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Use of nesting resources in an Australian arid-zone landbird community

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Abstract. We investigated the use of nesting resources in a landbird community in the arid zone near Peery Lake, north-western New South Wales. Over a 3.5-year period (1990–1994), which encompassed pre-drought, drought and post-drought conditions, we recorded 504 active nests and 51 breeding species, including open- (45% of all breeding species), hollow- (27%), mud- (8%), ground- (8%) and tunnel-nesters (4%), and species that nested both in the open and in hollows (8%). Almost 90% of observed nests were located in run-on habitats – major creeklines and minor creeklines. Forty-two species nested in, and 24 species nested only in, run-on habitats. Only 23 species nested in the much more extensive surrounding run-off habitats, but the nests of six species were located only in run-off areas. Most nests (90%) were located in plants, all of which were perennials, with 408 nests in live plants and 47 nests in dead plants. The live plants included 20 tree and shrub species ≥0.5 m tall and 4 subshrub and grass species <0.5 m tall. Most (88%) nests in perennial plants were in trees >4 m tall but often low down in the tree (only 47% of all nests in perennial plants were at heights >4 m). Different bird species favoured different plant species. Favoured trees included River Red Gum *Eucalyptus camaldulensis* for hollow-nesters, and Whitewood *Atalaya hemiglauca* and Black Box *Eucalyptus largiflorens* for open- and mud-nesters. Though fewer nests were located in plants <4 m tall, they were in a wider variety of plant species (16 species) than the larger number of nests in plants >4 m tall (14 plant species). Some nomadic species nested in low vegetation which, though perennial, died back and was unavailable in dry times. To support the nesting requirements of all birds, and to retain the diversity of arid-zone birds, the floristic and structural diversity of perennial plants needs to be maintained. This will be difficult to achieve if the current pattern of ongoing, incremental loss of trees and shrubs continues in the arid zone, particularly as the rate of loss is likely to be exacerbated by the impacts of climate change.

Introduction

The nesting success of birds is dependent on the availability of suitable nest sites (Recher 1991). Although some species, such as White-browed Woodswallow *Artamus superciliosus* (Recher & Schulz 1985), are flexible in their choice of nest sites, others have more specific nesting requirements (Heinsohn *et al.* 2003; Debus 2006; Renton *et al.* 2015). Factors that determine the suitability of nest sites include nest plant species and vegetation structure (Middleton 1979; Nalwanga *et al*. 2004), nest height above ground and concealment (Best & Stauffer 1980; Nias 1986) and, for hollow-nesters, characteristics of nest cavity (Goldingay 2009).

The arid Australian landscape is spatially heterogeneous. Topographical relief concentrates the limited rainfall into relatively small and mesic run-on areas (Morton *et al.* 2011). In arid north-western New South Wales, the typical run-on habitats comprise creeklines fringed by trees and/or shrubs and surrounded by drier run-off habitats. Such relatively mesic creekline habitats support the tallest trees, most structurally complex vegetation and also more birds and more bird species than are found in adjacent drier run-off habitats (Pavey & Nano 2009; Burbidge *et al.* 2010; Smith 2015). It is likely that the creekline habitats provide the greatest opportunities for nesting birds.

Since the 1860s, pastoral settlement of arid western New South Wales has been accompanied by ongoing, albeit fluctuating, levels of land degradation. The resultant continued loss of trees and shrubs, together with a lack of effective regeneration of many of these species, has long been a matter of concern (Anon. 1901; Allen 1983; Reid & Fleming 1992; Read 2004; Garnett *et al*. 2011). Many of the perennial species are long-lived, as demonstrated by the Beefwood *Grevillea striata* tree that marked the burial site in 1845 in north-western New South Wales of the early explorer, James Poole, and still stands today. The extent of loss of perennial plants may now be masked by their longevity (Garnett *et al*. 2011) but is likely to be exacerbated by the higher temperatures, more extreme heat events and changed rainfall patterns predicted to occur in western New South Wales as a result of climate change (Office of Environment & Heritage 2014; Herold *et al*. 2018).

In this study, we investigated the use of nesting resources in a landbird community in arid north-western New South Wales over a 3.5-year period (1990–1994) that encompassed pre-drought, drought and post-drought conditions (Smith 2015). We evaluated the importance of different habitats within a local study area and sought to confirm the likely importance of the relatively mesic run-on habitats. We asked whether a continued loss of perennial plants in the arid zone will impact the future nesting success of arid-zone birds.

Study area and methods

The 1500-ha study area (30°43′S, 143°33′E) abuts the north-western end of Peery Lake on the Paroo overflow system, ~50 km north-east of White Cliffs and 100 km north of Wilcannia in arid north-western New South Wales (Figure 1). At the time of study, the area was within a grazing leasehold, Peery Station, but it is now part of Paroo–Darling National Park.

