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Foraging behaviour of mulga birds in Western Australia. I. Use of resources and temporal effects

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Abstract. The foraging behaviour of mulga birds in the Murchison and Gascoyne Bioregions was studied in 1999 following a period of heavy rain and again in 2002 when it was dry. Mulga birds allocated foraging resources in a similar fashion to other bird communities, with species differing in the way that prey were taken, the substrates and plant species on which prey were found, and the heights at which prey were sought. The numbers of birds and bird species in the study areas declined with drier conditions and there was less breeding activity. Nomadic species, including honeyeaters, seed-eaters, and insect-eaters, largely left the area as it became drier and food resources changed. The birds that remained foraged differently when it was drier than when conditions were wetter and food more abundant. These observations illustrate the fragility of the mulga avifauna and its likely sensitivity to long-term climate change with predicted increasing temperatures, more extreme heat events, and reduced winter rainfall. Conservation of mulga birds and associated flora and fauna requires a whole-of-landscape approach and the adoption of land management practices by Australian governments and land managers that will allow species to adapt to climate change and guarantee their right to evolve.

Additional keywords: arid-zone conservation, dispersive species, effects of rainfall, feral herbivores, Gascoyne Bioregion, Murchison Bioregion, nomadic birds, resource allocation

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Introduction

In Western Australia, the mulga–eucalypt line represents the boundary between eucalypt (*Eucalyptus*) woodlands to the south and west and mulga (*Acacia*) shrublands to the north and east (Serventy and Whittell 1962). The line roughly conforms to the 250–300-mm isohyets and separates arid and semiarid habitats. In an earlier paper, we presented data on the foraging behaviour of eucalypt woodland birds along the mulga–eucalypt line on Mt Gibson Station in the Avon Wheatbelt Bioregion (Recher and Davis 2010).

In this paper, we present observations on the foraging behaviour of mulga birds in the Gascoyne and Murchison Bioregions. Both are dominated by low mulga woodlands (Bastin 2008) and have rich avifaunas, with Bell *et al.* (2013) recording 94 land bird species in the north-eastern sector of the Gascoyne. The way birds forage, the foods eaten, and their response to changes in foraging resources are core data in understanding ecological relationships among species and the way communities are assembled. These, in turn, are details required for the development and application of plans for conservation management where the goals are sustaining biodiversity by preventing the extinction of populations and species, while allowing species to evolve with changing local and global changes in climate.

The work presented here from 1999 was done following a period of heavy rainfall when the numbers and species of birds were high, followed by a briefer study in 2002 on the same plots when less rain had fallen and there were fewer birds. In studying the foraging behaviour of mulga birds when it was drier, we tested the hypothesis 'that independent of changes in species composition and abundances, there is no difference in the foraging behaviour of mulga birds between dry and wet periods'. We also provide information on the species composition of mulga communities in the Gascoyne and Murchison Bioregions contrasting wet and dry periods. We use these data, along with observations on the effects of grazing by sheep, cattle, and goats, to comment on the conservation of mulga and its avifauna.

Study locations

Gascoyne Bioregion

There was one study plot in the Gascoyne Bioregion. It was located on the Carnarvon/Mullewa Road, 35 km west of Gascoyne Junction (25.05°S, 115.21°E, 144 m above sea level). Gascoyne Junction is ~137 km east of Carnarvon (Fig. 1). The plot was selected as the closest site near Gascoyne Junction with easy access that was not heavily over-grazed. Horses, sheep,

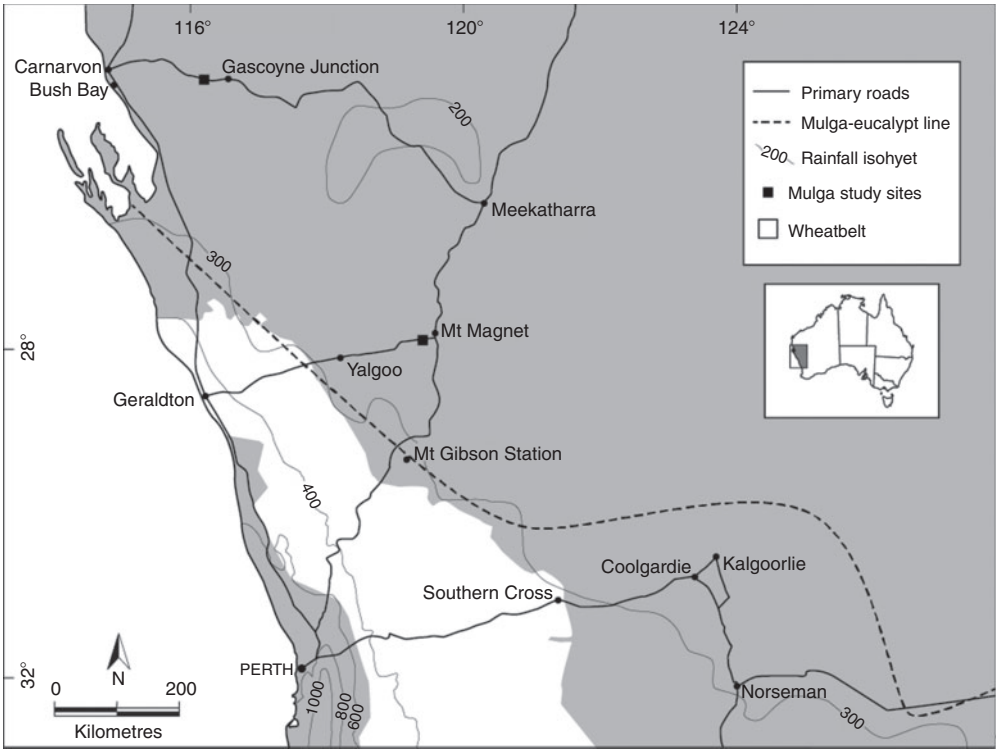

Fig. 1. Location of mulga study sites at Gascoyne Junction and Mount Magnet. The mulga–eucalypt line denotes the approximate boundary between woodlands dominated by eucalypts (*Eucalyptus* spp.) and shrublands dominated by *Acacia* spp. of which mulga (*A. aneura*) is a prominent and widespread species across arid Australia.

goats, cattle, kangaroos, and rabbits were present. The plot was irregular in shape and ~10–12 ha in area. Throughout the plot in 1999 there was extensive grass cover carrying an abundance of ripening seed. Grasshoppers (Orthoptera) were abundant in all grassy areas. Insect larvae (mainly Lepidoptera) were abundant on *Acacia* spp. and on the ground, in the litter, and on shrubs, annuals, and grasses. The topography of this plot was undulating with low sandy ridges separated by broad flats with a sandy clay soil. Dead wood, fallen and standing, was abundant.

Quantitative measurements of the vegetation were not made, but percentage cover for bare ground, litter, coarse woody debris, ground vegetation, shrubs, and canopy were estimated at points where robins (*Petroica* spp.) were observed to pounce on ground prey (Recher *et al.* 2002 provide details). Although such points may be biased by the foraging preferences of the species of robins present, they are useful to compare the plots in the two bioregions and illustrate the main structural features of the vegetation and its heterogeneity. All plant species identifications and names follow Mitchell and Wilcox (1994), with identifications and habitat measurements and descriptions by HFR. Data on cover are available only for 1999.

