Effects of surrounding land use change on nesting success of small-bodied birds in *Eucalyptus* woodland remnants

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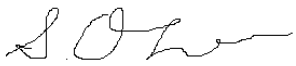
Candidate's declaration

This thesis contains no material which has been accepted for the award of any other degree or diploma in any university. The research presented in this Thesis represents original work that I carried out during my candidature at the Australian National University. To the best of author's knowledge, it contains no materials previously published or written by another person, except where due reference is made in the text.

Sachiko Okada 22 June 2020



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Abstract

Land has been extensively modified in response to human needs for thousands of years. In recent times, the change in land use from agricultural areas to tree plantations has been expanding worldwide to satisfy the increasing demands for wood/paper products. In Australia, some areas of cleared agricultural land have been transformed into exotic pine plantations, particularly in New South Wales (NSW). Species occurring in fragments of remnant native vegetation, including birds, may be influenced by the effects of new forms of surrounding land use dominated by exotic Radiata Pine (*Pinus radiata*) plantations.

In this thesis, I sought to quantify how the transformation of landscapes from grazing land to exotic pine plantations influenced the breeding success of small-bodied birds in woodland remnants. I also sought to determine if the results from artificial nests were broadly consistent with those obtained from natural nests. To achieve these aims, I conducted a series of studies of natural and artificial nests in the Nanangroe State Forest and in the surrounding private farmlands in south-eastern NSW, Australia. My study sites were *Eucalyptus* woodland remnants surrounded by one of two types of matrix; grazing land or maturing stands of Radiata pine plantation.

In the natural nest study (Chapter 2), I found significantly fewer nests in woodland remnants surrounded by the plantation than in woodland remnants located in farmland. The proportion of nests of generalist avian nest predators was significantly higher in woodland remnants surrounded by the plantation, compared to woodland remnants surrounded by farmland. In general, I found that breeding success of birds with a larger mean body mass was higher than small-bodied birds, and small-bodied birds reproduced more successfully at a lower nest height. Notably, nesting activity of some forest taxa, including species of conservation concern, was observed both in woodland remnants surrounded by the plantation and in the plantation matrix.

In experiments using two types of artificial nests (Chapter 3), I found the following patterns. **(1)** The majority of nest predators were birds. **(2)** There were higher levels of nest predation in woodland remnants surrounded by the plantation than in woodland remnants located within farmland, with cup nests being inferior to domed nests against nest predation in the both landscape contexts, and **(3)** Both natural and artificial nests were more susceptible to nest predation in woodland remnants surrounded by the plantation than in woodland remnants located within grazing paddocks.

Overall, my research has shown that land use change from grazing areas to exotic pine plantations may provide more habitats for small-bodied forest species including the Flame Robin (*Petroica phoenicea*), a vulnerable species in NSW. Conversely, landscape transformation may reduce the amount of habitat for ground-foraging small-bodied woodland birds, such as the Brown Treecreeper (*Climacteris picumnus victoriae*) and Dusky Woodswallow (*Artamus cyanopterus*), which are also vulnerable in NSW. Conservation of small-bodied forest versus woodland taxa may require different kinds of management within plantations. However, retaining woodland remnants within the boundaries of plantations benefits a range of kinds of native birds, including forest and woodland taxa.

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Chapter 1: Introduction

1.1 Background

Habitat loss through vegetation clearing is a key driver of biodiversity loss worldwide, including the loss of bird biota (Haddad et al., 2015; Ceballos et al., 2017). In some landscapes, however, further vegetation clearing may be limited because remnants are protected by laws or regulations (Fulton, 2018), or simply there may not be much vegetation left (Driscoll et al., 2013). Conversely, land use in areas where vegetation was cleared, has been modified in response to changing human needs (DeFries et al., 2007; Jose and Padmanabhan, 2015; Creutzig et al., 2019). Consequently, land use in areas adjacent to vegetation remnants can be subject to change, and this may be an emerging threat for biodiversity currently persisting in vegetation remnants (Lindenmayer et al., 2019).

Land use conversion from agriculture to tree plantations is a recent major form of landscape transformation worldwide, particularly to meet increasing demands for wood/paper products (FAO 2010; Paquette and Messier 2010; Hulvey et al. 2013; Mortelliti and Lindenmayer 2015; Lewis et al., 2019). The total area of tree plantations has been expanding worldwide, and it will exceed 300 million hectares by 2020 (FAO, 2010; Mortelliti and Lindenmayer, 2015).

In Australia, substantial areas of temperate *Eucalyptus* woodland, which is now one of the most threatened vegetation communities nationwide (Prober et al., 2017; Department of Environment and Energy, 2019), have been cleared to establish agricultural land (Yates and Hobbs, 1997; Gibbons and Boak, 2002; Lindenmayer et al., 2019). Many species of birds have experienced population declines as a result (Ford et al., 2001; Bennett and Watson, 2011). More recently, agricultural land, particularly in south-eastern New South Wales (NSW) but also in western Victoria and South Australia, has extensively and rapidly been

transforming to exotic Radiata Pine plantations (Lindenmayer et al., 2001). Indeed, the total area of pine plantations in NSW has been increasing annually (Forestry Corporation of NSW, 2016).

Landscape transformation from grazing land to exotic pine plantations is associated with a change of matrix surrounding patches of remnant native vegetation (where the matrix is defined as areas surrounding vegetation remnants; Driscoll et al., 2013). The effects of matrix change may affect movement/dispersal of species, resource availability and the abiotic environment (Driscoll et al., 2013). Matrix effects can be magnified by the land use intensification in matrix (Deikumah et al., 2013), or where the matrix is dominated by one type of land use rather than by multiple types of land use (Driscoll et al., 2013). In addition, a matrix may be utilised as breeding/foraging sites and/or movement corridors between remnants (Tubelis et al., 2004; Mortelliti and Lindenmayer, 2015), which may affect the dynamics of population of species inhabiting vegetation remnants. Furthermore, new species may colonise vegetation remnants due to a change of surrounding matrix (Lindenmayer et al., 2008; Lindenmayer et al., 2015). In contrast, a matrix may be so hostile that it acts as a fence or barrier and "trap" species within remnants (Harris and Reed, 2002; Schtickzelle and Baguette, 2003; Giubbina et al., 2018).

Breeding success is a critical ecological process which may influence population trajectories and hence affect species persistence (With et al. 2006; Cruz-McDonnell and Wolf 2016). The abundance and species richness of birds also may be affected by breeding success (Lindenmayer et al., 2009; Hansen et al., 2019). Reproductive success of birds occupying vegetation remnants can be influenced by matrix or landscape context effects (Cottam et al., 2009; Lindenmayer et al., 2009; Pretelli et al., 2015). However, few studies have quantified the effects of matrix change on bird breeding success in fragmented agricultural landscapes undergoing transformation to pine plantations.

Many artificial nest experiments have been conducted to quantify the factors affecting bird breeding success (Major and Kendal, 1996; Lewis et al., 2009; Ford, 2018). They have been used widely because nest predation is a major determinant of nest failure of natural nests (Ricklefs, 1969; Husby and Hoset, 2018), and the use of artificial nests can allow researchers to create studies with a large number of samples (Wilson et al., 1998; Moore and Robinson, 2004). The findings of some artificial nest experiments have contributed substantially to current knowledge about bird conservation and management (Major and Kendal, 1996; Burke et al., 2004). However, some authors have raised concerns about whether the results of artificial nest experiments accurately reflect reproductive success, daily survival rates and nest predation rates of natural nests (King et al., 1999; Zanette, 2002; Thompson and Burhans, 2004). In fact, results have been found to be different between artificial nest experiments and natural nest studies that both quantified the effects of the same factor (e.g. nest type and proximity to edge) (Major and Kendal, 1996; Fulton, 2019).

Two main reasons may explain differences in results between artificial nest and natural nest studies. First, many researchers assume that artificial nests are preyed upon in the same way as natural nests (Major and Kendal, 1996; Fulton and Ford, 2001). However, artificial nests/eggs may attract different nest predators to those of natural nests. Different kinds of nest predators may have different foraging strategies, hence different levels of nest predation may be detected between artificial and natural nests (Moore and Robinson, 2004; Chmel et al., 2018). To overcome this issue, effort needs to be injected into the preparation of artificial nests/eggs (Berry and Lill, 2003). In addition, the types of potential nest predators should be the same in studies of artificial and natural nests (Mezquida and Marone, 2003; Villard and Pärt, 2004; Chmel et al., 2018).

Second, differences in study conditions, such as the type of habitat and landscape characteristics, between artificial nest experiments and studies of natural nests, may lead to

differences in results between the two types of studies. Well-designed artificial nest experiments should be compared with natural nest studies that were conducted on the same study sites (Faaborg, 2004). However, to the best of my knowledge, no such study has been conducted in a landscape being transformed from agriculture to one dominated by pine plantations. Since conversion of degraded farmland to tree plantations is likely to expand to meet increasing demands for paper/wood products (Lindenmayer et al., 2015; FAO, 2016), it is critical to better understand how such landscape transformation would influence the survival of birds, and to verify if artificial nest experiments produce similar findings to those of natural nests.

1.2 Objectives, aims of thesis and thesis chapters

The objective of this thesis was to provide new insights into the impacts of landscape transformation from agricultural land to exotic pine plantations on the survival of small-bodied birds inhabiting vegetation remnants. To achieve this objective, I collected data on breeding success by observing natural nests and conducting artificial nest experiments in a landscape that is subject to extensive and rapid transformation from semi-cleared grazing land to Radiata pine plantations in south-eastern NSW, Australia.

The specific aims of my empirical study were as follows: **(1)** To determine if the reproductive success of small-bodied birds in woodland remnants varied between areas where the surrounding land was dominated by grazing farmland versus where it was dominated by pine plantation, and **(2)** To determine if the results of a natural nest study were similar to those from artificial nest experiment. A better understanding of matrix change effects on bird reproductive success may contribute to improved management of existing and prospective pine plantations for bird conservation.

In Chapter 2, I investigated bird breeding success in two landscape contexts; woodland remnants located in grazing land vs woodland remnants surrounded by a pine

plantation. I also sought to determine if any of the following factors influenced nesting success: **(1)** The amount of native woody vegetation cover in the vicinity of nests, **(2)** Bird life-history attributes (nest type and body mass), and **(3)** Nest characteristics (e.g. nest height).

Chapter 3 provides information on nest predators and nest predation risk in the two types of landscape contexts. Specifically, I posed the following three questions. **(1)** Are major predators on artificial nests different in the two types of landscape contexts, and due to such differences (if they exist), does nest predation risk differ in the two types of artificial nests (cup versus domed nest)? **(2)** Do levels of predation vary between the two types of landscape contexts? **(3)** Do predation rates of artificial nests reflect the relative predation rates of natural nests?

Chapter 4 contains a brief overview summary of the preceding chapters. It discusses the effects of matrix change on both forest and woodland taxa, the limitations of the study, and a short overview of artificial nest use in nest predation studies. Some recommendations are also presented for management of exotic pine plantations to enhance the conservation of bird biodiversity.

Following Chapter 4, I have provided several appendices, including species lists. The first list is a complete species list of natural nests that I found in the both types of landscape contexts. The other is a species list of birds for which breeding activities were incidentally observed in the pine plantation matrix adjacent to woodland remnants. I have also included several images of natural bird nests, woodland remnants in the study landscape, as well as examples of predation events captured by camera traps.

Chapters 2 and 3 are published papers in peer-reviewed scientific journals. Therefore, the formats are not consistent between chapters, and some of the content is similar.

Permits for conducting surveys were obtained from the New South Wales National Parks and Wildlife Service (SL100982). Ethics approval for the work reported here was granted by The Australian National University Animal Care and Ethics Committee (A2012/46, A2013/17).