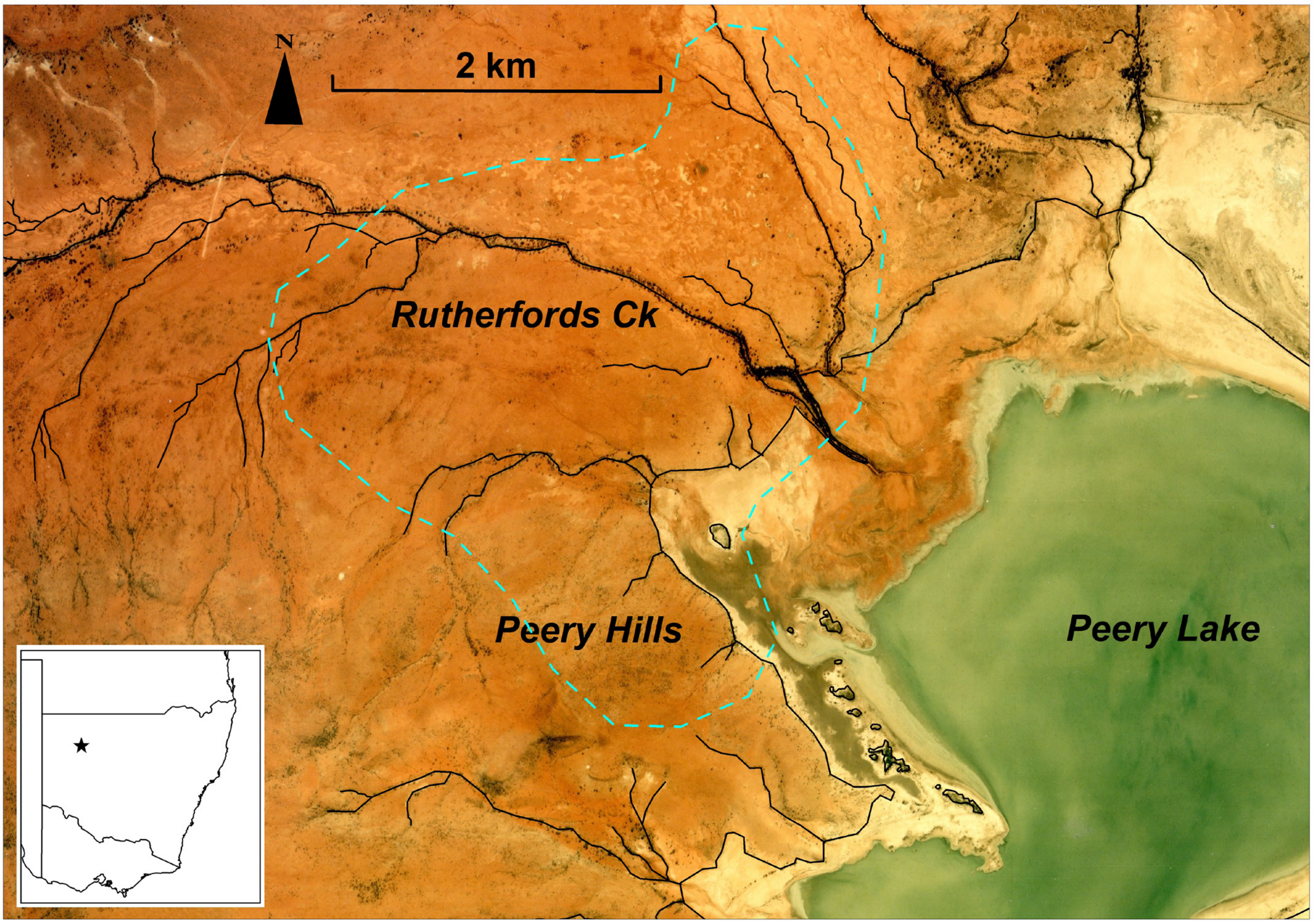

Figure 1. Location of the study area at the north-western end of Peery Lake in arid north-western New South Wales. Dashed light-blue outline indicates extent of study area. Air photo taken in August 1992 at the peak of the drought. Photo: Lands Department, NSW Government

The study area comprised four broad habitat types (Figure 2), including two run-on habitats – major creeklines and minor creeklines – and two run-off habitats – areas with sparse tall shrubs and low trees, and areas largely bereft of trees and tall shrubs (open plains). Major creeklines were dominated by River Red Gum *Eucalyptus camaldulensis*, Black Box *E. largiflorens* and River Cooba *Acacia stenophylla* woodland. Minor creeklines were fringed by shrubs and low trees, especially Whitewood *Atalaya hemiglauca*, Prickly Wattle *Acacia victoriae*, Mulga *A. aneura* and Lignum *Duma florulenta*. Run-off areas with trees and shrubs included Mulga scrub in the Peery Hills and Harlequin Eremophila *Eremophila duttonii* scrub on the plains. Vegetation on the open plains consisted of grasses, herbs and subshrubs (<0.5 m tall) including saltbushes *Atriplex* spp. and copperburrs *Sclerolaena* spp. These were a mixture of annuals, ephemerals and perennials but responded to rainfall, growing when conditions were good but dying right back in dry conditions. A detailed description of the study area is contained in Smith (1997); see also Smith & Smith (2023).

