Australian Field Ornithology 2023, **40**, 246–256
http://dx.doi.org/10.20938/afo40246256

Productivity and survival of Southern Scrub-robins in the South Australian Murray Mallee

Andrew J. Barker

School of Biological Sciences, University of Adelaide, Adelaide SA 5005, Australia
Email: andrewjbarker001@gmail.com

Abstract. The Southern Scrub-robin *Drymodes brunneopygia* is an Australian ground-foraging insectivorous bird that has suffered dramatic declines in the South Australian Murray Mallee, and within this region is now largely confined to four isolated patches (clusters) of territories on one privately owned farm at Bakara. In order to determine if Scrub-robins fare better in some habitats than others, colour-banded adults were intensively tracked to determine their productivity and survival in four habitat patches over a 3-year period between 2008 and 2011. At Bakara, survival of adult Scrub-robins was possibly lower in the North-west patch than in other patches. Most pairs were observed to breed; breeding started in late September/early October and lasted *c*. 1 month. Thirty-two percent (*n* = 22) of juveniles survived to >1 year. Juvenile survival was higher in the South and Heritage Agreement patches, and was greater in the wetter year (2010) than in the other years. More juvenile males survived to >1 year of age (*n* = 16) than did females (*n* = 6), and survival of juveniles was positively correlated with time spent in their natal territory. Three birds bred at 2 years of age. Scrub-robin survival at Bakara appears to be positively correlated with increased rainfall and higher shrub cover, particularly of Green Tea-tree *Leptospermum coriaceum* or Hard-leaf Wattle *Acacia sclerophylla*, as was observed in the South and Heritage Agreement patches.

Introduction

Habitat loss, fragmentation and degradation are generally considered the key causes of the declines of woodland birds in southern Australia (Ford *et al.* 2001; Vesk & Mac Nally 2006). The resulting agricultural landscapes are unsuitable for most native birds and surviving populations have been confined to smaller fragments of often suboptimal woodland (Reid 1999). These fragments are further degraded by factors such as edge effects and grazing pressure (Luck *et al.* 1999; Cooper & Walters 2002; Watson 2011). In order to protect woodland birds, it is important to understand the specific causes of their continuing declines (Bennett & Watson 2011). This can be determined by comparing the productivity and survival in areas where populations are relatively robust with birds living in less favourable habitat conditions. For example, Luck (2002) found that Rufous Treecreepers *Climacteris rufus* had higher breeding success in a continuous, unfragmented landscape. Reduced habitat quality brought about by grazing and removal of fallen timber negatively affected the survival of Brown Treecreepers *C. picumnus* and Hooded Robins *Melanodryas cucullata* (Ford *et al.* 2009). Additionally, other factors such as annual rainfall may positively influence survival of juveniles (Bolger *et al.* 2005; Mac Nally *et al.* 2009). The overall sustainability of populations can be established by determining if adult mortality is compensated by the maturation of juvenile birds reaching adulthood (Zanette 2000; Debus 2006).

One bird species of particular conservation concern across southern Australia is the Southern Scrub-robin *Drymodes brunneopygia*. This species (hereafter referred to as Scrub-robin) is a pair-breeding ground-foraging insectivore endemic to the dense shrublands of low-rainfall areas of southern Australia (Close 1982; Woinarski 1989, 1990; Cale & Mladovan 2007a; Turpin & Johnstone 2017). It is a small bird (female ~30 g, male ~37 g) occupying understorey vegetation layers often in Mallee across Western Australia, South Australia, Victoria and New South Wales (Higgins & Peter 2002). Scrub-robins occur either individually or in breeding pairs (often with one juvenile) where they defend year-round all-purpose territories in habitat of complex shrub layers. Within a local population ('patch': Hanski & Simberloff 1997), individual territories may adjoin others or be very close together (Brooker 1998). Scrub-robins lay only one egg per clutch, which may allow for greater parental care in birds (Higgins & Peter 2002; Lloyd & Martin 2016).

Few studies have focused on the productivity and survival of the Scrub-robin (Brooker 2001; Scoble 2012) but this species has declined across its range (Dell 1980; Saunders 1989; NSW Government 2023) and, along with other woodland birds (e.g. Purple-gaped Honeyeater *Lichenostomus cratitius*, Shy Heathwren *Calamanthus cautus*, Inland Thornbill *Acanthiza apicalis* and Gilbert's Whistler *Pachycephala inornata*), it is of critical conservation concern in the Murray Mallee of South Australia (Willoughby 2008). Of particular concern there has been the targeting of the Scrub-robin's optimal habitat (shrubby, loamy sands) for cereal cropping and the subsequent habitat loss that this has caused (Cale & Mladovan 2007b).

The South Australian Murray Mallee encompasses ~500,000 hectares but, because of widespread landscape clearance, the regional population of Scrub-robins here has been greatly reduced to an area near Bakara (34°39′S, 139°47′E). This area has had ~90% of its native vegetation cleared, mostly for grazing and cereal cropping, with the remaining vegetation (aside from the larger conservation reserves) becoming highly fragmented and degraded (Willoughby 2006; Cale & Willoughby 2009).

This study focuses on the factors influencing Scrub-robin productivity and survival in the South Australian Murray Mallee, where the species is largely confined to four isolated habitat patches on one privately owned farm at Bakara. In order to determine if Scrub-robins fare better in some habitats than others, colour-banded adults were intensively tracked to determine their productivity and survival in the four habitat patches over a 3-year period between 2008 and 2011. The context of the study is to inform avifauna restoration programs to halt further declines and localised extinctions of this species.

Methods

This study concentrates on the Scrub-robins located on a privately owned 2100-ha farm at Bakara, South Australia (Figure 1). One hundred and five Scrub-robins were mist-netted and colour-banded in accordance with the Australian Bird and Bat Banding Scheme. When a bird was caught, two bands were placed on each leg: a numbered metal band and a colour-band above it on the left leg and two colour-bands on the right leg, to enable individual birds to be identified by the unique combination of colour-bands. Birds were then referred to by the first initial of the three colours on their legs. The complete colour coding was: R = red, O = orange, Y= yellow, G = green, W = white, B = blue and N = black, and M = the metal registration band. Hence a bird referred to as 'YMRG' would have a yellow band above the metal band on the left leg and a red band above a green band on the right leg.

Eleven birds in very dense habitat were fitted with radio-trackers. The feathers on the mid to lower back were trimmed and the trackers (88-day battery life, 0.9 g, 26 pulses per minute) affixed with superglue. After setting of the glue, the birds were released and located again with a three-element folding Yagi antenna and an Icom® R10 RX5 radio-receiver (Advanced Telemetry Systems, Isanti, Minnesota, USA). Captured birds were aged by checking for lighter-coloured fringes to the primary-covert feathers to determine if the birds were in their first year of life, and then measured to determine sex (males larger than females: Higgins & Peter 2002; AJB pers. obs.). Tracking of Scrub-robins commenced in August 2008 and concluded in November 2011. Standard bird tracking took place within 2 h from dawn (when birds are most vocal), with one fieldworker visually searching and listening for calls and then recording observational data with binoculars. Recorded Scrub-robin calls were also used when and where Scrub-robins could not be found. Between late 2008 and December 2011, all territories were visited fortnightly and searched for 1–3 hours. No tracking took place on days over 35°C. Observational data (GPS position, behaviour, habitat use and bird identity) were recorded for each sighting. The tracking data waypoints were imported into ArcGIS10 geographical software (ESRI 2010) and the territory size for each bird (based on GPS locations of colour-banded birds) was calculated using 100% Minimum

