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A survey of outlying populations of the Grey Grasswren *Amytornis barbatus*

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Two subspecies of the Grey Grasswren occupy terminal swamps of separate inland rivers, *Amytornis barbatus barbatus* on the Bulloo River and *A. b. diamantina* in Goyder Lagoon on the Diamantina. There have been sporadic reports from three other discrete areas; the Eyre Creek, Diamantina River and Cooper Creek floodplains. In a survey of those outlying populations, Grey Grasswrens were sparsely and unevenly distributed, being found at eleven localities (including one within 20 kilometres of Goyder Lagoon) but undetected at 16 where they had been observed previously, in some cases over several years. All five populations appear to be isolated from one another by distances of between 50 and 150 kilometres over which suitable habitat appears to be absent. Grasswrens from Eyre Creek belong to the same subspecies as those in Goyder Lagoon where Eyre Creek terminates, suggesting that in relatively recent times those two populations at least have been in reproductive contact, but the subspecific status of the other two outlying populations remains unknown. Our findings indicate that the outlying populations are small and that one or more might be declining towards local extinction. On the other hand we infer that Grey Grasswrens may be more able to disperse during exceptional seasonal conditions than is widely assumed to apply to grasswren species. Factors that might explain why the outlying populations are small and/or declining are discussed.

INTRODUCTION

The Grey Grasswren *Amytornis barbatus* (Maluridae) occupies the floodplains of several inland river systems in Australia's arid zone. Preferred habitats include Lignum *Muehlenbeckia florulenta* shrublands of varying density, lining channels and waterholes and on swamp flats, as well as more open shrublands of Old-man Saltbush *Atriplex nummularia* ssp. *nummularia* and mixed shrub species, towards the floodplain periphery (Black *et al*. 2012). The species was first reported in 1921 on the Bulloo floodplain south of the Queensland/ New South Wales border (Chenery 1922; MacGillivray 1923; McAllan 2000), but identified as distinct and described only in 1967 (Favaloro and McEvey 1968). That population is presently known only from the terminal swamps of the Bulloo on both sides of the State border and although that population was considered to have declined substantially (Hardy 2002, 2010), this is disputed (I. McAllan pers. comm.). It is listed as vulnerable in Queensland under the *Nature Conservation Act 1992* and nationally under the *Environment Protection and Biodiversity Conservation Act 1999*, and as endangered under the *New South Wales Threatened Species Conservation Act 1995* and in the *Action Plan for Australian Birds 2010* (Garnett *et al.* 2011). A second population found in Goyder Lagoon, South Australia in 1975 (Cox 1976) and later described as a separate subspecies *A. b. diamantina* (Schodde and Christidis 1987), is listed as rare in the schedules of the *South Australian National Parks and Wildlife Act 1972* and its habitat is identified as a Conservation Priority in the *SA Arid Lands Draft Biodiversity Strategy (Department for Environment and Heritage 2008)*. That population is now believed to be relatively secure and its status is listed as 'least concern' by Garnett *et al.* (2011), following a targeted survey of Goyder Lagoon and the Warburton Creek floodplain immediately downstream (Black *et al.* 2009b). Those two well documented populations occupy the core distributions of their respective subspecies and will be considered here as the central populations.

Further Grey Grasswren records in Queensland include those of Schodde (1982), who provided unconfirmed reports from Lake Cudappan, which lies between catchments of the Diamantina River and Cooper Creek, and from Farrars Creek which enters the Diamantina River floodplain from the east. Joseph (1982) found Grey Grasswrens between Lake Machattie and Lake Koolivoo on the Georgina River/Eyre Creek floodplain between Birdsville and Bedourie and Jaensch and McFarland (2002) added a record from that vicinity and others from floodplain and channels at the southern edge of the Diamantina between Birdsville and Betoota. At Embarka Swamp, South Australia on the main branch of Cooper Creek west of Innamincka, May (1982) saw Grey Grasswrens twice in 1982 and again about a year later (Ian May, pers. comm.), but they were not seen subsequently (Reid 2000), and it later was inferred that a small satellite population might have become established briefly but had declined to local extinction (Black *et al.* 2009b, 2012). Grey Grasswrens were later identified in the Cooper Creek channels of south-west Queensland to the east and south of Ballera Gas Centre (Carpenter 2002). Several reports have followed from the Cooper Crossing south-east of Ballera Gas Centre and from Noccundra Waterhole on the Wilson River farther east (Birdlife Australia per A Silcocks, BirdingAus website).

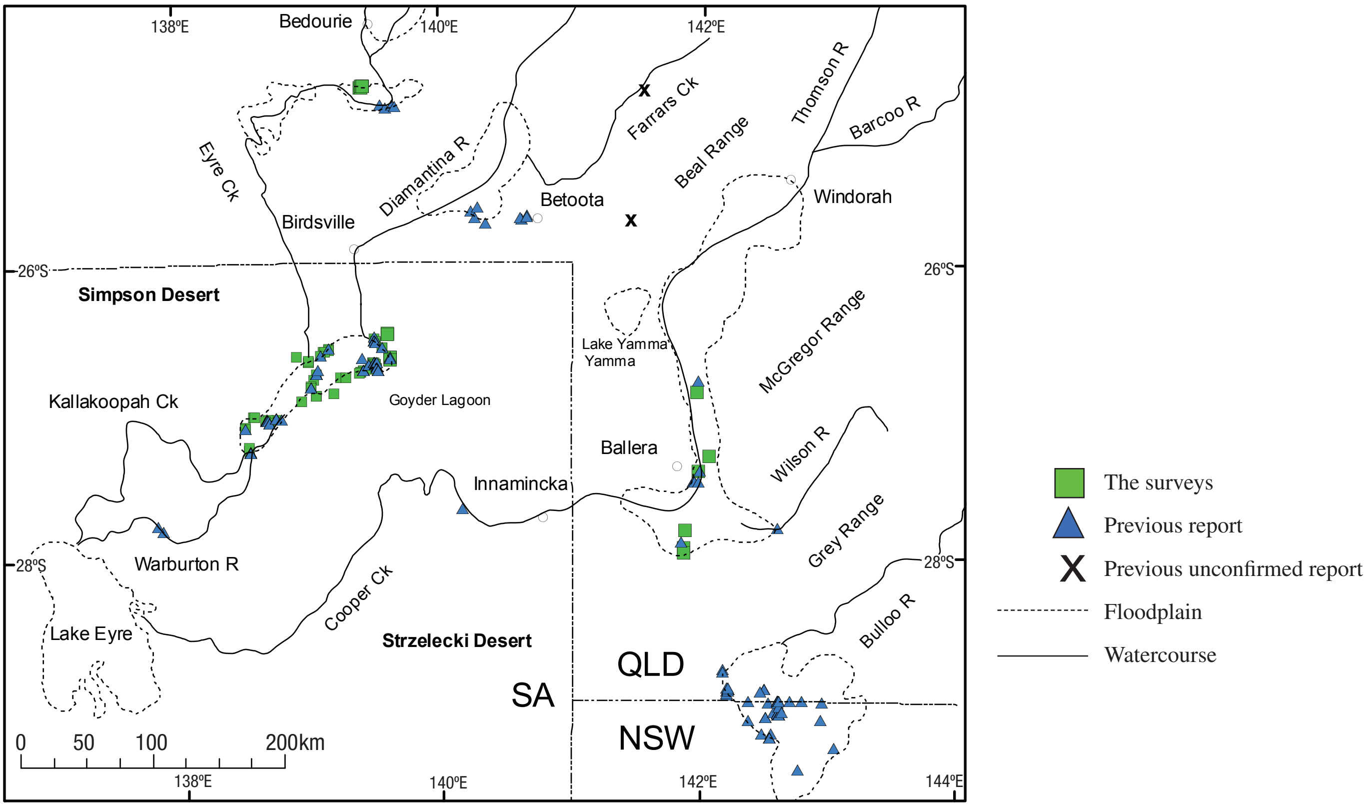

Figure 1. *Earlier records of the Grey Grasswren and those from the 2009 and present surveys; unconfirmed reports are indicated as X.*

The above records of Grey Grasswrens from within or between the floodplains of the Eyre Creek, Diamantina River and Cooper Creek systems, outside the known distribution of the central populations, will be referred to here as the outlying populations. We undertook to survey these outlying populations in 2012 and 2013 to gain an understanding of their size and potential connectivity with one another and with the central populations. We sought to determine whether the outlying populations are geographically separate from either the Bulloo (*A. b. barbatus*) or Goyder Lagoon (*A. b. diamantina*) populations and therefore possibly of distinct genetic and/or taxonomic identity. A further consideration was the size of outlying populations, which could inform an assessment of their conservation status. We also sought to document broad habitat characteristics and sources of disturbance among outlying populations along with micro-habitat structure at sites where Grey Grasswrens were present.

METHODS

We collated previous records of outlying populations of the Grey Grasswren, including specimens in the Queensland Museum and the National Wildlife Collection of CSIRO, Canberra, BirdLife Australia bird atlas data and published and unpublished records of the authors and others. The 18 localities of records are shown in Figure 1 and are summarised below:

Eyre Creek

1. 25 August, 13 October 1982, Cuttaburra Crossing on the Bedourie to Birdsville road 18 km south of Glengyle Homestead ~ 24º 55' S, 139º 39' E (Joseph 1982).
2. 13 October 1982, 9 km W of 1 above, south of Lake Koolivoo ~ 24º 56' S, 139º 33' E (Joseph 1982).
3. 24-25 October 1988 17 km south of Glengyle Homestead, ~ 24º 54.5' S, 139º 39' E (ANWC B41784-8, 41792)
4. 19 April 2001, Eyre Creek floodplain, north of Lake Koolivoo ~ 24º 53.6' S, 139º 35.7' E (Jaensch and McFarland 2002, RJ personal record).
5. 25 April 2009, south-east of Lake Koolivoo ~ 24º 56.3' S, 139º 36.0' E (G Dutson pers. comm. to RJ)

Diamantina River (all are from Jaensch and McFarland 2002)

1. 14 April 1984, Pelican Waterhole, Browns Creek, QM O22665, ~ 25º 41.5' S, 140º 36.5' E.
2. 20 April 1984, 'a channel' east of above, QM O22670, ~ 25º 41' S, 140º 40' E.
3. 20 April 1984, 'plain and channels' to the east of Thundapurty Waterhole, Diamantina Shire Survey ~ 25º 37.5' S, 140º 17.5' E.
4. 12 January 2001, 5 km south-east of Thundapurty Waterhole on the southern Diamantina floodplain, 25º 41' 36" S, 140º 16' 16" E.
5. 15 January 2001, periphery of Diamantina floodplain east of above, 25º 43' 42" S, 140º 20' 42" E.
6. 10 May 2002, near Thundapurty Waterhole, 25º 38' 51" S, 140º 14' 23" E.

Cooper Creek/Wilson River

1. 14 December 2001, 60 km S of Ballera Gas Centre, 27º 55' 00" S, 141º 50' 20" E (Carpenter 2002).
2. 14 December 2001, 17 km E of Ballera Gas Centre, 27º 25' 40" S, 141º 59' 00" E (Carpenter 2002).
3. 26 September 2005 and 21 May 2010, Cooper Crossing, 27º 30' S, 141º 56' E (Bill Moorhead, BirdingAus website).
4. 24 August 2006, Cooper Crossing, 27º 29' 58" S, 141º 58' 29" E (BirdLife Australia data).
5. 19 June 2007, Cooper Crossing, 27º 30' 05" S, 141º 56' 36" E (C Billingham, Birds Queensland).
6. 20 June 2009, Noccundra Waterhole, Wilson River, 27º 49' S, 142º 36' E (M Brasher, BirdingAus website).
7. 1990s, Buncheeda Swamp, ~ 26º 50' S, 141º 58' E (G Campbell, pers. comm. to GC).

Five field-survey trips were undertaken, the fifth with three, otherwise four observers, as follows:

1. 16-24 April 2012: the Eyre Creek floodplain between the towns of Bedourie and Birdsville and west to below the junction of Eyre Creek and the Mulligan River.
2. 12-21 August 2012: the Diamantina channels and floodplain east of Birdsville.

   Both of these surveys also included searches for sites of suitable habitat between the outlying populations and Goyder Lagoon itself.
3. 2-7 November 2012: the Cooper Creek and Wilson River floodplains to the south of and east of Ballera Gas Centre;
4. 19-26 May 2013: northern Cooper Creek floodplain from Ballera Gas Centre north to Windorah, including Lake Yamma Yamma; also Lake Cudappan and the southern edge of the Diamantina floodplain east of Birdsville.
5. 9-14 September 2013: Cooper Creek floodplain north-east, east and south of Ballera Gas Centre.

Localities of previous reliable records were visited to determine whether grasswrens were still present and searches were made in nearby areas, concentrating on those identified by local information, maps and aerial and satellite imagery as most likely to contain habitat suitable for the species. In the fourth trip from 19–26 May 2013 covering the northern Cooper floodplain we knew of only two Grey Grasswren records: the unconfirmed (and unlisted) report from Lake Cudappan, shown as X on the map, Figure 1 (Schodde 1982), and an imprecisely located landholder report from Buncheeda Swamp in the 1990s (Cooper 7 above). Searches were therefore directed at the most extensive areas of Lignum swamp as judged from examining maps and satellite imagery. In the third and fourth trips, personal knowledge (RJ) from previous aerial surveys of these floodplains also informed identification of target areas for searching. Where grasswrens were detected, a 200 metres vegetation transect was undertaken, using a range pole to measure cover at every two metres along the transect, recording shrub height in 25 centimetres categories. Methods used were those employed in the Goyder Lagoon/Warburton Creek study (Black *et al.* 2009b, 2012). The localities where grasswrens were detected and where negative searches commenced were recorded using a hand-held GPS unit.

RESULTS

Grey Grasswrens were found in the 2012–13 survey in 18 sites among the outlying populations at ten localities and in two sites at one locality north-east of Goyder Lagoon, where sites within 500 metres were deemed to be at the same locality. Of the 11 localities, only one was known from a precisely located earlier record and three were in Buncheeda Swamp, known only from a non-localised report. There were two in the Eyre Creek floodplain (Figures 2, 6) and eight in the floodplain of Cooper Creek, (Figures 3, 8), including Buncheeda Swamp. Apart from the locality upstream of Goyder Lagoon (Figures 4, 9) there were none on the Diamantina floodplain (Figures 5, 7). The searches that resulted in 20 survey records are described below and details of the 20 sites and eleven localities are listed in Appendix 1.

Eyre Creek floodplain

All previous records for this system have been alongside the Birdsville to Bedourie Road in Lignum where Eyre Creek crosses the road from east to west (known as Cuttaburra Crossing) on swampy floodplain (Joseph 1982; J. Young 1994 pers. comm. to AB; A. Silcocks (Birdlife Australia) 2001 pers. comm. to AB), and up to nine kilometres west on the southern shore of Lake Koolivoo and immediately to its north (Joseph 1982; Jaensch and McFarland 2002; A. Silcocks (BirdLife Australia) 2009 pers. comm. to AB; RJ personal records). These areas were examined thoroughly in April 2012, on the south side extending west to the limit of tall Lignum around Lake Koolivoo and east into Lignum restricted to the south-west aspect of Lake Machattie. The wetlands had undergone a moderate flood, with water persisting in most minor channels, and the Lignum had lush green foliage. We could not detect Grey Grasswrens at these localities at the time or during a subsequent search in August 2012.

Grey Grasswrens were found at a new locality on the Eyre Creek floodplain on 20 April 2012 approximately 20 kilometres north-west of Lake Koolivoo in healthy but sparsely foliaged Lignum in a dry area in the north-western corner of the floodplain (Figure 2). Three birds were heard and grasswrens were detected in the same area during the second survey on 18 August 2012; others were recorded at another site nearby and at three further sites up to two kilometres to the west and north-west on 19 August. The first survey was extended to the west (downstream) on the northern side of Eyre Creek to its junction with the Mulligan River and onto the southern side of Eyre Creek to include other wetlands around Kauri and Muncoonie Waterholes, co-incident with and then ahead of the advancing flood. We examined accessible areas of suitable floodplain habitat, chiefly Lignum, but also small areas of Old-man Saltbush, but no grasswren was located. From the Mulligan junction, Eyre Creek runs south through the Simpson Desert dunefield for about 150 kilometres to its entry into Goyder Lagoon and consists of a channel and multiple swale floodways containing little or no suitable Lignum habitat.

