced Honeyeater	*Lichenostomus chrysops*	0.82	0.58	0.34	0.53	0.58
White-eared Honeyeater	*Lichenostomus leucotis*	0.23	0.27	0.28	0.43	0.39
Yellow-tufted Honeyeater	*Lichenostomus melanops*	0.03	0.00	0.00	0.00	0.00
Red Wattlebird	*Anthochaera carunculata*	0.13	0.09	0.05	0.10	0.03
Red-browed Finch	*Neochmia temporalis*	0.00	0.05	0.00	0.00	0.00
White-winged Chough	*Corcorax melanorhamphos*	0.13	1.27	0.05	0.78	0.22
Pied Currawong	*Strepera graculina*	0.22	0.15	0.12	0.18	0.15
Grey Currawong	*Strepera versicolor*	0.24	0.39	0.15	0.20	0.29
Australian Magpie	*Gymnorhina tibicen*	0.09	0.21	0.03	0.19	0.28
Australian Raven	*Corvus coronoides*	0.03	0.00	0.03	0.03	0.00
Bassian Thrush	*Zoothera lunulata*	0.03	0.00	0.00	0.02	0.03
Common Blackbird	*Turdus merula*	0.05	0.00	0.00	0.02	0.05
Bird abundance (birds/count)		**33.73**	**34.22**	**29.54**	**31.52**	**31.75**
Bird species per count		**13.64**	**13.29**	**12.01**	**13.18**	**12.87**

Groups (birds per count)					
Brood parasites	0.22	0.16	0.20	0.18	0.12
Large hollow-nesters	2.25	2.75	1.95	2.26	1.73
Small hollow-nesters	4.95	4.22	4.09	4.90	4.52
All hollow-nesters	7.22	6.97	6.07	7.17	6.29
Bark foragers	3.72	3.47	3.77	3.77	3.67
Seed-eaters (low to ground)	0.00	0.07	0.00	0.00	0.00
Large seed-eaters (all levels)	1.89	2.19	1.42	1.79	1.32
Frugivores	0.15	0.03	0.00	0.02	0.08
Open-ground foragers	2.37	4.81	2.26	3.34	3.02
Damp-ground foragers	0.80	0.99	0.51	0.59	0.82
Low-understorey foragers	2.08	2.41	2.17	1.63	2.38
Shrub foragers	3.67	3.10	3.58	2.69	3.71
Canopy foragers	13.59	12.99	12.18	12.34	13.10
Nectarivores	4.70	3.65	3.25	4.92	3.47
Carnivores	0.99	1.21	0.83	0.97	0.87
Summer migrants	1.96	2.46	1.74	1.94	2.02
Uncommon species	0.64	0.36	0.18	0.58	0.41

Table 5 Mean bird abundances (birds per count) in the five Fire Effects Study Areas, Wombat State Forest, 1992–94 (averaged across five treatments and four assessment periods)

Common name	Scientific name	Fire Effects Study Area				
		Barkstead	Blakeville	Burnt Bridge	Kangaroo Creek	Musk Creek
Brown Goshawk	*Accipiter fasciatus*	0.00	0.00	0.00	0.03	0.00
Wedge-tailed Eagle	*Aquila audax*	0.00	0.00	0.00	0.00	0.03
Square-tailed Kite	*Lophoictinia isura*	0.00	0.00	0.00	0.03	0.00
Yellow-tailed Black-Cockatoo	*Calyptorhynchus funereus*	0.00	0.00	0.00	0.00	0.05
Gang-gang Cockatoo	*Callocephalon fimbriatum*	0.00	0.02	0.08	0.05	0.22
Sulphur-crested Cockatoo	*Cacatua galerita*	0.00	0.68	0.07	0.97	0.11
Crimson Rosella	*Platycercus elegans*	1.28	1.32	1.48	1.10	1.15
Blue-winged Parrot	*Neophema chrysostoma*	0.00	0.02	0.00	0.00	0.00
Laughing Kookaburra	*Dacelo novaeguineae*	0.10	1.03	0.39	0.33	0.44
Sacred Kingfisher	*Todiramphus sanctus*	0.00	0.05	0.00	0.23	0.03
Fan-tailed Cuckoo	*Cacomantis flabelliformis*	0.00	0.05	0.13	0.14	0.03
Shining Bronze-Cuckoo	*Chrysococcyx lucidus*	0.15	0.05	0.12	0.12	0.07
Welcome Swallow	*Hirundo neoxena*	0.13	0.00	0.00	0.00	0.00
Tree Martin	*Hirundo nigricans*	0.43	0.08	0.00	0.40	0.03
Grey Fantail	*Rhipidura fuliginosa*	2.23	1.54	2.80	3.01	2.53
Rufous Fantail	*Rhipidura rufifrons*	0.00	0.00	0.05	0.10	0.00
Satin Flycatcher	*Myiagra cyanoleuca*	0.00	0.05	0.07	0.59	0.50
Scarlet Robin	*Petroica multicolor*	0.14	0.70	0.12	0.29	0.32
Flame Robin	*Petroica phoenicea*	0.05	0.02	0.38	0.13	0.16
Eastern Yellow Robin	*Eopsaltria australis*	0.39	0.37	0.49	0.84	0.11
Golden Whistler	*Pachycephala pectoralis*	0.50	0.20	0.97	1.10	0.33
Rufous Whistler	*Pachycephala rufiventris*	0.70	0.71	0.73	2.02	0.56
Olive Whistler	*Pachycephala olivacea*	0.00	0.00	0.03	0.00	0.00
Grey Shrike-thrush	*Colluricincla harmonica*	1.04	1.47	1.40	2.10	1.13
Crested Shrike-tit	*Falcunculus frontatus*	0.05	0.00	0.08	0.17	0.00
Black-faced Cuckoo-shrike	*Coracina novaehollandiae*	0.10	0.28	0.23	0.11	0.20
Spotted Quail-thrush	*Cinclosoma punctatum*	0.00	0.04	0.00	0.00	0.03
Striated Thornbill	*Acanthiza lineata*	3.66	4.16	4.13	1.83	4.42
Brown Thornbill	*Acanthiza pusilla*	3.48	1.83	4.04	2.07	1.65
Buff-rumped Thornbill	*Acanthiza reguloides*	0.00	1.46	0.00	0.00	0.45
White-browed Scrubwren	*Sericornis frontalis*	3.38	0.74	3.26	2.43	0.83
Superb Fairy-wren	*Malurus cyaneus*	1.57	1.36	3.25	1.56	0.53
Dusky Woodswallow	*Artamus cyanopterus*	0.00	0.03	0.03	0.13	0.03
Varied Sittella	*Daphoenositta chrysoptera*	0.00	0.23	0.38	0.66	0.23
White-throated Treecreeper	*Cormobates leucophaeus*	1.36	2.92	2.26	2.83	2.93
Red-browed Treecreeper	*Climacteris erythrops*	0.05	0.38	0.36	0.98	0.28
Mistletoebird	*Dicaeum hirundinaceum*	0.00	0.03	0.00	0.00	0.00
Spotted Pardalote	*Pardalotus punctatus*	2.48	2.49	2.30	2.40	2.65
Striated Pardalote	*Pardalotus striatus*	0.05	2.68	0.66	1.74	1.98
Silvereye	*Zosterops lateralis*	0.00	0.06	0.05	0.03	0.00
White-naped Honeyeater	*Melithreptus lunatus*	0.75	1.28	2.60	7.51	1.71
Brown-headed Honeyeater	*Melithreptus brevirostris*	0.13	0.33	0.10	0.00	0.14
Eastern Spinebill	*Acanthorhynchus tenuirostris*	0.10	0.23	0.05	0.00	0.14
Yellow-faced Honeyeater	*Lichenostomus chrysops*	0.99	0.40	0.65	0.13	0.68
White-eared Honeyeater	*Lichenostomus leucotis*	0.38	0.45	0.48	0.08	0.22
Yellow-tufted Honeyeater	*Lichenostomus melanops*	0.00	0.00	0.00	0.03	0.00

