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Breeding patterns in an Australian arid-zone landbird community

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Abstract. In 1990–1994, over nine survey periods, we recorded a total of 684 breeding attempts deriving from 51 species in a landbird community in arid north-western New South Wales. We investigated whether breeding effort was related to regular seasonal patterns (spring vs winter) or to irregular fluctuations in rainfall (pre-drought vs drought vs isolated thunderstorm vs above-average rainfall post-drought). The total breeding effort and number of species breeding in the study area were not correlated with the numbers of individuals or species present at a given time. The overall breeding effort was influenced primarily by season but was modified by rainfall. Spring breeding predominated but the timing and magnitude of the breeding efforts of different movement groups (residents, nomads and migrants) and dietary groups varied. Within these groups, there were inconsistencies between individual species. Residents bred mainly in spring but only in low numbers during the drought. Some resident species with relatively stable food supplies also bred, though to a lesser extent, in winter. Residents did not respond to the breaking of the drought with prolonged or aseasonal breeding. The breeding of nomads appeared to follow rainfall more closely. The greatest nesting effort by nomads occurred in the spring after the drought broke, possibly because of a peak in the availability of foods suitable for the nomads at this time. The uncertainty and extremes of the arid-zone environment are now being exacerbated by ongoing anthropogenic climate change, which is likely to severely impact the breeding efforts of arid-zone birds.

Introduction

In arid Australia, the availability of food, water, shelter and nest sites for breeding birds is influenced by the area's low and unpredictable rainfall and its spatial heterogeneity. Run-on areas in the landscape are relatively small, mesic and fertile compared with the extensive run-off areas (Morton *et al.* 2011). Early European observers in the seemingly erratic Australian arid zone surmised (Carter 1889, p. 268) that "many species of birds lay here whenever a good rain falls, no matter what time of year". Carter's observations were supported by later anecdotal accounts of breeding following rain (McGilp 1919, 1924; Carnaby 1954; Robinson 1955; Immelmann 1963). Breeding appeared to be opportunistic and related to rainfall itself, "the very sight of rain appears to stimulate various species to courtship, with copulation and nest building beginning within hours after the start of precipitation" (Dawson & Bartholomew 1968, p. 387), or to the improvements in food supplies (Serventy & Marshall 1957; Keast 1959; Immelmann 1963, 1971, 1973; Ford & Sedgwick 1967; Serventy & Whittell 1967; Serventy 1971) and water availability (Williams 1979) that followed rain.

Several subsequent, longer-term studies of Australian arid-zone birds, including Emu *Dromaius novaehollandiae* (Davies 1973), Spinifex Pigeon *Geophaps plumifera* (Frith & Barker 1975), Budgerigar *Melopsittacus undulatus* (Wyndham 1983) and Zebra Finch *Taeniopygia castanotis* (Davies 1977), found an underlying seasonal pattern to breeding, as had been recorded in arid regions of Africa (Moreau 1950; Immelmann & Immelmann 1968), Asia (Marchant 1963) and North America (Dawson & Bartholomew 1968). However, neither opportunistic nor regular seasonal breeding patterns appear clear-cut across arid Australia. In contrast with Davies' (1977) finding that Zebra Finches were seasonal breeders in arid south-western Australia, Zann *et al.* (1995) found that, in a 7-year period in central Australia, Zebra Finches bred in response to significant rain at any time of year.

The uncertainty and extremes of the arid-zone environment are now being exacerbated by ongoing anthropogenic climate change (OEH 2014; Herold *et al.* 2018). It is important to have comprehensive benchmark data to discern changes in, and to effectively manage, the avifauna. In this study, we describe patterns observed in the breeding efforts of a bird community at the eastern edge of the Australian arid zone between 1990 and 1994. Over the 3.5-year period, the study area was subject to substantial fluctuations in rainfall, including a drought considered by local pastoralists to be the worst drought for >40 years (H. Barlow pers. comm.). We compare the breeding patterns over this period for resident, migratory and nomadic birds; species with different dietary preferences; and individual species. We investigate the extent to which the breeding effort was related to regular seasonal patterns and to short- or long-term fluctuations in rainfall.

Study area and methods

Study area

The 1500-ha study area (30°43′S, 143°33′E) (Figure 1) 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 western New South Wales. At the time of study, the area was within a grazing leasehold, Peery Station. It is now part of Paroo–Darling National Park. The study was undertaken between October 1990 and January 1994. Mean annual rainfall between 1961 and 1990 at the two closest weather stations was 270 mm at White Cliffs and 267 mm at Wilcannia (Bureau of Meteorology www.bom.gov.au). Rainfall in the 2 years preceding the study was average (Bureau of Meteorology;

