Size or quality. What matters in vegetation restoration for bird biodiversity in endangered temperate woodlands?

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Word count: 5540 words (excluding appendices (1443 words))

Running Head: Bird response to temperate woodland enhancement

Acknowledgments

We thank the Australian Research Council, the Ian Potter Foundation, The Vincent Fairfax Family Foundation, Murray Local Land Services, Riverina Local Land Services and the New

South Wales Environmental Trust for funding that allowed this study to be completed. Key contributors to the completion of field bird surveys included Thea O'Loughlin, Chris MacGregor, David Blair, Lachlan McBurney, David Smith, Clare Crane and members of the Canberra Ornithologists Group. Claire Shepherd and Tabitha Boyer assisted with manuscript preparation. Comments from Richard Beggs improved an earlier version of this paper.

Abstract

Vegetation restoration is a globally important form of management intervention designed to both remediate degraded land and to restore biodiversity. Using a 15-year controlled experimental study in endangered Australian temperate woodlands, we quantified the response of bird biota to vegetation enhancement leading to the re-establishment of an understorey, an increase in woodland patch size, or a combination of both. Our empirical results were characterized by marked variation in species richness and in the response of individual species to both time since enhancement and type of enhancement. For example, overall bird species richness initially responded negatively to enhancements but the effects were mitigated over time. Similar responses were identified for individual species such as the Rufous Songlark (*Megalurus mathewsii*). In the case of the Noisy Miner (*Manorina melanocephala*), responses to enhancement were negative and remained so over time. Conversely, the White-plumed Honeyeater (*Ptilotula penicillata*), Yellow-rumped Thornbill (*Acanthiza chrysorrhoa*) and Superb Fairy-wren (*Malarus cyaneus*) responded positively to enhancements. We also found evidence for variable responses to the kind of enhancement with some species responding to increased woodland patch size (e.g. Yellow-rumped Thornbill), others to a combination of enhancements (e.g. White-plumed Honeyeater), whereas yet others were agnostic to the kind of intervention that was implemented (e.g. Noisy Miner). Positive effects of enhancement were often time lagged for 6-8 years following

instigation of underplanting and/or increases in woodland patch size. The negative effects of patch enhancement on the Noisy Miner indicate that underplanting and/or increases in woodland patch size may represent ways in which the impacts on other bird taxa of this despotic, hyper-aggressive species might be mitigated.

Keywords: Woodland restoration, understorey creation, expanded patch size, woodland birds, south-eastern Australia

Introduction

Millions of hectares of degraded land globally are being targeted for restoration, especially in agricultural landscapes (Menz *et al.* 2013; Crouzeilles *et al.* 2016). There are many kinds of vegetation restoration and ways to do it (Lamb 2011; Suding *et al.* 2015; Palmer *et al.* 2016) with two broad overarching strategies being to increase the overall **amount** of vegetation cover or improve the **quality** of existing habitat. The size of areas of restored vegetation has been found to be important for biodiversity in many studies (e.g. Munro *et al.* 2007; Lindenmayer *et al.* 2010b); (reviewed by Crouzeilles *et al.* 2017). However, condition of restored vegetation also has a substantial influence on the effectiveness of restored areas for biodiversity conservation (Suding 2011; McAlpine *et al.* 2016). Whilst the best outcomes for biodiversity would often stem from both increasing the size of restored areas **and** improving the quality of the habitat being restored, limited funds or space may mean this option is not always possible. In which case, a key question is: Is it most ecologically-effective and cost-effective to spend limited funds increasing the size of patches of restored areas or improving the habitat condition of restored areas?

Remarkably, there appears to be few studies that have specifically addressed this somewhat simple question. This is a major knowledge gap given the billions of dollars that are currently being invested in restoration programs or are planned to be invested in the coming years and decades (Menz *et al.* 2013). In an attempt to close this knowledge gap, here

we report the results of an empirical study aimed at quantifying the response of bird biodiversity to improving the condition of woodlands versus increasing the size of woodlands. Our work was focused on the box-gum grassy woodlands of the South West Slopes of south-eastern Australia which is an endangered ecological community (Department of the Environment and Energy 2017). We established a 15-year study to contrast the bird biota of woodlands before and after management intervention (improving condition and/or increasing woodland patch size) at the same time as documenting the bird biota of control patches where no interventions were made. The response variables in our study were overall bird species richness, the richness of small-bodied species, the richness of all honeyeater species (Meliphagidae) and the occurrence of a suite of individual species. We focused on these measures because many small-bodied bird species in Australian temperate woodlands are also birds of conservation concern (Montague-Drake *et al.* 2009) and honeyeater species are often negatively impacted in degraded woodlands that are occupied by colonies of the Noisy Miner (*Manorina melanocephala*) (Mac Nally *et al.* 2012). Specifically our key question was:

Do birds respond to increasing time since restoration enhancement? If so, which kind of enhancement – an increase in woodland patch size or understorey establishment? We predicted at the outset of this study that the benefits of management interventions to improve woodlands would increase over time as vegetation matured and became functionally more important with understorey and/or increasing patch size. That is, there would be a lag between when vegetation was restored and when birds would begin to respond. We also postulated a stronger positive response for birds in patches where the understorey has been established. This was because intensive livestock grazing in Australian temperate woodlands has often resulted in the loss of understorey and other sub-canopy vegetation (Williams & Price 2011; McIntyre 2012; Sato *et al.* 2016; Lindenmayer *et al.* 2017) with understorey

vegetation being important for a range of species of woodland birds (Martin & McIntyre 2007; Antos *et al.* 2008; Montague-Drake *et al.* 2009). Finally, we predicted that the best overall outcomes from management intervention would be in those woodland patches subject to both underplanting **and** expansion in size because the combination of approaches would benefit both area-sensitive and understorey-associated species.