Estimates of cover in 1999 (mean percentage ± standard deviation; $n = 26$) for the Gascoyne plot were bare ground (63 ± 20%), litter (22 ± 20), coarse woody debris (6 ± 5), ground vegetation (10 ± 10), shrubs (16 ± 13), and canopy (4 ± 10). As cover was estimated for each layer of ground and vegetation, the total percentage cover can exceed 100%.

Table 1. The mean January–December rainfall (mm) for 1997–99 for Gascoyne Junction and Mount Magnet immediately preceding our study of foraging behaviour in 1999 and the long-term mean for the two locations

Also given is the total rainfall for 1999 and 2002, the years of the observations reported here. As most rain falls from mid-summer to mid-winter, mean and total rainfall for January–July is given for the same years

	1997–99	1999	2002	1907–2016	1996–2016
Gascoyne Junction					
January–December	348	400	112	216	
January–July	288	370	94	184	
Mount Magnet					
January–December	286	283	192		256
January–July	214	215	120		190

In 2002, after a period of low rainfall (Table 1), there was more bare ground, less ground vegetation, with little grass and no seed (HFR, pers. obs.). By 2002 shrubs had been heavily browsed by goats, with many plants, including cotton bush (*Ptilotus obovatus*), flannel bush (*Solanum lasiophyllum*), and bladder saltbush (*Atriplex vesicaria*), killed or eaten to near ground level. Goats had also begun to break down the taller branches of mulga (*Acacia aneura*) and other acacias. Grass was mainly dry, with little cover. Neither grasshoppers nor arthropod larvae were evident.

The Gascoyne plot had four distinct habitats:

1. *Tall acacia woodland*. The most abundant acacias were mulga (tree to 2–4 m high), bowgada (*A. linophylla*) (shrub to 2.5 m), curara (*A. tetragonophylla*) (small tree to 3 m), and gidgee (*A. pruinocarpa*) (large tree to 3–10 m). A least two other species of *Acacia* were present in small numbers, but were not identified. Among the acacia and in tangles of dead vegetation were small shrubs (generally less than 1 m high), with cotton bush, flannel bush, and bladder saltbush the most abundant. Scrambling saltbush (*Chenopodium gaudichaudianum*) was present as a vine.
2. *Bowgada shrubland*. In places bowgada formed nearly pure stands of low shrubs (<2.5 m). The ground was bare between shrubs, but under the shrubs there was a dense layer of litter and grass.
3. *Open clay pans*. These were open areas with patches of cotton bush and flannel bush in association with low (<15 cm) annuals (yellow bindi (*Sclerolaena cuneata*), grey bindi (*S. diacantha*), cottony bluebush (*Maireana carnosa*), and *Ptilotus* spp. were most abundant) and occurred in association with wind or kerosene grass (*Aristida contorta*) and broad-leaved wanderrie grass (*Monachather paradoxa*). A few gidgee and bowgada were present.
4. *Low sand ridges with open Acacia shrubland*. Bowgada and mulga dominated the sand ridges, with wanderrie wattle (*A. kempeana*) and two unidentified *Acacia* present. One of the latter was a tree to 3 m. Bowgada dominated the ridge tops. The most abundant shrubs were crinkled cassia (*Cassia* (*Senna*) *helmsii*) and an unidentified *Cassia*, with lesser numbers of flannel bush and cotton bush. Open areas were dominated by grasses, including broad-leaved wanderrie, wind grass, creeping wanderrie (*Eragrostis lanipes*), and *Stipa* spp.

Murchison Bioregion

Three study plots were located in the Murchison Bioregion near Mount Magnet (28.06°S, 117.85E, 426 m above sea level) along the Geraldton/Mount Magnet Road spaced 3–4 km apart 14–21 km west of the intersection with the Great Northern Highway (Fig. 1). Plots were irregular in shape and ~5 ha in area. Topographically, these plots were flat, with a hard clayey soil. The woodlands were more open than at Gascoyne Junction, with broad clear areas having only scattered trees or shrubs. We selected three plots in the Murchison to minimise repeat observations on the same individual birds and to ensure a broad sample of the avifauna in an area that was heavily overgrazed. To equalise the size area sampled, the data from the three plots were combined and compared with those obtained on the larger Gascoyne Junction plot.

In both 1999 and 2002, the three plots were similar in appearance and dominated by mulga and other acacias. All were heavily grazed by sheep and goats, but compared with other sites we could access had relatively good vegetation cover. *Acacia* species dominated the plots, but identification to species was difficult. Most *Acacia* were less than 3 m high, with maximum heights of 5–6 m. At least six species of *Acacia* were present, including mulga, bowgada, and miniritichie (*A. grasbyi*). In contrast to the plot at Gascoyne Junction, flannel bush was uncommon and cotton bush was absent, possibly as a consequence of overgrazing. Poverty bushes (*Eremophila* spp.) were abundant and in flower, as was a low-growing *Grevillea* sp. Ground vegetation, including grass, was sparse and heavily grazed. There were no grasshoppers, but caterpillars (mainly Lepidoptera) were abundant on the foliage of all species of wattle, on the ground, and among litter.

Estimates of cover for the three plots in 1999 (mean percentage ± standard deviation; $n = 44$), were bare ground (65 ± 16%), litter (17 ± 12), coarse woody debris (3 ± 3), ground vegetation (15 ± 16), shrubs (11 ± 11), and canopy (8 ± 13). As cover was estimated for each layer of ground and vegetation, the total percentage cover can exceed 100%. With the drier conditions of 2002, there was more bare ground, less ground vegetation, and fewer shrubs (HFR, pers. obs.). If present, arthropod larvae were not evident and there were no grasshoppers.

Climate

Gascoyne Junction and Mount Magnet have hot summers and mild winters. January is the hottest month, with the mean daily maximum temperature for January at Gascoyne Junction 41°C and 38°C at Mount Magnet. July is the coldest month, with the mean daily maximum temperature for July at Gascoyne Junction 23°C and 19°C at Mount Magnet. Mean annual rainfall for Gascoyne Junction (1907–2016) was 216 mm, and for Mount Magnet (1996–2016) it was 256 mm (Table 1), with most rain (74–85%) falling between January and July (mid-summer to mid-winter) in association with tropical lows and cyclones.

At both locations, annual rainfall in 1999 was greater than the long-term average (Table 1). Mean annual rainfall was also greater in the three years (1997–99) preceding the initial study, including the mid-winter/mid-summer period. Rainfall in 2002 was below average at Gascoyne Junction and Mount Magnet, including the mid-winter/mid-summer period (Table 1). Rainfall was below average in 2001 (145 mm) at Gascoyne Junction and above the long-term mean at Mount Magnet (294 mm).