We searched for nests during nine surveys of the study area between October 1990 and January 1994. Survey dates were: spring 1990 (10 October–7 November), winter 1991 (2–23 July), spring 1991 (1–21 October), winter 1992 (29 June–23 July), spring 1992 (22 September–18 October), autumn 1993 (9–22 April), winter 1993 (12–29 July), spring 1993 (28 September–20 October), and summer 1993–1994 (18–26 January 1994). The survey dates were spread to allow a comparison of the avifauna of the study area between years and seasons (spring vs winter). Nest searches were made by JS while undertaking systematic bird censuses of transects that sampled the local habitat variability (Smith 2015). The same transects were censused on five different mornings in each survey period. In all survey periods, we camped within the study area, which allowed us to undertake additional opportunistic nest searches throughout each survey day. It is likely that the detectability of nests was influenced by the size of a nest, its height above ground, and degree of concealment, and the variable nesting behaviours of different bird species. In order to counter such likely biases, nests were detected by scanning vegetation from ground level to tree tops (maximum tree height in the study area was 20 m), using binoculars as needed. We also detected nests from calls of adult and young birds at or near nests and by following birds carrying food or nesting material. On occasions, the skittish or aggressive behaviour of birds alerted us to the presence of a nearby nest.

For each active nest located, we recorded: the species of nesting bird, broad habitat type, nest type, species of nest plant, height and health (live or dead) of the nest plant, and height of nest above the ground. Nest types included open nests (made of plant material attached to the foliage or branch of a tree or shrub, and including domed nests), mud nests, hollow nests (inside a naturally occurring hollow in a

Figure 2. Habitat types in the study area. (a) Major creeklines fringed by eucalypt woodland, in this case River Red Gum woodland along the lower reaches of Rutherfords Creek, photographed in October 1990 when there was water in the creek. (b) Minor creeklines such as this example fringed by Prickly Wattles, photographed pre-drought in October 1990. (c) Run-off areas with low trees and shrubs such as open Mulga scrub on the Peery Hills, photographed post-drought in April 1993. (d) Run-off areas with no tree and shrub cover (open plains), photographed pre-drought in October 1990. Photos: Peter Smith

tree or shrub), ground nests (recording whether in the open or under cover), tunnel nests (inside tunnels dug into the ground by the birds), and vacant nests of other species. Heights were measured with a clinometer or estimated by summing 2 m (or part thereof) intervals along the plant's vertical axis.

The relative abundance of trees and shrubs was calculated across 19 bird census transects in the study area. At each of 111 points spaced at 100-m intervals along the transects, the ten closest trees (>4 m tall) and ten closest shrubs (0.5–4 m tall) were identified to species and recorded. The distances to the furthest tree and the furthest shrub were measured and used to calculate the density of each tree and shrub species (individuals/ha). If trees and shrubs were sparse, only those within 50 m of each point were included in the count. The mean density of each species was then calculated from the density values from all 111 points and used as a measure of their relative abundance in the study area. This was done separately for the tree layer and the shrub layer. Some plant species were represented in both layers but their densities were not combined – the tree layer and shrub layer were treated separately in the analyses.

Bird density and species richness varied greatly between the habitat types. Mean bird density ranged from 34.0 ± 2.1 birds ha^{-1} in transects along major creeklines to 1.8 ± 0.5 birds ha^{-1} on the open plains. Mean bird species richness ranged from 19.2 ± 0.9 species per census period along major creeklines to 5.3 ± 1.5 species per census period on the open plains (Smith 2015). A greater nest survey effort was devoted to the creeklines, where birds were concentrated and vegetation was more difficult to search, than to the run-off habitats, especially the open plains, where birds were scarce and generally easier to detect. During each survey period, we routinely searched the open plains each day for signs of nesting birds as we moved between creekline habitats. We did not record the time spent searching for nests in each habitat type.

Results

Nest records

A total of 504 active nests was found, deriving from 48 of the 51 species recorded breeding in the study area (Appendix 1). Evidence of breeding (adults accompanied by fledglings) was noted for Australian Ringneck *Barnardius zonarius*, Mulga Parrot *Psephotellus varius* and Orange Chat *Epthianura aurifrons* but nests were not located for these species. Australian Raven *Corvus coronoides* and Little Crow *C. bennetti* were both recorded nesting but not every corvid nest could be identified to species and therefore these two species have been combined in some analyses. The 51 breeding species included 34 residents, 11 nomads, five spring–summer migrants and one winter migrant (Smith 2015).

Use of broad habitat types for nesting

Most individuals and bird species nested in the two run-on habitats – major creeklines and minor creeklines. Sixty-one per cent of nests were located in eucalypt woodland that fringed major creeklines and 28% of nests were along minor creeklines. Nests of 42 species were found in run-on areas and 25 of these species nested only in run-on areas (Appendix 1). Only 11% of nests were located in the two run-off habitats, although 23 species were recorded nesting there. Nests of six species (Little Button-quail *Turnix velox*, Bluebonnet *Northiella haematogaster*, Black Honeyeater *Sugomel nigrum,* Crimson Chat *Epthianura tricolor*, Singing Honeyeater *Gavicalis virescens* and Red-capped Robin *Petroica goodenovii*) were found only in run-off areas. The most generalised in their use of habitats for nesting were Crested Pigeon *Ocyphaps lophotes*, Spiny-cheeked Honeyeater *Acanthagenys rufogularis* and Australian Magpie *Gymnorhina tibicen*, which nested in all four habitat types, though even these species nested more frequently in run-on than run-off habitats (Appendix 1).