Vegetation restoration is a globally important form of management intervention designed to both remediate degraded land and to restore biodiversity (Suding 2011; McAlpine *et al.* 2016; Crouzeilles *et al.* 2017). However, restoration can be costly and very large amounts of money are dedicated to restoring large areas of the earth's land surface (Menz *et al.* 2013). The new insights generated from the empirical study reported here will be important for efforts to improve both the ecological effectiveness and cost-effectiveness of restoration programs.

Methods

Study area

Our study region was a 150 x 120 km agricultural area within the South West Slopes bioregion of New South Wales, south-eastern Australia (Figure 1). The South West Slopes was formerly dominated by temperate eucalypt woodland (Lindenmayer *et al.* 2010a), but has been cleared of an estimated 85% of its original cover (Benson 2008) to facilitate livestock grazing and cereal cropping.

Study design

Our study encompassed 61 temperate eucalypt woodland remnants dominated by the following tree species: white box (*Eucalyptus albens*), yellow box (*E. melliodora*), Blakely's red gum (*E. blakelyi*), grey box (*E. microcarpa*), red stringybark (*E. macrorhyncha*), and red box (*E. polyanthemos*).

125 Of the 61 sites, ten were subject to 'underplanting' where an understorey of shrubs was
126 established by planting tubestock underneath an overstorey of old growth eucalypts. A total
127 of seven sites was expanded in size (but with no underplanting), again using tubestock.
128 Finally, seven sites were both underplanted and increased in size. In addition, we selected 37
129 sites not subject to any management interventions but were on the same farms or on similar
130 neighbouring farms to where patches had been enhanced (Figure 1). These 37 sites acted as
131 control or reference sites and were characterized by similar plant species composition and
132 vegetation structure at the outset of this study. The size of sites varied among treatments. The
133 size of control sites ranged from 0.6 to 44.7 ha (mean = 7.6, median = 4.2 ha). For
134 underplanted sites, the equivalent values were 2.8 to 48.5 ha (mean = 11.2, median = 4.8 ha).
135 Enlarged sites ranged from 0.5 to 5.5 ha (mean = 3.0 ha, median = 2.3 ha). Finally,
136 underplanted and enlarged sites ranged from 5.5 to 16.9 ha (mean = 8.0 ha, median = 6.8 ha).
137 The number of years since restoration intervention in our study varied from 6 to 15 years;
138 with the calendar year of commencement of restoration action ranging from 2000 to 2010.
139 Twenty-two of the 24 woodland patches subject to intervention were established in 2006 or
140 earlier (i.e. dating back to 2000). The sites selected for restoration interventions were targeted
141 primarily because organizations such as the Riverina and Murray Local Land Services had
142 identified them for on-the-ground works in partnership funding schemes with local
143 landowners. In addition, there needed to be a control patch (where no intervention occurred)
144 of similar size, type and condition on the same farm or adjacent farm to underpin our study
145 design.

146 ***Bird surveys***

147 We completed all bird surveys in spring. Due to farm access and other logistical
148 restrictions, not all sites could be surveyed in all survey years. We surveyed sites in 2002,
149 2004, 2006, 2008, 2009, 2011, 2013 and 2015, giving 483 site-by-year surveys. We gathered

150 bird data using repeated five-minute point-interval counts (*sensu* Pyke & Recher 1983) at 0
151 m, 100 m and 200 m along a fixed transect at each site. For sites less than 2 ha, we
152 established a 100 m long transect.

153 Bird species seen or heard within 50 m of each point were recorded. Detections >50
154 m from the count point were not included in our analyses. In any given year, each site was
155 surveyed by at least two observers on different days, giving a minimum of six point-interval
156 counts in each survey. For sites less than 2 ha, we completed three sets of point counts at two
157 stations. We conducted surveys for up to four hours from dawn on a given day. We did not
158 undertake surveys during poor weather (e.g. rain or high wind). A site surveyed early in the
159 morning on the first day of counts was surveyed later in the morning on second day of counts.
160 These protocols reduced the effects of observer heterogeneity, time of day, and day of survey
161 effects (Lindenmayer *et al.* 2009). The total dataset for our study comprised 2898 point
162 counts.

163 ***Statistical analyses***

164 We constructed models of the factors affecting overall bird species richness, the
165 richness of small-bodied species, the richness of honeyeater species, and the
166 presence/absence of a seven of individual bird species for which there were sufficient data to
167 conduct detailed statistical analyses. These species were the Superb Fairy-wren (*Malarus*
168 *cyaneus*), Yellow-rumped Thornbill (*Acanthiza chrysorrhoa*), Willie Wagtail (*Rhipidura*
169 *leucophrys*), White-plumed Honeyeater (*Lichenostomus penicillatus*), Rufous Songlark
170 (*Megalurus mathewsi*), Red Wattlebird (*Anthochaera carunculata*), and Noisy Miner
171 (*Manorina melanocephala*). These species were chosen due to their relative abundance and
172 because they have different life history attributes, are from different foraging guilds, have
173 widely varying body sizes and therefore may be expected to respond differently to
174 enhancements within Box-gum temperate woodlands.