Rainfall and temperature data are from the Australian Bureau of Meteorology using Stations 6022 (Gascoyne Junction) (http://www.bom.gov.au/jsp/ncc/cdio/weatherData/av?p_nccObsCode=136&p_display_type=dailyDataFile&p_startYear=&p_c=&p_stn_num=006022) and 6760 (Mount Magnet Aerodrome) (http://www.bom.gov.au/jsp/ncc/cdio/weatherData/av?p_nccObsCode=136&p_display_type=dailyDataFile&p_startYear=&p_c=&p_stn_num=6760).

Methods

In 1999, observations at Gascoyne Junction were made on 1–7 August 1999 and at Mount Magnet on 8–10 August 1999. In 2002, observations were made by HFR, on 20–24 July 2002 at Gascoyne Junction and 10–11 July 2002 at Mount Magnet. All observations, including counts of birds, in both 1999 and 2002 were made during fine weather, without rain or wind that would affect results.

We did not census birds on the plots in 1999, but kept a list of species and HFR estimated numbers. In 2002, HFR counted the number of individuals of each species seen or heard on the plots at Gascoyne Junction and Mount Magnet, with counts on the Mount Magnet plots combined to provide a single estimate of numbers for comparison with the Gascoyne Junction plot.

Additionally, the number of foraging observations for each species at each location provides a rough guide to relative abundances.

Foraging behaviour

Details of the procedures used to record foraging behaviour are given in Recher and Davis (1998, 2002) but, briefly, we recorded the species of bird, the substrate and height of the food, the type (e.g. grass, shrub), species or genus of plant from which food was taken, and the foraging manoeuvre or method used by the bird to take food. For substrates and manoeuvres we used the terminology of Recher *et al.* (1985) and Recher and Davis (1998, 2002). Observations commenced shortly after sunrise and, depending on weather conditions, continued to dusk. We minimised recording data on the same individuals by moving within and between plots. Foraging was recorded for all birds encountered. For each individual, we recorded up to five consecutive foraging manoeuvres commencing with the second observed manoeuvre, following Recher and Gebski (1989). Only manoeuvres in which the bird obtained or attempted to obtain food were recorded.

In this paper, we combine bark, dead wood, loose bark, and hanging bark as 'bark'; twigs and petioles, and live and dead leaves as 'foliage'; and bare ground, litter, logs, and coarse woody debris as 'ground'. 'Hover hawk' and 'hover glean' are combined with 'hover'. Rare behaviours (<0.1% of observations) were deleted from analyses.

Breeding behaviour

All courtship behaviour, including copulation and males feeding females, as well as nests and nest building, feeding young, and presence of fledglings, were taken as evidence of 'breeding'. Nests and locations of young were marked to prevent duplicate records.

Data analysis

In the analyses presented in this paper, only species with 10 or more foraging observations at one or more locations in either 1999 or 2002 were analysed. As nectar-feeding occurred disproportionately on the Mount Magnet sites where nectar-rich flowers were abundant relative to the Gascoyne Junction plot, nectar-feeding was excluded from analyses comparing the frequency of use of foraging substrates and manoeuvres. Chi-square was used to test for associations between species and locations in the frequency of use of foraging substrates and manoeuvres.

All statistical analyses were done using the PAST statistical package available from http://palaeoelectronica.org/2001_1/past/issue1_01.htm (Hammer *et al.* 2001; Hammer and Harper 2006).

Results

Bird species

A total of 60 species of birds was recorded on the plots at Gascoyne Junction and Mount Magnet, 43 at Gascoyne Junction and 48 at Mount Magnet (Table 2). In 1999, a total of 59 species was recorded, with 41 species at Gascoyne Junction and 46 at Mount Magnet; nomadic species, including budgerigar, crimson chat, white-winged triller, and zebra finch numbered in the hundreds on the Gascoyne Junction plot and formed large foraging flocks (Table 2). Scientific names of birds are given in Table 2. Budgerigar and zebra finch were absent from the Mount Magnet plots, but crimson chat and white-winged triller were abundant (Table 2).

Birds were less abundant in 2002 and there were fewer species: 26 at Gascoyne Junction and 21 at Mount Magnet for a total of 36 species (Table 2). At Gascoyne Junction there were few nomads, with black-faced cuckoo-shrike (20 individuals), white-winged triller (30), and zebra finch (30) the most abundant; budgerigars were absent (Table 2). Resident species, including chestnut-rumped thornbill, and splendid and variegated wrens, were the most frequently observed birds. On the Mount Magnet plots, chestnut-rumped thornbill (20 individuals) and yellow-throated miner (24) were the most frequently observed species (Table 2). Nomadic species, including crimson chat and white-winged triller, were absent.

Breeding was recorded at Gascoyne Junction in 1999 for nine species (22 records), and in 2002 for two species (5). At Mount Magnet, 11 species (24 records) were recorded breeding in 1999 and one species in 2002 (2). Given the broad definition of breeding used, including courtship, the earlier dates for the 2002 observations were unlikely to have affected the amount of breeding activity recorded.

Foraging behaviour

Ten or more foraging observations were recorded in at least one year at one location for 30 species, 20 at Gascoyne Junction and 26 at Mount Magnet. In 1999, sufficient data were collected to analyse the foraging behaviour of 19 species at Gascoyne Junction and 21 species at Mount Magnet. In 2002, sufficient data were collected to analyse the foraging behaviour of 10 species at Gascoyne Junction and 12 species at Mount Magnet. Species are grouped in guilds according the percentage use of substrates and foraging behaviours. Recher (2018) provides a detailed analysis of the foraging guild structure of mulga birds on these plots and in the Northern Territory.

In 1999, there were significant differences in the frequency of use of foraging substrates ($\gamma^2_3 = 39.69$, $P < 0.0001$) and manoeuvres ($\gamma^2_5 = 334.13$, $P < 0.0001$) between the Gascoyne Junction plot and those at Mount Magnet (Tables 3, 4). The differences in the frequency of use of foraging substrates ($\gamma^2_3 = 147.26$, $P < 0.0001$) and manoeuvres ($\gamma^2_6 = 130.27$, $P < 0.0001$) between the two locations persisted under the drier conditions in 2002 (Tables 3, 4).

There were significant differences at Gascoyne Junction between 1999 and 2002 in the use of foraging substrates ($\gamma^2_6 = 107.07$, $P < 0.0001$) and manoeuvres ($\gamma^2_4 = 41.522$, $P < 0.0001$) (Tables 3, 4). Differences at Mount Magnet between 1999 and 2002 in the use of foraging substrates ($\gamma^2_4 = 122.72$, $P < 0.0001$) and manoeuvres ($\gamma^2_6 = 73.431$, $P < 0.0001$) were also significant (Tables 3, 4).

