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The conservation value of paddock trees for birds in a variegated landscape in southern New South Wales. 1. Species composition and site occupancy patterns

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Abstract. The use of paddock trees by birds was assessed in a grazing landscape in southern New South Wales, Australia. Seventy paddock tree sites were surveyed for 20 min each in the morning, and 36 sites were surveyed again at midday in March 2000. During this time, the presence and abundance of birds was recorded. Several site and landscape variables were measured at each site. These included tree species, a tree size index, a measure of the crown cover density around the site, and proximity to the nearest woodland patch. During formal surveys, 31 bird species, including several woodland species, were observed using paddock trees. Data from bird surveys in woodland patches that were obtained in a separate study in November 1999 were used to compare whether there was a relationship between the abundance of a given bird species in woodland patches and paddock trees. Many birds commonly detected in woodland patches were also common in paddock trees. However, some birds with special habitat requirements were absent from paddock trees although they were common in woodland patches. Site occupancy patterns were modelled for several guilds of birds using logistic regression. Foliage-foraging birds were more likely to occupy clumps of trees and sites with a high tree size index. Nectarivores appeared to be more likely to be detected at sites more than 200 m from woodland, although this result was marginally non-significant ($P = 0.08$). The probability of detecting granivores was higher at sites with a low tree size index. Open country species were most likely to occupy large trees and sites that were located more than 200 m from the nearest woodland patch. The value of paddock trees may have been underestimated in the past because a wide variety of bird species use paddock trees on a regular basis. Ensuring the continued survival of paddock trees should be an important aspect of future conservation and revegetation efforts.

Introduction

Birds are a diverse taxonomic group with more than 4850 species worldwide (Crosby et al. 1994), comprising an estimated minimum of 200 billion individual birds (Gaston and Blackburn 1997). However, bird populations are declining throughout the world (Thiollay 1993, 1998; Kattan et al. 1994; Tellería and Santos 1995; Renjifo 1999; Robinson 1999). Although only one of more than 500 species of land bird (Keast 1985) has become extinct on the Australian mainland to date, a recent study predicted the possible extinction of 50% of existing species by the end of this century (Recher 1999).

The main factors threatening Australian birds are habitat loss and habitat fragmentation (Saunders 1989, 1994; Saunders and Curry 1990; Keast 1995), habitat degradation (Recher and Lim 1990; Recher and Serventy 1991; Glanznig 1995; Woinarski and Recher 1997; Arnold and Weeldenburg 1998), and the introduction of exotic organisms (May and Norton 1996; Pell and Tidemann 1997). While nature reserves have long been considered important for biodiversity conservation (e.g. Diamond 1975; Margules and Pressey 2000), several authors have recently emphasised the need for landscape-wide resource management (Hobbs et al. 1993a; Barrett et al. 1994; Saunders 1994) and off-reserve conservation (Recher and Lim 1990; Robinson 1991; Franklin 1993; Saunders et al. 1993; Purdie 1995; Lindenmayer and Franklin 1998).

Despite this shift in conservation paradigms, little is known about what features enhance the habitat suitability of the landscape matrix, i.e. the areas outside consolidated habitat patches. In forest production landscapes, retained habitat trees are often seen as important features (Recher 1991; Gibbons and Lindenmayer 1997; Wapstra and Taylor 1998). In Australian grazing landscapes, paddock trees may be valuable in a similar way. However, detailed data on the use of paddock trees by entire bird communities in Australian pastoral landscapes are almost non-existent. Even the most basic information, such as which species may use paddock trees, is sparse. Here, we present a first attempt to address some existing knowledge gaps.

This is the first of two papers addressing the value of paddock trees for birds in a pastoral landscape in southeastern Australia (see this issue: Fischer and Lindenmayer 2002). Our aims were: (1) to examine which birds use paddock trees, (2) to investigate how the bird community composition in paddock trees compared with the bird community composition in consolidated woodland patches in the surrounding landscape, and (3) to examine which factors were related to occupancy patterns at the site and landscape level.

Study site

Field work was carried out on the 'Nanangroe' and 'Riverbend' properties in southern New South Wales, Australia (34°58′ S, 148°29′ E; Figure 1). The study area is part of the eastern Australian wheat-sheep zone. At the time field work was conducted, the area was used for sheep (*Ovis ovis*) and cattle (*Bos taurus*) grazing. Most of the landscape was variegated (*sensu* McIntyre and Barrett 1992; McIntyre and Hobbs 1999) – in large parts of the study site, the landscape changed continously from small woodland patches (<10 ha) to paddock. Retained paddock trees in the study area included Yellow Box (*Eucalyptus melliodora*), White Box (*E. albens*), and Blakely's Red Gum (*E. blakelyi*) and to a lesser extent Long-leaved Box (*E. goniocalyx*), and Apple Box (*E. bridgesiana*). Other tree species occasionally encountered were Red Box (*E. Polyanthemos*), Red Stringybark (*E. macrorhyncha*), and Kurrajong (*Brachychiton populneus*). Understorey vegetation was virtually absent, and the ground cover included both native and introduced grasses (N. Keatinge, leaseholder of Nanangroe, personal communication).

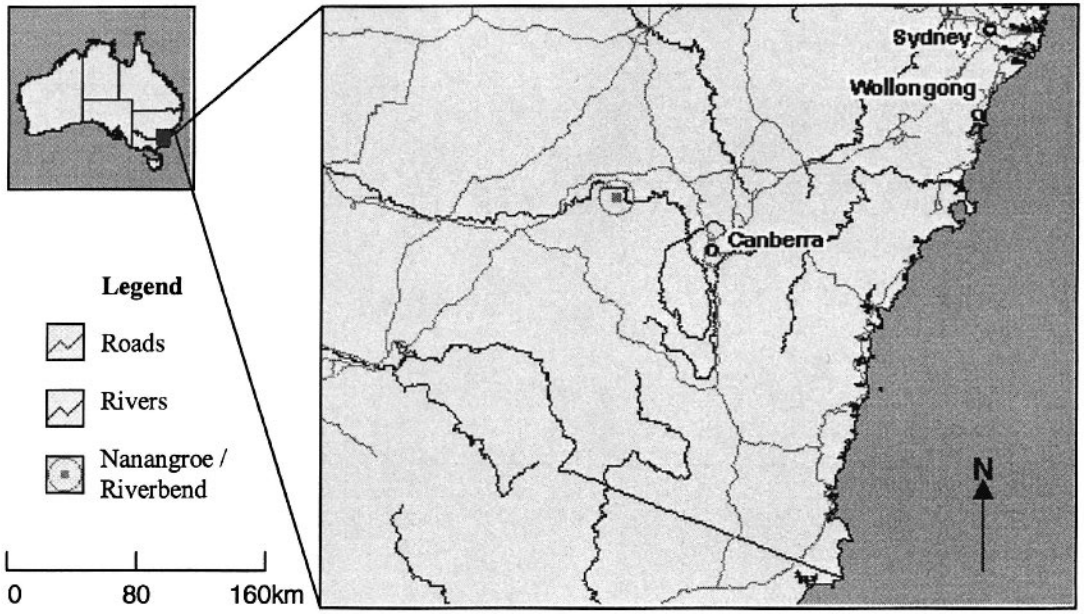

Figure 1. Location of Nanangroe and Riverbend (Gazetteer 2000).