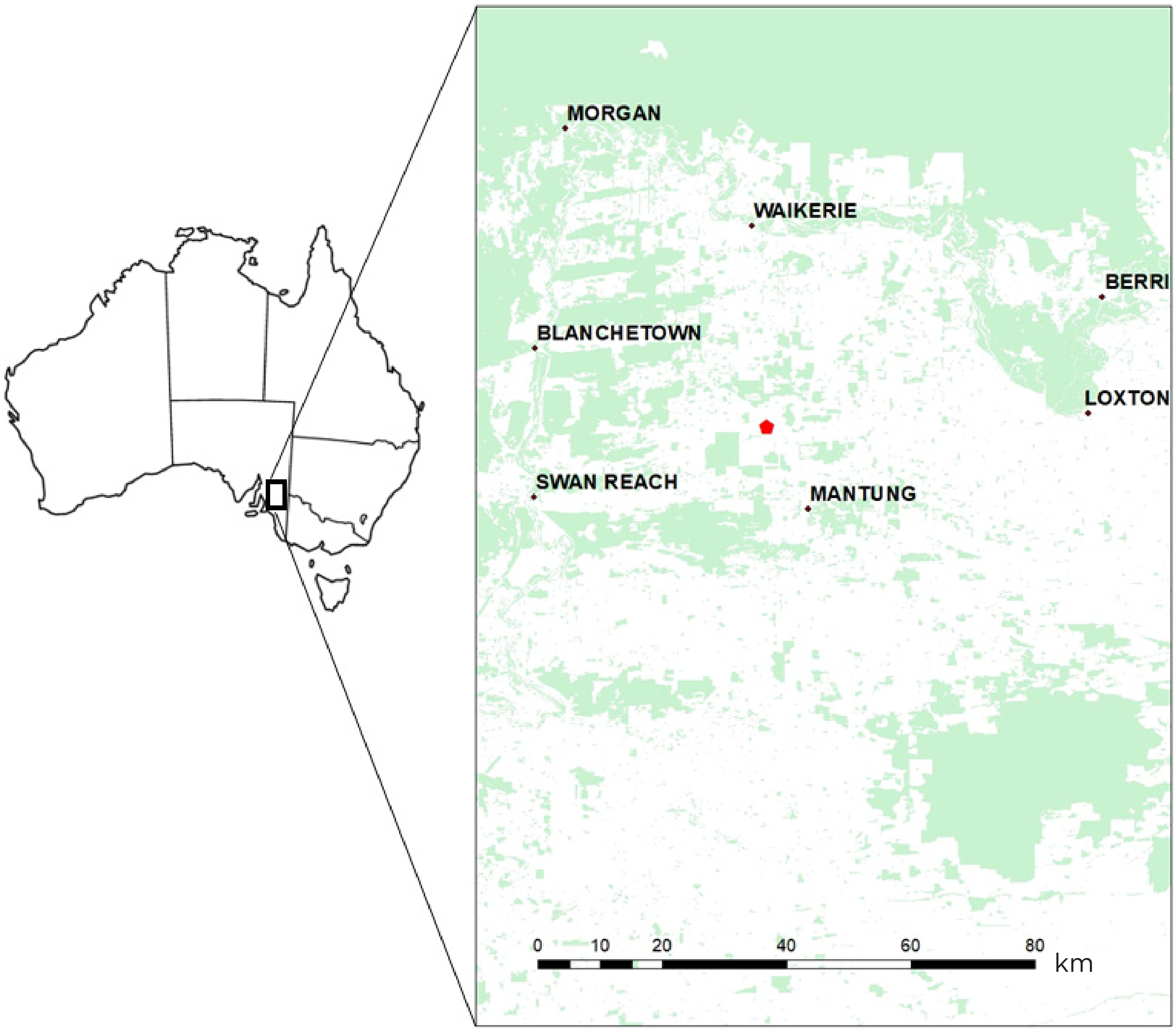

Figure 1. Location of the Murray Mallee. Red spot = Bakara; green areas indicate extant native vegetation.

Table 1. Variables analysed to determine correlative relationships with survival for >1 year of juvenile Southern Scrub-robins at Bakara, South Australia, 2008–2011.

Variable analysed	*Description*
Sex	Male or female
Year fledged	For each patch, between 2008 and 2011, the annual cohorts of juveniles surviving for ≥1 year were compared to determine if the juveniles of any year had a different survival rate from those of another year.
Movements	Juvenile survival was compared with where the juveniles were located (i.e. if they remained in the natal territory or in another territory or area) and for how long.
Rainfall	Annual rainfall at Bakara (Bureau of Meteorology 2015a) was compared with juvenile survival in each year.

Convex Polygons (MCPs) (Harris *et al.* 1990) using convex hulls through the ArcGIS toolbox (ESRI 2010). Observations of conflicts between neighbouring males also assisted in defining territorial limitations (Stefanski 1967). Patches were also measured using MCPs.

Vegetation surveys

Within each Scrub-robin territory, high-use (hotspot) and low-use (coldspot) areas were determined using kernel densities based on the locations of the accumulated fixes. A 30 m x 30 m quadrat was studied within these areas recording the species and percentage cover of understorey vegetation. A Kruskal–Wallis test (*H*) was used to explore the habitat variables between hotspots and coldspots in the four different patches at Bakara. In the event of a statistically significant result (P <0.05), subsequent pairwise comparisons were performed using a Mann–Whitney *U* statistic with an adjusted Bonferroni corrected α-level.

Survival of adults

Because of the regularity and intensity of the searches throughout Scrub-robin habitat and adjacent non-habitat, disappearance of birds was equated to death (Koenig *et al.* 2000). The number of adults that survived for 1 year after banding was determined as a percentage of all banded adults. The percentage of birds in each patch surviving for >1 year after banding was compared across patches. Adult survival for >1 or <1 year was compared with hotspot cover of Hard-leaf Wattle *Acacia sclerophylla* and Green Tea-tree *Leptospermum coriaceum* using a Mann–Whitney *U* test. Similarly, adult survival >1 and <1 year was compared with hotspot cover of total understorey in each territory using an independent *t*-test.

Identification of juveniles

Fledglings from a first-breeding attempt were aged approximately based on the date of first sighting minus 12 days (the length of the nestling period, consistently around late September/early October: Higgins & Peter 2002). Individuals that could not be trapped and closely inspected (e.g. through disappearance) were determined to be juveniles by their plumage, behaviour (naïve, playful), and interactions with other Scrub-robins in the same territory. There was minimal analysis of data on unbanded juveniles as there was little confidence in their positive re-identification.

Survival of juveniles

The relationship between survival of juveniles and a selection of other variables was examined, as listed in Table 1. The total number of juveniles surviving for >1 year was divided by the total number produced (every year, in each patch) to obtain the juvenile survival rate.

Territories across all patches were ranked according to hotspot understorey cover and split into two groups of upper and lower 50th percentiles of cover. A comparison between these two groups was then made on the number of juveniles that survived for >1 year, and in which patch they fledged.

For all years (2008–2011), the hotspot understorey cover of breeding territories that produced birds surviving for >1 year was compared with that of territories that produced no juveniles using an independent *t*-test. This was carried out in order to determine if there were differences between the amount of understorey cover in productive and non-productive territories.

In order to determine the ages at which birds <1 year old disappeared, birds that did not survive >1 year were grouped into age classes (of survival <1, 1–2, 2–3 months etc.) by subtracting the date of the last observation from the approximate hatching date.