Manoeuvres

Gascoyne Junction

In 1999, 10 species (53%) at Gascoyne Junction foraged primarily by gleaning (>80% of foraging manoeuvres) (Table 5). Gleaning was a frequent (>50%) behaviour for four other species, while white-browed babbler gleaned and probed (Table 5). Snatching was frequent (19–43%) for six species

Table 2. Birds recorded on mulga study plots at Gascoyne Junction (GJ) and Mount Magnet (MM) in 1999 and 2002

Numbers for 1999 are estimates of abundances in orders of magnitude. Numbers for 2002 are based on the number of individuals of each species seen or heard by HFR, with the three sites at Mount Magnet combined. Species recorded breeding are marked with an asterisk

		1999		2002	
		GJ	MM	GJ	MM
Australasian pipit	*Anthus novaeseelandiae*		1–10		
Australian bustard	*Ardeotis australis*	1			
Australian magpie	*Cracticus tibicen*		1–10		2
Australian raven	*Corvus coronoides*		1–10		
Black honeyeater	*Sugomel niger*		1–10*		
Black-eared cuckoo	*Chrysococcyx osculens*	1–10	1–10	2	1
Black-faced cuckoo-shrike	*Coracina novaehollandiae*	1–10	1–10	20	
Black-faced woodswallow	*Artamus cinereus*	10–100	10–100	15	5
Bourke's parrot	*Neopsephotus bourkii*		1–10		
Brown falcon	*Falco berigora*	1–10	1–10	1	
Brown goshawk	*Accipter fasciatus*		1–10		
Budgerigar	*Melopsittacus undulatus*	100–1000			
Chestnut-rumped thornbill	*Acanthiza uropygialis*	10–100*	10–100*	10–100*	20*
Cockatiel	*Nymphicus hollandicus*		1–10		
Collared sparrowhawk	*Accipiter cirrocephalus*	1–10			
Common bronzewing pigeon	*Phaps chalcoptera*	1–10			
Crested bellbird	*Oreoica gutturalis*	1–10	1–10	4	3
Crested pigeon	*Ocyphaps lophotes*	1–10	1–10		
Crimson chat	*Epthianura tricolor*	100–1000	100–1000	15	
Diamond dove	*Geopelia cuneata*	10–100	10–100	2	
Emu	*Dromaius novaehollandiae*	1–10	1–10	1	
Galah	*Eolophus roseicapillus*	10–100	10–100		
Grey butcherbird	*Cracticus torquatus*	1–10	1–10		2
Grey shrike-thrush	*Colluricincla harmonica*	1–10	1–10	1	1
Grey-crowned babbler	*Pomatostomus temporalis*		10–100		6
Hooded robin	*Melanodryas cucullata*		1–10*		
Horsfield's bronze-cuckoo	*Chrysococcyx basalis*	1–10	1–10	3	
Little button-quail	*Turnix velox*	10–100			
Little corella	*Cacatua sanguinea*	10–100			
Little crow	*Corvus bennetti*	10–100	10–100		5
Little eagle	*Hieraaetus morphnoides*	1–10	1–10	1	
Little falcon	*Falco longipennis*	1–10			
Magpie-lark	*Grallina cyanoleuca*		1–10		
Mulga parrot	*Psephotus varius*		1–10		
Nankeen kestrel	*Falco cenchroides*	1–10	1–10		
Pallid cuckoo	*Cuculus pallidus*		1–10	1	
Pied butcherbird	*Cracticus nigrogularis*			2	1
Pied Honeyeater	*Certhionyx variegatus*		1–10	1	
Port Lincoln parrot	*Barnardius zonarius*	1–10			2
Rainbow bee-eater	*Merops ornatus*	10–100			
Red-backed kingfisher	*Todiramphus pyrrhopygius*		1–10		
Red-capped robin	*Petroica goodenovii*	10–100*	10–100*	13*	2
Redthroat	*Pyrrholaemus brunneus*	10–100*			
Rufous whistler	*Pachycephala rufiventris*	10–100	10–100	6	1
Singing honeyeater	*Lichenostomus virescens*		10–100		2
Slaty-backed thornbill	*Acanthiza robustirostris*		1–10*		8
Southern whiteface	*Aphelocephala leucopsis*	10–100*	10–100*	6	5
Spiny-cheeked honeyeater	*Acanthagenys rufogularis*	10–100*	10–100*	10	3
Splendid wren	*Malurus splendens*	10–100*	10–100	10–100	
Torresian crow	*Corvus orru*	1–10	1–10		2
Variegated wren	*Malurus lamberti*	10–100*		10–100	
Wedge-tailed eagle	*Aquila audax*	1–10	1–10		
Western warbler	*Gerygone fusca*		1–10		2
White-browed babbler	*Pomatostomus superciliosus*	10–100	10–100		
White-fronted honeyeater	*Purnella albifrons*	10–100		1	
White-winged triller	*Lalage sueurii*	100–1000	100–1000*	30	
Willie wagtail	*Rhipidura leucophrys*	1–10*	1–10*	4	
Yellow-rumped thornbill	*Acanthiza chrysorrhoa*		1–10*		4
Yellow-throated miner	*Manorina flavigula*	10–100*	10–100*	1–10	24
Zebra finch	*Taeniopygia guttata*	10–100		30	
No. of species	60	41	46	26	21

Table 3. Percentage of substrates used by foraging birds at Gascoyne Junction (GJ) and Mount Magnet (MM) in 1999 and 2002
Nectar-feeding has been excluded from this table. Sample size in shown in parentheses

Substrate	1999		2002	
	GJ (1554)	MM (1367)	GJ (435)	MM (327)
Ground	62	51	60	52
Foliage	25	32	29	20
Bark	8	9	1	28
Air	5	8	10	0
Flower	<1	<1	0	0

Table 4. Percentage of manoeuvres used by foraging birds at Gascoyne Junction (GJ) and Mount Magnet (MM) in 1999 and 2002
Nectar-feeding has been excluded from this table. Sample size in shown in parentheses

Manouvre	1999		2002	
	GJ (1554)	MM (1367)	GJ (435)	MM (327)
Glean	75	55	68	76
Pounce	4	12	10	6
Sweep	0	0	3	0
Hawk	5	8	7	0
Hover	3	9	1	1
Snatch	8	1	10	1

(32%), with pouncing commonly (36–61%) used by three species (16%). Grey butcherbird gleaned, pounced, and snatched, while willie wagtail gleaned, hawked, hovered, and snatched (Table 5).

In 2002, six species at Gascoyne Junction foraged primarily by gleaning (>57%), two by pouncing (>59%), and two species took most prey from the air (>83%) (Table 6). Three of the gleaners, white-winged triller, splendid wren, and chestnut-rumped thornbill, frequently snatched prey (11–24%), with the splendid wren also hawking. Although primarily a pouncer, the red-capped robin also gleaned, snatched, and hawked. Of the aerial foragers, the willie wagtail took most prey by hawking and the black-faced woodswallow by sweeping (Table 6). The wagtail also snatched prey from foliage and gleaned prey from the ground.