Methods

Stratification and experimental design

The study area was stratified into four regions. Each of these was divided into two zones: within 200 m vs. further than 200 m from the nearest woodland patch (Figure 2). The delineation of woodland patch boundaries was subjective because of the variegated nature of the landscape. Within the study area, approximately 85 sites were identified from aerial photographs. These included single trees and clumps of trees. Clumps were defined as groups of 2–5 trees where the crowns were touching or nearly touching, and that were clearly separated from the nearest tree, clump or woodland patch. Clumps were chosen to be relatively similar in size, and the majority of clumps comprised two trees. Ground surveys were used to exclude some of the sites that had been identified from aerial photographs. Sites were excluded if the bird species composition was likely to be strongly influenced by factors that were not of primary interest to this study (e.g. where the trees had died or fallen over, were close to a dam, etc.). These procedures left 70 suitable paddock tree sites (Table 1).

Site and landscape variables

As part of the experimental design, clumps of trees and single trees were explicitly defined as separate types of site. The distinction between the two was made on the basis of the number of trees at a site (single tree vs. 2–5 trees), and did not take into account the size of the trees at a site. However, the relative size of a site – regardless of the number of trees it comprised – may influence the suitability of the site to birds. For example, under some circumstances, a single large tree may be more attractive to birds than a clump of two small trees. To account for the fact that birds may be responding to the relative size of a site, rather than the number of trees it comprised *per se*, a 'tree size index' was constructed that was independent of whether a site was a single tree or a clump of trees.

For each tree surveyed, the diameter at breast height was determined, and the basal area (cm^2) was calculated. In addition, the maximum width of the crown when projected vertically to the ground (m), and the height of the tree (m) were estimated. A volume-related 'tree size index' was calculated for each site (single tree or clump). For single trees, the values for basal area, tree height, and crown width were multiplied to obtain an index for tree size. Thus, a single tree scored a high 'tree size index' if it was tall, had a large crown, and a large basal area. For clumps, the average basal area of a tree, average height of a tree and sum of the crown widths of individual trees were multiplied to obtain the tree size index. The initial value for the tree size index for single trees and clumps was divided by 10000 to rescale it to smaller values. This was done solely to obtain more 'convenient' numbers for analysis (ranging from approximately 50 to 1000), and did not affect the significance of this index in later statistical models. However, it was important for parameter interpretation. Conceptually, the tree size index can be thought of as a

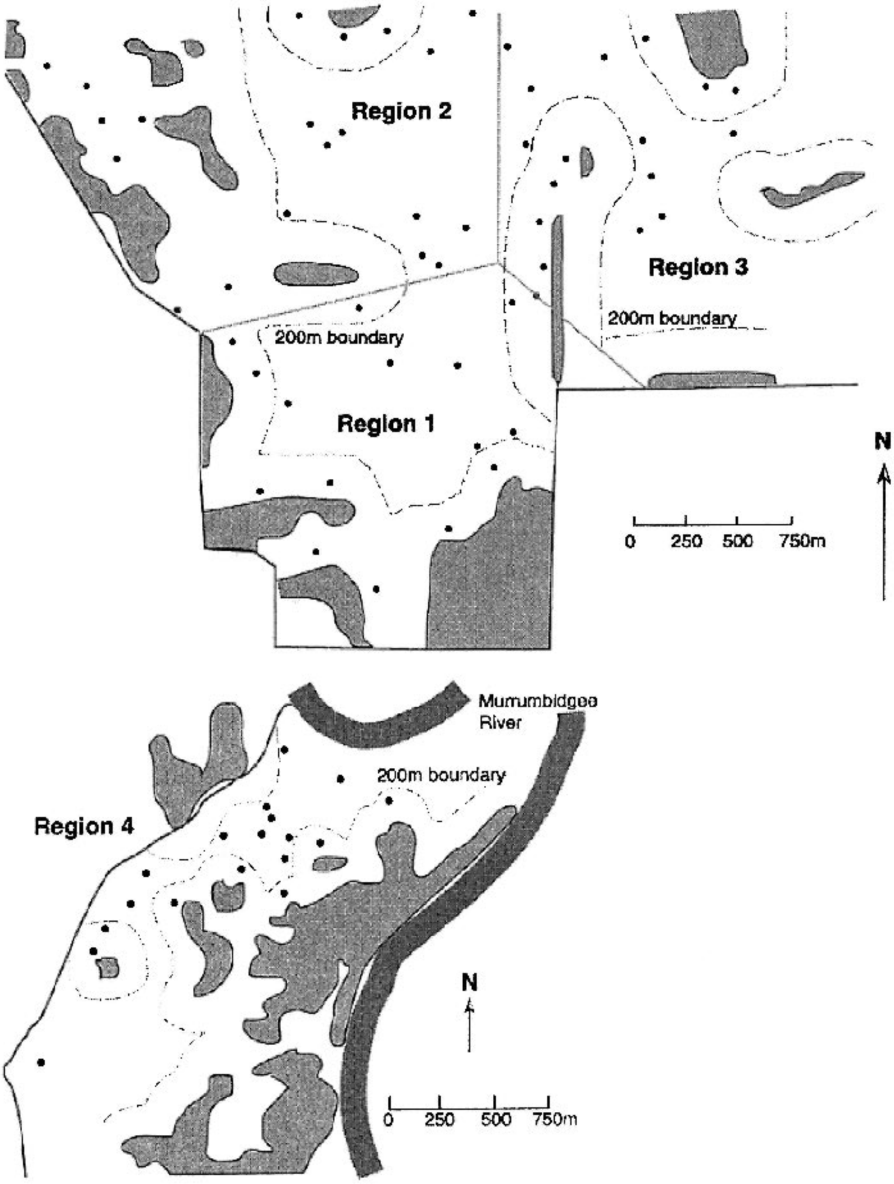

Figure 2. Stratification of the sections of Nanangroe (Regions 1–3) and Riverbend (Region 4) where field work was carried out. Survey sites are marked and zone boundaries are shown (see section 'Stratification and experimental design'). Woodland patches are shaded; note that areas outside of patches were variegated, and that survey sites were only a subset of all available paddock trees.