Figure 2. *Habitat at Eyre Creek site E1a, (shown ❋ on map Figure 6) Lignum with ephemeral Senecio, 18 August 2012.* (Photograph by R. Pedler)

Figure 4. *Habitat north of Goyder Lagoon near sites G1a, b (shown ❋ on map Figure 9) Lignum and Old-man Saltbush with Flock Bronzewings* Phaps histrionica *23 May 2011.* (Photograph by R. Pedler)

Figure 3. *Habitat near Cooper Creek sites C4a-f, (shown ❋ on map Figure 8) Lignum with Nutheads, Spike Rush and Queensland Bluebush, 6 November 2012.* (Photograph by G. Carpenter)

Figure 5. *East of Thundapurty Waterhole, site of January 2001 record (Diamantina 4, shown ❋ on map Figure 7) Lignum with Spike Rush and ephemeral Senecio, 15 August 2012.* (Photograph by R. Pedler)

Diamantina floodplain

The six previous records in the Diamantina channels and floodplain (Jaensch and McFarland 2002) are from a restricted area between Thundapurty Waterhole and a little beyond Pelican Waterhole on Browns Creek approximately 45 kilometres to the east A moderate flood followed by local rains two months earlier had dried and receded by mid-August 2012, allowing access to all sites. One site at the edge of Thundapurty Waterhole was in tall and dense Lignum; searches were made there and in similar vegetation for over two kilometres to the east and west. The sites of two other previous records approximately six and 18 kilometres to the east were in habitat as described by Jaensch and McFarland (2002): one near the edge of continuous floodplain vegetation (Figure 5) in tall (and fresh) Lignum over dense spike rush *Eleocharis plana*, the other in sparse Lignum lacking vigour in an isolated locality within the broader floodplain. The site of the Diamantina Shire survey record was not defined precisely, but an area of dense Lignum within the reported five-minute block was examined. Later David McFarland (pers. comm., 19 October 2012) reviewed original data and advised that the record had more likely come from Lignum in a major channel to the south, very close to Thundapurty Waterhole. The two sites of museum specimens from Browns Creek were also given only as five-minute blocks containing habitats of sparse low shrubs including chenopods, sparse low tussock grass and wooded channels. No significant areas of Lignum or Swamp Cane Grass *Eragrostis australasica* were found anywhere near those record sites but several small areas of low Cottonbush *Maireana aphylla* shrubland were present, perhaps the chenopods described.

No grasswrens were recorded at any of these Diamantina sites or at places containing what appeared to be suitable Lignum shrublands up to 15 kilometres west, 20 kilometres north and 25 kilometres north-east of Thundapurty Waterhole. Searches were also negative in mixed Lignum and other shrubs towards the northern limit of the Diamantina floodplain where crossed by the Betoota to Bedourie road and in Lignum in the downstream floodplain farther west to within approximately 10 kilometres of Birdsville. Two further searches on 25 May 2013 in two areas of large Lignum to the west of Thundapurty Waterhole also yielded no grasswrens.

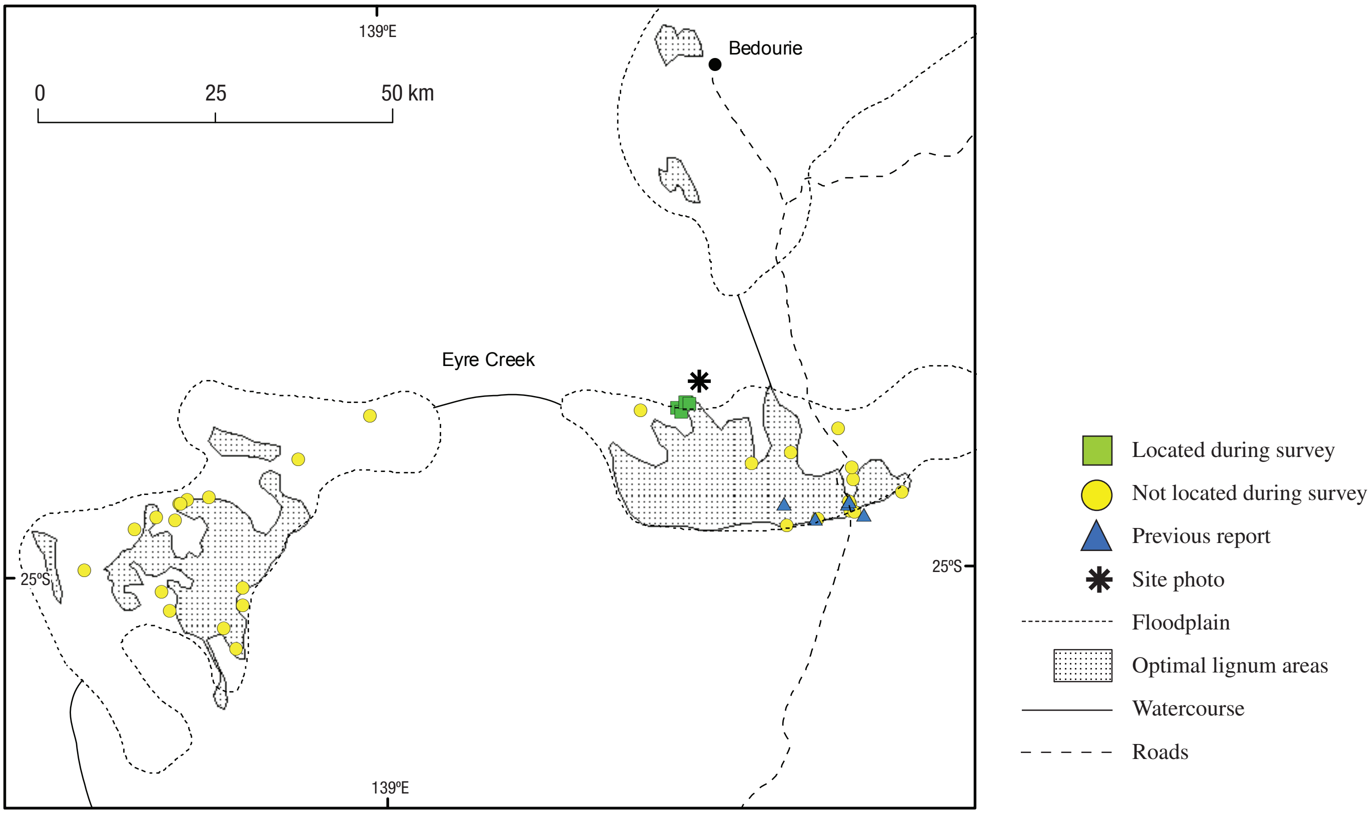

Figure 6. *Map of the Eyre Creek floodplain, showing its approximate limits, optimal areas of Lignum habitat, as identified from satellite imaging, previous Grey Grasswren records, survey records and negative search sites.*

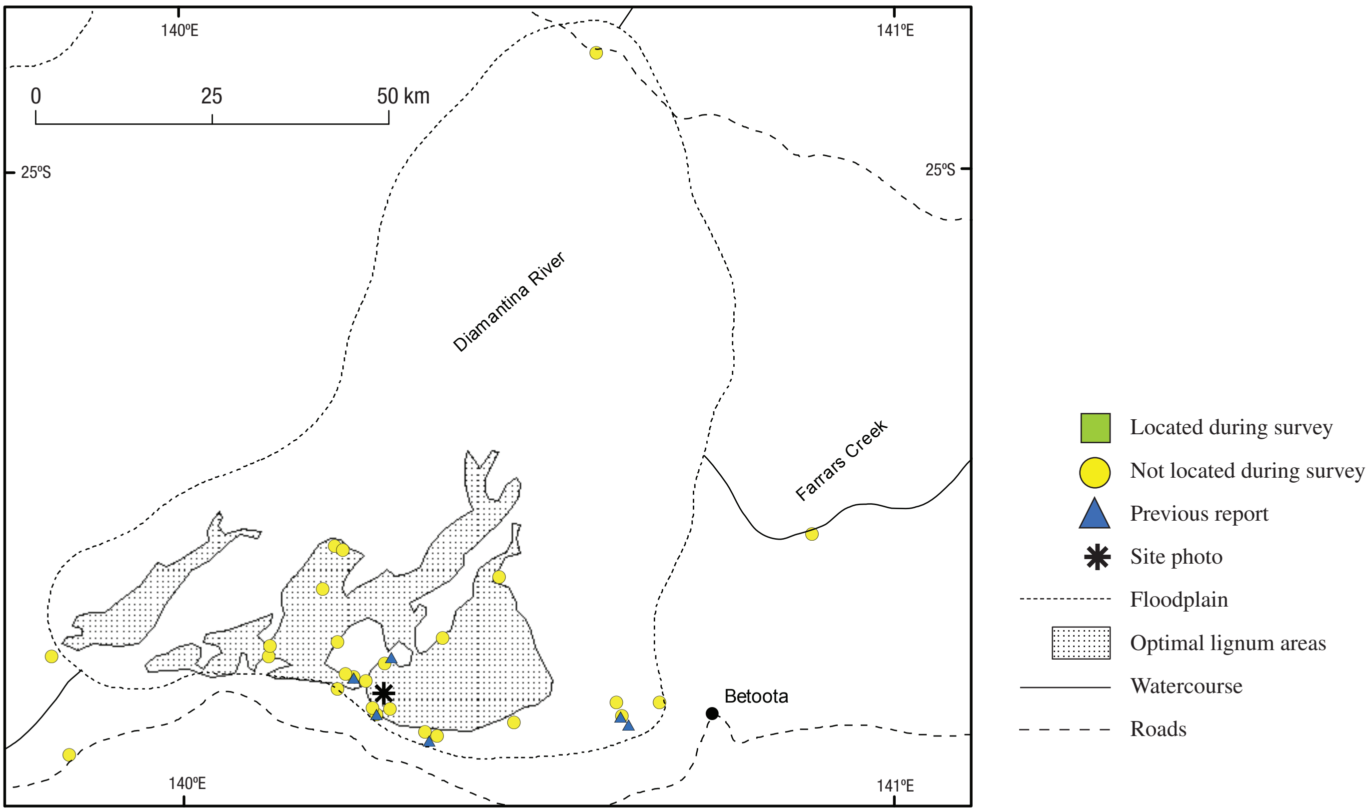

Figure 7. *Map of the Diamantina River channels and floodplain, showing its approximate limits, optimal areas of Lignum habitat, as identified from satellite imaging, previous Grey Grasswren records, survey records and negative search sites.*

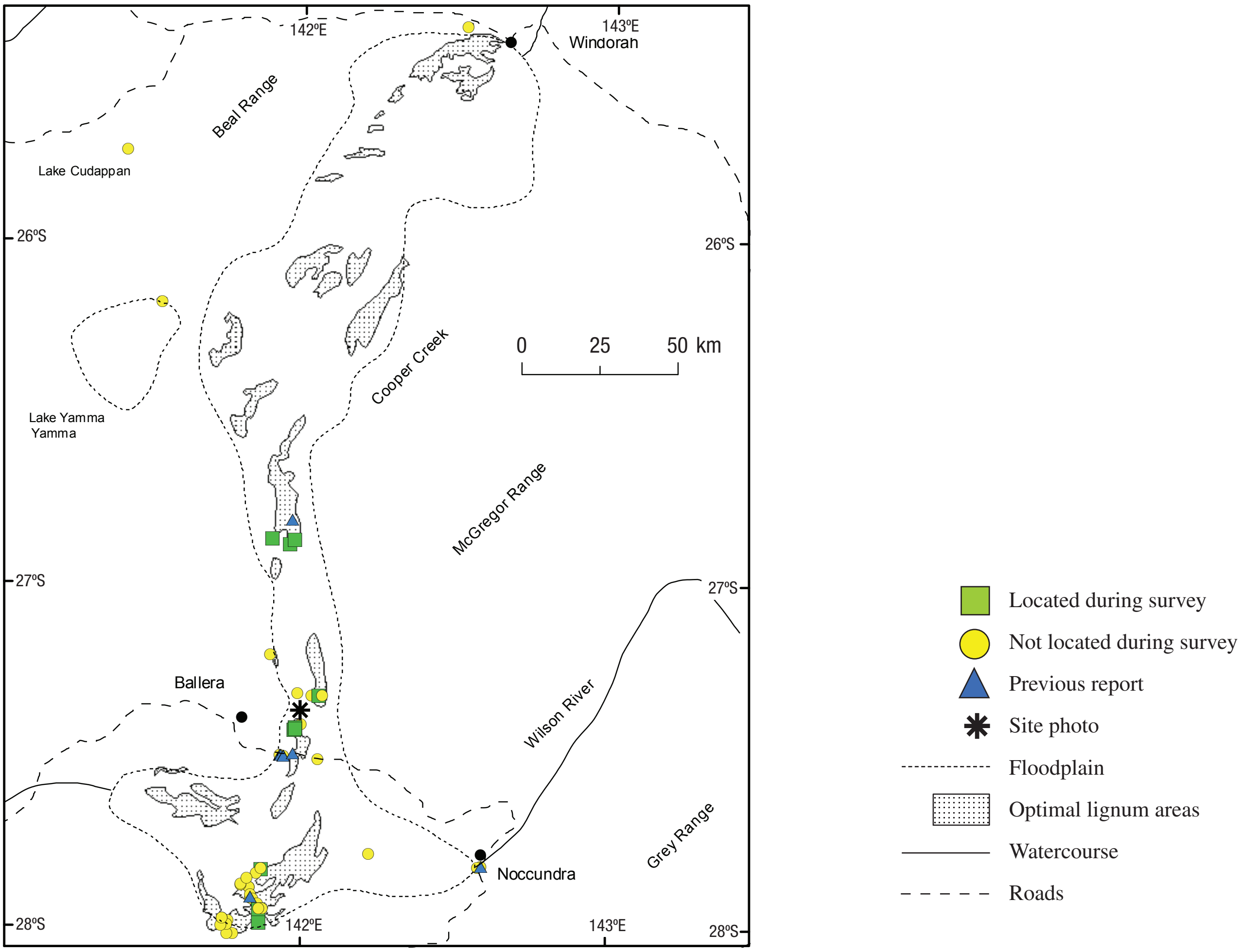

Figure 8. *Map of the Cooper Creek channels and floodplain, showing its approximate limits, optimal areas of Lignum habitat, as identified from satellite imaging, previous Grey Grasswren records, survey records and negative search sites.*

Cooper Creek and Wilson River floodplains

Grey Grasswrens have been reported on one or more occasions since 2009 at Noccundra Waterhole on the Wilson River approximately 50 kilometres to the east of the main Cooper channels. In November 2012 we examined the habitats surrounding the waterhole and farther downstream and then sought suitable areas west of Noccundra and south of Jackson, where the Wilson River and Cooper Creek floodplains merge; we examined one potential site but found no evidence of Grey Grasswrens. In November 2012 we also searched unsuccessfully for grasswrens at and near sites of several observations made between 2005 and 2010, up to 12 kilometres apart, where the Innamincka to Thargomindah road ("The Adventure Way") crosses many channels on the Cooper Creek floodplain. Next we investigated the area towards the southernmost bend of the Cooper floodplain where Grey Grasswrens were found in 2001, south of Little Tooley Wooley Waterhole (Carpenter 2002). We found no Grey Grasswrens at the 2001 site but recorded them at three nearby localities within 15 kilometres of each other near the southerly limit of the Cooper Creek floodplain on 4–5 November 2012. Despite the presence of ample Lignum habitat no grasswrens were detected during visits to sites farther south and west (to the area around Yetally Waterhole), but several observations were made of Yellow Chats and Tawny Grassbirds, neither documented previously from the southern Cooper floodplain (Jaensch *et al.* 2013). On 6 November 2012, we searched Carpenter's (2002) second locality from 2001, east of Ballera Gas Centre, and found grasswrens at four sites within 800 metres of each other (Figure 3).