Mt Magnet

At Mount Magnet in 1999, seven species (33%) were primarily gleaners (>77% of foraging manoeuvres) (Table 7). Additionally, slaty-backed thornbill, rufous whistler, and willie wagtail took the majority (~50%) of their prey by gleaning. Both took a large proportion of their prey by snatching (31 and 42% respectively), while the wagtail hawked (34%) and snatched (15%). Grey-crowned and white-browed babblers gleaned and probed, with grey-crowned babblers probing more frequently than white-browed babblers (81% versus 63%). Two species, hooded and red-capped robins, were pouncers (>80% of manoeuvres). Black-faced woodswallows pounced and

Table 5. Percentage use of foraging manoeuvres by mulga birds at Gascoyne Junction, Gascoyne Bioregion, in August 1999
All species for which 10 or more observations were available are shown (*N*). Species were ranked and grouped into foraging guilds based on percentage use of manoeuvres. No birds were observed sweeping in 1999

Guild and species	*N*	Manoeuvre					
		Glean	Probe	Pounce	Hawk	Hover	Snatch
Glean							
Budgerigar	385	100	0	0	0	0	0
Zebra finch	195	100	0	0	0	0	0
Southern whiteface	109	100	0	0	0	0	0
Crested bellbird	11	100	0	0	0	0	0
Common bronzewing	10	100	0	0	0	0	0
Crimson chat	91	97	0	0	0	0	3
Redthroat	63	95	0	0	2	0	3
Yellow-fronted miner	53	87	7	0	4	0	2
Spiny-cheeked honeyeater	12	84	8	0	0	0	8
Splendid wren	67	81	3	0	3	0	13
Glean and Probe							
White-browed babbler	67	22	78	0	0	0	0
Glean and Snatch							
Rufous whistler	54	53	0	2	2	0	43
Variegated wren	51	57	0	0	0	0	39
White-winged triller	58	69	0	2	0	5	24
Chestnut-rumped thornbill	97	55	0	0	7	18	19
Pounce							
Red-capped robin	69	4	0	61	20	4	11
Black-faced woodswallow	19	0	0	47	26	11	16
Grey butcherbird	11	37	0	36	0	0	27
Hawk, Hover, and Snatch							
Willie wagtail	106	17	0	3	42	18	20

Table 6. Percentage use of foraging manoeuvres by mulga birds at Gascoyne Junction, Gascoyne Bioregion, in July 2002
All species for which 10 or more observations were available are shown (*N*). Species were ranked and grouped into foraging guilds based on percentage use of manoeuvres

Guild and species	*N*	Manoeuvre					
		Glean	Pounce	Hover	Snatch	Hawk	Sweep
Glean							
Zebra finch	120	100	0	0	0	0	0
Southern whiteface	37	100	0	0	0	0	0
Crimson chat	22	100	0	0	0	0	0
White-winged triller	69	88	0	0	12	0	0
Splendid wren	35	72	0	0	17	11	0
Chestnut-rumped thornbill	21	57	0	19	24	0	0
Pounce							
Pied butcherbird	10	0	100	0	0	0	0
Red-capped robin	59	10	59	3	20	7	0
Aerial							
Willie wagtail	23	9	0	0	9	83	0
Black-faced woodswallow	18	0	0	0	0	17	83

Table 7. Percentage use of foraging manoeuvres by mulga birds at Mount Magnet, Murchison Bioregion, in August 1999
All species for which 10 or more observations in 2002 were available are shown (*N*). Species were ranked and grouped into foraging guilds based on percentage use of manoeuvres. No birds were observed sweeping

Guild and Species	*N*	Manoeuvre						
		Glean	Probe		Pounce	Hawk	Hover	Snatch
			Arthropod	Nectar				
Glean								
Southern whiteface	163	100	0	0	0	0	0	0
Bourke's parrot	82	100	0	0	0	0	0	0
Crimson chat	78	100	0	0	0	0	0	0
Yellow-rumped thornbill	73	100	0	0	0	0	0	0
Common bronzewing	12	100	0	0	0	0	0	0
White-winged triller	16	81	6	0	0	0	0	13
Chestnut-rumped thornbill	117	78	0	0	0	3	11	8
Glean, Snatch								
Slaty-backed thornbill	67	58	0	0	0	6	5	31
Rufous whistler	65	48	0	0	5	1	5	41
Glean, Hawk								
Willie wagtail	89	44	3	0	1	34	3	15
Glean and Probe								
Grey-crowned babbler	209	19	81	0	0	0	0	0
White-browed babbler	40	38	62	0	0	0	0	0
Nectar Foragers								
Singing honeyeater	70	7	0	93	0	0	0	0
Yellow-fronted miner	35	37	0	63	0	0	0	0
Spiny-cheeked honeyeater	56	21	0	63	0	0	16	0
Nectar and Aerial								
Black honeyeater	49	4	0	33	0	63	0	0
Pounce								
Hooded robin	66	8	0	0	88	1	0	3
Red-capped robin	92	5	5	0	81	5	2	2
Pounce and Hawk								
Black-faced woodswallow	60	13	0	0	38	40	0	9
Snatch								
Black-faced cuckoo-shrike	12	25	0	0	8	0	0	67
Western warbler	13	0	0	0	0	38	8	54

Table 8. Percentage use of foraging manoeuvres by mulga birds at Mount Magnet, Murchison Bioregion, in July 2002

All species for which 10 or more observations in 2002 were available are shown (*N*). Species were ranked and grouped into foraging guilds based on percentage use of manoeuvres. No birds were observed sweeping

Guild and Species	*N*	Manoeuvre				
		Glean	Probe	Pounce	Hover	Snatch
Glean						
Southern whiteface	45	100	0	0	0	0
Splendid wren	25	100	0	0	0	0
Port Lincoln parrot	10	100	0	0	0	0
Slaty-backed thornbill	10	100	0	0	0	0
Yellow-rumped thornbill	40	97	0	0	3	0
Chestnut-rumped thornbill	26	96	0	0	4	0
Glean and Probe						
Singing honeyeater	21	76	24	0	0	0
Yellow-throated miner	52	69	31	0	0	0
Grey-crowned babbler	70	30	70	0	0	0
Glean and Hover/Snatch						
Western warbler	12	66	0	0	17	17
Pounce						
Grey butcherbird	17	23	0	71	0	6
Red-capped robin	11	18	0	82	0	0

hawked in about equal proportions. Two species were primarily snatchers (>53%), with the black-faced cuckoo-shrike also gleaning and the western warbler hawking (Table 7). Four species took nectar and arthropods. Singing honeyeater and yellow-fronted miner took arthropods primarily by gleaning, with the spiny-cheeked honeyeater gleaning and hovering. The black honeyeater took arthropods by hawking (Table 7).

In 2002, at Mount Magnet 9 of the 12 species for which there were sufficient data for analysis were gleaners (>69% of foraging manoeuvres) (Table 8). Of these, the singing honeyeater and yellow-fronted miner also took food by probing, while the western warbler took a third of its prey by hovering and snatching. The grey-crowned babbler took most prey by probing (70%), but also gleaned. The grey butcherbird and red-capped robin pounced and gleaned (Table 8).