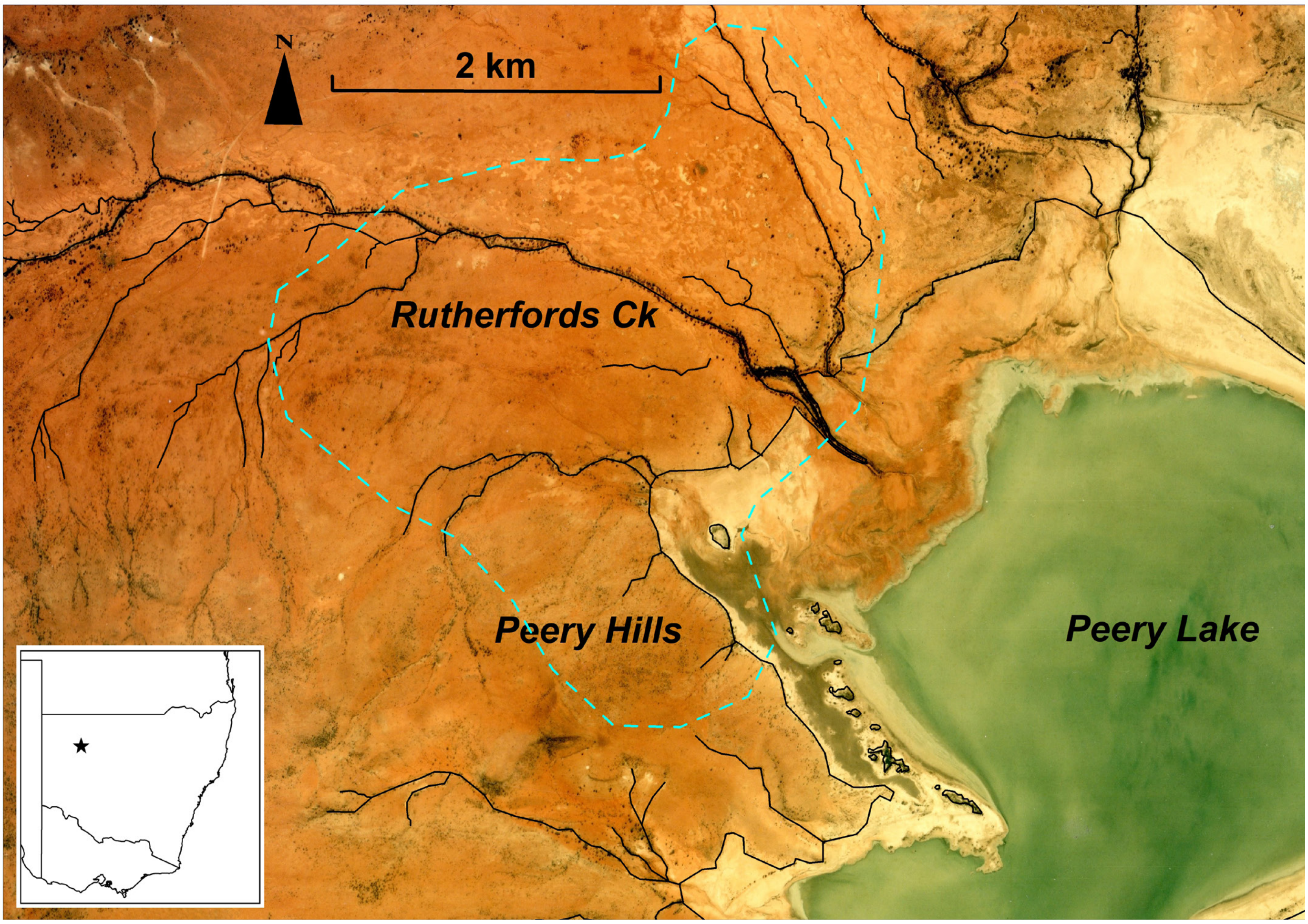

Figure 1. Location of the study area (dashed light-blue outline) at the north-western end of Peery Lake, western New South Wales. Air photo taken in August 1992 at the peak of the drought. Photo: Lands Department, NSW Government

G. Barlow pers. comm.). Between spring 1990 and spring 1992, the study area received no effective rainfall. In early spring 1992, an isolated thunderstorm filled waterholes in creeks, and between October 1992 and January 1993 rainfall was above average. In December 1992, heavy rain in the study area caused local flooding and brought an end to the drought. The study thus comprised three periods: pre-drought with average rainfall in 1989–1990, drought in 1991–1992, and post-drought with above-average rainfall in late 1992 and 1993. There was water in Peery Lake throughout the study.

The study area comprised four broad habitat types, 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) (Figure 2; see also Smith & Smith 2023). 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 *Acacia aneura* and Lignum *Duma florulenta*. Run-off areas with trees or tall shrubs included Mulga scrub in the Peery Hills and Harlequin Eremophila *Eremophila duttonii* scrub on the plains. Vegetation on the open plains varied in response to rainfall and included short-lived grasses, herbs and subshrubs including saltbushes *Atriplex* spp. and copperburrs *Sclerolaena* spp. A detailed description of the study area is contained in Smith (1997) and Smith & Smith (2023).

Assessment of breeding effort

On eight occasions between 1990 and 1993, a comparable effort was made by JS and PS to search for nests and other evidence of breeding by birds. In each survey period, searches were made by JS while undertaking systematic bird censuses that sampled habitat variability in the study area (Smith 2015). The same transects were sampled on five different mornings in each survey period. In all survey periods, we camped within the study area, which allowed us to undertake opportunistic searches for breeding birds throughout each survey day. In each of the eight main survey periods, the breeding effort was determined for each species as the number of pairs or groups of birds observed building nests or incubating or feeding nestlings or fledglings.

The eight survey periods included one pre-drought (spring 1990), four drought (winter and spring 1991 and 1992), and three post-drought (autumn, winter and spring 1993) periods. Survey dates were: 10 October–7 November 1990, 2–23 July 1991, 1–21 October 1991, 29 June–23 July 1992, 22 September–18 October 1992, 9–22 April 1993, 12–29 July 1993 and 28 September–20 October 1993. In addition, a brief survey was made

Figure 2. Study area during and after the drought. (a) View from the Mulga scrub on Peery Hills across the eastern end of the study area towards Rutherfords Creek and Peery Lake in October 1992 during the drought. (b) River Red Gum and Black Box woodland fringing Rutherfords Creek in October 1993 after the drought broke. Photos: Peter Smith

in summer 1993–1994: 18–26 January 1994; breeding records from this trip are included in Appendix 1 but, because the survey effort was much less, they are not included in the analyses.

