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Bird communities and effects of management in Heathy Woodlands in the Grampians/Gariwerd National Park

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ABSTRACT

Measuring biodiversity across time and space is fundamental in assessing effects of ecological management actions. Monitoring bird species richness and abundance within the Victorian Grampians/Gariwerd National Park (GGNP) Heathy Woodland Ecological Vegetation Class (EVC) is used to assess seasonal changes in bird community and foraging guild composition. Two 2-ha/20-min bird surveys were undertaken at 36 sites in each of six seasonal surveillance periods over 2 years (total 432 surveys), detecting 90 species. Mean site diversity was 8.40 species (se = 1.91, n = 36 sites) and mean abundance was 19.52 birds (se = 6.91, n = 36 sites). Spatial and temporal shifts in abundance and species richness are compared with data collected using the same method by Possingham et al. in SA's Mt Lofty Ranges (MLR) stringybark habitat and with data from the same GGNP sites in 2008 after widescale 2006 wildfires. Neither mean diversity nor abundance at each site changed significantly in the same season between years, but mean diversity in spring was higher than in both autumn and winter. Within Heathy Woodland habitat, the foliage searcher guild was the most diverse and abundant foraging guild across sites. With potential for ecosystem collapse in the MLR stringybark community and threats to the GGNP community, ongoing study of avian communities has potential to guide effective management both in the MLR and the GGNP. We assessed outcomes of GGNP fire history on avian diversity and abundance. A more diverse bird community may result where a mosaic burn of stringybark woodlands is achieved and in longer unburnt sites.

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Introduction

Understanding how human activity and associated environmental changes impact biodiversity is critical in development, implementation and assessment of effective landscape management and design strategies, particularly in the context of a rapidly changing climate (Lindenmayer et al., 2014). The measurement of biological diversity and comparison across time and space is confounded by natural changes in species composition and diversity that occur in all communities. Species have natural cycles in population abundance driven by factors ranging from cycles in environmental parameters like

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rainfall patterns through to community-based factors such as competition and predation. In turn, communities may undergo directional change from one state to another (e.g. following wildfire), they may be intrinsically undergoing succession, or they may be changing because of extrinsic factors such as disturbance, pollution, or invasive species.

Because National Parks are, in theory, relatively unaffected by other forms of anthropogenic disturbance, the monitoring of species in parks should facilitate inference regarding effects of climate change on population dynamics (Ray et al., 2017). Within the Grampians/Gariwerd National Park (GGNP) the widespread (Area: 45,182 ha, Figure 1) Heathy Woodlands Ecological Vegetation Class (EVC) is one of the nine ecosystems classified as a conservation asset (Parks Victoria, 2019). Historically it merited a Least Concern Bioregional Conservation Status within the Greater Grampians Bioregion (DSE, 2009), primarily because of its occurrence across this large tract of intact vegetation within the park. Despite this, Parks Victoria (2019) recently assessed as only "Fair" the condition of all six key ecological attributes (woodland habitat connectivity and structure, vegetation growth stage, floristic diversity, and small mammal, woodland bird and arboreal mammal diversity and extent) within the Heathy Woodland habitat with an ongoing declining trend evident. As such, the Heathy Woodland ecosystem is seen as vulnerable to serious degradation and requiring human intervention for it to recover or be restored. Complex interactions arising through loss of key species, effects of increased frequency and extent of fire, changing rainfall patterns, introduced predators, and increase in the extent of *Phytophthora cinnamomi* are impacting the structure, composition and productivity of vegetation in this ecosystem (Parks Victoria, 2019), with unknown consequences for dependent woodland birds.

Several management actions including baiting and winter burn programs have consequently been implemented by Parks Victoria (2019) within the Heathy Woodland community to address such threats as introduced predation (red foxes *Vulpes vulpes* and cats *Felis catus*); and wildfire (frequent, large-scale and high-intensity fires). Across the park, most woodlands affected by large-scale wildfires in 2006 (103,300 ha), 2013 and 2014 were intensely burnt over a large area, resulting in complete loss of the tree canopy and understorey and in some instances complete loss of trees (Stevens et al., 2012).

The monitoring of bird species richness and abundance within the Heathy Woodland community is one method of assessing the ecological outcomes of these interventions. Such sampling of a limited set of indicator species or taxonomic groups, in the context of a specific objective, can act as a surrogate for identifying changes to wider patterns of biodiversity (Caro & O'Doherty, 1999) and ecological integrity (Angermeier & Karr, 1994). Because terrestrial birds occupy relatively high trophic positions and provide important ecological functions such as seed dispersal and insect control, several aspects of terrestrial ecosystem change can be inferred efficiently by monitoring their diversity and abundance. They have been shown to be cost-effective and informative indicators for evaluating and monitoring the ecological consequences of habitat change and as indicators of the state of wildlife as they are wide-ranging in habitat use, tend to be at, or near, the top of the food chain, and because of their documented responses to changes in habitat condition at multiple spatial scales (Gardner et al., 2008; Loyn et al., 2009; Montague-Drake et al., 2009). For these reasons, terrestrial bird populations have been identified as "vital signs" by the U.S. National Park Service as their abundance can indicate park resource conditions and signal the effects of ecological stressors (Fancy

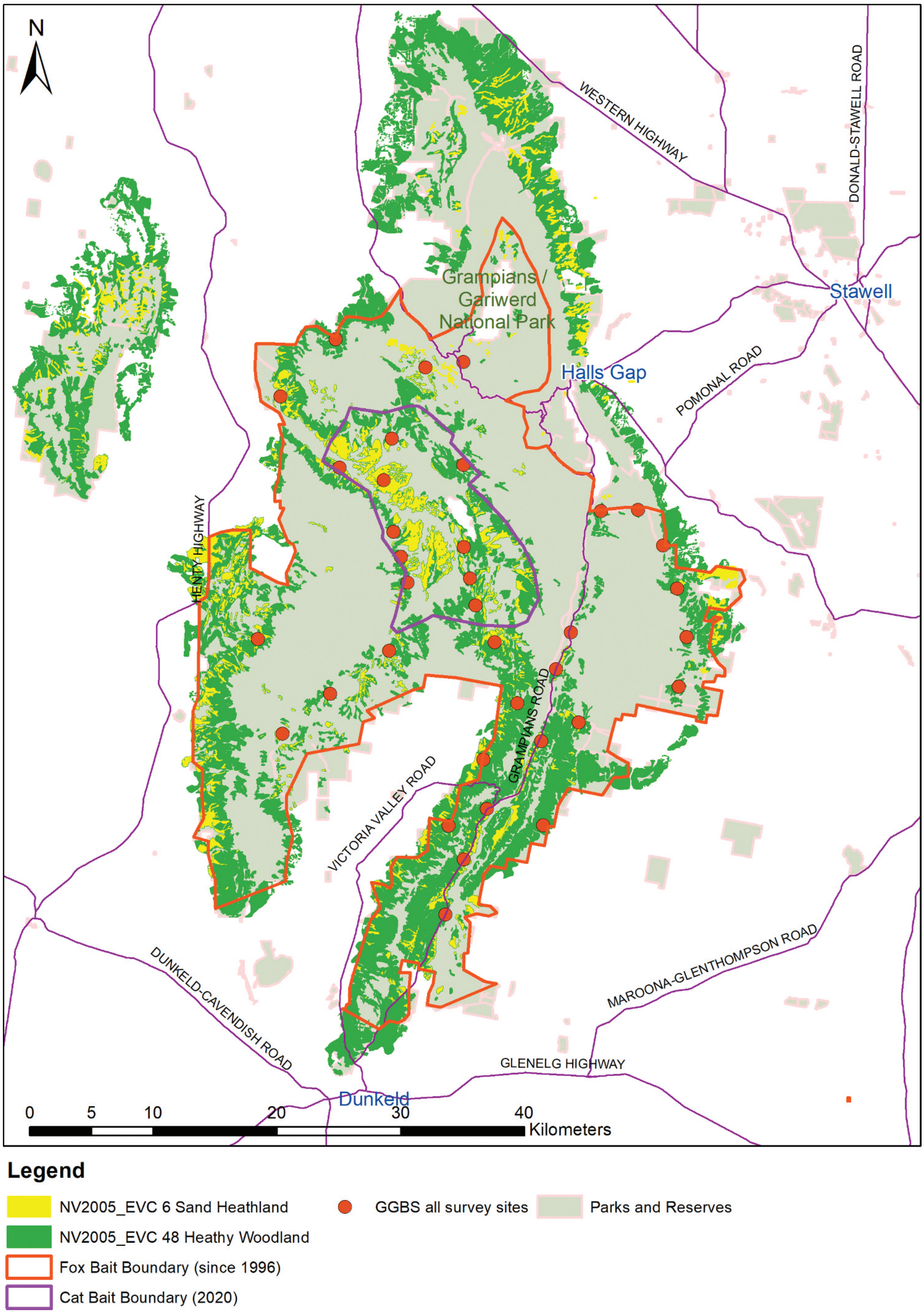

Figure 1. Distribution of EVC 48 Heathy Woodland and EVC 6 Sand Heathland in relation to monitoring sites across the Grampians/Gariwerd National Park.

et al., 2009). That said, Gregory et al. (2008) argued for caution in the use of birds as indicators because many species are highly mobile and a number are migratory, and consequently these species integrate environmental changes over huge areas using the environment in a manner and at a spatial scale unlike many other taxa.

The seasonal dynamics of bird communities in the widespread Heathy Woodlands in the GGNP are here assessed in the context of intense wildfire. Survey sites were established in 2008 as part of a long-term monitoring program designed to monitor recovery from large-scale wildfire in 2006 (Stevens et al., 2012). In 2020, after almost 25 years of consistent fox baiting, monitoring indicated feral cats were of a similar prevalence to foxes across the GGNP (Stevens et al., 2020). A program of feral cat control was implemented in part of the GGNP in 2021 (Figure 1) but the effect of this is not herein assessed. A comparison with the Mount Lofty Ranges (MLR) stringybark woodland avian community in South Australia (Possingham et al., 2004), a more summer-arid community currently undergoing significant decline (Guerin et al., 2023) may provide learnings for GGNP Heathy Woodland management.

We use survey of bird richness and abundance in Heathy Woodland of the GGNP over two years to investigate 1) avian community composition dynamics in heathy woodland habitat across time and space, and 2) post-fire change in the avian assemblage. This study provides a baseline data set that can be used to assess the impact of current and future management actions on avian diversity and abundance in the Heathy Woodlands EVC. It documents the avifauna found in 36 previously randomised 2-ha/20-min bird monitoring sites stratified spatially in the context of the 2006 wildfire across these stringybark woodlands. Surveys undertaken during six surveillance periods (spring 2019, autumn and spring 2020, and autumn, winter, and spring 2021) enable analyses of: avian abundance and species richness recorded at each site and in each season; species richness and abundance in each of 13 avian foraging guilds identified in this community; comparison and contrast of these data with the species recorded in detached stringybark woodlands in the Mt Lofty Ranges in 1999–2000 (Possingham et al., 2004) and at the same sites in the GGNP 10 years earlier in 2009 (Vinicombe, 2009); and uses Vinicombe's (2009) data to investigate changes in avian species richness due to time since fire.

Methods

The project study area was located within the GGNP in southwestern Victoria (Figure 2).

Survey sites

Bird surveys were undertaken at 36 pre-existing, randomised, survey sites (Figure 2) originally established to examine large-scale fire impact on fauna using the post-2006 wildfire landscape of the GGNP (Stevens et al., 2012). Sites were within both the National Park's "Grampians Ark" fox poison baiting perimeter (Figure 2), and the Heathy Woodland – EVC 48 (and some areas of Sand Heathland – EVC 6). In 2006, following the broad-scale wildfire, 36 sites were stratified and established within six categories of fire proximity and severity (Table 1: Fire mosaic low severity, fire severe peripheral, fire severe isolated, unburnt small patch, unburnt large patch, unburnt control; see Stevens et al. (2012) for detailed description). All sites were below 470 m Australian Height

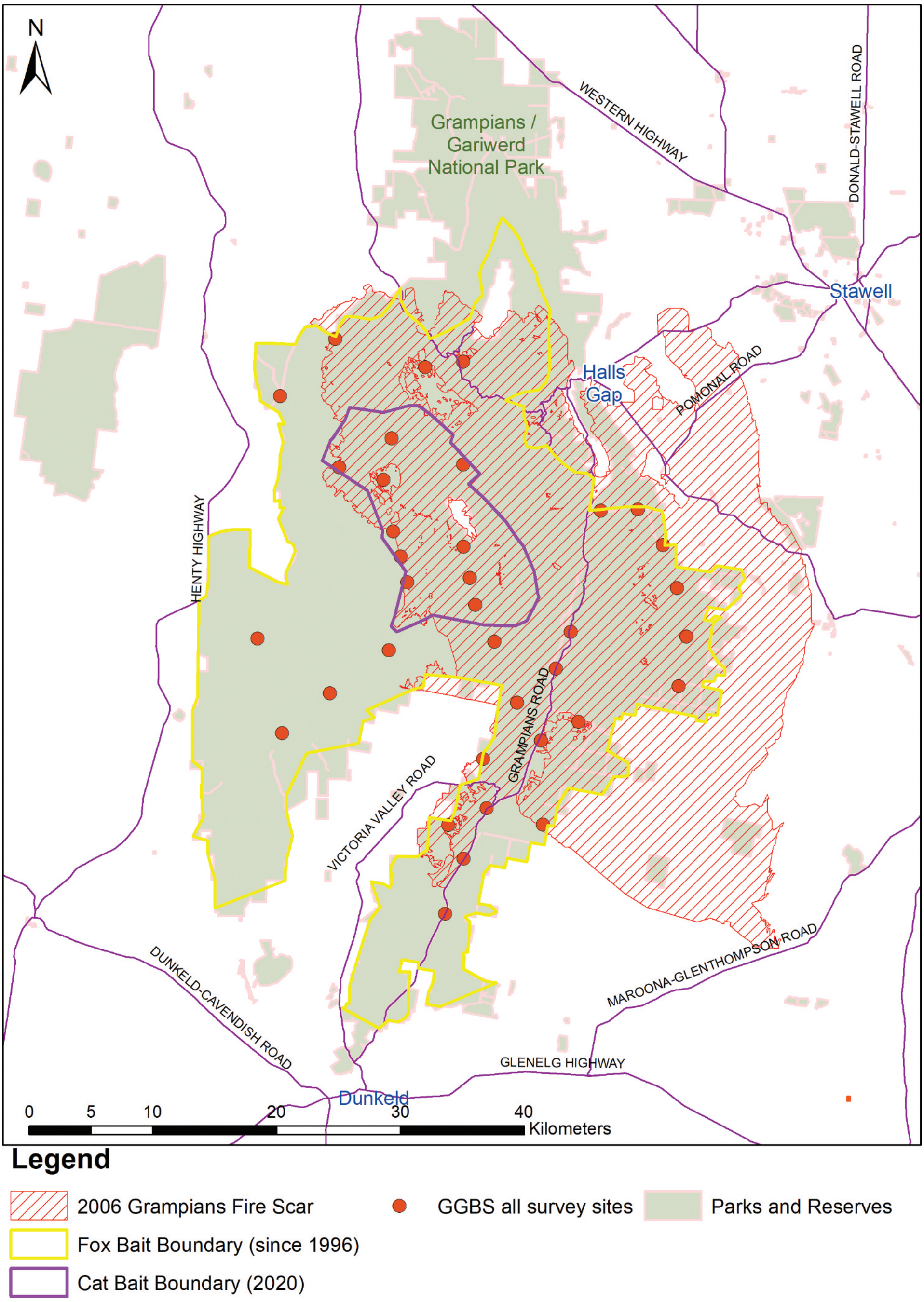

Figure 2. Locality map of the Grampians/Gariwerd National Park study site, boundary for both the fox baiting program (which has been running annually since 1996) and the cat baiting program initiated in 2020 (Stevens et al., 2020), extent of the 2006 severe landscape-scale wildfire (mega fire), and distribution of all Great Gariwerd Bird Survey (GGBS) sites.