For the fourth survey we lacked accurate localities for the two records known to us north of the last named site; those from Lake Cudappan and Buncheeda Swamp. We therefore identified the following areas from satellite imagery: six small or moderate sized areas of Lignum swamp north-east of Ballera Gas Centre; the extensive Buncheeda Swamp about 60 kilometres farther to the north-east; Lignum channels on the northern fringe of Lake Yamma Yamma; Candue Swamp farther upstream to the north-east; and 12 Mile Swamp near Windorah. We first investigated the area immediately north of the 6 November 2012 Grey Grasswren site-cluster but no grasswren was detected there. Three more of the six small areas of Lignum swamp were surveyed on 21 May 2013; grasswrens were heard about 12 kilometres north-east of the last 2012 locality but not seen, probably because rain had begun to set in, resulting in 15 to 25 millimetres falling over the whole of the planned survey area. An extended examination near the eastern margin of Buncheeda Swamp on 23 May 2013 was unsuccessful, other than the possible detection of contact calls,

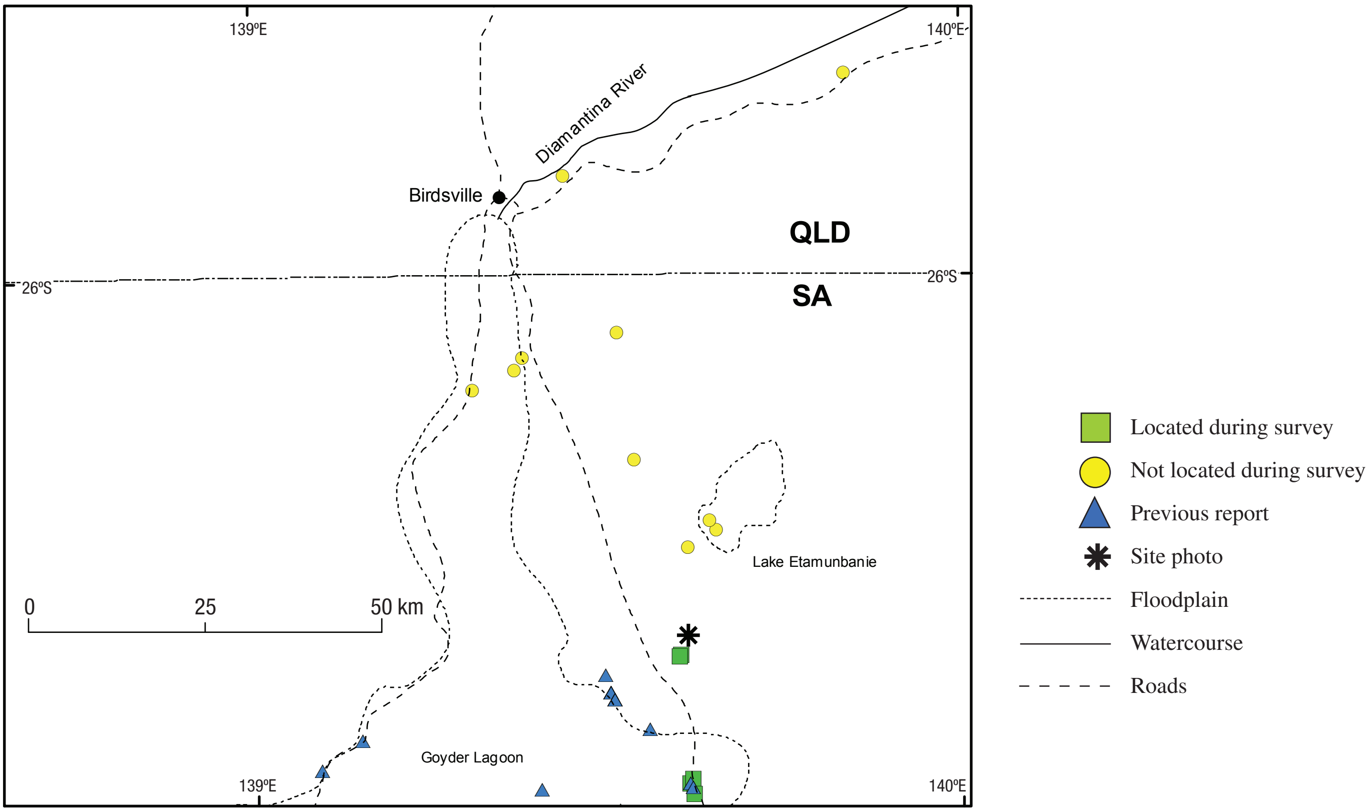

Figure 9. *Map of the southern Diamantina floodplain and northern Goyder Lagoon, showing its approximate limits, previous Grey Grasswren records, survey records and negative search sites.*

but at a channel near its southern extent (C6) at least three Grey Grasswrens were observed. No grasswren was detected at Lake Yamma Yamma or 12 Mile Swamp. Candue Swamp was inaccessible owing to extensive inundation of access tracks. We visited Lake Cudappan on 25 May 2013, but the apparently limited potential habitat for grasswrens, canegrass, scattered River Cooba (Belalie) *Acacia stenophylla* and sparse Lignum, had been severely burnt during extensive lightning fires of the previous summer.

On 11 September 2013 grasswrens were sought unsuccessfully at the site of the 23 May Buncheeda Swamp record (C6) but were seen and heard briefly to the north-west of that site near the northern end of Widindra Waterhole. On 12 September 2013 two grasswrens were located in Buncheeda Swamp where possible calls had been heard in May 2013. Searches on 13 September 2013 near the four closely located sites east of Ballera Gas Centre (C4a – C4d) revealed grasswrens in two places within the same general locality. A search near Tooley Wooley Waterhole which had almost dried out completely (Site C1) was negative.

Diamantina floodplain upstream from Goyder Lagoon

Grey Grasswrens were seen at two sites about eight kilometres north-east of Moongara Crossing on the Birdsville Track (26º 29' S) on 13 August 2012 in a mixed low shrubland of Lignum and Old-man Saltbush (Figure 4). This constituted a modest extension of known range north-east of Goyder Lagoon by about 20 kilometres but grasswrens were not detected in similar shrublands north to approximately 26º 21’ S, west of Lake Etamunbanie. Channels associated with the Diamantina overflow (Gumborie Creek) farther north, to Cudary Yard approximately 26º 04’ S, contained little if any suitable habitat. Areas of Lignum north of Goyder Lagoon, on the west of the main channel of the Diamantina, south to approximately 26º 14' S, and on the east, south to approximately 26º 08' S, were examined during the first and second survey trips but grasswrens were not found (Figure 9).

In summary, including two sites at a locality north-east of Goyder Lagoon, we detected Grey Grasswrens at 20 sites within eleven localities, two localities on Eyre Creek west of Lake Koolivooo, three on Cooper Creek at the southern end of Buncheeda Swamp, two on Cooper Creek east of Ballera Gas Centre, and three on the southern bend of Cooper Creek. We did not find Grey Grasswrens at previous localities on Eyre Creek near Lake Koolivoo, (reported between 1982 and 2009), at Noccundra Waterhole, (reported in 2009), at the Cooper Crossing southeast of Ballera (reports from 2005 to 2010) or in any part of the Diamantina floodplain (records in 1984 and 2001–2002), apart from immediately upstream of Goyder Lagoon (Figures 1, 6-9). Thus, of 36 sites at which Grey Grasswrens of the outlying populations have been recorded, 18 before and 18 during this study, only one pre-2012 site was found to be occupied during the survey, corresponding with the six 2012 sites C4a-C4f. In addition, when sites C1 (November 2012) and C6 (May 2013) were re-examined in September 2013 no grasswrens were found.

Table 1

Cover (per cent) at Grey Grasswren sites.

Cover type (heights in cm)	Goyder survey mean ± s. d.	E1a	E2b	E2c	C1	C2	C3	C4a	C6	This survey mean ± s. d.
Bare	34.5 ± 18.2	32	23	38	54	17	30	16	28	29.7 ± 12.3
Litter and non-shrub	34.5 ± 21.0	5	19	9	12	36	7	41	3	16.5 ± 14.4
Lignum <25	1	0	2	0	0	0	0	0	0	0.3
Lignum 26-50	1.4	4	4	4	0	0	0	0	0	1.5
Lignum 51-75	4.4	1	2	1	3	0	1	2	1	1.6
Lignum 76-100	7.1	3	2	3	8	2	1	4	4	3.4
Lignum 101-125	6.5	10	13	10	8	10	5	3	14	9.1
Lignum 126-150	4.8	8	9	8	7	8	15	16	13	10.5
Lignum 151-175	2.8	4	5	4	7	14	18	11	21	10.5
Lignum 176-200	3	10	2	10	1	12	17	2	14	8.5
Lignum >200	1.5	11	9	11	0	0	6	0	0	4.6
Lignum total	32.5 ± 16.2	63	48	51	34	46	63	36	67	51.0 ± 12.5
Other shrub cover with above		14	10	2	0	1	0	5	2	

Habitats

Habitats were documented in transects at eight grasswren sites, three on Eyre Creek (E1a, E2b, E2c) and five on Cooper Creek (C1-C4a, C6) floodplains. Their cover characteristics are shown in the Table and compared with the cover at Grey Grasswren sites from the Goyder/Warburton survey (Black *et al.* 2012). Note that, in the latter, each 25 centimetres height category represents the total of all shrubs in that category.

Cover characteristics of sites of the outlying populations of Grey Grasswren fall within the range of those found earlier in and downstream of Goyder Lagoon. Total Lignum cover varied from 34 percent to 67 percent and total shrub cover from 34 percent to 77 percent, compared with up to 76 percent in the earlier study, (Black *et al.* 2012) and the majority of sites reported here show comparatively high total and tall Lignum cover (Table 1). Cover other than Lignum at most Cooper Creek sites was dominated by dense, fresh or senescent Nutheads *Epaltes cunninghamii* (chiefly 50–100 cm in height), which was not present in any recordable quantity in the Goyder Lagoon study. Queensland Bluebush *Chenopodium auricomum* provided five percent cover at C4 and one percent at C9 and *Senecio* spp provided 10 percent cover at E4 and two percent at E5. Emergent River Cooba (Belalie) (1%) was present at C6; only at E1a did Old-man Saltbush contribute (14%) to the shrubland structure. In neither study did we devise any practical method of comparing grasswren-presence and grasswren-absence site characteristics as employed in surveys of Western and Thick-billed Grasswrens (Black *et al* 2009a, 2011). Some examples of habitats encountered during this survey are shown in Figures 2–5.

DISCUSSION

Population distribution, density and size

Compared with the 2009 survey, in which Grey Grasswrens were found at 54 localities in the Goyder Lagoon/Warburton Creek area over about eight days, they were detected at ten localities over about 24 days of searching among the outlying populations of Eyre Creek, Diamantina River and Cooper Creek during the current survey. Also in contrast to the Goyder Lagoon survey where 16 of 20 previous records were confirmed (Black *et al*. 2012), the current survey of outlying populations found grasswrens at only two localities (including Buncheeda Swamp) of 18 former record localities. Our survey of the Cooper Channel Country covered only a small proportion of the area of potential habitat, but those of the Eyre Creek and Diamantina floodplains achieved substantial coverage, and all three concentrated on habitat likely to be most suitable for Grey Grasswrens (Figures 2–5). Furthermore, two clusters of closely associated sites accounted for eleven of the 18 sites. We conclude therefore, that Grey Grasswrens are distributed very sparsely and unevenly in this vast area. Yet there are earlier and reliable reports from all three systems that we were unable to confirm. This suggests that one outlying population on the Diamantina River may no longer be extant and that the other two have declined significantly since they were first documented between the 1980s and 2000s, e.g. through repeated small-scale local site-extinctions. While the above comparisons of density do not necessarily indicate total abundance, our results nevertheless show that the three outlying populations of Grey Grasswren comprise relatively tiny numbers of birds in each of the river systems and collectively.

Significant gaps lacking suitable habitat separate the outlying populations from each other and from central populations. About 150 kilometres separate the Eyre Creek floodplain and Goyder Lagoon; between the Diamantina floodplain and the latter the gap is narrower with marginal habitat reducing it to about 50 kilometres. About 70 kilometres separate the Eyre Creek and Diamantina floodplains with only minimal potentially suitable habitat in low-lying drainage lines surrounding Bilpa Morea Claypan. The distance separating the Diamantina and Cooper floodplains is around 150 kilometres, but with the earlier unconfirmed record from Lake Cudappan situated enigmatically between the two. The distance between Noccundra and the terminal Bulloo is over 150 kilometres, with the Grey Range separating the Wilson (Lake Eyre Basin) and Bulloo catchments.

We find therefore that the Eyre Creek, upriver Diamantina and Cooper – Wilson populations are not currently in continuity with the larger central population in Goyder Lagoon. Yet Eyre Creek and Goyder Lagoon individuals are of the same subspecies and appear to belong to a single genetic pool (Christidis *et al.* 2010). The genetic identity of upriver Diamantina and Cooper Creek individuals is not yet determined and, in view of our findings, this question is of some moment. Birds from the Diamantina are (or were) relatively close geographically to those on Eyre Creek and the two river systems are hydrologically connected via Goyder Lagoon well upriver of the xeric and saline Lake Eyre environments. This suggests that they too might belong to the subspecies *A. b diamantina* but the same inference is not derived so readily for grasswrens in the Cooper Creek floodplain, with only the intervening historical but unconfirmed record at Lake Cudappan, a site now apparently unsuitable. The Cooper Creek population is certainly small and apparently isolated; its recent possible decline would provide additional evidence that it is threatened, and if genetically distinct it is a threatened subspecies. If, on the other hand, future analysis shows that it too belongs to the subspecies *A. b. diamantina*, the geographic separation of all three outlying populations from Goyder Lagoon and from one another would suggest that Grey Grasswrens are capable of substantial dispersal, perhaps at times during temporary breakdown of what are otherwise hostile barriers.

Grasswrens are widely considered to have poor dispersal ability (Higgins *et al.* 2001; Christidis *et al.* 2010) a factor considered relevant to their generally less secure conservation status in comparison with fairy-wrens (Skroblin and Murphy 2013). Their short rounded wings and wing to body mass relationship are however similar to those of fairy-wrens but neither group is thought to be capable of flying long distances (Rowley and Russell 1997). Schodde (1982) regarded the flight of grasswrens as weaker than fairy-wrens and showed that their sternum and its keel are shallower, suggesting a relative reduction in bulk of their pectoral muscles. Moreover grasswrens show pronounced taxonomic diversity and short range endemism, typical of poorly dispersing organisms (Schodde 1982; Austin *et al.* 2013).

While there is little direct evidence of how far grasswrens are able to disperse, among populations of the Striated Grasswren *Amytornis striatus* occupying vast tracts of Porcupine Grass *Triodia* spp. that are subject to periodic fires, birds may be absent from sites where they were recorded some years previously, yet found in the near vicinity (LP pers. obs.). Perhaps therefore grasswrens, or at least some grasswren species, may show more mobility than is generally assumed. A substantial level of mobility under particular circumstances, perhaps even as a common strategy for survival among Grey Grasswrens, might be inferred from the non-concordance of pre-2012 and recent survey records. The finding that they have apparently deserted places where they were observed over several or many years suggests that they do not show, in the outlying populations, the site (or at least locality) fidelity that characterises some grasswren species (Black *et al.* 2009a, 2011) or Grey Grasswrens in Goyder Lagoon (Black *et al.* 2012). Perhaps lesser locality fidelity in the Grey Grasswren is influenced by regimes of periodic habitat inundation, a stressor not experienced by other grasswren species. It should also be understood that regimes of inundation will differ year to year between river systems, as well as longitudinally within a given system and unpredictably even on one individual floodplain.

A comparison with the central Goyder Lagoon population

What explains the differences between Goyder Lagoon, where Grey Grasswrens have been found to be plentiful and faithful to locality, and the other inhabited areas of floodplain, where they appear to be unpredictably scattered and scarce? We believe the difference to be real and not a chance finding of the separate surveys; we list a number of possible explanations and further exploration of some of them is considered in the paragraphs below:

- A relative lack of refuges for grasswrens in the wetlands of outlying populations at times of flood and deep inundation, including the comparative rarity of Old-man Saltbush shrublands.
- Differences in the water regimes between Goyder Lagoon and the wetlands occupied by the outlying populations; also hypothetically, a recent change towards more extreme flooding intensity which might be having greater impact on upriver than downriver reaches and their associated floodplains.
- The greater floodplain area of Goyder Lagoon (~3,000 km²) with more extensive Lignum, Swamp Canegrass and fringing Old-man Saltbush shrubland, compared with the narrower upriver Diamantina and Eyre Creek floodplains and restricted areas of habitat on the wider Cooper floodplain.
- Comparatively greater destruction of habitat in the outlying populations by cattle grazing, feral animals and by fire; also potentially greater predation of the outlying populations by native and introduced carnivores;
- Unrecognised differences in the growth stage or other aspects of Lignum between areas inhabited by the central and outlying populations and the relationship of those differing ages and/or forms of Lignum to the habitat requirements of Grey Grasswrens;

Dispersal and refuges

It is possible that the extreme flood events of 1973–1977, similar to those of 2009–2012, were associated with major dispersal of Grey Grasswrens and the establishment of small satellite populations. The mechanism might involve displacement of grasswrens by flooding into habitats invigorated by repeated seasons of exceptional local rainfall that were capable of supporting them (perhaps over several years) during transit across usually inhospitable areas to other floodplain habitats. Such an explanation was offered for the presence of grasswrens for a brief period in the 1980s at Embarka Swamp, Cooper Creek, South Australia (May 1982, Black *et al.* 2009b, 2012). Floods certainly cause Grey Grasswrens to abandon long held territory. A major flood of the Bulloo River in 2000 displaced a dense population (47 individuals trapped in four days in 1991) from a Lignum site, apparently occupied continuously for the previous 16 years (Hardy 2002). Supportive evidence of flood-related displacement was provided by Black *et al.* (2012), including an observation of Grey Grasswrens occupying Sandhill Canegrass *Zygochloa paradoxa* hummock grassland on dunes at Koonchera within Goyder Lagoon when flooded in the mid-1980s (R. Kernot pers. comm. to GC). Large floods can also result in temporary defoliation of the Lignum, as observed in Eyre Creek in April 2009 and on other occasions (RJ personal observation) and could thus inhibit or delay the return of Grey Grasswrens to previously occupied sites.