Nest types

Twenty-three of the 51 breeding species (45%) were open-nesters and 14 (27%) were hollow-nesters (e.g. Galah *Eolophus roseicapilla*: Figure 3a) (Appendix 1). The term 'open-nesters' refers here to species that nested in the open, not inside hollows. Most of these were species that also built open nests in the sense of cup-shaped or plate-shaped nests (Figure 3b–c), but four 'open-nesters' built enclosed, globular nests: Purple-backed Fairy-wren *Malurus assimilis*, White-winged Fairy-wren *M. leucopterus*, Yellow-rumped Thornbill *Acanthiza chrysorrhoa* and Chestnut-crowned Babbler *Pomatostomus ruficeps*. Zebra Finch *Taeniopygia castanotis* also built an enclosed globular nest, either in the open or in a hollow. The three woodswallow species also nested both in the open and in hollows. Four species (8% of breeding species) built mud nests, four (8%) nested on the ground and two (4%) nested in tunnels dug into the ground. The mud-nesters included three species with open, bowl-shaped nests built in trees and shrubs (Magpie-lark *Grallina cyanoleuca*, White-winged Chough *Corcorax melanorhamphos* and Apostlebird *Struthidea cinerea*) and one colonial nester (Fairy Martin *Petrochelidon ariel*), which built enclosed, bottle-shaped nests on creekbanks (Figure 3d).

The ground-nesting Emu *Dromaius novaehollandiae* and Spotted Nightjar *Eurostopodus argus* laid their eggs in the open on bare ground or rudimentary mats of vegetation, and Little Button-quail and Rufous Songlark *Cincloramphus mathewsi* concealed their grassy nests in dense ground-layer vegetation. The two tunnel-nesters (Rainbow Bee-eater *Merops ornatus* and Red-backed Kingfisher *Todiramphus pyrrhopygius*) built their tunnels into creekbanks. All nest tunnels located were within 25 m of trees or shrubs in which these species frequently perched. The species with the most varied nest sites were woodswallows and Zebra Finch. Black-faced Woodswallow *Artamus cinereus* and Zebra Finch built grassy nests in dense foliage and in hollows, whereas White-browed and White-breasted Woodswallows *A. leucorynchus* built in tree forks, dense foliage, hollows and vacant mud nests of other species.

Use of plant species

Most nests (90%) were located in plants, with 408 nests in live plants and 47 nests in dead plants. The live plants, all of which were perennials, included 20 tree and shrub species ≥0.5 m tall, and four subshrub and grass species <0.5 m tall (Table 1). Apart from nests found in plants, which were used by 44 of the 51 breeding species, there were 11 nests on the ground (four ground-nesting species) and 38 nests in or on creekbanks (two tunnel-nesting species and Fairy Martin mud nests).

Of the nests in plants, 402 (88%) were in trees >4 m tall. Fourteen species of trees were used. The main trees used by hollow-nesters were River Red Gum (61% of nests), dead trees (17%) and Black Box (14%) (Figure 4a). The difference between the frequency of use of tree species by hollow-nesters and the relative abundance of the trees was χ^2 (6) = 166.26, P <0.001. The main contributors to the high χ^2 value were a preference for River Red Gum (χ^2 contribution 105.52) and an avoidance of River Cooba (χ^2 contribution 27.83), Whitewood (χ^2 contribution 21.02) and Mulga (χ^2 contribution 10.86).

The main nest trees for open- and mud-nesters were Whitewood (32% of nests), River Red Gum (24%) and Black Box (22%) (Figure 4b). The difference between the frequency of use of tree species by open- and mud-nesters and the relative abundance of the trees was significant [χ^2 (6) = 91.02, P <0.001]. The main contributors to the high χ^2 value were an avoidance of dead trees (χ^2 contribution 32.98), a preference for Whitewood (χ^2 contribution 27.17) and a preference for Black Box (χ^2 contribution 14.56).

Only 53 (12%) nests were found in plants <4 m high (Table 1). Most birds nesting in these lower plants were open- or mud-nesters but there were also four nests in

Figure 3. Examples of the varied nest types of birds recorded in the study area (a) Galah at a nest hollow in a dead tree. (b) Plate-shaped nest of Diamond Dove in a low River Cooba tree. (c) Cup-shaped nest of Crimson Chat in a Tangled Poverty-bush subshrub. (d) Bottle-shaped mud nests of Fairy Martins. Photos: Peter Smith

hollows in stumps <4 m high (one hollow-nester and three open-/hollow-nesters). A variety of plant species was used, with 43 nests recorded in 16 different perennial plant species and 10 nests in dead shrubs and stumps <4 m high. All of these nest plant species are considered perennial but two of the subshrubs and a grass, which provided nest sites for Crimson Chat and Variegated and White-winged Fairy-wrens, died back during the drought. There were insufficient data for a *chi*-square analysis but strong preferences for particular plant species were not evident.

Two species built nests in clumps of mistletoe growing in perennial plants: Black-faced Woodswallow (Mulga Mistletoe *Lysiana murrayi* in Dead Finish *Acacia tetragonophylla*) and Yellow-rumped Thornbill (dead mistletoe in Belah *Casuarina pauper* and live mistletoe in Santalum *Santalum lanceolatum*). These nests are included in Table 1 under the host plants.