A density-adjusted index of breeding effort was derived by dividing the total breeding effort by the mean density of birds at the site (individuals/ha) as determined in the corresponding censuses (Smith 2015).

Classification of breeding birds

Breeding birds were classified as residents, nomads, winter migrants or spring–summer migrants. The status of species was determined from movement patterns observed within the study area and a banding study over 3 years within the study area (Smith 2015). Birds were assigned to five dietary categories – plant, mixed plant/invertebrates, aerial invertebrates, other invertebrates, and carrion/live vertebrates – based on a study of foraging behaviour in the study area (Smith 1997) and a review of literature pertaining to birds of semi-arid/arid western New South Wales (Smith & Smith 1994).

Rainfall

Rainfall in the study area is presumed to be intermediate between that recorded for Wilcannia and White Cliffs. Monthly rainfall records for Wilcannia and White Cliffs for the study period and the preceding year are highly correlated [*r* (50) = 0.78, *P* <0.001]. The mean of the two sets of rainfall data was used to provide the best available indication of rainfall in the study area.

Analyses of data

Multivariate methods were used to compare the breeding efforts of birds in different seasons (spring and winter)

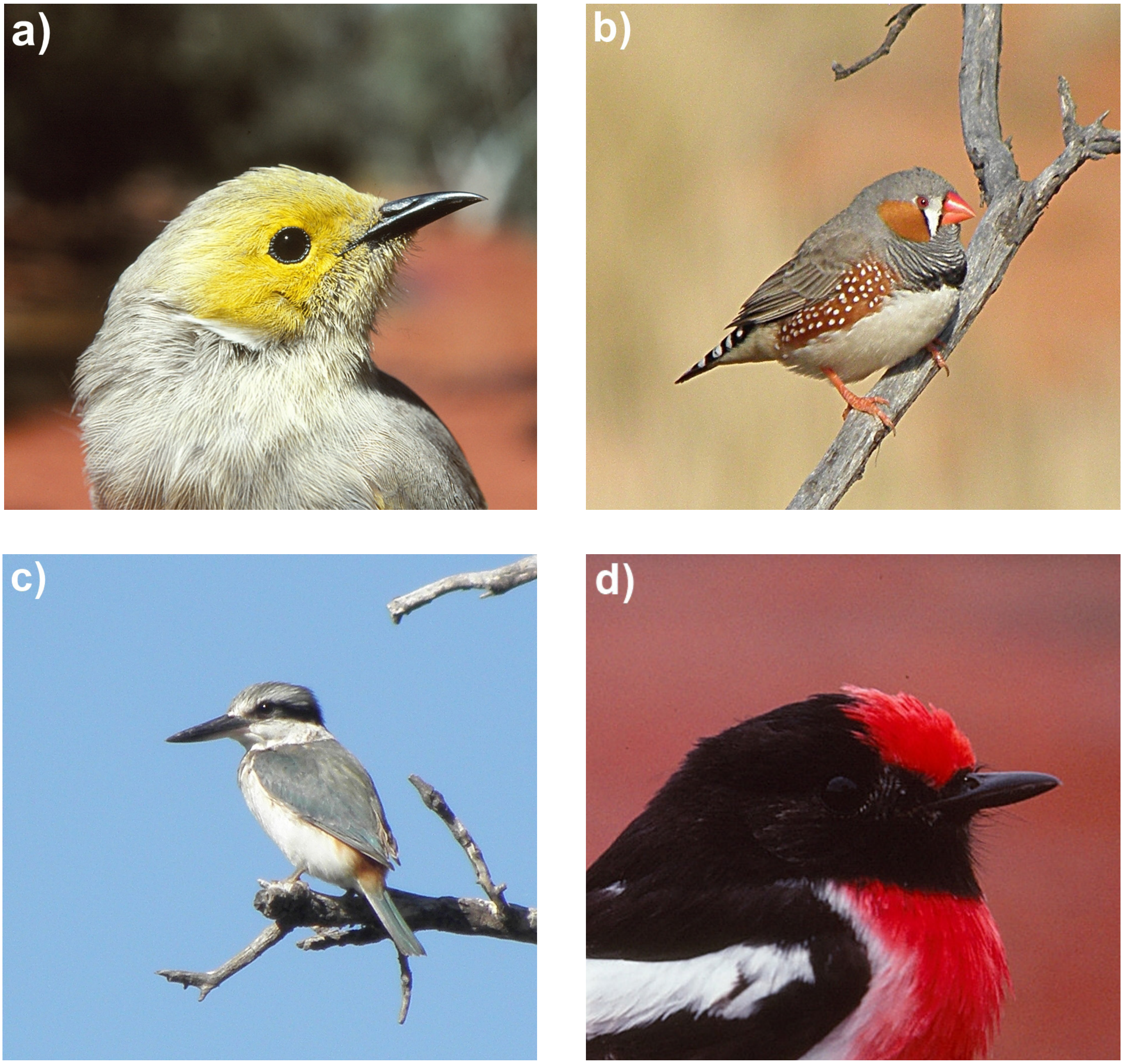

Figure 3. Examples of the bird species that nested in the study area and their varied movement patterns and diets. (a) White-plumed Honeyeater, a resident species with a mixed plant (nectar, exudates) and insect diet; (b) Zebra Finch, an irregular nomadic visitor with a plant diet (seeds); (c) Red-backed Kingfisher, a regular spring–summer migrant with a diet mainly of invertebrates but also some vertebrate prey; (d) Red-capped Robin, an insectivorous species that was a regular winter migrant to the study area and the only such species recorded nesting there. Photos: Peter Smith