Common name	Scientific name	Fire Effects Study Area				
		Barkstead	Blakeville	Burnt Bridge	Kangaroo Creek	Musk Creek
Red Wattlebird	*Anthochaera carunculata*	0.00	0.10	0.00	0.10	0.20
Red-browed Finch	*Neochmia temporalis*	0.00	0.00	0.00	0.05	0.00
White-winged Chough	*Corcorax melanorhamphos*	0.00	0.93	0.73	0.25	0.53
Pied Currawong	*Strepera graculina*	0.03	0.35	0.28	0.04	0.13
Grey Currawong	*Strepera versicolor*	0.23	0.27	0.37	0.18	0.23
Australian Magpie	*Gymnorhina tibicen*	0.00	0.15	0.04	0.25	0.35
Australian Raven	*Corvus coronoides*	0.00	0.06	0.00	0.03	0.00
Bassian Thrush	*Zoothera lunulata*	0.00	0.03	0.03	0.02	0.00
Common Blackbird	*Turdus merula*	0.00	0.00	0.05	0.07	0.00
Bird abundance (birds/count)		**25.90**	**31.62**	**35.65**	**39.23**	**28.35**
Bird species per count		**11.42**	**13.52**	**13.48**	**14.94**	**11.63**
Groups (birds per count)						
Brood parasites		0.15	0.10	0.25	0.26	0.10
Large hollow-nesters		1.39	3.12	2.01	2.45	1.98
Small hollow-nesters		1.88	6.09	3.28	6.18	5.26
All hollow nesters		3.28	9.26	5.30	8.64	7.24
Bark foragers		1.95	4.31	3.64	4.71	3.79
Low seed-eaters		0.00	0.02	0.00	0.05	0.00
Large seed-eaters		1.28	2.02	1.64	2.13	1.54
Frugivores		0.00	0.08	0.10	0.09	0.00
Open-ground foragers		1.75	4.66	4.52	2.48	2.37
Damp-ground foragers		0.62	0.69	0.95	1.11	0.34
Low-understorey foragers		3.38	0.74	3.28	2.43	0.83
Shrub foragers		3.98	2.15	5.19	3.42	2.01
Canopy foragers		10.41	13.42	12.42	13.92	14.04
Nectarivores		2.36	2.80	3.88	7.85	3.09
Carnivores		0.35	1.76	1.03	0.85	0.87
Summer migrants		1.40	1.37	1.74	3.98	1.63
Uncommon species		0.05	0.43	0.38	1.01	0.31

The most abundant feeding guild was the insectivorous canopy foragers, followed by the nectarivores, bark foragers, shrub foragers and open-ground foragers (Table 3). Frugivores and low seed-eaters were remarkably scarce. Most groups were represented by several species (Table 3), but the group of low-understorey foragers was dominated by one species (White-browed Scrubwren) with a second species (Olive Whistler) on a single area: hence the group is effectively synonymous with White-browed Scrubwrens. The group of low seed-eaters comprised two uncommon species (Red-browed Finch and Blue-winged Parrot). Sulphur-crested Cockatoos were not included in the group because they mainly fed on leaf galls in the canopy, or left the forest to feed in nearby farmland. Other local members of the group such as Common Bronzewing *Phaps chalcoptera* and the introduced European Goldfinch *Carduelis carduelis* were not observed on these assessments. The only introduced species observed on these assessments was Common Blackbird (Table 3).

Effects of treatments and interactions

Little difference was found between control and burnt treatment areas for any group except open-ground foragers, which were more abundant on burnt areas than controls (p = 0.105, Table 6, Figure 1).

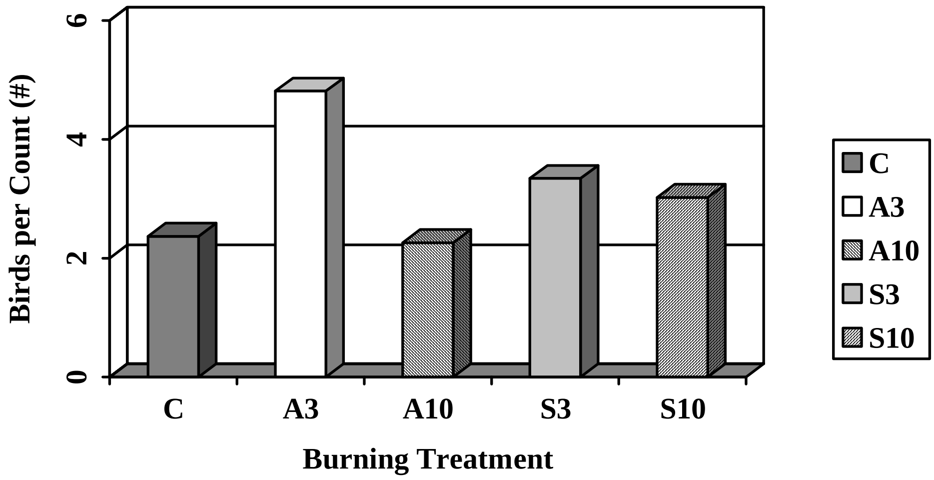

Figure 1 Mean abundances of open-ground foragers (birds per count) for each burning treatment, Wombat State Forest, 1992–94 (averaged across the five Fire Effects Study Areas and four assessment periods). C = control, A3 = frequent autumn burns, A10 = infrequent autumn burns, S3 = frequent spring burns, S10 = infrequent spring burns. These species were favoured by frequent burning (p = 0.013) especially when done in autumn.