Results

Scrub-robin patches and territories

Four clusters or patches of neighbouring/nearby Scrub-robin territories were studied in detail (Figure 2):

1. North patch (total territory MCP 25.5 ha, mean territory 2.16 ha, patch MCP 50.5 ha). Regrowth farmland habitat with 11 Scrub-robin territories consisting largely of *Eucalyptus* species (Red Mallee *E. oleosa,* Grey Mallee *E. socialis* and White Mallee *E. phenax*) and Sugarwood *Myoporum platycarpum* woodland with Black Paperbark *Melaleuca lanceolata*, Pale Turpentine-bush *Beyeria lechenaultii* and some Hard-leaf Wattle in the understorey. The area containing Hard-leaf Wattle was cleared and cropped only once, yielding an excellent cereal harvest (indicative of high soil quality: D. Northcott pers. comm.) and then left fallow. The other areas of this patch associated with the other understorey types were ploughed sometime after this but not farmed (H. Short pers. comm.).
2. South patch (total territory MCP 18 ha, mean territory 1.02 ha, patch MCP 96.4 ha). Regrowth farmland

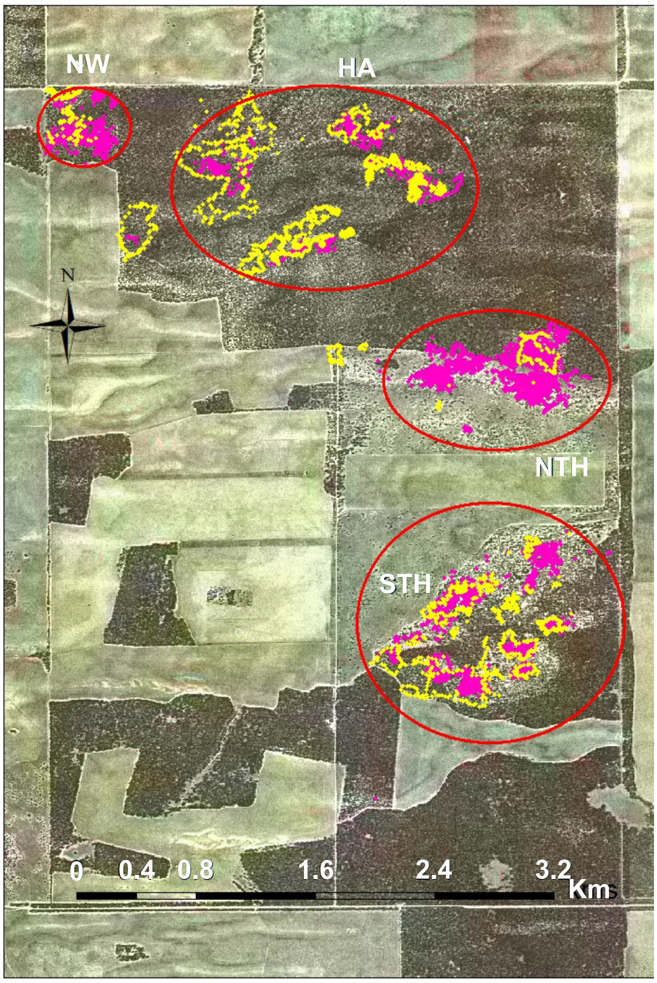

Figure 2. The farm at Bakara, SA, showing location of all observations of Southern Scrub-robins (magenta), and the perimeters of areas containing the key understorey species Hard-leaf Wattle or Green Tea-tree (yellow). Single yellow dots are isolated Hard-leaf Wattle or Green Tea-tree shrubs. The patches (circled in red) are: North-west (NW), Heritage Agreement (HA), North (NTH) and South (STH). Scale 1:20,000. Aerial photo, taken in 2000: courtesy of Department for Environment, Water & Natural Resources

with 17 territories consisting mostly of *Eucalyptus* species (Red Mallee, White Mallee and Grey Mallee) and Sugarwood woodland with Hard-leaf Wattle, Black Paperbark, Pale Turpentine-bush, Silver Cassia *Senna artemisioides* and Desert Hopbush *Dodonaea stenozyga* understoreys. This area was chained (partially cleared) once before 1965, and then yielded an outstanding cereal crop but was not farmed again (D. Northcott pers. comm.).

3. North-west patch (total territory MCP 8.6 ha, mean territory 1.89 ha, patch MCP 19.8 ha). Here there were five territories in *Eucalyptus* spp. woodland (primarily Red Mallee) with Hard-leaf Wattle, Black Paperbark and Desert Hopbush understorey. This regrowth area was chained before 1960 but never farmed (land 'too stony': D. Northcott pers. comm.).

4. Heritage Agreement (total territory MCP 8.1 ha, mean territory 0.9 ha, patch MCP 120.7 ha). Ten territories in habitat consisting mostly of old-growth Narrow-leaved Red Mallee *Eucalyptus leptophylla*, Ridge-fruited Mallee *E. incrassata* and Red Mallee woodland with a Green Tea-tree understorey. One section was chained around 1977 but never farmed (D. Northcott pers. comm.). This area was probably last burnt in the 1901 bushfires (Mantung-Maggea Land Management Group pers. comm.).

Figure 3. Habitat with Hard-leaf Wattle, South Patch, Bakara. Photo: Andrew J. Barker

Figure 4. Habitat with Green Tea-tree, Bakara Conservation Park. Photo: Andrew J. Barker

Survival of adult Scrub-robins

Seventy-seven per cent of a total of 66 adults survived for 1 year after banding. Thirty-two banded males (76%) survived for at least 1 year, as did 19 females (79%). Survival of adults was lowest in the North-west patch (57%) and highest in the North patch (87.5%). It was also high in the South (75%) and Heritage Agreement patches (73%). There was no statistical difference between survival in the four patches.

Vegetation surveys

Initial field observations at Bakara revealed that 85% of areas occupied by Scrub-robins contained Hard-leaf Wattle (naturally regrown farmland habitat: Figure 3) and Green Tea-tree (old-growth habitat: Figure 4). These two shrub species are hereafter referred to as 'key vegetation'. Significant differences were identified between the amount and percentage cover of key vegetation in both hotspots

Table 2. Mean percentage (standard error in parenthesis) of vegetation cover per 30 m x 30 m high-use (hotspot) and low-use (coldspot) areas within territories of Southern Scrub-robin patches [North (NTH), South (STH), North-west (NW) and Heritage Agreement (HA)] at Bakara, SA, 2008–2011. Patch use: c = coldspot, h = hotspot; see text. Vegetation: 1 = Hard-leaf Wattle *Acacia sclerophylla*, 2 = Green Tea-tree *Leptospermum coriaceum*, 3 = Black Paperbark *Melaleuca lanceolata*, 4 = Pale Turpentine-bush *Beyeria lechenaultia*, 5 = Comb Grevillea *Grevillea hueguelii*, 6 = Seaberry Saltbush *Rhagodia candolleana*, 7 = Bladder Saltbush *Atriplex vesicaria*, 8 = Silver Cassia *Senna artemisioides*, 9 = Desert Hopbush *Dodonaea stenozyga*, 10 = Wilhelmi's Wattle *Acacia wilhelmiana*, 11 = Eucalypt *Eucalyptus* spp. canopy, and 12 = Sugarwood *Myoporum platycarpum* canopy.

Patch (and use)	*Vegetation*											
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*
NTH (h)	5.4 (2.7)	–	5.7 (2.1)	3.9 (2.5)	1.5 (0.7)	0.6 (0.1)	6.4 (2.9)	0.2 (0.1)	–	–	22.7 (3.8)	3.6 (1.1)
NTH (c)	1.3 (0.8)	–	0.9 (0.5)	2.1 (1.0)	0.8 (0.4)	0.2 (0.1)	15.1 (4.0)	0.1 (0.1)	–	–	18.9 (5.6)	3.9 (1.5)
STH (h)	25.7 (4.4)	–	3.1 (1)	3.7 (0.8)	0.5 (0.1)	0.4 (0.1)	0.2 (0.1)	1.2 (0.7)	2.5 (1.6)	–	28.6 (3.9)	3.6 (15)
STH (c)	13.1 (3)	–	2.5 (1.1)	4.4 (2.0)	1.0 (1.0)	0.3 (0.1)	0.7 (0.4)	1.1 (0.4)	0.01 (0.01)	–	24.2 (3.9)	3.5 (1.0)
NW (h)	9.7 (8.7)	–	3.4 (2.6)	–	–	–	–	–	3.7 (1.9)	–	57.4 (1.0)	3.3 (3.3)
NW (c)	0.1 (0.1)	–	0.6 (0.6)	–	–	–	–	–	–	–	42 (3.4)	0.2 (0.2)
HA (h)	–	26.7 (3.1)	1.3 (0.6)	2.7 (1.2)	–	0.8 (0.3)	–	–	–	1.0 (0.3)	28.7 (1.7)	–
HA (c)	–	10.5 (5.4)	4.0 (2.0)	2.7 (1.5)	–	0.6 (0.2)	–	–	–	1.3 (0.7)	38 (6.6)	–

and coldspots, showing that the North patch had fewer of these shrubs than the South and Heritage Agreement patches. The subsequent pairwise comparisons (Mann–Whitney U statistic with adjusted Bonferroni corrected α-level) highlighted that there was significantly less cover and fewer key vegetation shrubs in hotspots of the North patch (5.4% cover, 1.3 shrub) than in the South (25.7%, 6.1 shrubs) and Heritage Agreement (26.7%, 7.5 shrubs) patches. Conversely, there were no significant differences between coldspot key vegetation across all the patches. The North-west patch had very low shrub cover but higher than average Eucalyptus canopy cover. Complete percentages of cover are given in Table 2.