175 Species richness was a count of the number of individual species detected on a site.
176 Small-bodied birds were defined as those less than 70 grams in mass. We selected this body
177 mass as it corresponds birds smaller than the Noisy Miner and which are often subject to
178 physical harassment by that honeyeater species (Mac Nally *et al.* 2012). We extracted body
179 size data from compilations of bird biology and ecology published in various ornithological
180 monographs (e.g. Higgins 1991-2006).

181 We considered the following variables in constructing statistical models to address
182 our research question: survey year (denoted by Y), years since any enhancement (size or
183 underplanting), denoted by YSE, years since under planting (denoted by YSUP), years since
184 increase in patch size (denoted by YSSI) and finally, years since both underplanting and size
185 increase (denoted by YSUPSI). For all years since enhancement variables, sites that were not
186 subject to enhancement were coded as zero. We allowed for potential of quadratic effects of
187 survey year and their interaction with time since enhancement (see Appendix Table 1 for a
188 listing of the 44 models we constructed). We employed leave-one-out-cross-validation-
189 information criteria (LOOIC) (Watanabe 2010; Gelman *et al.* 2014; Vehtari *et al.* 2016) to
190 choose the simplest model within two LOOIC units of the best fitting model (Appendix Table
191 2). We elected to retain log patch size in all models because of well documented species-area
192 relationships (Rosenzweig 1995) and also the fact that some species are more likely to occur
193 in large patches of woodland habitat (Montague-Drake *et al.* 2009).

194 The above models were fitted to overall bird species richness, richness of small-
195 bodied birds and the richness of honeyeater species via a multilevel Bayesian Poisson
196 regression model with random effects for farm and site within farm. A multilevel Bayesian
197 Logistic regression model was fit to presence/absence data for seven individual bird species.

198 We completed Bayesian regression analysis using the brms package in the statistical
199 program R (Buerkner 2017). We used the default priors and settings in the brms package to

generate 4000 (4 chains run for 2000 iterations with the first 1000 discarded for burn-in) Markov chain Monte Carlo (MCMC) samples from the posterior distribution. The chains exhibited adequate mixing as evidenced by the Gelman and Rubin diagnostic statistic being close to 1 for all model parameters and the chains showed very little evidence of auto-correlation (Gelman & Rubin 1992). We present posterior means and 95% credible intervals for relevant model parameters.

Results

Effects of time since enhancement and enhancement type

Our analyses contained evidence of a range of sometimes complex time since enhancement effects for the array of response variables examined (see Appendix Tables 3-12 for the final models selected for each response variable). We found an interaction between time since any kind of enhancement and the quadratic effect of year in models for overall species richness (Figure 2a), and the richness of small-bodied species (Figure 2b). The effect of enhancement was initially negative for overall species richness but this effect was mitigated in later years (after 2008). The richness of small-bodied bird species also was initially negatively affected by enhancement. However, this trend also reversed in later years (after 2009). We found evidence of an interaction between years since enhancement and year for the Rufous Songlark; enhancement negatively influenced the presence of the Rufous Songlark in all years, but this effect lessened in later years (Figure 3).

There was a negative association between years since enhancement (irrespective of intervention type) and the presence of the Noisy Miner (Figures 4a and 4b). The presence of Superb Fairy-wren was positively associated with time since any form of enhancement (Appendix Table 6). In the case of the Yellow-rumped Thornbill, the presence of the species increased with time since enhancements that led to an increase in patch size (Figure 5a). For the White-plumed Honeyeater, there was a positive response to time since both underplanting

and increase in patch size (Figure 5b). Finally, the best fitting model for the richness of honeyeater species and two individual species (the Willie Wagtail and Red Wattlebird) contained no effects of time since enhancement and/or the type of enhancement (Appendix Tables 8 and 11, respectively).

Other effects

In addition to the effects of time since enhancement and type of enhancement, our analyses also provided evidence of the effects of patch size and time (as reflected by survey year). We found evidence of a positive response to patch size for the Noisy Miner (Appendix Table 12) but negative effects for the Rufous Songlark (Appendix Table 10) and Yellow-rumped Thornbill (Appendix Table 7). There also was a marginal negative effect of patch size for the Willie Wagtail and the Red Wattlebird (Appendix Tables 8 and 11, respectively). There were no patch size effects for overall bird species richness (Appendix Table 3), small-bodied bird species richness (Appendix Table 4), and the richness of honeyeater species (Appendix Table 5).

There were positive survey year effects (reflecting changes over time) for the Yellow-rumped Thornbill (Appendix Table 7) but negative effects for the Noisy Miner (Appendix Table 12), White-plumed Honeyeater (Appendix Table 9) and the Rufous Songlark (Appendix Table 10). The richness of honeyeater species also decreased with survey year (Appendix Table 5).