Table 1. Number of paddock tree sites within each region and zone (number of sites surveyed a second time [i.e. at midday] in parentheses).

	Region 1 Nearest patch		Region 2 Nearest patch		Region 3 Nearest patch		Region 4 Nearest patch		Total
	<200 m	>200 m	<200 m	>200 m	<200 m	>200 m	<200 m	>200 m	
Single	4[3]	2[1]	6[3]	9[3]	4[3]	8[1]	3[3]	10[3]	46[20]
Clump	7[4]	3[1]	4[2]	1[1]	3[2]	1[1]	4[4]	1[1]	24[16]
Sum	16[9]		20[9]		16[7]		18[11]		70[36]

'rectangle' (width by height), modified by the average basal area of a tree. By including the average basal area in the index, greater weight was given to trees with a large basal area, i.e. generally older trees. Different ways of constructing a tree size index would have been equally feasible – the most critical condition was that the resulting index was not inherently dependent on whether the site was a single tree or a clump of trees.

Clumps and single trees were assigned a species category for later analyses (Table 2). In addition, for each site, the number of large and small crowns within a 100 m radius was determined from aerial photographs, and a crown cover index was calculated. This was done by assigning each small crown (~8 m diameter) a value of 1, and each large crown (~20 m diameter) a value of 2, and adding these values within the 100 m radius surrounding each site.

Bird surveys in paddock trees

Each paddock tree site was surveyed once for 20 min between 6.45 and 10 A.M. – the time when birds are most active (Keast 1994). A pilot study had shown that the cumulative number of birds in a tree generally started to reach an asymptote after 20 min, and this was therefore considered a suitable survey period. The presence and abundance of all birds was recorded during the surveys. Individuals of one species acting as a flock (i.e. arriving and departing together) were defined as an independently acting group for statistical analyses. Approximately half of the 70 field sites ($n = 36$, Table 1) were surveyed a second time at midday (between 12 and 2

Table 2. Classification of tree species into species categories.

Species association	Species category
Eucalyptus melliodora ($n = 31$)	1
E. melliodora/E. blakelyi ($n = 1$)	1
E. melliodora/E. albens ($n = 1$)	1
E. polyanthemos ($n = 1$)	1
E. blakelyi ($n = 15$)	2
E. albens ($n = 12$)	3
E. albens/E. blakelyi ($n = 1$)	3
E. goniocalyx ($n = 5$)	4
E. bridgesiana ($n = 3$)	4
Total: $n = 70$	

P.M.) using the same procedures as in the mornings. In addition to the formal surveys, a list of incidental observations of birds was kept. All land bird species observed during field work were recorded in this list, and it was noted whether they were using paddock trees when observed.

Bird surveys in patches

Data on the number of birds using paddock trees contained limited information because they did not take into consideration the bird species composition in the surrounding landscape. Therefore, data from recent field surveys of woodland patches in the surrounding landscape were used to create a baseline data set against which data from paddock trees could be compared. As part of a long-term natural experiment (Lindenmayer et al. 2001), 39 woodland patches, ranging between 0.5 and 10 ha in size, were surveyed on the Riverbend and Nanangroe properties in November 1999 (i.e. earlier in the same season). Surveys were conducted by experienced volunteers from the Canberra Ornithologists Group. Each patch was surveyed at three locations in the morning. At each location, the point interval count method (Pyke and Recher 1983) was used for 5 min. Each location was surveyed repeatedly by between two and four different observers to limit the effects of between-observer differences in the ability to detect birds (Cunningham et al. 1999). Although several site and landscape parameters were measured for each patch, for the purpose of this paper, only bird presence data were used.

Analysis of species composition

To quantify which birds used paddock trees (Aim #1 above), indices of the abundance of bird species in paddock trees were constructed. This was done by recording: (1) the number of paddock tree sites where a given species was recorded, (2) the number of independently acting groups of a species observed during the paddock tree surveys, and (3) the total number of individuals of a species observed during paddock tree surveys.

To compare the bird species composition in paddock trees with the species composition in woodland patches (Aim #2 above), only results from the morning surveys in paddock trees were used because this was the time of day during which patch data were obtained. Species were recorded that were: (1) present in both patches and paddock trees, and (2) common in patches, but absent during paddock tree surveys. A scatterplot was created of the number of woodland patches vs. the number of paddock tree sites where a given species was observed, to explore possible relationships between these variables. Normative statistical modelling (e.g. regression of the number of woodland patches on the number of paddock tree sites for any given species) was inappropriate because data points – i.e. species – were not independent.

Analysis of site occupancy patterns

To determine which factors were related to the use of paddock trees by birds at the

Table 3. Response and explanatory variables used to model site occupancy patterns (see Appendix for scientific names of birds).

Variable	Data type	Description	Notes
Response variables			
Independently acting groups	Count	Number of independently acting groups at a given paddock tree site	General linear mixed model
Species richness	Count	Number of species observed at a given site	General linear mixed model
Foliage foragers group A	Binary	Yellow-rumped Thornbill, White-plumed Honeyeater, Striated Pardalote	Logistic regression; AM and PM data
Magpie	Binary	Magpie	Logistic regression; AM and PM data
White-plumed Honeyeater	Binary	White-plumed Honeyeater	Logistic regression; AM and PM data
Foliage foragers group B[a]	Binary	Yellow-rumped Thornbill, White-plumed Honeyeater, Striated Pardalote, Black-faced Cuckoo-shrike	Logistic regression; AM data only
Nectarivores	Binary	Red Wattlebird, Noisy Friarbird	Logistic regression; AM data only
Open country species	Binary	Magpie, Magpie-lark, Willie Wagtail	Logistic regression; AM data only
Parrots	Binary	Crimson Rosella, Eastern Rosella	Logistic regression; AM data only
Granivores[a]	Binary	Crimson Rosella, Eastern Rosella, Galah	Logistic regression; AM data only
Explanatory variables			
Region	Categorical	Indicator for Regions 2–4 (Region 1 chosen as baseline)	
Close	Binary	Indicator for distance to woodland <200 m (>200 m chosen as baseline)	
AM	Binary	Indicator for morning data (midday chosen as baseline)	Used only when enough AM and PM data were available
Site	Categorical	Indicator for each site used as a random effect to take into account the dependency of data	Used only in general linear mixed models
Clump	Binary	Indicator for clump (single tree chosen as baseline)	
Dieback	Binary	Indicator for signs of dieback at site	
Tree species	Categorical	Indicator for tree species group	
Size	Continuous	Tree size index for each site	
Cover	Continuous	Crown cover index for each site	

