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# Response of Australia's woodland bird community to fire: a review and meta-analysis

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Main cover image: Regent honeyeater with a juvenile. Image: Mick Roderick

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## **Executive summary**

Better fire management is critical to prevent catastrophic loss of native ecosystems and for ecosystem maintenance into the future. Managing fire to benefit biodiversity requires understanding of post-fire responses of ecological communities. Australian woodland-dependent birds have lost an estimated 70% of their historic habitat to agricultural production and the Australian mega-fires of 2019-2020 burnt 12.6 million hectares of primarily forest and woodland. To understand woodland bird response to fire, we screened primary literature, conducted a meta-analysis to synthesize changes in bird species richness and abundance with time since fire, and compared differences in these metrics between burnt and unburnt sites using a vote counting approach. We identified and reviewed 75 relevant articles, only 24 of which were useful for our analyses. We found that bird species richness and abundance increased significantly with time since fire. When comparing burnt and unburnt sites, we 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. Our synthesis revealed clear patterns of post-fire response for forest and woodland bird richness and abundance and underscores the need to incorporate long post-fire recovery periods into fire mosaic planning.



Speckled warbler. Image: John Barkla

## Introduction

Forest fires are becoming more frequent and more intense as the planet warms and dries (MacKenzie et al. 2004). Fires can be catastrophic events that negatively impact species and habitats, or, when carefully managed, can prevent catastrophic events and help maintain ecosystems (Lindenmayer et al. 2010). To use fire as an effective conservation tool, we must better understand its impacts on all aspects of ecological communities (Clarke 2008).

Managing fire to benefit biodiversity requires understanding of post-fire responses of ecological communities (e.g., Sitters et al. 2014; Swan et al. 2015). Species' responses to fire vary among taxa and habitat, and even how the response is measured (Kelly et al. 2017; Sitters et al. 2016; Swan et al., 2015; Tingley et al. 2016). To understand overall effects of fire on an ecological community, multiple species' responses should ideally be measured over multiple time periods to gauge short- versus long-term responses.

Many Australian woodlands and forest habitats evolved with fire (Gill 1975), but fire frequency and intensity are increasing with hotter and drier conditions (Cary 2002; Abatzolgou & Williams 2016). Woodland and forest habitats were adversely impacted by the Australian mega-fires of 2019-2020 (Boer et al. 2020), which burnt 12.6 million hectares of primarily forest and woodland (Wintle et al. 2020) and killed an estimated three billion native vertebrates (van Eeden et al. 2020). In the temperate zone, woodlands are particularly at risk as nearly 70% of the pre-European extent has been cleared (Ford et al. 2001). Australian woodland birds form a distinct functional assemblage and have been nominated as a threatened ecological community under the Australian Environment Protection and Biodiversity Conservation Act, as many species are in decline (Fraser et al. 2019). Understanding how the woodland birds that make up this ecological community respond to fire should therefore be a priority in order to understand how fire management or protection might affect them.

There have been many studies investigating the impact of fire on birds of Australian woodlands and forests over time (Hobbs 2002; Sitters et al. 2016). However, most look at the impact of individual fire events (Barton et al. 2014; Lindenmayer et al. 2014; Loyn 1997) or fire history within a particular region (Davis et al. 2016; Gosper et al. 2019; Prowse et al. 2017). Synthesizing this research presents many challenges because fires vary in cause, severity, environmental context and time scales, as do the methodological approaches used to record ecological responses. Here, we examine whether it is possible to extract broad generalities from this diverse literature, by focusing on the effects of fire (wildfire and prescribed) on Australian woodland and forest bird species richness and abundance. To do this, we compiled and synthesized data extracted from peer-reviewed literature on bird response to fire over both short and long timescales, and asked the following questions:

- 1. How do Australian woodland and forest bird species richness and abundance change with time since fire?
- 2. How do bird species richness and abundance differ between recently burnt vs unburnt sites?

## Methods

We searched for peer-reviewed articles examining Australian woodland and forest bird response to fire. To address our first question, we extracted data from eligible articles that reported the effect of time since fire (hereafter 'TSF') on bird species richness and abundance. To address our second question, we extracted data from eligible articles comparing bird species richness and abundance at recently-burnt (less than three years since fire) and unburnt (more than eight years since fire) sites.

#### Literature search and screening

We followed the systematic review process outlined by the Collaboration for Environmental Evidence guidelines (Pullin et al. 2018): literature search; title/abstract screening for eligibility; data extraction; and analysis. Using relevant search strings (Appendix S1), we searched for primary literature for years 1900-2021 using Web of Science, and Scopus on 9 March 2021 for all date ranges. We only included articles written in English. The searching and title/abstract screening process involved a team of nine researchers, and the full-text screening and synthesis processes were performed by one of the authors (MG).

We found 312 unique primary research articles on Australian woodland and forest birds at the initial searching stage (Fig. 1). We found an additional four references that were cited in the primary literature (two dissertations and two reports). Of these, we identified 75 unique references (hereafter 'articles') that involved fire following the title/ abstract screening stage of the broader review (Fig. 1). One of the authors (MG) screened each article at the full text screening stage and selected articles that met all four of the following inclusion criteria:

- Population: The focal population included bird species from within Australia's sub-tropical and temperate woodland regions, which are nominated as a threatened ecological community and identified in Fraser et al. 2019 (species list- Table S1; map- Fig. 2). Some woodland bird species occur more broadly than woodland vegetation. In the interest of understanding impacts to this threatened group of species, we expanded our search to include fires across woodland, dry or damp sclerophyll, and open eucalypt forest.
- 2. Treatment: The study involved fire as a treatment within the study design, either wildfire or prescribed burns. We considered prescribed burns to be synonymous with 'planned' and 'controlled' burns. All burnt and unburnt sites were verified either from fire records and/or ground truthing by authors of each study. All sites considered for our first research question were known to be burnt at some time in the compiled fire history for each site; for our second research question, 'recently burnt' sites were those surveyed within three years of fire and 'unburnt' sites were those surveyed at least eight years since fire.
- 3. Comparator: The study had either an experimental design that included a comparator (included control-impact, before-after, before-after-control-impact), or was a time series or space-for-time substitution study if measuring effect of time since fire.
- 4. Outcome: The study measured total abundance and/or species richness in response to fire of all birds or any bird population or community group (e.g., woodland birds, feeding or foraging guild) as defined by the aforementioned species list and map.





Figure 1. Flow chart of all articles included at the searching, screening, and synthesis stages of this review. See Appendix S2 for full list of articles included in analyses.



**Figure 2.** Location of studies included in our analyses within Australia's sub-tropical and temperate woodland bioregions (following Fraser et al. 2019). Symbols indicate fire type and coloured regions represent habitat type (National Vegetation Information System (NVIS), version 6.0 major vegetation groups). Inset map shows the southeastern corner of Australia.

We found 35 articles during the full text screening stage that met all four inclusion criteria (Fig. 1).

#### **Data extraction**

We identified 31 articles suitable for data extraction that addressed at least one of our two research questions (Fig. 1). We extracted data on the study design, region, vegetation type, fire type, years when fire occurred, TSF, bird response variable (species richness, abundance), and survey method for each article. Individual articles were subdivided into 'records' based on the number of unique response variables (i.e., species richness and abundance), fire treatments (e.g., high and low severity fire), habitat types (e.g., woodland, forest), and/or species guilds (e.g., insectivores, nectarivores). If individual records from the same article contained overlapping sites (e.g., sites with all fire types vs sites with prescribed burns) or species (e.g., abundance of all species and abundance of nectarivores), we chose the record that was more inclusive and representative of other studies (e.g., all species vs a specific guild) to avoid pseudoreplication. Sometimes, different articles reported results from the same study, which we identified based on the similarity of authors, overlapping survey sites, years, and study design but tested different fire treatments (e.g., dry vs wet season burn); this was the case for Lindenmayer et al. 2014 and Lindenmayer et al. 2018, and for Valentine et al. 2007 and Valentine et al. 2012 (Appendix S2; Table S2). In such cases, and where the data appeared to overlap between the two studies, we retained only the record that contained more datapoints.

For each record, we extracted a time since fire value from the corresponding article as stated in the text. Where TSF was not explicitly stated but a minimum time since fire was given, we used this minimum as a conservative estimate of the number of years since a fire occurred at any given site. Where TSF was unknown (Loyn 1997 and Loyn & McNabb 2015; Appendix S2; Table S2), we used the minimum tolerable fire interval for comparable habitat types (from Cheal 2010) as a surrogate. Minimum tolerable fire intervals are determined by the time taken by native plant species to reproduce (Cheal 2010). If TSF was reported in a paper as a range, we took the minimum. For example, if a site was burnt 'at least 30 years ago', we set TSF at 30 years. If TSF was reported as less than X number of years, we used the preceding year as the TSF. For example, if TSF was reported as '< 3 years', we set TSF as 2 years.

