Australian Field Ornithology 2024, **41**, 59–69
http://dx.doi.org/10.20938/afo41059069

Roadside habitat connectivity for declining woodland birds in Australian farmland: A case study from the New South Wales South Western Slopes

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Abstract. The decline of birds in farmland is a conservation and land-management issue of global concern. Linear woodland corridors along roadsides in Australian farmland can play an important network role, maintaining ecological connectivity at the landscape scale and thereby supporting the survival of disturbance-sensitive woodland species. This paper presents a case study investigating the connectivity value of Old Narrandera Road, an old (pre-1870) roadside woodland corridor linking three larger woodland remnants near Wagga Wagga, in southern inland New South Wales, Australia. A survey of 120 plots along this corridor during 2018–2019 identified 81 bird species including 25 declining woodland birds of known conservation concern. Presence of the hyper-aggressive Noisy Miner *Manorina melanocephala* in survey plots was negatively correlated with total species richness and declining woodland bird assemblage richness and several species (predominantly small to medium-sized declining woodland birds rather than common farmland birds) exhibited a degree of spatial separation with Noisy Miners. One decliner, Grey-crowned Babbler *Pomatostomus temporalis*, showed a significant positive association with Noisy Miner, potentially reflecting a greater tolerance to harassment by Miners. Although the Noisy Miner is probably limiting realisation of the connectivity value of this woodland corridor at present, corridors as substantial and significant as Old Narrandera Road are scarce in the local landscape, and the woodland complex of three interconnected remnants it brings together is likely to be important for the local conservation of many declining woodland bird species.

Introduction

The decline of birds in farmland is a conservation and land-management issue of global concern (Chamberlain & Vickery 2002; Bolwig *et al*. 2006; Amano *et al*. 2010; Baldi & Batary 2011; Heldbjerg *et al*. 2018; Stanton *et al*. 2018; Busch *et al*. 2020). In southern inland Australia's modern agricultural regions, much of the original temperate woodland bird fauna has been lost or survives precariously, restricted to woodland remnants or dependent on vestigial woodland elements remaining in the agricultural matrix (Saunders & de Rebeira 1991; Fischer & Lindenmayer 2002; Radford & Bennett 2007; Haslem & Bennett 2008; Ford 2011; Bain *et al*. 2020; Murphy & Scarff 2023).

Numerous studies have highlighted the important value of linear corridors including hedgerows, fencerows, shelterbelts and riparian and roadside vegetation as ecological linkages in the agricultural matrix of farmland (e.g. Lack 1988; Kaufman & Kaufman 1989; Saunders & de Rebeira 1991; Haas 1995; Bradbury *et al*. 2000; Gelling *et al*. 2007; Lentini *et al*. 2011a; Batary *et al*. 2012; Bennett *et al*. 2014: Castro-Caro *et al*. 2015; Murphy 2021). In eastern Australia, the hyper-aggressive colonial Noisy Miner *Manorina melanocephala* actively excludes other bird species from small woodland remnants, predominantly small insectivorous and nectivorous passerines (Eyre *et al*. 2009; Maron *et al*. 2013; Bain *et al*. 2020), and can influence use of corridors by these species (Catterall *et al*. 1991; Hall *et al*. 2016).

This paper presents a case study of the value of a roadside woodland corridor for declining woodland birds in Australia's highly modified sheep–wheat belt (Smith *et al*. 2013). Previous studies by the author in Currawananna State Forest (SF), in the New South Wales (NSW) South Western Slopes bioregion (Murphy 2012, 2020), highlighted the local value of this woodland remnant for declining woodland birds and noted the possible connectivity significance of a roadside woodland corridor (Old Narrandera Road) linking this remnant to other remnants 9–15 km distant. The present study investigated the bird fauna of the Old Narrandera Road woodland corridor, and examined the influence of the Noisy Miner on total bird species diversity, on the declining woodland bird assemblage and on individual species, comparing declining woodland birds with common farmland birds.

Methods

Study area

The study area (Figure 1) (extending from about 34°54′S, 146°57′E to 35°0′S, 147°3′E) is located in Wiradjuri Aboriginal country between Wagga Wagga and Narrandera in the Lower Slopes subregion of the NSW South Western Slopes bioregion, Australia. This area supports mixed arable and pastoral farming, predominantly dryland cereal and canola cropping and sheep and beef cattle grazing. The climate is temperate with hot, dry summers and cool, moist winters. The study area comprised two sections of public road reserve (Old Narrandera Road) and adjacent travelling stock route (TSR) linking three larger woodland remnants: Matong SF (3176 ha), Kockibitoo SF (244 ha) and Currawananna SF (286 ha). Old Narrandera Road is thought to be the original coaching road between Wagga Wagga and Narrandera (Ellis 1990) and dates from at least 1868 (Anon. 1868), and the TSRs date from 1874 (NSW Department of Lands 1933, 1960).

