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The distribution and conservation status of Carpentarian grasswrens (*Amytornis dorotheae*), with reference to prevailing fire patterns

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Abstract. The Carpentarian grasswren (*Amytornis dorotheae*) is a small, shy passerine patchily distributed through *Triodia* systems in the central and southern parts of Australia's tropical savannas. Population decline has been reported in the Northern Territory, presumably due to mismanaged fire. The species is considered Endangered in the Northern Territory and Near Threatened in Queensland, but it is not listed Federally. Here, we present the results of over 3000 surveys conducted between 2008 and 2013. We show that Carpentarian grasswrens are divided into four populations, although the northernmost one (Borroloola) now appears to be extinct. The Area of Occupancy for the southernmost population appears to have declined by 28%, while only small numbers of isolated birds now occur at the two intervening populations. Our data suggest that the four populations appear to be at different stages on an extinction pathway, from population decline, to fragmentation and isolation, to extinction, and this seems to be related to worsening fire patterns as one moves northwards. We suggest that the Carpentarian grasswren be listed as Vulnerable at the State and Federal level, and that urgent investment in long-term regional fire management using prescribed burning is required to reverse the declines in the extant populations. For the presumed extinct Borroloola population, restoration will probably need to involve translocation coupled with effective fire management.

Additional keywords: extinction, fire management, savannas, threatened species.

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Introduction

The Carpentarian grasswren (*Amytornis dorotheae*) inhabits areas of relatively long unburnt spinifex (*Triodia* spp.) growing on dissected ranges and undulating rocky slopes across parts of Australia's tropical savannas (Higgins *et al.* 2001; Perry *et al.* 2011). The species' historical range stretched from near Borroloola in the Northern Territory, east to ~140°E and south to around Mt Isa (hereafter, Buckley River) (Fig. 1). It appears that occupancy is not continuous throughout this distribution, with a wide gap centred along the Gregory River separating the 'Gulf' birds from those further south (Higgins *et al.* 2001). Within these two broad areas, it seems the species' distribution is further subdivided, with more or less discrete populations near Borroloola, Wollogorang Station, Boodjamulla National Park and Buckley River, despite apparently contiguous habitat between some of these populations (Harrington and Fletcher, in litt.). Carpentarian grasswrens were first discovered by Europeans in the north-western part of their distribution in 1912 (Hill 1913), and this was extended eastwards into northern Queensland in 1976 (Higgins *et al.* 2001). However they were not recorded near Mount Isa until 1990 (Harris 1992), presumably owing in part to their cryptic behaviour. Indeed, detecting Carpentarian grasswrens continues to present a formidable challenge.

The vegetation communities inhabited by Carpentarian grasswrens are naturally highly flammable thanks in large part to the annual cycle of prolific growth during the monsoon, followed by landscape-scale curing during the dry season (roughly June to December). Therefore it is likely that fires have always featured in the species' ecology, including during both the pre- and postarrival periods of Aboriginal people. During these periods, Carpentarian grasswrens were probably able to cope with a particular combination of fire frequency and scale that allowed individuals to move through the landscape among patches of suitably aged habitat. However, over the past 200 years or so, northern Australian fire patterns have changed. The pre-European use of fire by Aboriginal people resulted in a fine-grained mix of postfire ages, and this contrasts with the contemporary setting that is characterised by more extensive