Australian National University

Statement of Contribution

This thesis is submitted as a Thesis by Compilation in accordance with https://policies.anu.edu.au/ppl/document/ANUP_003405

I declare that the research presented in this Thesis represents original work that I carried out during my candidature at the Australian National University, except for contributions to multi-author papers incorporated in the Thesis where my contributions are specified in this Statement of Contribution.

Title: How does a landscape transformation influence bird breeding success?

Authors: Sachiko Okada, David B Lindenmayer, Jeff T Wood, Mason J Crane, Jennifer C Pierson

Publication outlet: Landscape Ecology

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Contribution to paper:

	Okada, S	Lindenmayer, DB	Wood, JT	Crane, MJ	Pierson, JC
Conception or design of the study	75%	✓		✓	
Data collection	100%				
Data analysis and interpretation	50%		✓		
Drafting the manuscript	90%	✓			
Revision and edits of the manuscript	40%	✓	✓	✓	✓

Senior author or collaborating authors endorsement: Sachiko Okada

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Endorsed

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David Lindenmayer			5 April 2019
Primary Supervisor – Print Name	Signature		Date
ADRIAN MANNING		1/5/19	
Delegated Authority – Print Name	Signature	Date	

Chapter 2: How does a transforming landscape influence bird breeding success?

Citation: Okada, S., Lindenmayer, D. B., Wood, J. T., Crane, M. J., Pierson, J. C. (2017) How does a transforming landscape influence bird breeding success? *Landscape Ecology*, 32 (5), pp. 1039-1048

2.1 Abstract

Context

The conversion of agricultural landscapes to tree plantations is a major form of landscape transformation worldwide, but its effects on biodiversity, particularly key population processes like reproductive success, are poorly understood.

Objectives

We compared bird breeding success between woodland remnants surrounded by maturing stands of plantation Radiata Pine and a matched set of woodland remnants in semi-cleared grazing land.

Methods

Our study was conducted in the Nanangroe region in south-eastern New South Wales, Australia. Using repeated field measurement, we quantified bird breeding success in 23 woodland remnants; 13 surrounded by Radiata Pine plantations and 10 on farms where remnants were surrounded by semi-cleared grazing land. We matched the attributes of native remnant patches between two types of matrix.

Results

We found that: (1) there was approximately three times more nests per site in remnants within farmland than remnants surrounded by the plantation; (2) The proportion of nests of generalist (non-woodland dependent) avian nest predators in remnants surrounded by the pine plantation was significantly higher than that of remnants within farmland; and (3) species

with domed nests were more successful at nesting than species which constructed open cup/bowl nests in woodland remnants within farmlands.

Conclusions

Our findings suggest that reduced overall abundance of nests and relatively low levels of nesting success in woodland remnants surrounded by stands of plantation pine, may have been underpinned by resource limitation (e.g. invertebrate prey) and a high abundance of avian predators.

2.2 Introduction

Landscape conversion is a major driver of species decline and local extinction (Bobo et al., 2006; Dornelas et al., 2014; Davidai et al., 2015). The conversion of agricultural landscapes to tree plantations is a significant form of landscape transformation worldwide, and is part of meeting increasing demands for wood and paper products, as well as timber and carbon sequestration (FAO, 2010; Paquette and Messier, 2010; Hulvey et al., 2013; Mortelliti and Lindenmayer, 2015). Planted forests are predicted to cover 300 million hectares globally by 2020 (FAO, 2010; Lindenmayer et al., 2015a).

There is a wealth of literature on the response of biodiversity to agricultural landscape conversion to tree plantations (Lindenmayer and Fischer, 2006; Felton et al., 2010), particularly bird biota (Wilson et al., 2014; Lindenmayer et al., 2015b; Mortelliti and Lindenmayer, 2015). The vast majority of these studies have documented patterns of species distribution and abundance but the key ecological processes underpinning these patterns remain largely unstudied. Breeding success is a critical ecological process influencing the likely persistence of species in natural and human-modified landscapes (Gill, 1985; With et al., 2006; Cruz-McDonnell and Wolf, 2016). Yet, there have been remarkably few studies of bird breeding success in transforming landscapes (although see Zanette et al., 2000). This, in

turn, limits understanding of the factors governing species occurrence and patch occupancy in such landscapes.

Areas converted to tree plantations are often in fragmented landscapes that contain remnant patches of native vegetation (Lindenmayer, 2009; Driscoll et al., 2013). Some species occupying native vegetation patches may be susceptible to edge effects as well as changes in the surrounding matrix (Driscoll et al., 2013) including impaired breeding performance (Hinsley et al., 1999; Zanette et al., 2000). For example, nest predation rates may differ in smaller patches due to increased edge effects (Lahti, 2001; Newmark and Stanley, 2011) as well as potential differences in landscape context (Lloyd et al., 2005) such as the predator community occupying the matrix (Donovan et al., 1997; DeGregorio et al., 2014). Rates of nest parasitism are also influenced by both edge effects and landscape context (Lloyd et al., 2005; Howell et al., 2007). However, there have been few studies of matrix effects on breeding success of birds inhabiting plantation-dominated landscapes.

To close this knowledge gap, we conducted an empirical study of bird breeding success in patches of remnant native woodland surrounded by areas which, in the last two decades, have been undergoing transformation from semi-cleared grazing land to plantations of exotic Radiata Pine (*Pinus radiata*). We compared bird breeding success within woodland patches surrounded by maturing pine stands with a replicated set of woodland patches where the surrounding landscape was dominated by semi-cleared grazing farmlands. Specifically, we posed the following three key questions:

Q1. Are there differences in rates of breeding success between woodland remnants surrounded by pine plantations and woodland patches located in semi-cleared grazing paddocks? We postulated that bird breeding success would be higher in remnants surrounded by plantations than in remnants within farmlands. This prediction was based on likely differences in predator abundance and microclimatic conditions that would influence nesting

success. First, bird data previously collected in our study area showed that the number of species of avian predators within farmlands was significantly higher than in plantations (χ_1^2 = 14.421 and P = 0.001 for 2009, χ_1^2 = 15.109 and P = 0.001 for 2011). Second, remnants surrounded by pine plantations would be characterized by more stable micro-environmental conditions than remnants in semi-cleared grazing environments. Such conditions include reduced wind speeds and less variation in temperature. Reproductive performance in birds may be promoted under such conditions (see Hepp and Kennamer, 2012; DuRant et al., 2013). In addition, the two kinds of woodland patches in our study differed markedly in landscape context (*sensu* Lindenmayer and Fischer, 2006) and this will produce differences in edge contrast and edge effects, patterns of habitat connectivity, and other factors (Harper et al., 2005). Fragmentation theory and landscape ecology (matrix) theory suggest that differences in landscape context should have marked effects on biota, including reproductive success (see Driscoll et al., 2013).

Q2. Is there a relationship between bird breeding success and the amount of woody vegetation cover in the landscape surrounding nests? We postulated that nests in areas surrounded by large amounts of native woody vegetation cover would be more successful than nests where the amount of surrounding native woody cover was limited. We based this prediction on previous work showing that larger areas of native eucalypt woodland provide a greater variety of food resources for birds than small areas of woodland (Zanette et al., 2000).

Q3. Is there a relationship between bird breeding success and life-history attributes or nest characteristics and do these relationships vary between woodland patches in farmlands and plantations? Previous work has revealed that bird breeding success may be linked with life-history attributes such as nest type and nest height (Best and Stauffer, 1980; Collias, 1997; Noske et al., 2008; Colombelli-Négrel and Kleindorfer, 2009) although these relationships may vary between different ecosystems (e.g. Knutson et al., 2004; Massaro et

al., 2013). We predicted that relationships between life history attributes and bird breeding success would be prominent as an earlier experiment in a neighbouring region found depressed levels of occurrence among open cup nesters in forest patches surrounded by recently harvested pines versus uncut pine stands (Lindenmayer et al., 2009).

Breeding success is a critical ecological process influencing the persistence of bird species in natural and human-dominated landscapes (Gill, 1985; With et al., 2006; Cruz-McDonnell and Wolf, 2016). Therefore, our results will help inform effective strategies that attempt to integrate biodiversity conservation and wood production in plantation-dominated landscapes. This is particularly important as tree plantations occupy a large and rapidly increasing area worldwide (Lindenmayer et al., 2015a).

2.3 Methods

2.3.1 Study area

Our study area covers approximately 56 square kilometres in the Nanangroe region, 20 km south-east of Jugiong in south-eastern New South Wales, Australia (34˚55´-35˚0´S, 148˚25´-148˚35´E) (Fig. 2.1). The Nanangroe region has a temperate climate with an annual rainfall of 900- 1200 mm (Bureau of Meteorology, 2015). The native vegetation cover in our study area is dominated by White Box (*Eucalyptus albens*), Yellow Box (*E. melliodora*), Red stringybark (*E. macrorhyncha*), Red Box (*E. polyanthemos*), and Blakely's Red Gum (*E. blakelyi*). Approximately 80% of the original native vegetation in the region has been cleared for grazing and cropping since European settlement (Lindenmayer et al., 2008a). The region has been undergoing extensive landscape transformation from semi-cleared grazing land to Radiata Pine plantations since the late 1990s. A major series of studies of the response of biodiversity to this landscape transformation has been taking place at 131 long-term monitoring sites first established in 1998 (Lindenmayer et al., 2001, 2008a, 2015b; Mortelliti

et al., 2014, 2015a, 2015b; Mortelliti and Lindenmayer, 2015). The investigation reported here is the first to quantify patterns of bird breeding success at Nanangroe.

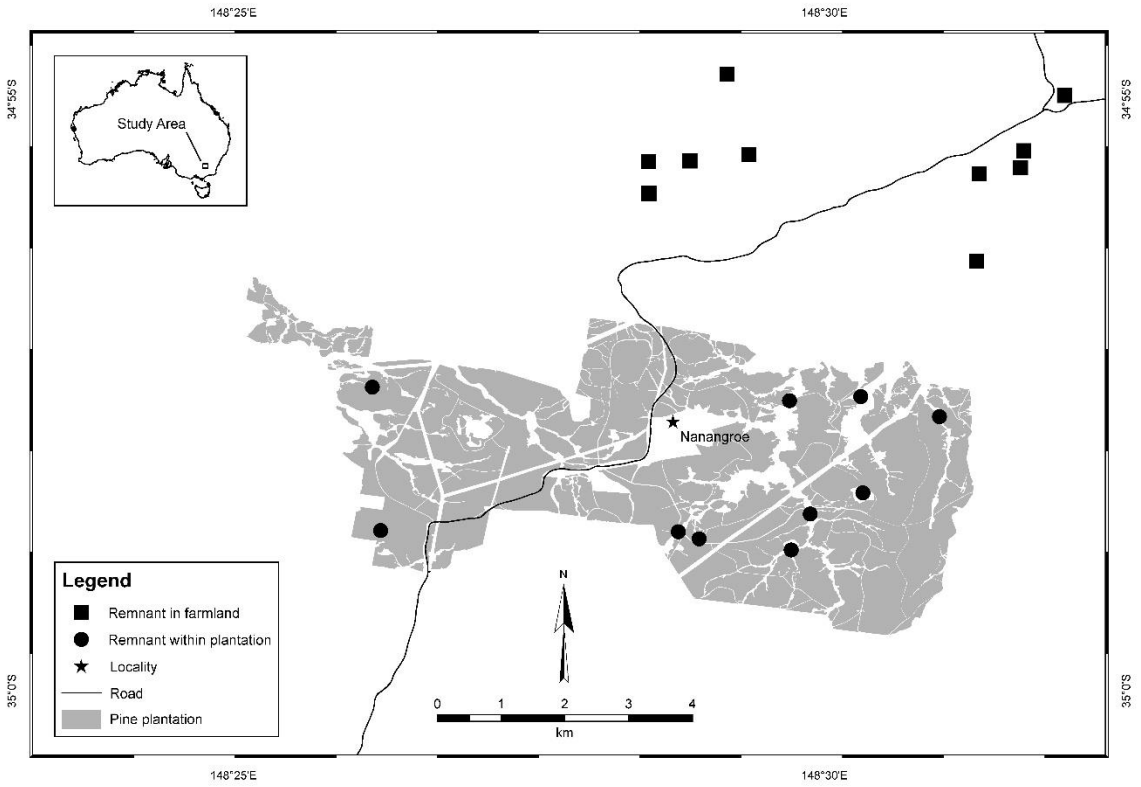

Figure 2.1 Sites where studies of bird breeding success were conducted. The squares show the location of remnant sites on farmlands and the circles indicate remnant sites within pine plantations

2.3.2 Study sites

For the study reported here on bird breeding success, we selected a subset of 23 woodland remnant sites from the 131 permanently-marked long-term monitoring sites at Nanangroe (for more details on the experimental design see Lindenmayer et al., 2001, 2008a). The 23 sites comprised 13 woodland remnant sites surrounded by Radiata Pine plantations and 10 sites on farms where remnants were surrounded by semi-cleared grazing land.