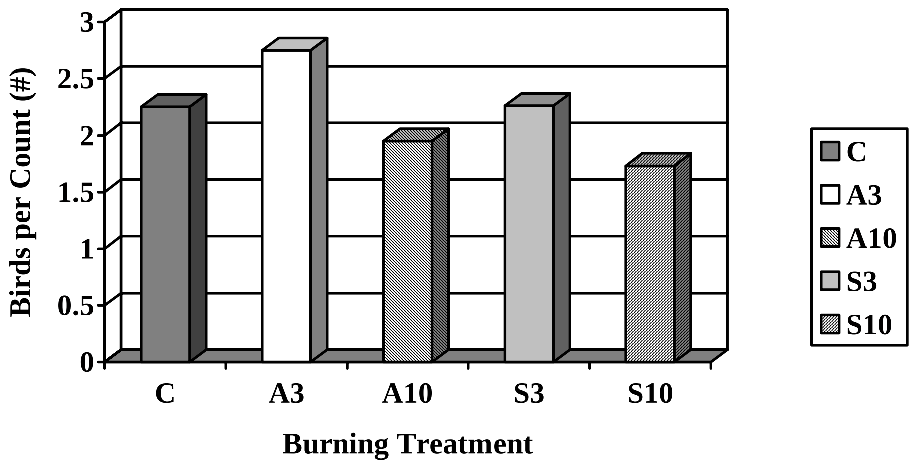

Figure 2 Mean abundances of large hollow-nesters (birds per count) for each burning treatment, Wombat State Forest, 1992–94 (averaged across the five Fire Effects Study Areas and four assessment periods). C = control, A3 = frequent autumn burns, A10 = infrequent autumn burns, S3 = frequent spring burns, S10 = infrequent spring burns. These species were favoured by frequent burning (p = 0.013) especially when done in autumn.

Table 6 Significance of differences between treatments for bird groups analysed, Wombat State Forest, 1992–94 (p values)

Bird group	Control vs Burn	Burning season	Burning frequency	Season x frequency
Bird abundance (birds/count)	.262	.989	.291	**.080**#
Bird species per count	.181	.473	.144	.357
Large hollow-nesters	.857	.385	**.109**#	.739
Small hollow-nesters	.315	.228	.574	.783
Bark foragers	.858	.684	.706	.452
Open-ground foragers	**.105**#	.495	**.013***	**.045***
Damp-ground foragers	.667	.752	.438	**.031***
Low-understorey foragers	.838	.306	.362	**.088**#
Shrub foragers	.452	.767	**.123**#	.570
Canopy foragers	.407	.892	.981	.440
Nectarivores	.369	.395	.293	.543

* = p < 0.05
# = p > 0.05 but some evidence that there may be an effect (p up to .125).

Burning season had no effect on any group, and the minimum p value found was 0.228 (Table 6). Burning frequency affected abundance of open-ground foragers (p = 0.013) and possibly large hollow-nesters (p = 0.109), both groups being more abundant on frequently (recently) burnt areas (Figures 1 and 2). There was weak evidence that shrub foragers were less numerous on frequently burnt areas than on controls or infrequently burnt areas (Figure 3, p = 0.123).

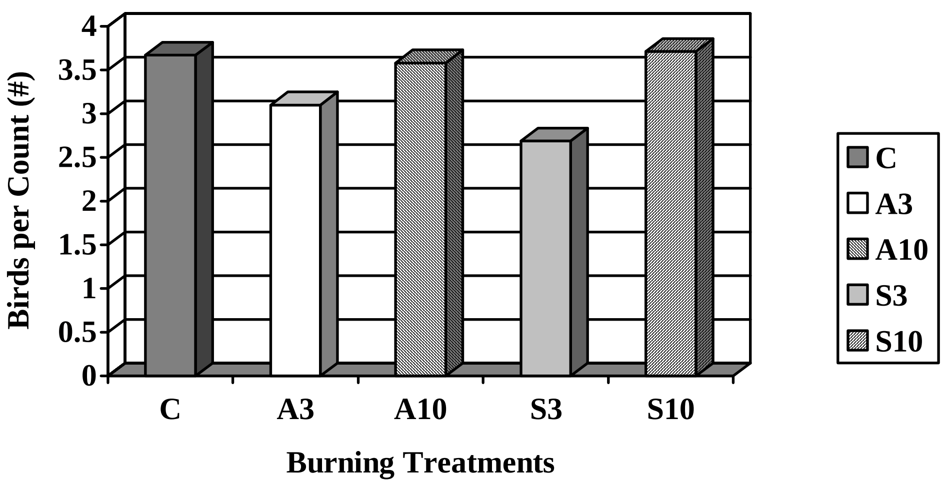

Figure 3 Mean abundances of shrub foragers (birds per count) for each burning treatment, Wombat State Forest, 1992–94 (averaged across the five Fire Effects Study Areas and four assessment periods). C = control, A3 = frequent autumn burns, A10 = infrequent autumn burns, S3 = frequent spring burns, S10 = infrequent spring burns. These species showed a trend to be disadvantaged by frequent burning (p = 0.123).

Four groups showed interactions between burning season and frequency (Table 6). Total bird abundance was higher in A3 than A10 treatments, but burning frequency made little difference to areas burned in spring, which supported intermediate levels of bird abundance (Table 4, p = 0.080 for interaction). Open-ground foragers were substantially more numerous in A3 than other treatments, and least numerous in A10 treatments: hence they favoured frequently or recently burnt areas when burning was done in autumn, but burning frequency made little difference to areas burned in spring (Figure 1, p = 0.065 for interaction). The pattern for this group accounts for most of the differences noted above for total bird abundance. Damp-ground foragers were more numerous in the A3 and S10 treatments (and controls) than in S3 or A10: they were adversely affected by infrequent burns when burning was done in autumn, and by frequent or recent burns when burning was done in spring (Figure 4, p = 0.031 for interaction). Low-understorey foragers were less numerous in the S3 than other treatments: frequent or recent burning reduced numbers of these birds when done in spring but made little difference when done in autumn (Figure 5, p = 0.088 for interaction). No other group showed any sign of interaction between burning season and frequency (Table 6).

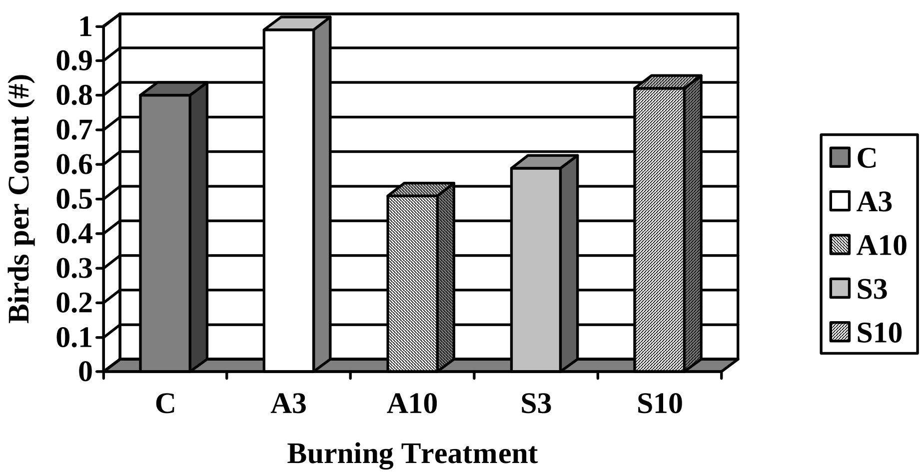

Figure 4 Mean abundances of damp-ground foragers (birds per count) for each burning treatment, Wombat State Forest, 1992–94 (averaged across the five Fire Effects Study Areas and four assessment periods). C = control, A3 = frequent autumn burns, A10 = infrequent autumn burns, S3 = frequent spring burns, S10 = infrequent spring burns. These species appeared to be disadvantaged by frequent spring burning or infrequent autumn burning (p = 0.03).