Table 1. Survey sites and associated fire and management history. Fire proximity is as defined in original site establishment by Stevens et al. (2012) following the 2006 wildfire. Grey row highlight indicates that a subsequent fire (or fires) has confounded the site stratification established following the 2006 wildfire.

Site	Wildfire 2006	Post 2006 wildfire site stratification. Fire Proximity	Year Last Fire	Cat Baiting
01A1	2006Wildfire	Mosaic-LowSeverity	2019	Control
02A1	2006Wildfire	Severe-Isolated	2006	Cat Bait
03A1	2006Wildfire	Severe-Peripheral	2006	Control
04A1	2006Wildfire	Severe-Peripheral	2006	Control
05A1	2006Wildfire	Severe-Isolated	2006	Cat Bait
06A1	2006Wildfire	Severe-Peripheral	2016	Control
07A1	Unburnt	Control	1986	Control
08A1	2006Wildfire	Severe-Peripheral	2014	Control
09A1	Unburnt	LPatch-RecentPresF	2004	Control
10A1	2006Wildfire	Severe-Peripheral	2020	Control
11A1	2006Wildfire	Severe-Peripheral	2013	Cat Bait
12A1	Unburnt	LPatch-RecentPresF	2005	Control
13A1	Unburnt	LPatch-RecentPresF	2014	Control
14A1	Unburnt	SmallPatch	2006	Control
15A1	2006Wildfire	Severe-Isolated	2006	Control
16A1	Unburnt	SmallPatch	2006	Control
17A1	2006Wildfire	Mosaic-LowSeverity	2006	Control
18A1	2006Wildfire	Severe-Peripheral	2013	Cat Bait
19A1	2006Wildfire	Severe-Isolated	2006	Control
20A1	2006Wildfire	Severe-Isolated	2006	Control
21A1	2006Wildfire	Severe-Isolated	2006	Control
22A1	Unburnt	Control	2013	Control
24A1	Unburnt	Control	2014	Control
25A1	Unburnt	Control	2013	Control
26A1	Unburnt	Control	2019	Control
27A1	Unburnt	Control	2013	Control
28A1	Unburnt	LPatch-RecentPresF	2014	Control
29A1	Unburnt	LPatch-RecentPresF	2014	Control
30A1	Unburnt	LPatch-RecentPresF	2017	Cat Bait
31G1	2006Wildfire	Mosaic-LowSeverity	2013	Cat Bait
33A1	2006Wildfire	Mosaic-LowSeverity	2015	Control
34A1	2006Wildfire	Mosaic-LowSeverity	2020	Control
35A1	2006Wildfire	Mosaic-LowSeverity	2006	Cat Bait
36A1	Unburnt	SmallPatch	1994	Cat Bait
37A1	Unburnt	SmallPatch	2005	Cat Bait
38A1	Unburnt	SmallPatch	1962	Cat Bait

Datum (AHD), located no closer than 2 km from another site, and with one quadrat edge within 300 m of a track or road. Sites were situated in the centre of a homogenous patch with respect to burn severity using a focal patch study design (Holland et al., 2004). These sites have been surveyed annually for small mammals since 2008 (Stevens et al., 2012).

Both Heathy Woodland and Sand Heathland cover an extensive area (55,693 ha) in the Greater Grampians Bioregion within the GGNP (Figure 1). The Heathy Woodlands EVC is generally associated with nutrient poor soil. It is typically a eucalypt dominated low woodland to 10 m tall and lacks a secondary tree layer, but generally supports a diverse array of narrow or ericoid-leaved shrubs. Characteristic tree species within this EVC are messmate stringybark *Eucalyptus obliqua* and brown stringybark *E. baxteri* with a tree canopy cover of around 15% (DSE, 2004). Sand Heathland EVC is generally a treeless heath occurring on deep infertile sands with occasional emergent eucalypts. It consists of a diverse, low, dense heathy shrub layer (DSE, 2004).

Since 2006, there have been three severe and large-scale wildfires across the region (i.e. 2013: 35,700 ha, 2014: 54,000 ha and 2015: 9358 ha) impacting differentially on the monitored sites. Several other smaller wildfires and control burns have also subsequently impacted individual or a small number of monitoring sites. Of the original 19 sites situated in burnt areas in 2006, six remained unburnt since then. Of the original 17 control sites, nine have since been burnt. Consequently, time since fire at all sites at the time of these surveys varied from 0 to 59 years (Table 1).

The wildfire landscape in the GGNP was used to measure how avian diversity and abundance has recovered in the Heathy Woodlands. This was assessed in three ways using the current studies data set: 1. avian community species richness and abundance at sites burnt in the 2006 wildfire landscape (three burnt categories, $n = 19$ sites) were compared with species richness at unburnt sites (three unburnt categories, $n = 17$ sites); 2. The 2006 fire landscape was ignored and instead "years since last fire" at each site was investigated through site-based species richness and bird abundance; and 3. Species richness was compared with that recorded by Vinicombe (2009) at the same sites three years post 2006 wildfire.

Between April and July 2009, Vinicombe (2009) surveyed 31 of the 36 sites in this study for bird species present. Over this period, ten 30-min surveys of a 150 m × 150 m area (2.25 ha) were undertaken at each site between sunrise and sunset. All bird species heard or sighted were recorded to obtain presence data only.

The Grampians Ark project has used 1080 poison baits for foxes since 1996 (Stevens et al., 2020). The program incrementally shifted techniques from a perimeter baiting program to a landscape scale, cross-tenure baiting program. All 36 bird monitoring sites now lie within the zone impacted by fox baiting, and it is consequently not possible to experimentally assess the impact of fox baiting on bird species richness or abundance through this project. But importantly, the bird diversity recorded in this study is in the context of reduced red fox numbers across the monitored landscape over 23+ years.

Monitoring program design

Survey dates

Over a 24-month period between December 2019 and November 2021, two 2-ha/20-min surveys were undertaken at each of the 36 sites during each of six surveillance periods (spring 2019, autumn and spring 2020, and autumn, winter, and spring 2021) for a total of 432 surveys over 48 survey days (Table 2), averaging nine surveys per day. The pairs of surveys undertaken at each site, and in each surveillance period, were completed on two separate days, one in the morning (between 8 am and 12 noon) and one on a different day in the afternoon (after 12 noon). Surveys were all undertaken by one surveyor (GK).

Survey method

Bird surveys followed standardised survey methodology of counts based on either visual or auditory identification during a 2-ha/20-min sample (Field et al., 2002, 2004, 2005; Loyn, 1986), with all counts constrained to only birds detected in and foraging above the two-hectare site.

Table 2. Survey dates.

Survey Number	Start Date	Finish Date	Days of Survey	Surveillance Period
1	02/12/2019	06/12/2019	5	Spring 2019
2	09/12/2019	12/12/2019	4	
3	14/04/2020	17/04/2020	4	Autumn 2020
4	21/04/2020	27/04/2020	4	
5	19/10/2020	22/10/2020	4	Spring 2020
6	26/10/2020	30/10/2020	4	
7	13/04/2021	19/04/2021	4	Autumn 2021
8	19/04/2021	24/04/2021	4	
9	16/08/2021	19/08/2021	4	Winter 2021
10	24/08/2021	27/08/2021	4	
11	07/10/2021	13/10/2021	4	Spring 2021
12	11/11/2021	19/11/2021	3	

Using guilds to investigate avian community structure

To investigate avian community structure within the stringybark community, all recorded bird species were assigned to foraging guilds following the guild classification developed by MacNally (1994) for birds of forests and woodlands of central Victoria. Guilds are used here in the sense of the routine manner and location in which individuals of a species gather food. Birds of each species were assigned to one of the 13 foraging guilds (Table 3): Bark prober (7 species), Bush carnivore (4 sp.), Carnivore (8 sp.), Foliage searcher (15 sp.), Frugivore (1 sp.), Granivore (17 sp.), Ground carnivore (13 sp.), Ground omnivore (3 sp.), Hawker (6 sp.), Nectarivore (7 sp.), Pouncer (7 sp.), Sweeper (2 sp.), and Wood searcher (7 sp.). For detailed guild descriptions, see MacNally (1994)

Comparative studies

Mount Lofty Ranges 1999. Data from Possingham et al. (2004) were used to investigate the hypothesis that avian species composition in stringybark woodlands in the Mount Lofty Ranges (MLR) in South Australia differed significantly from that in the same, but disjunct, habitat type in the GGNP. Possingham et al. (2004) surveyed a total of 38 sites situated in stringybark woodlands with a scrub and heath understorey, with each subject to six 2-ha/20-min survey events (termed "long surveys"), in the MLR between November 1999 and February 2000. Because of this timing, only data from GGNP spring surveys were used for comparison. The 2-ha/20-min surveys followed similar methods used to survey birds in similar habitat to those sampled in this study, making for a valid comparison between avian communities. For context, the MLR are around 400 km to the northwest of the GGNP and the stringybark woodlands are disjunct from eastern populations.

The MLR stringybark woodland habitat consisted of an upper storey of brown stringybark *E. baxteri* and/or messmate *E. obliqua* over a dense sclerophyllous understorey of acacias, banksias, leptospermums, hakeas, xanthorrhoeas, epacrids and various peas (Specht, 1972). The chosen sites had mature trees and relatively intact understoreys, were at least 50 m from the edge of the patch and on a mid-slope, avoiding gullies and ridge lines. As such, the community in which the surveys were undertaken is similar in composition and structure to the Greater Grampians bioregion Heathy Woodland (EVC 48) plant community in which the bird surveys were undertaken in this study.

Table 3. Site distribution and relative abundance of all species recorded during each seasonal surveillance period. Mean Count/survey in **bold** indicates that the species is one of the 30 most abundant species during that season. *The probability of recording a species during a survey (P_{re}) is the total on-site sightings for each of the surveys divided by the number of visits (Possingham et al. = 152 surveys, this study = 432 surveys). Note that one sighting means that one or more single birds or several groups of birds were recorded for one 20-min sample of a two-ha site.

					Autumn (N = 144 surveys)		Winter (N = 72 surveys)		Spring (N = 216 surveys)		*Probability (P_{re}) of recording during a survey		
ORDER Common Name	FAMILY *Scientific name*	Foraging guild	Sites Present	% Sites Present	% Surveys Recorded	Mean Count/ survey	% Surveys Recorded	Mean Count/ survey	% Surveys Recorded	Mean Count/ survey	This study: Spring only	This study: All surveys	Possingham et al. (2004)
ACCIPITRIFORMES	ACCIPITRIDAE												
Collared Sparrowhawk	*Accipiter cirrocephalus*	Predator	2	5.6	0.7	0.01	Not recorded		0.5	0.00	0.005	0.005	
Brown Goshawk	*Accipiter fasciatus*	Predator	2	5.6	0.7	0.01	Not recorded		0.5	0.00	0.005	0.005	
Wedge-tailed Eagle	*Aquila audax*	Predator	8	22.2	2.1	0.02	2.8	0.06	3.2	0.03	0.032	0.028	0.059
Swamp Harrier	*Circus approximans*	Predator	2	5.6	Not recorded		Not recorded		1.4	0.04	0.014	0.007	
Whistling Kite	*Haliastur sphenurus*	Predator	1	2.8	Not recorded		Not recorded		0.5	0.00	0.005	0.002	
ANSERIFORMES	ANATIDAE												
Pacific Black Duck	*Anas superciliosa*	Granivore	1	2.8	Not recorded		1.4	0.01	Not recorded			0.007	
CASUARIIFORMES	CASUARIIDAE												
Emu	*Dromaius novaehollandiae*	Granivore	3	8.3	Not recorded		1.4	0.01	0.9	0.01	0.009	0.007	
CHARADRIIFORMES	TURNICIDAE												
Red-chested Buttonquail	*Turnix pyrrhothorax*	Granivore	1	2.8	Not recorded		Not recorded		0.5	0.00	0.005	0.002	
COLUMBIFORMES	COLUMBIDAE												
Common Bronzewing	*Phaps chalcoptera*	Granivore	12	33.3	2.8	0.03	1.4	0.01	5.6	0.07	0.056	0.039	0.066
Brush Bronzewing	*Phaps elegans*	Granivore	2	5.6	0.7	0.01	1.4	0.01	Not recorded			0.005	0.033
CORACIIFORMES	ALCEDINIDAE												
Laughing Kookaburra	*Dacelo novaeguineae*	Pouncer	26	72.2	4.9	0.06	13.9	**0.19**	11.6	0.14	0.116	0.097	0.086
Sacred Kingfisher	*Todiramphus sanctus*	Pouncer	15	41.7	Not recorded		1.4	0.01	12.5	0.14	0.125	0.065	0.059
CUCULIFORMES	CUCULIDAE												
Fan-tailed Cuckoo	*Cacomantis flabelliformis*	Pouncer	19	52.8	Not recorded		1.4	0.01	11.1	0.13	0.111	0.058	0.059
Pallid Cuckoo	*Cacomantis pallidus*	Ground Carnivore	2	5.6	Not recorded		Not recorded		0.9	0.01	0.009	0.005	

(*Continued*)

Table 3. (Continued).