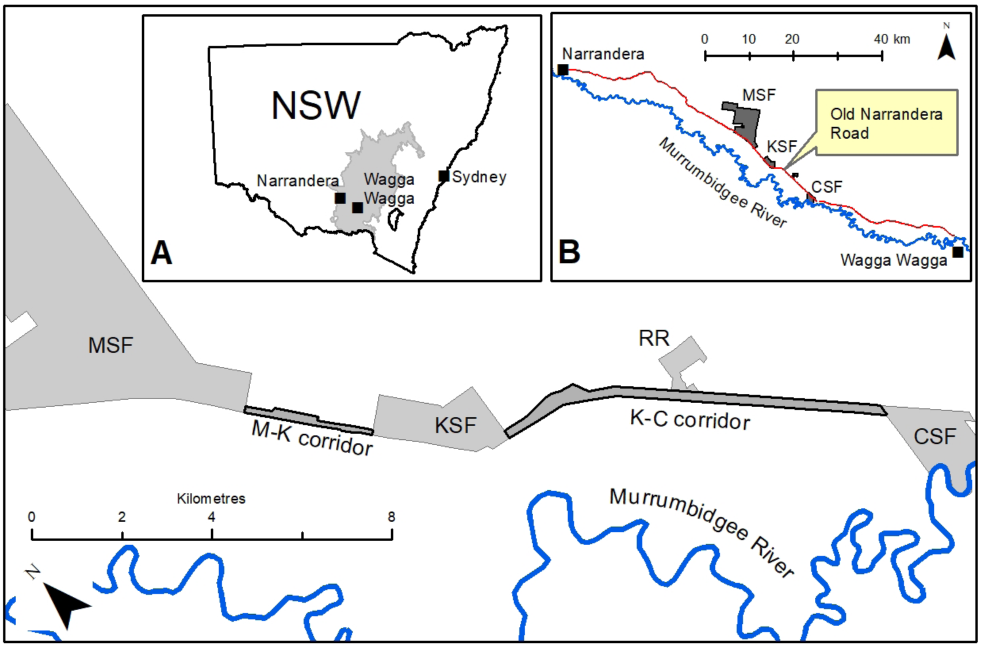

Figure 1. Old Narrandera Road study area showing three state forests and 'rocket' woodland remnant linked by this road/Travelling Stock Route linear woodland corridor. CSF = Currawananna State Forest, KSF = Kockibitoo State Forest, MSF = Matong State Forest, RR = rocket remnant, K–C corridor = Kockibitoo–Currwananna corridor, M–K corridor = Matong–Kockibitoo corridor. Inset map A: location of study area between Wagga Wagga and Narrandera in New South Wales (NSW) with shaded area showing NSW South Western Slopes bioregion. Inset map B: location of study area in relation to towns.

Cypress–eucalypt woodland surviving as a narrow linear remnant along this transport corridor was dominated by White Cypress Pine *Callitris glaucophylla* and Inland Grey Box *Eucalyptus microcarpa* with some Yellow Box *E. melliodora* and Buloke *Allocasuarina luehmannii*, corresponding to the vegetation found in Matong SF, Kockibitoo SF and the northern part of Currawananna SF (Burrows 1999; Murphy 2012) and contrasting sharply with the predominantly cleared surrounding agricultural landscape (Figure 2). The 2.9-km-long roadside and TSR woodland strip between Matong SF and Kockibitoo SF (M–K corridor) (comprising 41 ha of woodland) had an average width of 140 m (range 100–205 m) (including the bitumen-sealed road) and had an understorey of grasses and forbs, with shrubs very sparse to absent. The 8.6-km roadside and TSR woodland strip comprising the Kockibitoo–Currawananna (K–C) corridor (190 ha) had an average width of 220 m (range 190–430 m) and had a more complex understorey, with some areas in the road reserve having a well-developed shrub layer. Examples of the typical vegetation in the two sections are shown in Figure 3. A 57-ha cypress–eucalypt woodland remnant (referred to here as the 'rocket remnant' after a distinctive mailbox) was situated on private property mid-way along the K–C corridor (Figure 1).

Figure 2. Sharp interface between roadside woodland and farmland in Old Narrandera Road study area. Top: view of Matong–Kockibitoo corridor and farmland to north, June 2019. Photo: Michael J. Murphy. Bottom: aerial view of Matong–Kockibitoo corridor adjoining Kockibitoo State Forest. Source: SIX Maps, https://maps.six.nsw.gov.au

Survey methods

One hundred and twenty individual plots in the study area were surveyed for diurnal birds over the period March 2018 to December 2019. Survey effort was stratified by season (15 plots per season per year for 2 years) and stratified proportionally to the relative length of each corridor section (85 plots in the K–C corridor and 35 in the M–K corridor). At each plot, a 20-minute survey was done, listing all birds

Figure 3. Typical roadside vegetation in Old Narrandera Road study area. Top: Matong–Kockibitoo corridor, December 2019. Bottom: Kockibitoo–Currawananna corridor, June 2018. Photos: Michael J. Murphy

seen or heard while randomly walking within an area of 2 ha. Binoculars (7 × 50) were used to aid observation. Indirect signs such as nests were not included. Surveys were undertaken throughout daylight hours, and unfavourable weather conditions such as strong winds, heavy rain or extreme high temperatures were avoided. Plots sampled on the same day in a corridor section were >600 m apart (mean distance to nearest plot = 1.9 km ± Standard Error 0.2 km), except for two plots in the M–K corridor in December 2019 that were 385 m apart, and were otherwise randomly located along the corridor.

Identification of declining woodland birds and common farmland birds

Declining woodland birds were defined in this study as any woodland bird species listed on Schedules 1 (threatened species) or 3 (extinct species) of the NSW *Biodiversity Conservation Act 2016*, listed as a decliner by Reid (1999), as Endangered, Vulnerable or Near Threatened by Traill & Duncan (2000), or as likely to be at particular risk in the farmland matrix in the Wagga Wagga area by Murphy & Scarff (2023). Common farmland birds were taken from Murphy & Scarff (2023). One species, Superb Parrot *Polytelis swainsonii*, occurred in both the decliner and common farmland bird categories but was treated as a decliner in this study.

Analysis of data

The number of plots where each species was detected was tallied using the complete 120-plot dataset and species were assigned to one of four categories for overall frequency of detection: rare if recorded in <5% of plots (≤5 plots), uncommon if recorded in 5–25% of plots (6–30 plots), common (26–75% of plots: 31–90 plots) and abundant (>75% of plots: ≥91 plots). For known seasonal migrants, these categories were scaled to the number of seasons when they were detected. The survey results were also collated separately for the two corridor sections, and species accumulation curves, average plot species richness and total species richness values were calculated for each section.