Grey Grasswrens of the Goyder-Warburton population are known to occupy densely vegetated Lignum swamps and Lignum-lined channels, as well as much more open Lignum and other vegetation such as Old-man Saltbush and mixed species shrublands in more peripheral parts of the floodplain beyond the major Lignum swamps (Black *et al.* 2012). This led us to postulate the role of shrublands of varying composition at the periphery of the floodplain acting as refuges during times of grasswren displacement because of flood. We found Grey Grasswrens of the outlying Cooper Creek population only in dense and flood-invigorated Lignum but on Eyre Creek they were in sparsely foliaged Lignum on a more peripheral part of the floodplain. In the former case our observations were made following moderate or only minor flooding but in the latter at the time of a moderate flood. Old-man Saltbush shrublands are uncommon in the upriver reaches of the Channel Country compared with the Goyder-Warburton floodplain and were rarely encountered during these surveys. It is therefore plausible that a relative lack of flood-time refuge sites inhibits the maintenance of larger numbers in the outlying populations. It is also noteworthy that two early specimen records from near Browns Creek were certainly peripheral on the eastern Diamantina floodplain, at least 10 kilometres beyond major channels and extensive Lignum shrublands. Furthermore the (atypical) habitat described from the five-minute blocks from which those specimens were taken was of “sparse low shrubs including chenopods, sparse low tussock grass and wooded channels” (cited by Jaensch and McFarland 2002). At our visit on 17 August 2012 we could see no likely Grey Grasswren habitat and suspected a serious error of recorded locality. The only “wooded” channels (i.e. with trees or presumably Lignum) were near Pelican Waterhole and some smaller waterholes associated with Browns Creek. The surrounding area, including the stated record-localities did, however correspond with the given description and included tussock grasses, very low shrublands of samphire and *Sclerolaena* spp and small areas of Cottonbush *Maireana aphylla* low shrubland. A further Diamantina observation had been made beyond the continuous floodplain habitat and consisted only of “sparse isolated Lignum shrubs lacking vigour”; another, while consisting of Lignum, at the edge of the floodplain, was considered “not as dense as (some), about 30–10 m apart”, and, somewhat atypically, had a continuous understorey of dense Spike Rush *Eleocharis plana* (Jaensch and McFarland 2002, see also Figure 5), both records being at a time when the Lignum was inundated and the water level was rising. One possible interpretation of these observations (in 1984 and 2001) is that the grasswrens were forced into atypical habitats and localities following displacement from preferred habitat by its continuing inundation.

Flow regimes

While there are similarities between the vegetation of Goyder Lagoon and the floodplains of Eyre Creek, Diamantina River and Cooper Creek, differences in river flow regimes into and through these systems might be responsible for greater instability in the maintenance of habitat suitable for Grey Grasswrens in the outlying populations. Personal observation by some pastoral managers is that the water that enters Goyder Lagoon will stay there, flowing on through the Warburton Creek when inundated but occupying the lagoon for some time thereafter whereas, in upriver floodplains of the outlying populations, floodwaters are more likely to pass rapidly downstream. Flows in upper and middle reaches, particularly in the Diamantina which has no river-connected lakes to absorb floodwater, are sometimes relatively fast and deep, submerging and defoliating lignum and/or reducing the availability of potential grasswren habitat for several weeks or months in such years (RJ personal observation, with examination of satellite imagery and flood data). David Roshier (pers. comm.) observes that Goyder Lagoon is the largest of the Lignum swamps and has regular inflows and that these facts are likely to be of significance. Depth of inundation will also be pertinent and it is possible that this is less variable and less extreme in Goyder Lagoon than at other localities occupied by outlying populations but there is a paucity of information on hydrological conditions in all these systems. Justin Costelloe (pers. comm.) has identified the following potentially relevant factors for which good data are unavailable; the frequency and mean temporal duration of flows through a given reach, flow velocity, mean duration of periods without flow, the persistence of water after inflow has ceased, and the area of inundated preferred habitat and the depth of water around it. Such hydrological variables are almost certainly pertinent to the question of why the outlying populations of Grey Grasswren are sparsely distributed and may occupy different parts of the floodplain on a transient basis.

Habitat disturbance: fire and grazing

Grey Grasswrens of all populations occur entirely within properties whose principal land use is the grazing of cattle. Their habitat may be damaged if the grazing and trampling of cattle (and/or feral pigs) is excessive (Hardy 2010). While Lignum is relatively resilient to such activity, potential refuge habitats such as Old-man Saltbush and Swamp Canegrass may be more severely impacted (LP personal observations). The burning of Lignum is used as a management tool in parts of the Channel Country for opening up areas to encourage grass growth and enhance stock management (Jaensch 2009), and the practice was actively promoted in Queensland in comparatively recent times (Pressland *et al.* 1989). We found old burnt Lignum stumps at several localities, including Lake Cudappan and saw no Lignum on the western side of Lake Yamma Yamma where much existed up to 1974 (LP personal observation). These observations indicate that intermittent loss of Lignum is a real phenomenon and might apply more to habitats of the three outlying populations than to those at Goyder Lagoon. There is potential for localised grasswren populations to be eliminated by fire and, where this has been extensive or repeated over prolonged periods, larger populations could be lost, particularly where denser refuge areas of Lignum are burnt. Habitat disturbance certainly occurs as a result of land use for cattle grazing, including the use of fire, and it is possible that this could affect grasswrens at a local level or even result in broader population declines. However it is less likely that it has occurred on a sufficient scale to account for the very different population densities and total populations in Goyder Lagoon compared with those in the three outlying floodplains under discussion.

Seasonal differences

The two surveys were conducted several years apart. In October 2009 local conditions were favourable following a good autumn flood through Goyder Lagoon which reached Lake Eyre. Through April, August and November 2012 local conditions were again favourable but with increasing desiccation over time since major floods in 2010 and 2011, although ephemeral growth in Goyder Lagoon in 2009 appeared to have persisted more strongly than it did in the outlying wetlands in 2012. By May and September 2013 local conditions were at their worst, following a summer with extreme temperatures and only minor to moderate autumn flooding. It was observed on those trips that birds of all species generally were in very low numbers and it is the experience of all authors and corroborated by others, including local observers, that this situation prevailed through much of arid eastern Australia in 2013, suggesting that substantial mortality might have occurred from heat stress on days of extreme temperature during the previous summer. We cannot therefore discount the possibility that some decline may have occurred also in the Goyder Lagoon populations since it was surveyed in 2009.

Conservation and management

Decline in already small populations of a species over a short period is a serious concern for conservation managers, as reflected in criteria A, B and C for the application of IUCN Red List categories at a regional level (IUCN 2003). Our findings suggest decline in the Eyre and Diamantina populations, the latter possibly to local extinction; they also show that all three outlying populations are small and, if considered in isolation, are thereby threatened on that basis alone. The Eyre and Diamantina populations probably contain fewer than 250 adult birds and could be considered endangered purely under criterion D (IUCN 2003); likewise the Cooper population, with probably fewer than 1000 adult birds would be vulnerable. Threatening processes for the species were identified by McAllan and Cooper (1995) and Hardy (2002, 2010) as habitat degradation from grazing pressures of stock and rabbits and from disturbance by the rooting of feral pigs. Additional threats or potential threats suggested by Black *et al.* (2012) were deliberately lit fire, increasing fire intensity or frequency resulting from climate change, and change to the frequency of inundation as a result of climate change and/or potential future regulation or over-exploitation of water resources of the catchments. Garnett *et al.* (2011) listed threats to the Bulloo population as cattle grazing, especially in dry years, drought, habitat degradation by rabbits and pigs, fire, predation, water extraction and invasive weeds. In addition potential threats might arise from the provision of new stock watering points or in association with oil, coal and gas exploration and extraction, including oil and chemical spills and disruption of water flows.

Of the threats listed above, some such as fire and the browsing by cattle will have a direct impact by temporarily or permanently reducing available habitat for the species. Others, such as drought, climate change and increased water exploitation, might impact less directly but are potentially even more significant threats in the longer term. Upstream river regulation and/or harvest may be the greatest potential threat for grasswrens downstream because Lignum is a wetland-associated plant and the sparse local rainfall is generally insufficient for the viability of Lignum shrublands in the deep-cracking floodplain clay in these arid zone communities, periodic river flooding being essential. Hardy (2002) provided evidence of "ringbarking" of Lignum by rabbits and habitat degradation by pigs in the Bulloo catchment but whether such damaging activity constitutes a seriously deleterious process among the populations discussed here is uncertain. Disruption of hydrological parameters as a result of oil, gas and coal exploration is more hypothetical as a threat. The impacts of predation and weed invasion on Grey Grasswrens have not been studied but it seems unlikely that they will have acted differentially on the conservation of outlying compared with central populations unless through unidentified habitat differences.

Our findings suggest decline and/or dispersal with the threat of local extinction of one or more of the outlying populations, despite and perhaps partly because of a series of major flood events since 2009. If, as it presently appears, they are effectively isolated from the substantial Goyder Lagoon population several questions arise. Is their separation more apparent than real? If so, under what circumstances might the populations merge? Has their potential for reproductive contact declined and, if so, what are the reasons and can they be addressed and reversed? It is possible that DNA analysis of museum specimens might provide evidence of prolonged reproductive isolation perhaps approaching that separating the two known subspecies. This seems very unlikely however, since Eyre Creek specimens have been shown to be genetically close to and perhaps indistinguishable from those in Goyder Lagoon (Christidis *et al*. 2010), suggesting a single panmictic population of *A. barbatus diamantina*. It is possible that the extreme flood events of 1973–1977, similar to those experienced from 2009–2012, were associated with major dispersal of Grey Grasswrens and the establishment of small satellite populations. If that is so we might anticipate the future detection of Grey Grasswrens in places where we have not found them recently, such as on the Diamantina floodplain in Queensland or at Embarka Swamp on the main branch of Cooper Creek in South Australia. Alternatively, major flood events might be responsible for losses within small isolated populations. Whatever the real explanation for such fluctuating fortunes in the outlying populations of Grey Grasswrens, observations over several decades and through diverse conditions may be needed before their potential to recover or be self-sustaining in the longer term, or their suspected high mobility, can be judged. Determining the genetic relationships between all populations will have significant implications for the species' conservation and for clarification of its infra-specific taxonomy.

These outlying populations appear to be both sparser and smaller in total than the Goyder-Warburton population and, if dependent on that central population as a source, the critical significance of the latter for the conservation of the species is highlighted. While we found Grey Grasswrens relatively readily at 54 localities in the Goyder-Warburton floodplain (Black *et al.* 2012) we did not provide an estimate of its total adult population. While we have regarded it as secure, if containing fewer than 1000 adult birds it too would qualify as vulnerable under criterion D (IUCN 2003). The other central population, nominate *A. b. barbatus* has been reported to be in decline in New South Wales (Hardy 2010) and was considered endangered by Garnett *et al.* (2011), but a more detailed examination of its total distribution, including much potential Lignum habitat in Queensland is needed in order to further evaluate its conservation status.

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Appendix 1

Sites where Grey Grasswrens were detected during the survey.

Eyre Creek

E1a. 20 April 2012, one bird was seen and at least two were heard; 18 August 2012 ~ 20 km north-west of Lake Koolivoo, 24º 47' 26" S, 139º 25' 39" E. One or more were seen or heard at the same site on 18 August 2012.

E1b. 19 August 2012, probably three birds were seen ~ 300 m north-west of E1a, 24º 47' 20" S, 139º 25' 20" E.

E2a. 19 August 2012, one or more birds were seen ~ 1.5 km west of E1a, 24º 47' 44" S, 139º 24' 36" E.

E2b 19 August 2012, two birds were seen ~ 1.4 km south-west of E1a, 24º 48' 02" S, 139º 25' 00" E.

E2c. 19 August 2012, one bird was seen ~ 2 km west of E1a, 24º 47' 30" S, 139º 24' 20" E.

Cooper Creek

C1. 4 November 2012, three or four birds were seen ~ east of Tooley Wooley Waterhole, 27º 50' 09" S, 141º 52' 16" E.

C2. 5 November 2012, at least four birds were seen ~ eight km south of Little Tooley Wooley Waterhole, 27º 57' 02" S, 141º 51' 41" E.

C3. 5 November 2012, two birds were seen ~ four km south of C2, 27º59' 19" S, 141º 51' 58" E.

C4a. 6 November 2012, two birds were seen ~ seven km south of Wooroogoorah Waterhole, east of Ballera Gas Centre, 27º 25' 39" S, 141º 58' 43" E.

C4b. 6 November 2012, two birds were seen ~ 400 m north-west of C4a, 27º 25' 29" S, 141º 58' 37" E.

C4c. 6 November 2012, one or more birds were seen ~ 300 m north of C4b, 27º 25' 19" S, 141º 58' 34" E.

C4d. 6 November 2012, one or more birds were seen ~ between C4a and C4b, 27º 25' 34" S, 141º 58' 37" E.

C4e. 13 September 2013, two were heard and one seen 200 m east of C4b and north of C4a, 27º 25' 30" S, 141º 58' 47" E.

C4f. 13 September 2013, two were heard and one seen 200 m east of C4c and north of C4e, 27º 25' 24" S, 141º 58' 43" E.

C5. 21 May 2013, at least two birds were heard in rain but not seen ~ six km east of Bogaller Waterhole, 27º 19' 41" S, 142º 03' 16" E.

C6. 23 May 2013, three birds were seen ~ three km east of Widindra Waterhole, in Buncheeda Swamp, 26º 53' 26" S, 141º 57' 34" E.

C7. 11 September 2013, two birds were heard and one seen briefly near the northern end of Widindra Waterhole, 26º 52' 25" S, 141º 54' 15" E.

C8. 12 September 2013, two birds were seen at a locality in Buncheeda Swamp where possible calls had been detected in May, 26º 52' 28" S, 141º 58' 32" E.

Note that sites C4a to C4f are close to Cooper Creek site 2 of 14 December 2001, listed in the main text.

North-east of Goyder Lagoon

G1a, b. 13 August 2012, two sightings, each of two birds, about 300 m apart, north-east of Moongara Crossing, ~ 26º 29' S, 139º 36' E.

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Dynamics of the waterbird fauna of Peery Lake, arid north-western New South Wales, after flooding

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Waterbirds were surveyed at the north-western end of Peery Lake, a large freshwater overflow lake on the Paroo River, between October 1990 and January 1994, following a major flood that filled the lake in April 1990. Before drying, the lake was recharged by a moderate flood in January 1993 and retained water throughout the study. The survey area comprised about 555 hectares or 11 percent of the lake, plus the adjacent shoreline. Over nine survey periods, a total of 54 waterbird species was recorded, of which eight species were recorded breeding, although only in low numbers. Species richness in individual survey periods ranged between 17 and 42 species. The number of waterbirds in the survey area varied greatly between survey periods, from 636 to 14 359. Two species, Pink-eared Duck *Malacorhynchus membranaceus* and Grey Teal *Anas gracilis*, accounted for about 60 percent of all waterbirds, but the common species varied between survey periods. The responses of waterbirds to the two flood events were markedly different. Waterbird numbers were initially low after the first flood, peaking 27 months after flooding. By contrast, waterbird numbers were high in the first year after the second flood, but fell sharply 12 months after flooding. The abundance and diversity of waterbirds recorded on this small portion of Peery Lake affirmed the lake's importance to waterbirds. The study also showed the dynamic and highly variable nature of the waterbird fauna, whose response to particular flood cycles at the lake can differ widely and cannot be predicted by simple measures such as the size and salinity of the lake.

INTRODUCTION

The Paroo River rises in south-western Queensland and enters arid north-western New South Wales as a single channel that disperses into an 'overflow' area of reticulate channels and wetlands before reaching the Darling River (Figure 1). The Warrego River to the east is connected to the Paroo in NSW via Cuttaburra Creek. Flows in the Paroo are intermittent and irregular, only reaching the Darling in major flood events as in 1990 and 2010 (Bureau of Meteorology 2011). Floods normally develop in the headwaters of the Paroo River in Queensland, but heavy local rainfall in the middle to lower reaches of the catchment can also produce floods. The Paroo and Warrego Rivers are the only rivers in the Murray-Darling Basin that are free of regulation or significant water extraction (Kingsford 1999).

Wetlands in the Paroo River catchment can be divided into seven broad types: river channels and waterholes; claypans and Canegrass *Eragrostis australasica* swamps; Blackbox *Eucalyptus largiflorens* swamps; Spike-rush *Eleocharis* species swamps; Lignum *Muehlenbeckia florulenta* swamps and overflow plains; salt lakes; and freshwater lakes (Goodrick 1984; Kingsford and Porter 1999). Inundation of the wetlands by floodwaters from the upper Paroo or by local heavy rain occurs infrequently. Peery Lake is the largest of the freshwater overflow lakes, generally filling every two to ten years (Goodrick 1984) and taking up to three years to dry (G. Barlow, pers. comm.).

Surveys, mainly from the air, have established the importance of the Paroo wetlands to waterbirds in eastern Australia (Maher and Braithwaite 1992; Kingsford *et al.* 1994; Kingsford and Porter 1999, 2009; Kingsford and Lee 2010; Timms 1997, 2008, 2009; Timms and McDougall 2004). Lignum swamps provide breeding habitat, while freshwater overflow lakes, such as Peery Lake, hold water for longer than other wetlands and maintain populations between floods (Maher and Braithwaite 1992). Overall, at least 63 species of waterbirds have been recorded on the Paroo, including 38 species recorded breeding (Kingsford and Porter 1999). Peery Lake is one of the most significant lakes in the Paroo River catchment (Kingsford and Porter 1999) and in north-western New South Wales (Kingsford *et al*. 1994) in terms of the number of waterbird species and individuals it supports.

