Australian Field Ornithology 2025, **42**, 134–145
http://dx.doi.org/10.20938/afo42134145

Population monitoring of Bulloo Grey Grasswren *Amytornis barbatus barbatus* in the arid zone of far north-western New South Wales

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Abstract. Basic information about where a species occurs, and its population size and trajectory are fundamental to assessing conservation status, to guide conservation decision making and to measure the effectiveness of specific management actions. The Grey Grasswren *Amytornis barbatus* is a rare species that occurs in the arid zone of inland Australia. The remoteness of its habitat, recognised low detectability, and a likely boom–bust ecology impose considerable constraints on the design and implementation of a reliable and cost-effective survey methodology. We used a rapid, repeated call-playback method to survey Bulloo Grey Grasswren *A. b. barbatus* in far north-western New South Wales between 2015 and 2023. Grey Grasswren detection and non-detection data were used to explore the subspecies' response to habitat variables, survey conditions, rainfall and the presence of surface water. Grey Grasswren detections showed a strong positive response to the height of Lignum *Duma florulenta* and to significant rain events in the weeks before the survey. Our observations support the proposition that Lignum is a refuge habitat during periods of extended drought and that rain and/or flood is a key driver of population growth and dispersal.

Introduction

The Grey Grasswren *Amytornis barbatus* is a small, rare and cryptic species. It is typically difficult to detect using conventional survey techniques such as area- or point-based searches (e.g. Hardy 2010, 2022; Jaensch *et al.* 2013, 2014, 2021; Black *et al.* 2015).

Grey Grasswrens are distributed patchily over a large area of the arid zone of north-western New South Wales (NSW), north-eastern South Australia and south-western Queensland. Typically, they occupy vegetation types dominated by Lignum *Duma florulenta* but are also found in adjacent vegetation types with broader extents including those dominated by Swamp Canegrass *Eragrostis australasica* and Old Man Saltbush *Atriplex nummularia*. There is little information on the functional use of these vegetation types and their importance to the species (e.g. Black *et al*. 2015).

The subspecies Bulloo Grey Grasswren *A. b. barbatus* occurs in Queensland and NSW and is restricted to the terminal wetlands of the Bulloo River system (Hardy *et al.* 2021). Within NSW, it is restricted to Caryapundy Swamp and its eastern outflow channels as far as the northern margin of the Bulloo Overflow (Hardy 2010); subpopulations occur discontinuously from this point north to the Bulloo Lakes in Queensland, a distance of >70 km (Jaensch *et al.* 2021).

The Bulloo Grey Grasswren is listed as Endangered in Queensland (*Nature Conservation Act 1992*), Endangered in NSW (*Biodiversity Conservation Act 2016*) and Endangered nationally (*Environment Protection and Biodiversity Conservation Act 1999*). Since 2014, the NSW Department of Climate Change, Energy, the Environment and Water (DCCEEW) has funded conservation actions for the Bulloo Grey Grasswren through the Saving our Species (SOS) program (DCCEEW 2024). The SOS conservation project for Grey Grasswren is based in Narriearra Caryapundy Swamp National Park, which captures the entire species' historically known range in NSW (Figure 1). When the project began in 2014, Narriearra Station had been a grazing property for >100 years and, following its absorption of the abandoned sheep-grazing properties

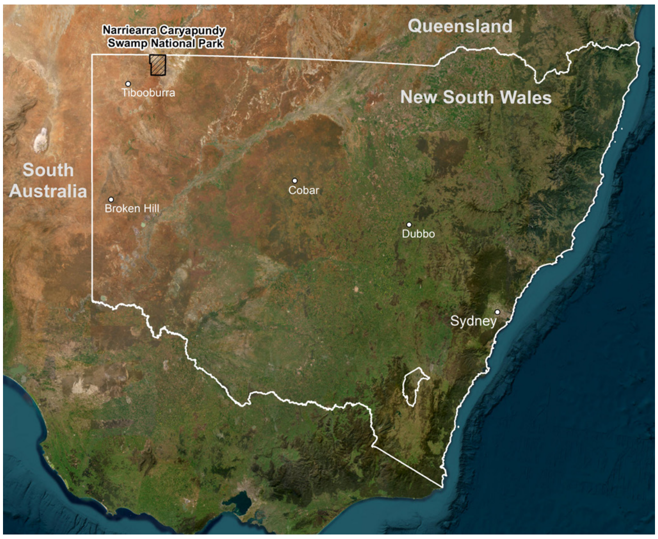

Figure 1. Location of Grey Grasswren Saving Our Species project area (Narriearra Caryapundy Swamp National Park) in far north-western New South Wales. Map source: World Imagery https://services.arcgisonline.com/ArcGIS/services

Connulpie and Teurika to its north, a cattle-grazing property since 1985. Cattle were thought to be a major threat to the Grey Grasswren in NSW (through destruction of Lignum habitat and suppression of Lignum regeneration following major floods), so the development of an effective survey method was considered essential to inform the recovery strategy for the subspecies. Purchase of Narriearra Station by the NSW Government to create Narriearra Caryapundy Swamp National Park in 2020 presented an additional incentive for the development of an effective survey method to measure the subspecies' response to a broad change in land use from cattle grazing to conservation management.

Hardy (2010) described the Bulloo Grey Grasswren as dependent on wetland vegetation dominated by dense clumps of tall Lignum for feeding and nesting. He also observed feeding in Swamp Canegrass (and occasionally nesting there during wet periods when Lignum was inundated) and in Old Man Saltbush and samphire *Halosarcia* spp. Lignum has been the focus of past surveys for the species (e.g. Hardy 2010, 2022; Jaensch *et al.* 2013, 2014, 2021; Black *et al.* 2015).

Hardy (2010) found that Bulloo Grey Grasswrens were most abundant in Lignum when conditions were dry. He suggested that tall dense Lignum might serve as a refuge during prolonged dry periods, with these birds occupying a broader range of vegetation types including Swamp Canegrass and Old Man Saltbush during periods of above-average rainfall. However, little is known of the use of Lignum and associated vegetation types and their relative importance to Grey Grasswrens (e.g. Black *et al.* 2011, 2015).

The aim of our study was to develop a reliable and cost-effective methodology to monitor the distribution and abundance of Grey Grasswrens and measure the success of targeted conservation actions for the subspecies. We analysed the results from repeated call-playback surveys conducted on Narriearra Station (and subsequently Narriearra Caryapundy Swamp National Park) and neighbouring properties between 2015 and 2023. We used detection data to explore the subspecies' response to habitat variables, survey conditions and rainfall events. We also discuss the potential for the use of passive acoustic monitoring for future population monitoring of Grey Grasswrens in NSW.

Methods

Bird surveys

A rapid call-playback survey method was used to determine presence/absence of Grey Grasswrens in Lignum-dominated vegetation in Narriearra Caryapundy Swamp National Park (Figure 2). Redthroat *Pyrrholaemus brunneus* was also included in call-playback surveys for Grey Grasswrens as the two species co-occur in the National Park, Redthroat is listed as Vulnerable in NSW under the *Biodiversity Conservation Act 2016*, and there is little known of its abundance and habitats. The location of survey sites was determined during a pilot study in 2015 on the basis that sites supported at least some Lignum, were adjacent to or easily accessible from a vehicular track and, where feasible, were at least 100 m apart. One hundred metres was assumed to exceed the distance (from the

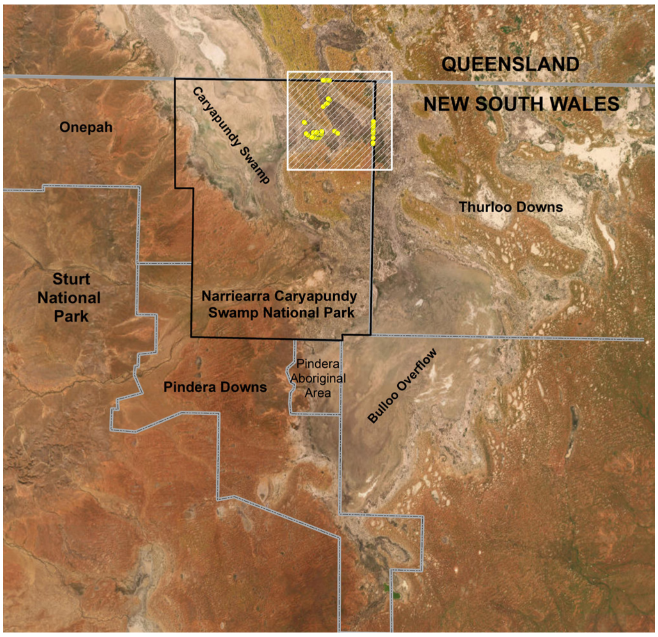

Figure 2. Study area (white hatching) within Narriearra Caryapundy Swamp National Park in far north-western New South Wales. Survey sites are shown as yellow spots.

observer) that a Grey Grasswren could detect broadcast calls and thereby satisfy the requirement for independent sampling.