and years of the study. The single autumn survey was not included in seasonal comparisons. Data (number of breeding records for each species in each survey period) were transformed using log (x + 1) so that analyses would not be dominated by a few very common species (Clarke 1993). Similarity between census periods was calculated using the Bray–Curtis association measure, and an ordination procedure (semi-strong-hybrid multidimensional scaling) was used to elucidate patterns in the data (PATN analysis: Belbin 1990).

Relationships between rainfall and the absolute and density-indexed breeding effort were examined using a correlation analysis. Rainfall totals in the previous 1 month, 2 months etc., up to 12 months were analysed to allow for a possible lag in response to rainfall.

Results

Breeding birds

Breeding attempts were recorded for 51 of the 95 native landbird species that we recorded in the study area (Appendix 1). 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 the two species have been combined in the analyses. Breeding species (Figure 3) included 34 residents, 11 nomads, five spring–summer migrants and one winter migrant, Red-capped Robin *Petroica goodenovii*. The highest numbers of breeding attempts were recorded for White-plumed Honeyeater *Ptilotula penicillata* (79 records), Willie Wagtail *Rhipidura leucophrys* (71), Tree Martin *Petrochelidon nigricans* (62) and Budgerigar (58). Breeding birds included 12 species that feed chiefly on plant matter, six on mixed plants/invertebrates, seven on aerial invertebrates, 21 on other invertebrates and five on carrion/live vertebrates. The 12 plant-feeders included 11 species that feed mainly on seeds and the Australian Ringneck *Barnardius zonarius*, which has a broader diet and feeds on seeds, fleshy fruits, flowers and foliage (Smith 1997). The six mixed plant/invertebrates-feeders included five honeyeaters and White-winged Triller *Lalage tricolor*.

Patterns in breeding effort

A total of 684 breeding attempts was recorded in the study. The total breeding effort was both lowest (autumn 1993, 12 records) and highest (spring 1993, 266 records) after the drought (Table 1). The breeding effort was not correlated with the mean density of birds at the site as determined in the corresponding censuses [r (7) = 0.29, P = 0.49]. The number of breeding species recorded in each survey period ranged from three (4.2% of all species then present at the site) in autumn 1993 to 38 (57.6%) in spring 1993 (Table 1) and was not correlated with the total number of species recorded at the site at that time [r (7) = 0.36, P = 0.39].

Differences in the species composition and abundance of breeding birds between survey periods appeared to be related to the effects of both season (spring vs winter) and rainfall (drought vs pre-drought vs local thunderstorm in spring 1992 vs drought-breaking rains in December 1992) (Figure 4). The ordination consistently separated spring survey periods from winter periods. The first three drought survey periods (winter and spring 1991 and winter 1992) were clearly separated from post-drought surveys in winter and spring 1993. The pre-drought spring 1990 survey and post-thunderstorm spring 1992 survey were intermediate. The greatest change in species composition and abundance of breeding birds occurred before the drought broke, between the winter 1992 survey and spring 1992 survey undertaken several weeks after the thunderstorm.

In each year, more species bred in spring than in winter (Figure 5). Resident species bred in each survey period, though more resident species bred in spring than in winter. Only residents bred in the winters of 1991 and 1992, when the area was gripped by drought. Nomadic species nested in autumn, winter and spring but (apart from spring 1992) not during the drought. Breeding nomadic species were most numerous in the spring after the drought whereas breeding spring–summer migratory species were most numerous in the spring before the drought. Breeding by birds from particular dietary groups varied between seasons and years. Aerial insectivores bred only in spring. Other insectivores bred in each spring and a few species of this group also bred in winter. Plant-feeders were the only dietary group of birds not to breed in spring 1991 at the height of the drought.

More individuals, as well as more species, bred in spring than in winter (Figure 6). The breeding efforts of residents and nomads declined with the onset of drought. In spring 1992, several weeks after the thunderstorm, the breeding effort of residents, especially White-plumed Honeyeater, Southern Whiteface *Aphelocephala leucopsis*, Willie Wagtail and Tree Martin, increased. At this time, an influx of nomadic White-browed Woodswallows *Artamus superciliosus* commenced nesting on arrival. The massive