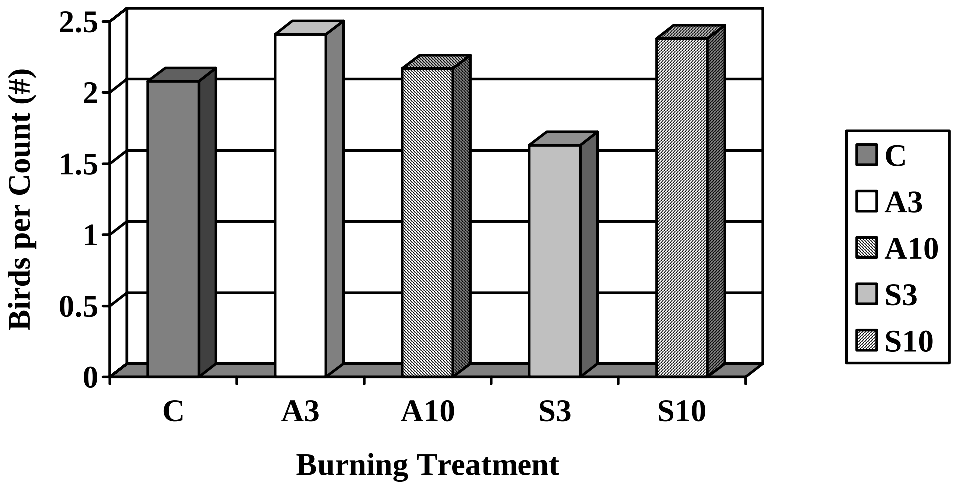

Figure 5 Mean abundances of low-understorey foragers (birds per count) for each burning treatment, Wombat State Forest, 1992–94 (averaged across the five Fire Effects Study Areas and four assessment periods). C = control, A3 = frequent autumn burns, A10 = infrequent autumn burns, S3 = frequent spring burns, S10 = infrequent spring burns. This group (dominated by White-browed Scrubwren) was disadvantaged by frequent spring burning ($p = 0.09$).

Effects of habitat covariables

Abundance of small and large hollow-nesters related strongly and positively to abundance of hollow-bearing trees (hollow density indices) assessed before treatment in 1985 ($p = 0.004$ and $p = 0.023$ respectively). These effects were lost when FESAs and burning treatments were included in the models. With large hollow-nesters the apparent effect of burning treatment was lost when hollows were included in the model: it seems that apparent effects of hollow-bearing trees or burning treatment supersede each other in this case. When small and large hollow-nesters were combined, both hollow-bearing trees ($p = 0.0003$) and burning treatments ($p = 0.0017$) contributed to a combined model.

Open-ground foragers showed a significant interaction between burning treatments and herb cover ($p = 0.019$). Herb cover generally exerted a negative effect on this group of birds, but herb growth was favoured by some of the burning treatments and site factors that opened up the stands, favouring these birds. Surprisingly, total plant cover and mineral earth did not contribute to these models.

Models for low-understorey foragers and shrub foragers were not improved by including habitat covariables, though there was some indication that legumes exerted a positive effect on the former group ($p = 0.052$).

Effects of assessment period and year of assessment at each season

In the main analysis, significant effects of assessment period were found for total bird abundance, species per count and abundance of open-ground foragers, bark foragers, canopy foragers, small hollow-nesters and large hollow-nesters ($p < 0.05$). Birds were generally more abundant in the second year (1993–94) than the first year (1992–93) (Table 7). A significant interaction between effects of assessment period and_treatment was found for total bird abundance ($p < 0.05$) and no other group. This was mainly due to high bird abundance (especially nectarivores) on controls in spring and autumn 1993–94.

Changes between assessment periods were examined further by considering years as fixed effects for each season of assessment (Table 7). Two groups were found to be significantly more common in spring 1993–94 than in the previous spring (canopy foragers, $p = 0.054$, and small hollow-nesters, $p = 0.007$). Large hollow-nesters were more common in spring 1992–93 than in the following spring ($p = 0.025$), and two groups were significantly more common in autumn 1993–94 than in the previous autumn (damp-ground foragers, $p = 0.035$ and nectarivores, $p < 0.001$). Total bird abundance and species per count were higher in autumn 1993–94 than in the previous autumn (Table 7, $p < 0.001$), mainly because of the increased abundance of nectarivores.

Interactions between year and treatment were found only for autumn assessments (Table 7). Two groups were more common on controls in 1993–94 than in the previous year, but showed little change over time on the burnt areas where abundances remained similar to those on the controls in 1992–93. These two groups were nectarivores (Table 7, $p = 0.048$ for interaction) and small hollow-nesters (Table 7, $p = 0.016$ for interaction). The group of all hollow-nesters showed the same pattern ($p = 0.035$) and this was mainly due to the contribution made by the small species. This group showed a further interaction with burning season ($p = 0.028$): their abundances increased between the two years on areas burned previously in autumn (though less than on controls) and decreased over the same period on areas burned previously in spring (Table 8).

Two groups changed in abundance on burnt areas between autumn 1992–93 and autumn 1993–94, with little change on the controls over the same period. These two groups were damp-ground foragers (Table 7, $p = 0.076$ for interaction) and low-understorey foragers (Table 7, $p = 0.075$ for interaction). Damp-ground foragers were much less common on burnt areas than controls in 1992–93 (1–2 years after fire) but had recovered by the following year (Table 7). Low-understorey foragers were more common on burnt areas than controls in 1992–93 and decreased in the following year (Table 7).

Table 7 Mean abundances of bird groups in autumn 1993 and autumn 1994 in control areas (mean of 5) and burnt areas (mean of 20), Wombat State Forest, and significance levels of differences between years and interactions between year and control versus burn (only shown where $p < 0.1$).