Recorded calls used for call-playback were those available on the *Michael Morcombe and David Stewart eGuide to the Birds of Australia* v 1.4 PDA Solution/ mydigitalearth.com. The 'group – contact calls and faint song' (24 seconds duration) was played on a continuous loop. For Redthroat the 'song' (28 seconds duration) was played on a continuous loop. Calls were broadcast using a blue-toothed Logitech UE MegaBoom portable speaker.

The survey protocol at each site involved 1 minute playback of Grey Grasswren calls, 1 minute listening period, 1 minute playback of Grey Grasswren calls, 1 minute listening period, 1 minute playback of Redthroat calls, and 1 minute listening period. The overall time spent at each survey site was *c.* 10 minutes.

The area sampled at each survey site for Grey Grasswren was estimated to be ~1 ha. This was based on the approximate distance (50 m) that broadcast calls could be heard by a human ear in Lignum-dominated vegetation in still wind conditions.

A record was made of hearing/sighting of Grey Grasswrens, and whether the hearing/sighting was unsolicited or more likely to be a response to the broadcast of Grey Grasswren/Redthroat calls. At each survey site the relative wind speed was recorded as a number between 0 and 4, where 0 was still conditions and 4 was very strong wind. Temperature (°C) and time were recorded at the start of each survey. Survey sites were accessed on foot, allowing ~50 m to approach on foot if accessing the site by vehicle.

The distribution of the survey sites in the National Park included five sites at Adelaide Gate; 11 at Two Mile Tank; four at Bartons Tank; 55 between Bullagree Tank, Bobs Hole Tank and Bartons Crossing (collectively referred to hereafter as Bartons Crossing), and 11 sites along the

Eastern Boundary of the National Park (Figure 3). The mean distance between survey sites (measured as the nearest neighbour to each survey site) was 166 m, with a range of 64–810 m.

Habitat assessment

Habitat data were collected at 81 survey sites in 2017, 2019 and 2021. The following data were recorded at each site within a plot radius of ~20 m:

1. Evidence of feral animal species: cattle and feral pig, cattle, none
2. Level of disturbance: minor, moderate, major
3. Average Lignum patch size: width (m), length (m), height (m)
4. Average Lignum patch spacing (m)
5. Percentage of plants with presence of leaves on stems e.g. 0% Lignum, 100% Old Man Saltbush
6. Average percentage area under shrubs covered by other growth around plant base and stems
7. Percentage area of bare ground
8. Percentage area damp/wet
9. Shrub layer (height 0.5–3 m) percentage crown cover: dominant species 1, dominant species 2, dominant species 3
10. Ground cover layer percentage crown cover: dominant species 1, dominant species 2, dominant species 3
11. Pellet count: cattle, pig, rabbit, kangaroo
12. Percentage cover of shrub species: Lignum, other species
13. Percentage cover of juvenile plants of dominant shrub species
14. Evidence of grazing on Lignum/saltbush: no, yes
15. Evidence of grazing on other plant species: no, goosefoot *Chenopodium* spp., large grass tussocks, Native Millet *Panicum decompositum* and/or grass sp., Swamp Canegrass, Bignonia Emu Bush *Eremophila bignoniiflora*

A map of the modelled extent of Lignum-dominated vegetation in far north-western NSW (provided by the NSW Office of Environment and Heritage, Science Division in 2018) was used, in combination with local knowledge and ground-based searching, to guide the location of surveys for Grey Grasswrens outside our study area. In 2018, surveys were conducted on Thurloo Downs (a pastoral property on the eastern boundary of the National Park: Figure 2). In 2020, surveys were conducted along the western edge of Caryapundy Swamp on Onepah (a pastoral property on the western boundary of the National Park) and in the National Park, and in the southern extremity of the Bulloo Overflow on Pindera Downs (a pastoral property on the southern boundary of the National Park: Figure 2). Surveys on the eastern side of Caryapundy Swamp and on the southern extremity of the Bulloo Overflow involved intensive searching in Lignum-dominated vegetation and the broadcast of Grey Grasswren calls, while the observer was stationary or during a meandering traverse of the Lignum patch.

Because of the low rate of Grey Grasswren detections, habitat assessments at each survey site in each survey year were naively considered as independent observations

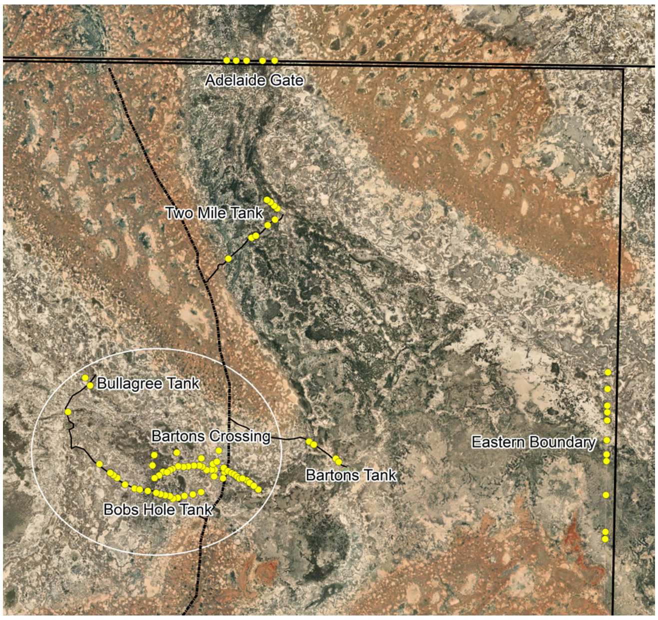

Figure 3. Study area in the north-eastern corner of Narriearra Caryapundy Swamp National Park showing survey sites (yellow spots) clustered in accessible patches of Lignum-dominated vegetation. For the statistical analyses, Bullagree Tank, Bartons Crossing and Bobs Hole Tank are collectively referred to as Bartons Crossing.

(noting habitat assessments were repeated in 2017, 2019 and 2021). Where Grey Grasswren was detected at a site in >1 year, or where there were multiple detections in 1 year, the habitat data for the year of the highest number of detections were used. If Grey Grasswren was not detected in any year then the habitat data were randomly selected from 2017, 2019 or 2021. Covariates for modelling were selected on the basis of data visualisation (violin or bar plots) and cross-correlations. Collinearity among habitat covariates was assessed using the Variance Inflation Factor (VIF) (Dormann *et al.* 2013). Through an iterative approach, variables with VIF >10 were successively removed until all strongly correlated variables were excluded from the analysis.

To estimate the relative importance of habitat covariates on Grey Grasswren detectability, a hierarchical generalised linear mixed model was fitted using the Bayesian Hierarchical Modelling of Species Communities (HMSC) framework available as a *R*-package Hmsc v 3.0.13 (Tikhonov *et al.* 2020). Habitat covariates were treated as fixed effects, while the spatial locations of survey sites were included as spatially explicit random effects to address inherent spatial structure (Tikhonov *et al*. 2020). As a response variable, the model used the presence/pseudo-absence Grey Grasswren data at each site. The model was fitted with binomial errors (probit link) using Four Markov Chain Monte Carlo chains resulting in 1000 posterior samples per chain. Model convergence was assessed using the Gelman–Rubin diagnostic, with all potential scale reduction factors found to be <1.1, indicating satisfactory convergence (Gelman & Rubin 1992).

Detection rate

Grey Grasswren was considered to be detected when at least one individual was heard, seen, or heard and seen

Table 1. Number of Grey Grasswren surveys sites and number of repeat surveys in each survey year over the study period 2015–2023.