The frequency of detection of Noisy Miner in the two corridor sections was compared using a 2 × 2 *chi*-squared contingency test (1 degree of freedom). Plot total species richness values were compared between sites where Noisy Miner was detected and sites where it was not detected in an unpaired *t*-test, with data from the two corridor sections combined. The hypothesis tested was that total species richness would be less at sites where Noisy Miner was present. The total species included some that are not woodland-dependent.

The influence of Noisy Miner on declining woodland birds at the assemblage level was investigated by comparing declining woodland bird species richness values between sites where Noisy Miner was detected and sites where it was not detected in an unpaired *t*-test, with data from the two corridor sections combined. The hypothesis tested was that the assemblage richness would be less at sites where Noisy Miners were present.

The degree of spatial affinity with Noisy Miner for individual declining woodland species and common farmland species was examined using two methods. For both methods, those species with >10% of plot records in both corridor sections (≥4 plots in M–K corridor and ≥9 in K–C corridor) were analysed using the full 120-plot dataset and those with >10% in only one section were analysed using the dataset for that section. Species with <10% of records in both sections were excluded from analysis. Firstly, comparisons were done using 2 × 2 *chi*-squared contingency tests (1 d.f.). If the null hypothesis of independence was rejected, the observed frequency of co-occurrence was compared with the statistically expected value to determine if the association identified was negative (observed co-occurrence less than predicted) or positive (observed greater than predicted). Secondly, the Jaccard Index (Ludwig & Reynolds 1988) was calculated as a measure of the strength of association of each species with Noisy Miner. This index is derived by dividing the number of plots where both species were detected by the total number of plots where at least one species was detected, and can range from zero (for complete separation) to one (for complete overlap). A Jaccard Index value of <0.05 was arbitrarily set as the requirement for a strong separation (representing <5% overlap between the species) and a value of 0.05–0.10 (representing 5–10% overlap) for a weaker separation.

All declining woodland bird species records were also mapped to identify any additional apparent patterns in spatial distribution.

Results

In total, 81 bird species were recorded during the field study (Appendix 1), of which 35 species were categorised as rare, 31 as uncommon, 15 as common and nil as abundant. The most frequently recorded species were Australian Magpie *Gymnorhina tibicen* (79 plots), Crested Pigeon *Ocyphaps lophotes* (70) and Galah *Eolophus roseicapilla* (58). Nineteen species (23% of the total) were represented by single plot records. Forty-two species were recorded in the M–K corridor and 76 in the K–C corridor. Species accumulation curves for the two sections are shown as Figure 4. Average plot total species richness was 7.7 + 0.5 (mean + Standard Error) in the M–K corridor and 11.3 + 0.4 species in the K–C corridor. Twenty-five declining woodland bird species were detected (11 in the M–K corridor and 23 in the K–C corridor) and 18 common farmland bird species were detected (16 in the M–K corridor and 17 in the K–C corridor) (Appendix 1).

Noisy Miner was common overall (recorded in 50 plots) and showed a significant (χ^2_1 = 56.29, P <0.001) association with the M–K corridor, being found in 94% of plots there compared with 20% of K–C corridor plots. Average plot total species richness where Noisy Miner was detected (9.0 + 0.5 species) was significantly less than where it was not detected (11.1 + 0.4 species) (one-tailed *t*-test: P = 0.001, t = – 3.0935, d.f. = 118). Average plot species richness for the declining woodland bird assemblage where Noisy Miner was detected (1.7 + 0.2 species) was significantly less than where it was not detected (3.7 + 0.3 species) (one-tailed *t*-test: P <0.001, t = 6.0748, d.f. = 118).

Eleven declining woodland species and 13 common farmland species had sufficient records for examination of patterns of spatial affinity with Noisy Miner (Table 1). White-browed Babbler *Pomatostomus superciliosus* and Rufous Whistler *Pachycephala rufiventris* showed a significant (P <0.05) negative association with Noisy Miner. Jaccard Indices showed strong separations with Noisy Miner for White-browed Babbler, Rufous Whistler and Eastern Yellow Robin *Eopsaltria australis*, and a weaker separation for Grey Shrike-thrush *Colluricincla harmonica*, Black-faced Cuckoo-shrike *Coracina novaehollandiae* and Red-capped Robin *Petroica goodenovii*. Overall, five of the six species identified as possibly responding negatively to Noisy Miner were declining woodland birds. Figure 5 shows a comparison of Jaccard Indices across all 24 declining woodland and common farmland species examined, divided into quartiles. The top three quartiles were dominated by common farmland birds (12 out of 18 species in total) and the bottom quartile (i.e. greatest separation) by declining woodland birds (five out of six species). Two species, Eastern Rosella *Platycercus eximius* (a common farmland bird) and Grey-crowned Babbler *Pomatostomus temporalis* (a declining woodland bird), showed a significant positive association with Noisy Miner (Table 1).

Mapped records illustrating some of the apparent negative spatial associations with Noisy Miner are presented in Figure 6A–C. Another pattern identified from examination of mapped records was a clustering of sightings of some species in the area of the K–C corridor adjacent to the rocket remnant, including Brown Treecreeper *Climacteris picumnus*, Eastern Yellow Robin (Figure 6C) and rarely recorded species such as Varied Sittella *Daphoenositta chrysoptera* and Diamond Firetail *Stagonopleura guttata* (Figure 6D).