Bird group	Autumn assessments					
	1993		1994		Significance (p)	
	Control	Burnt	Control	Burnt	Year	Year x (control vs burnt)
Bird abundance (birds/count)	29.00	27.73	37.30	31.07	<0.001	0.060
Bird species per count	11.36	10.24	14.80	13.25	<0.001	NS
Hollow-nesters	5.88	5.64	8.40	5.52	NS	0.035
Large hollow-nesters	1.62	1.63	2.32	1.55	NS	NS
Small hollow-nesters	4.25	4.00	6.10	3.90	NS	0.016
Bark foragers	3.79	4.15	5.21	4.18	NS	NS
Open-ground foragers	2.30	2.66	2.30	3.70	NS	NS
Damp-ground foragers	0.91	0.38	0.71	0.81	0.035	0.076
Low-understorey foragers	1.67	2.77	2.20	1.67	NS	0.075
Canopy foragers	11.34	10.40	14.27	10.75	NS	NS
Nectarivores	3.04	2.96	6.64	4.32	<0.001	0.048

NS = Not significant ($p > 0.05$).

Table 8 Mean abundances of hollow-nesters in autumn 1993 and autumn 1994 in control areas (C, mean of 5), areas burned in autumn (A, mean of 10) and areas burned in spring (S, mean of 10), Wombat State Forest. This group showed a significant interaction for autumn assessments between years, control versus burn and burning season (p = 0.028). Hollow-nesters increased between years on controls and to a lesser extent on areas burned in spring, but not on areas burned in autumn.

Autumn assessments	Season of burn		
	C	A	S
Autumn 1993	5.88	6.31	4.98
Autumn 1994	8.42	4.86	6.08

Open-ground foragers showed a significant interaction between year, control versus burning, burning frequency and burning season (p = 0.043). These birds were more numerous in A3 and S10 treatment areas in 1993–94 than the previous year, with little change between years elsewhere (Table 9). Some non-significant interactions were observed for four other groups (p ~ 0.1) but are unlikely to have biological meaning.

Table 9 Mean abundances of open-ground foragers in autumn 1993 and autumn 1994 for each burning treatment, Wombat State Forest, 1992–94 (averaged across the five Fire Effects Study Areas). C = control, A3 = frequent autumn burns, A10 = infrequent autumn burns, S3 = frequent spring burns, S10 = infrequent spring burns. This group showed a significant interaction for autumn assessments between years, control vs burn, burning season and burning frequency (p = 0.043). This group increased between years on A3 areas (where numbers were already high in 1993) and to a lesser extent on S10 areas, but showed little change on other areas. Numbers on A10 areas remained depressed compared with controls.

Autumn assessments	Treatment				
	C	A3	A10	S3	S10
Autumn 1993	2.30	4.09	1.71	2.93	2.75
Autumn 1994	2.30	7.20	1.60	2.41	3.60

Table 10 Mean numbers of bird species per count in autumn 1993 and autumn 1994 in control areas (C, mean of 5), areas burned frequently (3, mean of 10) and areas burned infrequently (10, mean of 10), Wombat State Forest. This group showed a significant interaction for autumn assessments between years, control versus burn and burning frequency (p = 0.021). Species per count increased between years on controls and to a lesser extent on infrequently burnt areas, but not on frequently-burnt areas.

Autumn assessments	Treatment		
	C	3	10
Autumn 1993	11.40	12.23	12.24
Autumn 1994	14.84	12.93	13.55

Total bird abundance showed an interaction ($p = 0.060$) between years and burning vs controls (Table 7), mainly because of the greater increase of nectarivores on controls than on burnt areas in the second autumn. Species per count showed a significant interaction between years, burning versus controls and burning frequency ($p = 0.021$). This measure increased between the two years on the controls and to a lesser extent on infrequently burnt areas, but not on frequently burnt areas.

Models using pre-treatment data as covariables

Models of treatment effects were not improved by including pre-treatment data as covariables. Pre-treatment abundances made significant contributions to models for low-understorey foragers ($p < 0.05$ for spring and autumn assessments), canopy foragers ($p < 0.05$ for autumn assessments only), nectarivores ($p = 0.005$ for autumn assessments, $p < 0.05$ for spring assessments), small hollow-nesters ($p = 0.002$ for autumn assessments, $p < 0.05$ for spring assessments) and all hollow-nesters ($p < 0.01$ for autumn assessments only).

There was substantial variation in bird abundances and species compositions between the five FESAs, but these remained stable over time. The large variance components associated with broad study areas explained most of the variance due to inherent site factors. This left little scope for further variance to be explained by using pre-treatment data as covariates.

Responses of minor groups (not formally analysed)

Inspection of data (Table 4) shows that seed-eaters low to the ground were only recorded on areas burned frequently in autumn, as discussed below for the two constituent species (Blue-winged Parrot and Red-browed Finch). Carnivores and summer migrants also tended to be least uncommon on these areas, the former mainly because of increased abundance of Laughing Kookaburras.

Brood parasites, frugivores and uncommon species were recorded in low and variable numbers, with maximum values in unburnt controls (Table 4). Frugivores were particularly scarce on burnt areas but the other groups showed no distinct pattern.

Responses of individual species

Responses of individual common species followed similar patterns to those described for groups (Table 4). Inspection of data suggests that some are favoured by a range of burning treatments (Scarlet Robin, Flame Robin, Australian Magpie and Varied Sittella) or by more specific burning treatments (e.g. Laughing Kookaburra by autumn burns; Satin Flycatcher and White-winged Chough by frequent or recent burns; White-eared Honeyeater by infrequent burns). Several species appeared to be favoured by frequent autumn burns (e.g. Eastern Yellow Robin, Buff-rumped Thornbill, Superb Fairy-wren, Grey Currawong), though Buff-rumped Thornbills were also common on the controls. Other species appeared to be disadvantaged by burning and most common on the controls (e.g. Shining Bronze-Cuckoo, Tree Martin, Golden Whistler, Spotted Pardalote) or the controls and one of the burning treatments (e.g. Sulphur-crested Cockatoo, Red-browed Treecreeper, Pied Currawong, with frequent spring burning being the favoured burning treatment in each of these cases). Brown Thornbills were common across all treatments but appeared to be disfavoured by frequent burns.

Several wide-ranging species were only observed on rare occasions (e.g. Square-tailed Kite, Yellow-tailed Black-Cockatoo), and were making incidental use of the study areas within large home ranges. However, observations showed that four uncommon species made specific use of the study areas. A male Blue-winged Parrot was defending a probable nest-site in a large living Messmate on the A3 area at Blakeville in spring 1993, where plentiful seed was available on grasses and low herbs following a burn 18 months previously. This was the only record of the species during the study. Small numbers of Red-browed Finches were observed occasionally on the S3 area at Kangaroo Creek, taking seeds from grasses and low vegetation near the creek: scattered populations appeared to be resident along creeks nearby. Spotted Quail-thrush were observed occasionally on three of the burning treatments (A3, S3 and S10) at two of the FESAs (Blakeville and Musk Creek). There were previous records from these FESAs and Kangaroo Creek. A small colony of Yellow-tufted Honeyeaters was resident in Manna Gums in a gully at Kangaroo Creek, occasionally visiting nearby experimental areas. During formal counts on these assessments they were only observed on the control. This species is common in box–ironbark forests in drier areas further north, but scarce in the immediate vicinity.