We selected our sites to generally match the conditions of native remnant patches between two types of matrix. The average size of woodland remnants within farmlands and

pine plantations was 5.2 hectares and 4.7 hectares, respectively (χ_1^2 = 0.026, P = 0.873). As riparian areas often support more biodiversity than elsewhere in a landscape (Jenkins et al., 2013), we considered they may be superior breeding habitats (i.e. invertebrates as food and plants as habitats and food). Therefore, we selected the same number of riparian sites from each of the two types of matrix (n = 3 in either type of matrix).

Vegetation cover in the majority of sites was intact and in a relatively good condition, with a midstorey of *Acacia* spp, *Kunzea* spp and *Eucalyptus* saplings. The understorey was dominated by the exotic Blackberry (*Rubus fruticosus*). Other habitat structures, such as hollow-bearing trees and fallen logs, also were present at all of our sites. There was an intermediate level of livestock grazing in all woodland remnants (i.e. sites in both the plantations and the farmlands).

2.3.3 Surveys for bird breeding success

The breeding season for the majority of bird species in our study region is August to February (Beruldsen, 2003). To maximise the chance of detecting breeding events, we searched for nests during the peak breeding season. Accordingly, we conducted surveys between September and December in 2012 and between October and December in 2013. Not all sites could be surveyed each year. In the farmland matrix, seven sites were surveyed in 2012 and ten in 2013. Corresponding figures for the pine matrix are eight and twelve sites.

We located nests by following birds with nesting materials or searching likely places for breeding such as clumps of mistletoe and in tree hollows. For each nest, we recorded the GPS coordinates of the nest, bird species, and the species of plant on which a nest was built. We also measured nest height from ground level.

Every site was visited at least eight times to search for new nests during each survey season. We re-visited the sites every 5-14 days, with more frequent visits towards the end of survey seasons to determine the fate of nestlings. At every visit, we recorded nesting stage

(building nest/incubating/nestlings/fledglings) until breeding success was determined. We defined the construction of nests as a 'Nesting Attempt' and the observation of at least one fledgling as 'Nesting Success'. We did not include nests in the analyses reported here for which we could not determine success.

We limited our nest searching efforts to an area within approximately 50 meters either side of a permanently marked 200 m transect on each of the 23 sites in our study. However, we also recorded and monitored nests incidentally found outside of this searching area. Every time we visited each site, we spent approximately two hours searching for new nests and a further 20 min of observation time to document the status (e.g., active vs inactive) of each nest.

We recorded all nests detected in our repeated surveys. However, for subsequent data analyses we excluded nests constructed by water birds (most of which have a fundamentally different nesting niche relative to other bird species) and those of the migratory White-browed Woodswallow (*Artamus superciliosus*). The White-browed Woodswallow is an irruptive, occasional migrant to our study area, and the large numbers that arrived to nest in 2013 would have skewed the results.

2.3.4 Definition of small versus large-bodied birds

To calculate a median body size of birds occurring in the study region, we used data from previous field surveys over the past 16 years for all of the species in the Nanangroe region (Lindenmayer et al., 2001, 2008a). We excluded water birds since they have very different breeding ecology relative to the remainder of the bird assemblage. Median body mass of all bird species in the study area was 48.25 grams, and we used this value to distinguish between small-bodied birds and large-bodied birds. For instance, we classified the Brown Treecreeper (*Climacteris picumnus victoriae*) and Rufous Songlark (*Cincloramphus mathewsi*) as small-bodied birds and the Magpie-lark (*Grallina cyanoleuca*) and Noisy

Friarbird (*Philemon corniculatus*) as large-bodied birds (Supplementary Material Appendix 1).

2.3.5 Woody vegetation cover

We used fine-scale satellite data on vegetation cover to calculate the amount of native woody vegetation cover (including scattered paddock trees) in radii of 50, 100, 200, 300 and 500 m surrounding each nest. Our source data were the time series grids of Forest Extent and Change (version 9), produced by the Australian Government Department of Environment (National Carbon Accounting System, http://pandora.nla.gov.au/pan/102841/20090728-0000/www.climatechange.gov.au/ncas/reports/tech09.html). We used Landsat satellite imagery to discriminate between forest and non-forest cover at a grid resolution of 25 m.

2.3.6 Statistical analyses

We compared the number of nests per site x year combination in remnants surrounded by pine plantations with those within farmlands by fitting a generalised linear model (GLM) with a quasi-Poisson response and a logarithmic link function. In a similar way, we compared the effect of the surrounding matrix on quantities such as success rate by assuming that the number observed had a quasi-binomial distribution. For these models, we used approximate F-tests to assess significance. To assess the effect of variables measured for individual nests, body mass of bird, nest height, and nest type, we used logistic regression with a logit link function and assumed a Bernoulli distribution for the data. The response variable was breeding success (0 = Failed, 1 = Success). We used Wald statistics to quantify the significance of the potential predictors.

As part of preliminary analyses, we tested for the effects of phylogeny on differences in the bird breeding success among the two different kinds of remnants but found no evidence for such effects. We suggest that this result may have been in part because of the large range of bird families (N = 23) that occurred in both kinds of remnants. We also tested for the

effects of spatial dependence in nesting success; successful nests may have been more likely to have been near to other successful nests, but again found no evidence for such effects. Finally, we tested for differences in the number of nests and nesting success between riparian and non-riparian areas and found no evidence for any significant differences between such kinds of sites. We used GenStat 64-bit Release 18.1 to conduct all statistical analyses.

2.4 Results

We found a total of 175 nests (42 species) over the two breeding seasons. Of these, five nests were constructed by water birds (Supplementary Material Appendix 1) and 12 were constructed by the White-browed Woodswallow were excluded from our study leaving 158 nests for subsequent data analyses. Of these 114 were in remnants surrounded by farmland (70 were small bodied bird species, 44 were large bodied species) and 44 were in remnants surrounded by plantation (24 were small bodied, 20 were large bodied).

2.4.1 Relationships between breeding success and matrix types

We detected an average of approximately three times more nests per site in remnants within farmlands than remnants surrounded by plantations ($F_{1,35} = 19.7$, $P < 0.001$; Table 2.1). The proportion of nests of generalist (non-woodland dependent) avian nest predators in remnants surrounded by pine plantations was significantly higher (31.8%) than that of remnants within farms (7.0%) ($F_{1,35} = 11.8$, $P = 0.002$).

Table 2.1 Total number of nests and number of species that were detected and analysed for breeding success and number of nests of avian predators.

	Total number of nests detected	**Number of nests analysed for breeding success**	**Number of nests of generalist avian nest predators**
Remnants within farmlands	131 (32spp)	114 (29spp)	8 (2spp)
Remnants within plantations	44 (21spp)	44 (21spp)	15 (6spp)
Total	175 (42spp)	158 (39spp)	23 (6spp)

Of the 158 nests selected for analyses of breeding success, 97 nests (27 species) successfully produced at least one fledgling. Overall, we found no difference in the rate of nest success between remnants within farmlands (63.2%) and remnants surrounded by plantations (56.8%) ($F_{1,35\text{-}0.39}$, P = 0.54).

2.4.2 Relationships between breeding success and vegetation cover

We found no relationships between nest success and the amount of native woody vegetation cover in the surrounding landscape (P > 0.05 for any radii).

2.4.3 Relationships between breeding success and bird life-history characteristics

2.4.3.1 Nest type

We found a significant relationship between nesting success and nest type (χ_1^2 = 6.113, P = 0.013) for remnants surrounded by farmland. The predicted breeding success of open cup/bowl nesters was 54.8% and that of domed nesters was 84%. By contrast, there was no difference in breeding success between two nest types in remnants surrounded by pine plantations (predicted success rate of cup/bowl nests = 0.333 ± 0.192, dome nests = 0.353 ± 0.116).

2.4.3.2 Body size

Larger species bred significantly more successfully than smaller species, irrespective of remnant type (χ_1^2 = 11.3, P < 0.001; Fig. 2.2). For our study, examples of bird species with 7 g of average body mass included the Brown Thornbill (*Acanthiza pusilla*) and the White-throated Gerygone (*Gerygone olivacea*). Example species with larger body mass were the Noisy Friarbird (*Philemon corniculatus*, 100 g body weight) and the Australian Raven (*Corvus coronoides*; 600 g body weight).

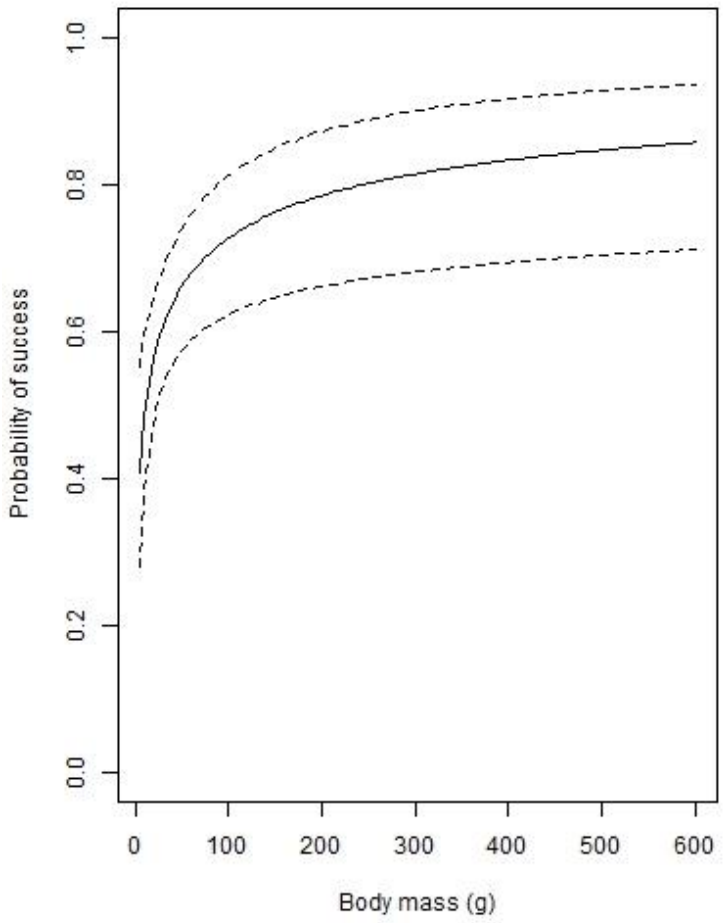

Figure 2.2 Predicted breeding success rates (y-axis) plotted against body mass with approximate 95% confidence intervals

2.4.3.3 Nest height

We found no significant relationships between breeding success and nest height when all birds were considered (χ_1^2 = 2.1, P = 0.142). We also failed to find a significant

relationship within either remnant type (X^2 = 3.511, P = 0.061). However, birds smaller than the median body mass bred significantly more successfully at a lower nest height (χ_1^2 = 7.8, P = 0.005), whereas the success rate of species with larger body mass than the median weight was significantly greater at a higher location (χ_1^2 = 4.477, P = 0.034). Predicted breeding success rates for smaller species were 64.7% and 43.4% for one meter and five metres of nest height, respectively.