Substrates and food

Gascoyne Junction

In 1999, seven species at Gascoyne Junction were ground-foragers (>59% of foraging manoeuvres) (Table 9). Budgerigar and zebra finch took seed from grasses. Five others also foraged on the ground (40–51%), but splendid wren, crimson chat, and yellow-fronted miner also gleaned foliage in shrubs and trees (37–51%). Black-faced woodswallow took 26% of its prey from

Table 9. Percentage use of foraging substrates by mulga birds at Gascoyne Junction, Gascoyne Bioregion, in August 1999

All species for which 10 or more observations were available are shown (*N*). Species are ranked and grouped into foraging guilds by percentage use of substrates from which arthropod prey were taken

Foraging guild and species	*N*	Substrate					
		Ground	Foliage	Bark	Air	Nectar	Insect
Ground							
Budgerigar	385	100	0	0	0	0	0
Crested bellbird	11	100	0	0	0	0	0
Common bronzewing	10	100	0	0	0	0	0
Zebra finch	195	97	3	0	0	0	0
Southern whiteface	109	86	14	0	0	0	0
Redthroat	63	78	6	14	2	0	0
Red-capped robin	69	59	12	9	20	0	0
Ground and Foliage							
Splendid wren	67	51	37	6	3	0	3
Crimson chat	91	49	51	0	0	0	0
Yellow-fronted miner	53	40	43	13	4	0	0
Ground and Aerial							
Black-faced woodswallow	19	47	16	11	26	0	0
Foliage							
Grey butcherbird	11	9	82	9	0	0	0
White-winged triller	58	15	78	7	0	0	0
Rufous whistler	54	5	78	15	2	0	0
Chestnut-rumped thornbill	97	5	68	19	7	0	1
Variegated wren	51	6	65	14	0	0	15
Spiny-cheeked honeyeater	12	0	50	42	0	8	0
Bark							
White-browed babbler	67	40	0	60	0	0	0
Aerial							
Willie wagtail	106	19	38	1	42	0	0

Table 10. Percentage use of foraging substrates by mulga birds at Gascoyne Junction, Gascoyne Bioregion, in July 2002
All species for which 10 or more observations were available are shown (*N*). Species are ranked and grouped into foraging guilds by percentage use of substrates from which arthropod prey were taken

Guilds and species	*N*	Substrate			
		Ground	Foliage	Bark	Air
Ground					
Zebra finch	120	100	0	0	0
Southern whiteface	37	100	0	0	0
Crimson chat	22	95	5	0	0
Foliage					
Chestnut-rumped thornbill	21	0	95	5	0
White-winged triller	69	29	71	0	0
Splendid wren	35	37	46	6	11
Bark					
Pied butcherbird	10	0	0	100	0
Red-capped robin	59	5	27	61	7
Aerial					
Black-faced woodswallow	18	0	0	0	100
Willie wagtail	23	9	9	0	82

the air, but also hovered and snatched prey from foliage and bark (27%). Foliage was the next most commonly used foraging substrate, with 10 species taking 37–82% of food from foliage, including that of ground vegetation (Table 9). Excluding seed-eaters, ground and foliage foragers fed on arthropod larvae and grasshoppers. White-browed babbler took 60% of its prey from bark, while willie wagtail gleaned foliage (38% of foraging manoeuvres; mainly hover/gleaning *Acacia* spp.) and hawked prey from the air. There were few flowers at Gascoyne Junction and only spiny-cheeked honeyeater took nectar (8%), although chestnut-rumped thornbill (1%), splendid (3%) and variegated (15%) wrens visited flowers and took insects (Table 9).

In 2002, three species at Gascoyne Junction foraged primarily on the ground, three on foliage, two on bark, and two were aerial foragers (Table 10). Among the foliage foragers, white-winged triller and splendid wren foraged extensively on the ground (29–37% of manoeuvres). The red-capped robin took prey mainly from bark (branches), but also from foliage (Table 10).

Mount Magnet

In 1999, nine species at Mount Magnet were primarily ground-foragers (>50% of foraging manoeuvres) (Table 11).

Table 11. Percentage use of foraging substrates by mulga woodland birds at Mount Magnet, Murchison Bioregion, in August 1999
All species for which 10 or more observations were available are shown (*N*). Species are ranked and grouped into foraging guilds by percentage use of substrates from which food was taken

Guild and Species	*N*	Substrate					
		Ground	Foliage	Bark	Air	Nectar	Insect
Ground							
Common bronzewing pigeon	12	100	0	0	0	0	0
Grey-crowned babbler	209	83	1	16	0	0	0
Red-capped robin	92	82	1	11	4	0	2
Bourke's parrot	82	98	2	0	0	0	0
Hooded robin	66	87	9	2	2	0	0
Black-faced woodswallow	60	50	10	0	40	0	0
White-browed babbler	40	87	13	0	0	0	0
Southern whiteface	163	68	32	0	0	0	0
Yellow-rumped thornbill	73	62	38	0	0	0	0
Foliage and Ground							
Black-faced cuckoo-shrike	12	8	92	0	0	0	0
Crimson chat	78	14	85	1	0	0	0
Foliage and Bark							
Slaty-backed thornbill	67	0	75	19	6	0	0
Chestnut-rumped thornbill	117	4	66	20	3	0	7
White-winged triller	16	0	69	31	0	0	0
Rufous whistler	65	5	60	34	1	0	0
Foliage and Aerial							
Western warbler	13	0	46	15	39	0	0
Willie wagtail	89	28	32	6	34	0	1
Aerial and Nectar							
Black honeyeater	49	0	4	0	63	33	0
Nectar and Foliage							
Singing honeyeater	70	0	7	0	0	93	0
Yellow-fronted miner	35	14	23	0	0	63	0
Spiny-cheeked honeyeater	56	5	32	0	0	63	0

Table 12. Percentage use of foraging substrates by mulga woodland birds at Mount Magnet, Murchison Bioregion, in July 2002
All species for which 10 or more observations were available are shown (*N*). Species are ranked and grouped into foraging guilds by percentage use of substrates from which food was taken

Guild and Species	*N*	Substrates			
		Ground	Foliage	Bark	Nectar
Ground Foragers					
Southern whiteface	45	100	0	0	0
Yellow-rumped thornbill	40	97	3	0	0
Red-capped robin	11	91	0	9	0
Grey butcherbird	17	88	6	6	0
Grey-crowned babbler	70	70	0	30	0
Foliage Foragers					
Western warbler	12	0	100	0	0
Splendid wren	25	20	80	0	0
Foliage and Bark Foragers					
Chestnut-rumped thornbill	26	0	77	23	0
Slaty-backed thornbill	10	0	40	60	0
Bark Foragers					
Port Lincoln parrot	10	0	0	100	0
Singing honeyeater	21	0	5	71	24
Yellow-throated miner	52	0	10	61	29

Of these, black-faced woodswallow took 40% of its prey aerially. Southern whiteface and yellow-rumped thornbill took prey from ground vegetation (32% and 38% respectively), as well as the ground and litter. The black-faced cuckoo-shrike and crimson chat took prey mainly from foliage (>84%), with the cuckoo-shrike foraging primarily on canopy foliage and the chat on ground vegetation. Four species were foliage and bark foragers: slaty-backed and chestnut-rumped thornbills, white-winged triller, and rufous whistler. Western warbler took prey from foliage, bark, and aerially. Willie wagtail took prey nearly equally from the ground, foliage, and air (Table 11). Four honeyeaters visited flowers for nectar, with the black honeyeater taking arthropods from the air. Singing and spiny-cheeked honeyeaters and yellow-fronted miner took most arthropod prey from foliage, with the spiny-cheeked honeyeater and the miner ground-foraging (Table 11). Arthropod larvae were the principal prey of ground and foliage foragers.