Discussion

We implemented a 15-year experiment to test aspects of the effectiveness of management interventions to enhance patches of the endangered box-gum grassy woodlands. There was no simple answer to the key question we posed at the outset of this investigation: Do birds respond to increasing time since restoration enhancement, and if so, which kind of enhancement – an increase in woodland patch size or understorey establishment? This was

because response of bird biota varied markedly depending on which measure was being examined and also often varied over time. For example, overall bird species richness initially responded negatively to enhancements but the effects were mitigated over time, similarly for individual species such as the Rufous Songlark. In the case of the Noisy Miner, responses to enhancement were negative and remained so over time. Conversely, the White-plumed Honeyeater, Yellow-rumped Thornbill and Superb Fairy-wren responded positively to enhancements. We also found evidence for variable responses to the kind of enhancement with some species responding to enhancements to increase woodland patch size (e.g. Yellow-rumped Thornbill), others to a combination of enhancements (e.g. White-plumed Honeyeater), whereas yet others were agnostic to the kind of intervention that was implemented (e.g. Noisy Miner). We further discuss the key findings of our study in the remainder of this paper and conclude with some commentary on the implications of our research for woodland restoration and management.

General findings

A key finding from this study was the marked variation in response to both time since enhancement and the type of enhancement. Unexpectedly, enhancement had a negative effect on overall bird species richness, although such effects dissipated over time (Figure 2a). It is possible that changes in woodland patches associated with management intervention such as soil disturbance and modification of the ground cover may initially have had negative effects on some taxa. In the case of the species of small-bodied bird species, it took approximately six years for negative effects of intervention to change to positive effects (Figure 2b). Thus, for these kinds of birds, there was a generally positive, although time-lagged, response to management intervention with increasing time since woodland patch enhancement. This was broadly consistent with expectations at the outset of this investigation (see Introduction) as well as a global meta-analysis of studies of the response of biodiversity to restoration

(Crouzeilles *et al.* 2016). Thus, the longer the time for restored vegetation to mature, the more suitable it is likely to become as habitat for more species of small-bodied birds. We suggest that, consistent with the landscape texture hypothesis (see Fischer *et al.* 2008), the development over time of an increased density of vegetation is the most likely explanation for temporal increases in the species richness of small-bodied bird species. We recognize, however, that the quadratic effects for overall species richness (Figure 2a) and the richness of small-bodied birds (Figure 2b) suggest that monitoring over longer periods than the 15 years of this study may be required to better determine if there is an ongoing temporal increase in these response variables.

An encouraging aspect of this study was the range of kinds of birds (e.g. small-bodied species, some species of honeyeaters) that responded positively to the enhancement of woodland patches. This suggests that enhancement, either to expand the size of existing woodland patches and/or establish understorey vegetation is an inherently positive management action for some kinds of woodland birds. For example, whilst there was evidence that species such as the White-plumed Honeyeater were undergoing declines, the opposite was the case in woodland patches that had been subject to either underplanting or an increase in size (Figure 5b).

An unexpected finding from our empirical study was that few of our final models differentiated between the effects of underplanting relative to the effects of increasing the size of woodland patches. That is, there were effects of time since enhancement *per se*, but not which kind of enhancement. One possible reason for this finding was that some bird species respond to the stand structural complexity (*sensu* Lindenmayer & Franklin 2002) created by establishing either understorey and shrub cover (as part of underplanting) or overstorey trees (that expand patch size). In essence, in the early years of an enhancement and when newly established plants are relatively immature, both kinds of vegetation

enhancement may have similar impacts on vegetation structure in terms of habitat suitability for birds. It is possible, that over longer periods than the duration of the study reported here, bird species may more clearly distinguish between different kinds of woodland enhancement. Again, long-term monitoring will be required to determine if this is indeed the case.

Our analysis revealed two individual species (the Red Wattlebird and Willie Wagtail) for which there were no responses to any of the enhancement variables we analysed. The reason for the paucity of responses remain unclear, particularly for the Willie Wagtail which, in other studies, has been found to be common in areas of planted (revegetated) temperate woodland (Lindenmayer *et al.* 2010b; Debus *et al.* 2017). In the case of the Red Wattlebird, which feeds extensively on flowering trees, understorey plantings and the establishment of areas of young trees to expand patches may not yet support enough large trees to provide the nectar and other flower-based resources that are important to such kinds of biodiversity.

Negative responses of the Noisy Miner to management intervention

We found strong evidence of reduced presence of the Noisy Miner in response to woodland enhancement. This was a positive result as this hyper-aggressive native honeyeater has major antagonistic impacts on many other bird species, leading to significantly impoverished bird species richness and highly simplified bird assemblages (Mac Nally *et al.* 2012; Mortelliti *et al.* 2016). Culling is one of the methods being trialled to help control the Noisy Miner (see Grey *et al.* 1997) but this has met with limited success in some heavily cleared farming landscapes (R. Beggs, personal communication, 2017). Past studies have shown that the Noisy Miner rarely occupies plantings (Lindenmayer *et al.* 2016) and efforts to enhance woodland remnants may render them unsuitable for this species. Therefore, the results of this study have helped identify a strategy to reduce populations of the Noisy Miner in patches of remnant woodland.

Implications for restoration management

Large areas of the earth's surface are degraded and in need of vegetation restoration. Indeed, restoration is a major global enterprise spanning millions of hectares (Crouzeilles *et al.* 2017) and attracting billions of dollars in investment (Menz *et al.* 2013). Therefore, work that both quantifies the effectiveness of such investments for biodiversity and compares the efficacy of different approaches is of clear importance. The study reported here is a rare investigation that contrasted different kinds of interventions in one of the world's most extensively modified, large-scale biomes (Hoekstra *et al.* 2005) and there are several important implications from our empirical study.