To address our first research question, data were extracted such that each datapoint (i.e., row within the dataframe) contained a TSF value and a species richness or abundance (outcome) value (Fig. 1). To address our second research question, data were extracted such that each datapoint (row) contained information about both the unburnt and burnt sites and statistics comparing them.

When values were presented in figures rather than as numbers within the article text or tables, we extracted them using WebPlotDigitizer (Rohatgi 2020).

#### Analysis

#### Question 1: Change in richness and abundance with time since fire (TSF analysis)

We took a two-step approach to address our first research question, first by describing the shapes of the relationships between TSF and individual species richness records, and second by calculating the overall slope of the relationships using a meta-analysis. The same process was repeated for records measuring bird abundance.

In the first step of our analysis, we identified the most plausible functional form of any relationship between each of species richness and abundance records, and time since fire. To do this, we compared the fit of a range of functions (null, linear, exponential, power, log-linear and Ricker) to each record (Appendix S3). Records with fewer than three datapoints were excluded as functions could not be fitted, leaving 19 articles and 53 records that could be used for this analysis (Table S2). We used AICc to identify the best fitting non-null models (within seven AICc units of the top model, not including the null) (Table S3). We checked diagnostic plots to ensure residuals did not display patterns following Walsh et al. (2020), Ritz and Streibig (2008) and Baty et al. (2015). Linear ( $y = \alpha + \beta x$ ) and log-linear ( $y = \alpha + \beta \ln(x)$ ) functions fit most species richness and abundance records better than did other functional forms (among models with delta AICc < 7). We compared linear and log-linear models and found similar model fit (delta AICc  $\leq 2$ ) so used both functions for our meta-analysis. As the meta-analysis incorporates a measure of variance from individual records, we were able to account for error in the case where the linear and log-linear functions were not the best-fit model for a record (20/53 records).

Following this initial step, we next conducted the meta-analysis of the effect of TSF on woodland and forest bird species richness and abundance. To do this, we used the beta coefficients (slopes) resulting from linear regression and log-linear models of each record as the effect size to compare the magnitude of effects across records and articles (Becker & Wu 2007, Bowman 2012, Peterson & Brown 2005). We calculated the pooled effect sizes (i.e., overall effect sizes) of all species richness and abundance records using multi-level random-effects (MLRE) models with the restricted maximum likelihood method in R (*rma.mvi* function in *metafor* package; Viechtbauer 2010). We included record nested within study as a random effect to account for potential non-independence among effect sizes derived from records within the same article. One record that measured bird abundance using a different sampling methodology (mist-netting rather than detecting individuals by sight and sound; Wooller & Calver 1988, Appendix S2) was an outlier in both abundance values and effect size so we excluded it from the analysis.

To test for heterogeneity in effect sizes among individual records, we used two measures (following Harrer et al. 2019): i) Cochran's Q-statistic, which is the difference between the observed effect sizes and the fixed-effect model estimate of the effect size, which is then squared, weighted and summed; and ii) prediction intervals calculated as part of the meta-analysis output, which take into account between-study variation and gives the range of effect size values within which we can expect effects of future studies to fall.

We checked for outliers and influential records using the *influence.rma.mv* function in the *metafor* package (Viechtbauer 2010). Standardised rules for identifying outliers in multi-level meta-analyses are a work in progress (Viechtbauer & Cheung 2010); thus, we define influential outliers as having plotted Cook's distances that are relatively large when visually compared with the other studies (Viechtbauer & Cheung 2010) and a 'dfbetas' value (i.e., how much a parameter estimate changes if the observation in question is dropped from the data set) larger than 1 (Viechtbauer 2010). We then re-ran the meta-analysis without outliers to check whether the pooled effect estimate we found was robust (Harrer et al. 2019). We checked for small sample publication bias using Egger's test of funnel plot asymmetry (*funnel* function in *metafor* package) and regression test (Egger et al. 1997), whereby smaller studies are less likely to be significant and have a large effect size and are therefore less likely to be reported and included in a meta-analysis (Borenstein et al. 2011; Harrer et al. 2019). We did this by including the sampling variance as a moderator in our models whereby a significant intercept indicates asymmetry and therefore publication bias (Sterne & Egger 2005).

# Question 2: Difference in richness and abundance between recently-burnt and unburnt sites (recently-burnt vs unburnt analysis)

We used a vote counting approach to summarise the number of significant positive, significant negative, or 'no significant difference' relationships reported between bird richness and abundance at recently burnt versus unburnt sites from 26 records across 12 articles (Fig. 1). We defined 'recently burnt' as sites that were surveyed within three years of fire and 'unburnt' as sites that were surveyed at least eight years after fire.

Within each article, we compared species richness and abundance between burnt and unburnt sites using details of statistical tests (p-value or equivalent metric and direction of relationship; Table S4). Results from vote counting allowed us to identify whether there are consistent directional effects of fire on species richness and abundance. We acknowledge that results of vote counting to assess overall effectiveness should be interpreted cautiously (Koricheva et al. 2013); however, this approach allowed us to include an additional three articles that we were not able to use for the meta-analysis. We standardised the significance level across records to  $\alpha = 0.05$  and tallied the number of records that found a significant positive effect, significant negative effect, or that found no difference (i.e., no statistically significant difference) between woodland and forest bird communities at burnt versus unburnt sites.



Yelllow box habitat. Image: John Briggs

## Results

#### Question 1: Change in bird richness and abundance with time since fire (TSF analysis)

#### Species richness

The linear and log-linear functions were among the best fit models (delta AICc  $\leq$  2) describing the shape of the relationship between TSF and species richness for 27% (6/22) of records, followed by the power (23%), Ricker (9%), and exponential functions (9%; Table S3). The null model was among the best fit models for 82% of records.

We included species richness data from 14 articles and 20 records in our TSF analysis. The majority of records (90%; 18/20) measured response of all species, with only two records that each measured response of a subset of the bird community (native species and woodland birds; Fig. 3). Sixty-five percent of species richness records measured the effect of wildfire on birds, 20% measured the effect of prescribed burns, and 15% measured the effect of both fire types on birds. TSF for wildfire ranged from one to 410 years (only two articles had TSF > 80 years — Gosper et al. 2019a and Hingston & Grove 2010; Appendix S2) while TSF for prescribed burns ranged from zero to 79 years. Eighty-five percent (17/20) of records across 13 articles measured longer-term (> 20 years) response of birds to fire and 15% of records from two articles measured shorter-term (< 20 years) response. The majority of articles were from Victoria (36%; 5/14) and Western Australia (29%), followed by New South Wales (14%), Queensland (7%), South Australia (7%), and Tasmania (7%) (Table S2).

Pooled effect sizes from meta-analyses that assumed both linear and log-linear relationships (hereafter 'linear' and 'log-linear meta-analysis model', respectively) indicated a significant positive effect of TSF on species richness. The linear meta-analysis model had an effect size of 0.064 (95% CI = 0.028-0.099; p = 0.0004; Fig. 3a) and the log-linear meta-analysis model had an effect size of 1.20 (95% CI: 0.83-1.5; Fig. 3b; Table S2). This means that, over the initial decade following fire for example, the number of bird species increased on average by 0.64 given a linear relationship and by 2.9 species given a log-linear relationship (Fig. 4). However, given that the slope of the log-linear function decreases with time, the function predicted that species richness increased by just 0.2 in the decade from 50 to 60 years. We limited our prediction of bird response to 100 years since fire as only two studies had maximum TSF greater than 100 (Gosper et al. 2019a and Hingston & Grove 2010; Appendix S2) and estimating TSF beyond this time point is highly uncertain (Gosper et al. 2013). An overwhelming majority of records showed a positive effect size (95%), while only one showed a negative effect size for species richness (Bamford 1986\_a; Fig. 3). However, we found significant heterogeneity among individual effect sizes for both the linear (Q statistic = 159; p < 0.0001) and log-linear metaanalysis model (Q = 70; p < 0.0001). Prediction intervals for the linear meta-analysis model overlapped zero (-0.045– 0.17), indicating the positive relationship between TSF and species richness is only robust in the context of included articles (Harrer et al. 2019). However, the prediction interval for the log-linear meta-analysis model did not overlap zero (0.086–2.2), indicating that the positive relationship is robust with a broader context of future studies.