The international conservation significance of the Paroo wetlands was recognised in 2007 when some of the major wetlands, including Peery Lake, were listed under the Ramsar Convention (wetlands listed were those within conservation reserves). Reasons for the listing included the diversity and abundance of waterbirds, the presence of threatened waterbird species, and the importance of the wetlands as waterbird breeding sites and drought refuges (Kingsford and Lee 2010).

Proposals to divert water from the Paroo for irrigation have been raised periodically. Such water withdrawals would likely impact adversely on the Paroo wetlands and their waterbirds (Kingsford 1999). In 2003 an agreement between the New South Wales and Queensland governments not to develop the Paroo was formalised in an *Intergovernmental Agreement for the Paroo River.* This agreement recognises the significance of the Paroo wetlands and their biodiversity as well as the value of research and monitoring to guide management of the area. However, the agreement is subject to on-going review and may not necessarily preclude future developments affecting wetland ecology and waterbirds on the Paroo.

The distribution and persistence of temporary wetlands across arid inland Australia is highly variable, reflecting the irregularity in timing, location and amount of rainfall (Roshier *et al*. 2001b). Rainfall in the Australian arid zone is extremely variable, even when compared with other arid regions of the world (Morton *et al*. 2011). Nevertheless, hindcasting of past wetland filling events suggests that there was no period greater than 12 months during the 20th century when wetland filling did not occur at least somewhere in the arid zone (Roshier *et al*. 2001b). This allows populations of mobile waterbirds to persist in the arid zone, even during droughts, by utilising a mosaic of wetlands, most of which are only suitable for brief periods (Roshier *et al*. 2001a; Kingsford and Norman 2002). Despite its low rainfall, arid Australia supports extraordinary numbers of waterbirds (Maher and Braithwaite 1992; Halse *et al.* 1998; Kingsford and Porter 2009), contrary to earlier perceptions that the mesic regions of Australia were more important (e.g. Frith 1963; Norman 1970). During the years from 1986 to 1997, which included the current study period, the most persistent temporary wetlands in inland Australia were mainly in the Paroo River catchment and the adjacent Lake Eyre Basin (Roshier *et al*. 2001b).

To further understand the dynamics of waterbird populations in arid Australia, we describe the results of ground surveys of waterbirds in the north-western portion of Peery Lake in 1990–94, following a major flood on the Paroo in April 1990. We describe changes in abundance and species composition as the lake progressively dried and became more saline and then re-charged in January 1993 when moderate flooding occurred, largely due to run-off from local rain.

STUDY AREA

Peery Lake (30°46'S, 143°36'E) covers 5026 hectares (Kingsford *et al.* 1994) in arid north-western New South Wales and is approximately 100 kilometres north of the junction of the Paroo and Darling Rivers near Wilcannia (Figure 1). At the time of our study Peery Lake was within a grazing leasehold, Peery Station. It was subsequently (2000) included in Paroo-Darling National Park.

In early 1990 heavy rain falling on saturated catchments in south-western Queensland caused major flooding on the Paroo River, with river heights approaching record levels (Bureau of Meteorology 2010). By April 1990, floodwater flowed into the southern end of Peery Lake, completely filling the lake. Subsequent drying was interrupted following torrential local rain between November 1992 and January 1993, when nearby White Cliffs and Wilcannia received between three and five times their average rainfall for these months (Bureau of Meteorology records), and local run-off re-charged the lake. The lake varied in size but held water throughout the study (October 1990 – January 1994).

Waterbirds were observed at the north-western end of the lake (Figure 2). Here, the lake adjoins open sandy flats and stony hills. Its perimeter is sparsely lined by trees or shrubs including River Red Gum *Eucalyptus camaldulensis*, Black Box, River Cooba *Acacia stenophylla*, Whitewood *Atalaya hemiglauca* and Boobialla *Myoporum montanum*. The sedge Pinrush *Cyperus gymnocaulos* is common along the lake margin. Three ephemeral creeks fringed by narrow bands of eucalypt riverine

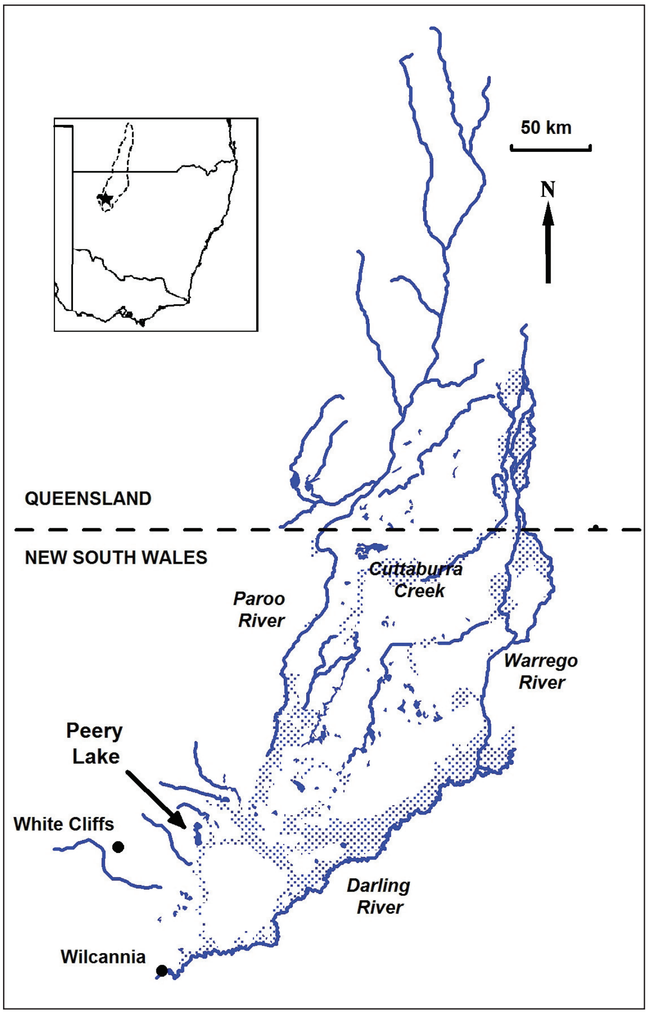

Figure 1. *Location of Peery Lake and the Paroo River.*

woodland enter the lake along this north-western perimeter. As the lake receded, its bed supported extensive patches of short-lived chenopods and herbs, including the Pop Saltbushes *Atriplex holocarpa* and *A. spongiosa*, Black-seeded Samphire *Tecticornia pergranulata*, Blue-rod *Morgania floribunda*, Desert Sneezeweed *Centipeda thespidioides* and Creeping Monkey-flower *Mimulus repens*. A number of extinct and active artesian springs, commonly referred to as mound springs, occur within this portion of the lake. The larger mounds became islands when the lake filled and supported sparse River Red Gums and Black Box (Figure 2). Smaller springs were submerged and treeless.

METHODS

Waterbirds (species of Anseriformes, Podicipediformes, Phalacrocoraciformes, Ciconiiformes, Gruiformes and Charadriiformes) were surveyed in nine periods between October 1990 and January 1994: 10 October–7 November 1990 (28 days), 2–23 July 1991 (22 days), 1–21 October 1991 (21 days), 29 June–23 July 1992 (25 days), 22 September–15 October 1992 (24 days), 7–22 April 1993 (16 days), 12–29 July 1993 (18 days), 28 September–20 October 1993 (23 days) and 18–26 January 1994 (9 days).

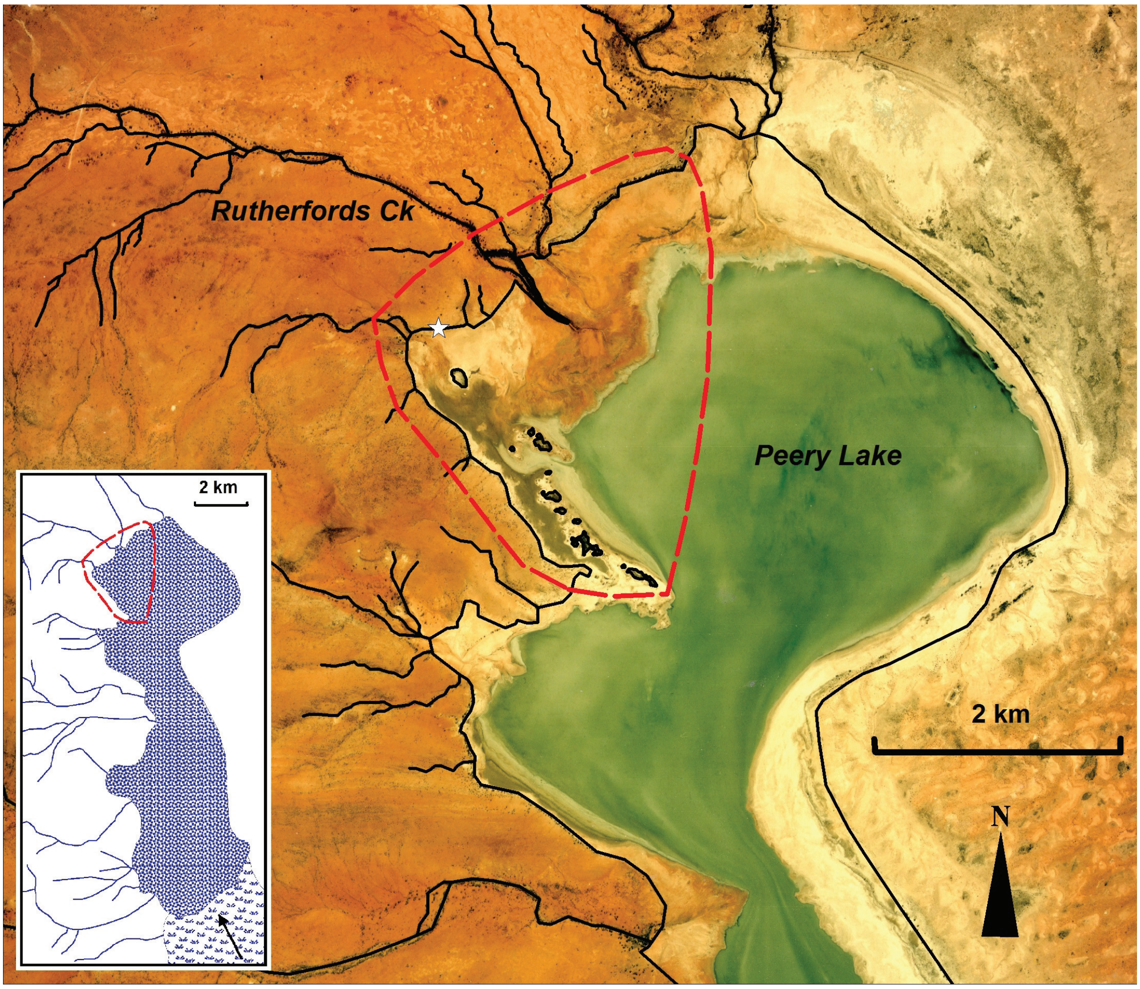

Figure 2. *Peery Lake study area (outlined in red). Reference point for measurement of water recession distances shown by white star. Air photo taken in August 1992.*

The survey area comprised about 555 hectares of the lake (11% of the lake's total area), plus the adjacent land around the shoreline when the lake was full (Figure 2). The waterbird species present within the survey area were identified and counted using binoculars. Birds flying over the survey area were included in counts. For large congregations of birds, numbers were estimated. In each survey period, counts were made opportunistically on a daily basis while surveying terrestrial birds in the vicinity. However, on some days of each survey period not all parts of the survey area were visited. Data analysed comprised the maximum number of individuals of each species recorded in each survey period, regardless of whether the maximum was derived from counts of all or part of the survey area. Evidence of breeding (birds nesting or tending young away from the nest) was also recorded.

The conductivity of the lake water, which is indicative of salinity, was measured in each survey period with a portable conductivity meter with a resolution of 100 µS/cm. Samples beyond the range of the meter (19 900 µS/cm) were diluted with distilled water to allow measurement. The horizontal distance that the water had receded from the April 1990 peak flood line was measured in each survey period from a fixed point on the lake perimeter (Figure 2). Regardless of changing water levels in the lake, the survey area remained constant throughout the study.

RESULTS

A total of 54 waterbird species was recorded during the study (Table 1). Four other wetland-associated bird species were also recorded but not analysed, including a small passerine (Little Grassbird *Megalurus gramineus*) and three raptors (Swamp Harrier *Circus approximans*, White-bellied Sea-Eagle *Haliaeetus leucogaster* and Whistling Kite *Haliastur sphenurus*). Pink-eared Duck (scientific names of waterbird species given in Table 1) (36%) and Grey Teal (24%) accounted for over half the total waterbirds recorded. Other common species were Red-necked Avocet (11%), Eurasian Coot (6%), Hoary-headed Grebe (4%) and Red-capped Plover (2%). Australasian Shoveler, Hardhead, Australian Wood Duck, Black Swan, Freckled Duck, Australian Pelican, Black-tailed Native Hen and Whiskered Tern each contributed about one percent to the total count, while the other 40 species each contributed less than one percent (Table 1). A large flock of about 500 unidentified migratory shorebirds seen flying over the lake in October 1992 also represented about one percent of the total waterbird count.

After the major flood in April 1990, the lake was initially fresh (within the human drinking range) but increased in conductivity as the water evaporated and receded (Figure 3). Conductivity

Table 1

Waterbirds at north-western end of Peery Lake, October 1990 – January 1994. Status of waterbirds of special conservation significance indicated as M = listed migratory species (Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*); E = endangered and V = vulnerable species (NSW *Threatened Species Conservation Act 1995*); C = species of concern at regional level (Smith *et al.* 1994). Numbers are the maximum counts/estimates for each species in each survey period. N = nesting, Y = tending young out of nest. % = contribution of each species to the total waterbird count.

Common name	Scientific name	Status	Oct 1990	July 1991	Oct 1991	Jul 1992	Oct 1992	Apr 1993	July 1993	Oct 1993	Jan 1994	Total	%
Musk Duck	*Biziura lobata*							1				1	<0.01
Freckled Duck	*Stictonetta naevosa*	V,C			5	400		20	50	200		675	1.36
Black Swan	*Cygnus atratus*		55,Y	33	74	2		6	200	250,NY	37	657	1.33
Australian Shelduck	*Tadorna tadornoides*		3			2			2	2		9	0.02
Australian Wood Duck	*Chenonetta jubata*		10	58	300	7		150	3		160	688	1.39
Pink-eared Duck	*Malacorhynchus membranaceus*		12	28	9	8000		2500	4000	3000	300	17,849	36.00
Australasian Shoveler	*Anas rhynchotis*			12		500		20	150	30	20	732	1.48
Grey Teal	*Anas gracilis*		20,N	500	400	3000	800	1500	2500	2000	1200	11,920	24.04
Pacific Black Duck	*Anas superciliosa*			7	7		20	1	2			37	0.07
Hardhead	*Aythya australis*			50	9			200	300	20	3	582	1.17
Blue-billed Duck	*Oxyura australis*	V,C						10	2	3		15	0.03
Hoary-headed Grebe[1]	*Poliocephalus poliocephalus*			60	30			1500	70	500		2160	4.36
Australasian Darter	*Anhinger novaehollandiae*			3	3			5	2	1	9	23	0.05
Little Pied Cormorant	*Microcarbo melanoleucos*			40				8	35	4		87	0.18
Great Cormorant	*Phalocrocorax carbo*			4	300				36	4	1	345	0.70
Little Black Cormorant	*Phalocrocorax sulcirostris*			110	10			25	9	4	20	178	0.36
Pied Cormorant	*Phalacrocorax varius*		2	1	100			8	35	4		150	0.30
Australian Pelican	*Pelecanus conspicillatus*		30	32	120	100	57	58	3	15	120	535	1.08
White-necked Heron	*Ardea pacifica*		1	1				2	2	1	1	8	0.02
Eastern Great Egret	*Ardea modesta*	M			1				1	1		3	0.01
White-faced Heron	*Egretta novaehollandiae*		2	7	1			6	2	1	2	21	0.04
Little Egret	*Egretta garzetta*									1		1	<0.01
Nankeen Night Heron	*Nycticorax caledonicus*		1		2		1	8		1	1	14	0.03
Glossy Ibis	*Plegadis falcinellus*	M	75					1				76	0.15
Australian White Ibis	*Threskiornis molucca*				2						1	3	0.01
Straw-necked Ibis	*Threskiornis spinicollis*		2		25	63	6	55		28	56	235	0.47
Royal Spoonbill	*Platalea regia*		4	2	4							10	0.02
Yellow-billed Spoonbill	*Platalea flavipes*		2	4	13	65		4		1	6	95	0.19
Brolga	*Grus rubicunda*	V,C	2					2	3	2		9	0.02
Black-tailed Native Hen	*Tribonyx ventralis*		300		120			153	1	3		577	1.16
Eurasian Coot	*Fulica atra*		1	260	50			500	1000	1000	3	2814	5.68
Black-winged Stilt	*Himantopus himantopus*					2	9	50,Y	1	2	9	73	0.15
Red-necked Avocet	*Recurvirostra novaehollandiae*					2000	3000	50	40	20	500	5610	11.31
Grey Plover	*Pluvialis squatarola*	M								1		1	<0.01
Red-capped Plover	*Charadruis ruficapillus*		4	14,N	150	200	19	300	50	80,N	200	1017	2.05
Oriental Plover	*Charadius veredus*	M			2							2	<0.01
Black-fronted Dotterel	*Elseyornis melanops*		2	15	20,N	4	1	10	15	6	4	77	0.16
Red-kneed Dotterel	*Erythrogonys cinctus*		6		10		1	10		1		28	0.06
Banded Lapwing	*Vanellus tricolor*		21,Y	3				5			7	36	0.07
Masked Lapwing	*Vanellus miles*		2	14	9	2	2	7	2	4,N	8	50	0.10
Latham's Snipe	*Gallinago hardwickii*	M,C					1					1	<0.01
Black-tailed Godwit	*Limosa limosa*	M,V						1				1	<0.01
Common Sandpiper	*Actitis hypoleucos*	M			1							1	<0.01
Common Greenshank	*Tringa nebularia*	M					2			2		4	0.01
Marsh Sandpiper	*Tringa stagnatilis*	M						9		7	30	46	0.09
Red-necked Stint	*Calidris ruficollis*	M		13	3	7		15		1	30	69	0.14
Sharp-tailed Sandpiper	*Calidris acuminata*	M			60		20	80		43	100	303	0.61
Curlew Sandpiper	*Calidris ferruginea*	M,E						50		2	20	72	0.15
Unidentified migratory shorebirds							500					500	1.01
Australian Pratincole	*Stiltia isabella*		50,Y		27					5	1	83	0.17
Gull-billed Tern	*Gelochelidon nicotica*		3		3		1	1		3	2	13	0.03
Caspian Tern	*Hydroprogne caspia*	M	4	2	9			7	1	8		31	0.06
Whiskered Tern	*Chlidonias hybrida*		19		13		500	1		10	150	693	1.40
White-winged Black Tern	*Chlidonias leucoptera*	M						200				200	0.40
Silver Gull	*Chroicocephalus novaehollandiae*		3	50	9	5	61	18	11	4	1	162	0.33
Total species			**27**	**26**	**35**	**17**	**18**	**42**	**30**	**42**	**31**	**54**	
Total waterbirds			**636**	**1323**	**1901**	**14 359**	**5001**	**7557**	**8528**	**7275**	**3002**	**49 582**	