Survival of adult Scrub-robins and hotspot cover of key vegetation

No correlation was observed between hotspot cover of the key vegetation shrubs Hard-leaf Wattle or Green Tea-tree and adult survival >1 year (median = 16.7% cover) or <1 year (13.8% cover) (U = 369.5, P = 0.932, z = – 0.086, r = – 0.01).

Scrub-robin productivity and survival of juveniles

Productivity

Breeding was observed in most occupied territories, and territories where breeding did not occur had only one Scrub-robin. Scrub-robin eggs at Bakara hatched in late September/early October, and the birds renested if the nest failed (but no breeding was observed after early November in any year). Evidence of courtship and breeding ranged from mutual chasing ('toing and froing') and carrying of nesting material and prey items (springtime records only) to the sighted confirmation of the presence of juveniles.

Scrub-robin nests were close to or on the ground under shrubs and the birds were not observed to nest in the same shrub in subsequent breeding seasons. Scrub-robins were observed to renest after nest failure (all in 2008) and, in 2010, one South patch pair, on a very large territory with abundant cover of Hard-leaf Wattle, renested and raised both the first and second fledglings simultaneously. In total, 68 juvenile Scrub-robins were produced in 2008–2011. No confirmed feeding of young birds was observed in any year after December when juveniles were *c*. 2 months old. Ten juveniles were detected in old-growth habitat (key understorey shrub Green Tea-tree) and 58 in revegetation (key understorey shrub Hard-leaf Wattle).

Rate of survival of juveniles

The annual juvenile survival rate for Scrub-robins in patches at Bakara between 2008 and 2011 was 0.33 (North patch 0.28, South 0.38, North-west 0.14 and Heritage Agreement 0.4). The annual juvenile survival rates during the years of this study were 0.19 (2008), 0.29 (2009) and 0.44 (2010).

Survival of juveniles for <1 year

Of the 68 juvenile Scrub-robins observed, 44 (64.7%) were not observed after 1 year of age. Eighteen (26.5%)

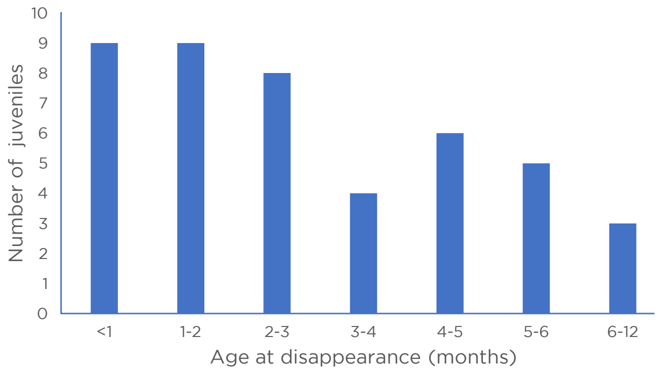

Figure 5. Number of juvenile Southern Scrub-robins that disappeared during their first year and their ages (months) at disappearance, Bakara, SA. Birds surviving >1 year are not included.

of these juveniles had disappeared by 2 months of age and in total 26 (38.2%) by 3 months (Figure 5). Many of these juveniles disappeared before they could be caught and banded.

Correlations between survival of juveniles for >1 year and other variables

1. Sex of banded birds

Eighty percent of banded male juveniles survived to >1 year of age compared with 50% of banded females (Table 3).

2. Total understorey cover

The top 50th percentile of territories (n = 21) with the highest hotspot understorey cover (29–55%) produced 15 juveniles that survived for >1 year, whereas the bottom percentile with lower hotspot understorey cover (7.7–28%) produced less than half this number of juveniles surviving for >1 year (n = 6). The patches with the highest percentage of territories in the upper 50th percentile were the South (66.7%) and Heritage Agreement (63.6%) patches. The North patch had 30% of territories in the upper percentile and the North-west patch had none.

No significant difference was found between percentage cover of key vegetation (Hard-leaf Wattle or Green Tea-tree) or total combined understorey cover in each hotspot for territories where fledglings survived for >1 or <1 year. However, territories where fledglings survived for >1 year had a higher median cover of understorey in hotspots (35.1%) than hotspots of territories where juveniles survived for <1 year (24.7%).

Table 3. Number of juvenile Southern Scrub-robins banded, sexed, and surviving to 1 year, Bakara, 2008–2011. One bird could not be confidently sexed.

	n
Number of juveniles banded	33
males	20
females	12
Males survived to 1 year	16
Females survived to 1 year	6
Banded birds not surviving to 1 year	11

No significant difference was found between the understorey cover of hotspots in territories that produced birds that survived >1 year compared with hotspots in territories that did not produce any juveniles [but non-breeding territories had a lower mean percentage cover (25% ± standard error 4.3%) than the more successful territories (32 ± 3.1%)]. The South and Heritage Agreement patches had greater juvenile survival and shrubbier landscapes (Table 4).

3. Year fledged

More juveniles that survived for >1 year were produced in 2010 than in 2009, and a greater percentage of all young produced in 2010 survived for >1 year (43%, n = 12) compared with 2009 (29%, n = 7: Table 5). Over the 3 years of this study, 32% of juveniles survived for >1 year.

4. Rainfall

A Kruskal–Wallis H test was performed on the monthly rainfall from 2008 to 2011 to determine if there was a statistically significant variation; from 2008 to 2011, monthly rainfall variation in the region was nearly significant [$H(2)$ = 5.78, P = 0.056]. *Post-hoc* Mann–Whitney U tests revealed that the greatest differences in rainfall were recorded between the years 2008 (median 17.9 mm) and 2010 (41.15 mm) (U = 33, z = – 2.25, P = 0.024, r = – 0.45), and to a lesser extent between 2009 (21.7 mm) and 2010 (41.2 mm) (U = 41, z = – 1.79, P = 0.073, r = – 0.37). No significant difference in monthly rainfall was observed between 2008 (17.9 mm) and 2009 (21.7 mm) (U = 63, z = – 52, P = 0.63, r = – 15). However, these statistical analyses should be treated with a degree of caution as the Bonferroni correction implies that in order to avoid inflated Type 1 errors, the P value of these tests should be divided by the number of tests carried out and thereby decreased to P <0.016 (Field 2013). Survival of juvenile Scrub-robins was high in 2010 at Bakara (Table 5).

Table 4. Total number of juvenile Southern Scrub-robins produced, the number of those surviving for >1 year, and the mean percentage of understorey vegetation cover of territory hotspots in their natal patch.

	Patch			
	North	*South*	*North-west*	*Heritage Agreement*
Total no. juveniles produced	18	33	7	10
No. juveniles surviving for >1 year	5	12	1	4
Mean % cover of key understorey per hotspot	5.4	25.7	9.7	26.7

Table 5. Breeding of Southern Scrub-robins at Bakara, SA, 2008–2011: number of territories that were monitored, number of pairs and single adults, number of fledglings produced, and number of fledglings that survived their first year. Percentages are shown in parentheses.

Year	*No. territories*	*No. pairs of adults*	*No. singles*	*No. pairs breeding*	*Total no. fledglings*	*No. juveniles surviving first year*
2008–2009	27	22	5	17 (77)	16	3 (19)
2009–2010	33	25	8	23 (92)	24	7 (29)
2010–2011	35	28	5	27 (96)	28	12 (43)
2008–2011					**68**	**22 (32)**

Table 6. Territory status of juvenile Southern Scrub-robins (separated by sex) surviving to 1 year (n = 22). The territory status refers to where a bird was at 1 year old: i.e. if it had stayed in its natal territory or occupied another territory or area peripheral to the natal territory.