First, our work has highlighted that there can be time lags between the implementation of enhancements and the positive responses of some bird biota. Much has been written about time lags in the loss of species from modified environments (e.g. extinction debts McCarthy *et al.* 1997; Berglund & Jonsson 2005; Ford *et al.* 2009), but less attention has been paid to the time lags it may take to recover habitat suitability for biodiversity in restored ecosystems (Vesk *et al.* 2008). This highlights the importance of policies that allow restored vegetation sufficient time to become habitat for biodiversity and, conversely, the deep-seated problems with recent legislative changes in some parts of Australia (such as in the State of New South Wales) that allow areas of restored vegetation to be cleared. Second, the results of this study suggest that establishing enhancements in woodlands can help counter major problems such as high populations of the Noisy Miner that have developed across large parts of Australian agricultural landscapes. Third, our work contained evidence that marked temporal declines in some species (such as the White-plumed Honeyeater) may be arrested by enhancement of woodland patches. Fourth, we found few differences in responses to the kind of enhancement. Hence, there can be value in either or both expanding the size of woodland patches or underplanting those patches. This creates important management options for farmers for whom a loss of land for livestock production

and cropping is one of the substantial barriers to establishing areas of revegetated woodland on farms. An alternative to expanding existing remnants is to establish an underplanted shrub and midstorey layer within those remnants, with limited (if any) loss of productive grazing land but with positive outcomes for native biota.

Conclusions

We quantified the response of bird biota to woodland patch enhancement in the endangered box-gum grassy woodlands of south-eastern Australia. Our empirical results were characterized by marked inter-specific and species richness variation in bird response to both time since enhancement and the type of enhancement. Positive effects of enhancement were often time lagged for 6-8 years following instigation of underplanting and/or increases in woodland patch size. Our final statistical models for species richness and for individual species responses typically did not distinguish between the effects of underplanting or increases in woodland patch size. This suggests that, for many species, either option will have positive effects. Notably, patch enhancement had negative effects on the Noisy Miner indicating that underplanting and/or increases in woodland patch size may represent ways in which the impacts on other bird taxa of this despotic, hyper-aggressive species might be mitigated.

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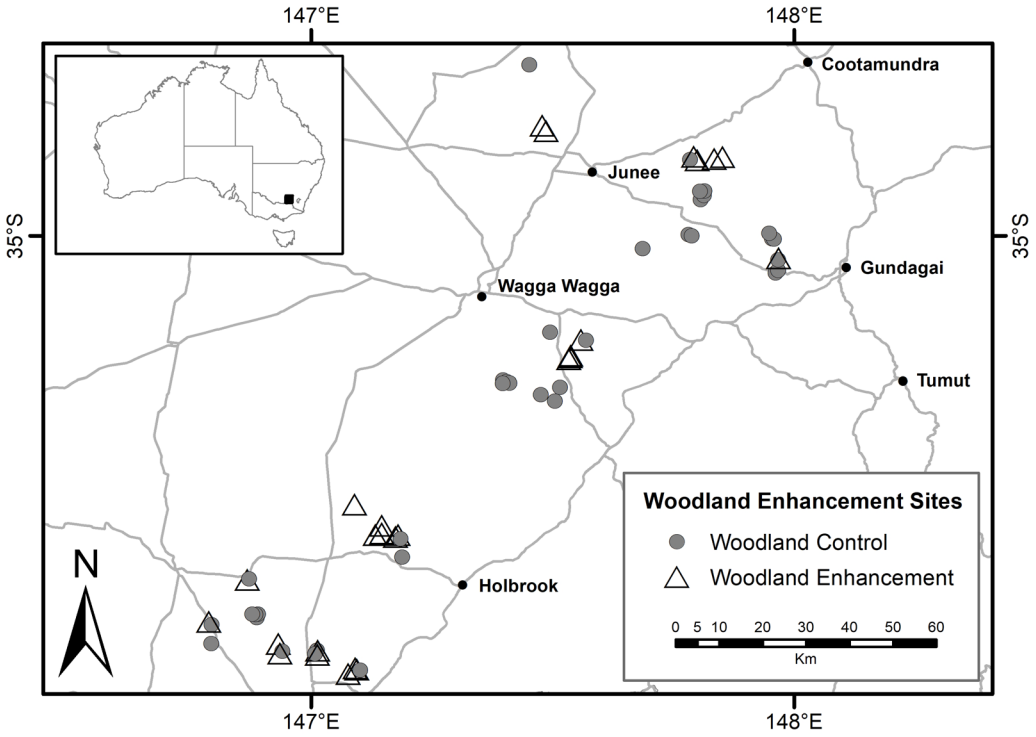
474 **Figure legends**

475 **Figure 1.** The study area showing the location of underplanting and patch expansion

476 treatments as well as the control patches (where no intervention occurred) subject to repeated

477 surveys of birds in the South West Slopes of New South Wales.



478

479

Figure 2. Plots showing interaction between the quadratic effect of survey year and years since any enhancement on (a) overall bird species richness and (b) richness of small-bodied species. The plots show the slope estimate for years since any enhancement for each survey year. The line of zero slope is indicated by the horizontal line and we present posterior means and 95% credible intervals.