[1]The Hoary-headed Grebe counts may have included some Australasian Grebe (*Tachybaptus novaehollandiae*) but this was not confirmed.

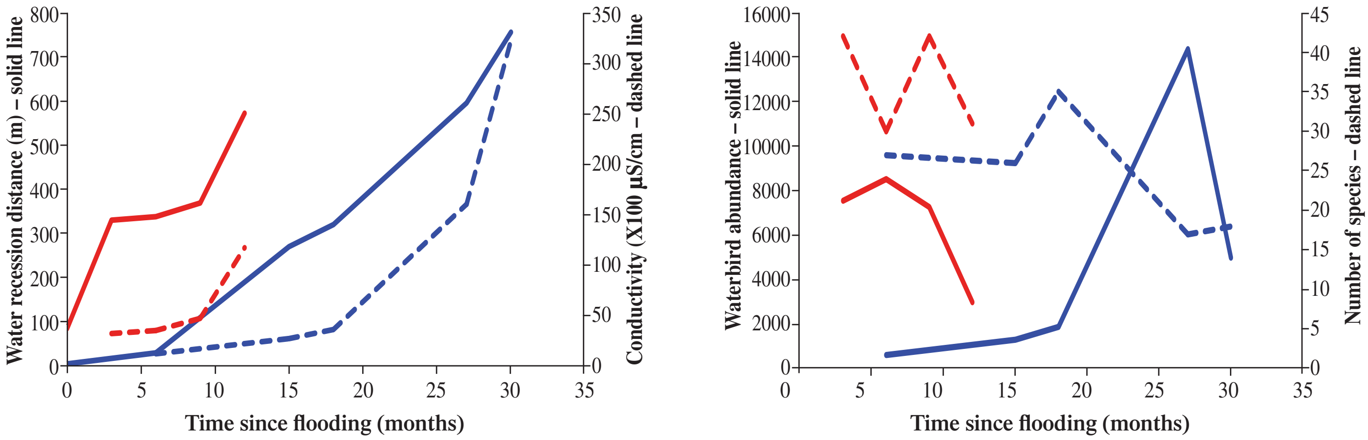

Figure 3. *Water recession distance, water conductivity, waterbird abundance and number of waterbird species recorded at north-western end of Peery Lake after floods in April 1990 (blue) and January 1993 (red).*

peaked in October 1992 when the lake water was 64 percent of the typical value for sea water and the lake had receded about 750 metres from its flood peak. Conductivity decreased after local flooding in January 1993 and the lake water became fresh again. Conductivity increased in the year after the second flood, and particularly during the last three months, as the lake receded again (Figure 3). There was a significant positive relationship between the distance the water had receded from the April 1990 peak flood level and its conductivity ($R = 0.88$, $P = 0.002$).

The number of waterbirds recorded varied widely across surveys, from 636 to 14 359 (Table 1). Waterbird numbers were low but increased steadily during the first 18 months after the April 1990 flood, then rose dramatically to reach a maximum 27 months after the flood, before dropping rapidly over the next three months as the lake reached its lowest level and highest conductivity for the study (Figure 3). After the January 1993 flood, by contrast, waterbird numbers were high for the first nine months after the flood before falling in the next three months as the water level fell and conductivity increased during the hot months of late spring and summer. After the second flood, waterbird numbers were lowest 12 months after the flood. The water recession distance and conductivity at this time were similar to the measurements 27 months after the first flood, when, by contrast, waterbird numbers were higher than at any other time during the study (Figure 3).

The number of species recorded in each survey period ranged from 17 to 42 (Table 1). After both floods, species richness was lowest in the same survey period when waterbird abundance was highest. In both cases, this was a winter survey (July 1992 and July 1993), when migratory shorebird and tern species were absent. The lowest species richness for the study was in July 1992, 27 months after the first flood, when many species were absent that had been present in July 1991 and were present again in July 1993, after the second flood (Pacific Black Duck, Hardhead, Hoary-headed Grebe, Australasian Darter, Little Pied Cormorant, Great Cormorant, Little Black Cormorant, Pied Cormorant, White-necked Heron, White-faced Heron, Eurasian Coot and Caspian Tern) (Table 1). Species richness was highest for the study in the first year after the second flood (Figure 3). By comparison, after the first flood, species richness did not peak until 18 months after flooding, although at a similar stage to the second flooding cycle in terms of water recession distance and conductivity (Figure 3).

The populations of individual species peaked at different times during the study (Table 2), so that there were different combinations of common species in each survey period. As an example of the large fluctuations that occurred between surveys, there were about 8000 Pink-eared Ducks in the survey area during the July 1992 survey, the largest population of any species during the study, and yet no Pink-eared Ducks were recorded during the October 1992 survey period, only three months later (Table 1). Only six of the 54 waterbird species recorded were present in every survey period (Grey Teal, Australian Pelican, Red-capped Plover, Black-fronted Dotterel, Masked Lapwing and Silver Gull) (Table 1). Large daily fluctuations in numbers also occurred for individual species during survey periods. For example, during the October 1992 survey period, the number of Red-necked Avocets in the survey area each day varied from about 3000 to none.

Only eight waterbird species were recorded breeding in the survey area (Table 1), mostly in October 1990 (six months after the first flood) and October 1993 (nine months after the second flood). The numbers of birds involved were small, except for a colony of nesting Black Swans spread over four mound spring islands in October 1993 (37 nests in all).

DISCUSSION

Over two flooding events (a major regional flood and subsequent local flooding), the north-western end of Peery Lake supported an abundant (up to 14 359 individuals recorded per survey period), rich (54 species recorded) and highly variable waterbird fauna, affirming its importance to waterbirds.

Maximum waterbird counts that have been recorded for Peery Lake in previous aerial surveys were 35 900 in March 1990 and 38 000 in March 1993 (Kingsford and Lee 2010). Our count of 14 359 waterbirds in the survey area in July 1992, covering only about 11 percent of the lake, represents a higher density of waterbirds than previously reported (26 birds/ha compared with 8/ha in March 1993), however, comparisons are tenuous for data

Table 2

Peak counts for waterbird species at north-western end of Peery Lake, October 1990 - January 1994. Species shown are those with maximum counts of at least 100 individuals during at least one survey period. The migratory shorebirds grouping includes Oriental Plover, Grey Plover, Common Sandpiper, Sharp-tailed Sandpiper, Curlew Sandpiper, Red-necked Stint, Latham's Snipe, Black-tailed Godwit, Common Greenshank, Marsh Sandpiper and unidentified birds.

Species	APRIL 1990 FLOOD	Oct 90	Jul 91	Oct 91	Jul 92	Oct 92	JANUARY 1993 FLOOD	Apr 93	Jul 93	Oct 93	Jan 94
Black-tailed Native Hen		300		120				153	1	3	
Little Black Cormorant			110	10				25	9	4	20
Pied Cormorant		2	1	100				8	35	4	
Great Cormorant			4	300					36	4	1
Australian Pelican		30	32	120	100	57		58	3	15	120
Australian Wood Duck		10	58	300	7			150	3		160
Freckled Duck				5	400			20	50	200	
Grey Teal		20	500	400	3000	800		1500	2500	2000	1200
Australasian Shoveler			12		500			20	150	30	20
Pink-eared Duck		12	28	9	8000			2500	4000	3000	300
Red-necked Avocet					2000	3000		50	40	20	500
Migratory shorebirds			13	66	7	523		155		56	180
Whiskered Tern		19		13		500		1		10	150
Hoary-headed Grebe			60	30				1500	70	500	
Red-capped Plover		4	14	150	200	19		300	50	80	200
White-winged Black Tern								200			
Hardhead			50	9				200	300	20	3
Eurasian Coot		1	260	50				500	1000	1000	3
Black Swan		55	33	74	2			6	200	250	37

derived using different counting methods (aerial versus ground based counts) and survey areas (part of lake close to shoreline versus entire lake). During our study, waterbird numbers and species richness varied on a daily basis as birds moved in and out of the survey area from other parts of Peery Lake or from other wetlands. Counts such as ours, combining maximum numbers of individuals per species over a prolonged survey period, are likely to provide higher measures of abundance and species richness than one-day counts. However, they provide a useful indication of the lake's potential to support waterbirds and allow for comparison between survey periods while taking account of daily fluctuations.

Large changes in waterbird species and numbers occurred between surveys. There was a regular seasonal component with 11 non-breeding migratory species from the Northern Hemisphere only present in spring-summer, including the White-winged Black Tern and 10 migratory shorebird species (Table 1). Whiskered Terns were also absent during winter surveys (Table 1). However, these migratory species represented only about four percent of the total waterbird count. Most variations in waterbirds at Peery Lake related to flooding cycles and the irregular movement of waterbirds between wetlands as conditions change, especially food availability (Timms and McDougall 2004). There was similar high variation between waterbird surveys only three months apart in north-western New South Wales over a study period (1987–93) that overlapped with the present study, and this variation was evident not only for individual wetlands, but also for the Paroo catchment as a whole (Roshier *et al*. 2002).

Waterbird numbers were lowest at the north-western end of Peery Lake in October 1990, six months after the major flood in April 1990 when, paradoxically, there was more water in the lake than in any other survey period. Elsewhere in the Paroo system, at this time, water was present in widespread ephemeral wetlands, notably the Lignum swamps, the most important waterbird breeding habitat on the Paroo (Maher and Braithwaite 1992). The Lake Eyre Basin to the west also experienced a major flood and in December 1990 an estimated half a million waterbirds were present along the lower Cooper Creek, including Lake Hope, Lake Blanche and Lake Eyre (Kingsford *et al.* 1999). Under such conditions, Peery Lake was probably of only minor significance as waterbird habitat. Despite this, large numbers of waterbirds (about 35 900) were recorded in aerial surveys of Peery Lake in March 1990, when the lake was filling (Kingsford and Lee 2010).

The importance of Peery Lake lies mainly in the prolonged period for which it holds water, for an inland wetland. As more ephemeral wetlands dry out, waterbirds concentrate on Peery Lake and other freshwater overflow lakes, which act as refuges for waterbirds on the Paroo between floods (Maher and Braithwaite 1992). The highest waterbird numbers recorded during the study were in July 1992, 27 months after the lake had filled, when most other Paroo wetlands had dried, and waterbirds had moved to Peery Lake. Waterbirds are also likely to have come from other drainage systems, especially the Lake Eyre system. Over the period 1987–93, the best predictor of waterbird abundance in the Paroo River catchment was large changes in wetland area in the Lake Eyre Basin and its component catchments rather than changes in wetland area in the Paroo catchment itself (Roshier *et al*. 2002).

After major flooding filled Peery Lake to capacity in April 1990, the lake was used by a succession of waterbirds. Common species whose numbers peaked in the first 18 months after the flood, while the lake was fresh and relatively full, included deep-water species feeding on fish, frogs and invertebrates (Australian Pelican, Great Cormorant, Little Black Cormorant and Pied Cormorant), and lakeside grazing species (Black-tailed Native Hen and Australian Wood Duck). In the following year, as the lake receded rapidly and became more saline, dabbling ducks feeding on a mixture of plants and invertebrates dominated (Pink-eared Duck, Grey Teal, Australasian Shoveler and Freckled Duck). Species diversity declined, but waterbird numbers increased dramatically, due mainly to very large populations of both Pink-eared Ducks and Grey Teal. By October 1992, 30 months after the lake had filled, when the water level was lowest and salinity highest, waterbird numbers had declined again, particularly dabbling ducks. However, at this time, wading and shoreline species that feed on invertebrates in saline habitats reached peak numbers (Red-necked Avocet and migratory shorebirds), together with Whiskered Terns flying over the water searching for small fish and invertebrates (waterbird diets based on Kingsford 1991).

The response of waterbirds to the second flood was markedly different to the first flood. Waterbird numbers were high for the first nine months after the second flood (higher than in all survey periods after the first flood except for July 1992), but had declined greatly by January 1994, only 12 months after the flood. After the first flood, waterbird numbers were initially low and peaked 27 months after the flood, before falling sharply in the next three months. The survey period after the second flood when waterbird numbers were lowest (January 1994) roughly corresponded, in terms of wetland area and salinity, to the survey period after the first flood when waterbird numbers were highest (July 1992).

The most common waterbirds after the second flood were again the Pink-eared Duck and Grey Teal. Other common waterbirds were two deep-water species, the Hoary-headed Grebe and Eurasian Coot (the former feeding on invertebrates, the latter on plants), both of which were less numerous after the first flood. Other species more common after the second than the first flood included two more deep-water species (Black Swan and Hardhead), a shoreline species (Red-capped Plover) and a tern (White-winged Black Tern). Another pronounced difference between the floods was the greater diversity of waterbird species present in the first year after the second flood than at any stage after the first flood (allowing for the lower number of species in winter, when migratory species were absent).

These differences between the two floods may be due to differences in food resources or other factors at Peery Lake, or differences in wetland availability, locally, regionally or nationally. The dynamic and highly variable nature of the lake's waterbird fauna shows that responses of waterbirds to particular flood cycles vary considerably and cannot be predicted by simple measures such as the amount of water in the lake and its salinity.

Despite the large numbers of waterbirds recorded, only eight species represented by only a few individuals bred in the study area (Table 1). The paucity of breeding records probably reflects a lack of suitable breeding habitat, especially areas of Lignum swamp (Maher and Braithwaite 1992). The several small islands within the study area, created by mound springs (Figure 2), were not major nesting sites during the survey periods, except for a colony of 37 Black Swan nests in October 1993. Australian Pelicans have also nested colonially on these islands in the past (G. Barlow, pers. comm.) and breed elsewhere on the lake (Maher 1991). Additional species that have been reported breeding on Peery Lake, although only in low numbers, include Pacific Black Duck, Hardhead, Pink-eared Duck, Yellow-billed Spoonbill, Royal Spoonbill, Australian White Ibis and Eurasian Coot (Kingsford *et al.* 1994). The spoonbill and ibis nests were presumably outside of our survey area at the southern end of the lake, which supports better breeding habitat, including large areas of Canegrass and Lignum (Kingsford *et al*. 1994).

Seventeen species recorded have special conservation significance at national, state or regional level (Table 1). One of the nationally listed migratory species, the Oriental Plover, which was recorded during the October 1991 survey period (two individuals), was only the third record for inland New South Wales and the first for the Upper Western region (Morris 1994). The Freckled Duck, listed as a vulnerable species in NSW, was recorded in substantial numbers after both floods, with about 400 in July 1992 and 200 in October 1993. Non-breeding Freckled Duck favour large, open, freshwater wetlands with little aquatic vegetation (Martindale 1984). Few places support large numbers of Freckled Duck, but include four lakes in the Paroo catchment: Numalla Lake (maximum count 9720), Lake Wyara (5540), Yantabangee Lake (2114) and Peery Lake (1373) (Kingsford and Porter 1999).