[a]Insufficient data were available to analyse the foliage-foraging Black-faced Cuckoo-Shrike and granivorous Galah by themselves. However, field observations of both species indicated that they behaved differently to the other members of their guild. Two groups of foliage foragers (‘A’ and ‘B’), and granivores (‘parrots’ and ‘granivores’) were therefore established and analysed separately.

site and landscape levels (Aim #3 above), general linear mixed models (Engel 1986) and logistic regression analysis (McCullagh and Nelder 1989) were used. For the response variables measured on a count scale (species richness and number of independently acting groups – Table 3), general linear mixed models were constructed using a combination of data gathered in the morning and afternoon. These data comprised 70 paddock tree sites surveyed in the morning, and 36 paddock tree sites re-surveyed in the afternoon. General linear mixed modelling distinguishes between random and fixed effects. Random effects account for the dependency of data points arising from the experimental design. For example, in this study, paddock tree sites were not independent of one another because some were located in the same 'zone' and/or 'region' (Figure 2), and because some sites were re-surveyed in the afternoon. Hence, 'region', 'close', 'AM', 'site' were modelled as random effects (Table 3). All other explanatory variables were modelled as fixed effects (e.g. 'clump', 'cover' etc.; see Table 3).

Logistic regression (McCullagh and Nelder 1989) was used to model the probability of detecting particular species at a site (Table 3). Presence/absence data for some uncommon species were grouped on the basis of foraging guild (Recher and Holmes 1985; Recher et al. 1985; Ford et al. 1986; Brooker et al. 1990; Mac Nally 1994) or broad habitat requirements (open-country species only; Cameron 1985; Dyrcz 1994; Bennett 1995; Luck et al. 1999). Only species recorded at a minimum of three of the 70 paddock sites were included in these groups. The response data for logistic regression analyses included morning and afternoon observations (70 + 36 = 106 data points) when data were sufficient. Because the response was binary, it was impossible to use general linear mixed modelling, and formally define random effects. To circumvent the problem of dependence as far as possible, 'Region' was fitted in all models to adjust for any inherent differences in the bird community composition across the landscape. The explanatory variables used for the logistic regression models included a number of continuous and categorical predictors (e.g. 'clump', 'cover', etc.; see Table 3).

Results

Species composition in paddock trees

Fifty-five bird species (including incidental observations) were observed in the study area in March 2000. Of these, 44 species were observed using paddock trees. During the formal field surveys, 31 species were recorded (Tables 4 and 5).

Comparison with the surrounding landscape

Eighty-eight bird species were observed in the 39 woodland patches surveyed in November 1999 (see Appendix). Most of the species that were common in patches (>10 patches) also were observed in paddock trees. Species that were never recorded in paddock trees (including afternoon surveys and incidental observations)

Table 4. List of all species observed during the survey period in March 2000 (* indicates introduced species).

Species	Paddock tree	Survey site
Wedge-tailed Eagle		
Nankeen Kestrel	×	
Stubble Quail		
Peaceful Dove	×	
Crested Pigeon	×	
Gang-gang Cockatoo	×	×
Galah	×	×
Sulphur-crested Cockatoo	×	×
Australian King Parrot	×	
Superb Parrot	×	
Crimson Rosella	×	×
Eastern Rosella	×	×
Red-rumped parrot	×	×
Laughing Kookaburra	×	×
Rainbow Bee-eater		
Welcome Swallow	×	
Tree Martin	×	×
Fairy Martin	×	×
Richard's Pipit		
Black-faced Cuckoo-shrike	×	×
Cicadabird	×	×
Jacky Winter	×	
Scarlet Robin	×	×
Crested Shrike-tit	×	×
Grey Shrike-thrush	×	
Restless Flycatcher	×	×
Grey Fantail	×	×
Willie Wagtail	×	×
Superb Fairy-wren	×	×
White-browed Scrubwren		
White-throated Gerygone		
Yellow-rumped Thornbill	×	×
Weebill		
White-throated Treecreeper		
Brown Treecreeper	×	
Red Wattlebird	×	×
Noisy Friarbird	×	×
Noisy Miner	×	
White-plumed Honeyeater	×	×
Silvereye	×	×
Mistletoebird	×	×
Spotted Pardalote		
Striated Pardalote	×	×
Red-browed Finch		
Diamond Firetail	×	×
European Goldfinch*	×	×
House Sparrow*		
Common Starling*	×	×

Table 4. (*continued*)

Species	Paddock tree	Survey site
Magpie-lark	×	×
White-winged Chough	×	
Dusky Woodswallow	×	×
Pied Currawong	×	
Australian Magpie	×	×
Australian Raven	×	×
Little Raven	×	
Total = 55	44	31

All land bird species (including incidental observations) are listed. Evidence for a species' use of paddock trees in general, and presence during formal surveys, respectively is indicated by a cross ('×'). The scientific names of all species are listed in the Appendix.

but were common in woodland patches were the Rufous Songlark (>30 patches), White-throated Treecreeper, Rufous Whistler, Yellow-faced Honeyeater (>20 patches), White-throated Gerygone, and White-browed Scrubwren (>10 patches).

Birds that were common in patches generally were also commonly observed in paddock trees. However, a scatterplot of the number of woodland patches vs. the number of paddock tree sites where a given species was observed showed two outliers: the White-plumed Honeyeater was recorded in an unexpectedly large number of paddock tree sites (28 woodland patches, 27 paddock tree sites), and the Sulphur-crested Cockatoo was recorded in an unexpectedly large number of woodland patches (37 woodland patches, 1 paddock tree site). When these outliers were excluded from the analysis, there was a strong positive relationship between the number of woodland patches and paddock tree sites in which a given species was observed (Figure 3).

Site occupancy patterns

General linear mixed models were constructed for data on 'species richness' and 'number of independently acting groups' (Table 3). None of the fixed or random effects were significantly related to species richness, i.e. the null model was chosen as the final model. The number of independently acting groups at a paddock tree site was significantly higher in the mornings than at midday ($P < 0.001$; Figure 4).