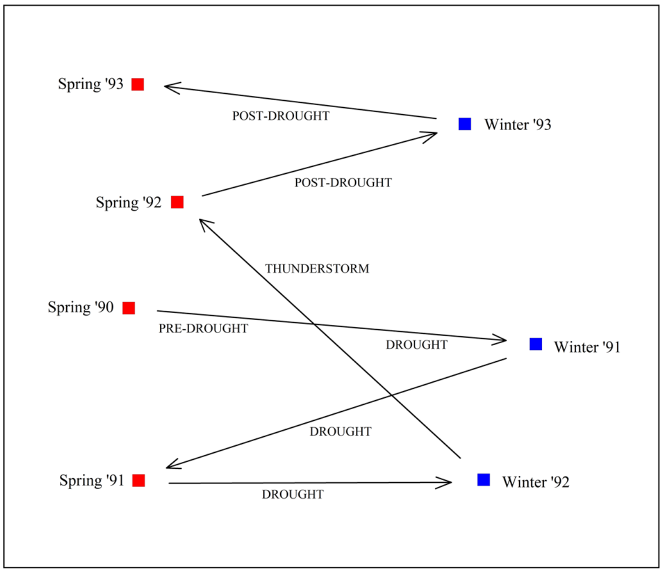

Figure 4. Ordination of the survey periods based on the number of breeding records of each species in each period in the arid study area in western New South Wales. Data were transformed using log (x + 1) to avoid analysis results being dominated by a few very common species. Ordination stress = 0. Axes scaled dependently. Red = spring data, blue = winter data. The horizontal axis reflects differences in breeding effort between spring and winter, and the vertical axis reflects the effects of rainfall on breeding effort.

Table 1. Breeding effort in spring 1990 to spring 1993 surveys: spring (Sp), winter (Wi) and autumn (Au). Mean bird density is mean density of birds recorded in 15 transects censused in each survey period (Smith 2015).

	Survey period							
	Pre-drought	*Drought*				*Post-drought*		
	Sp 90	*Wi 91*	*Sp 91*	*Wi 92*	*Sp 92*	*Au 93*	*Wi 93*	*Sp 93*
Total no. breeding records	124	13	48	17	153	12	41	266
Mean bird density (birds/ha)	19.5	9.4	10.8	9.5	8.2	18.8	11.0	16.7
No. species breeding	28	8	14	6	32	3	15	38
No. species at site	60	58	61	59	63	71	60	66
% species breeding	46.7	22.4	23.0	28.8	50.8	4.2	25.0	57.6

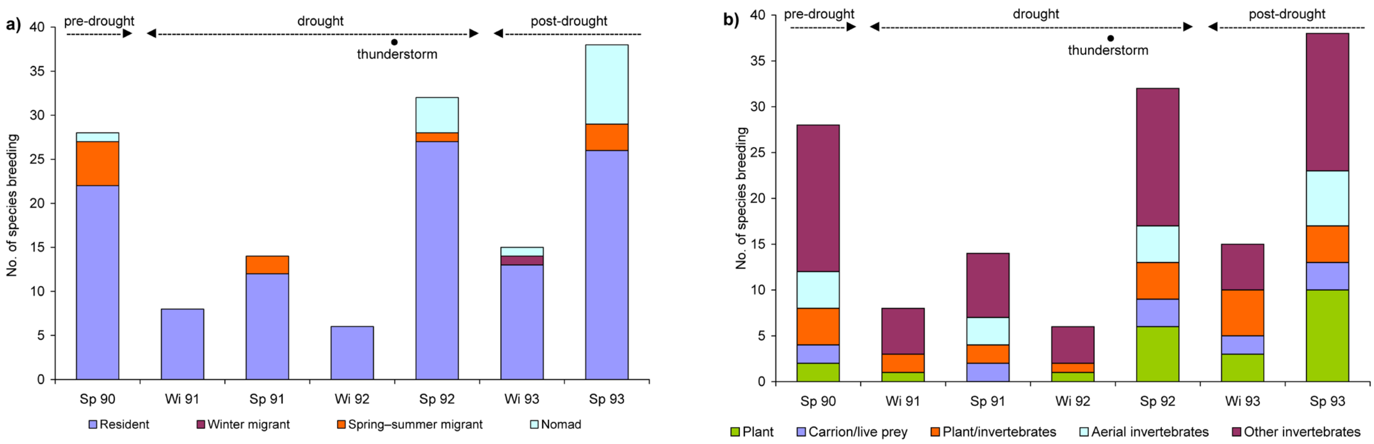

Figure 5. Number of bird species breeding in each survey period in relation to (a) movement patterns and (b) diet. Sp = spring, Wi = winter.

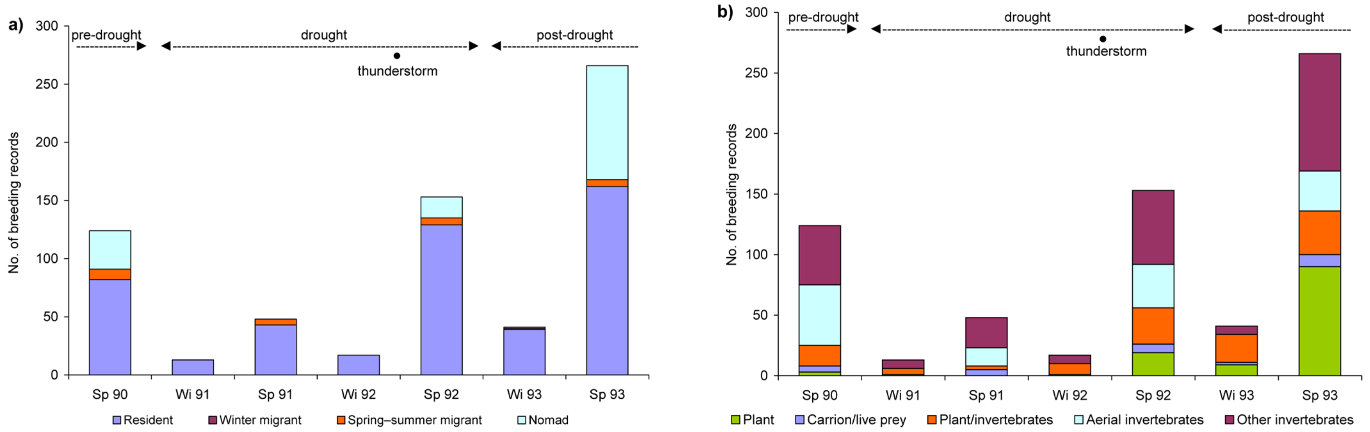

Figure 6. Number of breeding records of birds in each survey period in the study period between spring 1990 and spring 1993, in relation to (a) movement patterns and (b) diet. Sp = spring, Wi = winter.