Survey year	*Survey month (and date range)*	*Number of sites surveyed at least once*	*Number of sites surveyed at least twice*	*Number of sites surveyed at least three times*	*Number of sites surveyed more than three times*
2015	September (4–6)	96	38	3	0
2017	September (6–9)	66	18	13	0
2018	September (2–3)	33	33	33	0
2019	September (11–21)	81	79	45	40*
2021	December (14–20)	86	78	0	0
2023	September (5–9)	86	0	0	0
2023	December (4–7)	86	0	0	0

*Up to eight visits to some sites

at a survey site within a 5-minute survey period. Only detection data from survey sites in the National Park were included in the analysis, i.e. 135 sites, including 55 sites at Bartons Crossing. The detection rate (for each site) was then calculated as follows:

$$\frac{\text{Number of surveyed years with detection x 100}}{\text{Number of surveyed years}}$$

Detection probability

A standard occupancy modelling approach (MacKenzie *et al*. 2002) was used to account for false absences (i.e. imperfect detection) and estimate detectability based on detection/non-detection data. Because of the lack of meaningful spatial layers identifying habitat features and the sparse nature of the data, the modelling process was limited to implementing constant occupancy models. Because of the clear spatial structure in the occurrence of Grey Grasswrens the degree of spatial autocorrelation was assessed between sites where the subspecies was detected at least once. Occupancy models and associated estimates of detectability were derived using the package Unmarked v 0.12-3 (Fiske & Chandler 2011). Significant spatial autocorrelation was assessed using correlograms (based on Moran's *I*: Tiefelsdorf 2000) in package ncf (Bjornstad 2015).

Surface water

Landsat water count data were provided by NSW DCCEEW for each site and each survey (year/month) for the period 2 months before the survey, and 6 months before the survey. The water count is represented as a binary count of water presence/absence for each 30-m Landsat pixel (*Fisher et al. 2016).* No data were available for the September 2015 survey. For each 30-m pixel the information comprised the number of times when water was detected and the number of times when data were collected. A 100-m buffer zone and a 1000-m buffer zone were created for each survey site, for each survey (year/month), and for each buffer zone a 'water index' was calculated as follows:

$$\frac{\text{Number of times water was detected within the buffer}}{\text{Number of times data were collected inside the buffer}}$$

Rainfall

Rainfall data were downloaded from the Australian Government Bureau of Meteorology website for Tibooburra Airport (~65 km south-west of the National Park). Basic rainfall statistics, across years or across months of the years, were compared with the percentage of detections of Grey Grasswrens at survey sites in each year. The rainfall statistics included rainfall total over the period 1 month, 2 months and 3 months before the survey; total rainfall for the survey years 2015, 2017, 2018, 2019, 2021 and 2023; the mean rainfall across months for each survey year; and standard deviation of the rainfall across months for each survey year.

Results

Survey effort

The number of sites surveyed and the number of repeat visits to sites in each survey year are shown in Table 1. Local environmental conditions including wind, rainfall and surface water were the main constraints on the number of locations and number of repeat visits to survey sites that could be achieved in each survey year. Only in 2019

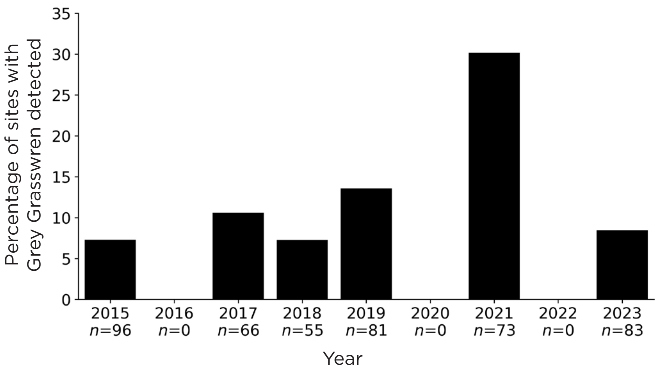

Figure 4. Percentage of sites where Grey Grasswrens were detected across all survey sites in each survey year over the study period 2015–2023. The number of survey sites is indicated below each bar.

were we able to undertake a large number of repeat visits to survey sites (i.e. 81 survey sites visited at least once, 79 twice, 45 three times, 40 four times, 32 five times, 31 six times, 28 seven times and 14 eight times). In spite of a number of repeat visits to sites in 2019, the percentage of sites where Grey Grasswrens were detected remained low.

Variation in detection across years

Notwithstanding the variability in the number of locations surveyed and the number of repeat visits to sites undertaken across years, the percentage of sites where Grey Grasswrens were detected was consistently low in 2015 (7%), 2017 (10%), 2018 (6%), 2019 (14%) and 2023 (7%). In contrast, the percentage of sites where Grey Grasswrens were detected in 2021 was high (i.e. 30%: Figure 4).

In 2018 and 2019, Grey Grasswrens were detected only at Bartons Crossing. In 2021, they were detected at 44% of sites at Bartons Crossing and at only 10% of sites elsewhere. In 2017, they were detected at 15% of sites at Bartons Crossing and at only 4% of sites elsewhere (Figure 5).

Detection probability

In 2019, we calculated the detection probability to inform the ongoing refinement of the survey methodology. Pooling of the detection data from 2015–2019 resulted in a data set of 157 sites with a maximum number of observations per site of 19, a mean number of observations per site of 4.3, and 23 sites with at least one detection. The detection estimate from this dataset was 0.074 ± standard error 0.0189. Figure 6 shows the cumulative detection probability curve based on detection data from 2015–2019.

The probability of detection using the rapid repeat survey method was clearly very low, i.e. <0.1. Occupancy estimates were considered unreliable because of the large standard errors arising from very low detection estimates.

Spatial distribution

Using all data from surveys conducted in 2015, 2017, 2018 and 2019, correlograms indicated significant positive spatial autocorrelation in Grey Grasswren occurrence out to a distance of ~2 km (Figure 7). This reflected the concentration of detections at Bartons Crossing. Only at single sites in single years were Grey Grasswrens detected outside Bartons Crossing (i.e. Bartons Tank 2017, Adelaide Gate 2021, Eastern Boundary 2021 and Bartons Tank 2023).

Grey Grasswrens were not detected at most survey sites over the study period 2015–2023 (Figure 8). At some sites at Bartons Crossing, they were detected in >1 year out of three (i.e. detection rate >30%) and at three sites they were detected in >1 year out of two (i.e. detection rate >50%).

At Bartons Crossing, where there was at least one Grey Grasswren detection over the study period, the subspecies was detected in two of 2 years at one site, four of 5 years at one site, four of 6 years at one site, three of 6 years at four sites, and two of 4 years at one site. In 2021, the subspecies was detected at 26 (87%) of 30 sites from two surveys, nine (35%) of which were detections in both surveys (Table 2).

Seasonal detection rate

In 2021, COVID-19 restrictions resulted in a delay in the survey timing until mid December. All previous surveys had been conducted in August–September. Although fortuitous, given the resulting high detection rate of Grey Grasswrens, the effect of season on the probability of detection could not be discounted. To explore this factor further, in 2023 we surveyed 86 sites in September, then again in December. The percentage of sites where Grey

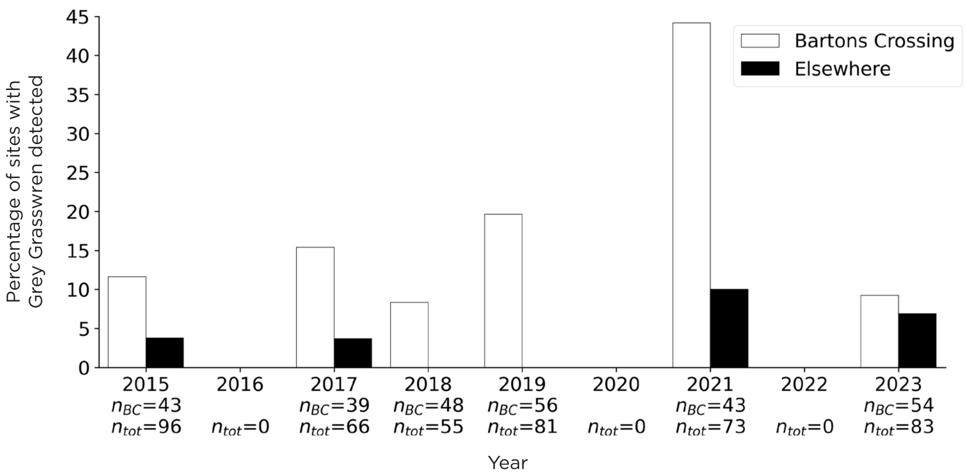

Figure 5. Percentage of sites where Grey Grasswrens were detected at Bartons Crossing compared with elsewhere in each survey year over the study period 2015–2023. n_{BC} = number of sites sampled at Bartons Crossing, n_{tot} = number of sites sampled across Narriearra Caryapundy Swamp National Park.