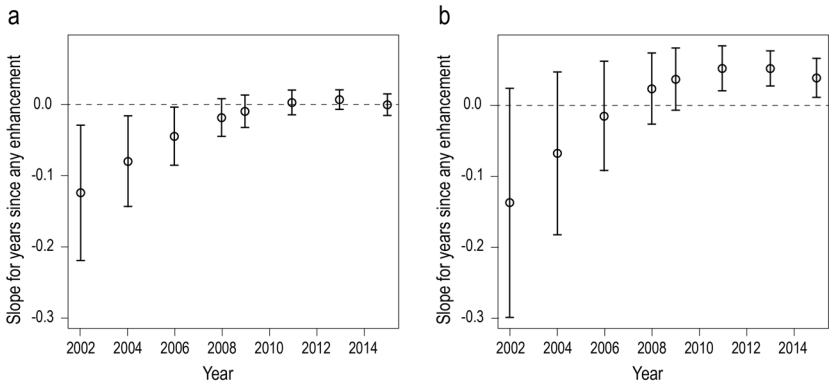


Figure 3. Relationships between the number of years elapsed since underplanting in woodland remnants and the response of the Rufous Songlark. The plot shows the slope estimate for years since any enhancement for each survey year. The line of zero slope is indicated by the horizontal line and we present posterior means and 95% credible intervals.

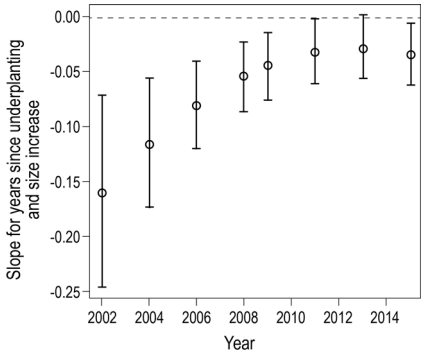


Figure 4. Relationships between the occurrence of the Noisy Miner and: (a) the number of years elapsed since enhancement in woodland remnants and (b) time (as reflected by survey year). For panel b): the solid line (and darker grey credible region) represent the probability of detection for control site, while the dashed line (and light grey credible region) represents a site that was enhanced in 2005. We plot posterior mean and 95% credible intervals (shaded area) as a function of years since any enhancement or survey year.

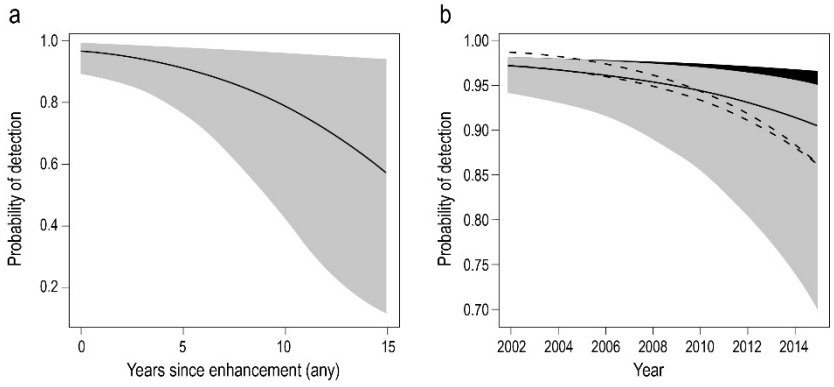
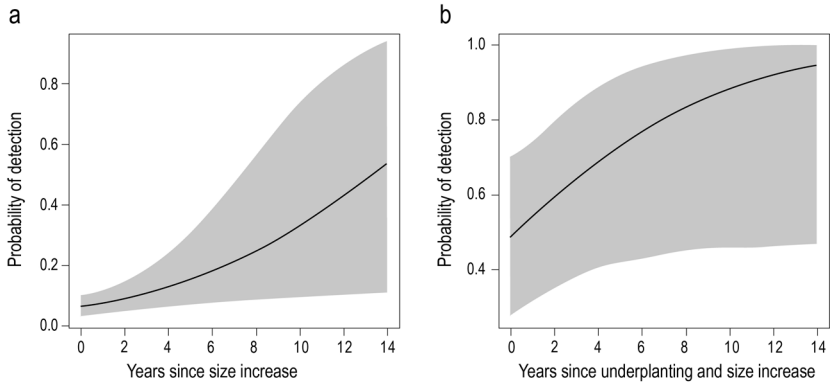


Figure 5. Relationships between the type of enhancement and the occurrence of the: (a) Yellow-rumped Thornbill (increased patch size) and (b) White-plumed Honeyeater (increased patch size and underplanting). We plot posterior mean and 95% credible intervals (shaded area) as a function of years since enhancement as appropriate for each species.



506 **Appendices**

507 **Appendix Table 1:** Listing of the 44 models considered. Note all models have log patch size
508 and a random effect for site included. Note, we have used the following shorthand in this
509 table: Y = survey year (standardized), YSE = years since enhancement (either increase in size
510 or under planting or both), YSUP = years since under planting, YSSI = years since size
511 increase and YSUPSI = years since under planting and size increase. Note that A:B indicates
512 the interaction between terms A and B and (A + B):(C+D) = A:C + A:D + B:C + B:D.