Record	Response	Fire type	Effect size	a
Bamford 1986_a	all_species	both	F	
Rainsford 2021_a	all_species	prescribed		
Hingston 2010_a	native_species	wild	•	
Gosper 2019_a	all_species	both		
Lindenmayer 2018_a	all_species	wild	H <b>a</b> -1	
Recher 1997_a	all_species	wild	⊨∎-I	
Lindenmayer 2014_a	all_species	wild	H <b>a</b> l	
Kuchinke 2018_a	all_species	both	<b>⊢</b>	
Prowse 2017_a	woodland_birds	prescribed	<b>⊢</b> ∎-1	
Lindenmayer 2008_a	all_species	wild	<b>÷</b> ∎	
Barton 2014_b	all_species	wild	<b>⊢</b> ∎-1	
Lindenmayer 2014_b	all_species	wild		
Valentine 2012_b	all_species	prescribed	· · ·	
Barton 2014_a	all_species	wild	⊢•	
Recher 1997_b	all_species	wild	<b>⊢</b> ∎	
Recher 2013_a	all_species	wild	+∎-i	
Robinson 2014_c	all_species	wild	<b>↓</b> • • •	
Robinson 2014_b	all_species	wild	<b>⊢</b>	
Valentine 2012_a	all_species	prescribed	H	
Robinson 2014_a	all_species	wild		
MLRE Model (Q = 159.26,	df = 19, p = 0.00)		•	
			•	
			- <u>i</u> - i	]
		-1	-0.5 0 0.	5 1
			Mean effect size	

Record	Response	Fire type	Effect size	b
Bamford 1986_a	all_species	both		
Rainsford 2021_a	all_species	prescribed	H <b>H</b> H	
Lindenmayer 2018_a	all_species	wild	<b>⊢</b> − − − −	
Lindenmayer 2014_a	all_species	wild	j <b>⊢∎</b> ⊣	
Recher 1997_b	all_species	wild		
Prowse 2017_a	woodland_birds	prescribed	j <b>_∎</b> _j	
Valentine 2012_b	all_species	prescribed		
Recher 1997_a	all_species	wild		
Lindenmayer 2008_a	all_species	wild	k <mark>i ∎</mark> −1	
Barton 2014_b	all_species	wild	<b>}</b> —∎—(	
Hingston 2010_a	native_species	wild	H∎H	
Kuchinke 2018_a	all_species	both	· · · · · ·	
Gosper 2019_a	all_species	both	<b>⊢−</b> →	
Valentine 2012_a	all_species	prescribed		i
Barton 2014_a	all_species	wild	H <b>H</b> H	
Lindenmayer 2014_b	all_species	wild	H	
Recher 2013_a	all_species	wild	⊢∎⊣	
Robinson 2014_c	all_species	wild		
Robinson 2014_b	all_species	wild		
Robinson 2014_a	all_species	wild		
MLRE Model (Q = 69.67,	df = 19, p = 0.00)		•	
		[	<u> </u>	
		-4	-1 2	5 8
			Mean effect	size

**Figure 3.** Forest plots showing the effect of time since fire for woodland and forest bird species richness. Effect size of 20 individual records from 14 articles represent beta coefficients (slopes) of a) linear and b) log-linear meta-analysis models (Table S2). The plot shows the individual effect sizes for each record, the group of birds recorded, fire type, and effect size estimate ± 95% confidence interval. Record (and study) were included as random effects to account for pseudoreplication (see Methods). The overall mean effect size of the meta-analysis is shown by the middle points of the diamond, and 95% confidence intervals are the left and right points of the diamond.



Figure 4. Predicted relationships between time since fire (years) and change in woodland and forest bird species richness for linear and log-linear functions. Data for each function were generated using the overall effect sizes from linear and log-linear meta-analysis models for slopes.

Using influence analysis, we found one outlier record for the linear meta-analysis model (Recher et al. 2013; Appendix S2). Removal of the outlier record did not change the significance of the effect of TSF on species richness but decreased the mean effect size for the linear model (effect size = 0.096; 95% CI = 0.014-0.18; p = 0.022) and resulted in increased heterogeneity (Q statistic = 3733; p < 0.0001) and a similar prediction interval (-0.18-0.37). We did not find any outlier records for the log-linear meta-analysis model. As the overall effect size of our linear meta-analysis of species richness records was unchanged following removal of outliers, we conclude that result was robust to outlier influence. We found evidence of publication bias for linear and log-linear models (Egger's test, linear model intercept: z = 3.2, p = 0.001; log-linear model: z = 5.9, p < 0.0001).

#### Abundance

The linear and log-linear functions were among the best fit models (delta AICc  $\leq$  2) describing the shape of the relationship between TSF and abundance for 39% (12/31) of records, followed by the exponential (19%), power (16%), and ricker functions (13%; Table S3). The null model was among the best fit models for 71% of abundance records.

We included abundance data from 10 articles and 29 records in our TSF analysis. The majority (62%; 18/29) of abundance records measured response of subsets of the bird community (based on foraging and habitat preference), and 38% of records measured response of all species (Fig. 5). Twenty-four percent of abundance records measured the effect of prescribed burns on birds, 38% measured the effect of wildfire, and 38% measured the effect of both fire types on birds. TSF for wildfire ranged from zero to 36 years (only one article had TSF > 80 years — Gosper et al. 2019b; Appendix S2), while TSF for prescribed burns ranged from zero to 79 years (Table S2). Eighty-six percent (25/29) of records across eight articles measured longer-term (> 20 years) response of birds to fire and 14% of records across three articles measured shorter-term (< 20 years) response. Half of the articles were from Victoria (5/10), followed by Western Australia (30%) and Queensland (20%) (Fig. 5).

Pooled effect sizes from linear and log-linear meta-analysis models indicated a significant, positive effect of TSF on total bird abundance (Fig. 5). The effect size was slightly positive for the linear meta-analysis model (0.23; 95% CI = 0.048-0.42; p = 0.014; Fig. 5a) and log-linear meta-analysis model (2.63; 95% CI = 0.22-5.04; p = 0.032; Fig. 5b). This means that over the initial decade following fire, the number of birds increased by 2.3 given a linear relationship and by 6.3 birds given a log-linear relationship (Fig. 6). As seen with species richness, the slope of the log-linear function decreases with time such that bird abundance increased by just 0.47 in the decade from 50 to 60 years. Forty-eight percent (14/29) of records showed decreasing abundance with TSF while 45% of records showed increasing abundance with TSF (Fig. 5). We detected significant heterogeneity among individual effect sizes for both the linear model (Q = 129; p < 0.0001) and the log-linear model (Q = 158; p < 0.0001). Prediction intervals for the linear and log-linear model overlapped zero (-0.31–0.78 and -4.5–9.8, respectively), indicating the positive relationship between TSF and abundance was only robust in the context of included articles (Harrer et al. 2019).



Regent Honeyeater. Image: Mick Roderick





**Figure 5.** Forest plots showing the effect of time since fire for woodland and forest bird abundance. Effect size of 29 individual records from 10 articles represent beta coefficients (slopes) of regression models using a) linear and b) log-linear functions. The plot shows the individual effect sizes for each record, the group of birds recorded, fire type, and effect size estimate ± 95% confidence interval. Record (and study) were included as random effects to account for pseudoreplication (see Methods). The overall mean effect size of the meta-analysis is shown by the middle points of the diamond, and 95% confidence intervals are the left and right points of the diamond. Heterogeneity was measured using Cochran's Q-statistic (Q). See Appendix S2 for full list of articles included in analyses.



**Figure 6.** Predicted relationships between time since fire (years) and change in woodland and forest bird abundance for linear and log-linear functions. Data for each function were generated using the overall effect sizes from linear and log-linear meta-analysis models for slopes.

We did not find outlier records using an influence analysis for either meta-analysis model. We found evidence of publication bias for the linear model based on significant Egger's tests (intercept z = 2.1, p = 0.036) but not for the log-linear model (intercept z = 1.7, p = 0.084).

# Question 2: Difference in richness and abundance at burnt and unburnt sites (recently-burnt vs unburnt analysis)

We identified 26 records from 12 articles that were eligible for the vote counting analysis (Table S2 & Table S4). The majority of records (81%; 21/26) from 11 articles measured response of all species and 19% from three articles measured response of a subset of the bird community (resident vs migrants, small passerines, lower-midstorey foragers; Table S4). Fifty-four percent (14/26) of records from six articles tested the effect of wildfire on bird species richness and abundance and 46% from six articles tested the effect of prescribed burns. TSF for unburnt sites ranged from 10 to 64 years for wildfire studies and eight to 79 years for prescribed burn studies. TSF for recently-burnt sites ranged from 0.1 to three years for wildfire studies and from zero to three years for prescribed burn studies. The majority of articles were from Victoria (50%; 6/12), followed by New South Wales (17%), Queensland (17%), and Western Australia (17%) (Table S2).