ORDER Common Name	FAMILY *Scientific name*	Foraging guild	Sites Present	% Sites Present	Autumn (*N* = 144 surveys) % Surveys Recorded	Autumn Mean Count/ survey	Winter (*N* = 72 surveys) % Surveys Recorded	Winter Mean Count/ survey	Spring (*N* = 216 surveys) % Surveys Recorded	Spring Mean Count/ survey	*Probability (P_{re}) of recording during a survey: This study: Spring only	This study: All surveys	Possingham et al. (2004)
Horsfield's Bronze Cuckoo	*Chalcites basalis*	Foliage Searcher	11	30.6	Not recorded		Not recorded		6.9	0.07	0.069	0.035	0.020
Shining Bronze cuckoo	*Chalcites lucidus*	Foliage Searcher	7	19.4	Not recorded		1.4	0.01	3.7	0.11	0.037	0.063	0.020
FALCONIFORMES	FALCONIDAE												
Brown Falcon	*Falco berigora*	Predator	1	2.8	Not recorded		Not recorded		0.5	0.00	0.005	0.002	
Nankeen Kestrel	*Falco cenchroides*	Predator	1	2.8	Not recorded		Not recorded		0.5	0.00	0.005	0.002	
PASSERIFORMES	ACANTHIZIDAE												
Striated Thornbill	*Acanthiza lineata*	Foliage Searcher	31	86.1	15.3	**0.65**	15.3	**0.58**	10.6	**0.31**	0.106	0.130	0.678
Yellow Thornbill	*Acanthiza nana*	Foliage Searcher	11	30.6	2.1	0.03	4.2	**0.11**	3.2	0.07	0.032	0.030	0.007
Brown Thornbill	*Acanthiza pusilla*	Foliage Searcher	36	100.0	50.0	**1.20**	50.0	**1.60**	45.4	**1.30**	0.454	0.477	0.605
Buff-rumped Thornbill	*Acanthiza reguloides*	Bush Carnivore	19	52.8	9.7	**0.35**	8.3	**0.21**	7.4	**0.26**	0.074	0.083	0.072
Striated Fieldwren	*Calamanthus fuliginosus*	Ground Carnivore	3	8.3	2.8	0.06	2.8	0.03	0.9	0.02	0.009	0.019	
White-throated gerygone	*Gerygone olivacea*	Foliage Searcher	1	2.8	Not recorded		Not recorded		0.5	0.00	0.005	0.002	
Chestnut-rumped Heathwren	*Hylacola pyrrhopygia*	Ground Carnivore	12	33.3	5.6	**0.09**	Not recorded		4.6	0.08	0.046	0.042	0.013
Speckled Warbler	*Pyrrholaemus sagittatus*	Ground Carnivore	1	2.8	0.7	0.01	Not recorded		0.9	0.01		0.002	
White-browed Scrubwren	*Sericornis frontalis*	Bush Carnivore	34	94.4	45.1	**1.08**	26.4	**0.58**	42.6	**1.09**	0.426	0.407	0.355
Weebill	*Smicrornis brevirostris*	Foliage Searcher	33	91.7	42.4	**1.40**	33.3	**1.00**	22.2	**0.48**	0.222	0.308	
	ARTAMIDAE												
Dusky Woodswallow	*Artamus cyanopterus*	Hawker	12	33.3	2.1	**0.11**	2.8	0.07	10.2	**0.23**	0.102	0.063	0.007
Australian Magpie	*Gymnorhina tibicen*	Ground Carnivore	6	16.7	1.4	0.06	2.8	0.04	1.4	0.02	0.014	0.016	0.066

(*Continued*)

Table 3. (Continued).

ORDER Common Name	FAMILY *Scientific name*	Foraging guild	Sites Present	% Sites Present	Autumn (*N* = 144 surveys) % Surveys Recorded	Autumn Mean Count/ survey	Winter (*N* = 72 surveys) % Surveys Recorded	Winter Mean Count/ survey	Spring (*N* = 216 surveys) % Surveys Recorded	Spring Mean Count/ survey	*Probability (P_{re}) of recording during a survey: This study: Spring only	This study: All surveys	Possingham et al. (2004)
Pied Currawong	*Strepera graculina*	Bark Prober	21	58.3	5.6	0.06	2.8	0.06	9.7	**0.17**	0.097	0.072	
Grey Currawong	*Strepera versicolour*	Bark Prober	28	77.8	13.9	**0.16**	9.7	0.10	12.0	**0.14**	0.120	0.123	0.230
	CAMPEPHAGIDAE												
Black-faced Cuckooshrike	*Coracina novaehollandiae*	Wood Searcher	18	50.0	1.4	0.02	Not recorded		13.0	**0.20**	0.130	0.069	0.178
White-winged Triller	*Lalage tricolor*	Wood Searcher	2	5.6	Not recorded		Not recorded		0.9	0.01	0.009	0.005	
	CLIMACTERIDAE												
Brown Treecreeper	*Climacteris picumnus*	Bark Prober	2	5.6	0.7	0.01	Not recorded		0.5	0.00	0.005	0.005	
White-throated Treecreeper	*Cormobates leucophaeus*	Bark Prober	34	94.4	54.9	**0.73**	55.6	**0.85**	42.1	**0.68**	0.421	0.486	0.678
	CORCORACIDAE												
White-winged chough	*Corcorax melanoramphos*	Ground Carnivore	1	2.8	Not recorded		Not recorded		0.5	0.00	0.005	0.002	
	CORVIDAE												
Australian Raven	*Corvus caronoides*	Ground Omnivore	3	8.3	1.4	0.01	Not recorded		0.5	0.01	0.005	0.007	
Little Raven	*Corvus mellori*	Ground Omnivore	9	25.0	4.2	0.06	4.2	0.06	0.9	0.01	0.009	0.025	0.059
Forest Raven	*Corvus tasmanicus*	Ground Omnivore	9	25.0	4.9	0.08	6.9	0.08	1.4	0.01	0.014	0.035	
	DICAEIDAE												
Mistletoebird	*Dicaeum hirundinaceum*	Frugivore	9	25.0	0.7	0.01	2.8	0.04	5.6	0.11	0.056	0.035	0.020
	ESTRILDIDAE												
Red-browed Finch	*Neochmia temporalis*	Granivore	2	5.6	Not recorded		1.4	0.06	1.4	0.06	0.014	0.009	0.079
Diamond Firetail	*Stagonopleura guttata*	Granivore	1	2.8	Not recorded		Not recorded		0.5	0.00	0.005	0.002	
	HIRUNDINIDAE												
Welcome Swallow	*Hirundo neoxena*	Sweeper	13	36.1	4.2	**0.14**	8.3	**0.17**	3.2	0.06	0.032	0.044	0.007

(*Continued*)

Table 3. (Continued).

ORDER Common Name	FAMILY *Scientific name*	Foraging guild	Sites Present	% Sites Present	Autumn (*N* = 144 surveys) % Surveys Recorded	Autumn Mean Count/ survey	Winter (*N* = 72 surveys) % Surveys Recorded	Winter Mean Count/ survey	Spring (*N* = 216 surveys) % Surveys Recorded	Spring Mean Count/ survey	*Probability (P_{re}) of recording during a survey: This study: Spring only	This study: All surveys	Possingham et al. (2004)
Tree Martin	*Petrochelidon nigricans*	Sweeper	3	8.3	2.1	0.03	Not recorded		Not recorded			0.007	0.020
	LOCUSTELLIDAE												
Rufous Songlark	*Megalurus mathewsi*	Bush Carnivore	1	2.8	Not recorded		Not recorded		0.9	0.01	0.009	0.005	
	MALURIDAE												
Superb Fairywren	*Malurus cyaneus*	Ground Carnivore	34	94.4	22.2	**0.56**	37.5	**1.04**	28.2	**0.74**	0.282	0.278	0.783
Southern Emu-wren	*Stipiturus malachurus*	Ground Carnivore	9	25.0	6.9	**0.18**	5.6	**0.10**	3.7	0.09	0.037	0.051	
	MELIPHAGIDAE												
Eastern Spinebill	*Acanthorhynchus tenuirostris*	Nectarivore	35	97.2	51.4	**1.01**	63.9	**1.57**	53.2	**0.87**	0.532	0.544	0.211
Red Wattlebird	*Anthochaera carunculata*	Nectarivore	27	75.0	21.5	**0.85**	11.1	**0.25**	12.5	**0.40**	0.125	0.153	0.197
Little Wattlebird	*Anthochaera chrysoptera*	Nectarivore	4	11.1	3.5	0.08	Not recorded		1.4	0.03	0.014	0.019	
Yellow-faced Honeyeater	*Caligavis chrysops*	Foliage Searcher	35	97.2	40.3	**1.51**	63.9	**1.96**	69.9	**2.29**	0.699	0.590	0.414
Tawny-crowned Honeyeater	*Glyciphila melanops*	Nectarivore	22	61.1	14.6	**0.30**	23.6	**0.83**	22.7	**0.42**	0.227	0.201	
Fuscous Honeyeater	*Lichenostomus fuscus*	Foliage Searcher	7	19.4	0.7	0.01	2.8	**0.03**	4.6	**0.32**	0.046	0.030	
Yellow-tufted Honeyeater	*Lichenostomus melanops*	Foliage Searcher	5	13.9	0.7	0.01	5.6	**0.25**	0.5	0.00	0.005	0.014	
Brown-headed Honeyeater	*Melithreptus brevirostris*	Foliage Searcher	20	55.6	6.3	**0.32**	5.6	**0.15**	9.3	**0.22**	0.093	0.076	0.013
White-naped Honeyeater	*Melithreptus lunatus*	Foliage Searcher	18	50.0	11.1	**0.57**	9.7	**0.28**	7.4	**0.19**	0.074	0.090	0.145
White-eared Honeyeater	*Nesoptilotis leucotis*	Wood Searcher	35	97.2	61.8	**1.18**	50.0	**1.10**	43.5	**0.88**	0.435	0.507	
New Holland Honeyeater	*Phylidonyris novaehollandiae*	Nectarivore	28	77.8	34.0	**2.13**	40.3	**2.11**	28.2	**0.99**	0.282	0.322	0.125

(*Continued*)

Table 3. (Continued).

ORDER Common Name	FAMILY *Scientific name*	Foraging guild	Sites Present	% Sites Present	Autumn (*N* = 144 surveys) % Surveys Recorded	Autumn Mean Count/ survey	Winter (*N* = 72 surveys) % Surveys Recorded	Winter Mean Count/ survey	Spring (*N* = 216 surveys) % Surveys Recorded	Spring Mean Count/ survey	*Probability (P_{re}) of recording during a survey: This study: Spring only	This study: All surveys	Possingham et al. (2004)
Crescent Honeyeater	*Phylidonyris pyrrhopterus*	Wood Searcher	16	44.4	4.9	**0.14**	9.7	**0.38**	5.1	0.09	0.051	0.058	0.375
White-plumed Honeyeater	*Ptilotula penicillata*	Foliage Searcher	1	2.8	Not recorded		1.4	0.01	Not recorded			0.002	
	MONARCHIDAE												
Restless Flycatcher	*Myiagra inquieta*	Hawker	2	5.6	0.7	0.01	Not recorded		0.5	0.00	0.005	0.005	
	NEOSITTIDAE												
Varied Sitella	*Dophoenositta chrysoptera*	Bark Prober	6	16.7	1.4	**0.13**	5.6	**0.24**	1.9	0.07	0.019	0.023	0.033
	PACHYCEPHALIDAE												
Grey Shrikethrush	*Colluricincla harmonica*	Bark Prober	32	88.9	17.4	**0.20**	26.4	**0.39**	30.6	**0.41**	0.306	0.255	0.441
Crested Shriketit	*Falcunculus frontatus*	Bark Prober	1	2.8	Not recorded		Not recorded		0.9	0.02	0.009	0.005	0.007
Rufous Whistler	*Pachycephala rufiventris*	Wood Searcher	28	77.8	1.4	0.01	2.8	0.03	43.1	**0.69**	0.431	0.225	0.276
Golden Whistler	*Pachycephala pectoralis*	Wood Searcher	17	47.2	5.6	0.06	4.2	0.04	5.1	0.06	0.051	0.051	0.013
	PARDALOTIDAE												
Spotted Pardalote	*Pardalotus punctatus*	Foliage Searcher	35	97.2	22.9	**0.44**	31.9	**0.57**	47.2	**0.86**	0.472	0.366	0.007
Striated Pardalote	*Pardalotus striatus*	Foliage Searcher	27	75.0	11.8	**0.16**	16.7	**0.39**	13.4	**0.26**	0.134	0.134	0.486
	PETROICIDAE												
Eastern Yellow Robin	*Eopsaltria australia*	Pouncer	18	50.0	11.1	**0.17**	5.6	0.06	11.1	**0.15**	0.111	0.102	
Hooded Robin	*Melanodryas cucullata*	Pouncer	1	2.8	1.4	0.02	1.4	0.03	0.5	0.00	0.005	0.009	
Jacky Winter	*Microeca fascinans*	Hawker	2	5.6	Not recorded		Not recorded		0.9	0.01	0.009	0.005	
Scarlet Robin	*Petroica multicolor*	Pouncer	29	80.6	23.6	**0.39**	26.4	**0.47**	23.6	**0.39**	0.236	0.241	0.178
Flame Robin	*Petroica phoenicea*	Pouncer	1	2.8	Not recorded		1.4	0.01	Not recorded			0.007	
	POMATOSTOMIDAE												
White-browed Babbler	*Pomastomus superciliosus*	Ground Carnivore	4	11.1	2.1	0.04	Not recorded		0.9	0.01	0.009	0.012	

(*Continued*)

Table 3. (Continued).

ORDER Common Name	FAMILY *Scientific name*	Foraging guild	Sites Present	% Sites Present	Autumn (N = 144 surveys) % Surveys Recorded	Autumn Mean Count/ survey	Winter (N = 72 surveys) % Surveys Recorded	Winter Mean Count/ survey	Spring (N = 216 surveys) % Surveys Recorded	Spring Mean Count/ survey	*Probability (P_{re}) of recording during a survey: This study: Spring only	This study: All surveys	Possingham et al. (2004)
	RHIPIDURIDAE												
Grey Fantail	*Rhipidura fuliginosa*	Hawker	35	97.2	34.0	**0.51**	18.1	**0.29**	62.0	**1.58**	0.620	0.454	0.849
Willie Wagtail	*Rhipidura leucophrys*	Hawker	1	2.8	Not recorded		Not recorded		0.5	0.00	0.005	0.002	
	TIMALIIDAE												
Silvereye	*Zosterops lateralis*	Bush Carnivore	1	2.8	Not recorded		Not recorded		0.5	0.01	0.037	0.002	0.263
	TURDIDAE												
*Common Blackbird	*Turdus merula*	Ground Carnivore	2	5.6	0.7	0.01	1.4	0.01	0.9	0.01	0.009	0.009	0.513
Bassian Thrush	*Zoothera lunulata*	Ground Carnivore	1	2.8	0.7	0.01	Not recorded		Not recorded			0.002	
PSITTACIFORMES	CACATUIDAE												
Sulphur-crested Cockatoo	*Cacatua galerita*	Granivore	13	36.1	2.1	0.03	8.3	**0.15**	7.4	0.11	0.074	0.058	0.059
Little Corella	*Cacatua sanguinea*	Granivore	1	2.8	0.7	0.03	Not recorded		Not recorded			0.002	
Long-billed Corella	*Cacatua tenuirostris*	Granivore	4	11.1	Not recorded		Not recorded		1.9	0.04	0.019	0.009	
Gang-gang cockatoo	*Callocephalon fimbriatum*	Granivore	23	63.9	7.6	**0.15**	8.3	**0.19**	8.8	**0.18**	0.088	0.083	
Yellow-tailed Black Cockatoo	*Zanda funereus*	Granivore	25	69.4	2.8	0.06	Not recorded		17.1	**0.49**	0.171	0.095	0.171
	PSITTACIDAE												
Musk Lorikeet	*Glossopsitta concinna*	Nectarivore	2	5.6	0.7	0.01	1.4	0.01	Not recorded			0.005	0.013
Purple-crowned Lorikeet	*Glossopsitta porphyrocephala*	Nectarivore	3	8.3	2.1	0.09	Not recorded		Not recorded			0.007	0.020
Blue-winged Parrot	*Neophema chyrsostoma*	Granivore	4	11.1	Not recorded		Not recorded		2.3	0.09	0.023	0.012	
Crimson Rosella	*Platycercus elegans*	Granivore	36	100.0	38.9	**1.04**	34.7	**0.72**	35.2	**0.71**	0.352	0.363	0.671
STRIGIFORMES	STRIGIDAE												
Southern Boobook	*Ninox novaeseelandiae*	Ground Carnivore	1	2.8	0.7	0.01	Not recorded		Not recorded			0.002	0.007

As part of their analysis, Possingham et al. (2004) determined the probability of recording a species, P_{re}, in a visit to a site. If a bird species was recorded as either one or more single birds or as several groups of birds during one 2-ha/20-min survey, this was equated to one sighting for that species. The P_{re} value was calculated by determining the total on-site sightings for that species for four of the independent visits and dividing it by the number of visits (i.e. $38 \times 4 = 152$ visits in total).