Discussion

Various studies have highlighted the important network value of linear woodland remnants along roadsides and TSRs in extensively cleared agricultural landscapes in Australia (e.g. Saunders & de Rebeira 1991; Lindenmayer *et al*. 2010, 2012; Lentini *et al*. 2011a,b; Davidson & O'Shannassy 2017; Murphy & Scarff 2023), corresponding to the well-documented value of hedgerows in European

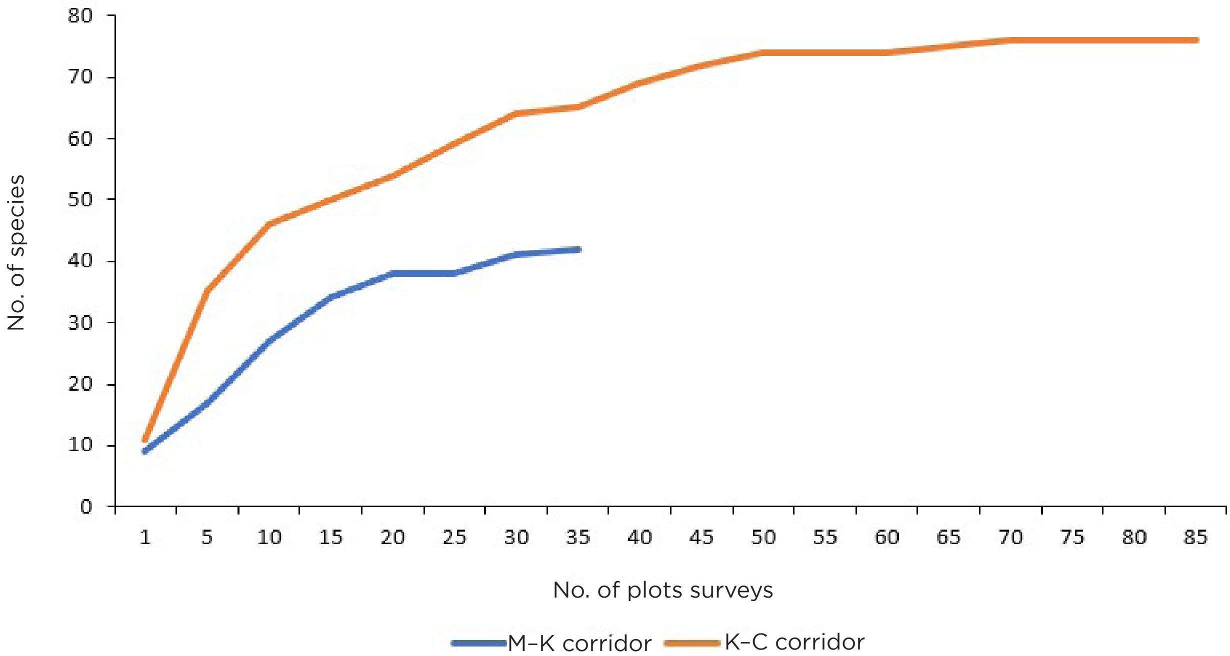

Figure 4. Separate species accumulation curves for two corridor sections in Old Narrandera Road study area. M–K corridor = Matong–Kockibitoo corridor, K–C corridor = Kockibitoo–Currawananna corridor.

Table 1. Analysis of spatial affinity of declining woodland birds and common farmland birds with Noisy Miner in Old Narrandera Road study area, NSW, 2018–2019. Refer to Appendix 1 for scientific names. D = declining woodland species, F = common farmland species. Chi-squared test: probability values <0.05 are shown in bold; * = *P* <0.05, ** = *P* <0.01, *** = *P* <0.001. Jaccard Index: strong negative associations (<0.05 overlap) are shown in bold, weaker negative associations (0.05–0.1 overlap) in italics. Refer to Methods for definitions

	No. plots with Noisy Miner	*No. plots without Noisy Miner*	*Chi-squared test*			*Jaccard Index*
			Chi-squared value	*P value*	*Association*	
Matong–Kockibitoo and Kockibitoo–Currawananna corridors combined						
Laughing Kookaburra[F]	14	13	1.4869	0.223	–	0.222
Galah[F]	20	38	2.3836	0.123	–	0.227
Red-rumped Parrot[F]	8	11	0.0018	0.966	–	0.121
Eastern Rosella[F]	34	13	29.9078	**<0.001*** **	Positive	0.540
Superb Parrot[D]	12	16	0.0213	0.884	–	0.182
Striated Pardalote[F]	11	14	0.0707	0.790	–	0.172
Grey-crowned Babbler[D]	20	15	4.8691	**0.027***	Positive	0.308
Black-faced Cuckoo-shrike[F]	6	12	0.6050	0.437	–	*0.097*
Australian Magpie[F]	34	45	0.1789	0.672	–	0.358
Willie Wagtail[F]	10	24	2.9314	0.087	–	0.135
Magpie-lark[F]	18	15	3.1061	0.078	–	0.277
Little Raven[F]	8	19	2.0768	0.150	–	0.116
Australian Raven[F]	13	15	0.3407	0.559	–	0.200
White-winged Chough[F]	13	20	0.0967	0.756	–	0.186
Apostlebird[D]	16	21	0.0547	0.815	–	0.225
Kockibitoo–Currawananna corridor						
Brown Treecreeper[D]	3	10	0.0908	0.763	–	0.111
Yellow-rumped Thornbill[F]	6	32	0.7615	0.383	–	0.122
Yellow Thornbill[D]	7	40	1.7133	0.191	–	0.123
Chestnut-rumped Thornbill[D]	4	11	0.5060	0.477	–	0.143
White-browed Babbler[D]	1	20	4.0476	**0.044***	Negative	**0.027**
Rufous Whistler[D]	1	29	8.0492	**0.005****	Negative	**0.022**
Grey Shrike-thrush[D]	3	23	1.6762	0.195	–	*0.075*
Red-capped Robin[D]	4	30	2.4020	0.121	–	*0.085*
Eastern Yellow Robin[D]	1	14	2.0238	0.155	–	**0.032**