Height of nest plants and nests

We recorded the heights of 411 nests above ground level together with the heights of the plants in which each of the nests was located. Nest plants ranged in height from <0.5 to 18 m. Most nest plants (83%) were trees (>4 m), with many fewer shrubs (0.5–4 m, 15%) and even fewer subshrubs and grasses (<0.5 m, 2%). However, over half of the nests located (53%), even when in trees, were in the shrub (0.5–4 m) height range, with fewer >4 m (44%) and very few (4%) located <0.5 m above ground (Figure 5).

Repeated use of nest sites

Several bird species nested in existing nests from previous breeding seasons. Yellow-rumped Thornbill (spring 1990, 1992; winter and spring 1993), Chestnut-crowned Babbler

Table 1. Plant species used by nesting birds in the study area, near Peery Lake, north-western New South Wales, 1990–1994.

Plant species	*No. of nests*
Trees >4 m high that persist during drought	
Mulga *Acacia aneura*	1
River Cooba *Acacia stenophylla*	19
Prickly Wattle *Acacia victoriae*	5
Rosewood *Alectryon oleifolius*	3
Whitewood *Atalaya hemiglauca*	69
Belah *Casuarina pauper*	5
Broad-leaf Hopbush *Dodonaea viscosa*	1
River Red Gum *Eucalyptus camaldulensis*	171
Red Box *Eucalyptus intertexta*	1
Black Box *Eucalyptus largiflorens*	72
Bimble Box *Eucalyptus populnea*	11
Leopardwood *Flindersia maculosa*	1
Beefwood *Grevillea striata*	5
Santalum *Santalum lanceolatum*	1
Dead trees	**37**
Shrubs 0.5–4 m high that persist during drought	
Mulga *Acacia aneura*	2
Dead Finish *Acacia tetragonophylla*	1
Prickly Wattle *Acacia victoriae*	2
Rosewood *Alectryon oleifolius*	2
Whitewood *Atalaya hemiglauca*	1
Belah *Casuarina pauper*	4
Broad-leaf Hopbush *Dodonaea viscosa*	1
Lignum *Duma florulenta*	3
Harlequin Eremophila *Eremophila duttonii*	3
Black Bluebush *Maireana pyramidata*	2
Boobialla *Myoporum montanum*	8
Weeping Pittosporum *Pittosporum angustifolium*	1
Perennial subshrubs that persist during drought	
Blackseed Samphire *Tecticornia pergranulata*	3
Perennial subshrubs that die back during drought	
Pale Poverty-bush *Sclerolaena divaricata*	2
Tangled Poverty-bush *Sclerolaena intricata*	7
Tufted perennial grasses that die back during drought	
Slender Panic *Paspalidium constrictum*	1
Dead shrubs and stumps	**10**
Total	**455**

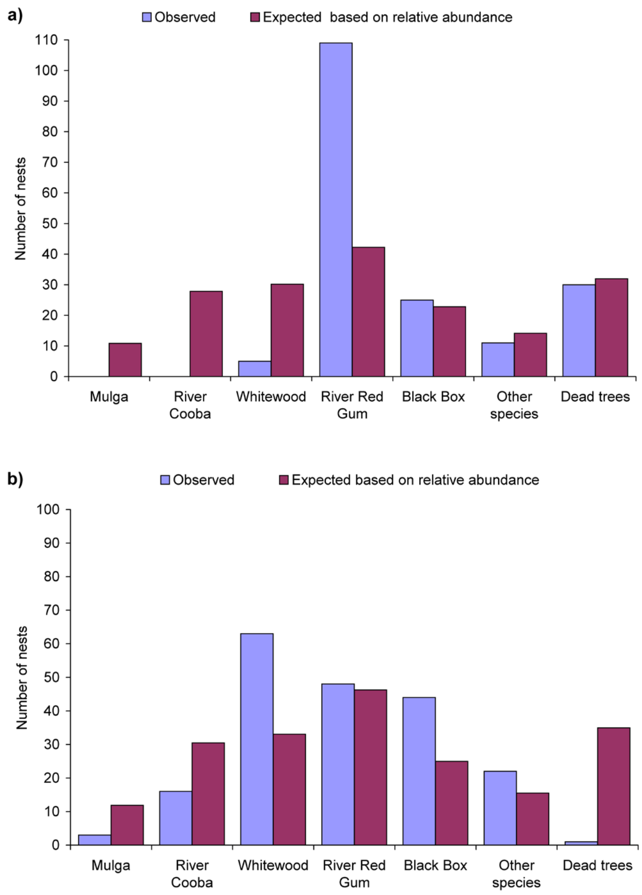

Figure 4. Tree species preferences of (a) hollow-nesters (180 nest records) and (b) open- and mud-nesters (197 nest records).