2.5 Discussion

The area of tree plantations is expanding globally at a rate of 5 million hectares annually (FAO, 2010; Guida-Johnson and Zuleta, 2013; Watson et al., 2014). Such kinds of landscape conversion can have significant impacts on biodiversity (Felton et al., 2010) and can influence the abundance and occurrence of bird species in remaining native vegetation patches (Waltert et al., 2004; Mortelliti et al., 2014). Quantifying how bird breeding success changes in transforming plantation landscapes is a critical part of understanding the ecological processes affecting patterns of species abundance and distribution in these human-modified environments.

We found reduced overall abundance of nests and relatively low levels of nesting success in woodland remnants surrounded by stands of plantation pine. There also were relationships between bird life-history characteristics and nest success, especially nest type. We discuss our key findings in the remainder of the paper and conclude with a summary of the conservation implications of this work.

2.5.1 Breeding success and matrix type

At the outset of our study we predicted that breeding success in woodland remnants surrounded by stands of Radiata Pine plantation would be higher than woodland remnants within farmlands. However, we found a trend for the opposite effect for birds for which

average body mass was smaller than a median size in the region. We also detected significantly more nests in remnants within farmlands than in remnants surrounded by stands of Radiata Pine plantation. Several factors may explain these results. First, densely spaced plantation trees may help conceal nests for some species thereby reducing the number of nests in adjacent woodland remnants which are surrounded by stands of plantation Radiata Pine. Second, there may be differences in food availability between woodland remnants within the different matrices (Driscoll et al., 2013). Invertebrates are a key prey item for many birds in our study area, particularly for smaller-bodied birds. Sweaney et al. (2015) found fewer ground-active beetles and a reduced overall beetle diversity in remnants surrounded by plantations than remnants within farmlands. Reduced availability of food may result in nests/nestlings being left unattended for long periods, leaving them susceptible to predation and/or starvation (Rastogi et al., 2006).

Differences in the abundance of avian predator nests may be a third factor explaining contrasts in breeding success between remnants within farmlands and remnants surrounded by stands of Radiata Pine plantation. Our long-term field survey data from the Nanangroe region indicated that avian predators were more abundant on farms than plantations in both 2012 (χ_1^2 = 10.582, P = 0.0019) and 2013 (χ_1^2 = 12.709, P = 0.001). However, surprisingly, we found significantly more nests of avian predators, particularly ravens, in remnants surrounded by pine plantations than in woodland remnants on farms (Supplementary Material Appendix 1). This suggests that the abundance of predators may not be directly related to the abundance of nests for some species of avian predators. The presence of nesting avian predators also may have discouraged other bird species from breeding.

Land surrounding woodland remnants (the matrix) could provide food resources and/or habitat for some bird species (Manning et al., 2004). Some species may have perceived pine trees at the edges of woodland remnants as being relatively safe nesting sites

(Chalfoun and Martin, 2010; Dukas, 2013), particularly small-bodied species such as the Grey Fantail (*Rhipidura albiscapa*) and various species of Thornbills (*Acanthiza* spp) (Supplementary Material Appendix 2).

2.5.2 Relationships between breeding success and vegetation cover

At the outset of this study we predicted that nest success would be greater at those nests characterized by large areas of surrounding native woody vegetation cover as found in other environments around the world, including those in Europe (Mackenzie et al., 2104). However, we found no evidence of such effects and the reasons for the paucity of such effects remains unclear. The discrepancy between the results of this study and those of other investigations suggests that the effects of the amount of surrounding vegetation cover on bird breeding success is an area for further study, potentially involving greater field effort and more sites that we were able to examine.

2.5.3 Relationships between breeding success and bird life history attributes

We found that for woodland remnants on farms, birds with domed nests bred significantly more successfully than species with open cup/bowl nests. However, there were no relationships between nest type and breeding success in remnants surrounded by pine plantations. This suggests that different mechanisms may be driving nest success in woodland remnants with different surrounding matrices. Our results may be attributed to several factors. In remnants on farms, differences in nest success may be driven by climate or predation pressures. First, birds with domed nests may have been better able to survive the extreme temperatures which characterized the 2013 field season (Supplementary Material Appendix 3) (Collias, 1997). Conversely, some species of open cup/bowl nesters, such as the Willie Wagtail (*Rhipidura leucophrys*) and Flycatchers (*Myiagra* spp), nested in exposed places, such as on dead branches, where visually cued avian predators could detect them (Gardner, 1998). In remnants surrounded by pine plantations, limited availability of food (Sweaney et

al., 2015) may underpin the absence of relationships between nest type and breeding success. We acknowledge that the relatively small sample size in our study also may have led to a paucity of relationships between nest type and breeding success, although extensive field searching coupled with the considerable difficulty in finding and then repeatedly monitoring nests in our study precluded the inclusion of more nests.

We found that larger species of birds bred significantly more successfully than smaller birds. Larger species may be able to better defend their nests than smaller species (Remeš et al., 2012). Ford (1999) found the Noisy Friarbird aggressively and successfully protected their conspicuous nests from avian predators. In our study, the Noisy Friarbird accounted for a large percentage of nests of larger species. Indeed, this species was characterised by a very high breeding success rate (71.4%).

We found that no significant relationships between breeding success and nest height either overall or within either of the types of woodland patches. However, the breeding success of smaller-bodied birds was negatively correlated with nest height and the opposite effect was identified for larger-bodied birds. In our study sites, the understorey was often comprised of thickets of the exotic Blackberry (*Rubus fruiticosus).* Although Blackberry is a weed of National Significance (Department of the Environment, 2016), thickets of this invasive plant species appeared to be useful for breeding by smaller-bodied birds. In fact, we found many nests of small-bodied birds in Blackberry thickets. It is a common for exotic plant species to provide some resources for wildlife in human-modified landscapes (Chambers and Dickman, 2002; Lampert et al., 2014).

2.6 Conclusions

We detected an average of approximately three times more nests per site in remnants within farmlands than remnants surrounded by plantations. The proportion of nests of generalist (non-woodland dependent) avian nest predators in remnants surrounded by pine

plantations was significantly higher than that of remnants within farmlands. In addition, species with domed nests were more successful at nesting than species that constructed open cup/bowl nests in woodland remnants within farmlands. Different mechanisms may be driving nest success in woodland remnants with different surrounding matrices. Resource limitations (e.g. invertebrate prey) and the abundance of avian predators may be a factor underpinning reduced overall abundance of nests and relatively low levels of nesting success in woodland remnants surrounded by stands of plantation pine.

2.7 Acknowledgements

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Australian National University

Statement of Contribution

This thesis is submitted as a Thesis by Compilation in accordance with https://policies.anu.edu.au/ppl/document/ANUP_003405

I declare that the research presented in this Thesis represents original work that I carried out during my candidature at the Australian National University, except for contributions to multi-author papers incorporated in the Thesis where my contributions are specified in this Statement of Contribution.

Title: Does land use change influence predation of bird nests?

Authors: Sachiko Okada, David B Lindenmayer, Jeff T Wood

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Data analysis and interpretation	50%		✓
Drafting the manuscript	90%	✓	
Revision and edits of the manuscript	40%	✓	✓

Senior author or collaborating authors endorsement: Sachiko Okada

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Candidate – Print Name	Signature	Date

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David Lindenmayer _____ 5 April 2019

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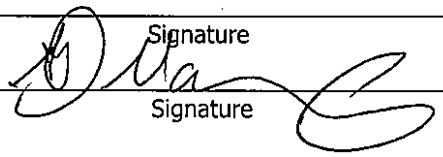
Primary Supervisor – Print Name	Signature	Date
ADRIAN MANNING		1/5/19
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Chapter 3: Does land use change influence predation of bird nests?

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3.1 Abstract

Worldwide, many areas of agricultural land which was once covered with native vegetation, have been converted to tree plantations. Such landscape transformation can influence the dynamics of wildlife populations through, for example, altering rates of predation (e.g. predation of nests of birds). Nest predation can influence reproductive success, and in turn, may alter populations by affecting juvenile recruitment. We quantified predation of bird nests in woodland remnants surrounded by two types of land use, grazing farmland and exotic Radiata pine (*Pinus radiata*) plantation. We also examined differences in predation rates between artificial and natural nests.

We found both artificial and natural nests were more susceptible to nest predation in woodland remnants surrounded by a pine plantation than in woodland remnants located within farmland. Our study suggests that higher levels of nest predation may reduce occupancy of woodland remnants by small-bodied birds over time, including species of conservation concern. This may have been occurred as a result of the conversion of semi-cleared grazing land to exotic pine plantation.

3.2 Introduction

Human-generated landscape change is pervasive globally with more than half of the planet's terrestrial land surface modified (Tilman et al., 2017). There has been substantial biodiversity loss as a result of direct habitat loss by clearing vegetation, including the loss of

bird biota (Maxwell et al., 2016; Ceballos et al., 2017). In addition to vegetation clearing, land use change in already developed areas which once used to be covered with original vegetation, may be an emerging threat to biodiversity (Lindenmayer et al., 2019). Among various types of land use change, matrix change (where the matrix is defined as areas surrounding vegetation remnants; Driscoll et al., 2013) from agricultural lands to tree plantations, is a widespread form of landscape transformation globally (FAO, 2010; Sánchez-Oliver et al., 2014; Madhavan et al., 2016; Phifer et al., 2017).

One of the likely underlying reasons for biodiversity loss in landscapes subject to land use change is reproductive failure, which, in turn, can influence population decline (Murcia, 1995; Okada et al., 2017). Predation of nests is one of the key reasons for reproductive failure in birds (Ricklefs, 1969; Gill, 1995; Husby and Hoset, 2018; Fulton, 2019), and the condition of the matrix surrounding remnant patches can be one of the factors affecting rates of predation (Driscoll et al., 2013), for example via increased access of invasive species to remnants (Stirnemann et al., 2015).

Many studies of bird reproductive success have used artificial nests (Major and Kendal, 1996; Lewis et al., 2009) to identify the factors affecting nest predation, in part because finding natural nests can be difficult and time consuming (Garner and Milne, 1998; Moore and Robinson, 2004). The use of artificial nests is prevalent in these studies despite arguments that they may not accurately reflect the rates of predation of natural nests (Pärt and Wretenberg, 2002; Berry and Lill, 2003). Indeed, few studies compare rates of predation of natural and artificial nests (reviewed in Major and Kendal, 1996; Fulton, 2019; but see Burke et al., 2004).