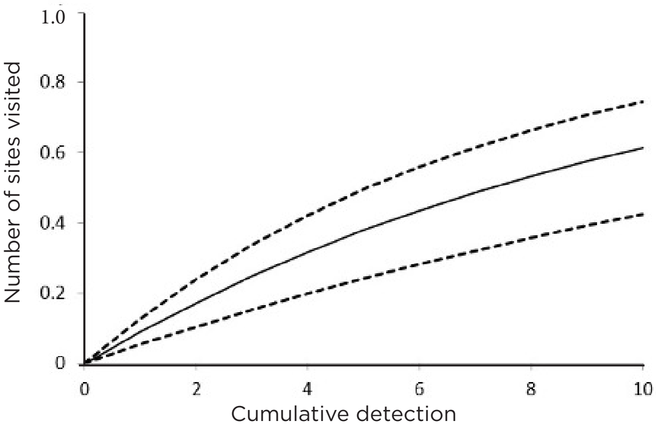

Figure 6. Cumulative detection probability curve (*y*-axis) for Grey Grasswren detection data (2015–2019) given the number of site visits (*x*-axis), based on each estimate (dotted lines are Confidence Intervals).

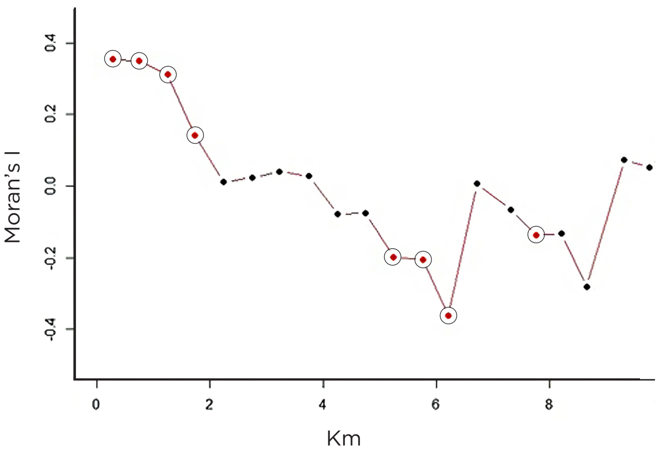

Figure 7. Correlogram of Moran's I using Grey Grasswren detection data pooled from 2015–2019. *y*-axis: Moran's *I* values, *x*-axis: distance out to 10 km; red dots indicate significance level to <0.01. Note that negative spatial autocorrelation is likely because of records being spatially disjunct from the main concentration of detections at Bartons Crossing.

Table 2. Survey sites with at least one Grey Grasswren detection at Bartons Crossing in 2015, 2017, 2018, 2019, 2021 and/or 2023. Site ID = site identity; number of detections/number of surveys: grey shading = detections, no shading = non-detections, dash = site not surveyed.

Site ID	*2015*	*2017*	*2018*	*2019*	*2021*	*2023*
333	0/2	1/3	–	1/7	0/2	0/2
337	0/2	1/3	–	1/8	2/2	1/2
338	0/1	1/2	–	0/7	1/1	0/2
346	0/1	0/3	0/3	1/8	0/2	0/2
347	0/2	0/1	0/3	1/8	2/2	0/2
348	0/2	0/3	0/3	1/8	1/1	0/2
349	0/2	0/3	0/3	1/8	1/2	0/2
350	0/2	1/3	0/3	0/8	2/2	0/2
351	0/2	0/1	0/3	0/8	2/2	0/2
352	0/2	0/3	0/3	2/8	1/2	1/2
353	0/2	0/1	0/3	0/8	2/2	0/2
354	0/2	0/3	2/3	4/8	2/2	0/2
355	0/1	0/1	0/3	1/8	1/2	0/2
356	0/1	0/3	0/3	0/7	2/2	0/2
357	0/1	1/1	0/3	1/8	0/2	2/2
362	0/1	0/1	0/3	0/2	1/2	0/2
402	1/2	0/2	0/1	1/7	2/2	0/2
403	1/3	0/2	0/1	0/7	2/2	0/2
404	1/3	0/2	0/1	0/7	1/2	0/2
410	–	–	0/1	0/3	1/2	0/2
416	0/2	1/1	3/3	2/8	1/2	0/2
1108	–	–	–	–	1/1	1/2
1113	–	–	0/4	0/2	1/1	0/2
1137	–	–	0/4	0/2	1/1	0/2
1142	–	–	1/3	0/2	0/1	0/2
1143	–	–	0/3	0/2	1/1	0/2
1146	–	–	0/3	0/2	1/1	0/2
1147	–	–	0/3	0/2	1/1	0/2
1150	–	–	0/3	0/2	1/1	1/2
1152	–	–	0/3	–	1/1	0/2

Grasswrens were detected was similar in September (4.4%, *n* = 3) and December (5.8%, *n* = 4). At only one site (at Bartons Crossing) was the subspecies detected in both September and December.

Response to timing of survey

Grey Grasswrens were detected during mornings and afternoons over the study period though they were slightly more prevalent in the mornings (Figure 9).

Response to rainfall

Maximum total rainfall in the 12 months before the survey (at Tibooburra Airport) occurred in 2021 (303 mm), corresponding with the highest detection rate of Grey Grasswrens over the survey period 2015–2023. Minimum total rainfall occurred in 2018 and 2019 (100 mm and 102 mm, respectively: Figure 10).

The pattern of rainfall per month was variable from year to year. However, a large rainfall event occurred in November 2021 before the December 2021 survey, when Grey Grasswrens were detected at a high proportion of sites (Figure 11).

Generally, water was rarely detected by Landsat around survey sites during the period 2 months before a survey and 6 months before a survey. The only survey where Grey Grasswrens were detected at some sites with some water was during the December 2021 survey. However, all water data values were low. In 2021, Grey Grasswren was detected at one site where water was detected 2 months before the survey and at four sites where water was detected 6 months before a survey. In December 2021 and September 2023, more than half of the sites where Grey Grasswrens were detected had water.