Among the 12 articles and 26 records we used for vote counting, we found 16 records of bird species richness and 10 records of total bird abundance at burnt and unburnt sites. When comparing across all fire types, 50% of species richness records (8/16) found that species numbers were statistically similar between burnt and unburnt sites, and 50% of records found significantly fewer species at burnt sites compared to unburnt sites. In contrast, 20% of total abundance records (2/10) were statistically similar between burnt and unburnt sites, 60% of records found significantly fewer species found significantly more individuals at burnt sites, and 20% of records found significantly more individuals at burnt sites, and 20% of records found significantly more individuals at burnt sites. When we examined this effect at sites burnt by prescribed versus wildfire, 100% of species richness records (7/7) showed that species numbers were statistically similar compared with sites unburnt by prescribed fire (Fig. 7). In contrast, 40% of abundance records (2/5) showed significantly more individuals at burnt sites and 40% showed that number of individuals was statistically similar at burnt and unburnt sites for prescribed fire, while only one abundance record found fewer individuals at unburnt sites (Fig. 7). At sites burnt by wildfires, the vast majority of species richness records revealed significantly fewer species (89%; 8/9) and all abundance records found significantly more likely to have a negative effect on species richness ( $\chi^2 = 9.14$ , p = 0.002) and abundance ( $\chi^2 = 6.7$ , p = 0.036) than prescribed fire.



**Figure 7.** Results of vote counting analysis showing direction of effect of prescribed fire and wildfire on bird species richness and total abundance compared with unburnt habitat. Only significant (p < 0.05) negative and positive effects are displayed. Total sample size of each record's outcome x fire type combination (with number of studies in brackets) is labeled at the bottom of squares. See Table S4 for a list of articles included in burnt vs unburnt analysis.

### Discussion

Across studies, despite the range of forest and woodland types, bird species richness and total abundance increased significantly with TSF. Bird species richness and abundance response to prescribed burning was mixed but was overwhelmingly negative in response to wildfire (Fig. 7). The studies included in our analyses were designed to answer different questions and done in response to different fires, so we might not expect general effects of fire on woodland and forest birds to emerge. However, by using meta-analysis and vote counting approaches, and extracting data in a systematic way, some clear patterns did emerge. Our findings underscore the need to incorporate long post-fire recovery periods into fire mosaic planning.

Results of the meta-analyses showed that bird species richness and abundance responded similarly after fire. Species richness and total bird abundance increased with TSF consistently across records, implying that more species and individual birds are able to recolonise as a landscape recovers, i.e., as habitat structure is restored and as insects recolonise (Haslem et al. 2016; Murphy et al. 2021; Woinarski & Recher 1997). It is worth noting that the bird response groups for abundance records were often subsets of the bird community rather than all species as was the case with most species richness records. These groups were often foraging guilds (e.g., nectarivore, granivore, insectivore) or functional groups (e.g., open ground foragers, tall shrub foragers), and so changes in abundance and species richness were the focus of our analyses because they are commonly-measured, community-level response metrics that enable a comparison across studies. Such metrics do not capture response of individual species or changes in ecological function of the bird community, which are important to consider for fire-sensitive species (e.g., Speckled Warbler *Chthonicola sagittata*; Murphy et al. 2021) or groups (e.g., shrub-dependent functional groups; Rainsford et al. 2021).

Results from the 'burnt versus unburnt' analysis revealed that species short-term (within 3 years) response to fire compared with their response at sites unburnt by fire (8-79 years since fire) depended on fire type. Prescribed fire was significantly less likely to negatively impact species richness and abundance compared to wildfire across a range of woodland and forest types. Prescribed burns are typically smaller in area, less severe and patchier, and occur in autumn or spring (Andersen et al. 2005; McCaw 2013; Penman et al. 2008), whereas wildfires can be larger, more severe, occur in late spring or summer, and result in fewer areas of unburnt habitat (Leonard et al. 2014; Loyn & McNabb 2015). Birds therefore have a greater capacity to remain in areas burnt by prescribed fire as the impact on habitat is less severe (Gill et al. 2013). We did not incorporate fire severity in our analyses as it was not consistently reported. However, for articles that provided this detail, we found that severity of prescribed fires was generally low (71% of articles) and involved burning of groundcover, while wildfires tended to be high severity (80% of articles) and resulted in the burning and killing of most vegetation from groundcover through to the canopy. Thus, wildfires are more likely to alter vegetation structure (i.e., less structural complexity) in ways that negatively impact the number of bird species and individual abundance (Davis et al. 2000; Valentine et al. 2007; Woinarski & Recher 1997).

Our findings highlight the importance of unburnt refuges within the burnt landscape matrix, in line with previous studies of fire in forests and woodlands (Berry & Sitters 2015; Murphy et al. 2021; Prowse et al. 2017; Robinson et al. 2014). This is especially true in the case of extensive and/or catastrophic wildfires, such as Australia's 2019-2020 megafires that displaced and killed approximately three billion vertebrates (van Eeden et al. 2020, Ward et al. 2020). Unburnt patches are also important when designing planned burns for woodland specialists (Prowse et al. 2017) and species associated with late-successional conditions (e.g., lower-midstorey foragers; Rainsford et al., 2021).

A key consideration of post-fire fauna response that we did not include in our analyses is proximity to unburnt areas, which can facilitate quicker post-fire recovery of forest birds (Murphy et al. 2021).

We excluded many articles that investigated the effect of fire on woodland or forest birds because they did not meet our inclusion criteria. For the TSF analysis, most of the excluded articles had too few datapoints to fit a function to the TSF x bird response relationship. For the burnt vs unburnt analysis, many articles were excluded because they did not report statistical differences for burnt and unburnt treatments or did not compare burnt and unburnt sites. We acknowledge that such articles may nonetheless contribute meaningful information about bird response to fire that could be better captured using different methodologies such as qualitative syntheses.

Diagnostic tests of meta-analysis results revealed significant heterogeneity and potential publication bias, which have important implications for interpretation of our findings. Significant heterogeneity (Q test result) suggests that pooled effect size estimate was likely influenced by moderators (i.e., covariates). We did not include moderators, which could have influenced bird response (e.g., fire severity, fire type), due to the already-small number of studies included in our analysis but as noted earlier, wildfires tended to be more severe than prescribed burns. Prediction intervals from richness and abundance meta-analysis models overlapped zero, indicating that results are only robust in the context of the included studies. However, because included studies spanned different forest and woodland habitat types, fire severities, and timeframes, we argue that the patterns revealed in our study of bird response to fire are broadly applicable within these contexts. Further, we aimed to synthesise data from existing studies to extract broad generalities rather than make specific recommendations for fire management. We also detected significant publication bias, which potentially weakens the inferences of our results as only studies with large effect sizes and significant results are reported. This is an unfortunate but common trend in scientific reporting and we encourage the publication of non-significant results or at least their inclusion as supplementary material or data.

We know that fire benefits species, as many of the ecosystems that they inhabit rely on fire to regenerate. However, in the short term, we found that fire depresses bird richness and abundance, and coupled with forest and woodland habitat loss (Ford 2011), increasing heat waves and drought conditions across much of Australia (CSIRO State of the Climate 2018; http://www.bom.gov.au/state-of-the-climate/2018/State-of-the-Climate-2018.pdf), poorly managed fire is an additional stressor on bird communities. The fact that prescribed burns were less likely to impact species richness and abundance points to the importance of careful fire management to reduce the risk of catastrophic wildfire. Further, the gradual increase in bird richness and abundance that continued decades after fire highlights the importance of retaining and protecting long-unburnt habitat in the landscape (Prowse et al., 2017).

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**Author contributions:** Title/abstract and full text screen: JW, MG; Methods: JW, MG, MM, NR; Data extraction and analysis: MG; Writing: JW, MG, MM, NR.

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## Appendices

**Appendix S1.** The combinations of search terms we used to collate all existing studies that test the response of woodland and forest birds to fire. We applied search terms to document title, abstract, and keywords and searched all years. Searches were conducted on 09/03/2021.