In 2002, five species foraged mainly on the ground (>70% of manoeuvres) (Table 12). Western warbler and splendid wren took >80% of their prey from foliage, with the wren also foraging on the ground. Chestnut-rumped and slaty-backed thornbills were foliage and bark foragers, with the former taking more prey from foliage (77%) and the latter from bark (60%) (Table 12). Three species were primarily bark foragers, with the singing honeyeater and yellow-throated miner also taking nectar (Table 12). The principal food taken at Mount Magnet from bark in 2002 was scale and honeydew of red mulga lerp (*Austrotachardia acaciae*). These were also the food taken by Port Lincoln parrots. Mulga lerp were not evident in 1999 at either Gascoyne Junction or Mount Magnet and were not found at Gascoyne Junction in 2002.

At Mount Magnet, babblers appeared to feed extensively on termites (Isoptera) taken by probing wood and ground, and by tossing and turning dead wood on the ground. This behaviour was pronounced in 2002.

Plant species

Combining observations from Gascoyne Junction and Mount Magnet, of 441 foraging observations where a plant was identified to species or type, 201 (46%) were of birds feeding in mulga. Another 71 observations (16%) were of species of *Acacia* not identified to species. In all, 24% of observations were of birds foraging on ground vegetation and grass. Shrubs and vines comprised 13% of observations. Sample sizes are too small to justify a finer analysis of plant species selection by species of birds.

Foraging heights

In Table 13 species are sorted by their mean foraging height range and grouped according to the vegetation layers in which they predominantly foraged. Although mean foraging heights differed between locations and years, species foraged within the same height range at Gascoyne Junction and Mount Magnet in 1999 and 2002 (Table 13). Twelve species took food primarily from the ground or from ground vegetation (grasses, forbs, herbs) (Table 13). Another 10 species foraged on the ground, but also fed in shrubs and trees. The remaining eight species foraged predominantly in shrubs and trees (Table 13).

Discussion

Avian species composition and abundances in mulga are rainfall dependent, with the abundance and variety of mulga vertebrates increasing following rain and decreasing with drought (Williams 2002; Burbidge and Fuller 2007; Maslin and Reid 2009; Letnic and Dickman 2010; Bell *et al.* 2013). The response to rainfall is particularly noticeable among birds where nomadic species respond rapidly to increases in food resources following rain and departing with drying conditions (Burbidge and Fuller 2007; Bell *et al.* 2013; Tischler *et al.* 2013). Recher and Davis (2014) reported similar patterns among eucalypt woodland birds in the Great Western Woodland. They found increased abundances and breeding activity during periods of above-average rainfall, with bird numbers and breeding declining with average or below-average rainfall. Food nomads, nectar-feeders, cuckoos, and raptors declined in abundance with less rain. The amount and pattern of rainfall also affected the abundance and breeding of ground, shrub, and canopy foragers, including migrants and nomads.

Following above-average rainfall mulga birds at Gascoyne Junction and Mount Magnet were abundant and actively breeding. By 2002 with reduced rainfall, and an absence of ephemeral ground vegetation, including grasses, bird numbers had declined and breeding was limited. In 1999, the mulga avifauna was numerically dominated by food nomads, including seed-eaters (e.g. budgerigar, diamond dove, zebra finch) and insect-eaters (e.g. black-faced woodswallow, crimson chat, white-winged triller). Food nomads formed large, mixed foraging flocks, which were preyed upon by a variety of raptors (Davis and Recher 2002). In addition to the absence of mixed foraging flocks and fewer food nomads in 2002, there were noticeable

Table 13. Mean and standard deviation (in parentheses) of foraging heights at Gascoyne Junction and Mount Magnet in 1999 and 2002
Species are listed from ground to canopy foragers according to their mean foraging height range, combining both sites and years. Only species for which 10 or more observations were available for that site and year are shown. Sample sizes are given in Tables 3 and 4. n.d., no observations for that site and year

	Gascoyne Junction		Mount Magnet		Height range
	1999	2002	1999	2002	1999–2002
Ground and Ground Vegetation (0–0.3 m)					
Common bronzewing pigeon	0 (0)	n.d.	0 (0)	n.d.	0
Pied butcherbird	n.d.	0 (0)	n.d.	n.d.	0
Bourke's parrot	n.d.	n.d.	0.001 (0.008)	n.d.	0.001
Zebra finch	0.003 (0.02)	0 (0)	n.d.	n.d.	0–0.003
Southern whiteface	0.01 (0.03)	0 (0)	n.d.	0 (0)	0–0.01
White-browed babbler	n.d.	n.d.	0.01 (0.03)	n.d.	0.01
Yellow-rumped thornbill	n.d.	n.d.	0.01 (0.03)	n.d.	0.01
Crested bellbird	0 (0)	n.d.	0.03 (0.05)	0.1 (0.3)	0–0.1
Crimson chat	0.1 (0.2)	0.03 (0.13)	0.07 (0.04)	n.d.	0.03–0.1
Hooded robin	n.d.	n.d.	0.1 (0.38)	n.d.	0.1
Budgerigar	0.22 (0.14)	n.d.	n.d.	n.d.	0.22
Redthroat	0.3 (0.57)	n.d.	n.d.	n.d.	0.3
Ground and Shrubs/Trees (0–3 m)					
Variegated wren	0.01 (0.03)	1.3 (0.8)	n.d.	n.d.	0.01–1.3
Splendid wren	0.6 (0.7)	1 (1.1)	0.18 (0.41)	1.8 (0.9)	0.18–1.8
Black-faced woodswallow	0.9 (1.2)	2.9 (2.1)	0.37 (0.66)	nd	0.37–2.9
Grey-crowned babbler	n.d.	n.d.	2.5 (0.3)	0.6 (1)	0.6–2.5
Willie wagtail	1.7 (1.5)	1.4 (1.6)	0.7 (1.3)	n.d.	0.7–1.7
Grey butcherbird	2.9 (1.3)	n.d.	0 (0)	0.15 (0.5)	0–2.9
Red-capped robin	2.9 (1.3)	0.8 (1.2)	0.1 (0.37)	0.1 (0.3)	0.1–2.9
White-winged triller	0.9 (1.14)	1 (1.5)	1.8 (1.8)	n.d.	0.9–1.8
Yellow-throated miner	1.5 (2.4)	2.6 (0.2)	1.4 (1.6)	2.7 (0.6)	1.4–2.7
Chestnut-rumped thornbill	1.8 (0.94)	3 (1.1)	1.5 (1.03)	1.8 (0.5)	1.5–3
Shrubs and Trees (1–3 m)					
Singing honeyeater	7 (0)	n.d.	0.9 (0.6)	2.2 (0.5)	0.9–7
Western warbler	1.1 (0.5)	3.1 (0.6)	2.5 (1.35)	2.2 (0.5)	1.1–3.1
Spiny-cheeked honeyeater	3.6 (0.94)	2.6 (0)	1.4 (1.5)	n.d.	1.4–3.6
Rufous whistler	n.d.	2.2 (0.5)	1.9 (1.05)	n.d.	1.9–2.2
Port Lincoln parrot	n.d.	n.d.	n.d.	2.2 (0.16)	2.2
Slaty-backed thornbill	n.d.	n.d.	2.3 (0.9)	2.5 (0.4)	2.3–2.5
Black-faced cuckoo-shrike	2.3	n.d.	2.6 (1.6)	n.d.	2.3–2.6
Black honeyeater	n.d.	n.d.	2.8 (1.7)	n.d.	2.8