To enable a comparison between the data set collected by Possingham et al. (2004) and this study, P_{re} was determined for each of the species in the GGNP study, both over all six surveillance periods and for the three spring surveillance periods. The spring surveillance periods from this study were used for comparative purposes as survey timing is most comparable with the late spring early summer survey period used in the Possingham et al. (2004) study.

Grampians Gariwerd National Park 2009. To assess the hypothesis that avian species richness and community composition had changed in the GGNP Heathy Woodlands because of time since fire, a comparison was undertaken between the proportion of sites at which each species was recorded in 2009 by Vinicombe (2009) and this study. The survey method used by Vinicombe (2009) differed from this study by incorporating a "random" walk through a slightly larger area (150 m × 150 m area = 2.25 ha) for a longer time (30 min), recording all bird species heard or seen. Ten surveys were conducted at each site, with site visits randomised throughout the day. Only species presence data were reported by Vinicombe (2009) and the original raw data has been lost.

Statistics

To estimate the number of bird species in the assemblage represented by the surveys, analyses were carried out using EstimateS Ver 9.1.0 (Colwell, 2013). Site-based species count rarefaction curves were created using 100 randomisation runs with 1.5X extrapolation. Individuals were randomised without replacement. We calculated S_{est} (analytical) i.e. the expected number of species in t-pooled samples with lower and upper 95% confidence intervals. The classic formula was used to determine Chao 1. All of the six assumptions required for sample-based rarefaction to be used rigorously to compare species richness in two or more samples or assemblages analysis were met (see Magurran & McGill, 2011, pp. 47–48 for these assumptions).

Changes in species richness (total number of species recorded in a survey) and abundance (total birds of all species per survey) at 36 sites within the Heathy Woodlands of the GGNP were the dependent variables used to assess the effects of the independent variables of season (autumn, winter, and spring) and both fire history and time since fire on the stringybark woodland bird community and guild composition.

A paired-sample *t*-test was used to compare the probability of detection of avian species (P_{re}) in stringybark woodland communities between the MLR (Possingham et al., 2004) and this study and to compare between the proportion of sites at which each species was recorded in 2009 (Vinicombe, 2009) and during this study.

To assess the influence of season on bird species richness and abundance at each site a two-way repeated measures analysis of variance (RM ANOVA) was used (SPSS v26 for

IBM). Mauchly's test was used to assess the assumption of sphericity. Where it was violated, and ε was less than 0.75, the degrees of freedom were corrected using Greenhouse – Geisser estimates of sphericity. A Tukey LSD *post hoc* pair-wise comparison was used to test for significant differences in mean Total Species Richness among each of the six Season's bird communities.

An empirical cumulative distribution function (eCDF) was used to compare avian community structure using species abundance among the autumn, winter, and spring seasons. This method corrects for different species diversities between communities allowing for valid comparisons (McGill, 2011).

A linear mixed model in R (version 4.0.5 31 March 2021) was used to analyse the impact of fire history on avian species richness at each site. All data were assessed for linearity, homogeneity of variance, collinearity, influential observations, normality of residuals and normality of random effects prior to analysis (Peterson, 2021; Wickham, 2016; Wickham et al., 2021). Models were fitted (Bates et al., 2015), assessed (Lüdecke et al., 2021) visualised (Lüdecke, 2021), and results reported (Lüdecke, 2018; Makowski et al., 2020) using the named resources.

Pearson product moment correlation coefficient and linear regression were used to determine the levels of association between year of last fire at a site and mean of total species richness in all surveys at each site and between year of last fire at a site and mean of total bird abundance in all surveys at each site.

Results

Twelve 2-ha/20-min surveys were undertaken at each of the 36 sites for a total of 432 surveys or 8640 min of survey time in the GGNP Heathy Woodlands. This represents 4 h of survey per site, with 40 min of survey at each site in each of six seasons: spring 2019, autumn and spring 2020 and autumn winter and spring 2021 (Table 2).

Composition of Avifauna

For all surveys in the GGNP combined, a total of 8410 birds were recorded from 90 species (Table 3) representing 13 orders and 34 families. The total number of species recorded at each site over the 12 surveys averaged 31.17 mean ± 0.804 se, range 14 to 40 species, $n = 36$ sites. A rarefaction estimated species richness (Colwell, 2013) extrapolated to 1.5X the number of surveys (Table 4, Figure 3) approached an asymptote at 95.30 ± 3.68 species, indicating an adequate survey effort to define the avian community in the Heathy Woodland habitat. The Chao 1 estimate of overall species richness was 101.14 ± 8.23 species. Rare species for this habitat type constituted around 29% of the species recorded: after 432 surveys there were 15 singleton (i.e. only recorded once in all surveys) species (Note: all species' scientific names are provided in Table 3. Whistling kite, Pacific black duck, red-chested buttonquail, brown falcon, nankeen kestrel, white-throated gerygone, white winged chough, diamond firetail, white-plumed honeyeater, flame robin, willie wagtail, silvereye, Bassian thrush, little corella, and southern boobook) and 11 doubletons (Brown goshawk, collared sparrowhawk, brush bronzewing, pallid cuckoo, white-winged triller, brown

Table 4. Rarefaction estimated species richness (Colwell, 2013) based on 12 surveys at 36 sites.

Number of surveys	Sest ± SD	Sest ± SD Extrapolation to 1.5 number of surveys	Estimated Species Richness			
			ACE mean	Chao 1 mean ± SD	Jack 1 mean ± SD	Bootstrap mean
432	90.00 ± 3.03	95.30 ± 3.68	101.74	101.14 ± 8.23	104.97 ± 4.05	97.38

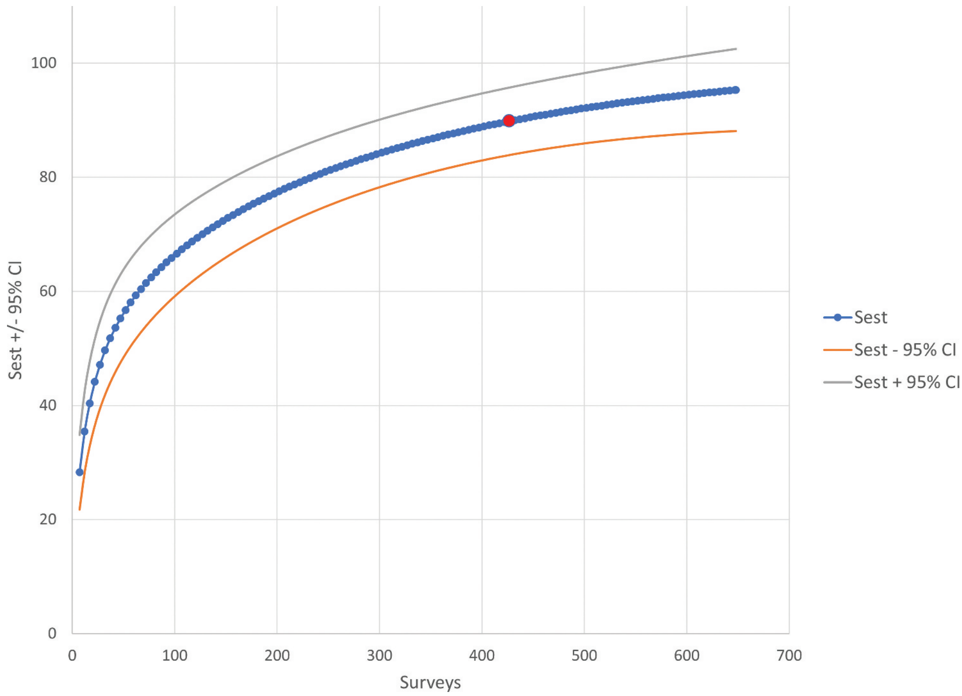

Figure 3. Sample based species accumulation rarefaction curve (S_{est}) for all surveys ($N = 432$ surveys) red dot, with 1.5X extrapolation. Solid lines equal 95% confidence interval.

treecreeper, rufous songlark, restless flycatcher, crested shriketit, jacky winter, and musk lorikeet).

The mean number of species at each site during each survey was 8.40 (se = 1.91, $n = 36$ sites). Mean number of birds recorded at each site during each survey was 19.52 (se = 6.91, $n = 36$ sites). Nineteen species were widespread across the Heathy Woodlands being recorded at over 75% of the sites surveyed (Table 4): brown thornbill, crimson rosella, eastern spinebill, grey fantail, spotted pardalote, white-eared honeyeater, yellow-faced honeyeater, superb fairywren, white-browed scrubwren, white-throated treecreeper, weebill, grey shrikethrush, striated thornbill, scarlet robin, grey currawong, New Holland honeyeater, rufous whistler, red wattlebird, striated pardalote. Forty-four species were recorded at more than 25% of the sites. The white-browed babbler, little wattlebird, long-billed corella, blue-winged parrot, yellow-tufted honeyeater, Australian magpie, varied sitella, shining bronze cuckoo, fuscous honeyeater, and wedge-tailed eagle were recorded at between 10% and 24% of the sites. Either low density, clustered distribution, seasonal transitional use, or occupancy of fringing habitat appear to play a role in site occupancy for these species.

Species of honeyeater differed greatly in the nature of their distribution and abundance across sites within the Heathy Woodlands. Three species were widespread being recorded at all 35 treed sites. Eastern spinebill occurred in ones and twos, yellow-faced honeyeaters often in small flocks, and white-eared honeyeaters typically in pairs. Red wattlebirds were recorded at 75% of sites typically in pairs or small groups. New Holland honeyeaters were generally widespread (78% of sites) and at times very abundant, but were absent from most of the sites in the Victoria Valley and around the Billawin Range. Many species of honeyeater were patchy in distribution: Both brown-headed honeyeaters (in small flocks) and tawny-crowned honeyeaters (singly or in pairs) were recorded at around 60% of sites. White-naped honeyeaters were recorded occasionally at 50% of sites, but often at two sites in the Moora Valley (05A1 and 35A1) and at site 15A1 in tall forest. Crescent honeyeaters were recorded at 44% of sites in small groups but with seasonal variation in abundance. Fuscous honeyeaters were recorded, typically repeatedly, at the same 20% of sites, in colonies. Three honeyeater species were rarely recorded in this habitat: Yellow-tufted honeyeaters at five sites, with a cluster at three sites around Moomgalg (Wallaby) Rocks; little wattlebirds at four sites, and the white-plumed honeyeater at only one site.

Comparison with Possingham et al.'s (2004) data from Mt Lofty Ranges stringybark habitat

Possingham et al. (2004) recorded 69 species in their late spring early summer surveys of stringybark woodland habitat in the MLR. This consisted of 55 species on the 2-ha sites, 27 overhead transients and 62 off site. Of the species recorded on site in the MLR stringybark woodlands, 48 were also recorded in the GGNP (Table 3). The markedly higher diversity recorded in the stringybark woodlands in the GGNP (90 species) is likely predominantly the product of a greater survey effort. The 69 species recorded in the MLR after 152 surveys fall well within the 95% confidence interval, at the same number of surveys, for the sample-based species accumulation rarefaction curve for the GGNP (Figure 3). A small number of species have range limits that do not include both survey regions (e.g. elegant parrot, striated field wren, and forest raven). However, putting aside the five feral species and five wetland species, of the remaining 59 species recorded in the brown stringybark woodlands in the MLR, 86.4% of the species were also present in the GGNP surveys. Eight of the nine species not recorded in the GGNP in this study are known to occur in the GGNP. The absence of the weebill from the brown stringybark woodland in MLR is worthy of note as it is a common species in the same habitat in the GGNP.