To close this knowledge gap, we quantified relationships between rates of predation of nests within woodland remnants surrounded by cleared farmland versus woodland remnants located within stands of plantation Radiata Pine. Different kinds of matrix

environments (hereafter termed landscape contexts) may support different species of predators (Robertshaw and Harden, 1989; Driscoll et al., 2013). We therefore sought to determine if this translated into different rates of predation on different types of nests (cup vs domed nests). We then compared nest predation rates from an artificial nest experiment with data on nesting failure obtained in a previous study of natural nests in the same landscape (Okada et al., 2017). Specifically, we posed the following three questions**:**

Q1 Are there differences in the types of predators responsible for predation of artificial nests in the different landscape contexts? We predicted birds would be the major predators of artificial nests in both landscape contexts. We made this prediction because Belder et al. (unpublished data) found generalist avian nest predators, such as the Australian Magpie (*Cracticus tibicen*), Pied Currawong (*Strepera graculina*) and Australian Raven (*Corvus coronoides*), were the major nest predators on natural nests in semi-cleared agricultural regions. We also predicted that the avian predator assemblage would be different in the two landscape contexts, with the Australian Raven being responsible for greater levels of nest predation in woodland remnants surrounded by plantations than in remnants located in farmland. This is because we found Australian Raven nests only in woodland patches within plantation (Okada et al., 2017).

Q2 Are there landscape context effects on overall predation rates of artificial nests or on predation rates of different types of nests (artificial cup vs artificial domed nests)? We predicted that woodland patches located within the plantation would be subject to higher levels of predation than woodland patches in farmland, with artificial open cup nests being at greatest risk of predation in both landscape context types. There are three reasons why we made this prediction. First, there were significantly more nests of avian predators in woodland remnants within the plantation than in woodland remnants located within farmland (Okada et al., 2017), which may in turn lead to higher levels of predation. Second, small-

bodied birds constructed fewer nests in woodland patches within the plantation (Okada et al., 2017), which may have been a result of avoiding places subject to higher risks of predation (Roos and Pärt, 2004; Eggers et al., 2006). Third, nest type is a trade-off with other life history traits for bird reproductive success (Fulton, 2018). However, artificial nests do not have such trade-off, and visually-cued avian predators may more easily locate artificial open cup nests than artificial domed nests as the former were installed in conspicuous places, consistent with where actual open-cup nests are found in the wild (Beruldsen, 2003).

Q3 Do predation rates of artificial nest experiments reflect the relative predation rates of natural nests? We predicted that predation rates in the two landscape contexts would be similar for artificial and natural nests. In addition, for the reasons outlined above, we predicted that rates of predation of both artificial and natural nests would be highest in woodland remnants surrounded by the plantation. We made this prediction because we ensured that factors which may affect levels of nest predation (e.g. patch size and vegetation structure), were similar among sites in the two landscape contexts as well as in the both studies of natural and artificial nests. Given this, relationships between landscape context and nest predation should be similar between artificial and natural nests.

Quantifying the factors affecting rates of nest predation is critical for understanding the dynamics of populations of species in modified environments. This empirical study therefore provides new insights to guide management strategies for biodiversity conservation in landscapes undergoing rapid transformation such as those supporting newly established areas of exotic pine plantations.

3.3 Methods

3.3.1 Study area

Our study area was the Nanangroe region, 20 km south-east of Jugiong in New South Wales, south-eastern Australia. The study area covers approximately 56 square km and has a

temperate climate with an annual rainfall of 900-1200 mm (Bureau of Meteorology, 2018). Native vegetation cover is dominated by White Box (*Eucalyptus albens*), Yellow Box (*E. melliodora*), Red Stringybark (*E. macrorhyncha*), Red Box (*E. polyanthemos*), and Blakely's Red Gum (*E. blakelyi*). Approximately 80% of original vegetation cover in the study region has been cleared for grazing and cropping since European settlement (Lindenmayer et al., 2008a, 2019). The region is now characterised by remnant patches of native woodland with some of the areas surrounding them converted to plantations of Radiata Pine in the 1990s. A series of studies on the response of biodiversity to this form of landscape transformation has been taking place at 131 long-term monitoring sites first established in 1998 (Lindenmayer et al., 2001, 2019; Mortelliti and Lindenmayer, 2015).

3.3.2 Study sites

This investigation encompassed 24 woodland remnants in which we deployed artificial nests. Twelve of the woodland remnants were located within semi-grazing farmland and the remainder were surrounded by stands of Radiata Pine plantation. We carefully matched the characteristics of the woodland patches in the two landscape contexts on the basis of proximity to riparian area, vegetation structure, patch size, patch shape and topography. The mean size of woodland remnants was similar between the two landscape contexts (4.9 hectares and 4.7 hectares for remnants within farmland and plantation, respectively (χ_1^2 = 0.089, P = 0.931)). There was an intermediate intensity of domestic livestock grazing in all 24 woodland remnants.

3.3.3 Artificial nests

We handcrafted two types of artificial nests. One was an open-cup nest, using a half tennis ball decorated with the bark of coconuts (Photo 3.1a) (see Lindenmayer et al., 1999). A second type of nest was a domed nest. We purchased woven bamboo nests (13 mm x 60 mm), which were fully covered with finely clipped hay and small pieces of hand-torn weed

mat (Photo 3.1b). We sprayed all artificial nests with bird-droppings dissolved in water so the odours would resemble actual nests and hence would potentially be attractive to mammalian predators (Fulton and Ford, 2001). Artificial cup nests resembled nests of flycatchers (*Myiagra* spp) and the Willie Wagtail (*Rhipidura leucophrys*), and artificial domed nests had

similar appearance to that of thornbills (*Acanthiza* spp) and gerygones (*Gerygone* spp).

Photo 3.1 An artificial open cup nest (a) and an artificial domed nest (b)

3.3.4 Real and Plasticine Eggs

We used Japanese quail (*Coturnix japonica*) eggs for this study. These eggs were cream colour with brown speckles. We were aware of the fact that the shell of the quail eggs is too thick to be broken by some small mammals, such as the House Mouse (*Mus musculus*) and Antechinus spp (Fulton and Ford, 2003), but we could not obtain a sufficient number of smaller eggs, such as those of the House Sparrow (*Passer domesticus*) or from species of finches. To increase the chances of obtaining the imprints of small mammalian predators, plasticine eggs also were used. The plasticine eggs were created by mixing blocks of cream-coloured plasticine with a pinch of soil and scraps of finely clipped hay for natural colouring and speckling. We connected eggs to nests with garden wire to avoid losing the imprints of predators (Fulton, 2018) and also to prevent eggs from being displaced from a nest due to strong winds (this occurred during a pilot study), which in turn would have resulted in loss being incorrectly attributed to predation.

We found only two plasticine eggs with teeth marks (presumably of Rattus species) during the experiment, with the remainder showing signs of beak marks of birds. There was no significant difference in overall predation rates between quail eggs and plasticine eggs (χ_1^2< 0.001, P = 1.00). We therefore regarded disappearance of a quail egg or cracks in a quail egg as evidence of predation. We then placed each of the two types of eggs in an artificial nest.

3.3.5 Camera traps

We used Scoutguard camera traps (Primos TRUTH Cam 46) to identify predators of artificial nests. We established at least one camera at each study site, with an equal number of cameras monitored at each type of artificial nest within each landscape context. A total of 136 cameras was used over three survey seasons to identify nest predators.

3.3.6 Pilot Study

Prior to the implementation of our main experiment, we conducted a pilot study on four sites to determine which animals were responsible for predation of nests. The pilot study was completed in January 2013 and targeted two woodland remnants in each landscape context. We found that predators of artificial nests were birds (the Australian Raven, the Australian Magpie and the Grey Butcherbird (*Cracticus torquatus*)).

3.3.7 Experiments of artificial nest predation

We completed a series of experiments using artificial nests over a two year period, with one spring survey (early November in 2013) and two summer surveys (mid-January in 2014 and 2015). A total of 720 artificial nests was placed at 1-2 m height in the 24 woodland remnants. At each study site, we installed four cup nests and four domed nests. We also placed two of each type of nest on pine trees within 5 m from the edge of woodland remnant sites surrounded by stands of plantation pine. This was to determine if pine trees at the edge

of woodland remnants located within plantation were subject to different rates of predation relative to woodland remnants.

We positioned artificial nests in locations similar to places where natural nests were located in the study region (Okada et al., 2017) such as on tree branches, shrubs, in thickets of Blackberry (*Rubus fruticosus*), or in clumps of mistletoe spp. We located nests at least 20 m apart (Hausmann et al., 2005) to avoid potential density-dependent nest predation (Mitchell and Brown, 1990; Flockhart et al., 2016). We did not use flagging tape to mark artificial nests (Yahner and Wright, 1985). We also did not visit sites during the period when nests were established (5 days for summer surveys and 3 days for spring survey) to avoid potentially increasing the chances they would be detected by predators (Picman and Schriml, 1994).

3.3.8 Predation of natural nests

We observed natural nests of birds in spring 2012 and 2013 to determine the breeding success of birds in woodland remnants surrounded by farmland or pine plantation in the Nanangroe region. This part of the study encompassed 23 woodland remnants, with 10 remnants within farmland and the reminder in woodland remnants within the Radiata Pine plantation (see Okada et al., 2017 for details). 22 remnants in the natural nest study plus two additional patches were used in the artificial nest experiment described above. From the breeding success study, we quantified differences in the rate of nest failure of small-bodied birds in woodland remnants in the two types of landscape contexts. As the major reason for nesting failure was nest predation (see also Ricklefs, 1969; Martin, 1993), we then compared nesting failure of natural nests with nest predation of artificial nests (see the section below 'Statistical Analyses' for details).

3.3.9 Statistical Analyses

For the camera data, we fitted a generalised linear model (GLM) to the counts of each bird species for the two landscape contexts (remnants surrounded by farmland versus

remnants in the pine plantation). We assumed a Poisson distribution with a logarithmic link function. Where the response was presence or absence of predation, we fitted GLMs, but this time assuming a Bernoulli distribution with a logit link.

For the comparison of artificial and natural nests, we used the number of nests affected in each site as the response. In this case, we fitted a hierarchical generalised linear model (HGLM) so that we could allow for a site random effect. We assumed a binomial distribution with a logit link for the response and we assumed a beta-distribution with a logit link for the random effect.

3.4 Results

We installed a total of 720 artificial nests, including 360 artificial cup nests and 360 artificial domed nests. We failed to locate two of the cup nests throughout the experiments, and hence quantified the fate of 718 nests. We found 205 artificial nests were preyed upon (Table 3.1).

*Table 3.1 Numbers of nests installed and preyed upon in each type of landscape contexts over three time periods (P= the pine matrix adjacent to RP, RF=woodland remnants in farmland, RP=woodland remnants within the plantation). *2 nests were missing from*

	Spring		Summer 1		Summer 2	
	Installed	Preyed	Installed	Preyed	Installed	Preyed
RF	96	32	96	23	96	13
RP	*96	57	96	13	96	21
P	48	24	48	10	48	12
TTL	238	113	240	46	240	46

3.4.1 Predators on artificial nests

The only predators identified by infra-red cameras were birds; the Australian Raven (Photo 3.2a), the Australian Magpie (Photo 3.2b), the Grey Shrike-thrush (*Colluricincla harmonica*), the Pied Currawong, and the Grey Butcherbird.

Photo 3.2 The Australian Raven destroying an artificial domed nest (3.2a) and the Australian Magpie preying on quail egg in an artificial cup nest (3.2b).

The species responsible for nest predation was identified in 28 % of nest predation events (Fig. 3.1). The Australian Raven was responsible for more nest predation than any other species (χ^2_3 = 19.81, P < 0.001). We also found that nest predation by all species was significantly higher in woodland remnants located in the plantation (6.750 nests ± 1.299 per site) than in woodland remnants located in farmland (3.25 nests ± 0.901 per site) (χ^2_1 = 4.69, P = 0.030).