Logistic regression models using morning and afternoon data were constructed for the response variables 'Foliage foragers group A', 'White-plumed Honeyeater', and 'Magpie' (Table 3). The final model for the probability of detecting a foliage foraging bird ('Group A') was the null model. However, there was a notable (although non-significant; $P > 0.05$) trend for an increased probability of detecting a foliage forager in Region 4. The only significant explanatory variable for the probability of detecting the 'White-plumed Honeyeater' was an interaction between 'AM' and 'clump'. This interaction indicated that the White-plumed Honeyeater was significantly more likely to be detected in clumps in the morning ($P = 0.01$; Table 6). The probability of detecting a 'Magpie' was significantly higher at

Table 5. Abundance of species recorded during formal surveys.

Species	No. of AM sites $n = 70$	No. of PM sites $n = 36$	Number of independently acting groups (ind. groups)	Mean size ind. acting group: mean [S.E.] (mean size)	Ind. groups × mean size
White-plumed Honeyeater	27	12	83	1.58 [0.01]	131
Red Wattlebird	7	4	36	2.83 [0.08]	102
Noisy Friarbird	9	0	24	2.88 [0.17]	69
Yellow-rumped Thornbill	4	5	17	3.47 [0.39]	59
Common Starling	0	1	1	40 [*n*/*a*]	40
Australian Magpie	12	6	23	1.35 [0.03]	31
Eastern Rosella	9	1	15	1.80 [0.06]	27
Crimson Rosella	6	1	12	2 [0.10]	24
Silvereye	1	0	3	7.67 [3.56]	23
Galah	3	0	5	3.8 [0.45]	19
Dusky Woodswallow	4	0	6	2.67 [0.34]	16
Striated Pardalote	6	3	10	1.60 [0.12]	16
Willie Wagtail	6	1	10	1.30 [0.05]	13
Black-faced Cuckoo-shrike	6	1	9	1.33 [0.06]	12
Red-rumped Parrot	1	1	3	3.33 [0.51]	10
Magpie-lark	3	1	5	1.60 [0.18]	8
Sulphur-crested Cockatoo	1	1	2	2.50 [0.35]	5
Laughing Kookaburra	2	1	3	1.50 [0.19]	5
Tree Martin	1	0	1	5 [*n*/*a*]	5
Fairy Martin	1	0	2	2 [0.71]	4
Superb Fairy-wren	1	0	1	4 [*n*/*a*]	4
European Goldfinch	1	0	2	2 [0.00]	4
Australian Raven	0	1	1	2 [*n*/*a*]	2
Diamond Firetail	1	0	1	2 [*n*/*a*]	2
Gang-gang Cockatoo	1	0	1	2 [*n*/*a*]	2
Grey Fantail	2	0	2	1 [0.00]	2
Scarlet Robin	1	0	2	1 [0.00]	2
Cicadabird	1	0	1	1 [*n*/*a*]	1
Crested Shrike-tit	1	0	1	1 [*n*/*a*]	1
Mistletoebird	0	1	1	1 [*n*/*a*]	1
Restless Flycatcher	0	1	1	1 [*n*/*a*]	1
Unidentified	7	1	21	1.19 [0.02]	25
Sum			305		666

The column 'Ind. groups × mean size' is an approximation of the total number of birds recorded of one species (assuming no individual was recorded multiple times, which is likely to be incorrect for some mobile species).

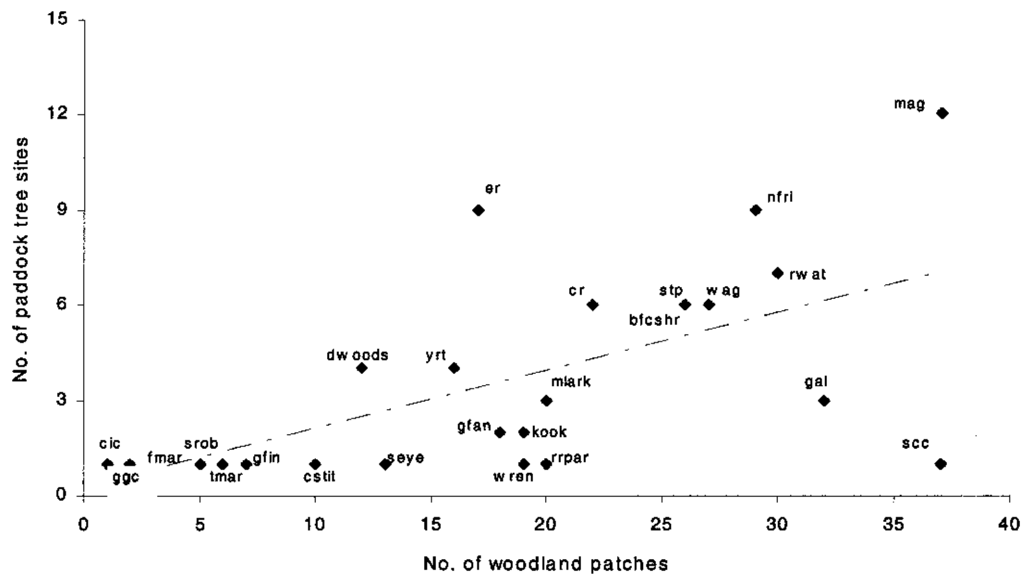

Figure 3. Number of woodland patches vs. number of paddock tree sites where a species was observed. Species abbreviations in alphabetical order are: bfcshr – Black-faced Cuckoo-shrike, cic – Cicadabird, cr – Crimson Rosella, cstit – Crested Shrike-tit, dwoods – Dusky Woodswallow, er – Eastern Rosella, fmar – Fairy Martin, gal – Galah, gfan – Grey Fantail, gfin – European Goldfinch, ggc – Gang-gang Cockatoo, kook – Laughing Kookaburra, mag – Australian Magpie, mlark – Magpie-lark, nfri – Noisy Friarbird, rrpar – Red-rumped Parrot, scc – Sulphur-crested Cockatoo, seye –Silvereye, srob – Scarlet Robin, stp – Striated Pardalote, tmar – Tree Martin, wag – Willie Wagtail, wat – Red Wattlebird, wren – Superb Fairy-Wren, yrt – Yellow-rumped Thornbill. The dashed line serves illustration purposes only.