A paired samples *t*-test comparing the probability of recording (P_{re}) each of the 48 species recorded at both locations, in a spring survey in the GGNP and the MLR (Table 3) found a highly significant, moderately positive correlation between the two bird communities ($r = 0.527$, $n = 48$, $p < 0.001$***, Figure 4). The null hypothesis that the mean differences in probability of recording the species between the two communities was zero was accepted ($t_{47} = -1.269$, p (2-tailed) = 0.211). Species like the grey fantail, yellow-faced honeyeater, eastern spinebill, white-browed scrub wren, brown thornbill, white throated

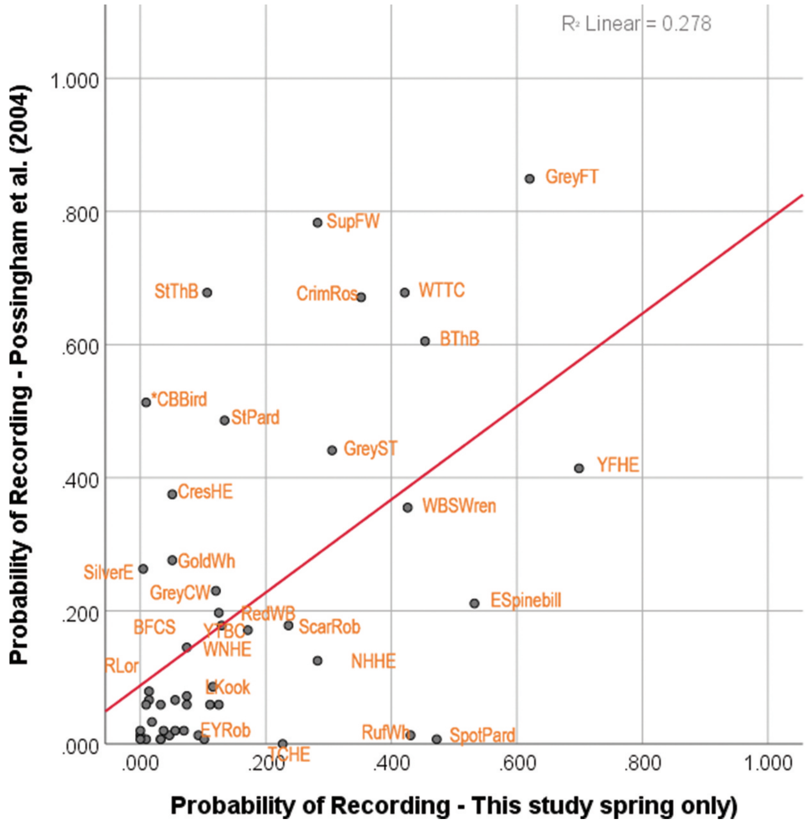

Figure 4. Comparison with data from Possingham et al. (2004) of the probability of recording a species at a site (P_{re}) in stringybark habitat in spring in the Grampians (this study) and the Mt Lofty Ranges for those species recorded at both locations. P_{re} is the total on-site sightings for each of the surveys divided by the number of visits (Possingham et al. = 152 surveys, this study (spring only) = 216 surveys). Note that one sighting means that one or more single birds or several groups of birds were recorded for one 20-minute sample of a 2-ha site. Red line indicates line of best fit ($N = 48$ species, $r = 0.527$, $p < 0.001$***).

treecreeper, superb fairywren, crimson rosella, grey shrike-thrush, New Holland honeyeater, scarlet robin, yellow-tailed black-cockatoo, red-wattlebird, golden whistler, grey currawong, black-faced cuckoo shrike, white-naped honeyeater, laughing kookaburra, and sacred kingfisher are a highly detected component of the stringybark woodland avian community in both locations. Species with markedly higher probability of recording in the GGNP were the spotted pardalote, rufous whistler, and tawny-crowned honeyeater. Conversely, species with a markedly higher probability of recording in the MLR were the striated thornbill, common blackbird, striated pardalote, crescent honeyeater, and silvereye.

Five of the ten species with the highest P_{re} (range 0.590 to 0.322) in the GGNP (in descending order: yellow-faced honeyeater#10, eastern spinebill, white-eared honeyeater, white-throated treecreeper#3, brown thornbill#6, grey fantail#1, white-browed scrubwren, spotted pardalote, crimson rosella#5, and New Holland honeyeater) occurred in the top ten (marked with # and rank) in the MLR surveys. The six highest P_{re} scores (range 0.849 to 0.605) for species in the MLR were above the highest score for the GGNP indicating up to a two-fold higher likelihood of being recorded in the stringybark woodlands in the MLR. Four of the remaining five species from the top ten in the MLR are in the top 20 in the GGNP: superb fairy-wren[#12], striated thornbill[#19], striated pardalote[#18], and grey shrikethrush[#13]. Of note is the presence of the common blackbird in over half of the surveys in the MLR. This species was only recorded at one site (Site 03A1) on the eastern boundary of the GGNP.

Comparison with the avifauna present in the Grampians/Gariwerd National Park in 2009

Vinicombe (2009) recorded a total of 64 bird species during 310 30-min surveys in April to July 2009, a time of the year when species richness in Heathy Woodlands in the GGNP is generally relatively lower. Survey data for two autumn (2020 and 2021) and one winter (2021) surveillance periods from this GGNP study (six 2-ha/20-min surveys at each of 36 sites = total 216 surveys) were combined to assess any changes in avian diversity over the intervening 11+ years. This current study recorded 72 species in these seasons. This higher number is despite having data from only 70% of the surveys across a smaller area (2.00 versus 2.25 ha) for a shorter survey period (20 versus 30 min), suggesting either a higher detection rate or greater species richness and/or abundance across the sites in 2020–21 compared with 2009. Vinicombe (2009) recorded ten species not recorded in the autumn/winter surveys in this study: blue-winged parrot, silvereye, jacky winter, crested shrike-tit, nankeen kestrel, Australian owlet nightjar, noisy miner, painted button-quail, satin flycatcher, and spotted quail-thrush. The first five of these species were recorded in spring surveys in this study, but as with Vinicombe (2009), in low numbers. Detection of the nocturnal Australian owlet nightjar is problematic in diurnal surveys. The noisy miner, painted button-quail and satin flycatcher are species still recorded in the GGNP region. The spotted quail-thrush recorded in 2009 is a rare sighting and, if still present in the GGNP, may be in very low numbers.

A paired samples *t*-test comparing the proportion of sites where each species was recorded, for the 83 species present in both 2009 and this study, found a strong and highly significant positive correlation between the two bird communities ($r = 0.794$, $n = 83$ species, $p < 0.001$***, Figure 5). The null hypothesis that there was no mean difference in the proportion of sites where each species was recorded between 2009 and this study was rejected ($t_{82} = -2.938$, p (2-tailed) $= 0.004$**). On average this study recorded bird species at a significantly greater proportion of sites than in 2009. This finding supports the conclusion that 15 years after the 2006 fires, both bird species richness and abundance appear to be higher in the Heathy Woodlands than in 2009.

While most species were recorded at fewer sites in 2009, there are four relatively common species in this study that were absent from surveys in 2009: Little raven, rufous whistler, yellow-tailed black-cockatoo, and striated fieldwren. Furthermore, seven species that were recorded at 10% or less of sites in 2009 were more relatively widespread in this

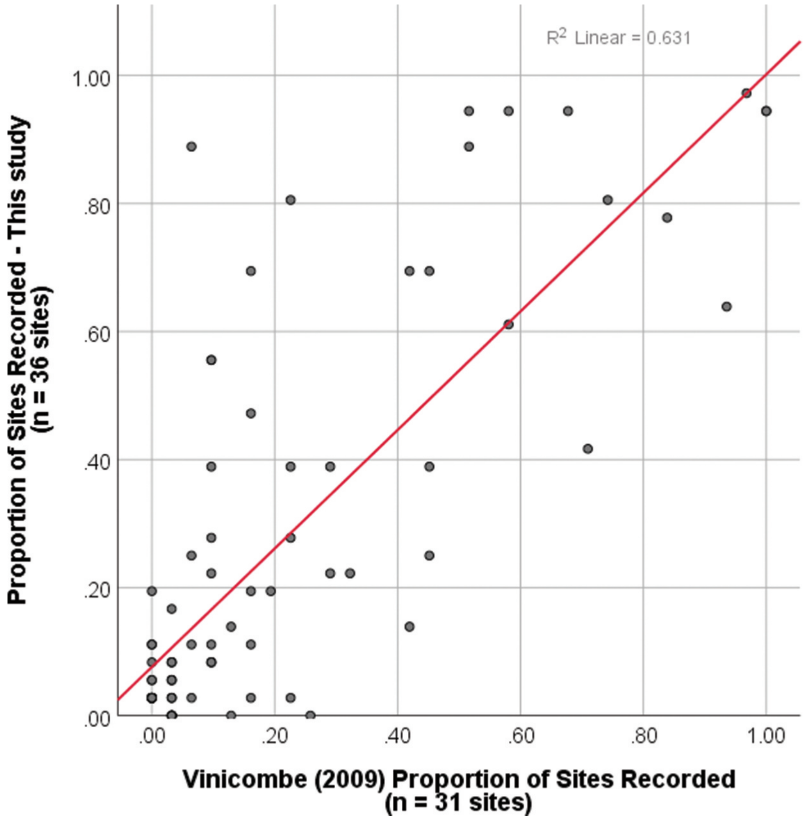

Figure 5. Comparison between Vinicombe (2009) and the present study (autumn and winter surveys only) of the proportion of sites each species is recorded at. Red line indicates line of best fit ($N = 83$ species, $r = 0.794$, $p < 0.001$***).

study. These species are: weebill, spotted pardalote, striated pardalote, grey currawong, laughing kookaburra, pied currawong, and crescent honeyeater.

In 2009, a little over three years after the 2006 wildfires, the unburnt control sites held the highest diversity of both bird species and guilds of bird (Figure 2, Vinicombe, 2009). Ten years later this was no longer the case (see below).

Influence of season on avian diversity and abundance

A two-way repeated measures analysis of variance (RM ANOVA) was used for the major analysis to compare both bird community species richness and abundance between seasons over the six surveillance periods. The total number of species recorded in the two surveys at each site (Species Richness) and the mean number of birds recorded in the two surveys at each site (Bird Abundance) were determined for each of the six surveillance periods: spring 2019, autumn and spring 2020, and autumn winter and spring 2021. Mauchly's test indicated that the assumption of sphericity is valid for Total Species Richness $\chi^2 = 13.01$, $p = 0.527$, but had been violated for Bird Abundance $\chi^2 = 37.60$, $p = 0.001$***, therefore the degrees of freedom were corrected using Greenhouse–Geisser estimates of sphericity ($\varepsilon = 0.714$).

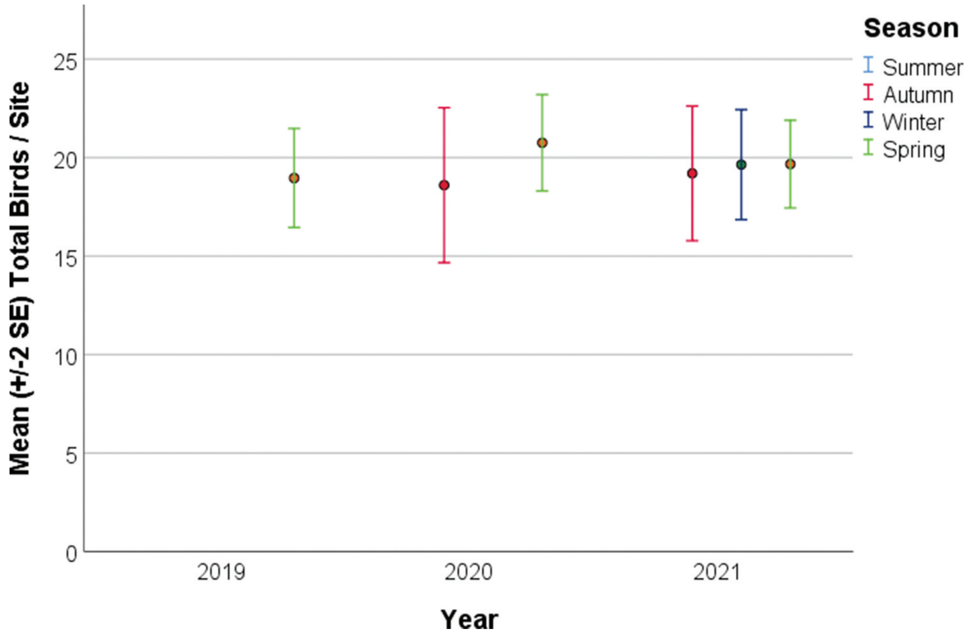

Figure 6. Mean (±2SE) total number of birds recorded in each survey at each site for the six seasons of monitoring.

There was a significant effect of Season on the mean Total Species Richness ($F_{5,175} = 2.431$. $p = 0.037$*) but not on mean Bird Abundance ($F_{3.57,125.02} = 0.315$, $p = 0.847$). Bird Abundance at each site did not change significantly between Seasons (Figure 6). A Tukey LSD *post hoc* pair-wise comparison of mean Total Species Richness among Seasons found no significant differences between the three spring counts (2019, 2020 and 2021), or between the two autumn counts (2020 and 2021). The mean Total Species Richness was significantly higher in spring 2020 than in both autumn 2021 (Mean difference = 2.278 species, se = 0.773, $p = 0.006$**) and winter 2021 (Mean difference = 1.778 species, se = 0.853, $p = 0.044$*). The mean Total Species Richness for spring 2021 is also higher than for autumn 2021 (Mean difference = 2.278 species, se = 0.847, $p = 0.011$*) and winter 2021 (Mean difference = 1.778 species, se = 0.748, $p = 0.023$*). Mean Total Species Richness at sites did not differ significantly between the same seasons among years, but mean Total Species Richness in spring was higher than that recorded in both autumn and winter (Figure 7).

Species recorded changed with season (Table 3). A comparison of seasonal effects on species abundance in each community using the empirical cumulative distribution function (eCDF) (Figure 8) shows a higher evenness in the abundance of species present in the winter avian community than the autumn and spring communities. Within this habitat type, the most abundant species are mostly resident and in numerical terms dominate the avian community throughout the year. For the most abundant 30 species in spring, 25 are also among the most abundant 30 species in autumn and 22 are among the most abundant 30 species in winter. In both autumn and winter, species like the rufous whistler, yellow-tailed black cockatoo, fuscous honeyeater, black-faced cuckoo shrike, and pied currawong are recorded in much lower abundances than in spring. The dusky

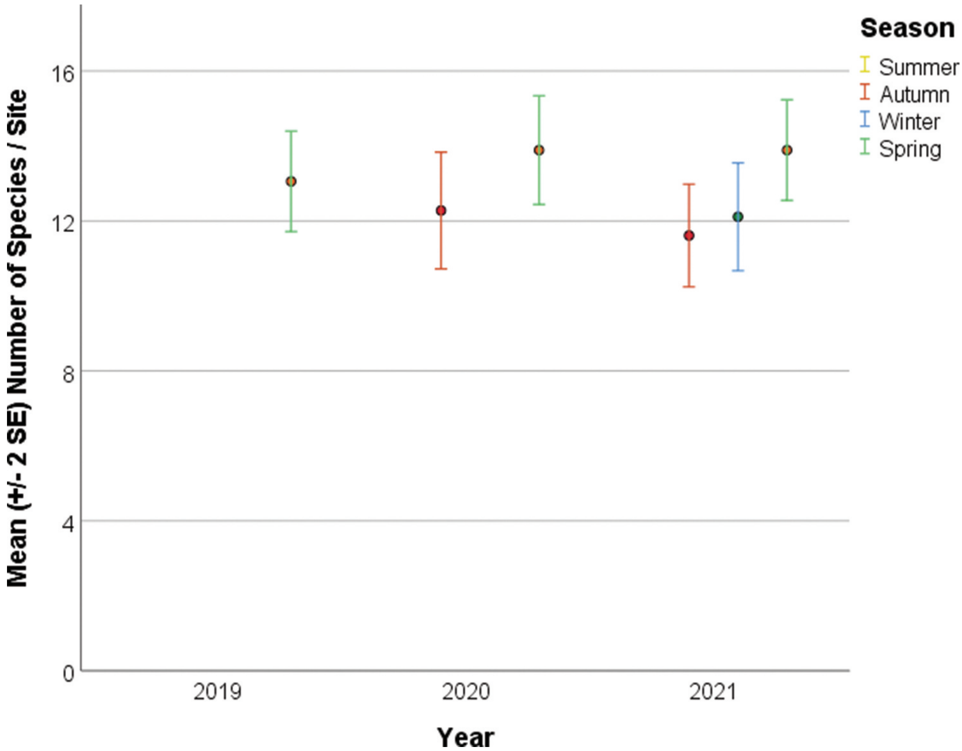

Figure 7. Mean (±2SE) total species richness at each site for the six seasons of monitoring.

woodswallow, eastern yellow robin and grey currawong were also recorded less often in winter. The most abundant 30% of species have similar relative abundances in winter and autumn, but with the higher overall population of birds in spring the relative abundances of this group decline (Figure 9). The middle abundance species (ranked 30% to 60%) are relatively more common in the winter population than the autumn and spring populations.