Search string	Web of Science	Scopus
(bird OR avifauna) AND (woodland OR savanna* OR forest OR eucalypt*) AND (Australia OR "New South Wales" OR Queensland OR "Northern Territory" OR Victoria OR Tasmania OR "Australian Capital Territory" OR "South Australia" OR "Western Australia" OR NSW OR QLD OR NT OR Vic OR Tas OR ACT OR SA OR WA) AND TOPIC: (fire OR burn*)	232	203
Total once duplicates removed		312

Appendix S2. Reference list of articles included in time-since-fire and burnt vs unburnt analyses.

- \* Wooller & Calver 1988 was excluded from TSF analysis as an outlier
- Bamford, M. J. (1986). The dynamics of small vertebrates in relation to fire in Banksia woodland near Perth, Western Australia (Doctoral dissertation, Murdoch University).
- Barr, R., Wright, W., & Rayment, P. (2011). Thinning, fire and birds in Boola Boola State Forest, Victoria, Australia. *Australian Forestry*, 74(1), 43-53.
- Barton, P. S., Ikin, K., Smith, A. L., MacGregor, C., & Lindenmayer, D. B. (2014). Vegetation structure moderates the effect of fire on bird assemblages in a heterogeneous landscape. *Landscape Ecology*, 29(4), 703-714.
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- Gosper, C. R., Watson, S. J., Fox, E., Burbidge, A. H., Craig, M. D., Douglas, T. K., Fitzsimons, J. A., McNee, S., Nicholls, A. O., O'Connor, J., Prober, S. M., Watson, D. M., & Yates, C. J. (2019b). Fire-mediated habitat change regulates woodland bird species and functional group occurrence. *Ecological Applications*, 29(8), e01997.
- Green, K. E. N., & Sanecki, G. (2006). Immediate and short-term responses of bird and mammal assemblages to a subalpine wildfire in the Snowy Mountains, Australia. *Austral Ecology*, 31(6), 673-681.
- Hingston, A. B., & Grove, S. (2010). From clearfell coupe to old-growth forest: Succession of bird assemblages in Tasmanian lowland wet eucalypt forests. *Forest Ecology and Management*, 259(3), 459-468.
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- \*Wooller, R. D., & Calver, M. C. (1988). Changes in an assemblage of small birds in the understorey of dry sclerophyll forest in southwestern Australia after fire. *Wildlife Research*, 15(3), 331-338.

**Appendix S3.** Data from 'Gosper\_2019\_a' species richness record showing different fitted functions : a) linear; b) power; c) log-linear; d) exponential; and e) Ricker. The best fit function model (power; b) is in bold.



## Supplementary Information

Table S1. List of woodland and forest bird species from Fraser et al. (2019).

Species	Scientific name
Apostlebird	Struthidea cinerea
Australasian Pipit	Anthus novaeseelandiae
Australian Hobby	Falco longipennis
Australian Magpie	Gymnorhina tibicen
Australian Owlet-nightjar	Aegotheles cristatus
Australian Raven	Corvus coronoides
Australian Ringneck	Barnardius zonarius
Banded Lapwing	Vanellus tricolor
Barking Owl	Ninox connivens
Black Honeyeater	Sugomel nigrum
Black-breasted Buzzard	Hamirostra melanosternon
Black-chinned Honeyeater	Melithreptus gularis
Black-eared Cuckoo	Chrysococcyx osculans
Black-faced Cuckoo-shrike	Coracina novaehollandiae
Black-faced Woodswallow	Artamus cinereus
Black-headed Honeyeater	Melithreptus affinis
Black-throated Finch	Poephila cincta
Blue Bonnet	Northiella haematogaster
Blue-breasted Fairy-wren	Malurus pulcherrimus
Blue-winged Kookaburra	Dacelo leachii
Blue-winged Parrot	Neophema chrysostoma
Brown Falcon	Falco berigora
Brown Goshawk	Accipiter fasciatus
Brown Honeyeater	Lichmera indistincta
Brown Quail	Coturnix ypsilophora
Brown Thornbill	Acanthiza pusilla
Brown Treecreeper	Climacteris picumnus
Brown-headed Honeyeater	Melithreptus brevirostris
Brush Bronzewing	Phaps elegans
Budgerigar	Melopsittacus undulatus
Buff-rumped Thornbill	Acanthiza reguloides
Bush Stone-curlew	Burhinus grallarius
Carnaby's Black-Cockatoo	Calyptorhynchus latirostris
Chestnut Quail-thrush	Cinclosoma castanotum
Chestnut-breasted Quail-thrush	Cinclosoma castaneothorax
Chestnut-rumped Heathwren	Hylacola pyrrhopygia
Chestnut-rumped Thornbill	Acanthiza uropygialis
Collared Sparrowhawk	Accipiter cirrocephalus
Common Bronzewing	Phaps chalcoptera
Crescent Honeyeater	Phylidonyris pyrrhoptera
Crested Bellbird	Oreoica gutturalis
Crested Shrike-tit	Falcunculus frontatus
Crimson Chat	Epthianura tricolor
Diamond Firetail	Stagonopleura guttata
Double-barred Finch	Taeniopygia bichenovii
Dusky Robin	Melanodryas vittata
Dusky Woodswallow	Artamus cyanopterus

Species	Scientific name
Eastern Barn Owl	Tyto alba
Eastern Rosella	Platycercus eximius
Eastern Spinebill	Acanthorhynchus tenuirostris
Eastern Yellow Robin	Eopsaltria australis
Elegant Parrot	Neophema elegans
Emu	Dromaius novaehollandiae
Fan-tailed Cuckoo	Cacomantis flabelliformis
Flame Robin	Petroica phoenicea
Forest Raven	Corvus tasmanicus
Forty-spotted Pardalote	Pardalotus quadragintus
Fuscous Honeyeater	Lichenostomus fuscus
Galah	Cacatua roseicapilla
Gilbert's Whistler	Pachycephala inornata
Glossy Black-Cockatoo	Calyptorhynchus lathami
Golden Whistler	Pachycephala pectoralis
Green Rosella	Platycercus caledonicus
Grey Butcherbird	Cracticus torquatus
Grey Currawong	Strepera versicolor
Grey Fantail	Rhipidura fuliginosa
Grey Goshawk	Accipiter novaehollandiae
Grey Shrike-thrush	Colluricincla harmonica
Grey-crowned Babbler	Pomatostomus temporalis
Ground Cuckoo-shrike	Coracina maxima
Hooded Robin	Melanodryas cucullata
Horsfield's Bronze-Cuckoo	Chrysococcyx basalis
Inland Thornbill	Acanthiza apicalis
Jacky Winter	Microeca leucophaea
Laughing Kookaburra	Dacelo novaeguineae
Leaden Flycatcher	Myiagra rubecula
Little Button-quail	Turnix velox
Little Crow	Corvus bennetti
Little Eagle	Hieraaetus morphnoides
Little Friarbird	Philemon citreogularis
Little Lorikeet	Glossopsitta pusilla
Little Raven	Corvus mellori
Long-billed Corella	Cacatua tenuirostris
Magpie-lark	Grallina cyanoleuca
Major Mitchell's Cockatoo	Lophochroa leadbeateri
Malleefowl	Leipoa ocellata
Masked Owl	Tyto novaehollandiae
Masked Woodswallow	Artamus personatus
Mistletoebird	Dicaeum hirundinaceum
Mulga Parrot	Psephotus varius
Musk Lorikeet	Glossopsitta concinna
New Holland Honeyeater	Phylidonyris novaehollandiae
Noisy Friarbird	Philemon corniculatus
Noisy Miner	Manorina melanocephala
Olive Whistler	Pachycephala olivacea
Olive-backed Oriole	Oriolus sagittatus
Painted Button-guail	Turnix varius