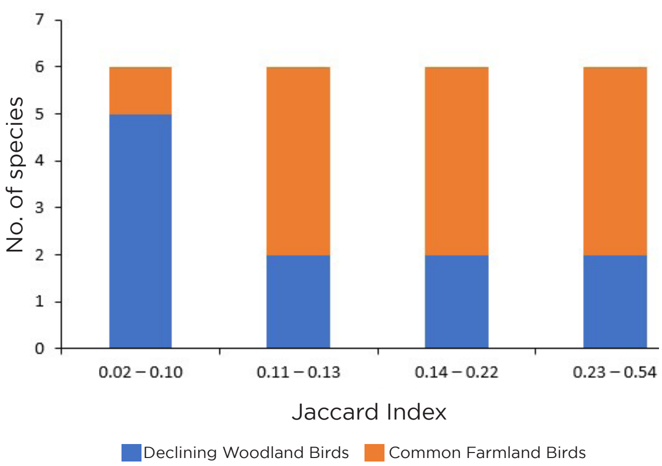

Figure 5. Comparison of Jaccard Index scores for spatial association with Noisy Miner for 11 declining woodland birds and 13 common farmland birds in Old Narrandera Road study area.

farmland (e.g. Williams 1967; Lack 1988; Bradbury *et al*. 2000; Gelling *et al*. 2007; Batary *et al*. 2012; Castro-Caro *et al*. 2015). The present study investigated the Old Narrandera Road woodland corridor, documenting the occurrence of a range of woodland bird fauna including 25 declining woodland species (eight listed as threatened in NSW). Almost one quarter (23%) of the total species detected were represented by single records (including five declining woodland species), suggesting that, notwithstanding the considerable survey effort focused in this case study (120 plots × 20 min./plot = 40 h of field survey), further survey would be likely to identify additional species.

Linking corridors can theoretically provide two types of connectivity for fauna: by enabling individuals to travel between habitat patches and by supporting resident populations within the corridor and thereby enabling gene flow between habitat patches, and the same corridor can function in different ways for different species (Bennett

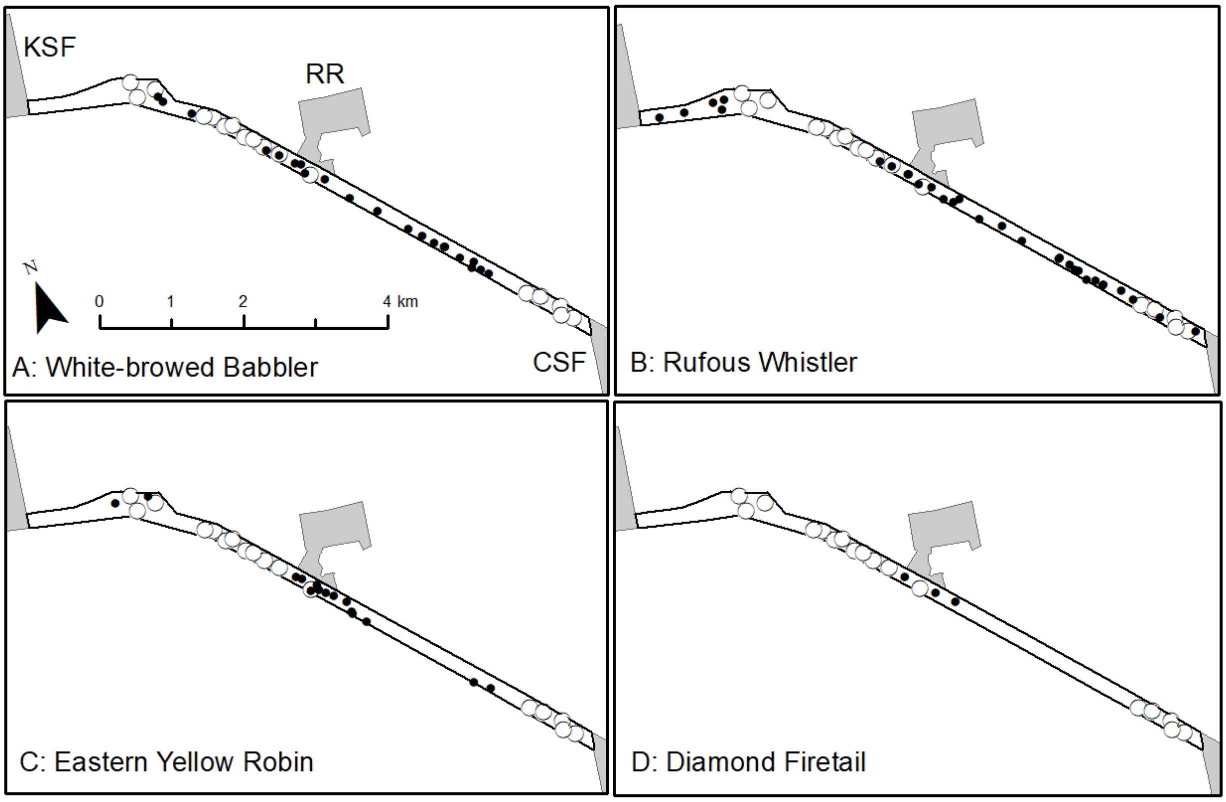

Figure 6. Mapped records of four declining woodland bird species in Kockibitoo–Currawananna woodland corridor showing spatial patterns in relation to Noisy Miner records. A: White-browed Babbler, B: Rufous Whistler, C: Eastern Yellow Robin, D: Diamond Firetail. CSF = Currawananna State Forest, KSF = Kockibitoo State Forest, RR = 'rocket' woodland remnant. Declining woodland bird records are shown as small solid circles and Noisy Miner records as larger open circles.