Altogether, four species were observed only on the controls during these assessments (Wedge-tailed Eagle, Square-tailed Kite, Mistletoebird and Yellow-tufted Honeyeater), and six were observed only on burnt areas during these assessments (Brown Goshawk, Yellow-tailed Black-Cockatoo, Blue-winged Parrot, Spotted Quail-thrush, Olive Whistler and Red-browed Finch—Table 4). Note that there were four times as many burnt areas as controls. The remaining 45 species were observed both on the controls and burnt areas. No species was observed on areas before burning treatments and not subsequently.

Feeding behaviour

Observations showed that most bird species continued to forage in expected ways in burnt areas, as in controls. Four exceptions are summarised below along with an observation on bird response to the experimental fire front. These qualitative observations arise from multiple visits to the study areas between 1985 and 1994.

Crimson Rosellas often took seeds from low shrubs such as Fireweed *Senecio* sp. a year or two after burning treatments. During an intense flowering episode in autumn 1987, flocks of Crimson Rosellas were seen feeding on eucalypt blossom in the canopy, along with Musk Lorikeets *Glossopsitta concinna* and Little Lorikeets *G. pusilla* which were rare visitors to these forests. These flocks were concentrated in recently burnt areas (2–30 weeks earlier), despite widespread flowering at the time.

White-browed Scrubwrens were seen feeding along high eucalypt branches on burnt sites when the fire was still smouldering, in contrast to their normal behaviour of foraging close to the ground. When the fire cooled they were also seen along with other insectivorous birds foraging among the ash. In subsequent years the species persisted wherever dense cover remained, including burnt shrubs, rushes or fallen branches, patches of unburnt vegetation and regenerating thickets of shrubs, rushes or bracken. They continued to make occasional use of higher branches for foraging; this was not observed on unburnt areas.

A Brown Goshawk was watched as it hunted for reptiles on foot in a recently burnt site, running over the open ground and peering under charred logs. This contrasts with its more common behaviour of pursuing large birds in flight below the canopy.

Eastern Yellow Robins persisted in recently burnt sites, perching sideways on tree-trunks and pouncing on invertebrate prey on the ground. This is normal behaviour for the species, but usually they remain close to cover.

During one of the experimental burns, a flock of Striated Thornbills was watched feeding among eucalypt foliage, only 30 m from the fire front that was burning quietly with flames reaching to similar heights to the thornbills.

Discussion

Few studies of fuel reduction burning have used a replicated experimental approach to examine effects of burning season and frequency on birds as in this study. Hence the results are new, even though they may provide few surprises. The general pattern is similar to that observed after the first round of burning (Loyn et al. 1992), with a high degree of stability in terms of total bird abundance, species per count and species composition. The main responses in the earlier work were a temporary increase in open-ground foragers and seed-eaters close to the ground on burnt areas; a small decrease in shrub or low-understorey foragers, and an influx of nectarivores to some recently burnt sites. The present work confirmed that open-ground foragers increase in number after fuel reduction burning, and this increase is particularly pronounced when burning is done in autumn. High numbers of this group continued to be recorded up to three years after experimental burns and, indeed, appeared to increase on autumn assessments between two and three years after fire (Table 9). However, their numbers were depressed on infrequently burnt areas, suggesting that the increases would be temporary. Similar patterns have been observed after wildfire (Loyn 1997), with some species increasing and then declining soon after the fire (e.g. Scarlet Robin) and one continuing to increase over a longer time (Superb Fairy-wren, which was the commonest bird in the group in both studies). The present study also showed a small influx to burnt sites of birds that take seeds close to the ground (Table 4), although the group was too scarce to warrant formal analysis. Similar influxes have been observed after wildfire elsewhere (e.g. Wooller & Calver 1988; Hewish 1983; Reilly 1991a,b), and may be much larger than in this study, especially in northern Australia (Woinarski 1990; Woinarski & Recher 1997).

Some evidence was found for decreases in the various groups of birds that used shrub layers, although decreases were generally small and were not significant, or occurred only in particular treatments. Frequent autumn burning appeared to be the most beneficial treatment for open-ground foragers, and frequent spring burning to be the most detrimental for species that use the shrub layers. Autumn burns are generally more intense than spring burns, as litter and vegetation have dried out over summer. This may produce greater benefits for species that forage from open ground. Usually the burns were not hot enough to destroy the shrub structure, even though many shrubs were killed. Spring burns may impact on shrub and understorey foragers by burning nests or nest-sites, though the impact on the population appears to be small and temporary. The differences involved significant season by frequency interactions in some cases but were not large, and do not suggest that fuel reduction burning should always be carried out at a particular season. Except as an interaction, burning season had no effect on any group.

Nectarivores behaved differently from the earlier years of the study, showing great variation with time and place. They are discussed further under temporal changes, below. As in earlier assessments, canopy foragers and bark foragers showed little response to treatment. These results contrast with effects of wildfire (Recher et al. 1975; Christensen et al. 1985; Christensen & Abbott 1989; Reilly 1991a, b; Loyn 1997; Woinarski & Recher 1997). Wildfire reduces canopy foragers and nectarivores greatly when the canopy burns. Bark foragers and understorey foragers appear to be relatively resilient to the effects of both fuel reduction burning and wildfire. This has also been shown with respect to fuel reduction burning by previous work in Wombat State Forest, in which there was a high survival rate of banded birds after single fires (Cowley 1974), and by work in Western Australia (Kimber 1974; Christensen & Kimber 1975; Rowley & Brooker 1987; Brooker & Rowley 1991). However, recent work in Western Australia has suggested that birds inhabiting shrub layers may be adversely affected by fire regimes involving frequent burning (Russell & Rowley 1993).

Several factors may contribute to the general stability of the bird fauna on the set of treatment areas in this study. Firstly, most bird species are insectivorous, and work on these areas has shown surprising stability among active ground-layer invertebrates (Neumann & Tolhurst 1991; Collett et al. 1993; Neumann et al. 1995; Collett 1998). Invertebrate prey will continue to be available for insectivorous birds with any of the burning regimes examined, despite some changes in abundance. Work in Western Australia has also shown that many invertebrate groups are highly resilient to fires, despite marked changes in abundance of some species (Friend & Williams 1996).

Secondly, the forest has an open structure with a mosaic of shrubs and open ground regardless of recent burning history. The proportions of shrubs and open ground are changed by burning (Tolhurst 1996 a, b) but these changes are quantitative and do not generally result in complete loss or gain of structural features on any site. Hence habitat remains for most species regardless of management. Some exceptions are the species that need extensive areas of open ground for foraging (e.g. White-winged Chough) or rely on ephemeral food sources such as flushes of grass seeds that may be produced after fire (e.g. Red-browed Finch, Blue-winged Parrot). These species are likely to suffer if fire is excluded from large areas for long periods of time. They were not observed on the treatment areas before the experimental burning.