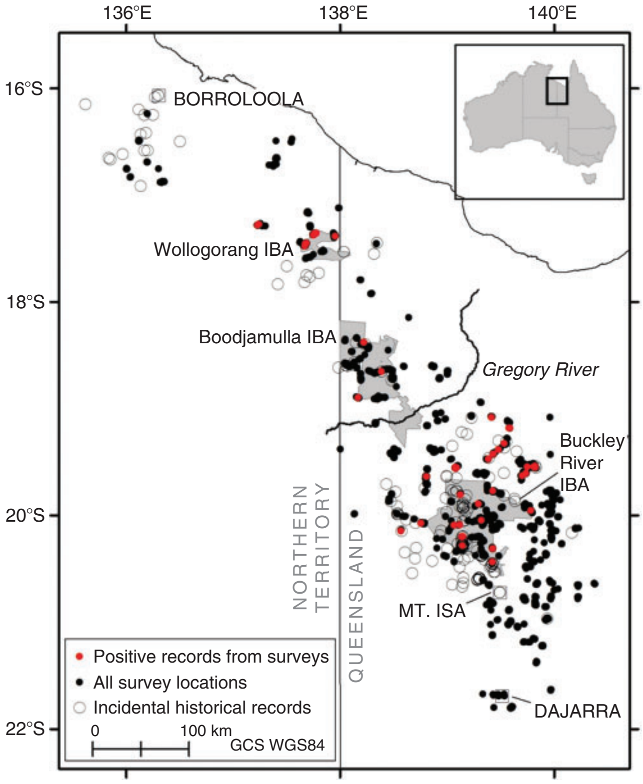

Fig. 1. The locations of incidental historical Carpentarian grasswren records in relation to call-playback surveys conducted between 2008 and 2013. The locations of positive records arising from these surveys are also shown.

and frequent fires in the mid to late dry season (roughly August to December) (Russell-Smith 2002; Russell-Smith *et al.* 2003). These contemporary patterns now see large parts of the landscape homogenised and maintained in relatively early postfire successional states. The most commonly applied management tool to combat mid-to-late dry-season fires is early dry-season prescribed burning (Andersen *et al.* 2005). In practice this can be difficult to achieve (Allan and Baker 1990), although there are some examples of successful multiyear programs that have demonstrated a reduction in the incidence of large, mid-to-late dry-season fires at a landscape scale (Legge *et al.* 2011; Price *et al.* 2012).

Given the contemporary pattern of burning and their reliance on relatively long (3–4 year old) unburnt spinifex for breeding and shelter (Perry *et al.* 2011), it is intuitive that Carpentarian grasswrens may be under threat. The current IUCN status for this species was determined in 2000 as Near Threatened, based on an assumed population decline from deteriorating quality of the habitat due to frequent and extensive fires (IUCN 2015). Indeed, Perry *et al.* (2011) showed that Carpentarian grasswrens were absent from seven out of eight historically occupied sites in the Northern Territory and they identified wildfires as the main cause for this decline. Consequently, Northern Territory legislation currently classifies the species as Endangered (NT Department of Land Resource Management 2015), while in Queensland it is currently listed as Near Threatened (*Nature Conservation (Wildlife) Regulation 2006*). They are currently not listed on the Federal *Environment Protection and Biodiversity Conservation Act 1999*.

In 2008 Birdlife Australia declared three 'Important Bird Areas' (IBAs) based on the Carpentarian grasswren at three of the aforementioned populations – Buckley River, Boodjamulla and Wollogorang (Fig. 1). As part of the IBA monitoring program, Birdlife Northern Queensland has been undertaking surveys at various places since 2008 to clarify the species' current distribution and status. This paper reports on the results of these surveys. It also examines the prevailing fire patterns at each of the populations to help elucidate the relationship between fire and population decline.

Methods

Field surveys

Surveys were conducted in 2008, 2009, 2011 and 2013, during May–August and mostly (~80%) between sunrise and midday. Fig. 1 shows the location of surveys. The *a priori* aim of the surveys was to clarify the current distribution of Carpentarian grasswrens, including surveying the intervening areas between the aforementioned populations, as well as beyond their southern known limit. In 2011, surveys focussed on Boodjamulla National Park, where a Robinson-44 helicopter was used to gain access to remote places. Four-wheel-drive vehicles were used in other years. Survey locations were selected on the basis of the availability of large (>~2 ha) patches of apparently suitable habitat (dominated by *Triodia* spp. and >3 years since the last fire), as defined by fire scar maps drawn using data from the North Australia Fire Information website (www.firenorth.org.au). Actual survey points within these patches were 300 m from the edge of a habitat boundary (including edges delineating habitat that had been burnt <3 years earlier), and more than 200 m from the next nearest survey point.

In total, 38 volunteers used call-playback to ascertain occupancy by Carpentarian grasswrens, but the numbers of participants varied in each year. Volunteers worked in teams of two to maximise the likelihood of detecting Carpentarian grasswrens. Recorded calls of Carpentarian grasswrens were broadcast through 3-W speakers for ~20 s, after which observers scanned and listened for a response for ~30 s. After this, a distress call of the red-backed fairy-wren (*Malurus melanocephalus*) was played with subsequent scanning and listening for another ~30 s. This call has been shown to elicit a response in a wide range of species, including other malurids (S. Murphy, unpubl. data). Locations were recorded using hand-held GPS units.