2003). Tracking the movement of individual birds or investigating genetic exchange between populations in the three state forests were outside the scope of the present study. Although documenting the utilisation of the Old Narrandera Road corridor as habitat by the target group (declining woodland birds) does not necessarily confirm population connectivity function between the linked remnants (see Horskins *et al*. 2006), the occurrence of the species within the corridor is a necessary basic pre-condition for either type of connectivity.

Insight into the local context of the Old Narrandera Road study area can be gained by comparison with nearby studies. Murphy & Scarff (2023) investigated the bird fauna of a 342-km^2 area of farmland located ~10–30 km south-south-east of Currawananna SF. They concluded that a suite of small to medium-sized insectivores, including Speckled Warbler *Pyrrholaemus sagittatus*, Southern Whiteface *Aphelocephala leucopsis*, Chestnut-rumped Thornbill *Acanthiza uropygialis*, Buff-rumped Thornbill *A. reguloides*, White-browed Babbler and Eastern Yellow Robin, all well represented in larger local woodland remnants, might have been lost from the intervening agricultural matrix. Five of these six species were detected in the present study: Speckled Warbler, Southern Whiteface, Chestnut-rumped Thornbill, White-browed Babbler and Eastern Yellow Robin in the K–C corridor and Chestnut-rumped Thornbill also (once) in the M–K corridor. Most of the plots in the present study would be categorised as 'high score' roadside woodland (defined as >12 trees/200 m of roadside) by the scoring system used by Murphy & Scarff (2023), compared with fewer than a third of the roadside sites in that study. Additional key differences between the two study areas were the relatively narrower road corridors in the Murphy & Scarff (2023) study (with many only 20–40 m wide and the largest 60 m wide) and the greater distance from large woodland remnants (maximum 14.5 km compared with maximum 4.3 km in the present study). Road width has been reported to be a significant predictor of roadside conservation value in the region (Spooner & Lunt 2004) and greater corridor use has been reported closer to habitat patches than further away (Downes *et al*. 1997). Another farmland bird study ~30–50 km east-south-east of Currawananna SF (Martin *et al*. 2011) reported only two of the species of concern highlighted by Murphy & Scarff (2023): Buff-rumped Thornbill and Eastern Yellow Robin (the latter only in woodland remnants). These comparisons indicate that roadside woodland corridors as substantial and significant as Old Narrandera Road are scarce in the local landscape.

The significant conservation value of the Old Narrandera Road woodland corridor is in part a reflection of its age. Older roads and TSRs, established before or at the commencement of the period of extensive and rapid land clearing in the region in 1870–1900 (associated with the Robertson Land Acts in NSW and the break-up of the large squatter runs), effectively protected linear corridors of intact woodland (Spooner & Lunt 2004). These roads generally now have higher roadside conservation value than younger (post-1900) roads that were established in landscapes that had already been predominantly cleared (Spooner & Lunt 2004; Spooner & Smallbone 2009).

The occurrence of woodland birds in the Old Narrandera Road study area varied between the two sections of corridor examined. Based on the theoretical premise that a shorter corridor between close remnants would be more likely to function as a link than a longer corridor between more distant remnants, one might have expected the M–K corridor to be more effective than the K–C corridor and that more woodland birds would be found there. However, the total number of species for the M–K corridor was ~55% of that found in the K–C corridor, and only three declining woodland species (Superb Parrot, Grey-crowned Babbler and Apostlebird *Struthidea cinerea*) were found in >10% of plots there compared with 11 species in the K–C corridor. The lower species richness in the M–K corridor is unlikely to have been because of the smaller number of plots surveyed there, with the M–K species accumulation curve consistently below the K–C curve and both flattening out towards the end of the survey. The study identified a congregation of records for several declining woodland bird species where the K-C corridor abutted another woodland remnant (the rocket remnant), suggesting that this small remnant was a valuable node in this corridor, potentially serving as a staging post between the larger Currawananna and Kockibitoo remnants.

Although causal factors for the differences in the bird faunas of the M–K and K–C corridors were not experimentally tested in this observational study, the Noisy Miner is considered likely to play a key role. It was detected with significantly greater frequency in the M–K corridor than the K–C corridor. Overall, total bird species richness and declining woodland bird assemblage richness were significantly lower in plots where Noisy Miner was recorded, and a suite of species (predominantly smaller-bodied declining woodland birds) was found to have a degree of apparent spatial separation with Noisy Miner. It is noteworthy that the three declining woodland birds with the greatest spatial overlap with Noisy Miner (Superb Parrot, Grey-crowned Babbler and Apostlebird) are all of body size larger than Noisy Miner. Numerous studies have reported on the adverse impact of the Noisy Miner on other bird species, particularly small insectivores and nectarivores (e.g. Eyre *et al*. 2009; Maron *et al*. 2011, 2013; Montague-Drake *et al*. 2011; Val *et al*. 2018; Bain *et al*. 2020; Kutt *et al*. 2021). Hall *et al*. (2016), studying roadside woodland in farmland in northern Victoria, reported that the richness of woodland birds at sites where Noisy Miner was abundant was ~20% of that of sites where it was absent. Experimental reduction in Noisy Miner numbers in small woodland remnants has generally been followed by increases in the diversity and abundance of small insectivorous and nectivorous birds, although results have been inconsistent and of uncertain duration (Melton *et al*. 2021).