Territory status	*Number of birds*
Stay in natal territory, male	12
Stay in natal territory, female	3
Occupy another territory	3
Occupy another territory	3
Occupy periphery of natal territory	1

5. Movements of Scrub-robins

Survival of juveniles was positively correlated with time spent in their natal territory. A Mann–Whitney *U* test revealed that of all the juvenile Scrub-robins that were resighted after leaving their natal territory, those that remained longer in the natal territory (median 311 days in natal territory) lived longer than those that dispersed earlier (median 69 days, U = 1, P <0.05, z = – 2.37, r = 0.66).

Table 6 shows the territory status of all juveniles (separated by sex) that survived for >1 year, at *c*. 1 year of age. Most birds surviving to 1 year (both males and females) were still in their natal territory at that time (68%, n =15); approximately half of these birds remained in the absence of one or both adults. Despite the Heritage Agreement patch having comparatively high juvenile survival, only one bird that fledged in this patch and survived for >1 year (n = 3) remained in its natal territory for >1 year.

Juvenile productivity – minimum breeding age

Only three of the 33 juveniles banded during this study (9%) were observed to breed, although seven birds that had fledged throughout the field study were observed to occupy vacant breeding territories. All three breeding birds (two females and one male) were 2 years of age when they started to breed, and all bred in the South patch. One female, colour-banded YMGY, emigrated from the North dune patch, almost 1 km away. The other two birds bred on or very close to their natal territories. Only five juveniles (from the 2008 and 2009 cohorts) were observed to live >2 years of age.

Discussion

Survival of adults

This study was carried out to document the factors influencing productivity and survival of Scrub-robins in the South Australian Murray Mallee.

Survival of males and females for >1 year

Seventy-six percent of banded males survived to at least 1 year after initial capture in this study at Bakara, as did 79% of all females. At Peron Peninsula in Western Australia, Brooker (2001) observed that 70% of 23 banded adult Scrub-robins survived to 1 year after banding. This overall survival rate is similar to other small Australian and New Zealand species that have been studied. Russell *et al.* (2004) found similar annual survival rates for the White-breasted Robin *Quoyornis georgianus* (males 86%, females 79%) in Karri *Eucalyptus diversicolor* forest, as well as other perching birds that they reviewed. Gardner *et al.* (2003) observed 77% annual survival of adult Speckled Warblers *Pyrrholaemus sagittatus* in open Inland Scribbly Gum *E. rossii,* Brittle Gum *E. mannifera* and Red Stringybark *E. macrorhyncha* woodland. Almost 80% annual adult survival was also recorded for the Red-winged Fairy-wren *Malurus elegans* in Wandoo *E. wandoo* woodland (Russell & Rowley 2000). In the grassy open forest and eucalypt woodland of Imbota Nature Reserve, NSW, Debus (2006) observed annual survival of adult Eastern Yellow Robins *Eopsaltria australis* of 71% but that of Scarlet Robins *Petroica boodang* was lower (58%).

Adult Scrub-robins in my study generally had high survival, which is typical amongst tropical and Southern Hemisphere birds possibly because of low productivity in a dry environment (Russell 2000) and decreased breeding effort (Fry 1977). At Bakara, this was evident by the unexpectedly high adult survival in the small North patch, which had large territories, reduced shrub cover and low abundance of Hard-leaf Wattle, all of which suggest lower quality habitat than in the other patches.

There were no statistically discernible differences between survival of adult Scrub-robins and patch, gender, vegetation and habitat type, although survival did appear lower in the North-west patch, which was smaller than the other patches. Similarly, patch size was not found to influence the survival of adult Eastern Yellow Robins (Zanette 2000). At Bakara, one Scrub-robin territory with less understorey cover than the other territories on the same patch (North patch) had two adults (and a juvenile) disappear from it and this area was not observed to be re-occupied. The North and North-west patches had larger territories and less hotspot Hard-leaf Wattle and Green Tea-tree shrub cover. This suggests that the level of shrub cover and composition of the understorey may influence the survival of adults and/or juveniles. In fact, the North-west Patch (which had the sparsest understorey cover), and whose occupants appeared to depend largely on *Eucalyptus* cover, had the lowest survival of both adult males and females of all patches.

Survival of females

Fewer adult females than adult males were banded in my study. At Peron Peninsula, WA, Brooker (2001) observed that male Scrub-robins tended to live longer than females, but this was not immediately apparent at Bakara. Predation of adult passerines can be biased towards females because of their greater parental care (Brown 1997), and the reduced cover exacerbated by habitat loss (Gibbs & Faaborg 1990). American Redstarts *Setophaga ruticilla* had increased mortality of females, which nest in low shrubs, and this could partly explain the existence of lone male territories in this species (Sherry & Holmes 1989).

Disappearance of Scrub-robins from patches

Scrub-robins from four patches could no longer be located during my fieldwork or just before the fieldwork began. These groups all lacked females, were isolated (mean distance from nearest patch with a female 2604 m, *n* = 3) and had only one or two territories in each patch. These birds could have been inexperienced, as Zanette (2001) found that less-experienced male Eastern Yellow Robins were more often observed in small habitat fragments and paired with females less often. Villard *et al.* (1993) also noted that another ground-foraging insectivore, the Ovenbird *Seiurus aurocapilla,* had better pairing success in habitat that was less isolated. Cooper & Walters (2002) found that the inability of female Brown Treecreepers to reach isolated territories occupied by lone, more philopatric males can explain why these territories eventually disappear. At Bakara, the overall poorer adult survival of Scrub-robins in the small North-west patch highlights the importance of large habitat patches to arrest avifaunal decline (Luck 2002).

Productivity (adult and juvenile)

Most pairs of Southern Scrub-robins were observed to breed, and generally the territories where no breeding took place had only one adult. Brooker (1998) observed a similar pattern at Peron Peninsula, WA: most Scrub-robins there occurred as pairs and a nestling fledged successfully at 63% of all nests (*n* = 11). At Gluepot Reserve, SA, Scrub-robin nest success was 58.8% in 2002 (*n* = 17 nests: Donaghey & Donaghey 2017) and 90.9% of territories (*n* = 11) produced a fledgling (R. Donaghey pers. comm.). At Bakara, 85% of territories with two Scrub-robins produced young. The first breeding at Bakara occurred in late September/early October and some pairs bred later, especially if the first fledgling disappeared. In comparison, at Peron Peninsula, Scrub-robins began breeding in July and August (Brooker 2001) and, at Gluepot Reserve, the breeding season extended from late August to at least 11 November, when the last young fledged (Donaghey pers. comm. 2022). The later breeding times at Bakara were within the July–January timeframe recorded as the breeding season across the Scrub-robin's range (Higgins & Peter 2002). Three juveniles at Bakara (7.5% of all juveniles fledged in the 2008 and 2009 cohorts) were observed to reach adulthood and breed at 2 years of age; two of them bred either in their natal territory or immediately adjacent to it. At Peron Peninsula, Brooker (2001, p. 185) stated that "two scrub-robins resighted at one year of age were each courting a partner, close to their natal site" but courting behaviour was not described. Only five (12.5%) of all the Bakara juveniles were observed to attain the minimum observed breeding age of 2 years.

Survival of juveniles

Survival to 1 year of age

Half of all the juvenile Scrub-robins observed disappeared in their initial months before they could be caught and banded, and 26.5% of these disappeared before reaching 2 months of age, which is typically a very vulnerable period of avian development (Kershner *et al.* 2004). Zann & Runciman (1994) also noted that the period from fledging to independence was when the most Zebra Finch *Taeniopygia castanotis* mortality was observed. At Bakara, the mean percentage of juveniles surviving to >1 year of age, from 2008 to 2011 (all years), was 32%, indicating that more young birds are disappearing than reaching adulthood.