Inland waterbirds are mobile and nomadic (Lawler and Briggs 1991; Briggs 1992), moving widely between dispersed wetlands as conditions change in the boom and bust arid environment. Movements occur at local, regional and continental scales, resulting in rapid and irregular fluctuations in the numbers and species of waterbirds present on an individual wetland, of which this study is an example. Ultimately, the conservation of waterbirds in Australia depends not only on the reservation of a selection of important wetlands such as Peery Lake, but also on a landscape-scale approach to wetland and waterbird conservation on and off reserves. Major conservation measures are needed to address threats both within the Paroo catchment, such as potential increased extraction of water for irrigated agriculture (Kingsford 1999), and more widely, such as the potential future impact of climate change in inland Australia. Climate change impacts, exacerbated by extraction of water for irrigation, could be catastrophic for waterbirds relying on a mosaic of inland wetlands for survival.

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Breeding diet and behaviour of a pair of Grey Falcons *Falco hypoleucos* and their offspring in north-western New South Wales

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The diet of a pair of Grey Falcons *Falco hypoleucos* was investigated in Sturt National Park, arid north-western New South Wales, by analysis of pellets and orts collected during October–December 2003 beneath a nest in a riparian Coolibah *Eucalyptus coolabah* beside a gibber plain. The falcons fledged a brood of four young in a year of above-average rainfall in the first half (and average rainfall overall), from an estimated egg-laying date of early August. The falcons' breeding diet (n = 62 prey items from 58 dietary samples) consisted, by number, mainly of birds (99%, 63% being parrots) and one mammal; parrots formed most of the biomass (90%) of identified avian prey. Geometric Mean Prey Weight was 29.6 grams, and dietary diversity (Shannon Index) was 1.98. Small–medium (<100 g) granivorous birds were selected as prey (P <0.01). The juvenile offspring accompanied their hunting parents, associating with them for at least five months post-fledging.

INTRODUCTION

The endemic Grey Falcon *Falco hypoleucos*, of the Australian arid and semi-arid zones, was recently reassessed as meeting IUCN criteria for nationally vulnerable, with a global population estimated as possibly fewer than 1000 individuals (Garnett *et al.* 2011). It was also recently upgraded to endangered in New South Wales, under the NSW *Threatened Species Conservation Act 1995* (NSW Scientific Committee 2009, 2010). Previous unquantified prey lists, and recent quantified dietary studies, have characterised this falcon's diet as mainly birds (mostly granivorous pigeons and parrots), with secondary prey of small mammals and reptiles (see Czechura and Debus 1985; Olsen and Olsen 1986; Marchant and Higgins 1993; Harrison 2000; Aumann 2001; Falkenberg 2011; Sutton 2011; Watson 2011; Schoenjahn 2013a). However, no published studies exist on this species in New South Wales, where ecological information is required for its conservation and management.

The Grey Falcon's breeding and hunting behaviour is little described, other than anecdotally (see Watson 2011 for a review), although it has been suggested that the post-fledging dependence period may last almost until the next breeding season (e.g. Marchant and Higgins 1993; Schoenjahn 2011, 2013b). Baylis and van Gessel (2011) briefly described the behaviour of two Grey Falcon pairs and offspring early in the post-fledging period.

The present study sought to determine the breeding diet of a Grey Falcon pair and offspring in arid north-western NSW in 2003, in relation to potentially available prey species, and whether the falcons selected avian prey according to characteristics of prey species such as diet, social structure or habitat. Our study represents the largest quantified sample of Grey Falcon prey identified to species level reported to date. Some behavioural observations of the falcon pair and offspring associating during the post-fledging period, with juveniles accompanying the hunting adults, are also presented.

STUDY AREA AND METHODS

The study area was in Sturt National Park (NP; 325 329 ha) near Tibooburra (29°42 S, 142°03 E) in the extreme north-west corner of New South Wales (exact locality of the falcons' nest site withheld). The landscape within the study area consists of undulating gibber plains interspersed with mesas ('jump-ups'), vegetated with saltbush *Atriplex* spp., other chenopods and grasses (Mitchell grasses *Astrebla* spp. and others), and traversed by ephemeral creeks lined with River Red Gum *Eucalyptus camaldulensis*, Coolibah *E. coolabah* and Gidgee *Acacia cambagei*. The climate is arid, with a mean annual rainfall of 223 mm and mean annual temperature of 27.4°C (maxima up to 49°C) at the time of the study (Denny 1975; NPWS 1996; Montague-Drake and Croft 2004). Overall, Tibooburra received average rainfall in 2003, though above average in the first half of the year, with strong peaks in February and April and lesser peaks in June, August and November, before a decline to generally drier conditions in 2004 (other than a small peak in May 2004) (Australian Bureau of Meteorology data; Table 1).

The falcons' active nest in 2003 was a corvid's stick nest high in the crown of a living Coolibah approximately 15 metres tall, beside a well-wooded intermittently flowing creek adjoining an open gibber plain (Figure1). The nest site was within approximately 10 kilometres of each of three permanent water sources frequented regularly by many avian species. The nearest of these was an open earth tank preferred by flocks of small parrot species.

Table 1

Monthly rainfall (mm) for the study area in 2003 and 2004 against the long-term average 1886–2013 (Tibooburra weather station, Bureau of Meteorology data).

Year	J	F	M	A	M	J	J	A	S	O	N	D	Total
2003	2.2	44.6	0	58.6	12.8	23.8	2.8	33	0	8.2	20.2	16.6	222.8
2004	1.8	13	3.4	4.8	37.6	16	9.4	20.8	17.6	4	27	0	155.4
All (av.)	28	29.8	24.8	14.4	18	16.6	16.4	11.5	12.3	18.2	18	22.1	227.2

Figure 1. *Nest site of Grey Falcons, in crown of Coolibah* Eucalyptus coolabah *~15 m tall, Sturt National Park, 28 July 2003.*
Photo: David Roshier.

The nest was located within the Channel Country Bioregion (see Thackway and Creswell 1995; NPWS 2003), which is characterised by an extensive stream system with wide floodplains and large waterholes. Vegetation in this area consists of riparian eucalypts (River Red Gum, Coolibah and Black Box *Eucalyptus largiflorens*), with tall shrubs (Gidgee and River Cooba *Acacia stenophylla*) and lower shrubs (e.g. Prickly Wattle *A. victoriae*, Thorny Saltbush *Rhagodia spinescens*), amid gibber plains vegetated with grasses and low shrubs.

On 28 July 2003, DR and IW found the nest when one of a pair of Grey Falcons present flushed from the tree. In late August/early September, IW and UK confirmed a Grey Falcon incubating on the nest, and on 13 October observed four Grey Falcon chicks therein (in both cases observed distantly by telephoto lens). All four chicks had fledged by the time of the next visit by DR and IW on 29 October. The falcon pair and four fledglings were in flight nearby and, as activity around the nest tree presented no risk to the juveniles, the major dietary sampling was then conducted. By the next visit on 26 December, the falcons had vacated the nest area, although the group of six (assumed to be the same birds, given the rarity of the species) was still present in the wider area.

Pellets and other dietary remains were collected from the ground directly beneath the vacated nest on 29 October (55 pellets) by DR and IW, with a further three pellets collected on 26 December. The pellets were all of similar size, confidently ascribed to the Grey Falcon pair on the basis of their freshness when collected late in the breeding cycle, and because Grey Falcons had been observed in and around the tree over the past three months and no old pellets were found. To avoid disturbance, minimise visits to the site and maximise valuable data, the ground was not cleared or plastic sheeting/shadecloth emplaced before further collections. Although the lack of such collection practice may introduce dietary biases related to prior occupants of the nest (see Discussion), there was no reason to suspect that the pellets belonged to any other raptor species or previous breeding activity. Furthermore, the nest tree was in a creekline that floods, and the ground beneath the nest would be cleared of any pellets after significant rain, thus preventing long-term accumulations. On each site visit, the nest tree and contiguous creekline trees for two kilometres either side of the nest were searched (negatively) for other raptors and nests.

Each dietary sample (pellet or ort), stored at Sturt NP for later analysis by IJ, was individually bagged and labelled, soaked in 70 percent ethanol for 24 hours, washed with water on a mesh cloth, and dried for 48 hours. Prey items were identified using a local reference collection (bird specimens or feathers held at Sturt NP) and a bird identification key constructed from 94 avian species of body size less than 34 centimetres in total length (bill tip to tail tip, i.e. the maximum prey size recorded for Grey Falcons) known to inhabit the area, and using prey species listed in the literature (cited above) as a guide. Mammal hair was identified microscopically (400× magnification) using the software program 'Hair ID' (Ecobyte Pty Ltd; www.ecobyte.com.au). The minimum number of prey individuals of each species in the total sample was calculated from body parts and main feathers (remiges or rectrices); this method accounts for individual items appearing in more than one pellet, by not assuming that one pellet necessarily equals one prey item (e.g. Olsen *et al.* 2006).

The avian assemblage of Sturt NP was determined from the Park's extensive species lists (Sturt NP fauna database, per Park staff, researchers and visiting ornithologists: NPWS 1996; I. Witte). To investigate prey selection, avian prey-species variables (for species <34 cm in length) were categorised by diet (granivorous/frugivorous, omnivorous or insectivorous); preferred terrestrial habitats among those available in Sturt NP (open/saltbush, open/lightly timbered, lightly timbered, woodland, or all habitat types); and social structure (solitary/pairs, pairs/small groups, flocks, or all three). Information on these aspects of the ecology of prey and their mean body weights were obtained from the literature (Higgins 1999; Higgins *et al.* 2001; Higgins *et al.* 2006). Avian species found in pellets were categorised as 'small' (<20 g), 'medium' (20–100 g) and 'large' (>100 g). Adjusted prey biomasses, to account for wastage factors of different-sized prey, follow the formula of Baker-Gabb (1984) for avian and mammalian prey. Geometric Mean Prey Weight (GMPW) and dietary diversity (species richness and evenness: Shannon Index) were calculated following Aumann (2001) and Olsen *et al.* (2006) as applicable.

Data were analysed using PASW 17.0 (SPSS 2009). Statistical analysis was by Pearson chi-squared tests (Hannagan1997) in cross-tabulations for a normal distribution (expected versus observed) of recorded prey species against diet category, social structure and habitat for those species.

Opportunistic observations on the Grey Falcon pair and offspring in Sturt NP were made by IW around her residence for about five months post-fledging, over the period October 2003–February 2004 when the group of six falcons was seen regularly. During this time the juveniles were readily distinguishable by their dull bare-part colours, compared with the adults' bright yellow eye-rings (among *Falco*, a difference especially strong in Grey Falcons, e.g. Schoenjahn 2010). The juveniles were not marked, nor the nest tree climbed, to avoid disturbance to a rare and threatened species. As it is highly unlikely that there would be more than one group of six Grey Falcons in the area, it was assumed that the frequent sightings in October–February all referred to the pair and offspring from the sampled nest.

RESULTS

Breeding chronology

From comparison with photographs of known-age Peregrine Falcon *Falco peregrinus* chicks (in Olsen 1995, p. 157), i.e. the relative emergence of plumage versus down at weekly or fortnightly intervals, the Grey Falcon chicks were estimated to be about half-grown on 13 October (i.e. ~3 weeks old, from a known nestling period of six weeks for both falcon species), and had fledged by 29 October. Hatching would have been in mid-September and, allowing five weeks for incubation (Marchant and Higgins 1993), egg-laying would have occurred in early August.

The falcons did not use the nest in the following drier year (2004), when it was instead occupied by a breeding pair of Nankeen Kestrels *Falco cenchroides*.

Grey Falcons in Sturt NP

A pair of Grey Falcons had been present in the area of the subject nest at least since IW arrived in the Park in 2001, though rarely seen with offspring (other than in 2003), and in September 2012 a pair had two young in that area (IW pers. obs.). Based on our observations, and on reliable reports from other observers since 2001, there appeared to be three breeding pairs of Grey Falcons in the Park: one pair at a lake in the west and one pair around permanent ground tanks/dams in the north, as well as the subject pair in the east (respectively ~20 km apart).

Diet

The breeding-diet sample consisted, by number, of 99 percent birds, of which the most frequent were Budgerigar *Melopsittacus undulatus* (31%), Blue Bonnet *Northiella haematogaster* (19%) and Zebra Finch *Taenopygia guttata* (19%), and one percent small mammals (a single House Mouse *Mus musculus*; *n* ≥62 prey items from 58 pellets). Cockatiels *Nymphicus hollandicus* contributed a further eight percent and parrots collectively 63 percent by number (Table 2). The unidentified small brown birds (8%) were presumably passerines, here assumed to be similar in size to the passerine species or genera listed in Table 2. The 11 identified bird species formed 12 percent of the potential avian prey species (i.e. ≤33 cm in length) recorded for Sturt NP. The House Mouse is a widespread introduced species, abundant in Sturt NP and partly diurnal (pers. obs.), whereas the local native rodents and dasyurid marsupials are predominantly nocturnal (Van Dyck and Strahan 2008).

Budgerigar was represented in almost half of the pellets (*n* = 23, 40%, representing 19+ individuals), with Blue Bonnet and Zebra Finch well represented (each in 15 pellets, 26%, 12+ individuals each), and Cockatiel in seven pellets (12%, 5+ individuals). The other three parrot species in Table 2 appeared in one pellet each (collectively, 5% of pellets). Five identified avian prey species (46%) were small, four (36%) were medium and two (18%) were large. Forty individual bird items (66%) were small, 19 (31%) medium and two (3%) large, indicating a strong bias for small–medium birds (<100 g) (χ^2 = 35.698, d.f. = 2, *P* = 0.0005; i.e. selection for small birds, avoidance of large birds).

By biomass, Blue Bonnets contributed 37 percent, Budgerigars 23 percent and Cockatiels 17 percent, and parrots collectively 90 percent to the dietary sample (Table 2). The medium-weight species in the prey profile, i.e. the mid-sized parrots listed in Table 2 (Blue Bonnet and Cockatiel), contributed nearly two-thirds (60%) of dietary biomass. GMPW and dietary diversity (Shannon Index) were 29.6 grams and 1.98, respectively.

More granivorous/frugivorous species were found in the dietary sample than expected from the local avian assemblage of appropriate body size, and fewer insectivorous species (46% vs 18%, with 36% omnivorous; χ^2 = 9.786, d.f. = 2, *P* = 0.007). By contrast, the avian assemblage (species <34 cm) of the land habitats of Sturt NP was dominated by insectivorous species (58%, with 30% omnivores and only 12% granivores/frugivores). There were no significant deviations from the expected occurrence of prey species in the dietary samples, with respect to social structure (χ^2 = 5.395, d.f. = 3, *P* = 0.145) or the prey species' preferred local habitats (χ^2 = 5.523, d.f. = 4, *P* = 0.238). However, 82 percent of prey individuals were from species that commonly flock. The falcons' prey profile in Sturt NP can thus be characterised as predominantly flocking, ground-feeding granivores.

Table 2

Breeding diet of a pair of Grey Falcons and their nestlings in Sturt National Park, from pellets and orts (*n* = 58 samples) collected in October–December 2003. Unidentified birds are assigned a mean weight for the identified passerines. Adjusted biomasses (to nearest gram), allowing for wastage, follow Baker-Gabb (1984).

Species	Wt (g)	*n*	% *n*	Adj. biomass (g)	% biomass
Cockatiel *Nymphicus hollandicus*	88	5	8.1	385	17
Red-winged Parrot *Aprosmictus erythropterus*	150	1	1.6	132	6
Australian Ringneck *Barnardius zonarius*	127	1	1.6	112	5
Blue Bonnet *Northiella haematogaster*	82	12	19.4	864	37
Mulga Parrot *Psephotus varius*	60	1	1.6	57	2
Budgerigar *Melopsittacus undulatus*	29	19	30.6	532	23
Splendid Fairy-wren *Malurus splendens*	9	1	1.6	9	<1
Variegated Fairy-wren *Malurus lamberti*	8	2	3.3	15	<1
Crimson Chat *Epthianura tricolor*	10	1	1.6	10	<1
Horsfield's Bushlark *Mirafra javanica*	23	1	1.6	22	1
Zebra Finch *Taeniopygia guttata*	12	12	19.4	132	6
Unidentified small brown bird	12	5	8.1	55	2
House Mouse *Mus musculus*	17	1	1.6	15	<1
Total		62	100.1	2325	100

Behaviour

The four offspring were still together with the parents five months post-fledging. One sighting was of the juveniles accompanying the hunting adults over a homestead garden and around nearby earth tanks, the falcons repeatedly swooping as a group above the house and garden. The garden was densely planted with native vegetation and regularly watered, creating a moist refuge in the predominantly arid landscape. It thus harboured a high density of small birds. The effect of the falcons swooping was possibly to flush the small birds that had taken cover in this refuge. Otherwise, the group of six falcons was often seen flying or perching around the homestead dam in the early or late afternoons, throughout the observation period (October–February).