Eastern Rosella and Grey-crowned Babbler were found to have significant positive spatial associations with Noisy Miner in the present study. The former is unsurprising as a common farmland bird but the result for the declining Grey-crowned Babbler was unexpected. However, Stevens *et al*. (2015), working in northern Victorian farmland, similarly reported that Noisy Miner occurred at all sites where Grey-crowned Babbler was recorded. The tendency to co-occur may simply reflect a shared preference for open habitats, but several authors have reported that Grey-crowned Babbler has a relatively high tolerance or resilience to harassment by Noisy Miner (Lambert & Ford 2016; Newman 2017; Westgate *et al*. 2021). Westgate *et al*. (2021) listed Grey-crowned Babbler and Eastern Rosella as the two species having the highest tolerance to Noisy Miner of 36 species investigated in that study.

Two additional differences of note between the M–K and K–C woodland corridors were the corridor width and the structural complexity of the vegetation. The K–C corridor was on average >1.5 times wider than the M–K corridor. Arnold & Weeldenburg (1990) and Saunders & de Rebeira (1991), studying birds of roadsides in Western Australian farmland, both reported that species richness increased with road verge width. The edge-effects inherent in narrower corridors are likely to limit their value for edge-sensitive species (Soule & Gilpin 1991). The K–C corridor also included areas with a well-developed shrub layer, while shrubs were sparse or absent along the M–K corridor. Greater structural complexity of vegetation has been widely reported to have a positive effect on woodland bird species diversity, including species of conservation concern (Watson *et al*. 2003; Tassicker *et al*. 2006; Huth & Possingham 2011; Lentini *et al*. 2011a; Maron *et al*. 2011; Val *et al*. 2018). Chestnut-rumped Thornbill (detected in 3% of plots in the M–K corridor compared with 18% in the K–C corridor in the present study), for example, has previously been reported to be positively associated with native shrub cover in TSRs (Lindenmayer *et al*. 2012). In contrast, Cousin & Phillips (2008) found no significant correlation between species richness of birds and habitat complexity in Wandoo *Eucalyptus wandoo* woodlands in south-western Western Australia, and conjectured that the absence of a relationship there was related to the resource-poor nature of that environment. They did find one species with a significant positive association with habitat complexity: the Western Yellow Robin *Eopsaltria griseogularis* (a congener of the Eastern Yellow Robin found in the present study).

These three factors (Noisy Miner, corridor width and vegetation structural complexity) are thought to be inter-related. The disturbance-tolerant Noisy Miner favours woodland edges and is more likely to dominate in narrower corridors (Clarke & Oldland 2007). It also favours areas with altered vegetation structure, particularly where shrub cover has been reduced (Eyre *et al*. 2009; Val *et al*. 2018). Conversely, even small remnants may escape domination by Noisy Miner and support high species richness of small passerines if they retain a relatively intact shrub layer (Maron 2008; Westgate *et al*. 2021).

Conclusion

The present study has shown that the Old Narrandera Road woodland corridor is utilised as habitat by a suite of declining woodland bird species and therefore potentially provides valuable links in a Matong–Kockibitoo–Currawananna woodland complex, enabling connected populations to function as a metapopulation and thereby increasing the likelihood of long-term survival. Interconnected woodland remnants of this size and configuration are scarce in the local landscape and this complex is likely to be important for the local conservation of many declining woodland bird species. The Old Narrandera Road woodland corridor is therefore considered of high conservation value. The Noisy Miner is probably limiting realisation of this value at present, particularly in the M–K corridor. Actions to encourage shrub regeneration there would help reduce this impact and thereby improve the corridor's effectiveness.

Acknowledgements

I thank Sue and Jess Murphy for their support during this study, Irma Noller for her hospitality and her unfailing interest in robins and babblers, Peter Murphy who introduced me to the birds of the New South Wales South Western Slopes in the early 1970s and reviewers Jeremy Simmonds and Doug Robinson for constructive comments on an earlier draft of this paper.

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Received 12 August 2023, accepted 27 January 2024, published online 7 May 2024

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Appendix 1. Birds of Old Narrandera Road study area, NSW, 2018–2019, showing the number of plots where each species was recorded and frequency of detection categories. Nomenclature and order of species are based on BirdLife Australia (2022). Species: D = declining woodland species, F = common farmland species, I = introduced species. M–K corridor = Matong–Kockibitoo corridor, K–C corridor = Kockibitoo–Currawananna corridor. Frequency category: C = common, U = uncommon, R = rare. Values in parentheses were changed by seasonal adjustment. Refer to Methods for definitions.