A greater percentage of the surviving birds was from the South and Heritage Agreement patches. These two patches also had fewer juveniles permanently disappear than did the North and North-west patches. Additionally, these two patches had significantly more Hard-leaf Wattle and Green Tea-tree in better condition and more total combined understorey cover than the other two patches surveyed, as well as smaller territories and more territories with breeding pairs, all of which are indicative of superior habitat. Similarly, greater area of brambles *Rubus* spp. in territories correlated with increased nesting success of Superb Fairy-wrens *Malurus cyaneus* (Nias & Ford 1992). Many studies consider predation as being the greatest contributor to juvenile mortality (Dowling 2003; Debus 2006). Half of all Eastern Yellow Robin nests were predated at Langwarrin, Victoria, from August 1999 to February 2000 (Berry 2001). The frequent observation at Bakara of Scrub-robins nesting in shrubby areas, and leaving their recently fledged young in dense shrubby areas while searching for prey items nearby indicates that a key function of shrubby vegetation to ground-foraging Scrub-robins is to provide protective cover from predation (Whittingham & Evans 2004).

Survival of female juveniles

A higher percentage of male (80%, *n* = 16) than female (50%, *n* = 6) juveniles survived for 1 year. Similarly, Green

& Cockburn (2001) observed lower survival of female juvenile Brown Thornbills *Acanthiza pusilla* and male juveniles of that species in better condition than females, which probably contributed to increased longevity.

Understorey cover

It was anticipated that survival of juvenile Scrub-robins could be correlated with a higher percentage cover of understorey vegetation in the natal territory, as habitat structure and quality can affect avian reproductive success (Zimmerman 1971; Luck 2003; Doerr *et al.* 2006). At Bakara, the Scrub-robins that lived longest fledged from the territories with the most understorey cover. Similarly, the two patches with higher juvenile survival to 1 year (South and Heritage Agreement) had greater understorey cover than the other two (North and North-west), perhaps partly because of increased food abundance in this habitat type (not measured in this study). In the Southern Emu-wren *Stipiturus malachurus* at Portland, Victoria, survival of fledglings is higher in invertebrate-rich closed heathland habitat with fewer predators than in habitats with less-dense understorey (Maguire 2006). Other studies strongly correlate Scrub-robin presence with relatively dense understorey layers (Brooker 2001; Higgins & Peter 2002).

Predators

Predation is a likely cause of the high juvenile mortality of Scrub-robins at Bakara; because of the lower survival of juveniles in the less shrubby territories, habitat quality is also likely to be a determining factor in predation and mortality rates. Red Foxes *Vulpes vulpes* were regularly seen in Scrub-robin patches at Bakara, and their tracks were found in most territories. The radio-tracker of an adult Scrub-robin that was never resighted was found in canid faeces in its territory (which had low understorey cover and was thus suboptimal). Avian predators in the study area include the common Grey Currawong *Strepera versicolor*, a nest predator in fragmented landscapes (Gardner 1998), and Australian Raven *Corvus coronoides*, a predator of Scrub-robin nests (Higgins & Peter 2002). Amongst Australasian Robins (Petroicidae), nest predation is the chief cause of nest failure in Scarlet and Flame Robins *Petroica phoenicia* (Robinson 1990), Eastern Yellow Robin (Zanette & Jenkins 2000), Hooded Robin (Fitri & Ford 2003), Jacky Winter *Microeca fascinans* (Wood *et al.* 2008; Donaghey & Donaghey 2017) and Red-capped Robin (Dowling 2003; Powys 2004). In a review by Newton (1998), 80% of all nest failures were attributable to predation, and with ground-nesting birds in shrub habitats this is especially the case (Martin 1993). Red Foxes are one of the commonest predators of birds worldwide, and ground-nesting birds like Scrub-robins are particularly vulnerable. Predation of Scrub-robins by Cats *Felis catus* and foxes could be exacerbated by this species' inquisitive nature, for which it is renowned (Higgins & Peter 2002)

Weather

Increased juvenile Southern Scrub-robin survival was also correlated with greater rainfall. The year 2010 was very wet at Bakara, and the second wettest year in Australia since recording began in 1900 (Bureau of Meteorology 2015a,b). This was probably associated with the strong La Niña event in 2010–2012 (Bureau of Meteorology 2020). Studies of other avian species have shown increases in nest success with above-average rainfall (Peach *et al.* 1991; Grant & Grant 1992; Barbraud *et al.* 1999; Hernandez *et al*. 2005) and greater abundance of juveniles (Tarroux & McNeil 2003) and overall population growth (Grant & Grant 2000; Russell 2000; Brooke *et al.* 2012). This phenomenon has been linked to increased abundance of arthropods during wetter than normal years (Fuentes & Campusano 1985; Blancher & Robertson 1987; Bolger *et al*. 2005). Across the Scrub-robin's entire range, rainfall has either been very low or the lowest recorded since 1990 in a pattern which is typical of global warming and not natural variability (CSIRO 2015). Predictably, as reviewed by Chambers *et al.* (2005), such climatic changes are likely to have a devastating effect on already declining avian populations, especially Mallee birds, which tend to lose bioclimatic range with every 1°C increase in temperature (Brereton *et al.* 1995; Rowley & Russell 2002, Scoble 2012).

Time in natal territory

Juveniles (especially males) that remained longer in their natal territory survived longer, with most young Scrub-robins surviving ≥1 year still being present in their natal territory (see also Barker 2023). This extended parental care appears to be an important trait in improving the survival of juveniles in species with small clutches and year-round territories (Russell 2000). Brown Thornbill (Green & Cockburn 2001) and Red-winged Fairy-wren (Russell & Rowley 2000) juveniles that dispersed later experienced less mortality and were significantly more likely to occupy a nearby breeding vacancy. With fully occupied available habitat, young Superb Fairy-wrens could delay dispersal to wait for an optimal breeding vacancy to arise (Pruett-Jones & Lewis 1990). At Bakara, however, only one juvenile Scrub-robin (from the Heritage Agreement patch) that survived >1 year remained in its natal territory. The birds in this patch were predominantly observed to annex unoccupied habitat surrounding the adults' territory. Clearly, this is an advantage of fledging in a large patch with abundant unoccupied (but slightly inferior) key vegetation that provides suitable habitat for floating birds without a territory (Villard *et al.* 1993).

Acknowledgements

I thank Henry Short for access to the farm at Bakara; Darrel Northcott for visiting the farm to explain the clearance history; Bill Breed, Phillip Northeast, Tom Bradley and David Paton for assistance with fieldwork and reading a draft. Reviewers Denis Saunders, Jeff Turpin, and Richard Donaghey and editors James Fitzsimons and Julia Hurley provided critical comments that improved the manuscript. Ethics and permits for this research were: S-2010-082, S-2013-107A and S-2016-069. Funding was provided by a University of Adelaide Divisional Scholarship, The Native Vegetation Council Grant 08/09/10 and the 2011 Russell Baudinette Scholarship.

References

Barbraud, C., Barbraud, J.C. & Barbraud, M. (1999). Population dynamics of the White Stork *Ciconia ciconia* in western France. *Ibis* **141**, 469–479.