Thirdly, the experimental areas were small (3–35 ha) and surrounded by forest with a mosaic of fire histories. We do not know how species would respond if broadscale burning was conducted at an intensity great enough to eliminate patches of unburnt vegetation from large areas. Present conclusions may apply to broadscale burns only if those burns are patchy and leave substantial areas of forest unburned. Fortunately, this is typically the case where broadscale fuel reduction is undertaken.

Finally, the forest structure means that the commonest species are those that inhabit the canopy layers, and hence are separated spatially from the main physical effects of fuel reduction burning. More marked effects might be expected in shrubbier forests where higher proportions of the bird community inhabit substrates directly affected by fuel reduction burning.

Responses of individual species

Responses of individual species were not analysed formally, but many of the patterns observed (Table 4) accord with experience from elsewhere, even when they relate to species that were recorded in low numbers. For example, Blue-winged Parrots and Red-browed Finches have been found to occupy wet forest sites after recent logging and burning (Loyn 1985). Canopy-foraging Satin Flycatchers were particularly common three years after wildfire in East Gippsland (Loyn 1997), as in this study. White-eared Honeyeaters favour regrowth aged 5–12 years (Loyn 1985) and this may explain their apparent preference for infrequently burnt sites, as assessed in this study 6–8 years after burning.

Temporal changes

Several groups of birds increased in abundance between the two years of assessment (across all treatments, either in spring or autumn) and it seems that the second year was the more productive, perhaps reflecting recovery from low-rainfall years of the early 1990s. Interactions between year and treatment related solely to changes in autumn abundance between the two years, suggesting that bird abundances were more stable from year to year in spring (when birds were confined to finite systems of breeding territories) than in autumn (when birds were more mobile, and when numbers were boosted to varying extents by production of young in the previous breeding season). The interactions involved changes in abundance on burnt areas for two groups that usually feed in moist situations close to the ground (damp-ground foragers increasing and low-understorey foragers decreasing), and increases on controls for two groups that feed mainly in the canopy (nectarivores and small hollow-nesters). It seems that birds feeding mainly in the canopy were better able to respond to a good year on controls than burnt areas. Birds that feed in moist situations close to the ground may have been responding to successional changes after fires, with density of low vegetation reaching its maximum 2–3 years after fire.

Nectarivores may be particularly sensitive to changes in fire management, and respond in complex ways. If tree canopies are burned by wildfire, there may be a dramatic exodus of nectarivores following loss of food resources in the area affected (Loyn 1997). However, drought and fire can also stimulate flowering and lead to influxes of nectarivores (Smith 1989). During an intense flowering episode in a previous assessment of this study, nectarivores were found to be more abundant on recently burnt areas than controls (Loyn et al. 1992), in contrast to the current results. Pending further work, a tentative conclusion is that numbers of nectarivores can be influenced by local factors including fuel reduction burning, at the local stand scale, but this influence may be positive or negative at different times.

If treatment effects were strongly influenced by time since fire, it would be expected that most year-by-treatment interactions would relate to temporal changes on the burnt areas rather than the controls, whereas in fact they were equally divided. This gives some confidence that results reflect the intended treatments (including burning frequency) without undue influence from time since fire, which is necessarily linked with burning frequency. However, it is likely that all of the differences between frequently and infrequently burnt areas reported in this study could be related to time since fire rather than any cumulative effects of multiple fires.

Implications for management

The study shows that effects of fuel reduction burning are far milder than those of severe wildfire (Recher et al. 1985; Woinarski 1990; Reilly 1991a,b; Loyn 1997; Woinarski & Recher 1997), especially on nectarivores and canopy-foraging insectivores. Hence, if fuel reduction burning is effective in reducing the extent or severity of wildfire, these groups may benefit from that protection. Further work is needed to quantify the effectiveness of fuel reduction burning strategies in different forest types. The work in Wombat State Forest has helped do this for one forest type, and indicated ways in which this management can be improved (Tolhurst et al. 1992; Tolhurst 1996a). However, any benefits of this sort could be lost if there are long-term changes in vegetation. The risks of such changes are greatest under regimes of frequent burning (Woinarski & Recher 1997). The present study suggests that the greatest short-term benefits of fuel reduction to birds arise with frequent burns, but it is important to note that this is because the greatest responses occur in early successional stages, not because of any inherent advantage in frequent burns.

The study suggests that effects of burning in spring or autumn are quite similar (on subsequent bird abundance, compared with unburnt controls) and there is no clear case for burning at one season and not the other. However, the beneficial effects of fire appear to be somewhat greater with autumn burns (probably because they are more intense) and the detrimental effects somewhat greater with spring burns (probably because birds are nesting then). It may be prudent to conduct fewer spring burns than autumn burns, but to maintain diversity by continuing to conduct some burns at both seasons.

A policy of extensive fire exclusion would seem undesirable, as some birds respond positively to fire, and some species may depend on it in this forest type (e.g. White-winged Chough, Spotted Quail-thrush, Blue-winged Parrot and Red-browed Finch). Fuel reduction burning serves to provide patches of habitat at suitable successional stages on an annual basis. This may add to the stability of habitat at the landscape scale, although it does not mimic the patterns expected under a regime of occasional extensive wildfires.

A policy of extensive broadscale burning would be highly undesirable, as birds may need access to unburnt vegetation within their home-ranges, especially in the immediate aftermath of the fire as noted for mammals by Newsome et al. (1975), Catling and Newsome (1981), Humphries (1994), Tolhurst (1996c) and Friend (1993). The present study provides no information on the ability of birds to persist in areas subject to such treatment. The precautionary approach is to ensure that any broadscale burning is done patchily, to produce a mosaic of burnt and unburnt vegetation with many large unburnt areas. At a national level, many threatened species depend on habitats that remain unburned for long periods (Woinarski & Recher 1997), and identification and protection of such habitats should be an important management goal.

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References

Brooker, M.G., Rowley, I. 1991. Impact of wildfire on the nesting behaviour of birds in heathland. *Wildlife Research* **18**, 249–63.

Catling, P. C., Newsome, A. E. 1981. Responses of the Australian vertebrate fauna to fire. pp. 273–310. **In**: *Fire and the Australian biota,* A.M. Gill, R. H. Groves and I. R. Noble (eds.). Australian Academy of Science, Canberra

Cheney, N. P. 1976. Bushfire disasters in Australia. *Aust. For.* **39**, 245–68.

Christensen, P., Abbott, I. 1989. Impact of fire in the eucalypt forest ecosystem of southern Western Australia: a critical review. *Aust. For.* **52**, 103–21.

Christensen, P. E. S., Wardell-Johnson, G., Kimber, P. 1985. Birds and fire in south-western forests. pp. 291–99 *in Birds of eucalypt forests and woodlands: ecology, conservation, management,* A Keast, H. F. Recher, H. Ford, and D. Saunders (eds.). Surrey Beatty and Sons, Chipping Norton.

Collett, N.G. 1998. Effects of two short rotation prescribed fires in autumn on surface-active arthropods and earthworms in dry sclerophyll eucalypt forest of west-central Victoria. *For. Ecol. Manage.* **107**, 253–73.