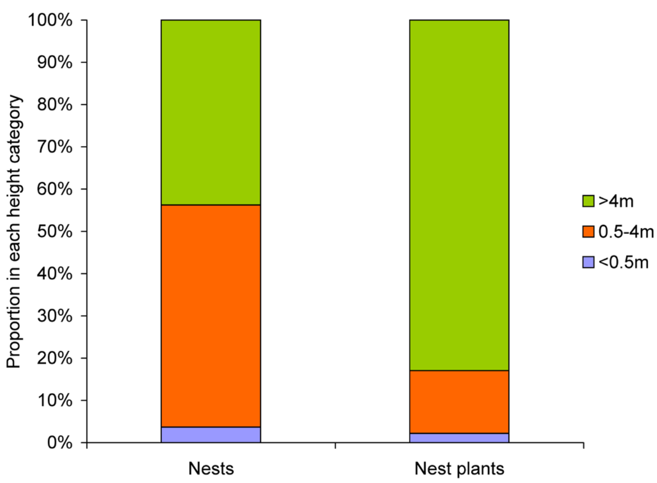

Figure 5. Comparison of heights of nests above ground and the heights of the plants in which nests were located (411 nest records in live or dead plants).

(same nest used in spring 1991, 1992, 1993) and White-winged Chough (spring 1990 and 1992) re-used nests of their own species. Hollows were re-used by Southern Whiteface *Aphelocephala leucopsis* (same hollow in spring 1990, winter and spring 1992, spring 1993), Chestnut-rumped Thornbill *Acanthiza uropygialis* (winter and spring 1991) and Tree Martin *Petrochelidon nigricans* (spring 1992, 1993). Of the birds re-using nests, one pair of individually marked Tree Martins fledged young from the same hollow in a Black Box in spring 1992 and spring 1993. These were the only banded birds (of 401 banded birds) observed re-using nests.

Vacant nests of other species were used by Nankeen Kestrel *Falco cenchroides* (same corvid stick nest in spring 1990 and 1992), Chestnut-rumped Thornbill (the same Fairy Martin mud nest in winter and spring 1991), White-browed Woodswallow (Magpie-lark and Apostlebird mud nests) and White-breasted Woodswallow (Magpie-lark mud nest). In spring 1992, Yellow-rumped Thornbills built a nest in the base of a corvid nest occupied simultaneously by Nankeen Kestrels.

Discussion

In this study, almost 90% of the 504 nests located were associated with the two run-on habitats (major creeklines and minor creeklines). Of the 48 species for which nests were located, 42 species nested in run-on areas and 24 of these nested only in run-on areas. Although it is likely that not all active nests present during the study period were detected, the differences between habitat types were marked. The importance of creekline habitats to birds of Australian arid areas has long been recognised (e.g. Pianka & Pianka 1970; Wyndham 1978; Brooker *et al.* 1979; Henle 1989). The concentration of nests found within the relatively small areas of run-on habitats within the study area (Figure 1) emphasised the importance of these habitats as nesting sites in arid areas. These creekline habitats supported denser and structurally and floristically more diverse trees and shrubs than were found in adjacent run-off areas (Smith 2015) and thus provided a greater variety and density of potential nest sites than in run-off areas. The creekline habitats also provided a relatively regular supply of nesting opportunities compared with the run-off habitats, where the type and quantity of vegetation cover fluctuated in response to rainfall. Several favoured nest plant species, including River Red Gum and Black Box, are closely associated with creeklines and their supplies of subterranean water. Certain features of creeklines also provided nesting opportunities lacking in run-off habitats. The largest trees in the study area, River Red Gums, grew in the major creekline habitat. Large trees such as these provide the greatest density of hollows as well as the largest hollows (Lindenmayer *et al.* 2000). Creekbanks provided sites for Fairy Martins to attach their mud nests and for Red-backed Kingfisher and Rainbow Bee-eater to build their tunnel nests. Holes scoured in creekbeds held water for several weeks after rain and their muddy rims supplied building material for mud-nesters. Even Emu and Spotted Nightjar, which nest on open ground, nested in run-on creekline habitats as well as run-off habitats.

For five of the six species that nested only in run-off areas (Little Button-quail, Bluebonnet, Black Honeyeater, Singing Honeyeater and Red-capped Robin), only one or two nests were recorded and it is not possible to determine a real preference for run-off areas from such low numbers. The sixth species, Crimson Chat, built eight nests in run-off areas, but none were found in run-on areas, suggesting that for this species there is a preference for nesting in run-off areas.Resident bird species nested either in perennial plants or on the ground and although their nesting efforts were curtailed during the drought (Smith & Smith 2023), this was not because of a lack of suitable nest sites. Some nomadic species, however, used nest sites that were available only when site conditions were good. Little Button-quail, Crimson Chat and Rufous Songlark, for example, nested only in spring 1993 when they built their nests in dense, low (<0.5 m high) ground-layer or subshrub vegetation. This type of vegetation died back in the study area when conditions were dry but then regrew after the drought broke in late 1992.

In arid areas, fidelity to a nest site would assist birds to respond quickly to irregular and limited periods in which conditions are favourable for nesting. An attachment of individuals to a specific nest site was demonstrated here for Tree Martins and has been shown elsewhere for several species, including Wedge-tailed Eagle *Aquila audax* (Hughes & Hughes 1984), Rainbow Bee-eater (Lill 1993), Galah (Rowley 1990), Major Mitchell's Cockatoo *Cacatua leadbeateri* (Rowley & Chapman 1991) and Yellow-rumped Thornbill (Ford 1963). Further banding studies are needed to determine how prevalent individual attachments by birds to specific nest sites are in the Australian arid zone. Multiple records of species re-using nests were a feature of this study but, apart from one pair of banded Tree Martins, it was unclear whether these were the same individuals.