total breeding effort in the following post-drought spring 1993 was in part because of the increased effort of nomads, including Budgerigar (53 records), Crimson Chat *Epthianura tricolor* (14 records), Rufous Songlark *Cincloramphus mathewsi* (9 records) and Zebra Finch *Taeniopygia castanotis* (7 records). Crimson Chat and Rufous Songlark bred at the site only in spring 1993. In contrast, the nomadic Fairy Martin *Petrochelidon ariel* bred only during the pre-drought spring 1990 survey, when the 33 records for breeding nomads all derived from two Fairy Martin colonies. The breeding effort of migrants was relatively consistent and low over the study period. Carrion/live prey- and invertebrate-feeders bred mainly in spring. The plant-feeders were the group that varied most between years in number of breeding records, ranging from zero in spring 1991 to 90 in spring 1993.

Comparison of absolute and density-indexed breeding effort

The numbers of breeding records for all birds and for both residents and nomads peaked in spring 1993 and for spring–summer migrants in spring 1990 (Figure 6). In contrast, the density-adjusted breeding effort for all birds, residents and spring–summer migrants was greatest in spring 1992 and for nomads in spring 1990 (Table 2).

Relationship of breeding effort to rainfall

Over the entire study period, the absolute and density-indexed breeding efforts of all birds, residents, nomads and spring–summer migrants were not significantly correlated with rainfall in the previous month or the previous cumulative 1–12 months. When the results of the spring surveys were considered in isolation, the absolute breeding effort of nomads was correlated with rainfall in the previous 1 month [$r(3) = 0.997$, $P < 0.01$] and with rainfall in the previous 4 months [$r(3) = 0.996$, $P < 0.01$]. These were the only significant correlations with rainfall.

Discussion

In this 3.5-year study, changes in the breeding effort within a landbird community in arid north-western New South Wales were influenced primarily by season but were modified by prevailing site conditions. Temporal changes in bird assemblages in arid Australia appear to be related to both seasonal and rainfall impacts (Smith 2015; Pascoe *et al*. 2021). Greater numbers of both individuals and species attempted breeding in spring than in winter in both wet and drought years of the study. A predominance of spring breeding has also been reported for birds in the eastern portion of the Australian arid zone by Denny *et al*. (1977), Schmidt (1978) and Henle (1989). In arid north-western

Table 2. Density-adjusted index of breeding effort, spring 1990 to spring 1993. Index value is the number of breeding records divided by the mean density of birds at the site. Season: autumn (Au), spring (Sp), winter (Wi). * indicates not present at site in that census period.

	Survey period							
	Pre-drought	*Drought*				*Post-drought*		
	Sp 90	*Wi 91*	*Sp 91*	*Wi 92*	*Sp 92*	*Au 93*	*Wi 93*	*Sp 93*
All birds	6.4	1.4	4.5	1.8	18.6	0.6	3.7	16.0
Residents	4.5	1.4	4.2	2.0	17.7	0.5	4.1	16.4
Nomads	63.2	0	0	0	30.6	0.9	0.7	15.2
Spring–summer migrants	13.9	*	13.8	*	19.0	0	0	17.7

Australia, Carnaby (1954) observed that nesting occurred mainly in late winter/early spring, with most nests recorded in August, and with a second smaller peak in nesting in autumn. In southern Western Australia, compilation of breeding records (nests with eggs) indicated that birds bred predominantly in spring (Davies 1979), with the highest number of breeding records in the arid inland recorded in September, and the second highest in August.

In our study, numbers of individuals and of species breeding were greatly reduced during drought. However, the relationship between rainfall and breeding was complex.

Patterns in the timing and magnitude of the breeding efforts of different movement groups (residents, nomads and migrants) and different dietary groups varied. Within these groups, there were inconsistencies between individual species. Resident species showed a largely regular seasonal pattern of breeding, but their efforts were reduced when conditions at the site deteriorated, and only small numbers attempted to breed during the drought. After two dry years, a localised thunderstorm several weeks before the spring 1992 survey appeared to be sufficient stimulus to promote breeding in residents. The storm filled waterholes in creeks and promoted germination of ground-layer vegetation and, at this time, resident birds reached their greatest breeding effort on a *per capita* basis. Carnaby (1954), in north-western Western Australia, noted a similar effect when local thunderstorms after a period of dry conditions promoted breeding within the localised area where rain fell. Drought-breaking rain fell in our study area in December 1992. In 1993, a year of above-average rainfall, the breeding effort of residents was low in autumn and winter but much increased in spring compared with the springs before (1990) and at the height of the drought (1991). Residents did not respond to the breaking of the drought with prolonged or aseasonal breeding and a rapid population increase. There was no evidence of a boom-and-bust cycle among residents in response to the flush of plant growth after the drought. In fragmented, semi-arid woodland of central-western New South Wales, Ellis & Taylor (2014) also found that populations of landbird species increased slowly over post-drought years.