differences in the foraging behaviour and food resources of birds in 1999 compared with 2002.

In 1999, grass seed was abundant at Gascoyne Junction and attracted large numbers of seed-eaters. In the absence of an abundance of grass, seed-eaters were absent or less plentiful at Mount Magnet. Arthropod larvae were abundant at both locations on the ground, among ground vegetation, and on shrubs and wattles. There was also an abundance of grasshoppers at Gascoyne Junction, but none at Mount Magnet. Larvae and grasshoppers provided an abundance of food for ground and foliage foragers, including food nomads; chats, trillers, and woodswallows were abundant at both Gascoyne Junction and Mount Magnet. Arthropod larvae were also an abundant food resource at Hamilton Downs in the Northern Territory and attracted a similar array of bird species (Recher and Davis 1997). In the absence of grasshoppers and much reduced abundances of caterpillars in 2002, birds foraged differently and used different foraging substrates. This was particularly noticeable at Mount Magnet where in 1999 there were fewer food resources even under favourable conditions as a consequence of overgrazing and less topographic and floristic variety in habitat.

In 1999, gleaning and snatching/hovering were the most common foraging behaviours, with ground, ground vegetation, and the foliage of *Acacia* species the most common foraging substrates. This reflected the abundance of grass seed and grasshoppers at Gascoyne Junction and of arthropod larvae in litter, on ground vegetation, and on shrubs and trees at both Gascoyne Junction and Mount Magnet. In 2002, there was less vegetation. This was particularly evident at Gascoyne Junction where there was little grass and where goats had eaten most shrubs to the ground and were in the process of breaking branches from mulga and other species of *Acacia.* Bird numbers had declined and there was noticeably less breeding activity. The species remaining on the plots foraged significantly differently from 1999, with the differences related to the food resources available. At Gascoyne Junction, black-faced woodswallow and willie wagtail did more aerial foraging, including

sweeping by woodswallows, and less ground and foliage foraging, reflecting the absence of larvae and grasshoppers that had been their principal prey in 1999. No aerial foraging was recorded in 2002 at Mount Magnet, which is largely explained by the absence or reduced abundance of woodswallows, wagtails, black honeyeater, and western warbler, all which were present and frequent aerial foragers in 1999. Similarly, there was less ground pouncing at Mount Magnet in 2002 than in 1999, explained by the absence of hooded robin and fewer woodswallows and the absence of ground larvae. There was also less ground-pouncing at Gascoyne Junction in 2002, with red-capped robin, a ground-pouncer in 1999, taking most of its prey by pouncing and snatching bark and foliage, again reflecting the reduced abundance of ground prey.

One of the more pronounced differences between 1999 and 2002 was the increased use of bark as a foraging substrate at Mount Magnet and, to a lesser degree, at Gascoyne Junction. While not a factor at Gascoyne Junction, the greater use of bark is explained by an outbreak of red mulga lerp, which became a significant food for thornbills and honeyeaters.

Despite the differences between 1999 and 2002 in the ways birds foraged for food and the substrates used, there were few differences in the foraging height range of the different species. We recognise that some of the differences in foraging behaviour between years and locations may be attributed to the relatively small sample sizes for some species, especially in 2002. Nonetheless, the differences reported are consistent between sites and the explanation for these differences fit the observations of changes in available food resources. Mulga birds use a wide range of foraging manoeuvres and substrates, but these differ between locations and years according to resource availability. Such flexibility in foraging behaviour is essential for survival in arid and semiarid environments, such as mulga, where the abundance and type of food available changes significantly with rainfall. The alternative is to be nomadic and continually move across the landscape over long distances in search of food. A consequence is that a large proportion of the mulga avifauna is nomadic and, as at Gascoyne Junction and Mount Magnet between 1999 and 2002, mulga bird communities change significantly in species abundances and composition according to rainfall.

Conservation

The response of birds to rainfall that we observed in the Gascoyne and Murchison Bioregions highlights the likely sensitivity of mulga communities to long-term climate change. With climate change predicted to continue and intensify as atmospheric greenhouse gases of human origin increase, the climate of southern Australia is predicted to become hotter with more extreme heat events and reduced rainfall (BOM/CSIRO 2016). Climate change will not necessarily be uniform across southern Australia and there is evidence of an increase in annual rainfall in the Gascoyne and Murchison Bioregions (Bastin 2014).

Despite any increase in rainfall, annual rainfall on these mulga lands is highly variable (Bastin 2014) and conservation of mulga habitats and their flora and fauna in Western Australia must take into consideration a continuing change of climatic conditions. Arid and semiarid environments in Australia are naturally exposed to extreme fluctuations in annual rainfall and subject to extreme heat. These are why fauna populations in the arid and semiarid regions of Australia fluctuate widely between seasons and years and why so much of the avifauna is nomadic or migratory. It is only through whole-of-landscape conservation and management, such as advocated by Woinarski *et al.* (2014) for outback Australia, that Australia's arid and semiarid biodiversity can be conserved for the wellbeing of future generations.

The overgrazing and degradation of pastoral lands at Mount Magnet and around most of Gascoyne Junction that was evident in 1999 intensified with drier conditions by 2002. The destruction of almost all shrubs and the breaking down of mulga and other trees by goats at Gascoyne Junction between 1999 and 2002 highlighted not only the fragility of these environments, but the absence of sustainable pastoral management in any sense of the meaning of 'sustainable'. Only when governments and people accept the need to conserve Australia's biodiversity for the wellbeing of the nation and its people and recognise the right of other species to survive and evolve will a program of landscape management develop that provides not only for the needs of sedentary species, but protects the needs of migratory and nomadic species. The alternative is to take heart from the words of Henry Nix who advised HFR 'not to worry, because after the goats there will be the camels'; Australia's mulga lands will then resemble the arid wastelands of North Africa which long ago took the path that the Murchison and Gascoyne now follow.

Conflicts of interest

The author declares no conflicts of interest.

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