Of the 90 species recorded across all surveys, 80 species were recorded in spring (Table 3), eight of the ten species not recorded were singletons or doubletons. Tree martins and purple-crowned lorikeets were only recorded during the autumn surveys suggesting this habitat type may be used for foraging after breeding, which for both species is typically finished by January/February (Higgins, 1999; Higgins et al., 2006). Eighteen (69%) of the singleton and doubleton species were recorded in the spring period suggesting higher levels of activity and/or detectability for these rarer species in this habitat (e.g. through increased calling) during this period. Spring is the period when five raptor species were recorded, with only the two accipiters (collared sparrowhawk and brown goshawk) recorded outside this period in autumn. During autumn 64 species were recorded. Fifteen of the 26 species not recorded were singleton and doubleton species. During the autumn period cuckoo species are migrating north and absent from the region, blue-winged parrots also appear to be absent from this habitat type. The red-browed finch, emu and the sacred kingfisher were not detected during autumn and may be foraging in other nearby habitat types. Twenty-one of the 34 species not recorded in

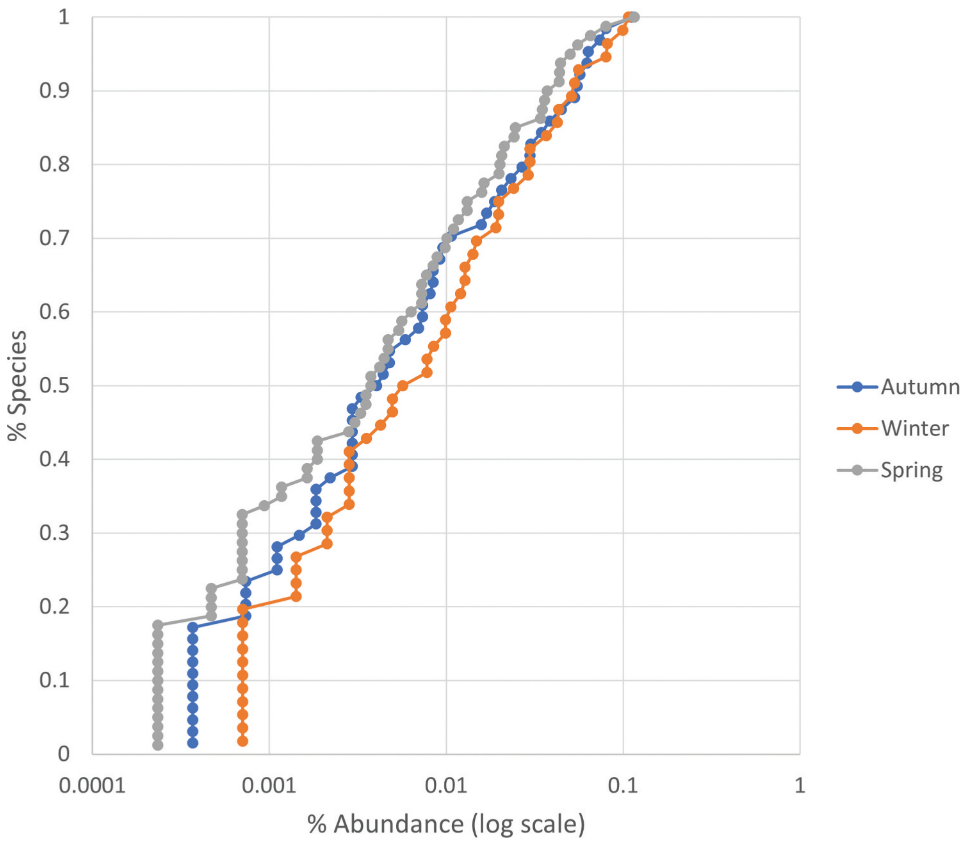

Figure 8. Empirical cumulative distribution function (eCDF) comparison between seasons.

winter were singleton and doubleton species. Of the remaining species, the swamp harrier and white-browed babbler are also in low density in this habitat. Tree martins, purple crowned lorikeets, blue-winged parrots, Horsfield's bronze cuckoo, black-faced cuckoo-shrike, long-billed corella, and yellow-tailed black cockatoo were not detected and may not be present in this habitat in winter, perhaps because of localised or migratory movements. Fifty-six species were recorded during the winter surveys. The little wattlebird and chestnut-rumped heathwren may be difficult to detect at this time of year. The Pacific black duck, white-plumed honeyeater and flame robin were only detected in winter. The flame robin moves to lower altitudes during the winter (March to August (Blakers et al., 1984; Higgins & Peter, 2002; Robinson, 1990)) returning to breed in higher altitudes in spring, and may have been in transition through this mid-altitude habitat when recorded.

Impact of fire history on avian species richness and abundance

To compare avian community species richness at sites burnt in the 2006 wildfire (Wildfire2006, $n = 19$ sites) with species richness at unburnt sites (Unburnt, $n = 17$ sites), total species richness in each survey at each site was aggregated to obtain the

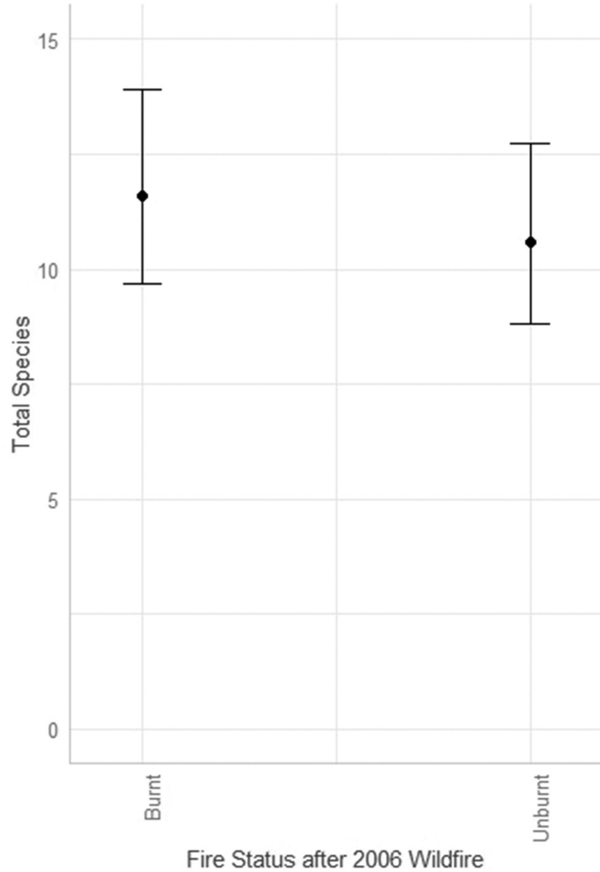

Figure 9. Predicted mean ±95% CI of total species at a site for the burnt and unburnt sites after the 2006 wildfire in the linear mixed model.

total species richness at each site in each season in each year. A Poisson mixed model (estimated using ML and Nelder – Mead optimiser) was fitted to predict Total Species Richness with Wildfire 2006, Season and Survey Year (formula: TotalSpeciesRichness ~ Wildfire2006 + Season + SurveyYear). The model included Site and Fire Proximity as random effects (formula: list (~1 | Site, ~1 | FireProx)). The model's total explanatory power is substantial (conditional $R^2 = 0.31$), and the fixed effects component (marginal R^2) is 0.06. The model's intercept, corresponding to Wildfire 2006 = Burnt, Season = Autumn and Survey Year = 2019, is at 2.45 (95% CI: 2.27, 2.63, $p < 0.001$***). Ninety-five percent Confidence Intervals (CIs) and p-values were computed using the Wald approximation. Within this model: the effect of Wildfire2006 is statistically non-significant and negative ($\beta = -0.09$, 95% CI: −0.28, 0.10, $p = 0.350$; Std. $\beta = -0.09$, 95% CI: −0.28, 0.10) and mean species richness is not significantly lower in the unburnt sites than in the burnt sites (Figure 9). As previously determined, the effect of Season [Spring] is statistically significant and positive ($\beta = 0.15$, 95% CI: 0.06, 0.24, $p = 0.001$***; Std. $\beta = 0.15$, 95% CI: 0.06, 0.24). All other effects are statistically non-significant.

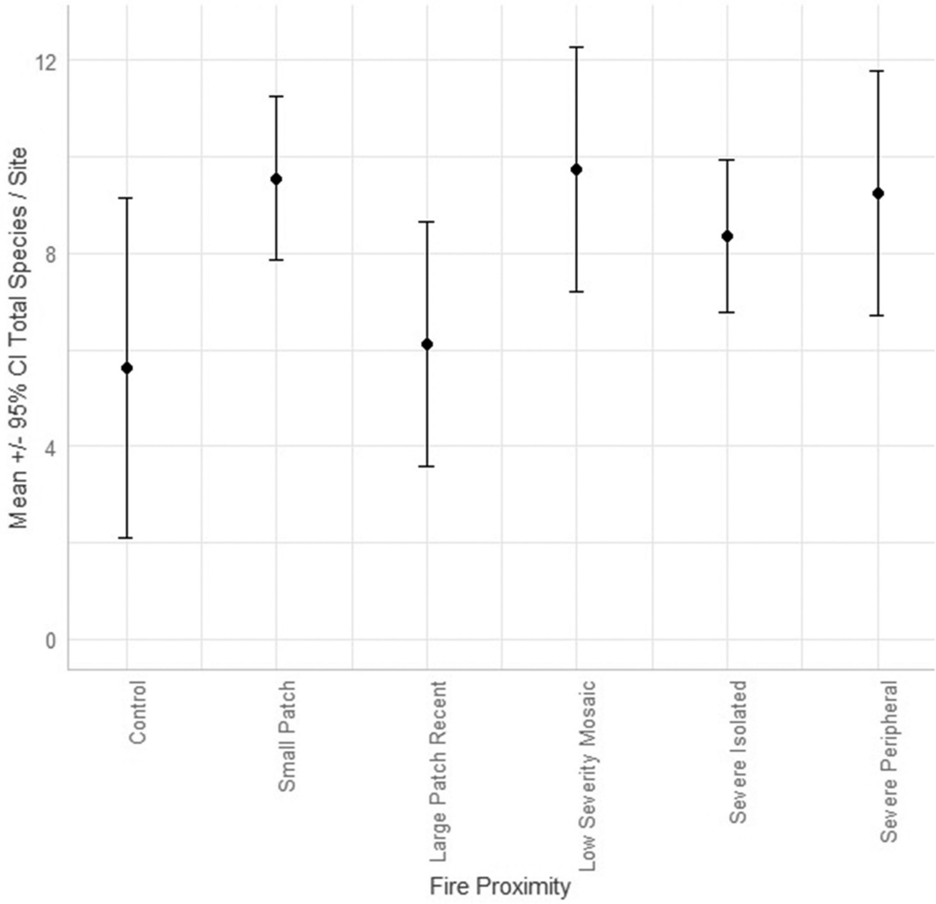

Figure 10. Predicted mean ±95% CI of total species at a site for each of the fire Proximity categories in the linear mixed model.

Because fires at 19 sites (Table 1, grey highlight) after the 2006 Wildfire have confounded analysis of the impact of fires on bird species richness at these sites, a linear mixed model (estimated using REML and nloptwrap optimiser) was fitted to predict Total Species Richness with Fire Proximity and Season for the remaining 17 sites only. The number of bird species in each survey at each site was aggregated to obtain the Total Species Richness at each site in each season in each year. Data were normally distributed. The model included Site and Survey as random effects (formula: lmer (TotalSpeciesRichness ~ FireProx + (1|Site) + (1|Survey + Season), data = df)). The model's total explanatory power is substantial (conditional R^2 = 0.28), and the fixed effects component (marginal R^2) is 0.13. The model's intercept, corresponding to FireProx = Control and Season = Autumn is at 5.62 (95% CI: 2.09, 9.15, $t_{205} = 3.12$, $p = 0.002$**). Ninety-five percent CIs and p-values were computed using the Wald approximation. Within this model, the effect of FireProx [Small Patch] is statistically significant and positive ($\beta = 3.93$, 95% CI: 0.14, 7.72, $t_{205} = 2.03$, $p = 0.042$*; Std. $\beta = 1.03$, 95% CI: 0.04, 2.02). The effect of both FireProx [Low

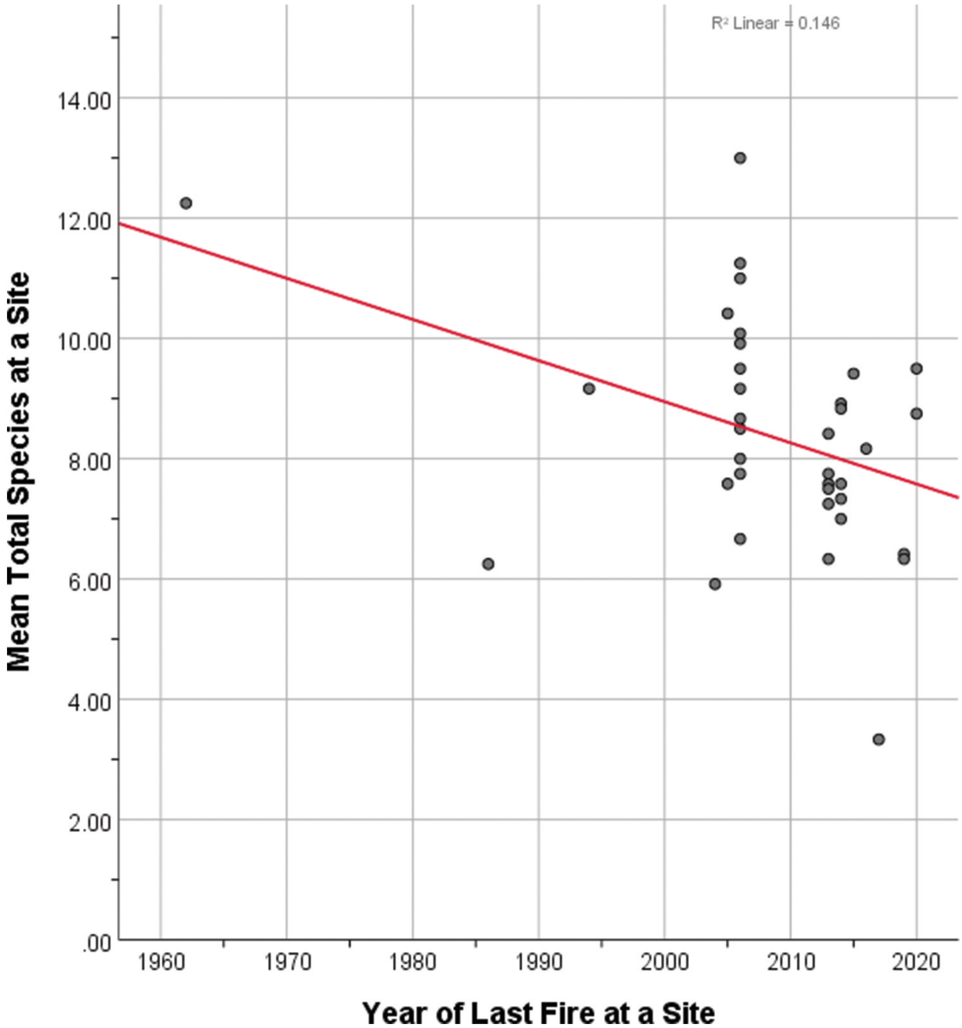

Figure 11. Impact of time since fire on mean species richness at each site.