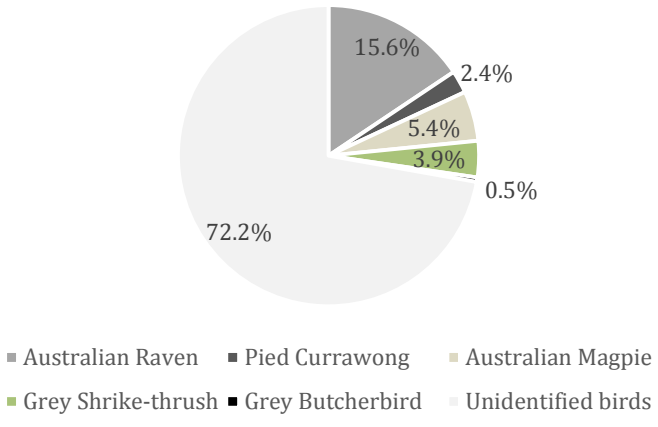

Figure 3.1 Percentage predation by identified predators (Australian Raven 15.6%, Pied Currawong 2.4%, Australian Magpie 5.4%, Grey Shrike-thrush 3.9%, Grey Butcherbird 0.5%, Unidentified birds 72.2%) in relation to overall predation events.

The Pied Currawong preyed only on artificial cup nests while all the other species preyed on both types of nests (the Grey Butcherbird was excluded because the species preyed only a single nest) (Fig. 3.2). The Australian Raven made holes in many domed nests to remove eggs (Photo 3.2a).

Evidence of mammals preying on artificial nests was rare in the main experiments. Images of only one Squirrel Glider (*Petaurus norfolcensis*) and two Common Brushtail Possums (*Trichosurus vulpecula*) were captured near artificial open cup nests in remnants surrounded by pine plantation. However, we were unable to confirm if these two species had actually preyed on eggs.

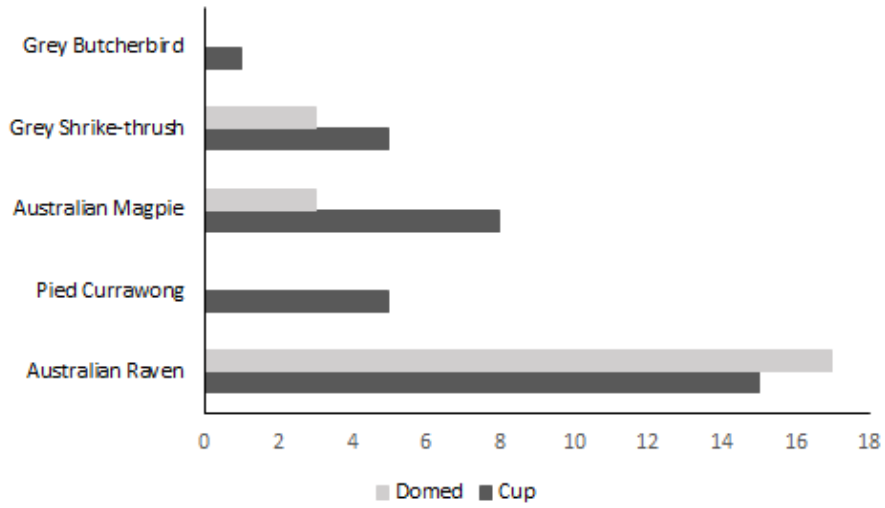

Figure 3.2 Numbers of predation events of artificial domed and open cup nests by predators identified by cameras (y axis is name of predator species identified by camera trap, x axis is the number of predation events preyed by the identified predators).

3.4.2 Effects of landscape context type on overall nest predation

We found a significantly higher overall rate of predation of artificial nests in woodland remnants surrounded by plantation than in woodland patches within farmlands (χ_1^2 = 7.18, P = 0.007) (Table 3.2). We also found a significantly higher level of nest predation in

spring than summer (χ_1^2 = 45.47, P < 0.001). Nest predation was approximately 2.5 times higher in spring than in summer. In spring, the difference in nest predation between the two landscape contexts was greater (χ_1^2 = 14.12, P < 0.001) than the differences for spring and summer combined (Table 3.2).

Table 3.2 Mean predicted nest predation rates (and 95% confidence intervals) for woodland remnants in farmland (RF), woodland remnants within the plantation (RP) and the pine matrix adjacent to RP (P) in the spring season only or in both spring and summer

Landscape context	Spring	Spring + Summer
RF	0.332 ± 0.0456	0.236 ± 0.0230
RP	0.608 ± 0.0476	0.321 ± 0.0251
P	0.499 ± 0.0680	0.319 ± 0.0352

Rates of predation in Radiata Pine stands adjacent to remnant woodland patches surrounded by the plantation were not significantly different to those in the woodland remnants within pine plantation (Table 3.2).

3.4.3 Effects of matrix type on nest predation of different kinds of artificial nests

We found significantly greater levels of predation on artificial open cup nests than artificial domed nests, both in woodland patches surrounded by pine stands and woodland patches located in farmland (χ_1^2 = 22.60, P < 0.001) (Table 3.3).

Table 3.3 Mean predicted nest predation rates (and 95% confidence intervals) of open cup nests (Cup) and domed nests (Domed) in woodland remnants within farmland (RF) and in woodland remnants within the plantation (RP).

Landscape context	Cup	Domed
RF	0.487 ± 0.106	0.155 ± 0.060
RP	0.776 ± 0.076	0.401 ± 0.102

3.4.4 Differences in nest predation between natural and artificial nests

We found the levels of nest predation of both artificial and natural nests were significantly greater in woodland remnants located within plantation than in woodland patches surrounded by farmland (χ_1^2 = 5.91, P = 0.015). We also found that the two types of nests suffered similar levels of predation in woodland remnants located within farmland (0.33 ± 0.06 for artificial nests, 0.33 ± 0.07 for natural nests) while the level of predation of artificial nests (0.63 ± 0.07) was higher than for natural nests (0.43 ± 0.09) in woodland patches surrounded by plantation.

3.5 Discussion

Significant amounts of biodiversity have been lost due to landscape modification worldwide (Sodhi et al., 2010; Ceballos et al., 2017), including bird biota. Land use change may influence rates of nest predation (Driscoll et al., 2013). Predation is a primary cause of nesting failure (Ricklefs, 1969) and can lead to population decline (Murcia, 1995; Belder et al., 2018) along with other factors. This is why many researchers have sought to quantify the factors affecting nesting success/failure of birds often through the use of artificial nests (VanderHaegen and DeGraaf, 1996; Chiarello et al., 2008; Ponce et al., 2018). However, few studies have compared findings from artificial nest experiments with the results of companion studies on natural nests (Fulton, 2019). Here we investigated the effects of differences in landscape context on predation of artificial nests, and compared the effects with those on natural nests.

3.5.1 Major type of predators

As predicted at the outset of this study, the major predators of artificial nests were birds, including imprints of unidentified bird species on plasticine eggs. This could be because heavily fragmented habitats in agricultural landscapes often attract generalist avian nest predators (Cox et al., 2012). The Australian Raven was responsible for more predation of

artificial nests than any other species among identified predators. However, species responsible for 72% of predation events remain unidentified. Therefore, we cannot exclude the possibility that other species of avian predators are major predators in our study (e.g. the Pied Currawong and the Australian Magpie). The Common Brushtail Possum and the Squirrel Glider may also have been responsible for some of the predation events.

3.5.2 Effects of the kind of landscape context on predation rates of artificial nests

At the outset of this study, we predicted that overall rates of predation of artificial nests would be higher in woodland remnants surrounded by the pine plantation than in woodland patches within farmland. Our findings were broadly consistent with this prediction. Density dependent predation was not the reason for our results as nesting attempts and nesting success were relatively lower in woodland patches surrounded by the plantation than in woodland patches located in farmland (Okada et al., 2017). It is likely there were a higher number of avian predators in woodland remnants located within plantation since such areas supported a greater number of nests of avian predators, particularly the Australian Raven (Okada et al., 2017). Higher levels of predation was expected where there was a greater abundance of avian predators as indicated by predator removal experiments (Fulton and Ford, 2001). The reasons for avian predators being more likely to breed in woodland remnants within the plantation remain unclear, but perhaps more and better food resources may have attracted them (Fulton, 2018). Woodland remnants surrounded by plantation may provide more abundant of food such as invertebrates in winter (Robson et al., 2009) when generalist avian nest predators start to breed (Beruldsen, 2003). Higher levels of tree cover within the plantation may also better conceal their nests/nestlings from predators such as the Wedge-tailed Eagle (*Aquila audax*).

3.5.3 Difference in nest predation between two kinds of artificial nests in either type of landscape contexts

At the outset of our study, we predicted that artificial open cup nests would be subject to higher levels of predation than artificial domed nests in both types of landscape context. Our findings were consistent with this prediction. Differences in nest locations between two types of artificial nests were possibly a key reason for this result. Artificial open cup nests, which were located in conspicuous places representative of those used by the species of open cup nesters, would have been easier to find by visually-cued avian predators, whereas it may have been more difficult to find more cryptically-located domed nests in the absence of cues generated by activities of parent birds (Major and Kendal, 1996). These conditions would have been the same in the two landscape contexts as the attributes of both kinds of woodland remnants were similar. Notably, the two types of landscape contexts supported different assemblages of avian predators, but this did not translate into different rates of predation between open cup and domed nests. This result is consistent with the results of a recent meta-analysis on nest predation (Fulton, 2019).

3.5.4 Do artificial nest experiments reflect the relative rates of predation of natural nests?

We found that both artificial and natural nests were more susceptible to predation in woodland remnants located within the plantation than in woodland remnants surrounded by farmland. We also found that artificial and natural nests were subject to similar levels of predation in woodland remnants located within farmland while artificial nests were more susceptible to predation than natural nests in woodland patches surrounded by plantation. These findings were broadly consistent with our predictions at the outset of this study. There are several possible explanations for these results.

First, a higher abundance of generalist avian nest predators may have contributed to higher levels of nest predation on both artificial and natural nests in woodland remnants

surrounded by the plantation. In addition, various species of avian predators start to breed in mid-late winter, which is earlier than species that they may prey upon (Beruldsen, 2003). Both our artificial nest experiment and nesting success study (Okada et al., 2017) may have coincided with a high energy demanding period for feeding young of avian predators. This may have led to the elevated levels of predation rates on both artificial and natural nests, but particularly on undefended artificial nests in woodland remnants within the plantation (King et al., 1999; Husby and Hoset, 2018).

Second, differences in resource availability may be a key factor influencing our results. Less food may have contributed to higher levels of nest predation in woodland remnants located within the plantation. Limited food, may result in small-bodied birds having longer periods away from the nest in search of food and thereby failing to defend their nests from predators (Rastogi et al., 2006). Better reproductive performance/lower nest predation of small-bodied birds was reported where abundant food was available (Zanette et al., 2003; Fulton, 2013). Competition for nesting materials among small-bodied birds also may have caused indirect nest failure (Fulton, 2006). Indeed, our trap cameras recorded that the Grey Fantail (*Rhipidura albiscapa*) and unidentified Thornbill spp. removed nesting material from our artificial cup nests in woodland remnants within the plantation.

Lastly, we acknowledge that caution is needed in simple comparisons between landscape contexts in predation rates on assemblages of small-bodied birds. For example, there are likely to be differences in life history attributes among the different species assemblages that occur in the two landscape contexts. There also may have been differences in the amount and diversity of invertebrate prey for small-bodied birds in the two landscape contexts, with a lower diversity of invertebrates in woodland remnants located within the plantation (Robson et al., 2009; Sweaney et al., 2015). This may, in turn, have influenced site occupancy by some specialist species (Zanette and Jenkins, 2000; Zanette et al., 2000) and

hence overall breeding success by small-bodied birds. Indeed, we found a significantly lower number of natural nests in woodland remnants surrounded by the pine plantation compared to woodland patches located in grazing land (Okada et al., 2017). In addition, we found nests of species of conservation concern (*sensu* Montague-Drake et al., 2009; Reid, 1999) only in woodland remnants surrounded by farmland (Supplementary Material Appendix 1). Therefore, landscape transformation from grazing land to exotic pine plantation may have caused higher levels of nest predation on some species of small-bodied birds. This, in turn, may lead to lower rates of occupancy of woodland remnants by small-bodied birds, particularly species of conservation concern due to altered predation risk (Roos and Pärt, 2004; Eggers et al., 2006).