Barker, A.J. (2023). Dispersal of juvenile Southern Scrub-robins *Drymodes brunneopygia* in the Murray Mallee of South Australia. *Corella* **47**, 88-97.
Bennett, A.F. & Watson, D.M. (2011). Declining woodland birds – is our science making a difference? *Emu* **111**, i–vi.
Berry, L. (2001). Breeding biology and nesting success of the Eastern Yellow Robin and the New Holland Honeyeater in a southern Victorian woodland. *Emu - Austral Ornithology* **101**, 191–197.
Blancher, P.J. & Robertson, R.J. (1987). Effect of food supply on the breeding biology of Western Kingbirds. *Ecology* **68**, 723–732.
Bolger, D.T., Patten, M.A. & Bostock, D.C. (2005). Avian reproductive failure in response to an extreme climatic event. *Oecologia* **142**, 398–406.
Brereton, R., Bennett, S. & Mansergh, I. (1995). Enhanced greenhouse climate change and its potential effects on selected fauna of south eastern Australia: A trend analysis. *Biological Conservation* **12**, 339–354.
Brooke, M. de L., Flower, T.P., Campbell, E.M., Mainwaring, M.C., Davies, S. & Welbergen, J.A. (2012). Rainfall-related population growth and adult sex ratio change in the Critically Endangered Raso lark (*Alauda razae*). *Animal Conservation* **15**, 466–471.
Brooker, B. (2001). Biology of the Southern Scrub-robin (*Drymodes brunneopygia*) at Peron Peninsula, Western Australia. *Emu* **101**, 181–190.
Brooker, B.M. (1998). A Comparison of the Ecology of an Assemblage of Ground-dwelling Birds in an Arid Environment. PhD Thesis. Murdoch University, Perth.
Brown, K.P. (1997). Predation at nests of two New Zealand endemic passerines: Implications for bird community restoration. *Pacific Conservation Biology* **3**, 91–98.
Bureau of Meteorology (2015a). Monthly mean maximum temperature Loxton Research Centre. Bureau of Meteorology. Available online: http://www.bom.gov.au/jsp/ncc/cdio/weatherData/av?p_nccObsCode=36&p_display_type=dataFile&p_startYear=&p_c=&p_stn_num=024024 (accessed 16 May 2015).
Bureau of Meteorology (2015b). Record rainfall and widespread flooding. Bureau of Meteorology. Available online: http://www.bom.gov.au/climate/enso/history/ln-2010-12/rainfall-flooding.shtml (accessed 11 May 2015).
Bureau of Meteorology (2020). Climate driver update: La Niña underway in the tropical Pacific. Bureau of Meteorology. Available online: http://www.bom.gov.au/climate/enso/?utm_medium=email&utm_source=enso-wrapup&utm_campaign=public-weather&utm_term=enso&utm_content=text-01012020--ENSO-wrap (accessed 20 September 2020).
Cale, P. & Mladovan, L. (2007a). *Southern Scrub-robin (*Drymodes brunneopygia*)*. Report to Department of Environment & Heritage, Berri, South Australia.
Cale, P. & Mladovan, L. (2007b). *The Effect of Altered Grazing Regimes on the Composition of Mallee Bird Assemblages in the Rangelands: Report on Trial, 2007*. Report to South Australian Murray Darling Basin Natural Resource Management Committee. Department of Environment & Heritage, Berri, SA.
Cale, P. & Willoughby, N. (2009). An alternative stable state model for landscape scale restoration in South Australia. In: Hobbs, R.J. & Sunding, K.N. (Eds). *New Models for Ecosystem Dynamics and Restoration*, pp. 295–310. Island Press, Washington DC, USA.
Chambers, L.E., Hughes, L. & Weston, M.A. (2005). Climate change and its impact on Australia's avifauna. *Emu* **105**, 1–20.
Close, D.H. (1982). Birds of the Ninety Mile Desert. In: Harris, C.R., Reeves, A.E. & Symon, D.E. (Eds). *The Ninety Mile Desert of South Australia,* pp. 81–86. Nature Conservation Society of South Australia, Adelaide.
Cooper, C.B. & Walters, J.R. (2002). Experimental evidence of disrupted dispersal causing decline of an Australian passerine in fragmented habitat. *Conservation Biology* **16**, 471–478.
CSIRO (2015). *The Report - State of the Climate 2014.* Available online: http://www.csiro.au/en/Research/OandA/Areas/Assessing-our-climate/State-of-the-Climate/2014-SoC-Report (accessed 16 May 2015).
Debus, S.J.S. (2006). Breeding and population parameters of robins in a woodland remnant in northern New South Wales, Australia. *Emu* **106**, 147–156.
Dell, J. (1980). Birds of Yorkrakine Rock, East Yorkrakine and North Bungulla Nature Reserves. *Records of the Western Australian Museum Supplement* **12**, 55–67.
Doerr, V.A.J., Doerr, E.D. & Jenkins, S.H. (2006). Habitat selection in two Australasian treecreepers: What cues should they use? *Emu* **106**, 93–103.
Donaghey, R.H. & Donaghey, C.A. (2017). Parental care and breeding strategies of the Jacky Winter and its life-history traits compared with other Australasian robins, and northern temperate and tropical songbirds. *Australian Field Ornithology* **34,** 98–110.
Dowling, D.K. (2003). Breeding biology of the Red-capped Robin. *Australian Journal of Zoology* **51**, 533–549.
ESRI (2010). *ArcGIS Desktop: Release 10*. Environmental Systems Research Institute, Redlands, California, USA..
Field, A. (2013). *Discovering Statistics using SPSS*. 3rd edn. Sage Publications, London.
Fitri, L. & Ford, H.A. (2003). Breeding biology of Hooded Robins *Melanodryas cucullata* in New England, New South Wales. *Corella* **27**, 68–74.
Ford, H.A., Barrett, G.W., Saunders, D.A. & Recher, H.F. (2001). Why have birds in the woodlands of southern Australia declined? *Biological Conservation* **97**, 71–88.
Ford, H.A., Walters, J.R., Cooper, C.B., Debus, S.J.S. & Doerr, V.A.J. (2009). Extinction debt or habitat change? – Ongoing losses of woodland birds in north-eastern New South Wales, Australia. *Biological Conservation* **142**, 3182–3190.
Fry, C.H. (1977). The evolutionary significance of cooperative breeding in birds. In: Stone-house, B. & Perrins, C.M. (Eds). *Evolutionary Ecology*, pp. 127–136. University Park Press, Baltimore, Maryland, USA.
Fuentes, E.R. & Campusano, C. (1985). Pest outbreaks and rainfall in the semi-arid region of Chile. *Journal of Arid Environments* **8**, 67–72.
Gardner, J.L. (1998). Experimental evidence of edge related predation in a fragmented agricultural landscape. *Australian Journal of Ecology* **23**, 311–321.
Gardner, J.L., Magrath, R.D. & Kokko, H. (2003). Stepping stones of life: Natal dispersal in the group-living but noncooperative speckled warbler. *Animal Behaviour* **66**, 521–530.
Gibbs, J.P. & Faaborg, J. (1990). Estimating the viability of Ovenbird and Kentucky Warbler populations in forest fragments. *Conservation Biology* **4**, 193–196.
Grant, P.R. & Grant, B.R. (1992). Demography and the genetically effective sizes of two populations of Darwin's finches. *Ecology* **73**, 766–784.
Grant, P.R. & Grant, B.R. (2000). Non-random fitness variation in two populations of Darwin's finches. *Proceedings of the Royal Society of London B* **267**, 131–138.
Green, D.J. & Cockburn, A. (2001). Post-fledging care, philopatry and recruitment in Brown Thornbills. *Journal of Animal Ecology* **70**, 505–514
Hanski, I. & Simberloff, D (1997). The metapopulation approach, its history, conceptual domain and application to conservation. In: Hanski, I. & Gilpin, M.E. (Eds). *Metapopulation Biology: Ecology, Genetics and Evolution*, pp. 5–26. Academic Press, San Diego, California, USA.
Harris, S., Creswell, W.J., Forde, P.G., Trewhella, W.J., Woollard, T. & Wray, S. (1990). Home-range analysis using radio-tracking data- a review of problems and techniques particularly as applied to the study of mammals. *Mammal Review* **20**, 97–123.
Hernández, F., Hernández, F., Arredondo, J.A., Bryant, F.C., Brennan, L.A. & Bingham, R.L. (2005). Influence of precipitation on demographics of Northern Bobwhites in southern Texas. *Wildlife Society Bulletin* **33**, 1071–1079.

Higgins, P.J. & Peter, J.M. (Eds) (2002). *Handbook of Australian, New Zealand & Antarctic Birds, Volume 6: Pardalotes to shrike-thrushes*. Oxford University Press, Melbourne.