Extent and Area of Occupancy

Extent of Occupancy (EOO) is the overall geographic spread of a taxon and is calculated by constructing a shape that includes all point locations (Gaston and Fuller 2009). Despite the issue of EOO potentially overestimating a taxon's range, Gaston and Fuller (2009) suggest that areas where a species is suspected to be absent should actually be included in EOO calculations because of the difficulty in determining the threshold for identifying such range discontinuities. However, because extensive surveys for the Carpentarian grasswren were conducted in suitable habitat between populations that failed to detect them

Table 1. Raw survey effort and results, compared with the number of sites at which birds should have been detected given alternate detection probabilities

Year	No. of surveys	No. of sites with Carpentarian grasswrens	Expected survey results under alternate detection probabilities			
			0.75	0.5	0.25	0.07
2008	1412	13	17	26	52	186
2009	1001	31	41	62	124	443
2011	277	5	7	10	20	71
2013	495	10	13	20	40	143

(see later) (Fig. 1), we felt that estimating EOO for each population separately was justified. Also, discrete measures of EOO were required for subsequent analyses that involved fire. Accordingly, a minimum convex polygon was created separately for each of the four Carpentarian grasswren populations. Two series of EOOs were calculated, before and after 2000, to examine change in EOO through time. The year 2000 was chosen somewhat arbitrarily, although it did provide a convenient cut-off that roughly halved the confirmed point locations of Carpentarian grasswrens (136 records before 2000 and 115 after 2000).

In contrast to EOO, the Area of Occupancy (AOO) is a measure of all cells in a grid that contain point records. AOO does take into account unsuitable habitat within an EOO and therefore is better correlated with population size (Gaston and Fuller 2009). Estimates of AOO are heavily influenced by grid size, which should be biologically appropriate (IUCN 2001). In the absence of reliable biological data, the IUCN Standards and Petitions Working Group (IUCN 2006) suggests that a size of 2×2 km is a suitable reference scale for many species and was thus used to calculate AOO for Carpentarian grasswrens. As with the analysis of EOO, a threshold of 2000 was used to structure the Carpentarian grasswren data to examine change over time. Historical point-location data for EOO and AOO calculations included all records we could find that extended back to 1912. They were sourced from the two atlases of Australian birds (Blakers *et al.* 1984; Barrett *et al.* 2003), Atlas of Living Australia (www.ala.org.au) and incidental unpublished records, and added to the data collected during our systematic surveys in 2008–13. All spatial manipulations were performed using the GIS program ArcMap 10.0 (Environmental System Research Institute Inc., Redlands, CA).

Resampling historical locations and detection probability

A subset of survey locations at the two southernmost populations (i.e. Boodjamulla and Buckley River) were near sites that were previously known to be occupied by Carpentarian grasswrens. As such, a *post hoc* aim of this study was to determine whether or not there was any evidence that Carpentarian grasswrens had disappeared from these locations. This analysis mirrors the approach used by Perry *et al.* (2011), and complements our AOO analysis. A historical site was treated as being resurveyed if call-playback was conducted within 300 m. Results from previous call-playback surveys could be treated as historical records for the analyses of 2009, 2011 and 2013 data (i.e. 2008 data could be used for analyses involving 2009, 2011 and 2013 data, 2009 data could be used for 2011 and 2013 analyses, and so on).

As foreshadowed in the Introduction, Carpentarian grasswrens are notoriously cryptic and difficult to detect, even with call-playback. Accordingly, different estimates of detection probability were used to explore what effect this might have on inferring population decline, based on their disappearance from historically occupied sites. A detection probability of 1.0 assumes that if a bird is present it will be detected all of the time, while a detection probability of 0.5 assumes that if a bird is present it will be detected only half of the time, and so on.

The alternate detection probabilities were also applied to the entire raw survey results from each year (i.e. not just those surveys that were conducted at historically occupied sites) by dividing the number of sites where Carpentarian grasswrens were detected in a year by each detection probability. This had the effect of inflating the raw survey results, and by doing so it was possible to gauge, albeit roughly, what the most realistic detection probability was likely to be, which further helped in the interpretation of population change.

Results

Extent and Area of Occupancy

In total, 3185 surveys were conducted across all years. These resulted in 58 locations where one or more Carpentarian grasswrens were detected; these locations are shown in Fig. 1. Table 1 shows the breakdown of survey results in each year. No Carpentarian grasswrens were detected in the Borroloola area despite 82 surveys in suitable habitat. The 2009 surveys near Wollogorang extended the known distribution of this population ~50 km to the north-west of the nearest known historically occupied site. Surveys elsewhere failed to detect Carpentarian grasswrens beyond the historically known envelopes for each population. For example, no Carpentarian grasswrens were detected south of Mount Isa despite comprehensive surveys that extended beyond Dajarra. Table 2 shows the change in EOO and AOO for the four populations.