In contrast with residents, nomads were generally absent and did not nest at all at the site when conditions were poor. Following the thunderstorm in spring 1992, the only nomad to show a concerted breeding effort was the White-browed Woodswallow, an aerial insectivore. Other aerial insectivores, including the resident Black-faced Woodswallow *Artamus cinereus* and Tree Martin, also showed an increased breeding effort at this time. Small numbers of nomadic seed-eaters – Cockatiel *Nymphicus hollandicus*, Budgerigar and Zebra Finch – also bred in spring 1992. Numbers of nomads in the study area peaked in autumn and spring 1993, after the drought (Smith 2015), but the breeding effort per nomad was far greater in spring than in autumn. White-browed Woodswallow and Zebra Finch were striking examples of the rapidity with which nomads could complete a breeding cycle.

The breeding effort of migratory species, whose populations are determined by conditions in both their non-breeding and breeding habitats, was relatively constant between years. Sacred *Todiramphus sanctus* and Red-backed Kingfishers *T. pyrrhopygius* were recorded nesting only in spring 1990. However, pairs of these species, as well as other spring–summer migrants, were courting, but not yet nesting, in all spring surveys. Spring–summer migrants appeared to nest later than residents and, by conducting spring surveys in October each year, it is likely that their breeding efforts were underestimated. The earlier breeding in spring 1990 might have been induced by the close availability of water in the adjacent Peery Lake at this time. Possibly the migrants arrived earlier in 1990 (and hence nested earlier) because of climatic factors within or outside the study area. Monthly rather than seasonal (spring vs winter) surveys would have allowed a finer determination of the nesting patterns of migrants and also of resident and nomadic species.

The 51 breeding species showed considerable individual variation in the timing and magnitude of their breeding efforts. Though spring breeding predominated, some species, such as White-plumed Honeyeater, Yellow-throated Miner *Manorina flavigula* and Southern Whiteface, also nested in winter, though to a lesser extent. Emu, Black Honeyeater *Sugomel nigrum* and Red-capped Robin were recorded nesting only in winter. The breeding effort of most species increased or remained steady after the drought, but the resident Striated Pardalote *Pardalotus striatus* and Chestnut-rumped Thornbill *Acanthiza uropygialis*, which had nested in each winter and spring of the drought, were not found nesting at all in the post-drought surveys.

Davies (1979) related the timing of breeding in the arid zone to the availability of food for adult birds rather than potential food for their young. Differences in the types of food eaten and dietary breadths of individual species (Smith 1997) could be expected to lead to differences in the timing and magnitude of species' breeding efforts and responses to rainfall. Nix (1976) suggested that breeding seasons of insectivores, nectarivores, frugivores and granivores would succeed each other, just as the stages of plant growth succeeded each other. In arid areas, the availability of food is influenced by the amount and timing of rainfall but is complicated by localised spatial heterogeneity, as run-on areas allow for greater regularity of plant growth than in run-off areas (Ludwig 1987). In perennial plants, the timing, if not the quantity, of foliage, flower and fruit production, is relatively regular (Davies 1976) compared with short-lived herbs and grasses, which can produce vast quantities of seeds and fruits (Westoby 1980), the timing and quantity of which are more directly tied to short-term rainfall fluctuations.

In this study, spring breeding might have predominated because this was the period of maximum food availability for most bird species. Some resident species that concentrated on the relatively stable food supplies offered by perennial plants growing in the more mesic portions of the site (e.g. White-plumed Honeyeater: Smith 1997) were able to nest every spring and, to a lesser extent, also every winter. The breeding of nomads appeared to follow rainfall more closely as these birds move away from areas of drought and seek out areas with more favourable conditions. After the drought, the greater nesting effort by nomads in spring than in autumn might simply have reflected the greater availability in spring of foods (e.g. seeds and fruits of ephemeral grasses and shrubs) suitable for the nomadic species present.

Long-term studies are needed to confirm that the varied breeding patterns of individual species are determined by the timing and availability of food for each bird species rather than by more consistent seasonal cues such as day length. Measures of temporal variability regarding the availability of different dietary items for birds would be invaluable. In this study, it would have been interesting to see if an isolated thunderstorm in winter during drought would be sufficient stimulus to promote breeding, as appeared to occur after the thunderstorm in spring 1992. The breeding efforts of birds may vary according to the differing resource needs of each species and in response to a rainfall regime (including factors such as amount and duration of rainfall, preceding rainfall pattern, and associated temperatures) rather than simply to rainfall. Given the varied diets and movement patterns of different species, and the variability in the timing and regularity of plant production that occurs between different plant life forms within regions and between regions within the Australian arid zone (Zann *et al*. 1995), it is not surprising that generalisations made about the breeding of arid-zone birds have appeared contradictory.

The greater climatic uncertainty and extremes associated with anthropogenic climate change are likely to impact the breeding efforts and success rates of Australian arid-zone birds. Predicted increases in the frequency and severity of droughts and continued warming (Herold *et al*. 2018) are likely to diminish breeding opportunities. Whether such change will be countered by changes in the frequency and amount of rainfall, including predicted more intense heavy rainfall events (Bureau of Meteorology & CSIRO 2020), is uncertain. Recurring droughts are a feature of the Australian arid zone. However, recurring, more severe and frequent droughts, coupled with warming and extreme heat events, will produce new challenges for breeding birds.