Species	Scientific name
Painted Honeyeater	Grantiella picta
Pale-headed Rosella	Platycercus adscitus
Pallid Cuckoo	Cuculus pallidus
Peaceful Dove	Geopelia striata
Peregrine Falcon	Falco peregrinus
Pied Butcherbird	Cracticus nigrogularis
Pied Currawong	Strepera graculina
Pied Honeyeater	Certhionyx variegatus
Purple-crowned Lorikeet	Glossopsitta porphyrocephala
Rainbow Bee-eater	Merops ornatus
Rainbow Lorikeet	Trichoglossus moluccanus
Red Wattlebird	Anthochaera carunculata
Red-backed Kingfisher	Todiramphus pyrrhopygius
Red-browed Finch	Neochmia temporalis
Red-browed Pardalote	Pardalotus rubricatus
Red-capped Parrot	Purpureicephalus spurius
Red-capped Robin	Petroica goodenovii
Red-eared Firetail	Stagonopleura oculata
Red-rumped Parrot	Psephotus haematonotus
Red-tailed Black-Cockatoo	Calyptorhynchus banksii
Red-winged Parrot	Aprosmictus erythropterus
Redthroat	Pyrrholaemus brunneus
Regent Honeyeater	Xanthomyza phrygia
Regent Parrot	Polytelis anthopeplus
Restless Flycatcher	Myiagra inquieta
Rufous Songlark	Cincloramphus mathewsi
Rufous Treecreeper	Climacteris rufus
Rufous Whistler	Pachycephala rufiventris
Sacred Kingfisher	Todiramphus sanctus
Satin Flycatcher	Myiagra cyanoleuca
Scarlet Honeyeater	Myzomela sanguinolenta
Scarlet Robin	Petroica multicolor
Shining Bronze-Cuckoo	Chrysococcyx lucidus
Shy Heathwren	Hylacola cauta
Silvereye	Zosterops lateralis
Singing Honeyeater	Lichenostomus virescens
Southern Boobook	Ninox boobook
Southern Scrub-robin	Drymodes brunneopygia
Southern Whiteface	Aphelocephala leucopsis
Speckled Warbler	Chthonicola sagittata
Spiny-cheeked Honeyeater	Acanthagenys rufogularis
Splendid Fairy-wren	Malurus splendens
Spotted Bowerbird	Chlamydera maculata
Spotted Nightjar	Eurostopodus argus
Spotted Pardalote	Pardalotus punctatus
Spotted Quail-thrush	Cinclosoma punctatum
Square-tailed Kite	Lophoictinia isura
Striated Pardalote	Pardalotus striatus
Striated Thornbill	Acanthiza lineata
Striped Honeyeater	Plectorhyncha lanceolata

Species	Scientific name
Strong-billed honeyeater	Melithreptus validirostris
Sulphur-crested Cockatoo	Cacatua galerita
Superb Fairy-wren	Malurus cyaneus
Superb Parrot	Polytelis swainsonii
Swamp Harrier	Circus approximans
Swift Parrot	Lathamus discolor
Tasmanian Thornbill	Acanthiza ewingii
Tawny Frogmouth	Podargus strigoides
Tawny-crowned Honeyeater	Phylidonyris melanops
Tree Martin	Hirundo nigricans
Turquoise Parrot	Neophema pulchella
Varied Sittella	Daphoenositta chrysoptera
Variegated Fairy-wren	Malurus lamberti
Wedge-tailed Eagle	Aquila audax
Weebill	Smicrornis brevirostris
Welcome Swallow	Hirundo neoxena
Western Corella	Cacatua pastinator
Western Gerygone	Gerygone fusca
Western Rosella	Platycercus icterotis
Western Spinebill	Acanthorhynchus superciliosus
Western Thornbill	Acanthiza inornata
Western Wattlebird	Anthochaera lunulata
Western Yellow Robin	Eopsaltria griseogularis
White-bellied Cuckoo-shrike	Coracina papuensis
White-breasted Robin	Eopsaltria georgiana
White-browed Babbler	Pomatostomus superciliosus
White-browed Scrubwren	Sericornis frontalis
White-browed Treecreeper	Climacteris affinis
White-browed Woodswallow	Artamus superciliosus
White-cheeked Honeyeater	Phylidonyris niger
White-eared Honeyeater	Lichenostomus leucotis
White-fronted Honeyeater	Purnella albifrons
White-naped Honeyeater	Melithreptus lunatus
White-plumed Honeyeater	Lichenostomus penicillatus
White-throated Gerygone	Gerygone olivacea
White-throated Honeyeater	Melithreptus albogularis
White-throated Nightjar	Eurostopodus mystacalis
White-throated Treecreeper	Corombates leucophaeus
White-winged Triller	Lalage sueurii
Willie Wagtail	Rhipidura leucophrys
Yellow Thornbill	Acanthiza nana
Yellow Wattlebird	Anthochaera paradoxa
Yellow-faced Honeyeater	Lichenostomus chrysops
Yellow-plumed Honeyeater	Lichenostomus ornatus
Yellow-rumped Thornbill	Acanthiza chrysorrhoa
Yellow-tailed Black-Cockatoo	Calyptorhynchus funereus
Yellow-throated honeyeater	Nesoptilotis flavicollis
Yellow-throated Miner	Manorina flavigula
Yellow-tufted Honeyeater	Lichenostomus melanops

**Table S2**. Summary of articles included in the time-since-fire and burnt vs unburnt analyses, which research question each addressed, study design, location, vegetation type, fire type and timeline, bird response type, community group, and survey method. The full list of articles and titles can be found in Appendix S2.

BA = Before/after; CI = Control/impact; Corr = Correlational; BACI = before/after, control/impact; presc = prescribed; abund = abundance; rich = species richness

Article	Research question/ No. records			Site details		Fire			Bird response	
Citation	Q1 No. records	Q2 No. records	Study design	Region/ State	Veg type	Fire type/ first-last year	TSF range (yrs)	Response type	Community group	Survey method/ Area
Bamford _1986	1	1	BA; CI	SW Western Australia	banksia woodland	both/ 1985	0.6-21; 0.4-23	rich	All spp	general census/ NR
Barr_2011 _AustFore	NA	2	BA	Boola Boola State Forest/ VIC	mixed eucalypt forest	wild/ 2006- 2007	0.1-37	abund; rich	All spp	20-min 2ha search
Barton_2014 _ LandEcol	2	NA	CI	Jervis Bay Territory/ NSW	woodland and forest	wild/ 2003	0.8-37	rich	All spp	point count/ 0.76ha
Gosper_2019 _ BiolCons	1	NA	Corr	Great Western Woodlands/ WA	gimlet woodland	both/ 1613- 2007	6-410	rich	All spp; Major wheatbelt decliners, wheatbelt no- change/ increasers	20-min 2ha search
Gosper_2019 _ EcolApp	1	NA	Corr	Great Western Woodlands/ WA	gimlet woodland	both/ 1613- 2007	6-409	abund	Bark insectivores	20-min 2ha search
Green_2006 _ AustEcol	NA	2	BA	Snowy Mountains/ NSW	snowgum woodland	wild/ 2003	0.7-64	rich	Residents, migrants	line transect/ 27ha
Hingston_2010_ ForEcoMan	1	NA	CI/ Corr	southern Tasmania	lowland wet eucalypt forest	wild/ 1759- 1967	42-250	rich	All native species	point count/ 0.25ha
Howes_2009_ WildRes	NA	2	CI	Carnarvon National Park/ QLD	subtropical eucalypt woodland	wild/ 2003	2-NR	abund; rich	Small passerines	20-min 2ha search
Kuchinke _2018	11	NA	BACI; Corr	Central Victorian Uplands	heathy dry forest	both/ 2012	0.3-11; 0-75	abund; rich	All spp; bark foragers, canopy foragers, carnivores, damp ground foragers, nectarivore, open ground foragers, open trees foragers, seeds ground foragers, seeds trees foragers, tall shrubs foragers	20-min 2ha search
Kuchinke_2020_ ForEcoMan	NA	2	BACI	Central Victorian Uplands	heathy dry forest	presc/ 2012	0.3-8	abund; rich	All spp	20-min 2ha search
Lindenmayer_2008_ EcolApp	1	1	BACI; CI	Booderee National Park/ NSW	woodland	wild/ 2003	0.8-32	rich	All spp	point count/ NR