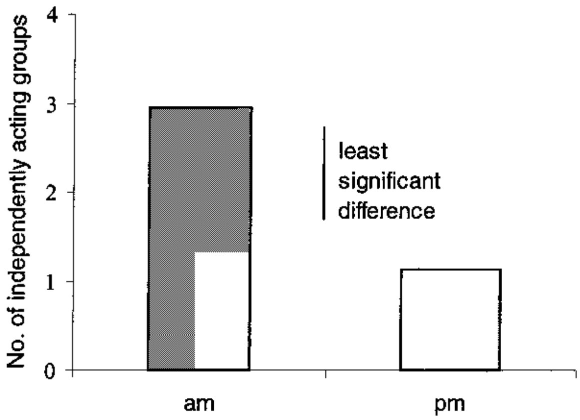

Figure 4. Predicted mean number of independently acting groups during a 20 min survey at morning and midday ($P < 0.001$).

paddock tree sites that were far from woodland patches (i.e. >200 m; $P < 0.01$; Table 6).

Logistic regression models using morning data only were constructed for the response variables 'Foliage foragers group B', 'Nectarivores', 'Parrots', 'Granivores' and 'Open country species' (Table 3). Foliage foragers of 'Group B' were significantly more likely to be observed in clumps ($P = 0.04$), and in paddock tree sites with a large tree size index ($P = 0.05$; Table 6). The probability of detecting 'Nectarivores' appeared to be higher at paddock tree sites located more than 200 m from woodland patches, although this result was marginally non-significant ($P = 0.08$). The final model for 'Parrots' was the null model. When cockatoos and parrots were combined in the group of 'Granivores', the tree size index was statistically significant ($P < 0.05$). The parameter estimate indicated that granivores were significantly more likely to be detected at paddock tree sites with a small tree size index (Table 6). Finally, the model for 'Open-country species' indicated that these species were more likely to be detected at paddock tree sites far from woodland patches (i.e. >200 m; $P < 0.05$), and at paddock tree sites with a large size index ($P < 0.05$; Table 6).

Discussion

Species composition in paddock trees

Paddock trees were used by a wide range of birds. The most commonly observed species in this study were the White-plumed Honeyeater, Red Wattlebird, and Noisy Friarbird (Table 5). These birds are members of the honeyeater family (Meliphagidae), and are frequently associated with woodland vegetation (e.g. Pizzey and Knight 1997; Green and Catterall 1998), although they also may utilise parks and gardens (Pizzey and Knight 1997).

Other common species recorded included typical 'open country' species, like the

Table 6. Regression equations for logistic regression models (with 'Region 1' as the baseline, and the 'Region' indicators included in all models).

Response	Linear predictor for logit (response)
AM and PM data	
White-plumed Honeyeater	$-2.143 + 1.919(\text{Region 2}) + 0.893(\text{Region 3}) + 2.854(\text{Region 4}) - 0.706(\text{clump}) - 0.531(\text{AM}) + 2.49(\text{clump} \times \text{AM})$
Magpie	$-0.755 + 0.012(\text{Region 2}) - 0.572(\text{Region 3}) - 0.278(\text{Region 4}) - 1.467(\text{close})$
AM data only	
Foliage foragers group B	$-3.47 + 2.675(\text{Region 2}) + 2.031(\text{Region 3}) + 4.27(\text{Region 4}) + 1.432(\text{clump}) + 0.00267(\text{size})$
Granivores	$-0.964 + 0.51(\text{Region 2}) + 1.038(\text{Region 3}) + 1.224(\text{Region 4}) - 0.00313(\text{size})$
Open country species	$-1.660 + 0.346(\text{Region 2}) + 0.457(\text{Region 3}) + 0.303(\text{Region 4}) - 1.426(\text{close}) + 0.00284(\text{size})$

No significant relationships with any of the predictors were found for 'Foliage foragers group A', 'Necativores', and 'Parrots'.

Australian Magpie, Willie Wagtail and Magpie-lark (Saunders and Curry 1990; Bennett 1995; Catterall et al. 1997; Green and Catterall 1998; Luck et al. 1999). Aggressive or introduced species that are abundant in farmland in some regions, such as the Noisy Miner or Common Starling, were uncommon in the study area (Table 5). Given that interspecific aggression is often displayed by these species (e.g. Catterall et al. 1997; Grey et al. 1997, 1998; Pell and Tidemann 1997; Green and Catterall 1998; Mac Nally et al. 2000), other bird taxa have probably benefited from their absence.

Granivores also were common throughout the study area. Many parrots and cockatoos use paddock trees for nesting, but feed in open areas (e.g. Saunders 1979; Wyndham and Cannon 1985; Mawson and Long 1994), and some have expanded their range since the development of agriculture (e.g. the Galah; Saunders 1985; Saunders and Curry 1990; Saunders and Ingram 1995; James et al. 1999). Farmland therefore appears to be high quality habitat for these species.

In addition, several birds that are traditionally considered to be woodland species were observed using paddock trees. These included (among others; Table 4) the Striated Padalote, Scarlet Robin, Grey Shrike-thrush, and Crested Shrike-tit – all of which are generally classified as woodland or forest species (Simpson and Day 1996). This new finding demonstrates the value of small habitat features, including single paddock trees, for species that are traditionally thought to be strongly associated with consolidated woodland patches.

Relationship between species composition in paddock trees and patches

Birds commonly observed in paddock trees also tended to be common in woodland patches in the surrounding landscape. This result is broadly consistent with the suggestion that the extent to which a species uses the matrix may be a key factor in determining patch occupancy (Diamond et al. 1987; Laurance 1991; Gascon et al. 1999), and emphasises the importance of the matrix for animals (Franklin 1993; Lindenmayer and Franklin 1998). Our findings suggest that it was inappropriate to assume that the matrix was 'hostile' for several of the bird taxa in the study area.

A complementary interpretation of the results is that the landscape represented a habitat continuum, so that some birds did not distinguish between patches and paddocks as perceived by humans. McIntyre and Barrett (1992, p. 147) defined a variegated landscape to be "a constantly shifting mosaic of habitat of varying suitability". They found that this conceptual model was more appropriate for birds in the New England Tablelands (New South Wales) than the more traditionally applied patch-matrix-corridor model by Forman (1995). In South Africa, Ingham and Samways (1996) explicitly compared the patch-matrix-corridor model and the variegation model for macroinvertebrates, and found that most taxa responded to the landscape as a continuum. In this study, we also found that the concept of a variegated landscape, i.e. a habitat continuum, was consistent with the way many birds used the landscape.

Some species were common in patches, but uncommon or absent in paddock trees – e.g. the Brown Treecreeper, White-throated Treecreeper, White-browed Scrubwren. The absence of these species in paddock trees could be explained by their habitat requirements. For example, treecreepers have specialised foraging requirements and are generally reliant on woodland patches (Walters et al. 1999; Weekes 1999). Similarly, the White-browed Scrubwren forages in shrubs (Cunningham et al. 1999), which were absent in the paddocks we surveyed. Thus, while the loosely vegetated paddocks of Nanangroe and Riverbend provided habitat for many bird taxa, some were reliant on the presence of structurally more complex woodland patches.