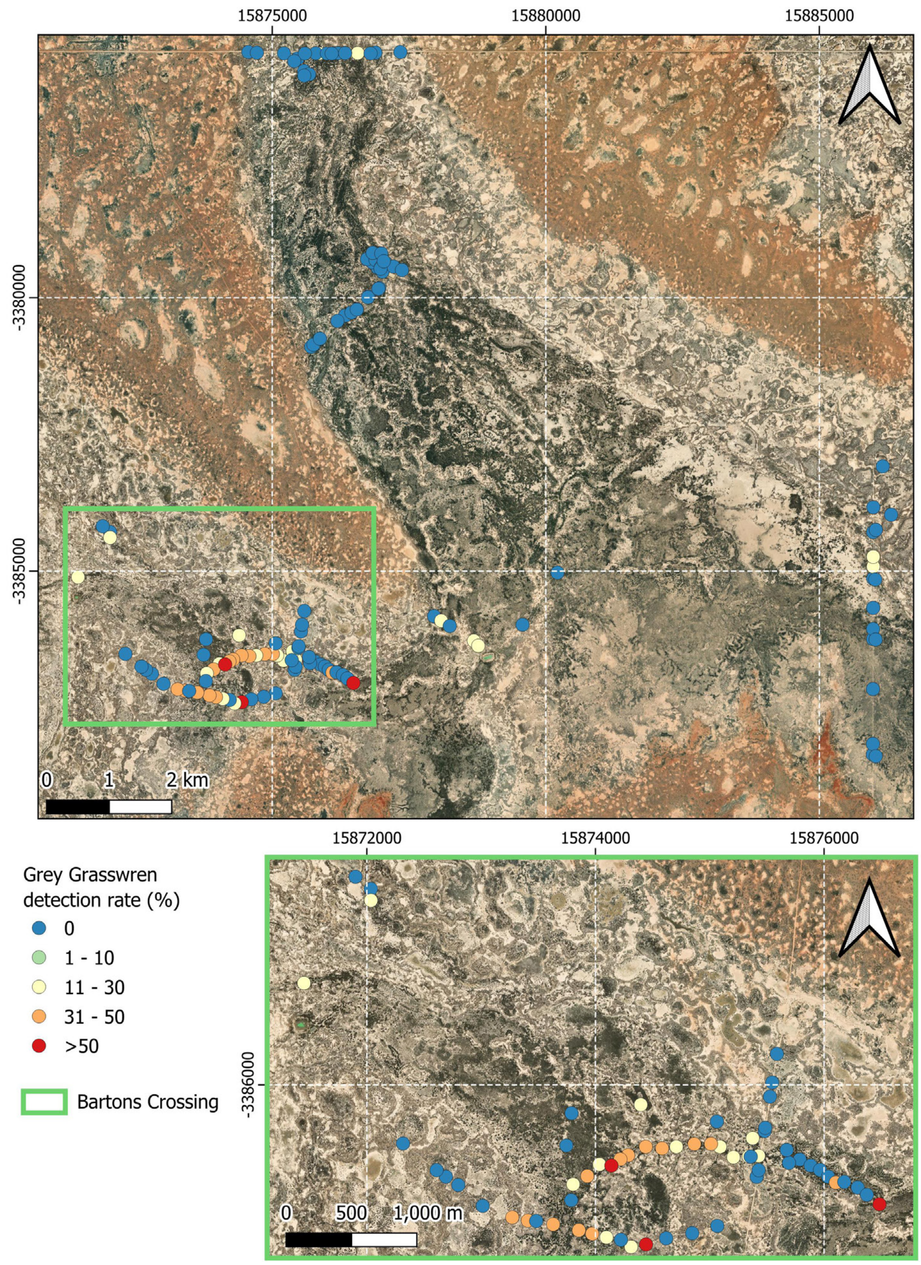

Figure 8. Grey Grasswren detection rate, i.e. percentage of survey years when Grey Grasswrens were detected at a survey site over the study period 2015–2023. The inset shows the detection rate at Bartons Crossing sites (coordinate reference system WGS 84).

Response to survey conditions

To assess the impact of survey conditions on Grey Grasswren detectability, a model was fitted with the following covariates: month of survey (September or December); time (minutes after sunrise); wind (0, 1, 2, 3, 4); temperature (°C); and rainfall at Tibooburra the month before survey. The response to these covariates was calculated. Using a level of statistical support of 0.95, detections of Grey Grasswren had a strong positive response to rain, suggesting that the subspecies is more likely to be detected when rain occurred in the weeks before the survey. Grey Grasswrens also had a small negative response to time since sunrise, suggesting that they are more likely to be detected in the morning. According to this model, the other covariates did not appear to significantly affect the detectability of Grey Grasswrens.

Response to habitat variables

Grey Grasswrens were only detected when the shrub community was dominated by Lignum (as the only dominant shrub species; n = 218) and not when the site was dominated by goosefoot (n = 7), Swamp Canegrass (n = 7) or Old Man Saltbush (n =1). They were only detected during surveys where the mean height of the Lignum patch was between 1.5 and 3 m, with a median across detections of 2.5 m.

The Grey Grasswren was only detected at sites that had ≥20% bare ground and only at sites that were not wet or damp. When the dominant ground cover species was the waterweed *Osteocarpum acropterum* (short-lived species likely to respond to inundation/rainfall; n = 6) or Hairy Carpet-weed *Glinus lotoides* (generally short-lived in temporarily flooded areas; n = 3) the

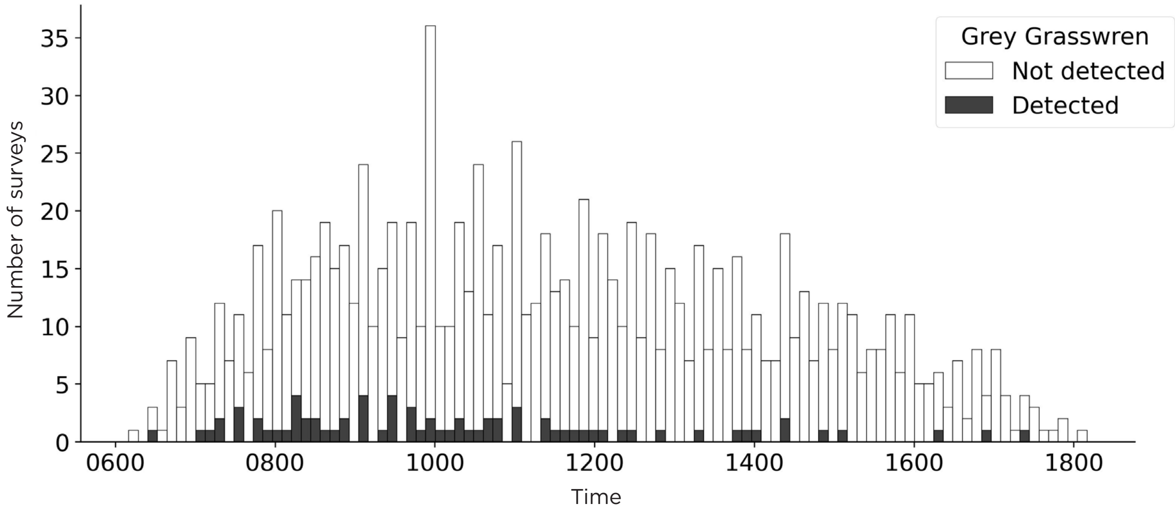

Figure 9. Grey Grasswren detections throughout the day, from 0600 to 1800 h. Each bar represents the number of surveys conducted within specific time frames, with white segments denoting no detection, and black segments denoting detection.

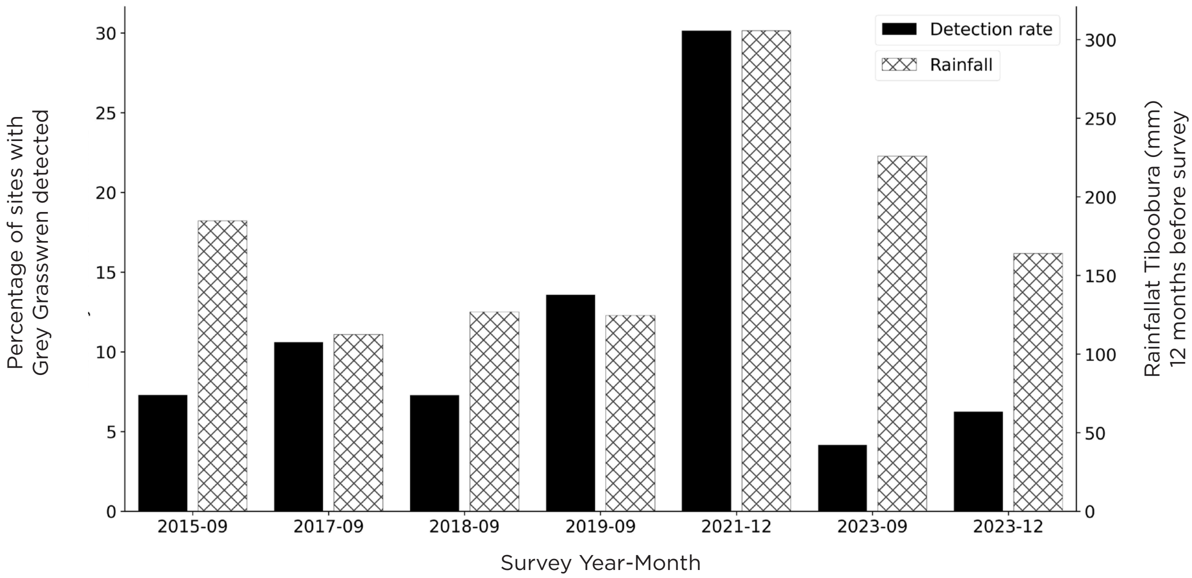

Figure 10. Percentage of sites where Grey Grasswrens were detected compared with the total rainfall in the 12 months before the survey.