DISCUSSION

Nest site and breeding

The nest site, breeding habitat and estimated laying date are consistent with published information on this species (e.g. Marchant and Higgins 1993; Falkenberg 2011; Sutton 2011). Similarly, the successful brood of four is consistent with prior inferences about the relationship between effective rainfall in the pre-breeding months and the Grey Falcon's breeding productivity (Falkenberg 2011; Sutton 2011). Elsewhere in the arid zone, avian species richness and the presence of nomadic bird species (i.e. Grey Falcon prey) are positively related to rainfall, notably in some cases with that falling in the first half of the year (Paltridge and Southgate 2001; Burbidge and Fuller 2007; Bell *et al.* 2013).

The adoption of the nest by Nankeen Kestrels in 2004 provides another example of Grey Falcons not reusing a nest in subsequent year(s) (e.g. Falkenberg 2011; Schoenjahn 2013a). The possible reasons deserve investigation, but may relate to non-breeding by Grey Falcons in poor seasons.

Diet

The dietary sample from the Grey Falcon nest in Sturt NP consisted almost entirely of birds, especially ground-feeding granivores that were abundant in the open/semi-open landscape during the breeding event, with selection for small–medium birds and particularly parrots of 30–90 grams. Pigeons or doves, as found in other studies (e.g. Schoenjahn 2013a), were not recorded as prey in Sturt NP, even though they were present. The falcons did not otherwise select prey species on the basis of habitat or social structure, although prey individuals were predominantly from flocking species.

Given that most pellets (95%) dated from the nestling period and potentially earlier, it is possible that much of the prey was caught by the male while the larger female was incubating or brooding. In Grey Falcons, and raptors generally, males provide most of the food to the incubating/brooding female until the chicks can thermoregulate and thus free the female to hunt (e.g. Marchant and Higgins 1993; Olsen 1995; Falkenberg 2011).

Potential biases in this study include the likely male-biased prey provision in the October sample, and possible scavenging (by foxes) or weathering (by rain) of post-October pellets, as only three pellets were found in late December. The adult female may have contributed more (and larger) prey in November–December than was represented by those few pellets. On the other hand, incidental literature records of prey as large as the Crested Pigeon *Ocyphaps lophotes* and Galah *Eolophus roseicapillus* may reflect biased observations (e.g. sightings at waterholes, feeding on large prey on the ground in the open (Olsen and Olsen 1986), and hence ease of seeing and identifying large prey).

The Grey Falcon's prey profile in north-western NSW, including its GMPW and specialisation on a narrow range of avian prey, was similar to that of comparable samples from elsewhere in the arid zone (Aumann 2001; Sutton 2011;

Schoenjahn 2013a). It also confirms or amplifies smaller samples or anecdotal (unquantified) prey lists from the arid zone (Olsen and Olsen 1986; Marchant and Higgins 1993; Harrison 2000; Falkenberg 2011; Watson 2011), including an apparent preference for Blue Bonnets and Red-rumped Parrots *Psephotus haematonotus* in south-western New South Wales (Schrader in Czechura and Debus 1985). Being granivores, the falcon's prey species would need to drink daily, or almost so, thus providing a focus for predation at water sources. Such water sources, even in national parks, now of necessity include retained artificial stock-watering points, following the past degradation and loss of natural sources (e.g. 'native wells') by stock, feral animals and changed human land use (see Croft *et al.* 2007).

It is recognised that dietary analyses based on orts and pellets from beneath active nests may be subject to biases, including those resulting from multiple raptor species sequentially using the same nests or perches and depositing pellets or orts thereunder (e.g. Schoenjahn 2013a). However, this bias is unlikely in our study (e.g. the Brown Falcon *Falco berigora* and Peregrine Falcon were not recorded in the area during the study; the nest was in a live tree, in a solitary rather than semi-colonial raptor situation, and not on a popular perch such as a telecommunications tower). As most prior Australian raptor dietary studies based on pellets or orts are potentially affected by this bias, albeit minimally, inter- and intraspecific comparisons of dietary parameters would still be valid. Furthermore, the Grey Falcon's prey profile in this study is very similar to that based on direct observation of prey by Schoenjahn (2013a): he recorded 99 birds and two mammals captured, all 23 identified birds being ground-feeding granivores in the same size range as found in the Sturt NP sample.

Behaviour

The long period of juvenile association with parents is consistent with previous observations that the Grey Falcon's post-fledging dependence period may last many months, and perhaps up to a year (Marchant and Higgins 1993; Schoenjahn 2011, 2013b). That juveniles accompany hunting adults for five months or longer suggests they practise the difficult and complex task of catching birds in flight by observing and perhaps imitating the adults, although hunting behaviour is at least partly innate and refined by experience (e.g. Olsen 1995). The many anecdotal reports of parent-offspring groups of Grey Falcons being maintained for long periods post-fledging, and the lack of credible reports of Grey Falcons eating insects or carrion (e.g. Marchant and Higgins 1993), suggest that juveniles have a long 'apprenticeship' on mostly avian prey. This aspect contrasts with some other bird-eating falcons in which juveniles initially take 'easy' prey such as insects and/or some carrion (e.g. Australian Hobby *Falco longipennis*, Black Falcon *F. subniger*: Marchant and Higgins 1993; S. Debus pers. comm.).

Conservation implications

The Grey Falcon appears to have a maximum brood size of four (Schoenjahn 2013a). Possible factors in the success of the large brood at Sturt NP include the above-average rainfall in autumn 2003, and its effect on prey resources and populations in the following months (i.e. the falcon's pre-laying and breeding season). In addition, Sturt NP is a conservation reserve (~30 years in 2003), and the removal of stock and the positive effects of the rabbit calicivirus pandemic (since 1995) on vegetation recovery probably worked in concert to maximise the availability of avian prey resources. Similar conclusions on the positive influence of rainfall, habitat reservation and reduction of rabbit numbers on Grey Falcon productivity have been suggested for other parts of the arid zone (Falkenberg 2011; Sutton 2011).

There are no data on fluctuations in the reproductive success or prey profile of the Grey Falcon in arid New South Wales in response to seasonal conditions (weather or prey fluctuations). As recommended by Garnett *et al.* (2011), better ecological and baseline demographic information is still required for the conservation of this species. On present information, it appears likely that large, de-stocked conservation reserves in the arid zone could be a significant contribution to the management of the Grey Falcon and its prey base, and therefore of the other threatened or declining species that share its environment.

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RECOVERY ROUND-UP

This section is prepared with the co-operation of the Secretary, Australian Bird and Bat Banding Schemes, Australian Nature Conservation Agency. The recoveries are only a selection of the thousands received each year; they are not a complete list and should not be analysed in full or part without prior consent of the banders concerned. Longevity and distance records refer to the ABBBS unless otherwise stated. The distance is the shortest distance in kilometres along the direct line joining the place of banding and recovery; the compass direction refers to the same direct line. (There is no implication regarding the distance flown or the route followed by the bird). Where available ABBBS age codes have been included in the banding data.

Recovery or longevity items may be submitted directly to me whereupon their merits for inclusion will be considered.

Hon. Editor

The following abbreviations appear in this issue:

AWSG - Australasian Wader Study Group.

Magpie Goose *Anseranas semipalmata*

(a) 130-17463. Adult (2+) banded by R.E. Chatto at Woolner near Lake Finniss, NT on 8 Sep. 1995. Recovered dead at Acacia Gap Road, NT (taken to protect crops) on 27 Dec. 2014, over 19 years, 3 months after banding. 53 km SW.

(b) 130-30614. Juvenile (J) banded by M.N. Maddock at the Wetlands Centre, Sandgate Road, Shortland, near Newcastle, NSW on 18 Jan. 1990. Band number read in field at banding place on 28 Dec. 2014, over 24 years, 11 months after banding.

(This is the oldest recorded for the species.)

Northern Giant-Petrel *Macronectes halli*

131-33119. Nestling banded by The Antarctic Division at Eagle Point, Macquarie Island, Tas. on 15 Jan. 1977. Recovered dead near banding place on 23 Jun. 2011, over 34 years, 5 months after banding. 5 km ENE.

(This is the oldest recorded for the species.)

Australasian Gannet *Morus serrator*

(a) 131-67197. Nestling banded by F.I. Norman on Popes Eye off Queenscliffe, Port Phillip, Vic. on 14 Dec. 1992. Recovered dead between Point Wilson and Kirk Point, North Corio Bay, Vic. on 21 Feb. 2015, over 22 years, 2 months after banding. 30 km NW.

(b) 131-71438. Nestling banded by C.G. Cooper on Lawrence Rocks State Faunal Reserve, Portland, Vic. on 19 Dec. 1989. Recovered sick, at Bondi Beach, NSW (taken into care at Taronga Zoo, Sydney) on 6 Nov. 2014, over 24 years, 10 months after banding. 997 km NNE.

Ruddy Turnstone *Arenaria interpres*

051-96319. Adult (3+) banded by AWSG at Beaches Crab Creek Road, Roebuck Bay, Broome, WA on 29 Aug. 1998. Recovered or band number read in field five times, the last occasion by C.J. Hassell at Observatory Beach, Crab Creek Road, Broome, WA on 23 Dec. 2014, over 16 years, 3 months after banding. 26 km E.

Green Catbird *Ailuroedus crassirostris*

081-85102. Adult (2+) banded by S.G. Lane at Moonee near Coffs Harbour, NSW on 20 Oct. 1984. Recaptured, released alive with band one hundred and ninty two (192) times, the last occasion on 7 Sep. 1999, over 14 years 10 months after banding.

(This is the oldest recorded for the species.)

NOTE: Although this is not a recent record it has been included for the following reasons; it is the oldest record for the species as well as having being retrapped 192 times. While this would at first appear to be a record in itself there is a record within the ABBBS Data Base for a Satin Bowerbird, Band No. 082-66849 also banded and retrapped by S.G. Lane on 236 occasions.

Extraction of this record along with its information on recapture times has only been possible due to improvements in the ABBBS database reporting functions. For many years it has been difficult to recognise and obtain records when they were entered electronically in bulk files into the database, especially where data were entered from paper copies by contractor's offsite.

Satin Bowerbird *Ptilonorhynchus violaceus*

082-49206. Adult (4+) banded by G. Borgia at Wallaby Creek, Urbenville, NSW on 5 Sep. 1985. Recaptured, released alive with band at banding place five times the last occasion on 21 Sep. 2010, over 25 years after banding.

(This is the oldest recorded for the species.)

Variegated Fairy-wren *Malurus lamberti*

019-34216. Adult (2+) male banded by A.J. Leishman at the Australian Native Botanic Gardens, Mount Annan, NSW on 21 Dec. 2008. Recaptured, released alive with band at banding place twice the last occasion on 9 Dec. 2014 over 5 years, 11 months after banding.

Eastern Spinebill *Acanthorhynchus tenuirostris*

019-35677. Adult (1+) male banded by D. McKay at Burrendong Arboretum, near Wellington, NSW on 5 May. 2007. Recaptured, released alive with band at banding place twice the last occasion by J. W. Hardy on 21 Sep. 2014, over 7 years 4 months after banding.

White-plumed Honeyeater *Lichenostomus penicillatus*

025-98747. Adult (1+) male banded by L. W. Filewood at Burrendong Arboretum, near Wellington, NSW on 15 Feb. 2003. Recaptured, released alive with band at banding place twice the last occasion by J.W. Farrell on 20 Sep. 2014, over 11 years 7 months after banding.

Olive-backed Oriole *Oriolus sagittatus*

062-93399. Immature (1) banded by A & A Leishman at Camden Airport, NSW on 26 Nov. 2007. Recaptured, released alive with band at banding place twice, the last occasion on 17 Dec. 2014, over 7 years after banding.

(This is the oldest recorded for the species.)

Magpie-lark *Grallina cyanoleuca*

061-51108. Adult (1+) male banded by R.D. Magrath at the Australian National University Campus, Canberra, ACT on 30 May 1995. Recovered dead at banding place on 18 July 2007, over 12 years, 1 month after banding.

(This is the oldest recorded for the species.)

Crimson Finch *Neochmia phaeton*

026-25512. Adult (1+) female banded by S. Legge at Mornington Wildlife Sanctuary, WA on 16 Jul. 2004. Recaptured, released alive with band at banding place ten times the last occasion on 29 Apr. 2010, over 5 years, 9 months after banding.

(This is the oldest recorded for the species.)

Gouldian Finch *Erythrura gouldiae*

026-29148. Adult (1+) male banded by S. Legge at Mornington Wildlife Sanctuary, WA on 31 Dec. 2004. Recaptured, released alive with band at banding place on 22 Jan. 2010, over 5 years after banding.

(This is the oldest recorded for the species.)

Notice to Contributors

Manuscripts relating to any form of avian research will be considered for publication. Field studies are preferred particularly where identification of individual birds, as by banding, has formed an integral part of the study. Some broad areas of research which do not necessarily require individual identification include morphometric analyses, techniques, species diversity and density studies as well as behavioural investigations. Behavioural, plumage and breeding studies can be conducted in captivity but must provide basic ornithological knowledge rather than avicultural interest.

Manuscripts are classified as either major articles (more than 1,500 words) or minor articles (500 to 1,500 words). Minor articles need no summary. Shorter notes relating to almost any aspect of ornithology are welcomed but must adhere to the aims of the Association. Species lists or sightings which are not discussed in relation to historical evidence or scientific parameters are not suitable for publication in *Corella.* Authors proposing to prepare Seabird Island items should contact the Assistant Editor,Seabird Islands, and obtain a copy of the guidelines.

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Contributors are requested to observe the following points when submitting articles and notes for publication in *Corella*.

Manuscripts:

A guide to the format required for tables, figures and manuscripts can be attained by reference to a recent edition of the journal and more specifically to the Publication Style found on the ABSA website.

Articles or notes should be sent via email to the editor as a .doc or .rtf file or typewritten and submitted in triplicate via post. Double spacing is required with typing on one side of the paper only. Margins of not less than 25 mm width at the left hand side and top, with similar or slightly smaller at the right hand side of the page are required.

All pages of the manuscript must be numbered consecutively, including those containing references, tables and captions to illustrations, the latter placed in after the text. No underlining and no abbreviations should be used within the text.

The *Style Manual for Authors,Editors and Printers* (6th edition 2002; John Wiley & Sons Australia, Ltd.) is the guide for this journal. Spelling generally follows the Macquarie Dictionary.

Nomenclature and Classifications follow:

Christidis, L. and Boles, W. E. (2008). 'Systematics and Taxonomy of Australian Birds'. (CSIRO: Collingwood, Victoria).

Proper nouns, particularly place and bird names must commence with a capital letter.

Headings are as follows: **HEADING – capitals and bold** (e.g. **RESULTS**)
Sub Heading – lower case and italics (e.g. *Ecology*)

Referencing:

References to other articles should be shown in the text – '. . . Bell and Ferrier (1985) stated that . . .'or '…. this is consistent with other studies (Jones 1983; Bell and Ferrier 1985).'– and in the Reference Section as:

Bell, H. L. and Ferrier, S. (1985). The reliability of estimates of density from transect counts. *Corella* 9: 3-13.

Jones, J. C. (1983). 'Sampling Techniques in Ornithology.'(Surrey Beatty and Sons: Chipping Norton, NSW.)

Figures (Maps and Graphs) and Tables:

The printable area of the page is 18 cm x 27 cm; double column figures/tables will be 18 cm across; single column figures/ tables will be 8.5 cm across; widths between one column and double column can also be accommodated.

The captions for figures should be typed up onto a page separate from the figure.

Maps

Maps should be clear and relevant to the study and can be submitted in a variety of formats (.tif, .eps, .pcx) but the recommended one is a high resolution .jpg file (colour is acceptable). In some instances simply listing the latitude and longitude may suffice instead of a published map. Maps should only show necessary information. Excessive labelling(including names of towns, roads, rivers) will clutter the figure making it difficult to locate key place names. Photocopies of original hand drawn maps are not suitable for publication. They should be submitted only initially. When the paper is accepted for publication, the originals must be submitted so that they can be scanned into an appropriate electronic format.

Graphs

Lines should be thick and dark and any fill used should show a clear distinction between sets of data (colour fills are acceptable). Borders around the graph and the key are not necessary. The recommended format is an .xls file – this makes it very easy to adjust fills, thickness of lines etc, if necessary.

Where possible, please present the figure at final size. Figures that seem satisfactory when they are large, can present problems when they are reduced. Remember that if the figure has to be reduced for publication the figure will reduce equally in all dimensions i.e. both width and height will reduce. This can cause some problems, such as: (i) Line graphs where the lines are very close together can lose clarity. (ii) The typeface will reduce. Please ensure that the final typeface size AFTER reduction will be a minimum of 10 times Times New Roman typeface.

Tables

The recommended format is an .xls file but tables created in Word are acceptable. These should normally have a maximum size of one page but larger tables can be accommodated, if necessary.

FOR MORE DETAILED INFORMATION OR ASSISTANCE IN THE PREPARATION OF FIGURES PLEASE CONTACT THE PRODUCTION EDITOR.

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