Site occupancy patterns

The number of independently acting groups observed during a 20-min period was significantly higher in the morning than at midday. This result is consistent with other studies that have shown that many birds reach their peak activity levels in the morning (e.g. Dyrcz 1994; Keast 1994). None of the other explanatory variables describing tree, site and landscape attributes were significantly related to the number of independently acting groups or species richness at a site. Prior to the commencement of the study, we expected that sites with a high cover index or sites close to woodland would attract more birds. The absence of cover effects suggests that not only densely vegetated areas, but also sparsely vegetated parts of the landscape were used by a considerable number of birds.

There was no strong relationship between foliage-foraging birds and the amount of cover at the landscape scale, but significant relationships with the probability of detection were found at the site level (Table 6). That site variables were more important than landscape variables illustrates the mobility of some of the foliage-foraging species recorded in this study. The White-plumed Honeyeater and Black-faced Cuckoo-shrike in particular, but also the smaller Striated Pardalote, were frequently observed to cross large gaps (>100 m).

Nectarivores showed a trend to preferentially use sites more than 200 m from the nearest woodland patch. This finding is consistent with a study by Luck et al. (1999), who found that the Red Wattlebird was associated with natural habitat edges, i.e. it seemed to prefer a semi-open habitat. Similarly, the Noisy Friarbird has been reported to move large distances across farmland (Ford and Barrett 1995).

Granivores were more likely to be detected in small trees than in large trees. These birds are reliant on large hollow-bearing trees for breeding (Saunders 1979; Rowley and Chapman 1991; Mawson and Long 1994; Gibbons and Lindenmayer 1997). However, they frequently feed on the ground, and therefore small trees may be convenient locations for rest and shelter. Alternatively, granivores may have preferred small trees because tree size was correlated with other factors not measured in this study.

Open-country species were more likely to be detected at sites more than 200 m from the nearest woodland patch, which is consistent with their habitat preferences reported elsewhere (Cameron 1985; Bennett 1995; Catterall et al. 1997; Luck et al. 1999). Some open country species also preferred sites with a large tree size index. A possible explanation for this result is that larger trees may have provided better perches for hunting or roosting (Cameron 1985; Dyrcz 1994; personal observation).

Implications for conservation and ecosystem restoration

This study illustrated that paddock trees may complement more consolidated woodland patches for a range of bird taxa. Hence, both patches and paddock trees should be important targets of future conservation strategies, because the loss of either could adversely affect avian populations. Landscape-wide resource management may be particularly important not only because animals may use the entire landscape at any given point of time, but also because some animals are reliant on different parts of the landscape at different stages of their life cycle (Law and Dickman 1998). Law and Dickman (1998) argued that different sections of a landscape mosaic may be important for vertebrates at various temporal scales. In this study, for example, cockatoos often roosted in relatively densely vegetated areas near woodland patches (Lindenmayer et al. 1996), but during the day were often found to use paddock trees or open pastures. Similarly, some species may be largely restricted to woodland patches, but may use paddock trees as stepping stones to move between foraging sites (Fischer and Lindenmayer 2002), or to disperse after the breeding period (although this suggestion has not been examined in detail). Therefore, it is important to maintain the entire landscape mosaic of patches and paddock trees, and not only conserve those sections of the landscape that have traditionally had a higher conservation profile (i.e. the patches; see also Law and Dickman 1998).

We found that both isolated and partially isolated paddock trees appeared to provide a suitable habitat for many of the species examined in our regression analyses. Even some of the infrequently observed species were found at paddock tree sites where the surrounding cover was sparse (e.g. Scarlet Robin). Thus, it should not be assumed that a given paddock tree is worthless simply because it appears from a human perspective to be isolated.

Paddock trees are under stress from stock damage, exposure to wind, salinity, water stress, and insect attack (Landsberg and Wylie 1983; Mawson and Long 1994). In a recent study, Ozolins (1999) found that the abundance of paddock trees in central West New South Wales had declined by 20% over the last 30 years, and several authors have warned that there is a lack of regeneration of paddock trees due to trampling and grazing of seedlings by cattle (e.g. Saunders 1979, 1985; Department of Arts, Heritage and the Environment 1986).

In a recent paper, McIntyre and Hobbs (1999) suggested that as a result of human land modification, landscapes could be classified into four broad categories: intact, variegated, fragmented or relictual. They argued that as human impact increases, the amount of original land cover decreases, remnants become more degraded, and edges between modified and unmodified land become more pronounced. Paddock trees are important as habitat and stepping stones (Fischer and Lindenmayer 2002), and may prevent currently variegated grazing landscapes from becoming fragmented. Given that fragmentation is among the main processes threatening biodiversity (Saunders et al. 1991), ensuring the continued survival of paddock trees should be an important aspect of future conservation efforts in Australian grazing landscapes.

Similarly, ecosystem restoration should attempt to consider the value of scattered

Table 7. Some commonly recommended revegetation strategies and their theoretical basis.

Recommended revegetation principle	Theoretical foundation	References
Increase the size of existing patches	Island biogeography (MacArthur and Wilson 1967)	Barrett (1997), Watson (1999)
Link existing patches with corridors	Landscape ecology (Forman and Godron 1986)	Saunders and de Rebeira (1991), Recher (1993)
Enhance structural complexity of patches	Niche and guild Theory (e.g. Wiens 1989)	Hobbs et al. (1993b), Recher (1993), Fenton (1997)

vegetation in the landscape matrix. Some commonly recommended principles for revegetation are listed in Table 7. None of these is fully adequate to ensure the ongoing availability of variegated landscapes, because none specifically targets the landscape matrix. Further research is required on the feasibility of establishing scattered vegetation as part of restoration strategies.

Conclusions and questions for future research

We have been able to demonstrate that more bird species than previously thought make use of paddock trees in one way or another. To our knowledge, this was the first study on birds in Australian paddock trees, and as such, it is a starting point for much needed additional research on this topic. The following questions in particular are ones that we were unable to address in this study, but which should be examined more closely in the future.

1. What do birds do when they use paddock trees? Are they foraging, preening, perching, resting etc.? We attempted to address this question, but given the dense crowns of many paddock trees, a single observer was unable to record sufficient information for analysis.
2. Do any bird species breed in paddock trees? Our study was not concerned with breeding, and was conducted at the end of the breeding season. Breeding data would be a valuable addition to the information we presented.
3. How are bird assemblages in woodland patches affected by the presence or absence of paddock trees nearby? We found some evidence that occupancy patterns of birds in patches and paddock trees may be somewhat related, but a more powerful experimental design examining woodland patches situated in a matrix with and without paddock trees would be needed to fully answer this question.
4. Which other animals use paddock trees, and in what way, and how frequently?
5. Are there consistent patterns across different study sites?