3.6 Conclusions

We found that both artificial and natural nests of small-bodied birds suffered higher levels of nest predation in woodland remnants located within the plantation than in woodland remnants surrounded by farmland. Other factors, such as resource availability (which can affect nesting and levels of nest predation) may differ between landscape contexts. Given that many factors are likely to cause the population decline rather than one single factor, our findings suggest that changing land use from semi-cleared grazing farmland to a pine plantation may reduce occupancy of woodland remnants by small-bodied birds.

3.7 Acknowledgements

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Chapter 4: Discussion

This thesis provides new insights into the breeding ecology of small-bodied birds in woodland remnants in a fragmented landscape that is undergoing a transformation from semi-cleared grazing land to an exotic Radiata Pine plantation. This final chapter includes a summary of key findings of the preceding chapters, an overview of the effects of the matrix change on forest and woodland birds, the limitations of the study, and a short overview on suggested use of artificial nests for predicting nest predation risk. Some recommendations for management of pine plantations are provided, separately for forest birds, such as the Flame Robin, and woodland birds like the Brown Treecreeper and Dusky Woodswallow, all of which are vulnerable species in NSW (Office of Environment & Heritage, 2019).

4.1 Key findings

In Chapter 2, I posed a series of questions associated with the breeding success of natural bird nests in woodland remnants within a landscape being transformed from farmland to an exotic Radiata Pine plantation. Overall breeding success rates, including those for small-bodied birds, were not significantly different between the two types of landscape contexts. However, there were significantly fewer nests per site in woodland remnants surrounded by the plantation, compared to woodland remnants surrounded by grazing land. The proportion of nests of generalist (non-woodland dependent) avian nest predators was significantly higher in woodland remnants surrounded by the plantation. Overall, species with a larger mean body mass reproduced more successfully than smaller bodied birds. In addition, small-bodied birds (species with a mean body mass of < 48.25 g, see Chapter 2.3.4) nested more successfully at a lower height, where thickets of exotic Blackberry or dense native shrubs occurred. Notably, breeding activity by species of forest taxa, including the Eastern Yellow Robin a declining species in sheep-wheat belt of NSW (Reid, 1999), was observed in the pine plantation matrix.

In Chapter 3, I examined levels of nest predation on two types of artificial nests (cup and domed nests) in the two types of landscape contexts. The predators of artificial nests of small-bodied birds that I identified were all bird species, with the Australian Raven being the species responsible for most nest predation. Levels of nest predation of artificial nests were significantly higher in woodland remnants surrounded by the pine plantation than in woodland remnants surrounded by farmland. Cup nests suffered from nest predation more than domed nests in the both types of landscape contexts. I found that both artificial nests and natural nests of small-bodied birds were more susceptible to nest predation in woodland remnants surrounded by the pine plantation than in woodland remnants located within farmland. There was similar levels of nest predation for artificial and natural nests in woodland remnants located within grazing land. However, levels of nest predation of artificial nests were significantly higher than that of natural nests in woodland remnants surrounded by the pine plantation.

4.2 Effects of the landscape conversion and recommended management

4.2.1 Birds of forest taxa

The landscape transformation from semi-cleared grazing land to an exotic pine plantation may have increased habitats for some species of forest taxa. Breeding activity of some species of forest taxa, such as the White-browed Scrub-wren (*Sericornis frontalis*), Grey Fantail and Eastern Yellow Robin (*Eopsaltria australis*), was observed in the plantation matrix (Appendix 2). Earlier studies in the same study system (Lindenmayer et al., 2008) showed that some of those species first colonised the plantation matrix, and have then "spilled over" into the adjacent woodland remnants. Other species of forest taxa, such as the Flame Robin, which is an altitudinal migrant, also may have experienced increased site occupancy of woodland remnants in spring because woodland remnants surrounded by the

plantation have become contextually similar to forests due to the surrounding matured plantation matrix (Lindenmayer et al., 2009).

However, the matrix surrounding woodland remnants within the boundary of the pine plantation will soon dramatically change when the pine trees are subject to clearfell harvesting. Until replanted pines become matured, the forest-like plantation landscape will resemble an agricultural landscape. Ongoing monitoring will be important to document the effects of such changes in the matrix surrounding woodland remnants. To mitigate the potential negative effects of such changes in the matrix on forest taxa that have colonised woodland remnants surrounded by the plantation matrix (see Brady et al., 2009), I make the following management recommendations.

1. Retain woodland remnants because they are providing resources, such as food and breeding sites for forest taxa, including the Flame Robin. In the absence of these woodland remnants, some species will lose access to suitable habitat.
2. Avoid clear-cutting the plantation all at once to ensure the connectivity between woodland remnants. This may assist forest taxa that have colonised (and then nested in) the plantation landscape to move to find suitable food and nesting resources (Recher, 2007; Lindenmayer et al., 2009).
3. Plant and establish endemic species of shrubs. This will encourage small-bodied birds to nest, including forest taxa, and may enhance the breeding success (Chapter 2; Ford, 2011). Enhancement plantings should be undertaken before Blackberry thickets are removed to provide nesting habitats. Removal of the Blackberry may help to reduce the abundance of nest predators such as the Pied Currawong (Fulton and Ford, 2001).
4. Monitor woodland remnants surrounded by the plantation because they may be ecological traps (Reino et al., 2018). Many species of birds, including forest

species of conservation concern, such as the Flame Robin, were found to have nested in woodland remnants surrounded by the stands of pine, but nesting success was low.

4.2.2 Birds of woodland dependent taxa

The matrix change from grazing land to a pine plantation may have reduced habitats for some small-bodied birds that are strongly associated with open woodlands or open country. Data on natural nests, showed that the majority of ground-foraging small-bodied birds (Ford et al., 1988; Recher and Davis, 2010) and which had nested in woodland remnants located within farmland, constructed cup nests. Examples included the Dusky Woodswallow, Jacky Winter (*Microeca fascinans*), Restless Flycatcher (*Myiagra inquieta*), Rufous Songlark, and Willie Wagtail. In contrast, ground-foraging small-bodied birds that bred in woodland remnants surrounded by the plantation, such as the Yellow-rumped Thornbill (*Acanthiza chrysorrhoa*) and Buff-rumped Thornbill (*Acanthiza reguloides*) (Ford et al., 1988), constructed domed nests. A possible mechanism for this pattern of difference in the choice of habitats among species from the same foraging guild, may be susceptibility to nest predation (refer to Beckmann et al., 2015; Tolvanen et al., 2017). As outlined in Chapter 3, cup nests are inferior to domed nests in terms of nest predation. Birds with a smaller mean body mass are also more susceptible to nest predation (Chapter 2). Hence, those ground-foraging small-bodied birds that constructed cup nests, may have responded more quickly to perceived higher nest predation risk than those that constructed domed nests, and moved to woodland remnants located within grazing land, where nest predation risk was lower (Chapter 3).

The following management activities in the pine plantation may enhance site occupancy of woodland remnants embedded within the plantation by ground-foraging small woodland birds, particularly those that construct domed nests.

1. Retain woodland remnants within the boundary of the plantation. This is because they provide habitats for ground-foraging small-bodied birds, particularly those which construct domed nests.
2. Plant endemic dense-shrubs in woodland remnants within the boundary of the plantation. This will provide foraging areas and shelter sites for ground-foraging small-bodied birds.
3. Create a buffer zone of native grassland in the area surrounding woodland remnants when the plantation is harvested.
4. Enhance the quality of the ground cover by adding fallen timber and leaf litters or by controlling exotic grasses/weeds (Montague-Drake et al., 2009; Ford, 2011; Watson, 2015). These activities may attract many species of ground-foraging small-bodied birds.

4.3 Suggested use of artificial nests

I found that the effects of the landscape transformation on nest predation were consistent between artificial and natural nests. This may have been because both studies were conducted at the same sites, as Faaborg (2004) suggested was appropriate to do. Hence, the only differences observed were due to the matrix type. Despite this, my artificial nest experiments failed to accurately predict relative predation rates of natural nests in woodland remnants surrounded by the pine plantation. In this system, the use of artificial nest experiments may effectively reflect natural nest predation risk. This information together with other critical data, such as abundance of bird species and life history traits, could help deepen our understanding on how avian populations are shaped in particular habitats (Villard and Pärt, 2004; see Lindenmayer et al., 2009).

4.4 Limitations of the study and suggested areas for further study

I spent an equal amount of time (refer to Chapter 2.3.3) at each site searching for natural nests. However, I only found a paucity of nests in woodland remnants surrounded by the pine plantation. More nests in woodland remnants surrounded by the plantation, may need to be found to create a more robust dataset for analysis. Observing more breeding birds of ground-foraging small-bodied woodland species would be also required to test the mechanism that I proposed regarding predation risk affecting the choice of nesting sites.

4.5 Conclusion

My research has shown that expansion of pine plantations may provide habitat for some bird of forest taxa but create unsuitable environmental conditions for woodland dependent vulnerable species, such as the Brown Treecreeper, and Dusky Woodswallow. Different management measures may therefore be required to conserve woodland remnants within the boundary of plantations depending on which species are targeted for conservation. However, retaining woodland remnants within the plantation will benefit a range of small-bodied bird species. Further monitoring of birds and bird nesting success will be invaluable, especially as the plantations in the study area are approaching an age where they will be subject to clearfell harvesting and the landscapes may then resemble a semi-cleared agricultural environment.

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Appendix 1 A list of natural nests found in woodland remnants

The below is a list of species of natural nests that I found in the both types of landscape contexts, with average body mass and nest type. * indicates raptors and generalist avian nest predators. # indicates species of conservation concern. RF means woodland remnants surrounded by grazing fields and RP for woodland remnants surrounded by the stands of Radiata Pine plantation.