Species		*M–K corridor*	*K–C corridor*	*Total*	*Frequency category*
Australian Wood Duck	*Chenonetta jubata*	3	3	6	U
Pacific Black Duck	*Anas superciliosa*	0	1	1	R
Common Bronzewing	*Phaps chalcoptera*	1	6	7	U
Crested Pigeon	*Ocyphaps lophotes*	21	49	70	C
Peaceful Dove[D]	*Geopelia placida*	0	2	2	R
Straw-necked Ibis[F]	*Threskiornis spinicollis*	0	1	1	R
White-faced Heron	*Egretta novaehollandiae*	0	2	2	R
Banded Lapwing[D]	*Vanellus tricolor*	1	0	1	R
Masked Lapwing	*Vanellus miles*	1	0	1	R
Southern Boobook	*Ninox boobook*	0	2	2	R
Wedge-tailed Eagle	*Aquila audax*	0	1	1	R
Brown Goshawk	*Accipiter fasciatus*	0	1	1	R
Whistling Kite[D]	*Haliastur sphenurus*	1	4	5	R
Rainbow Bee-eater[D]	*Merops ornatus*	1	5	6	U
Oriental Dollarbird	*Eurystomus orientalis*	0	1	1	R
Laughing Kookaburra[F]	*Dacelo novaeguineae*	12	15	27	U
Nankeen Kestrel	*Falco cenchroides*	0	5	5	R
Brown Falcon	*Falco berigora*	0	4	4	R
Cockatiel	*Nymphicus hollandicus*	1	4	5	R
Galah[F]	*Eolophus roseicapilla*	14	44	58	C
Little Corella	*Cacatua sanguinea*	0	8	8	U
Sulphur-crested Cockatoo	*Cacatua galerita*	2	20	22	U
Red-rumped Parrot[F]	*Psephotus haematonotus*	6	13	19	U
Bluebonnet	*Northiella haematogaster*	0	9	9	U
Yellow Rosella	*Platycercus elegans flaveolus*	2	16	18	U
Eastern Rosella[F]	*Platycercus eximius*	24	23	47	C
Australian Ringneck	*Barnardius zonarius*	1	0	1	R
Musk Lorikeet	*Glossopsitta concinna*	0	1	1	R
Superb Parrot[D]	*Polytelis swainsonii*	9	19	28	U
Brown Treecreeper[D]	*Climacteris picumnus*	0	13	13	U
Superb Fairy-wren	*Malurus cyaneus*	0	8	8	U
Blue-faced Honeyeater	*Entomyzon cyanotis*	0	2	2	R
Brown-headed Honeyeater[D]	*Melithreptus brevirostris*	0	2	2	R
Striped Honeyeater	*Plectorhyncha lanceolata*	0	1	1	R
White-fronted Chat[D]	*Epthianura albifrons*	1	0	1	R
Spiny-cheeked Honeyeater	*Acanthagenys rufogularis*	0	1	1	R
Red Wattlebird[F]	*Anthochaera carunculata*	1	0	1	R
White-plumed Honeyeater	*Ptilotula penicillata*	1	6	7	U
Noisy Miner[F]	*Manorina melanocephala*	33	17	50	C
Striated Pardalote[F]	*Pardalotus striatus*	8	17	25	U
Western Gerygone	*Gerygone fusca*	1	33	34	C
Weebill	*Smicrornis brevirostris*	2	12	14	U
Speckled Warbler[D]	*Pyrrholaemus sagittatus*	0	4	4	R

Table 1 continued.

Species		M–K corridor	K–C corridor	Total	Frequency category
Southern Whiteface[D]	*Aphelocephala leucopsis*	0	4	4	R
Yellow-rumped Thornbill[F]	*Acanthiza chrysorrhoa*	2	38	40	C
Yellow Thornbill[D]	*Acanthiza nana*	3	47	50	C
Inland Thornbill	*Acanthiza apicalis*	0	17	17	U
Chestnut-rumped Thornbill[D]	*Acanthiza uropygialis*	1	15	16	U
Grey-crowned Babbler[D]	*Pomatostomus temporalis*	16	19	35	C
White-browed Babbler[D]	*Pomatostomus superciliosus*	0	21	21	U
Varied Sittella[D]	*Daphoenositta chrysoptera*	0	4	4	R
Rufous Whistler[D]	*Pachycephala rufiventris*	1	30	31	C
Golden Whistler	*Pachycephala pectoralis*	0	2	2	(U)
Grey Shrike-thrush[D]	*Colluricincla harmonica*	0	26	26	U
Ground Cuckoo-shrike	*Coracina maxima*	0	1	1	R
Black-faced Cuckoo-shrike[F]	*Coracina novaehollandiae*	4	14	18	U
White-winged Triller	*Lalage tricolor*	1	5	6	U
Pied Currawong	*Strepera graculina*	0	1	1	R
Australian Magpie[F]	*Gymnorhina tibicen*	21	58	79	C
Pied Butcherbird	*Cracticus nigrogularis*	4	18	22	U
Grey Butcherbird	*Cracticus torquatus*	16	8	24	U
White-browed Woodswallow[D]	*Artamus superciliosus*	0	1	1	R
White-breasted Woodswallow	*Artamus leucorynchus*	0	1	1	R
Willie Wagtail[F]	*Rhipidura leucophrys*	4	30	34	C
Grey Fantail	*Rhipidura albiscapa*	0	27	27	U
Restless Flycatcher[D]	*Myiagra inquieta*	0	1	1	R
Magpie-lark[F]	*Grallina cyanoleuca*	15	18	33	C
Little Raven[F]	*Corvus mellori*	5	22	27	U
Australian Raven[F]	*Corvus coronoides*	10	18	28	U
White-winged Chough[F]	*Corcorax melanorhamphos*	7	26	33	C
Apostlebird[D]	*Struthidea cinerea*	10	27	37	C
Flame Robin[D]	*Petroica phoenicea*	0	1	1	R
Red-capped Robin[D]	*Petroica goodenovii*	1	34	35	C
Eastern Yellow Robin[D]	*Eopsaltria australis*	0	15	15	U
Brown Songlark[F]	*Cincloramphus cruralis*	2	4	6	U
Tree Martin[D]	*Petrochelidon nigricans*	0	2	2	R
Welcome Swallow	*Hirundo neoxena*	1	4	5	R
Silvereye	*Zosterops lateralis*	0	2	2	R
Common Starling[I, F]	*Sturnus vulgaris*	0	8	8	U
Diamond Firetail[D]	*Stagonopleura guttata*	0	3	3	R
Double-barred Finch	*Taeniopygia bichenovii*	0	10	10	U
Total species		**42**	**76**	**81**	
Total records		**271**	**957**	**1228**	
Mean species richness per plot		**7.7**	**11.3**	**10.2**	