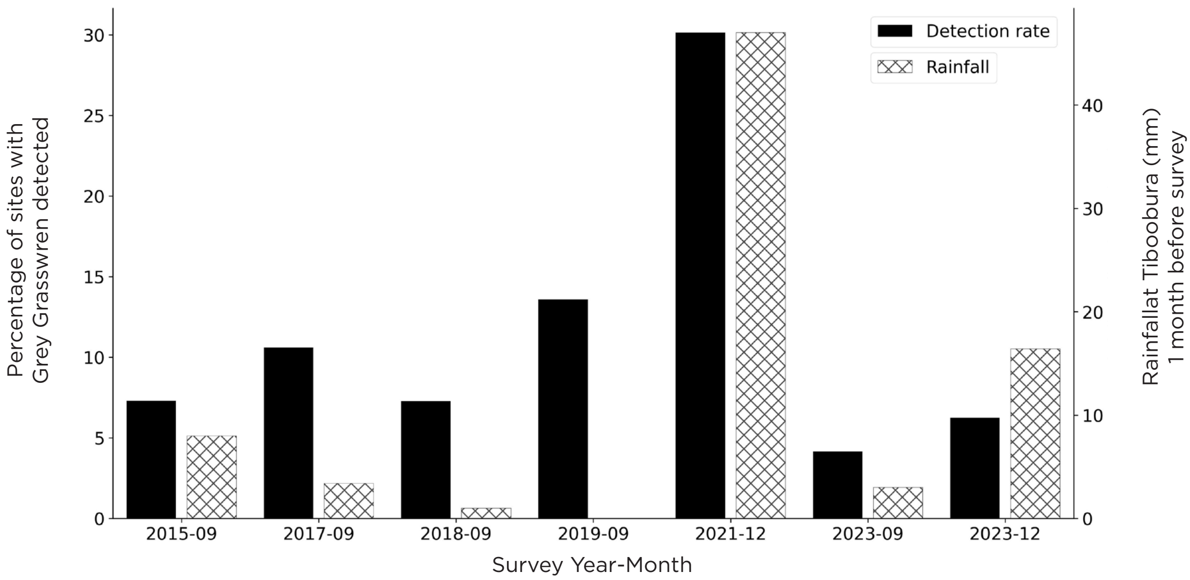

Figure 11. Percentage of sites where Grey Grasswrens were detected compared with the total rainfall in the month before the survey.

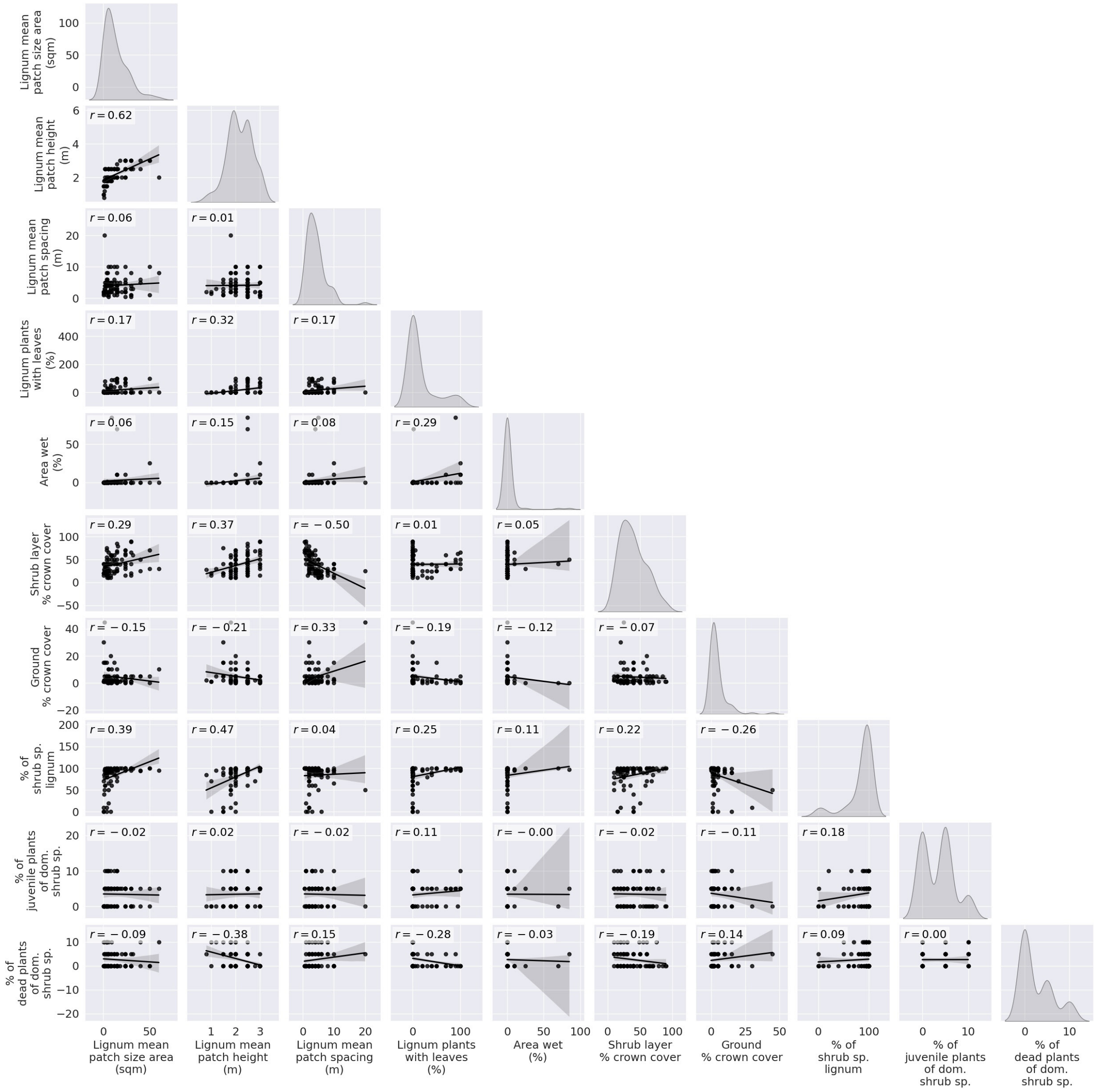

Figure 12. The correlation between continuous habitat variables. The matrix shows the pairwise relationships in the dataset. The diagonal plots are computed using a univariate kernel density estimate. For each correlation plot, the Pearson correlation coefficient between two different covariates is indicated.

proportion of detections was >50%. When Hairy Carpet-weed and/or Tall Nut-heads *Ethuliopsis cunninghamii* (an annual on alluvial flats and around ephemeral swamps; *n* = 16) were subdominant in the ground cover, the proportion of Grey Grasswren detections was >50%.The prevalence of detections was higher during surveys with no observed disturbance (22%) compared with those with some disturbance (10%).

Covariates retained in modelling of Grey Grasswren habitat data included: disturbance (level); Lignum mean patch size (area m^2); height (m); and spacing (m); percentage of Lignum plants, in a radius of 20 m, with presence of leaves on stems; percentage area wet/damp; shrub layer (height 0.5–3 m) percentage crown cover; shrub layer dominant 1; ground cover percentage crown cover; proportion of shrub species – Lignum; percentage of juvenile plants of dominant shrub species (20-m radius); percentage of dead plants of dominant shrub species (20-m radius). The correlation between the continuous variables is shown in Figure 12.

When fitting a model to the habitat data, the partition of the explained variance for the fitted model showed that the spatial component accounted for 59% of the variance, suggesting the presence of spatially structured variations in Grey Grasswren distribution that were not captured by the chosen set of habitat covariates (e.g. landscape-scale processes may be masking fine-scale habitat variables). The habitat covariates explained only a small proportion of the variance: 9.2% for the percentage of the area that was wet/damp, 8% for the percentage of dead plants of the dominant shrub species within 20 m, and 5.3% for the mean height of the Lignum patch.

The subspecies’ responses to covariates were also calculated. Using a level of statistical support of 0.95, this analysis showed that Grey Grasswren had a strong positive response to Lignum height, a relatively small positive response to the percentage of dead Lignum in the shrub crown cover and the percentage Lignum crown cover, and a strong negative response to disturbance.

Thirty sites on Thurloo Downs were surveyed for Grey Grasswren in September 2018. Additional surveys were conducted in 2019 along the western margin of Caryapundy Swamp and in the southern extremity of the Bulloo Overflow. No Grey Grasswrens were detected during either of these surveys.