Model #	Terms
1	1
2	Y
3	Y + Y^2
4	YSE
5	Y + YSE
6	Y + Y^2 + YSE
7	Y + YSE
8	Y + Y^2 + YSE + Y:YSE
9	Y + Y^2 + YSE + Y:YSE + Y^2:YSE
10	YSUP
11	YSSI
12	YSUPSI
13	YSUP + YSSI
14	YSUP + YSUPSI
15	YSSI + YSUPSI
16	YSUP + YSSI + YSUPSI

17	Y + YSUP
18	Y + Y^2+ YSUP
19	Y + YSSI
20	Y + Y^2+ YSSI
21	Y + YSUPSI
22	Y + Y^2+ YSUPSI
23	Y + YSUP + YSSI
24	Y + Y^2+ YSUP + YSSI
25	Y + YSUP + YSUPSI
26	Y + Y^2+ YSUP + YSUPSI
27	Y + YSSI + YSUPSI
28	Y + Y^2 + YSSI + YSUPSI
29	Y + YSUP + YSSI + YSUPSI
30	Y + Y^2+ YSUP + YSSI + YSUPSI
31	Y + YSUP + Y:YSUP
32	Y + Y^2+ YSUP + (Y + Y^2):YSUP
33	Y + YSSI:Y:YSSI
34	Y + Y^2+ YSSI + (Y +Y^2):YSSI
35	Y + YSUPSI + Y:YSUPSI
36	Y + Y^2 + YSUPSI + (Y + Y^2):YSUPSI
37	Y + YSUP + YSSI + Y:(YSUP + YSSI)
38	Y + Y^2 + YSUP + YSSI + (Y + Y^2):(YSUP + YSSI)
39	Y + YSUP + YSUPSI + Y:(YSUP + YSUPSI)
40	Y + Y^2+ YSUP + YSUPSI + (Y + Y^2):(YSUP + YSUPSI)

41	Y + YSSI + YSUPSI + Y:(YSSI + YSUPSI)
42	Y + Y^2 + YSSI + YSUPSI + (Y + Y^2):(YSSI + YSUPSI)
43	Y + YSUP + YSSI + YSUPSI + Y:(YSUP + YSSI + YSUPSI)
44	Y + Y^2 + YSUP + YSSI + YSUPSI + (Y + Y^2):(YSUP + YSSI + YSUPSI)

513

514 **Appendix Table 2:** Delta LOOIC (leave one out cross-validation information criteria) for each of the ten response variables and the 44 models.

515 The simplest model within 2 delta LOOIC is bolded for each response variable. The list of models fit is given in Appendix Table 1.

Model Number	SR	Small Bird SR	Honeyeater SR	Superb Fairy-wren	Yellow-rumped Thornbill	Willie Wagtail	White-plumed Honeyeater	Rufous Songlark	Red Wattlebird	Noisy Miner
1	12.7	31.8	8.2	61.2	16.8	**0**	3.4	3.3	**0**	37
2	15.1	28	**0**	15.7	4.6	2.1	3.2	6.1	2.1	5.9
3	7	27.9	1.8	18.2	7	4	6.1	8.2	0.3	7.1
4	13.8	4.2	7.6	**1.6**	8.1	1.8	3	4.5	1.3	7.1
5	15.2	5.3	0.5	0	4.8	1.1	2	5.8	2.8	**1.4**
6	6.2	2.8	2.1	3.3	7.3	3.2	2.9	8.6	1.7	0
7	16.1	6.2	1.8	3.4	7.9	1.4	2.1	8.6	2	2.8
8	5.3	4.5	3	4.7	10.4	4	3.9	10.6	2.5	2.3
9	**0**	**0**	4.4	5	10.5	2.3	4.5	12.6	6.5	4.7
10	14	26	8.2	30.6	18.3	1.4	6.1	2.7	0.8	27.3
11	11.6	20.6	8.6	46.4	5.4	3.1	6.8	6.3	1.6	29.8
12	13.8	26.3	8.9	48.8	17.8	2.3	**1.7**	3.6	3.3	29.3

13	14.2	13.2	8.7	14.9	7	5.2	8	5	1.5	19.2
14	17	19.2	9.6	17.2	19.2	4.1	3.2	2.6	3.9	17.2
15	13.8	13.3	9.2	35.5	6.6	5.4	4.6	6.2	5.2	22.3
16	15.8	7.2	10.5	4.8	8.2	6.9	5.9	6.4	6.3	8.8
17	16.7	25.8	1	3.1	7.3	3.9	5.9	5.9	2.1	7
18	7.9	25.7	2.6	9.1	9.6	6.5	6.7	7.4	0.8	6.4
19	13.7	20.8	0.7	17.6	**0**	6.6	5.1	7.4	3.6	8
20	4.5	21.8	2.5	20.7	4	7.8	8.7	9.7	2.5	8.6
21	16.6	24.7	1.4	14.9	7	6.2	0	7	4.4	3.5
22	8	24.8	3	18.4	8.4	6.7	1.9	8.2	5.2	5.1
23	14.5	16.8	2.7	7.5	3.4	4.5	7.2	7.5	3	7.8
24	6.6	14.4	4	11.2	6	8	11.7	10.1	2.6	7
25	18.4	20.2	2.4	2.8	8.8	5.8	0.4	5.3	5.1	2.7
26	10	19.8	4	6.6	10.8	7.9	2	7.6	4.4	2
27	15	15.9	2.6	17.8	2.1	7.3	0	7.9	6.7	4
28	6.6	13.4	3.7	19.9	5.6	10.3	3.5	10	5.7	5
29	16.4	8.7	3.4	3.3	4.9	6.7	1.3	7.5	6.8	3.6