Forty-four of the 51 breeding species in the study area built their nests in trees and shrubs. Most nests located in plants were built in trees >4 m tall but the nests themselves were often located at a height of 0.5–4 m above ground in what could be considered the 'shrub layer'. However, the nest height categories were not strictly comparable with vegetation layers. Trees were low (<20 m) and most, including the favoured River Red Gum and Black Box, exhibited a typical woodland growth form. They branched extensively near the ground and foliage extended from near ground level to the tops of trees. Concealment of nests is likely to reduce the impacts of avian predators on nesting success (Latif *et al.* 2011). Possibly better shelter and protection for nests occurred within the lower, rather than the upper, levels of trees. It is also possible that we could detect nests more easily in lower vegetation.

On the open plains, much the most extensive habitat in the study area, 22 of a total of 25 nests located were in isolated trees and shrubs, which dot these areas. The other three nests were on open ground (Emu, 2 nests) or in low grassy vegetation (Little Button-quail, 1 nest). The reliance of breeding birds on trees and shrubs for nest sites stands in contrast with their feeding habits. More than half the breeding birds were ground-feeders and the trees and shrubs in which ground-feeders nested supplied little, if any, of their foraging habitat (Smith 1997).

Birds were recorded nesting in 24 different plant species, including 20 tree and shrub species ≥0.5 m tall and four perennial subshrub and grass species <0.5 m tall. Certain plants were especially important to nesting birds and different bird species favoured different plant species. Favoured trees included River Red Gum for hollow-nesters, and Whitewood and Black Box for open- and mud-nesters (River Red Gums were also often used by open- and mud-nesters but were not specially selected: Figure 4b). The hollows of mature River Red Gums had varied capacities and entrance sizes and were thus suitable for birds with varied preferences for dimensions of hollows and nest entrances. Tree Martins increased the suitability of available hollows by partially plugging entrances of hollows with mud to achieve a preferred entrance size. Reducing the entrance size presumably has the effect of excluding larger hollow-nesting birds as well as potential predators. Budgerigars *Melopsittacus undulatus* nested in live and dead trees and frequently used dead spouts in live River Red Gums. Whitewood and Black Box might have been preferred by Apostlebirds because their branches provided suitable attachment points for mud-nests. In a study in southern central New South Wales, Woxvold (2004) recorded 111 Apostlebird nests in various rough-barked trees but only a single nest in a smooth-barked tree (River Red Gum). Apostlebirds build relatively large mud nests (external diameter ~15 cm: Woxvold 2004) and rough bark may be better than smooth bark (as found on the River Red Gum) for nest attachment. Open- and mud-nesting species avoided dead trees, where the absence of foliage would make it difficult to conceal a nest.

Fewer nests were found in shrubs, subshrubs and grasses than in trees, but a wider range of low plant species than tree species was used, possibly reflecting the greater array of shrub and ground-layer plant species present in the study area. Some shrubs providing nest sites, such as Harlequin Eremophila, Lignum and Black Bluebush *Maireana pyramidata*, have dense foliage and a compact habit that offers good shelter and protection for smaller birds. Characteristics of nest hollows of some arid-zone birds have been described by Saunders *et al*. (1982), Rowley (1990) and Rowley & Chapman (1991). Characteristics of trees and shrubs that make them suitable for open- and mud-nesters warrant further study.

The continued availability of suitable nest sites for most arid-zone birds is thus dependent on the retention and adequate regeneration of trees and shrubs. Hollow-nesting species, which in this study ranged in size from Chestnut-rumped Thornbill (7 g) to Little Corella *Cacatua sanguinea* (318 g), require hollows of varied size. In eucalypts, such as River Red Gums, which provided many of the hollows, only very old trees (often >200 years old: Gibbons & Lindenmayer 2002), provide large hollows. Trees spanning a range of age classes are needed to meet the future needs of hollow-nesters. For species such as Little Button-quail, Crimson Chat and Rufous Songlark, which nest in dense, low vegetation, the conservation of ground-layer vegetation is important.

In arid central Australia, Pavey & Nano (2009) identified strong associations between bird species and vegetation at a landscape scale. They concluded that failure to conserve the range of broadscale vegetation types would threaten bird diversity. In our study in arid north-western New South Wales, we found that perennial plant species and the most mesic creekline habitats provided the greatest opportunities for nesting birds. However, to meet the nesting requirements of all bird species, and hence to retain local bird diversity, the floristic and structural diversity of perennial plants and creekline vegetation, as well as more variable ground-layer vegetation in run-off habitats, needs to be maintained. The conservation of broadscale vegetation types as well as the local floristic and structural diversity of vegetation will be difficult to achieve if factors driving land degradation, such as land clearing, overgrazing by stock, feral animals and kangaroos, erosion, and inappropriate fire regimes, continue. Land degradation, including the loss of perennial plants and integrity of creeklines, in arid Australia is likely to be compounded by the impacts of climate change. Across arid Australia, the predicted and unfolding increases in temperature- and drought-related extremes, including the number and duration of heatwaves (Herold *et al.* 2018) are likely to have significant deleterious impacts on the birds and their nesting resources.