Discussion

Grey Grasswrens are difficult to detect; hence, confidence of true absence is a significant issue for conventional survey techniques for the species. This was reflected in our study by low detection rates in most years (i.e. 2015, 2017, 2018, 2019 and 2023). The estimated detectability for Grey Grasswrens (given presence) for a single site visit was extremely low and indicated that many repeat site surveys may be required to achieve an acceptable level of confidence in absences. Alternatively, longer-duration site visits might assist in increasing detectability. However, given the large number of repeat site visits and/or extended duration of site surveys required to increase detectability, a rapid repeat survey method is unlikely to be cost-effective for future monitoring of Grey Grasswrens. Note that our sampling design was strongly influenced by the accessibility of survey sites and the survey sites were not representative of the distribution of Lignum within the National Park, nor did we sample other habitats thought to be used by the species such as Old Man Saltbush, Swamp Canegrass and samphire.

In December 2021, the percentage of survey sites where Grey Grasswrens were detected was remarkably high (30%) whereas in all other years (2015, 2017, 2018, 2019 and 2023) this was <15%. In 2021, the prevalence of detections at Bartons Crossing reached 44%. We consider these results reflect a real increase in the detectability and occupancy of the subspecies when compared with other survey years. These detection data, combined with observations of multiple birds at single survey sites (presumably family groups), likely reflected a resurgence of the Grey Grasswren population in the National Park in 2021, particularly at Bartons Crossing. Jaensch *et al.* (2021) also conducted surveys for Grey Grasswrens in 2021 (23–30 April) in Queensland in the far north-west of the Bulloo Lakes floodplain. They noted that many sightings involved groups of five or more Grey Grasswrens, "suggesting that successful breeding had occurred recently, probably following extensive flooding in 2020" (p. 1). These observations support the proposition that the resurgence of Bulloo Grey Grasswrens might have occurred more broadly within the Bulloo Lakes floodplain in 2021.

Grey Grasswren detection data (including incidental detections made between survey sites) support the proposition that Bartons Crossing is a drought refuge for the subspecies in NSW. The channels running east to west between Bartons Crossing and Bullagree Tank appear to retain moisture from local rains and flood for a longer period of time than elsewhere in the National Park. The low-lying nature and strong channelisation of substrate at Bartons Crossing may be key to the resilience of Lignum and hence the resilience of Grey Grasswrens at this location during periods of drought. In 2019, a low prevalence of detections overall, but the presence of some survey sites with repeat detections, suggests that the habitat at Bartons Crossing remained suitable for both foraging and breeding during drought. In contrast, a high prevalence of detections in 2021, including repeat detections and multiple detections at several survey sites, suggests a burgeoning population growth in a year of rainfall well above average. Hardy (2002) found high capture rates of Bulloo Grey Grasswrens by mist-netting during periods of drought. He suggested that Lignum might serve as a refuge during drought and support high densities of Grey Grasswrens as the number of birds captured during drought was much higher than expected for years of normal rainfall.

Wind, rain and flood influenced both the number of survey locations that could be accessed, and the number of repeat surveys achieved. The unpredictable nature of rain and wind, combined with the remoteness of the study area, reduced the scope and repetition of our surveys in most years from optimal to barely adequate.

The absence of detections at most survey sites in the National Park does not imply absence of Grey Grasswrens. It is more likely that abundance at these locations was very low. On the other hand, the absence of detections since 1991 near the eastern boundary of the National Park probably reflects local extinction of the subspecies at this location, until more recent recolonisation. We detected Grey Grasswrens on the eastern boundary of the National Park at two sites in September 2021. Previous authors (e.g. Hardy 2010; Black *et al*. 2015) suggested that Grey Grasswrens may be able to disperse during exceptional seasonal conditions of high rainfall and/or major floods. Farrell *et al.* (2014) suspected that the detection of Grey Grasswrens near the eastern boundary of the National Park in 1991 was from a subpopulation that established when major floods from the Bulloo River flowed into channels leading directly onto Thurloo Downs from Queensland and habitat had regenerated. When Hardy (2010) visited this location in 2009 no suitable habitat was found.

Purchase of Narriearra Station in 2020 to be a National Park corresponds with the end of a long period of drought and a swing to above-average rainfall. However, aside from an upward trend in rainfall, the most obvious change that occurred at survey sites since 2017 (when habitat data were first collected) was a reduction in evidence of cattle damage. Since 2019, ~100 head of cattle have been in the National Park and there was no evidence of recent cattle presence or cattle damage at survey sites in 2021 and 2023. We consider this dramatic decline in the abundance of cattle as a result of the drought, followed by the creation of a National Park, might have contributed to the apparent resurgence of Grey Grasswrens. The reduction in the density of cattle in the National Park is likely to foster natural regeneration of Lignum and assist in restoration of the historical distribution of these vegetation communities.

Several survey techniques have been reported for Grey Grasswrens. For example, Farrell *et al.* (2014, 2015) surveyed Bulloo Grey Grasswrens along transects though they detected few birds using this technique. Black *et al.* (2011) surveyed Lake Eyre Basin Grey Grasswrens by slowly walking through an area over a 30-minute period. They usually detected birds first by hearing and noted that birds rarely responded to high-pitched squeaks or playback of Grey Grasswren or other grasswren calls. Jaensch *et al.* (2013, 2014) based their surveys on detecting Bulloo Grey

Grasswren calls, particularly alarm calls, which are often on arrival of observers or their vehicle. They walked around survey sites (often over an area of diameter >300 m) listening for calls for at least 15 minutes and watching the ground for Grey Grasswrens moving between shrubs in the dense shrub cover. Jaensch *et al.* (2021) conducted broad area searches of ~500-m radius over 25–153 minutes and more detailed 2-ha searches over 20 minutes when Grey Grasswrens were detected. They walked in a line of five observers spread ~20 m apart through prospective habitat.

Because the reported survey techniques rely heavily on expert knowledge and expert call recognition, meaningful comparisons of detectability and abundance of Grey Grasswrens between studies is problematic. Notwithstanding the variability in survey methods, all previous studies identified the importance of Lignum to the Grey Grasswren. If other vegetation types are used more frequently for breeding and foraging when Lignum is inundated, or more frequently for foraging when birds are breeding and roosting in Lignum, then this may influence detectability of Grey Grasswrens in Lignum, not only on a seasonal basis but also diurnally.

Conclusions

Although crude, our rapid survey method is likely to be effective in tracking broad trends in the abundance and distribution of Grey Grasswrens in Narriearra Caryapundy Swamp National Park. The detection data from our study indicate that in most survey years the abundance of the birds was very low and that the population in NSW contracted to a drought refuge at Bartons Crossing. Local extinctions might have occurred at some locations since the start of our study. Following severe drought, an upswing to above-average rainfall coincided with a dramatic increase in the abundance of Grey Grasswrens at Bartons Crossing. High annual rainfall also coincided with the first year of our study when Grey Grasswrens were detected on the eastern boundary of the National Park (where they had not been detected for 30 years). We conclude that the return to high rainfall stimulated a burgeoning population growth at Bartons Crossing and to favourable conditions for dispersal. We interpret the detection of Grey Grasswrens on the eastern boundary of the National Park as evidence of recolonisation following local extinction that probably happened sometime between 1991 and 2009.

The results of our study support the proposition that Lignum is the refuge for Grey Grasswrens during periods of climatic extremes (Hardy 2010) and that they may occupy Lignum during the long dry and hot times that are normal and move to more-open drier habitats on the periphery when Lignum is flooded for extended periods (Black *et al.* 2015).

Recommendations for future monitoring

The emerging threat of climate change in the arid region of central Australia, including potential increases in the duration and intensity of droughts and increases in the magnitude of extreme rainfall events (Evans *et al.* 2017) and heat waves (Herold *et al.* 2018), will likely pose challenges for the conservation management of Grey Grasswrens. There are potential benefits from increased intensity of extreme rainfall events (i.e. boom conditions) for both breeding and dispersal though the benefits may be countered by extended and more-intense drought periods (bust phase), testing the resilience of 'drought refuges' such as Bartons Crossing. Cost-effective methods for population and habitat monitoring will therefore be important to inform conservation strategies and management actions for this species in an uncertain future.