Collett, N.G., Neumann, F.G., Tolhurst, K.G. 1993. Effects of two short rotation prescribed fires in spring on surface-active arthropods and earthworms in dry sclerophyll eucalypt forest of west-central Victoria. *Aust. For.* **56**, 49–60.

Commonwealth of Australia 1996. Fire and Biodiversity. The effects and effectiveness of fire management. Biodiversity Series, Paper No. 8, Dept. Environment, Sport and Territories, Canberra.

Cowley, R. D. 1971. Birds and forest management. *Aust. For.* **35**, 234–50.

Emison, W.B., Beardsell, C.M., Norman, F.I., Loyn, R.H., Bennett, S.C. 1987. Atlas of Victorian Birds. CFL/RAOU, 271 pp.

Friend, G. R. 1993. Impact of fire on small vertebrates in mallee woodlands and heathlands of temperate Australia - a review. *Biological Conservation* **65**, 99–114.

Friend, G.R., Williams, M.R. 1996. Impact of fire on invertebrate communities in mallee-heath shrublands of southwestern Australia. *Pacific Conservation Biology* **2:** 244–67.

Gill, A. M., Groves, R. H., Noble. R. 1981 (eds). *Fire and the Australian Biota.* Aust. Academy of Science, Canberra.

Hewish, M. 1983. The effect of a wildfire on birdlife in a eucalypt forest: a preliminary report on the Ledederg Gorge seven weeks after the Wombat State Forest fire. *Geelong Naturalist* **20**, 3–16.

Humphries, R.K. 1994. The effects of single autumn and spring prescribed fires on small mammal and reptile ecology in Wombat State Forest. M.App. Sci. Thesis, University of Ballarat.

Loyn, R.H. 1985. Bird populations in successional forests of Mountain Ash *Eucalyptus regnans. Emu* **85**, 213–30.

Loyn, R. H. 1985. Ecology, distribution and density of birds in Victorian forests. pp. 33–46 *in Birds of eucalypt forests and woodlands: ecology, conservation, management.* In A. Keast, H. F. Recher, H. Ford and D. Saunders (eds.), Surrey Beatty and Sons, Chipping Norton.

Loyn, R.H. 1986. The 20 minute search - a simple method for counting forest birds. *Corella.* **10**, 58–60.

Loyn, R.H. 1997. Effects of an extensive wildfire on birds in far eastern Victoria. *Pacific Conservation Biology* **3**, 221–34.

Neumann, F.G., Tolhurst, K. 1991. Effects of fuel reduction burning on epigeal arthropods and earthworms in dry sclerophyll eucalypt forest of west-central Victoria. *Aust. J. Ecol.* **16**, 315–30.

Neumann, F.G., Collett, N.G., Tolhurst, K.G. 1995. Coleoptera in litter of dry sclerophyll eucalypt forest and the effects of low-intensity prescribed fire on their activity and composition in west-central Victoria. *Aust. For.* **58**, 83–98.

Newsome, A. E., McIlroy, J,. Catling, P. 1975. The effects of extensive wildfire on populations of twenty ground vertebrates in south-east Australia. *Proceedings of the Ecological Society of Australia.* **9**, 107–23.

Rawson, R.P., Billing, P.R., Duncan, S.F. 1983. The 1982-83 forest fires in Victoria. *Aust. For.* **46**, 163–72.

Recher H. F., Allen, D., Gowing, G. 1985. The impact of wildfire on birds in an intensively logged forest. pp. 283–90 *in Birds of eucalypt forests and woodlands: ecology, conservation, management*, A. Keast, H. F. Recher, H. Ford, & D. Saunders (eds.), Surrey Beatty and Sons, Chipping Norton.

Recher, H. F., Lunney, D., Posamentier, H. 1975. A grand natural experiment - the Nadgee wildfire. *Australian Natural History* **18**, 150–63.

Reilly, P. 1991a. The effect of wildfire on bird populations in a Victorian coastal habitat. *Emu* **91**: 100–06.

Reilly, P. 1991b. The effect of wildfire on bush bird populations in six Victorian coastal habitats. *Corella* **15**, 134–42.

Rowley, I., and Brooker, M. 1987. The response of a small insectivorous bird to fire in heathlands. pp. 211–18 *in Nature Conservation: the role of remnants of native vegetation* D. A. Saunders, G. W. Arnold. A. A. Burbidge, & A. J. M. Hopkins (eds), Surrey Beatty and Sons, Chipping Norton.

Russell, E.M. and Rowley, I. 1993. Demography of the cooperatively breeding Splendid Fairy-wren, *Malurus splendens* (Maluridae). *Australian Journal of Zoology* **41:** 475–505.

Smith, P. 1989. Changes in a forest bird community during a period of fire and drought near Bega, New South Wales. Australian Journal of Ecology 14. 41–54.

Tolhurst, K.G. 1996a. The effects of fuel reduction burning on fuel loads in a dry sclerophyll forest. pp. 17–20 in Commonwealth of Australia 1996.

Tolhurst, K.G. 1996b. Effects of fuel reduction burning on flora in a dry sclerophyll forest. pp. 97–107 in Commonwealth of Australia 1996.

Tolhurst, K.G. 1996c. Effects of fuel reduction burning on fauna in a dry sclerophyll forest. pp. 113–21 in Commonwealth of Australia 1996.

Tolhurst, K.G., Kelly, N. 2003. Effects of repeated low-intensity fire on fuel dynamics in a mixed eucalypt foothill forest in south-eastern Australia. *Research Report* No. 62, Fire Management, Department of Susytainability and Environment, Victoria.

Tolhurst, K.G., Flinn, D.W., Loyn, R.H., Wilson, A.G., Foletta, I. 1992. Ecological effects of fuel reduction burning in a dry sclerophyll forest: a summary of principal research findings and their management implications. Dept. Conservation & Environment, Melb.

Tomkins, I.B., Kellas, J.D., Tolhurst, K.G., Oswin, D.A. 1991. Effects of fire intensity on soil chemistry in a eucalypt forest. *Aust. J. Soil Res.* **29**, 25–47.

Woinarski, J.C.Z. 1990. Effects of fire on the bird communities of tropical woodlands and open forests in northern Australia. *Australian Journal of Ecology* **15**, 1–22.

Woinarski, J.C.Z., Recher, H.F. 1997. Impact and response: a review of the effects of fire on the Australian avifauna. *Pacific Conservation Biology* **3**, 183–205.

Woodgate, P.W., Peel. W.D., Ritman, K.T., Coram, J.E., Brady, A., Rule, A.J., Banks, J.C.G., 1994. A study of the old-growth forests of East Gippsland. Dept. Conservation & Natural Resources, Victoria.

Wooller, R. D., Calver, M. C., 1988. Changes in an assemblage of small birds in the understorey of dry sclerophyll forest in south-western Australia after fire. *Australian Wildlife Research* **15,** 331–38.