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Appendix 1. Nest types and occurrence of nests in broad habitat types in the study area near Peery Lake, in the arid zone, north-western New South Wales, 1990–1994. Nest types are: hollow (H), ground (G), mud (M), open (O), and tunnel (T). Status is based on the pattern of occurrence of each species in the study area: resident (R), nomad (N), spring–summer migrant (S) and winter migrant (W). Figures are the number of nests for each species in each broad habitat type. * indicates likely location of nests for species recorded with fledglings.

Common name	*Scientific name*	*Status, nest type*	*Broad habitat type*			
			Run-off		*Run-on*	
			Open plain	*Trees/ shrubs*	*Minor creek*	*Major creek*
Emu	*Dromaius novaehollandiae*	R, G	2			2
Crested Pigeon	*Ocyphaps lophotes*	R, O	2	1	5	2
Diamond Dove	*Geopelia cuneata*	N, O			1	3
Spotted Nightjar	*Eurostopodus argus*	R, G			1	
Little Button-quail	*Turnix velox*	N, G	1			
Collared Sparrowhawk	*Accipiter cirrocephalus*	R, O				2
Rainbow Bee-eater	*Merops ornatus*	S, T				4
Sacred Kingfisher	*Todiramphus sanctus*	S, H				1
Red-backed Kingfisher	*Todiramphus pyrrhopygius*	S, T			1	
Nankeen Kestrel	*Falco cenchroides*	R, O			3	
Cockatiel	*Nymphicus hollandicus*	N, H				5
Galah	*Eolophus roseicapilla*	R, H			1	10
Little Corella	*Cacatua sanguinea*	R, H				7
Bluebonnet	*Northiella haematogaster*	R, H		1		
Budgerigar	*Melopsittacus undulatus*	N, H			13	45
Brown Treecreeper	*Climacteris picumnus*	R, H				8
Purple-backed Fairy-wren	*Malurus assimilis*	R, O			4	3
White-winged Fairy-wren	*Malurus leucopterus*	R, O	1		3	
Black Honeyeater	*Sugomel nigrum*	N, O		1		
Crimson Chat	*Epthianura tricolor*	N, O	6	2		
Spiny-cheeked Honeyeater	*Acanthagenys rufogularis*	R, O	1	1	5	1
Singing Honeyeater	*Gavicalis virescens*	R, O		2		
White-plumed Honeyeater	*Ptilotula penicillata*	R, O			12	25
Yellow-throated Miner	*Manorina flavigula*	R, O		6	9	1
Striated Pardalote	*Pardalotus striatus*	R, H			3	1
Southern Whiteface	*Aphelocephala leucopsis*	R, H	8		8	
Yellow-rumped Thornbill	*Acanthiza chrysorrhoa*	R, O	2		1	
Chestnut-rumped Thornbill	*Acanthiza uropygialis*	R, H		2	3	
Chestnut-crowned Babbler	*Pomatostomus ruficeps*	R, O		1	8	
Grey Shrike-thrush	*Colluricincla harmonica*	R, H				2
Black-faced Cuckoo-shrike	*Coracina novaehollandiae*	R, O			4	1
White-winged Triller	*Lalage tricolor*	S, O			4	
Australian Magpie	*Gymnorhina tibicen*	R, O	1	2	5	2
Pied Butcherbird	*Cracticus nigrogularis*	R, O		1	1	1
White-browed Woodswallow	*Artamus superciliosus*	N, H/O				7
Black-faced Woodswallow	*Artamus cinereus*	R, H/O			2	1
White-breasted Woodswallow	*Artamus leucorynchus*	S, H/O		1	1	7
Willie Wagtail	*Rhipidura leucophrys*	R, O		1	17	34
Magpie-lark	*Grallina cyanoleuca*	R, M		1	7	11
Little Crow/Australian Raven	*Corvus bennetti/C. coronoides*	R, O			3	3

Appendix 1 continued

Common name	Scientific name	Status, nest type	Broad habitat type			
			Run-off		Run-on	
			Open plain	Trees/ shrubs	Minor creek	Major creek
White-winged Chough	*Corcorax melanorhamphos*	R, M				1
Apostlebird	*Struthidea cinerea*	R, M		3	7	14
Red-capped Robin	*Petroica goodenovii*	W, O		1		
Rufous Songlark	*Cincloramphus mathewsi*	N, G		1	1	3
Fairy Martin	*Petrochelidon ariel*	N, M				33
Tree Martin	*Petrochelidon nigricans*	R, H				66
Zebra Finch	*Taeniopygia castanotis*	N, H/O	1		10	2
Mulga Parrot	*Psephotellus varius*	R, H			*	*
Australian Ringneck	*Barnardius zonarius*	R, H				*
Orange Chat	*Epthianura aurifrons*	N, O	*			
Total species			**10**	**17**	**29**	**32**
Total nests			**25**	**28**	**143**	**308**