Given the continuing decline of paddock trees in Australian grazing landscapes, we believe that these questions are in urgent need of attention.

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Appendix

List of bird species of Nanangroe and Riverbend.

Common name	Scientific name	Patch	Paddock tree
Stubble Quail	*Coturnix pectoralis*	×	
Australian Wood Duck	*Chenonetta jubata*	×	
Pacific Black Duck	*Anas superciliosa*	×	
Little Pied Cormorant	*Phalacrocorax melanoleucos*	×	
White-faced Heron	*Egretta novaehollandiae*	×	
Straw-necked Ibis	*Threskiornis spinicollis*	×	
Wedge-tailed Eagle	*Aquila audax*	×	
Brown Falcon	*Falco berigora*	×	
Nankeen Kestrel	*F. cenchroides*	×	×
Masked Lapwing	*Vanellus miles*	×	
Common Bronzewing	*Phaps chalcoptera*	×	
Crested Pigeon	*Ocyphaps lophotes*	×	×
Peaceful Dove	*Geopelia striata*	×	×
Gang-gang Cockatoo	*Callocephalon fimbriatum*	×	×
Galah	*Cacatua roseicapilla*	×	×
Sulphur-crested Cockatoo	*C. galerita*	×	×
Australian King-Parrot	*Alisterus scapularis*	×	×
Superb Parrot	*Polytelis swainsonii*		×
Crimson Rosella	*Platycercus elegans*	×	×
Eastern Rosella	*P. eximius*	×	×
Red-rumped Parrot	*Psephotus haematonotus*	×	×
Pallid Cuckoo	*Cuculus pallidus*	×	
Fan-tailed Cuckoo	*Cu. Flabelliformis*	×	
Horsefield's Bronze-cuckoo	*Chrysococcyx basalis*	×	
Shining Bronze-cuckoo	*Ch. lucidus*	×	
Laughing Kookaburra	*Dacelo novaeguineae*	×	×
Sacred Kingfisher	*Todiramphus sanctus*	×	
Rainbow Bee-eater	*Merops ornatus*	×	
White-throated Treecreeper	*Cormobates leucophaeus*	×	
Brown Treecreeper	*Climacteris picumnus*	×	×
Superb Fairy-wren	*Malurus cyaneus*	×	×
Spotted Pardalote	*Paradalotus punctatus*	×	
Straited Pardalote	*Pa. Straitus*	×	×
White-browed Scrubwren	*Sericornis frontalis*	×	
Weebill	*Smicrornis brevirostris*	×	
Western Gerygone	*Gerygone fusca*	×	
White-throated Gerygone	*G. olivacea*	×	
Brown Thornbill	*Acanthiza pusilla*	×	
Buff-rumped Thornbill	*A. reguloides*	×	
Yellow-rumped Thornbill	*A. chrysorrhoa*	×	×
Striated Thornbill	*A. lineata*	×	
Red Wattlebird	*Anthochaera carunculata*	×	×
Noisy Friarbird	*Philemon corniculatus*	×	×
Little Friarbird	*Philemon citreogularis*	×	
Noisy Miner	*Manorina melanocephala*	×	×
Yellow-faced Honeyeater	*Lichenostomus chrysops*	×	

Appendix. (*Continued*)

Common name	Scientific name	Patch	Paddock tree
White-plumed Honeyeater	*Li. penicillatus*	×	×
Black-chinned Honeyeater	*Melithreptus gularis*	×	
Brown-headed Honeyeater	*M. brevirostris*	×	
Crescent Honeyeater	*Phylidonyris pyrrhoptera*	×	
New Holland Honeyeater	*P. novaehollandiae*	×	
Eastern Spinebill	*Acanthorhynchus tenuirostris*	×	
Jacky Winter	*Microeca fascinans*	×	×
Scarlet Robin	*Petroica multicolor*	×	×
Flame Robin	*Pe. phoenica*	×	
Spotted Quail-thrush	*Cinclosoma punctatum*	×	
Varied Sitella	*Daphoenositta chrysoptera*	×	
Crested Shrike-tit	*Falcunculus frontatus*	×	×
Rufous Whistler	*Pachycephala rufiventris*	×	
Grey Shrike-thrush	*Colluricinla harmonica*	×	×
Leaden Flycatcher	*Myiagra rubecula*	×	
Restless Flycatcher	*M. inquieta*	×	×
Magpie-lark	*Grallina cyanoleuca*	×	×
Grey Fantail	*Rhipidura fuliginosa*	×	×
Willie Wagtail	*R. leucophrys*	×	×
Black-faced Cuckoo-shrike	*Coracina novaehollandiae*	×	×
Cicadabird	*C. tenuirostris*	×	×
White-winged Triller	*Lalage sueurii*	×	
Olive-backed Oriole	*Oriolus sagittatus*	×	
Dusky Woodswallow	*Artamus cyanopterus*	×	×
Grey Butcherbird	*Cracticus torquatus*	×	
Australian Magpie	*Gymnorhina tibicen*	×	×
Pied Currawong	*Strepera graculina*	×	×
Australian Raven	*Corvus coronoides*	×	×
Little Raven	*Co. mellori*	×	×
White-winged Chough	*Corcorax melanorhamphos*	×	×
Richard's Pipit	*Anthus novaeseelandiae*	×	
House Sparrow	*Passer domesticus*	×	
Red-browed Finch	*Neochima temporalis*	×	
Diamond Firetail	*Stagonopleura guttata*		×
European Goldfinch	*Carduelis carduelis*	×	×
Mistletoebird	*Dicaeum hirundinaceum*	×	×
Welcome Swallow	*H. neoxena*	×	×
Tree Martin	*H. nigricans*	×	×
Fairy Martin	*H. ariel*	×	×
Clamarous Reed-warbler	*Acrocephalus stentoreus*	×	
Rufous Songlark	*Cincloramphus mathewsi*	×	
Silvereye	*Zosterops lateralis*	×	×
Common Blackbird	*Turdus merula*	×	
Common Starling	*Sturnus vulgaris*	×	×

The list shows all species that were observed in the patch surveys (November 1999), and/or in paddock trees (March 2000; including incidental observations). Presence is indicated by an ×. The order of species and their scientific names follow Christidis and Boles (1994).

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