Severity Mosaic] (β = 4.12, 95% CI: −0.11, 8.36, t_{205} = 1.91, p = 0.056; Std. β = 1.08, 95% CI: −0.03, 2.19) and FireProx [Severe Peripheral] (β = 3.62, 95% CI: −0.61, 7.86, t_{206} = 1.68, p = 0.094; Std. β = 0.95, 95% CI: −0.16, 2.06) show a strong but not-significant positive trend. Again, the effect of Season [Spring] is statistically significant and positive (β = 1.31, 95% CI: 0.26, 2.36, t_{205} = 2.44, p = 0.015*; Std. β = 0.34, 95% CI: 0.07, 0.62). All other effects are non-significant: FireProx [Mosaic d] (β = 2.74, 95% CI: −1.00, 6.47, t_{205} = 1.44, p = 0.151; Std. beta = 0.72, 95% CI: −0.26, 1.69); FireProx [Large Patch Recent] (β = 0.50, 95% CI: −3.74, 4.74, t_{205} = 0.23, p = 0.817; Std. β = 0.13, 95% CI: −0.98, 1.24).

The three unburnt sampling categories differed in mean species richness 13+ years after the 2006 wildfires. Mean total species richness within each season at the only Control site left unburnt since 2006 (Site 07A1) and at the two unburnt Large Patch recent Control Burn sites (09A1 and 12A1) was significantly lower than that recorded at the five Small Patches of unburnt vegetation (sites 14A1, 16A1, 36A1, 37A1 and 38A1) within the 2006 wildfire perimeter (Figure 10). Given the weak non-significant trend for higher mean species richness in the burnt sites and the markedly higher mean species richness in the small patches of unburnt vegetation within the 2006 wildfire perimeter a more diverse bird community may result where a mosaic burn of the stringybark woodland is achieved.

Pearson product moment correlation coefficient and linear regression were used to assess the impact of years since last fire on species richness and bird abundance at each site. The mean of total species richness in each survey at each site and the mean of total abundance of birds in each survey at each site were calculated. Species richness at each site approached normality, and species abundance was slightly positively skewed. There was a significant ($F_{1,34} = 5.827$, $p = 0.021^*$) weak negative correlation ($r = 0.383$, $r^2 = 0.146$) between the year of the last fire at a site and the mean total species richness recorded at that site (Mean Total Species Richness = −0.068 (±0.028 se) Year of Fire + 145.75 (±56.9 se)) (Figure 11). There was also a significant ($F_{1,34} = 6.856$, $p = 0.013^*$) weak negative correlation ($r = 0.410$, $r^2 = 0.168$) between the year of the last fire at a site and the mean total abundance of birds recorded at that site (Mean Total Bird Abundance = −0.267 (±0.102 se) Year of Fire + 555.7 (±204 se)) (Figure 12). Both mean bird species richness and mean abundance at a site tended to decrease as the time since the last fire decreased. The Heathy Woodland long unburnt sites tended to support both relatively higher species richness and bird abundance on average in comparison with recently burnt sites.

Foraging guilds

Within the Heathy Woodland habitat, the foliage searcher guild (six honeyeater species, three thornbill species, weebills and two pardalote species) was the most diverse and abundant foraging guild at each site (Figure 13), with a mean of nearly eight species per site. Bark probers, granivores, nectarivores, pouncers and wood searchers averaged between three and four species at each site, but of these guilds the nectarivores (six honeyeater species and lorikeets) were the most abundant. The other three guilds, together with the less diverse bush and ground carnivores and hawkers, typically average between one and two birds per survey at each site. The last four guilds (carnivores, frugivores, ground omnivores and sweepers) are generally widespread, but low in both diversity and numbers at each site.

When the diversity of species in each guild within each survey is aggregated across each site, the number of species within each guild at each site is remarkably similar over the six seasons of survey (Figure 14). A notable exception is site 30A1. Unlike the other sites, 30A1 consists of EVC 6 Sand Heathland lacking tall trees. In this habitat, both bird species richness and abundance are limited. The absence of those species reliant upon the canopy, limbs, and bark substrates of the trees, emphasises the importance of the trees for many of the guilds present in stringybark woodlands. The overall abundance of birds recorded in each guild at sites varied by up to nearly a factor of four between sites like 01A1, 07A1, 09A1, 11A1 (and 30A1) with low abundances and relatively high abundances at sites like 15A1, 35A1, 37A1 and 38A1. Sites 35A1, 37A1, and 38A1 all lie in the centre of the GGNP, south of the Moora Moora Reservoir and in the centre of both the

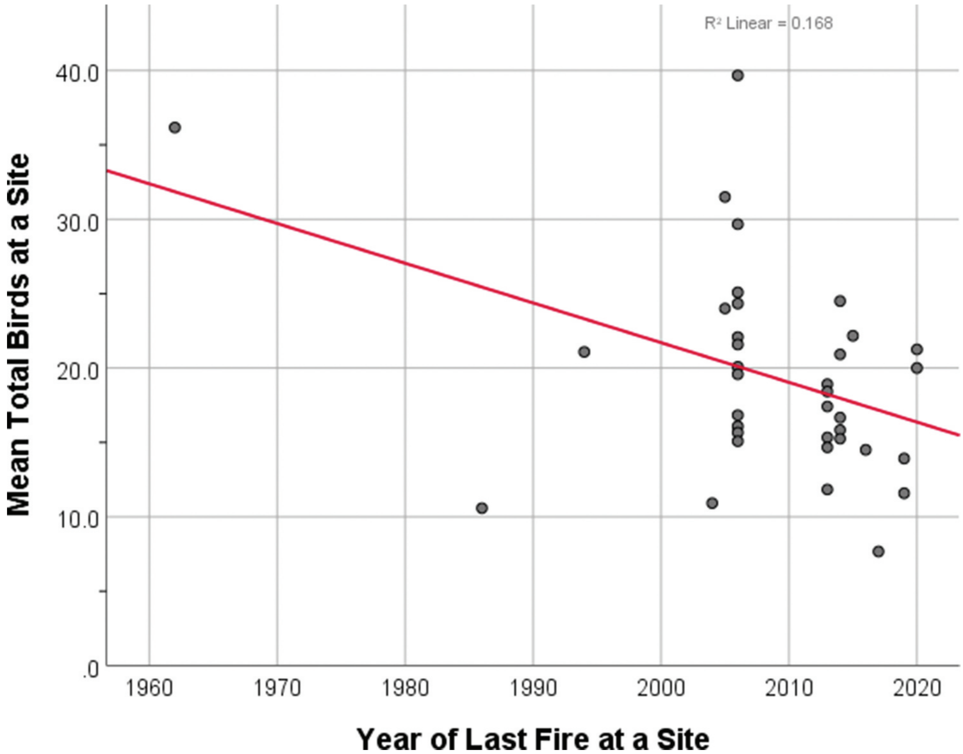

Figure 12. Impact of time since fire on mean bird abundance at each site.

fox baiting and cat baiting zones and are relatively long unburnt having last experienced a wildfire in 2006, 2005 and 1962, respectively. Sites 37A1 and 38A1 are within small unburnt patches situated within the 2006 wildfire scar. Site 15A1 is a relatively dense and tall component of stringybark forest in a higher rainfall area to the west of Seven Dials Range that last experienced a wildfire as a low severity mosaic burn in 2006. It lies in the fox baiting zone but outside the cat baiting zone. There is no apparent pattern associated with the sites with relatively low bird abundances. Sites 01A1, 07A1, 09A1 and 11A1 are dispersed widely across the park, lie outside the cat baiting zone, and were last burnt in 2019, 1986, 2004 and 2013, respectively.

When the overall species composition of each guild at each site is examined, it is apparent that while the number of species recorded in each guild at each site is relatively similar, the species composition of those guilds varies between sites (Figure 15). This relates to both spatial and temporal patterns of dispersal, clumping in flocks at specific sites and seasonal movement into and out of Heathy Woodlands. Guilds like the bark probers, bush carnivores, foliage searchers, nectarivores, pouncers, and wood searchers average at each site between just under 40% and just over 50% of the full complement of species in that guild across the Heathy Woodlands. The white-throated treecreeper was recorded at 34 of 35 treed sites and the grey shrike thrush at 32 of the 35 treed sites. The grey currawong and pied currawong at 28 and 21 of the 35 treed sites, respectively. The varied sitella was much patchier in distribution being recorded at only six sites.

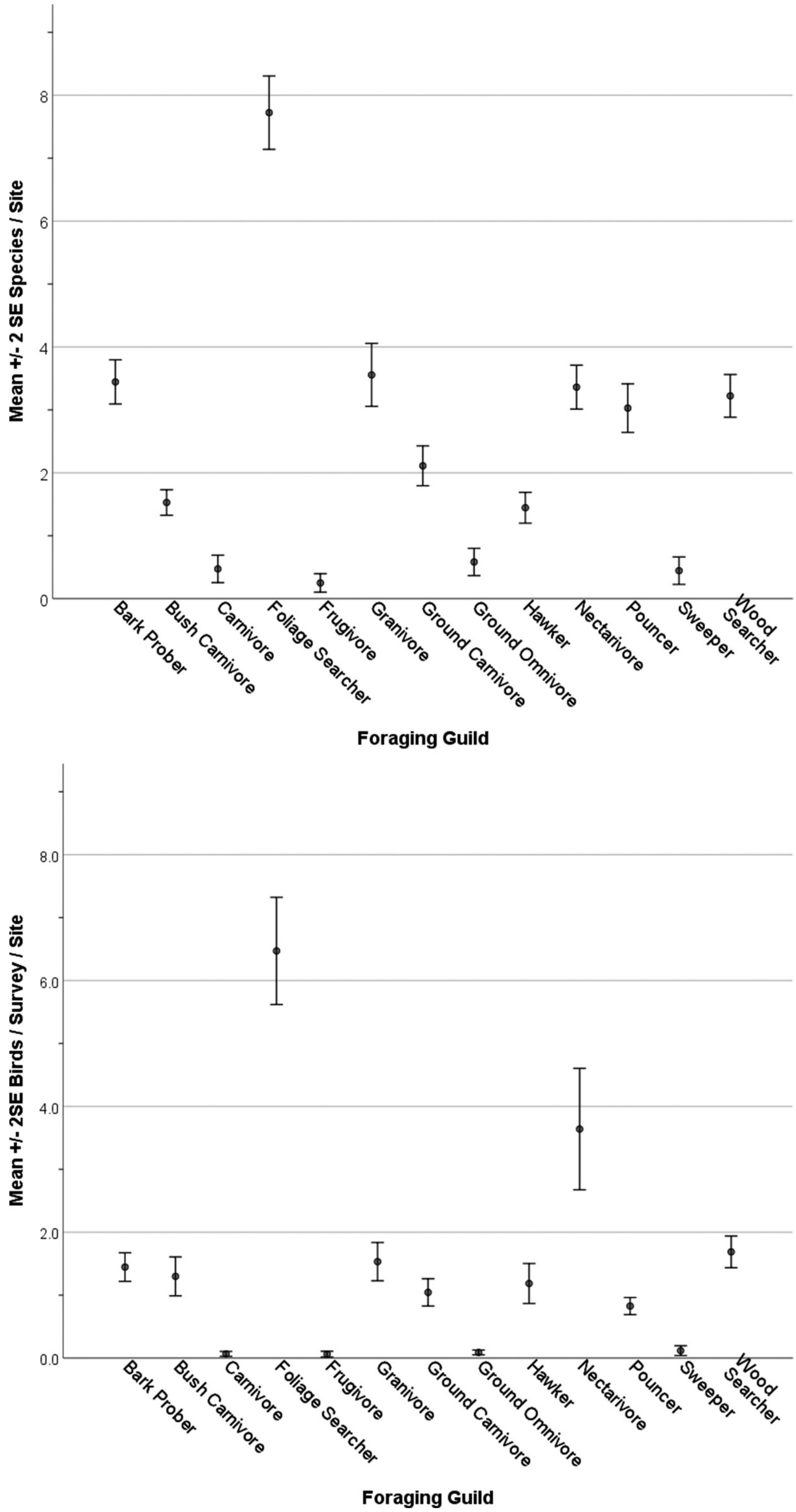

Figure 13. Mean (±2 se), **Top**, bird species richness in each foraging guild at each site and **Bottom**, bird abundance (birds/2-ha) in each foraging guild in each 2-ha/20-min survey.