Remnant type	Common name	Scientific name	No of Nest	Nest type	Foraging substrates (provided only for small-bodied birds)	Mean body mass
RF	*Australian Magpie	*Cracticus tibicen*	6	Stick Platform		296
RF	Black-faced Cuckoo-shrike	*Coracina novaehollandiae*	2	Cup/Bowl		118
RF	Brown Treecreeper#	*Climacteris picumnus*	2	Hollow/Burrow	Ground/Bark	32
RF	Buff-rumped Thornbill	*Acanthiza reguloides*	4	Dome	Ground	8
RF	Dusky Woodswallow#	*Artamus cyanopterus*	2	Cup/Bowl	Ground/Air	35
RF	Grey Fantail	*Rhipidura albiscapa*	4	Cup/Bowl	Air	8
RF	Jacky Winter#	*Microeca fascinans*	2	Cup/Bowl	Air	16
RF	Leaden Flycatcher	*Myiagra rubecula*	5	Cup/Bowl	Air/Foliage	14
RF	Magpie-lark	*Grallina cyanoleuca*	4	Cup/Bowl		87
RF	Mistletoebird	*Dicaeum hirundinaceum*	3	Dome	Foliage	9
RF	Noisy Friarbird	*Philemon corniculatus*	27	Cup/Bowl		101
RF	*Pied Currawong	*Strepera graculina*	2	Stick Platform		332
RF	Rainbow Bee-eater	*Merops ornatus*	1	Hollow/Burrow	Air	27
RF	Red Wattlebird	*Anthochaera carunculata*	1	Cup/Bowl		114
RF	Restless Flycatcher#	*Myiagra inquieta*	2	Cup/Bowl	Ground/Air	21
RF	Rufous Songlark	*Cincloramphus mathewsi*	2	Cup/Bowl	Ground	29
RF	Rufous Whistler#	*Pachycephala rufiventris*	1	Cup/Bowl	Foliage	25
RF	Silvereye	*Zosterops lateralis*	2	Cup/Bowl	Foliage	12
RF	Spotted Pardolate	*Pardalotus punctatus*	1	Hollow/Burrow	Foliage	9
RF	Striated Pardalote	*Pardalotus striatus*	2	Hollow/Burrow	Foliage	12
RF	Superb Fairy-wren	*Malurus cyaneus*	5	Dome	Ground	10
RF	Western Gerygone	*Gerygone fusca*	1	Dome		7
RF	White-throated Gerygone	*Gerygone olivacea*	6	Dome	Foliage	7

RF	White-throated Treecreeper	*Cormobates leucophaea*	2	Hollow/Burrow	Bark	23
RF	White-winged Chough	*Corcorax melanorhamphos*	2	Cup/Bowl		368
RF	White-winged Triller	*Lalage sueurii*	5	Cup/Bowl	Foliage	25
RF	Willie Wagtail	*Rhipidura leucophrys*	11	Cup/Bowl	Air	21
RF	Yellow-faced Honeyeater	*Caligavis chrysops*	1	Cup/Bowl	Foliage	17
RF	Yellow-rumped Thornbill	*Acanthiza chrysorrhoa*	6	Dome	Ground	10
RP	*Australian Magpie	*Cracticus tibicen*	6	Stick Platform		296
RP	*Australian Raven	*Corvus coronoides*	4	Stick Platform		638
RP	Brown Thornbill	*Acanthiza pusilla*	2	Dome	Foliage	7
RP	Buff-rumped Thornbill	*Acanthiza reguloides*	3	Dome	Ground	8
RP	*Collared Sparrowhawk	*Accipiter cirrocephalus*	1	Stick Platform		172
RP	Crimson Rosella	*Platycercus elegans*	2	Hollow/Burrow		133
RP	Flame Robin	*Petroica phoenicea*	2	Cup/Bowl	Ground	13
RP	*Grey Butcherbird	*Cracticus torquatus*	1	Stick Platform		88
RP	Grey Fantail	*Rhipidura albiscapa*	1	Cup/Bowl	Air	8
RP	*Laughing Kookaburra	*Dacelo novaeguineae*	1	Hollow/Burrow		339
RP	Noisy Friarbird	*Philemon corniculatus*	1	Cup/Bowl		101
RP	*Pied Currawong	*Strepera graculina*	2	Stick Platform		332
RP	Red Wattlebird	*Anthochaera carunculata*	2	Cup/Bowl		114
RP	Sacred Kingfisher	*Todiramphus sanctus*	1	Hollow/Burrow	Ground	43
RP	Striated Pardalote	*Pardalotus striatus*	2	Hollow/Burrow	Foliage	12
RP	Superb Fairy-wren	*Malurus cyaneus*	4	Dome	Ground	10
RP	Weebill	*Smicrornis brevirostris*	1	Dome	Foliage	6
RP	White-browed Scrub-wren	*Sericornis frontalis*	1	Dome	Ground	13
RP	White-throated Gerygone	*Gerygone olivacea*	5	Dome	Foliage	7
RP	White-throated Treecreeper	*Cormobates leucophaea*	1	Hollow/Burrow	Bark	23
RP	Yellow-rumped Thornbill	*Acanthiza chrysorrhoa*	1	Dome	Ground	10
A total number of Nests for statistical analyses				158		
Birds excluded from statistical analyses	Australasian Grebe	*Tachybaptus novaehollandiae*	3	Waterweed Platform		219
	White-faced Heron	*Egretta novaehollandiae*	2	Stick Platform		585
	White-browed Woodswallow#	*Artamus superciliosus*	12	Cup/Bowl		36

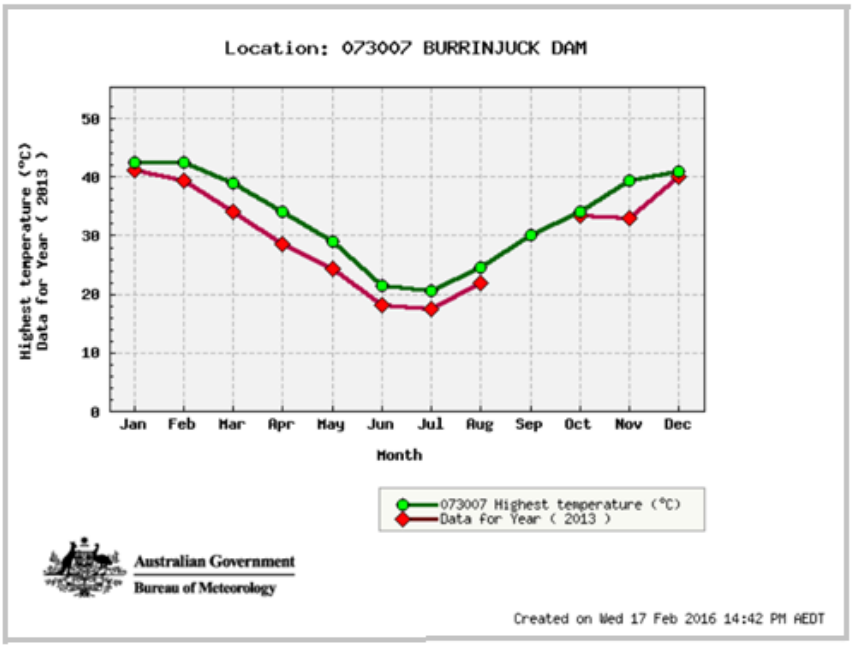
Appendix 2 A list of species which nested in the plantation matrix

The below is a list of bird species which showed evidence of nesting in pine trees. # indicates species of conservation concern.

Common name	Scientific name	Abundance	Breeding stage/Behaviours
Brown Thornbill	*Acanthiza pusilla*	1	Fledglings observed
Brown Thornbill	*Acanthiza pusilla*	2	Carrying food into pine stands
Buff-rumped Thornbill	*Acanthiza reguloides*	1	Carrying food into pine stands
Buff-rumped Thornbill	*Acanthiza reguloides*	1	Carrying nesting materials into pine stands
Eastern Yellow Robin#	*Eopsaltria australis*	1	Incubating on nest in pine tree
Grey Fantail	*Rhipidura albiscapa*	1	Fledglings
Grey Fantail	*Rhipidura albiscapa*	1	Incubating on nest in pine tree
Grey Fantail	*Rhipidura albiscapa*	3	Carrying nesting materials into pine stands
Silvereye	*Zosterops lateralis*	1	Carrying nesting materials into pine stands
White-browed Scrubwren	*Sericornis frontalis*	1	Feeding nestlings
White-browed Scrubwren	*Sericornis frontalis*	1	Nestlings heard
Yellow-faced Honeyeater	*Caligavis chrysops*	1	Feeding fledglings
Yellow-faced Honeyeater	*Caligavis chrysops*	1	Carrying nesting materials into pine stands
Yellow-rumped Thornbill	*Acanthiza chrysorrhoa*	1	Fledglings observed

Appendix 3 Highest temperature of a month in 2013

The below is a figure and a table derived from Bureau of Meteorology website, showing the highest temperature per month in 2013 at Burrinjuck Dam weather station, compared with historical highest temperature per month from 1965 to 2016.



Statistics	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Years
Highest temperature (°C) for years 1965 to 2016	42.5	42.4	39.0	34.0	29.0	21.5	20.6	24.5	30.0	34.0	39.4	40.9	42.5	50
Statistics	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Annual**	**Years**
Highest temperature (°C) for year 2013	41.1	39.4	34.0	28.5	24.3	18.1	17.5	22.0		33.5	33.0	40.0		1

Appendix 4 Images of the study landscape, natural nests and predators on artificial nests

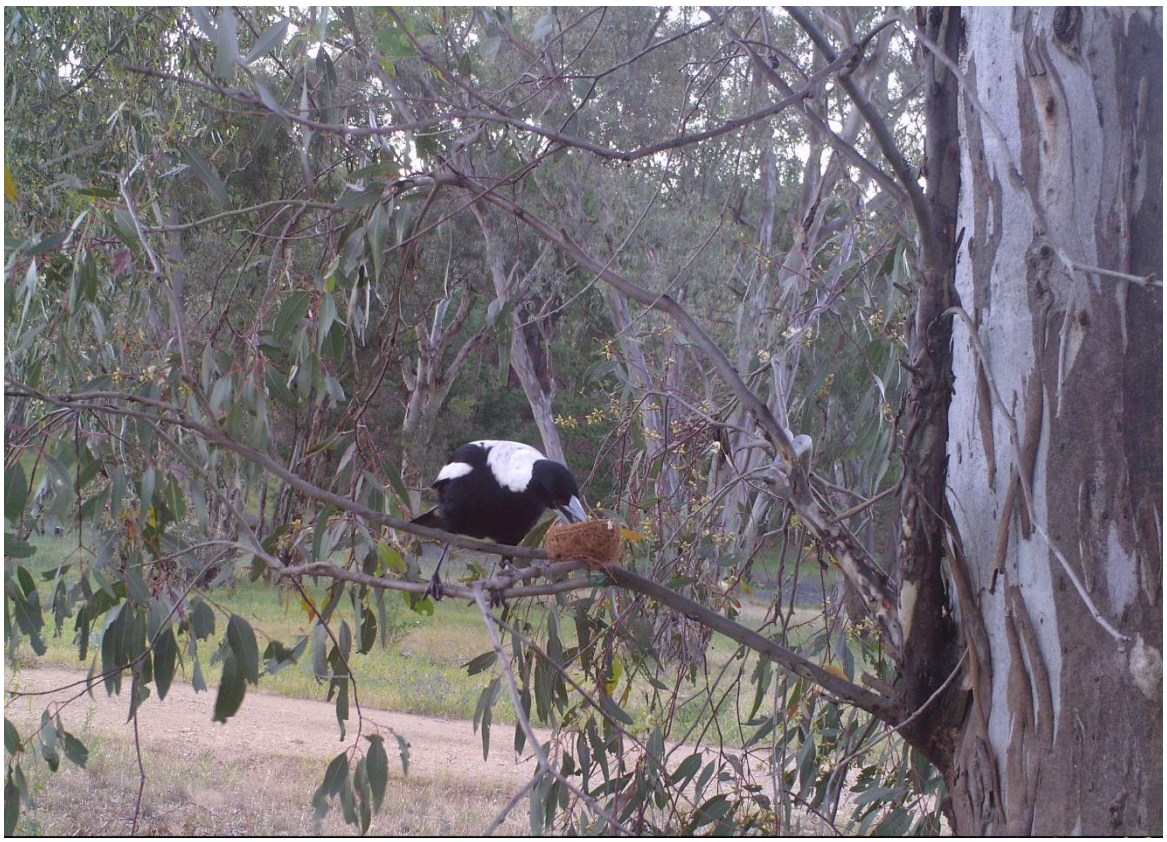
The study landscape being transformed into one dominated by Radiata Pine plantation

Woodland remnants in the Nanangroe State Forest (Radiata Pine plantation)

A nest and eggs of the Rufous Songlark

Two nestlings of the Mistletoebird

A Grey Shrike-thrush pecking a quail egg in an artificial cup nest



An Australian Magpie eating a quail egg or a plasticine egg in an artificial cup nest