Article	Rese questio reco	earch on/ No. ords		Site details		Fire			Bird response	
Citation	Q1 No. records	Q2 No. records	Study design	Region/ State	Veg type	Fire type/ first-last year	TSF range (yrs)	Response type	Community group	Survey method/ Area
Lindenmayer_2014_ DivandDis_a	2	NA	BACI	Central highlands Victoria	mountain ash forest	wild/ 2009	0.8-34	rich	All spp	point count/ 0.79ha
Lindenmayer_2018_ JoofApEc	1	NA	CI	Central highlands Victoria	mountain ash forest	wild/ 2009	0.8-77	rich	All spp	point count/ 0.79ha
Loyn_1997_ PaciConsBiol	4	NA	BA	East Gippsland/ VIC	sclerophyll forest (damp, dry, wet)	wild/ 1983	0.1-30	abund	All spp	20-min 2ha search
Loyn _2003	NA	2	BA	Wombat state forest/ VIC	mixed eucalypt	presc/ 1985- 1992	0.1-18	abund; rich	All spp	20-min 3ha or 2ha search
Loyn_2015 _JoofOr	6	NA	CI	Wombat State Forest and Bunyip State Park/ VIC	foothill eucalypt forest (Wombat); heathy, tall shrubby, and wetter forest (Bunyip)	presc (Wombat)/ 1984-2011; wild (Bunyip)/ 2009	0.25-37	abund	Forest birds, open- country birds	20-min 2ha search
Prowse_2017_ BiolCons_a	1	NA	CI/ Corr	Mt Lofty Ranges/ SA	temperate eucalypt woodland	presc/ 2001	0-51	rich	Woodland birds	20-min 2ha search
Rainsford_2021_ EcolApp	2	2	CI	Highlands Southern Fall/ VIC	foothill forest	presc/ 1977- 2017	0-79	abund; rich	All spp; lower-midstorey foragers; lower dietary versatility; open nest	20-min 2ha search
Recher_1997_ WildRese_a	2	1	BA; CI	Kings Park, Perth/ WA	urban woodland/ park	wild/ 1989	0.7-10; 5-36	rich	All spp	line transect/ 194-453m
Recher_2013_ PaciConsBiol	2	NA	CI	Great Western Woodlands/ WA	eucalypt woodland	wild/ 2005	0.8-30	abund; rich	All spp	20-min 3ha search
Robinson_2014_ ForEcoandMan	6	6	CI	Central highlands Victoria	mixed eucalypt foothill forest	wild/ 2009	1.7-21	abund; rich	All spp	point count/ 1.13ha
Sitters_2015 _ InJoofWiFi	NA	1	BACI	Otway Ranges/ VIC	tall-open forest	presc/ 2012	NA	rich	All spp	point count/ 4ha
Valentine_2007_ BiolCons	1	4	BACI; CI	Einasleigh Uplands/ QLD	open eucalypt woodland	presc/ 1999- 2000	<1-10; 0.4-13	abund; rich	All spp	30-min 1.25ha search
Valentine_2012_ AustEcol	3	NA	CI	Einasleigh Uplands/ QLD	open eucalypt woodland	presc/ 1999- 2002	1.1-13	abund; rich	All spp	30-min 1.25ha search
Wooller_1988 _ AustWildRese	2	NA	BA	Manjimup/ WA	dry sclerophyll forest, jarrah, marri	presc/ 1982	0.2-8	abund; rich	All spp	mist-net/ 12m

**Table S3.** Model summaries for each species richness and abundance record, showing top models (delta AICc < 7), function, sample size, AICc, and delta AIC. 'Inf' or infinite values for AICc indicate the model is over-parameterised, i.e., when degrees of freedom  $\geq$  number of observations - 1.

\* Gosper 2019\_a (species richness) = Gosper 2019 BiolCons; \*\*Gosper 2019\_a (abundance) = Gosper 2019 EcolApp

Response	Record ID	Function	Ν	AICc	∆AICc
Species richness	Bamford 1986_a	null	16	105.6	0.00
		exponential 2 params	16	106.9	1.24
		linear	16	107.0	1.38
		log linear	16	108.4	2.79
		power 2 params	16	108.7	3.05
Species richness	Barton 2014_a	null	4	34.0	0.00
		linear	4	Inf	NA
		power 2 params	4	Inf	NA
		Ricker	4	Inf	NA
		log linear	4	Inf	NA
Species richness	Barton 2014_b	null	4	29.8	0.00
		linear	4	Inf	NA
		power 2 params	4	Inf	NA
		Ricker	4	Inf	NA
		log linear	4	Inf	NA
Species richness	Gosper 2019_a*	power 2 params	53	314.8	0.00
		log linear	53	314.9	0.13
		linear	53	315.4	0.69
		exponential 3 params	53	316.3	1.58
		exponential 2 params	53	319.3	4.53
Species richness	Hingston 2010_a	log linear	6	18.7	0.00
		power 2 params	6	18.7	0.02
		linear	6	20.0	1.26
		null	6	23.1	4.37
		Ricker	6	24.4	5.67
Species richness	Kuchinke 2018_a	null	5	36.9	0.00
Species richness	Lindenmayer 2008_a	null	6	31.3	0.00
		exponential 2 params	6	36.0	4.70
		power 2 params	6	37.8	6.50
		log linear	6	38.1	6.77
Species richness	Lindenmayer 2014_a	linear	9	30.7	0.00
		log linear	9	32.0	1.29
		null	9	32.4	1.75
		power 2 params	9	32.6	1.89
Species richness	Lindenmayer 2014_b	log linear	9	30.1	0.00
		power 2 params	9	30.4	0.30
		linear	9	31.9	1.82
		exponential 3 params	9	35.1	5.04
		power 3 params	9	36.9	6.83
Species richness	Lindenmayer 2018_a	null	4	34.3	0.00
		linear	4	Inf	NA
		power 2 params	4	Inf	NA
		Ricker	4	Inf	NA
		log linear	4	Inf	NA

Response	Record ID	Function	N	AICc	∆AlCc
Species richness	Lindenmayer 2018_b	null	4	32.7	0.00
		linear	4	Inf	NA
		power 2 params	4	Inf	NA
		Ricker	4	Inf	NA
		log linear	4	Inf	NA
Species richness	Prowse 2017_a	log linear	22	83.6	0.00
		linear	22	83.8	0.19
		null	22	84.8	1.26
		exponential 3 params	22	86.1	2.50
		power 3 params	22	86.2	2.62
Species richness	Rainsford 2021_a	null	4	23.8	0.00
		Ricker	4	Inf	NA
		log linear	4	Inf	NA
Species richness	Recher 1997_a	null	6	21.8	0.00
Species richness	Recher 1997_b	null	4	42.7	0.00
		linear	4	Inf	NA
		power 2 params	4	Inf	NA
		Ricker	4	Inf	NA
		log linear	4	Inf	NA
Species richness	Recher 2013_a	power 2 params	11	37.0	0.00
		log linear	11	37.1	0.04
		linear	11	39.3	2.25
		exponential 2 params	11	40.4	3.43
		exponential 3 params	11	42.5	5.44
		Ricker	11	42.6	5.60
Species richness	Robinson 2014_a	null	6	43.6	0.00
		Ricker	6	43.7	0.10
		power 2 params	6	49.1	5.46
		log linear	6	49.2	5.54
		linear	6	49.6	5.93
Species richness	Robinson 2014_b	null	6	38.6	0.00
		Ricker	6	39.2	0.62
		power 2 params	6	43.0	4.40
		log linear	6	43.1	4.50
		linear	6	43.4	4.85
Species richness	Robinson 2014_c	null	6	37.8	0.00
		Ricker	6	43.0	5.23
		power 2 params	6	43.4	5.59
		log linear	6	43.4	5.65
		linear	6	43.6	5.84
Species richness	Valentine 2012_a		9	54.8	
			9	57.8	2.95
		log linear	9	58.5	5.55
Chaption richts	Valantina 2012 -	power 2 params	9	58.5	5./1
species richness	valentine 2012_b		9	52./	0.00
		power 2 params	9	57.2	4.4/
		lingar	9	57.2	4.50
		unear	9	57.5	4.60

Response	Record ID	Function	N	AICc	∆AICc
Species richness	Wooller 1988_a	null	6	41.6	0.00
Abundance	Gosper 2019_a**	Ricker	46	64.3	0.00
		linear	46	65.6	1.32
		log linear	46	67.1	2.79
Abundance	Kuchinke 2018_a	log linear	70	228.4	0.00
		linear	70	230.9	2.46
Abundance	Kuchinke 2018_b	log linear	141	636.0	0.00
		exponential 3 params	141	637.1	1.09
		null	141	637.6	1.53
		linear	141	637.8	1.81
Abundance	Kuchinke 2018_c	log linear	139	627.9	0.00
		exponential 3 params	139	629.0	1.15
		null	139	629.2	1.36
		linear	139	629.6	1.71
Abundance	Kuchinke 2018_d	log linear	141	636.1	0.00
		exponential 3 params	141	637.3	1.12
		null	141	637.6	1.46
		linear	141	638.0	1.81
Abundance	Kuchinke 2018_e	log linear	141	636.2	0.00
		null	141	637.3	1.12
		linear	141	637.9	1.64
Abundance	Kuchinke 2018_f	log linear	139	627.3	0.00
		null	139	630.2	2.90
		linear	139	630.3	2.98
Abundance	Kuchinke 2018_g	log linear	141	636.6	0.00
		exponential 3 params	141	637.7	1.11
		null	141	638.0	1.36
		linear	141	638.4	1.78
Abundance	Kuchinke 2018_h	log linear	141	636.4	0.00
		exponential 3 params	141	637.5	1.12
		null	141	637.8	1.45
		linear	141	638.2	1.82
Abundance	Kuchinke 2018_i	log linear	141	636.8	0.00
		null	141	638.2	1.48
		linear	141	638.6	1.87
Abundance	Kuchinke 2018_j	log linear	148	690.5	0.00
		null	148	691.4	0.83
<u> </u>		linear	148	693.4	2.90
Abundance	Loyn 1997_a	null	5	37.4	0.00
Abundance	Loyn 1997_b	null	5	39.7	0.00
Abundance	Loyn 1997_c	null	5	42.4	0.00
Abundance	Loyn 1997_d	null	5	48.0	0.00
Abundance	Loyn 2015_a	power 2 params	3	-19.2	0.00
		Ricker	3	-17.2	1.95
		log linear	3	-16.5	2.73
		linear	3	-15.4	3.83
Abundance	Loyn 2015_b	power 2 params	3	-17.2	0.00
		Ricker	3	-17.2	0.002