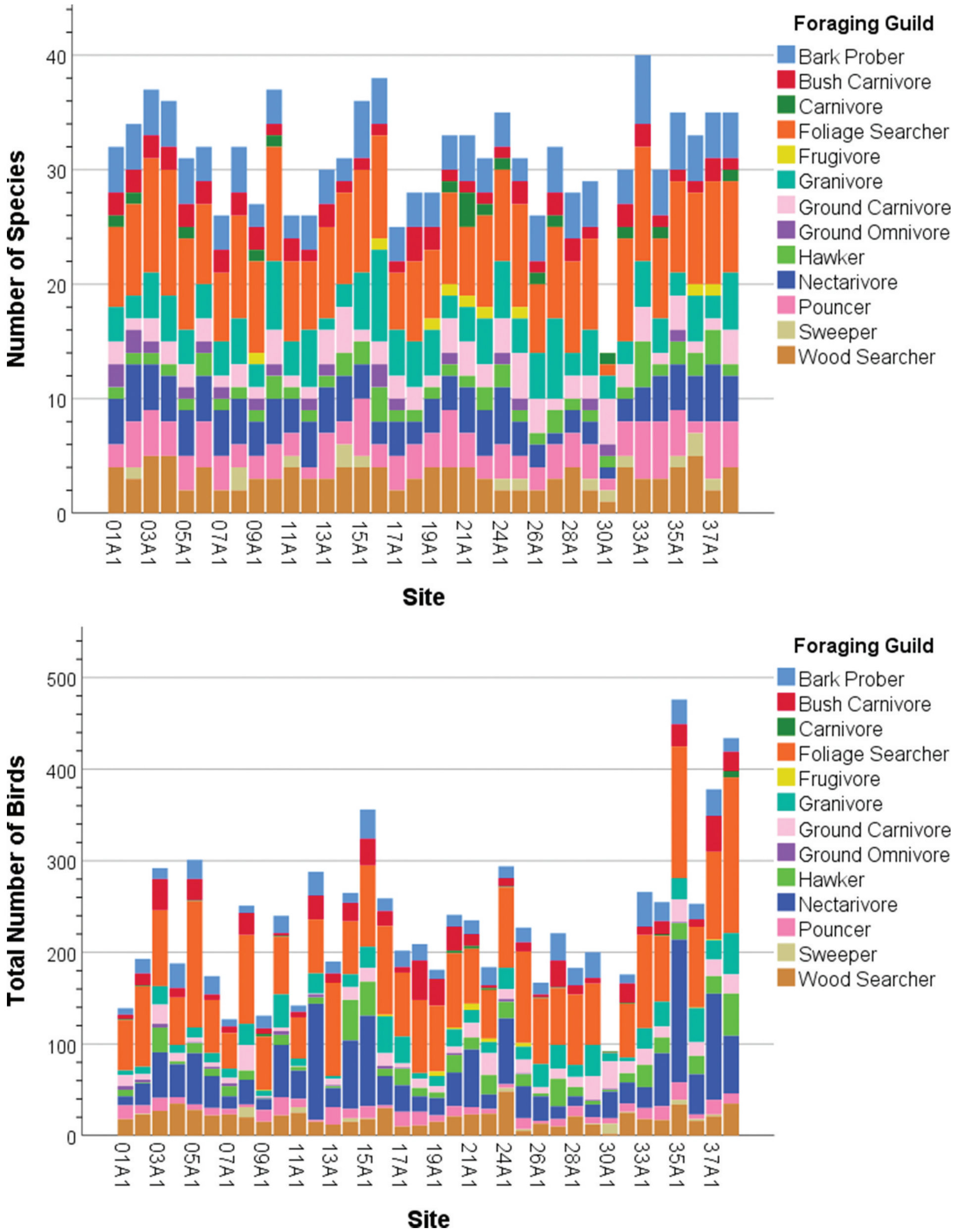

Figure 14. Total number of (**Top**) bird species and (**Bottom**) birds recorded in each foraging guild at each site aggregated for all 12 2-ha/20-min surveys combined.

The remaining guilds (except for the carnivores) average between 16% and 25% of the possible full complement of species in the guild at a site. The grey fantail was recorded at all sites. Together with the dusky woodswallow (15 sites) these two species are the predominant hawker species in the Heathy Woodland. Jacky winter and restless flycatchers were found at two sites and the willie wagtail at one, representing infrequent visitors to, or low-density residents in, the Heathy Woodland. Given the low trophic level of

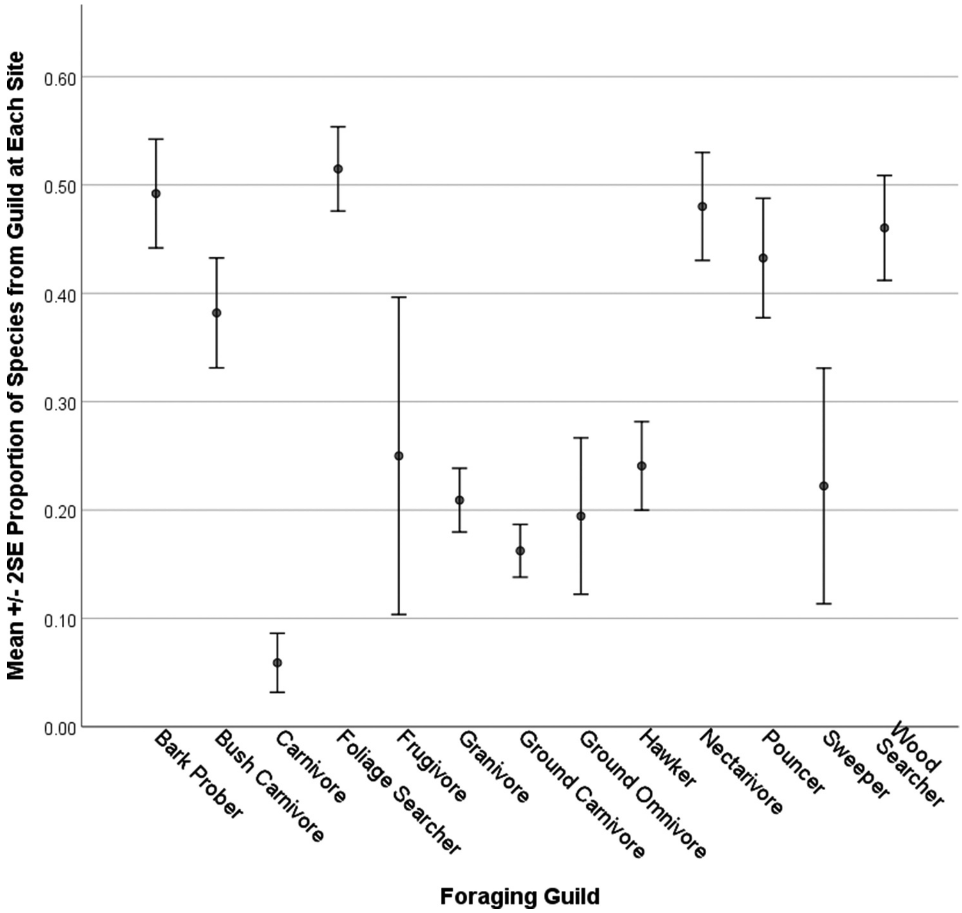

Figure 15. Proportion of the total number of species in each foraging guild recorded at each site aggregated for all 12 2-ha/20-min surveys at a site.

species in the diverse granivore foraging guild, the low species diversity (only 20% of the possible species recorded on average at each site), and those typically in low abundance, is unexpected. The predominantly arboreal gang gang cockatoos and crimson rosellas were recorded at most sites and in relatively high abundance. The remaining guild members are terrestrial and their presence in very low numbers at only a few sites suggests either that Heathy Woodlands provide little foraging resource or alternatively that there are other factors limiting their numbers. The low numbers of quail and bronzewing correspond with the low numbers of birds in many ground dwelling guilds. The mistletoe bird is the only frugivore present in the Heathy Woodlands. It was recorded at only seven sites in relatively low abundance. The diverse carnivore group is composed of species that occur at relatively low densities across the landscape, a product of their high trophic level.

Discussion

This bird monitoring program provided information to assess avian community response to a range of identified environmental pressures threatening the widespread Heathy Woodland habitat within the GGNP and to guide associated park management actions designed to ameliorate these threats.

A diverse range of bird species use the GGNP Heathy Woodland habitat. There have been 203 bird species recorded in the GGNP, 52 of which are wetland-dependent species (Victoria, 2014). The diversity of birds recorded in the stringybark woodlands (EVC 48 Heathy Woodlands) in the GGNP in this study represent 59% of the remaining 151 species recorded. Given the large area of Heathy Woodland in the GGNP, this habitat is demonstrated to be a significant component for the avifauna of the park. Eight introduced bird species have been recorded in the GGNP, but only one of these (common blackbird) was recorded within the Heathy Woodland community and then at only one site.

During these surveys, around a quarter of the bird species were only rarely encountered. Rarity in species is the state of having a low abundance and/or a small range size (Gaston, 1994). In this study, with its focus on the avian community within Heathy Woodland, the concept of rarity relates only to frequency of occurrence within the stringybark woodland and not the wider distribution (range) of the species. Here, rare species are defined as species recorded only once or twice (singleton or doubleton species, respectively) in the 432 surveys across 36 sites. Of the 90 species recorded, 26 were rare in this habitat type. This number is just above the suggested cut-off point at the first quartile in terms of proportion of species (Gaston, 1994). One record in 432 2-ha surveys has a density estimate around one bird detected/8.6 km^2 of Heathy Woodland surveyed for the species. Five of the rare species are widespread raptors typically in lower densities over multiple habitat types. The southern boobook is likely to be in higher densities, but the survey method used here is inappropriate to maximise detectability of this nocturnal species. The Pacific black duck is unlikely to be using this habitat *per se*, perhaps simply moving out of a nearby habitat. Of the remaining 19 species, seven are migratory or partly migratory (flame robin, pallid cuckoo, white-winged triller, rufous songlark, restless flycatcher, white-throated gerygone (Higgins, 1999; Higgins & Peter, 2002; Higgins et al., 2006)) or rarely recorded (red-chested button quail (Marchant & Higgins, 1993)), four are ground foragers (white-winged chough, diamond firetail, Bassian thrush and brush bronzewing (MacNally, 1994)) that are in very low densities in this habitat, and six species (white-plumed honeyeater, willie wagtail, silvereye, brown treecreeper, crested shriketit, jacky winter) are widespread insectivores that are uncommon in this habitat type. The little corella is rarely recorded in the GGNP. The musk lorikeet is generally widespread across the GGNP but appears to not favour the stringybark woodland habitat type, a behaviour also noted in brown stringybark (*E. baxteri*) on the Fleurieu Peninsula in SA (Paton et al., 1994). None of the species recorded in these surveys are endemic to the GGNP, nor do any of the species merit a significant conservation status.

The avian species composition across two disjunct population of stringybark woodland are remarkably consistent. The species richness in the GGNP Heathy Woodland habitat is slightly higher in comparison to that recorded in similar habitat in the MLR (Possingham et al., 2004). Apart from a few species with range limits, bird community composition is similar between the stringybark woodland habitat in the MLR and that in the GGNP. Most of the common species are common at both localities, with local variations like the higher densities of the spotted pardalote, rufous whistler, and tawny-crowned honeyeater in the GGNP and the striated thornbill, common blackbird, striated pardalote, crescent honeyeater, and silvereye in the MLR. The absence of the weebill from the MLR records in the same habitat as it is recorded in the GGNP is noteworthy. Weebills are noted as largely absent from the Fleurieu Peninsula in South Australia and the Western District of Victoria, except for the southern parts of Millicent Plain and in The Grampians (Higgins & Peter, 2002).

The threats to the stringybark woodland in the GGNP provide an interesting comparison with the stringybark woodland community in the MLR which is undergoing widespread but patchy stand collapse due to a combination of summer water stress, *Phytophthora*, borer infestation and fire impacts (Guerin et al., 2023). The essential similarity of the avian communities in these widely separated stringybark woodlands suggests habitat structure within stringybark woodland, independent of the integrity of the mosaic, may be one of the key drivers of avian community composition for this woodland habitat. Given this, the impact of canopy dieback and the high rate of tree mortality, particularly for the messmate stringybark, there is a need for further research to determine any impact on the avian community. Indeed, a long-term study of birds in MLR stringybark woodlands shows that 58% of 65 species studied exhibited a significant decline in relative abundance (Prowse et al., 2021). Understanding the role of climate change amongst other factors in the potential for major ecosystem disturbance in the stringybark woodlands will have implications for management not just in the MLR, but also in the GGNP.

The response of the avian community to fire regimes in the GGNP Heathy Woodlands is complex. Longer unburnt sites and areas with patchy mosaics of burnt/unburnt areas appear to have maintained a higher diversity of birds. The lower diversity of birds recorded at the GGNP monitored sites in 2009 compared with this study suggests that bird communities, 3 years after the 2006 fire, were still recovering/re-establishing as the Heathy Woodland plant community regenerated. Vinicombe (2009) did not report on bird abundance in his study making direct comparisons between the bird community in 2009 and in this study less informative. Where authors have been able to collect data on bird community diversity and abundance before and after fire in eucalypt forests and woodlands the responses have been mixed with some studies recording increased diversity and abundance in the first few years post fire (Christensen & Kimber, 1975; Christensen et al., 1985), others recording lower abundance (Smith, 1985) or both lower diversity and abundance (Recher et al., 1985). Kelly et al. (2017) found inter-fire interval was the most influential component of the fire regime on species occurrence. In an extensive review and metanalysis, Gibson et al. (2021) found that bird species richness and abundance increased significantly with time since fire. When comparing burnt and unburnt sites, they found species response to fire was significantly influenced by fire type. Wildfire had consistently negative effects on bird species richness and abundance, whereas prescribed fire had no effect on species richness and mixed effects on bird abundance. In the stringybark woodland habitat in the GGNP, both species diversity and species abundance increased with time since fire.

Importantly, with respect to the 2006 wildfire, sites located in small unburnt patches within the 2006 wildfire perimeter showed the highest mean bird species richness when compared with all other burnt and control sites, suggesting that mosaic burns may play an important role in maintaining avian diversity in this habitat type. The data on diversity and abundance of birds in the stringybark woodland habitat supports the current Parks Victoria plan (Parks Victoria, 2019) to manage fire in the GGNP landscape to decrease the likelihood of the intensity and extent of fires that have occurred over the last 15 years and increasing the diversity of burn histories in fire-dependent ecosystems like the Heathy Woodland (stringybark woodland). The current practice of colder burns in winter increases the likelihood of a mosaic burn outcome with potential benefits for associated bird community diversity and abundance.

The GGNP Heathy Woodland community supports an avian community of 13 foraging guilds. These guilds vary in diversity and importance within the stringybark community. The foliage searcher guild is the most diverse and abundant foraging guild. The next tier of guilds in diversity and abundance are the bark probers, granivores, nectarivores, pouncers and wood searchers. The nectarivores are the most abundant guild among these. These two guilds together with the wood searcher guild make honeyeaters (Family Meliphagidae) a characteristic and important component of the avifauna in the stringybark woodland community. The diversity of species within each guild over the duration of the study is remarkably consistent between sites, but the composition of bird species within each guild varies among sites. The importance of bark, twigs and canopy as substrate for many of the most diverse and abundant guilds (bark probers, wood searchers and foliage searchers) in the stringybark woodlands reiterates that observed in other Eucalypt communities (Recher et al., 1985). Ground-foraging birds of temperate woodlands of southern Australia are prominent among bird species considered to be susceptible to and undergoing population decline (Recher, 1999). In the context of the only fair and declining condition of Heathy Woodland habitat recorded in the GGNP, the current low abundance and diversity of terrestrial members of the granivore guild in particular warrants further investigation. Graminoid plants constitute a significant component (30%) of the Heathy Woodland EVC understorey (DSE, 2004) suggesting that the granivore guild could have historically be present in higher abundance than currently recorded within the Heathy Woodland. Antos and Bennett (2006) found no significant differences were evident in the foraging ecologies of common and declining ground feeding woodland birds in woodland sites in northern Victoria. With species in this group having a broad range in foraging ecology, they concluded that the conservation of diverse assemblages of ground-foraging birds requires the maintenance of heterogeneous ground layers and careful management of disturbance processes.

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Data availability statement

Data are available https://doi.org/10.25451/flinders.24248698

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