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Appendix 1. Breeding records from the study area in arid western New South Wales: spring 1990 to summer 1993–1994. Numbers for each survey period indicate number of breeding records for each species in that survey period. Status of birds: resident (R), nomad (N), spring–summer migrant (S), winter migrant (W). Dietary categories: aerial invertebrates (A), carrion/live vertebrates (C), mixed (plant and invertebrates) (M), other invertebrates (O), plant (P). Season: Au = autumn, Sp = spring, Su = summer, Wi = winter.

Common name	*Scientific name*	*Status, diet*	*Survey period*									*Total records*
			Sp 90	*Wi 91*	*Sp 91*	*Wi 92*	*Sp 92*	*Au 93*	*Wi 93*	*Sp 93*	*Su 93–94*	
Emu	*Dromaius novaehollandiae*	R, P				1			3			4
Crested Pigeon	*Ocyphaps lophotes*	R, P	1				3			6	2	12
Diamond Dove	*Geopelia cuneata*	N, P								4		4
Spotted Nightjar	*Eurostopodus argus*	R, A								1		1
Little Button-quail	*Turnix velox*	N, P								1		1
Collared Sparrowhawk	*Accipiter cirrocephalus*	R, C			1					1		2
Rainbow Bee-eater	*Merops ornatus*	S, A	1		3					1		5
Sacred Kingfisher	*Todiramphus sanctus*	S, O	1									1
Red-backed Kingfisher	*Todiramphus pyrrhopygius*	S, O	1									1
Nankeen Kestrel	*Falco cenchroides*	R, C	2				2					4
Cockatiel	*Nymphicus hollandicus*	N, P					1			5		6
Galah	*Eolophus roseicapilla*	R, P	2				7		3	3		15
Little Corella	*Cacatua sanguinea*	R, P							3	4		7
Bluebonnet	*Northiella haematogaster*	R, P								4		4
Mulga Parrot	*Psephotellus varius*	R, P					2					2
Australian Ringneck	*Barnardius zonarius*	R, P		1						3		4
Budgerigar	*Melopsittacus undulatus*	N, P					5			53		58
Brown Treecreeper	*Climacteris picumnus*	R, O	3		3		2			4		12
Purple-backed Fairy-wren	*Malurus assimilis*	R, O	3		3		2			6		14
White-winged Fairy-wren	*Malurus leucopterus*	R, O	3		1		1			3		8
Black Honeyeater	*Sugomel nigrum*	N, M							1			1
Crimson Chat	*Epthianura tricolor*	N, O								14		14
Orange Chat	*Epthianura aurifrons*	N, O								1		1
Spiny-cheeked Honeyeater	*Acanthagenys rufogularis*	R, M	6				5		1	3		15
Singing Honeyeater	*Gavicalis virescens*	R, M			1		1		3			5
White-plumed Honeyeater	*Ptilotula penicillata*	R, M	5	4	2	9	19	5	12	23		79
Yellow-throated Miner	*Manorina flavigula*	R, M	2	1			5		6	8		22
Striated Pardalote	*Pardalotus striatus*	R, O	2		3	3	2					10

Appendix 1 continued

Common name	*Scientific name*	*Status, diet*	*Survey period*									*Total records*
			Sp 90	*Wi 91*	*Sp 91*	*Wi 92*	*Sp 92*	*Au 93*	*Wi 93*	*Sp 93*	*Su 93–94*	
Southern Whiteface	*Aphelocephala leucopsis*	R, O	2	2		2	7		2	4		19
Yellow-rumped Thornbill	*Acanthiza chrysorrhoa*	R, O	2	1		1	3		2	3		12
Chestnut-rumped Thornbill	*Acanthiza uropygialis*	R, O	3	2	3	1	3					12
Chestnut-crowned Babbler	*Pomatostomus ruficeps*	R, O	1	1	1		2		1	4		10
Grey Shrike-thrush	*Colluricincla harmonica*	R, O					2	1				3
Black-faced Cuckoo-shrike	*Coracina novaehollandiae*	R, O	4				4			2	2	12
White-winged Triller	*Lalage tricolor*	S, M	4							2		6
Australian Magpie	*Gymnorhina tibicen*	R, O	3				3			7		13
Pied Butcherbird	*Cracticus nigrogularis*	R, C	3				1		1	1	1	7
White-browed Woodswallow	*Artamus superciliosus*	N, A					11			4		15
Black-faced Woodswallow	*Artamus cinereus*	R, A					3			2		5
White-breasted Woodswallow	*Artamus leucorynchus*	S, A	2		2		6			3	1	14
Willie Wagtail	*Rhipidura leucophrys*	R, O	12		11		21		1	22	4	71
Magpie-lark	*Grallina cyanoleuca*	R, O	5				7			9		21
Little Crow/Australian Raven	*Corvus bennetti/C. coronoides*	R, C			4		4		1	8		17
White-winged Chough	*Corcorax melanorhamphos*	R, O	1				1			1		3
Apostlebird	*Struthidea cinerea*	R, O	3	1			1			8		13
Red-capped Robin	*Petroica goodenovii*	W, O							1			1
Rufous Songlark	*Cincloramphus mathewsi*	N, O								9		9
Fairy Martin	*Petrochelidon ariel*	N, A	33									33
Tree Martin	*Petrochelidon nigricans*	R, A	14		10		16			22		62
Zebra Finch	*Taeniopygia castanotis*	N, P					1	6		7		14