Kershner, E.L., Walk, J.W. & Werner, R.E. (2004). Postfledging movements and survival of juvenile Eastern Meadowlarks (*Sturnella magna*) in Illinois. *Auk* **121**, 1146–1154.

Koenig, W.D., Hooge, P.N., Stanback, M.T. & Haydock, J. (2000). Natal dispersal in the cooperatively breeding Acorn Woodpecker. *Condor* **102**, 492–502.

Lloyd, P. & Martin, T.E. (2016). Fledgling survival increases with development time and adult survival across north and south temperate zones. *Ibis* **158**, 135–143.

Luck, G.W. (2002). The habitat requirements of the rufous treecreeper (*Climacteris rufa*). 1. Preferential habitat use demonstrated at multiple spatial scales. *Biological Conservation* **105**, 383–394.

Luck, G. (2003). Differences in the reproductive success and survival of the rufous treecreeper (*Climacteris rufa*) between a fragmented and unfragmented landscape. *Biological Conservation* **109**, 1–14.

Luck, G.W., Possingham, H.P. & Paton, D.C. (1999). Bird responses at inherent and induced edges in the Murray Mallee, South Australia. 2. Nest predation as an edge effect. *Emu* **99**, 170–175.

Mac Nally, R., Bennett, A.F., Thomson, J.R., Radford, J.Q., Unmack, G., Horrocks, G. & Vesk, P.A. (2009). Collapse of an avifauna: Climate change appears to exacerbate habitat loss and degradation. *Diversity and Distributions* **15**, 720–730.

Maguire, G.S. (2006). Territory quality, survival and reproductive success in southern emu-wrens *Stipiturus malachurus. Journal of Avian Biology* **37**, 579–593.

Martin, T.E. (1993). Nest predation among vegetation layers and habitat types: Revising the dogmas. *American Naturalist* **141**, 897–913.

Newton, I. (1998). *Population Limitation in Birds*. Academic Press, San Diego, California, USA.

Nias, R.C. & Ford, H.A. (1992). The influence of group size and habitat on reproductive success in the Superb Fairy-wren *Malurus cyaneus. Emu* **92**, 238–243.

NSW Government (2023). Help save the Southern Scrub-robin *Drymodes brunneopygia*. Saving our Species. NSW Government, Sydney. Available online: https://www.environment.nsw.gov.au/savingourspeciesapp/ViewFile.aspx?ReportProjectID=1142&ReportProfileID=10252

Peach, W., Baillie, S. & Underhill, L. (1991). Survival of British Sedge Warblers *Acrocephalus schoenobaenus* in relation to West African rainfall. *Ibis* **113**, 300–305.

Powys, V. (2004). Breeding biology of the Red-capped Robin *Petroica goodenovii* in Capertee Valley, New South Wales. *Corella* **28**, 4–10.

Pruett-Jones, S.G. & Lewis, M.J. (1990). Sex ratio and habitat limitation promote delayed dispersal in superb fairy-wrens. *Nature* **348**, 541–542.

Reid, J.R.W. (1999). *Threatened and Declining Birds in the New South Wales Sheep–Wheat Belt: I. Diagnosis, Characteristics and Management*. CSIRO Wildlife and Ecology, Canberra.

Robinson, D. (1990). The nesting ecology of sympatric Scarlet Robin *Petroica multicolor* and Flame Robin *P. phoenicea* populations in open eucalypt forest. *Emu* **90**, 40–52.

Rowley, I. & Russell, E. (2002). A population study of the Blue-breasted Fairy-wren, *Malurus pulcherrimus*, at Dryandra, Western Australia. *Emu* **102**, 127–135.

Russell, E. & Rowley, I. (2000). Demography and social organisation of the red-winged fairy-wren, *Malurus elegans. Australian Journal of Zoology* **48**, 161–200.

Russell, E.M. (2000). Avian life histories: Is extended parental care the southern secret? *Emu* **100**, 377–399.

Russell, E.M., Brown, R.J. & Brown, M.N. (2004). Life history of the white-breasted robin, *Eopsaltria georgiana* (Petroicidae), in south-western Australia. *Australian Journal of Zoology* **52**, 111–145.

Saunders, D.A. (1989). Changes in the avifauna of a region, district and remnant as a result of fragmentation of native vegetation: The wheatbelt of Western Australia. A case study. *Biological Conservation* **50**, 99–135.

Scoble, J. (2012). No Place to go and Nowhere to be? Characterising Demography of the Southern Scrub-robin (*Drymodes brunneopygia*) using Molecular and Modelling Tools for Conservation. PhD Thesis. University of Adelaide, Adelaide.

Sherry, T.W. & Holmes, R.T. (1989). Age-specific social dominance affects habitat use by breeding American redstarts (*Setophaga ruticilla*)*:* A removal experiment. *Behavioral Ecology and Sociobiology* **25**, 327–333.

Stefanski, R.A. (1967). Utilization of the breeding territory in the Black-capped Chickadee. *Condor* **69**, 259–267.

Tarroux, A. & McNeil, R. (2003). Influence of rain on the breeding and moulting phenology of birds in a thorn woodland of northeastern Venezuela. *Ornitología Neotropical* **14**, 371–380.

Turpin, J.M. & Johnstone, R.E. (2017). An isolated population of the southern scrub-robin (*Drymodes brunneopygia*) in the Great Victoria Desert. *Pacific Conservation Biology* **23**, 95–106.

Vesk, P.A. & Mac Nally, R. (2006). The clock is ticking – revegetation and habitat for birds and arboreal mammals in rural landscapes of southern Australia. *Agriculture, Ecosystems and Environment* **112**, 356–366.

Villard, M.A., Martin, P.R. & Drummond, C.G. (1993). Habitat fragmentation and pairing success in the Ovenbird (*Seiurus aurocapillus*). *Auk* **110**, 759–768.

Watson, D.M. (2011). A productivity-based explanation for woodland bird declines: Poorer soils yield less food. *Emu – Austral Ornithology* **111**, 10–18.

Whittingham, M.J. & Evans, K.L. (2004). The effects of habitat structure on predation risk of birds in agricultural landscapes. *Ibis* **146** (Supplement **2**), 210–220.

Willoughby, N. (2006). *A Vegetation Strategy for the Murray Mallee. Towards a Habitat Restoration Strategy for the Murray Mallee*. Report to Department for Environment & Heritage South Australia.

Willoughby, N. (2008). *Northern Murray Mallee Landscape Restoration Trial. Final Report. December 2008 Draft*. Department for Environment & Heritage, South Australia.

Woinarski, J.C.Z. (1989). The vertebrate fauna of broombush (*Melaleuca uncinata*) vegetation in north-western Victoria, with reference to effects of broombrush harvesting. *Australian Wildlife Research* **16**, 217–238.

Woinarski, J.C.Z. (1990*). Broombush in the Victorian Mallee: The Vertebrate Fauna of Broombush Vegetation in North-western Victoria and the Environmental Effects of the Broombush Harvesting Industry*. Conservation Council of Victoria, Melbourne.

Wood, K.A., Thompson, N. & Ley, A.J. (2008). Breeding territories and breeding success of the Jacky Winter *Microeca fascinans* in south-eastern Queensland. *Australian Field Ornithology* **25**, 121–131.

Zanette, L. (2000). Fragment size and the demography of an area-sensitive songbird. *Journal of Animal Ecology* **69**, 458–470.

Zanette, L. (2001). Indicators of habitat quality and the reproductive output of a forest songbird in small and large fragments. *Journal of Avian Biology* **32**, 38–46.

Zanette, L. & Jenkins, B. (2000). Nesting success and nest predators in forest fragments: A study using real and artificial nests. *Auk* **117**, 445–454.

Zann, R. & Runciman, D. (1994). Survivorship, dispersal and sex ratios of Zebra Finches *Taeniopygia guttata* in southeast Australia. *Ibis* **136**, 136–146.

Zimmerman, J.L. (1971). The territory and its density dependent effect in *Spiza americana*. *Auk* **88**, 591–612.

Received 27 September 2021, accepted 22 June 2023, published online 13 November 2023

■