30	7.5	5.5	4.6	6.1	7.5	9.9	3.7	10.4	4.9	2.3
31	17.6	27.2	1.7	8	10.1	4	7.7	5.8	1.1	7.7
32	8.6	25	4.7	12.9	17.6	8.2	13	10	4.5	9.3
33	15.4	21.9	1.5	19.3	3.4	5.9	6.7	8.2	3.3	10.6
34	4.4	21.6	6.5	29	9.1	6	13.7	12.8	7	13.5
35	19.1	27.6	3.3	17.6	7.8	5.7	0	10.1	10.6	4.3
36	11.5	27.3	6.5	24.6	12.4	11.1	1.4	**0**	16	7.5
37	19.9	19.4	3.4	12.9	10.6	8.7	14.6	10	2.5	10.6
38	6.7	16.2	8.7	22.2	18.2	8.1	18.9	14.5	11	18
39	22.4	24.6	4.3	9.3	13.4	7	5.2	9.4	7.7	4.8
40	12.5	23.8	9.3	15.7	23.4	12.4	8.8	0.8	21.9	11.1
41	19.9	22	5.5	22.7	6.6	10.4	6.3	12.9	11.4	8.3
42	9.6	18.5	10.4	34.5	14.9	10.9	8.1	4.7	22.9	13.3
43	23.5	14.4	7.3	10.4	12.3	11.7	8.9	12.8	9.2	7.3
44	9.9	9.8	12.6	20.1	27	13.8	14.1	6.9	26.4	15.7

516

Appendix Table 3: Model summary for overall species richness, where LPS = log patch size, YSE = years since enhancement (any) and Y = survey year standardized.

	Estimate	l-95% CI	u-95% CI
Intercept	2.553	2.407	2.705
LPS	-0.013	-0.093	0.064
YSE	-0.014	-0.038	0.01
Y	-0.018	-0.05	0.014
Y^2	-0.048	-0.08	-0.018
YSE:Y	0.039	0.011	0.067
YSE:Y^2	-0.02	-0.035	-0.003
Site random effect	0.278	0.227	0.343

Appendix Table 4: Model summary for small bird species richness, where LPS = log patch size, YSE = years since enhancement (any) and Y = survey year standardized.

	Estimate	l-95% CI	u-95% CI
Intercept	1.513	1.118	1.889
LPS	-0.194	-0.408	0.023
YSE	0.031	-0.014	0.078
Y	-0.029	-0.083	0.024
Y^2	-0.04	-0.094	0.014
YSE:Y	0.055	0.008	0.102
YSE:Y^2	-0.032	-0.057	-0.006
Site random effect	0.801	0.658	0.987

523 **Appendix Table 5:** Model summary for Honeyeater species richness, where LPS = log patch
524 size and Y = survey year standardized.

	Estimate	l-95% CI	u-95% CI
Intercept	0.464	0.315	0.615
LPS	-0.01	-0.092	0.074
Y	-0.104	-0.176	-0.035
Site random effect	0.16	0.021	0.279

525

526 **Appendix Table 6:** Model summary for Superb Fairy-wren, where LPS = log patch size and
527 YSE = years since enhancement (any).

	Estimate	l-95% CI	u-95% CI
Intercept	-4.212	-6.517	-2.373
LPS	-0.508	-1.697	0.577
YSE	0.536	0.373	0.731
Site random effect	3.003	1.975	4.491

528

529 **Appendix Table 7:** Model summary for Yellow-rumped Thornbill, where LPS = log patch
530 size, Y = survey year and YSSI = years since size increase.

	Estimate	l-95% CI	u-95% CI
Intercept	-1.807	-2.779	-0.948
LPS	-0.609	-1.175	-0.102
Y	0.44	0.117	0.77
YSSI	0.207	0.04	0.39
Site random effect	1.372	0.85	2.026

531

532 **Appendix Table 8:** Model summary for Willie Wagtail, where LPS = log patch size.

	Estimate	l-95% CI	u-95% CI
Intercept	1.593	0.214	3.093
LPS	-0.769	-1.605	0.021
Site random effect	2.724	1.999	3.703

533

534 **Appendix Table 9:** Model summary for White-plumed Honeyeater, where LPS = log patch

535 size and YSUPSI = years since under planting and size increase

	Estimate	l-95% CI	u-95% CI
Intercept	1.057	-0.64	2.876
LPS	-0.729	-1.721	0.174
YSUPSI	0.213	-0.005	0.444
Site random effect	3.239	2.336	4.444

536

537 **Appendix Table 10:** Model summary for Rufous Songlark, where LPS = log patch size, Y =

538 survey year (standardized), and YSUPSI = years since under planting and size increase.

	Estimate	l-95% CI	u-95% CI
Intercept	-0.121	-1.126	0.836
LPS	-0.538	-1.067	-0.002
Y	0.036	-0.194	0.264
Y^2	0.035	-0.226	0.289
YSUPSI	-0.131	-0.54	0.253
Y:YSUPSI	1.368	0.5	2.429
Y^2:YSUPSI	-0.839	-1.465	-0.324

Site random effect	1.764	1.285	2.385

Appendix Table 11: Model summary for Red Wattlebird, where LPS = log patch size.

	Estimate	l-95% CI	u-95% CI
Intercept	-1.67	-2.63	-0.814
LPS	-0.481	-1.015	0.015
Site random effect	1.302	0.739	2.004

Appendix Table 12: Model summary for Noisy Miner, where LPS = log patch size, Y = survey year (standardized) and YSE = years since enhancement (any).

	Estimate	l-95% CI	u-95% CI
Intercept	0.983	-0.86	2.952
LPS	1.545	0.399	2.892
Y	-0.627	-1.025	-0.244
YSE	-0.206	-0.388	-0.044
Site random effect	3.334	2.265	4.817