The remoteness of habitat, low detectability and a likely boom–bust ecology impose considerable constraints on the design and implementation of a reliable and cost-effective survey methodology for Grey Grasswrens. We suggest that passive acoustic monitoring (PAM) may have application to overcoming these issues. PAM allows the collection of large amounts of reproducible and standardised data over long time periods and in remote locations (Shonfield & Bane 2017; Darras *et al.* 2019), which is not feasible using traditional survey approaches for Grey Grasswrens. Once deployed, acoustic recorders will not be deterred by the climatic and weather extremes that plague traditional field-survey approaches. Extended battery life and increased memory-storage capacity of modern acoustic recorders provide scope for long-term deployment. To this end, in 2023 we collected reference calls of Grey Grasswrens and other bird species that commonly called at our survey sites (i.e. Redthroat, White-winged Fairy-wren *Malurus leucopterus* and Purple-backed Fairy-wren *M. assimilis*). Initial assessment of the potential for PAM is promising. Acoustic recorders are now being deployed at our survey sites by the NSW National Parks and Wildlife Service and NSW Department of Climate Change, Energy, the Environment and Water to characterise the unsolicited calling behaviour of Grey Grasswrens and hence the likely detectability of the subspecies using PAM, and to collect additional acoustic data for validation and training of an automated detection algorithm.

Acknowledgements

This study was funded by the New South Wales Department of Climate Change, Energy, the Environment and Water (DCCEEW) through the Saving Our Species program. We acknowledge that Narriearra Caryapundy Swamp National Park is in the traditional Country of the Karengappa Aboriginal People and that Wongkumara People and Malyangapa People also have traditional ties to the region. We thank Bill O'Conner and his family for their hospitality and allowing us to undertake fieldwork on Narriearra Station from 2015 until the property was purchased by the NSW Government for a National Park in October 2020. We also thank Peter Hughes (Manager, Thurloo Downs), George Williams (Manager, Onepah) and Nic Stevenson (Manager, Pindera Downs). We thank the NSW National Parks and Wildlife Service (NPWS) for permission to survey in the National Park, logistical support, and accommodation at Mt Wood Homestead, Sturt National Park. Several individuals provided support to this study; in particular, we thank Jaymie Norris (NPWS), Dan Hough (NPWS), Aimee Hough (NPWS), Graeme Armstrong (NPWS), Grant Adams (NPWS), Nic Stevenson (NPWS), David Coote (DCCEEW) and Jamie Hayman (Wild Dog Destruction Board). Surveys were conducted under NSW, DCCEEW, Animal Research Authority No. 240604/01 Saving Our Species Monitoring of the Grey Grasswren.

References

Bjornstad, O. (2015). Ncf: Spatial nonparametric covariance functions. R package version 0.5-92. Available at: https://cran.r-project.org/web/packages/ncf/ncf.pdf.

Black, A.B., Carpenter, G., Jaensch, R., Pedler, L. & Pedler, R. (2015). A survey of outlying populations of the Grey Grasswren *Amytornis barbatus* (Maluridae). *Corella* **39**, 25–37.

Black, A.B., Carpenter, G., Pedler, R., Pedler, L. & Langdon, P. (2011). Habitats of the Grey Grasswren *Amytornis barbatus diamantina* and a review of the species' distribution. *Corella* **36**, 29–37.

Darras, K., Batáry, P., Furnas, B.J., Grass, I., Mulyani, Y.A. & Tscharntke, T. (2019). Autonomous sound recording outperforms human observation for sampling birds: A systematic map and user guide. *Ecological Applications* **29**, e01954.

DCCEEW (Department of Climate Change, Energy, the Environment and Water) (2024). Grey Grasswren – Profile: https://threatenedspecies.bionet.nsw.gov.au/profile?id=10047

Dormann, C.F., Elith, J., Bacher, S., Buchman, C., Carl, G., Carré, G., García Marquéz, J.R., Gruber, B., Lafourcade, B., Leitão, P.J., Münkemülla, L.T., McClean, C., Osborne, P. E., Rhineking, B., Shröder, B., Skidmore, A.K., Zurell, D. & Lautenbach, S. (2013). Collinearity: A review of methods to deal with it and a simulation study evaluating their performance. *Ecography* **36**, 27–46.

Evans, J.P., Argueso, D., Olson R. & DiLuca, A. (2017). Bias-corrected regional climate projections of extreme rainfall in south-east Australia. *Theoretical and Applied Climatology* **130**, 1085–1098.

Farrell, J.R., Hardy, J.W. & Wilkins, K. (2014). *Report to the Saving Our Species Program of the Office of Environment and Heritage on the Status of the Grey Grasswren* Amytornis barbatus barbatus *in North-western NSW in 2014.* Australian Bird Study Association Inc., Sydney.

Farrell, J.R., Hardy, J.W. & Wilkins, K. (2015). *Report to the Saving Our Species Program of the Office of Environment and Heritage on the Status of the Grey Grasswren* Amytornis barbatus barbatus *in North-western NSW in 2015.* Australian Bird Study Association Inc., Sydney.

Fisher, A., Flood, N & Danaher, T. (2016). Comparing Landsat water index methods for automated water classification in eastern Australia. *Remote Sensing of Environment* **175**, 167–182.

Fiske, I.J. & Chandler R.B. (2011). Unmarked: An R package for fitting hierarchical models of wildlife occurrence and abundance. *Journal of Statistical Software* **43**, 1–23.

Gelman, A. & Rubin, D.B. (1992). Inference from iterative simulation using multiple sequences. *Statistical Science* **7**, 457–472.

Hardy, J.W. (2002). A banding study of the Grey Grasswren *Amytornis barbatus barbatus* in the Caryapundy Swamp of south-western Queensland. *Corella* **26**, 106–109.

Hardy, J.W. (2010). Distribution, status and options for the future management of the Grey Grasswren *Amytornis barbatus barbatus* in New South Wales. *Corella* **34**, 25–35.

Hardy, J.W. (2022). *Trapping and Radio-tracking of Grey Grasswrens* Amytornis barbatus barbatus *at Narriearra Caryapundy Swamp National Park in North-western NSW in 2022.* Report to Saving Our Species Program, NSW Department of Planning and Environment, Dubbo, NSW.

Hardy, J.W., Farrell, J., Pedler, L.P., Jaensch, R.P. & Garnett S.T (2021). Bulloo Grey Grasswren *Amytornis barbatus barbatus*. In: Garnett, S.T & Baker, G.B. (Eds). *Action Plan for Australian Birds 2020*, pp. 530–533. CSIRO Publishing, Melbourne.

Herold, N., Ekstom, M., Kala, J., Goldie, J. & Evans, J.P. (2018). Australian climate extremes in the 21st century according to a regional climate model ensemble: Implications for health and agriculture. *Weather and Climate Extremes* **20**, 54–68.

Jaensch, R., Day, L., van Osta, J. & Jaensch, T. (2014). *Developing Capacity for Management of Habitat of Grey Grasswren (Endangered) in the Bulloo Lakes System: Report on the 2014 Expedition.* Report to South-West NRM (Natural Resource Management), Jaensch Ornithology and Conservation.

Jaensch, R., Pedler, L. & Wingett, D. (2013). *Managing a High-profile Biodiversity Asset: Identifying Habitat and Hotspots for Occurrence of Grey Grasswren in the Bulloo Lakes System*. Report to South-West NRM (Natural Resource Management), Charleville, Qld.

Jaensch, R., Treilibs, V., Treilibs, R., Charbonneau, P., Wall, J. & Maurer, G. (2021). *A Survey of Grey Grasswren in the North-west Bulloo Lakes Floodplain, Queensland, in April 2021*. BirdLife Australia, Melbourne.

MacKenzie D.I., Nichols J.D., Lachman G.B., Droege S., Royle J. & Langtimm C.A. (2002). Estimating site occupancy rates when detection probabilities are less than one. *Ecology* **83**, 2248–2255.

Shonfield, J. & Bayne, E.M. (2017). Autonomous recording units in avian ecological research: Current use and future applications. *Avian Conservation and Ecology* **12**, 14.

Tiefelsdorf, M. (2000). *Modeling Spatial Processes: The Identification and Analysis of Spatial Relationships in Regression Residuals by Means of Morans' I.* Cambridge University Press, Cambridge, UK.

Tikhonov, G., Duan, L., Abrego, N., Newell, G., White, M., Dunson, D. & Ovaskainen, O. (2020). Computationally efficient joint species distribution modeling of big spatial data. *Ecology* **101**, e02929.

Received 28 OCtober 2024, accepted 6 May 2025, published online 29 August 2025
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