Response	Record ID	Function	N	AICc	∆AlCc
Abundance	Loyn 2015_c	null	4	39.9	0.00
Abundance	Loyn 2015_d	null	4	38.9	0.00
Abundance	Loyn 2015_e	power 2 params	3	-16.3	0.00
		log linear	3	-16.1	0.22
		linear	3	-14.8	1.58
Abundance	Loyn 2015_f	linear	3	-15.0	0.00
		log linear	3	-12.2	2.77
		power 2 params	3	-12.1	2.91
Abundance	Rainsford 2021_a	power 3 params	4	-59.3	0.00
Abundance	Recher 1997_a	null	4	60.9	0.00
Abundance	Recher 2013_a	linear	11	80.7	0.00
		power 2 params	11	80.8	0.06
		log linear	11	81.0	0.31
		exponential 2 params	11	81.3	0.52
		Ricker	11	81.3	0.59
		power 3 params	11	86.0	5.23
Abundance	Robinson 2014_a	null	6	51.9	0.00
		Ricker	6	54.1	2.18
		power 2 params	6	56.9	4.99
		log linear	6	57.0	5.04
		linear	6	57.3	5.41
Abundance	Robinson 2014_b	null	6	51.9	0.00
		Ricker	6	54.8	2.85
		power 2 params	6	57.2	5.32
		log linear	6	57.3	5.36
		linear	6	57.6	5.69
Abundance	Robinson 2014_c	null	6	49.8	0.00
		Ricker	6	51.9	2.07
		power 2 params	6	54.5	4.72
		log linear	6	54.6	4.77
		linear	6	54.9	5.10
Abundance	Valentine 2007_a	null	4	39.4	0.00
Abundance	Valentine 2007_b	null	4	44.2	0.00
Abundance	Valentine 2012_a	null	9	65.8	0.00
		linear	9	70.6	4.73
		log linear	9	70.6	4.80
		power 2 params	9	70.6	4.80
Abundance	Wooller 1988_a	null	6	65.7	0.00
		linear	6	67.1	1.31
		log linear	6	71.4	5.71
		power 2 params	6	72.5	6.81

Article Burnt sites Unburnt sites Bird response Statistics No. No. Direction of Response TSF TSF Community Description Citation Description burnt unburnt Test relationship p-val (yrs) (yrs) group type sites sites to fire 0.6 unburnt habitat, same site, 0 Bamford\_1986 prescribed burn, 1 1 21 All spp Rich Chi square ns before fire variable intensity Barr 2011 AustFore 4 37 4 0.1 ANOVA 0.03 wildfire affected unburnt patches before fire All spp Abund \_\_\_\_ 4 of the 6 sites (both thinned and unthinned sites) Barr 2011 AustFore 37 4 0.1 0.001 wildfire affected 4 unburnt patches before fire All spp Rich ANOVA 4 of the 6 sites Green 2006 wildfire in Jan-Feb NR 07 64 same sites before fire NR Residents Rich Chi square < 0.0001 \_\_\_\_ AustEcol 2003, removed most understorey and tree canopy Green 2006 Chi square wildfire in Jan-Feb NR 0.7 same sites before fire NR 64 Migrants Rich < 0.0001 AustEcol 2003 removed most understorey and tree canopy Howes 2009 wildfire 2003 8 < 3 unburnt woodland 16 NR Small passerines Abund Bayesian model 100 \_\_\_\_ WildRes averaging Howes\_2009\_ wildfire 2003 8 < 3 unburnt woodland 16 NR Small passerines Rich Bayesian model 100 \_\_\_\_ WildRes averaging Kuchinke\_2020\_ prescribed burns 14 0.3 unburnt woodland 13 8 0.34 0 All Species Abund GLMM ForEcoMan in autumn 2012 Kuchinke\_2020\_ 14 unburnt woodland 13 8 Rich GI MM 0.48 0 prescribed burns 0.3 All species ForEcoMan in autumn 2012 Lindenmayer\_2008\_ wildfire in 2003 NR 0.8 unburnt woodland sites NR 32 Rich GLMM 0.003 All spp \_\_\_\_ EcolApp Loyn\_2003 prescribed burns, 25 0.1 unburnt woodland as control 5 18 All spp NR 0.26 0 Abund 5 different types sites of treatments 5 Loyn\_2003 25 01 18 NR 0.18 0 prescribed burns. unburnt woodland All spp Rich 5 different types of treatments Rainsford 2021 prescribed fires 11 sites last burnt by wildfire 9 79 Lower-midstorey ANOVA < 0.05 0-3 Abund \_\_\_\_ EcolApp in 1939 in autumn foragers Rainsford\_2021\_ 11 0-3 sites last burnt by wildfire 9 79 ANOVA 0 prescribed fires All species Rich NR EcolApp in autumn in 1939

Table S4. Summary of articles included in the burnt vs unburnt analysis. The full list of articles and titles can be found in the Appendix. NR = not reported; ns = not significant.

Article	Burnt sites		Unburnt sites		Bird response		Statistics				
Citation	Description	No. burnt sites	TSF (yrs)	Description	No. unburnt sites	TSF (yrs)	Community group	Response type	Test	p-val	Direction of relationship to fire
Recher_1997_ WildRese_a	wildfire in spring 1993-1994	4	0.7	transect before fire in spring 1986 (Sept-Nov), one transect section was not burned	4	10	All spp	Rich	NR	NA	0
Robinson_2014_ ForEcoandMan	wildfire, long TSF interval prior to fire (>20 yrs) x ground burnt	13	1.7	long fire interval x unburnt	13	21	All spp	Abund	ANOVA	0.002	
Robinson_2014_ ForEcoandMan	wildfire, long TSF prior to fire (>20 yrs) x crown scorch	6	1.7	long fire interval x unburnt	13	21	All spp	Abund	ANOVA	0.008	_
Robinson_2014_ ForEcoandMan	wildfire, long TSF prior to fire (>20 yrs) x crown burnt	7	1.7	long fire interval x unburnt	13	21	All spp	Abund	ANOVA	0.002	_
Robinson_2014_ ForEcoandMan	wildfire, long TSF prior to fire (>20 yrs) x ground burnt	13	1.7	long fire interval x unburnt	13	21	All spp	Rich	ANOVA	0.005	_
Robinson_2014_ ForEcoandMan	wildfire, long TSF prior to fire (>20 yrs) x crown scorch	6	1.7	long fire interval x unburnt	13	21	All spp	Rich	ANOVA	0.04	_
Robinson_2014_ ForEcoandMan	wildfire, long TSF prior to fire (>20 yrs) x crown burnt	7	1.7	long fire interval x unburnt	13	21	All spp	Rich	ANOVA	0.0002	_
Sitters_2015_ InJoofWiFi	prescribed burn, low-intensity and patchy	48	<u>≤</u> 1	sites that were not burnt	48	29	All spp	Rich	GLMM	NR	0
Valentine_2007_ BiolCons	dry season burn for weed control	6	<pre>&lt; 1</pre>	unburnt control plot on same site	6	10	All spp	Abund	ANOVA	0.003	+
Valentine_2007_ BiolCons	wet season burn for weed control	6	<u>≤</u> 1	unburnt control plot on same site	6	10	All spp	Abund	ANOVA	0.003	+
Valentine_2007_ BiolCons	dry season burn for weed control	6	≤ 1	unburnt control plot on same site	6	10	All spp	Rich	ANOVA	NA	0
Valentine_2007_ BiolCons	wet season burn for weed control	6	≤ 1	unburnt control plot on same site	6	10	All spp	Rich	ANOVA	NA	0

Further information: http://www.nespthreatenedspecies.edu.au

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