Resampling historical locations

Table 3 shows the results of 49 surveys conducted within 300 m of a historically occupied site. Coincidentally, Carpentarian grasswrens were detected at only one (different) site in each survey year. Table 3 also shows percentage change per year

Table 2. Change in the Extent and Area of Occupancy for Carpentarian grasswrens before and after 2000
Areas are in hectares. Percentage change is the difference between post-2000 and pre-2000 areas, as a proportion of the pre-2000 area

Population	Extent of Occupancy			Area of Occupancy		
	Pre-2000	Post-2000	% change	Pre-2000	Post-2000	% change
Borroloola	532 997	0	−100	6400	0	−100
Wollogorang	153 609	62 514	−59	3600	3600	0
Boodjamulla	29 346	111 429	+280	2400	2400	0
Buckley River	2 100 060	1 723 899	−18	28 400	20 400	−28
Total	2 816 012	1 897 842	−33	40 800	26 400	−35

Table 3. Percentage change in historical site occupancy by Carpentarian grasswrens, taking into account varying detection probabilities
The last column shows what the detection probability would need to be for there to be no decline in Carpentarian grasswrens. *n*, number of surveys conducted within a 300-m radius of a historical Carpentarian Grasswren record

Year	*n*	No. of Carpentarian grasswrens detected	% change using alternate detection probability				Detection probability for 0% change
			1.0	0.75	0.5	0.25	
2008	6	1	−83	−78	−67	−33	0.17
2009	13	1	−92	−90	−85	−69	0.08
2011	15	1	−93	−91	−87	−73	0.07
2013	15	1	−93	−91	−87	−73	0.07

under alternate detection probabilities. At one end of the scale, using a detection probability of 1.0, Carpentarian grasswrens had disappeared from 83–93% of sites. Using a detection probability of 0.25, the declines were between 33 and 73%. A detection probability of between 0.17 and 0.07 was needed for there to be no decline based on the raw survey data. Table 1 shows the results for all surveys adjusted according to the alternate detection probabilities used in Table 3.

Discussion

Population limits and decline

Three main results have emerged from this study that we believe have implications for the conservation status of Carpentarian grasswrens. First, the survey results support the notion that Carpentarian grasswren populations are discrete, with no evidence of occupancy in the intervening areas despite apparently suitable habitat. Reasons for this apparent discontinuity are unclear; however, there are similar examples in other *Amytornis* species of absence from superficially suitable habitat (e.g. *A. rowleyi* south of Winton, Queensland: S. Murphy, unpubl. data) and so the situation described here may not be that unusual or reflect ecological dysfunction. However, population disjunction may have implications for the long-term management of individual populations. For example, dispersal from neighbouring populations may not be a reliable mechanism for restoring the Borroloola population, and instead conservation managers may need to resort to translocation.

Second, combining the historical dataset with the results of the systematic surveys and using a cut-off at 2000 for confirmed locations, the overall AOO of Carpentarian grasswrens has reduced by 35%. Considering each population separately, birds at Borroloola have apparently all but disappeared (100% decline in AOO) whereas AOO for both Wollogorang and Boodjamulla remains unchanged. Intermediate to these results was the Buckley River population that now occupies ∼20 000 ha, down from a pre-2000 estimate of 28 000 ha (28% decline).

Estimates of EOO mostly reflect the decline in AOO, although a single point-record after 2000 in the south of Boodjamulla IBA effectively meant that the estimate of EOO for that population increased by 280%. This demonstrates the disproportionate effect that point observations at the edges of distributions can have on estimates of EOO, compared with AOO calculations where each point record has effectively the same weighting on the final area calculation. Despite this, our analyses show an overall decline in EOO of 33%, which we argue is cause for concern when one considers the extensive survey effort at the edges of the populations that would have maintained or increased estimates of EOO had Carpentarian grasswrens been detected.

Third, during the surveys very few Carpentarian grasswrens were detected at locations that were known to be occupied at some point in the past, a situation echoed in the surveys conducted by Perry *et al.* (2011). Even adjusting for low levels of detection, the evidence suggests a decline of 33–73% (based on a 0.25 detection probability). Analyses presented here

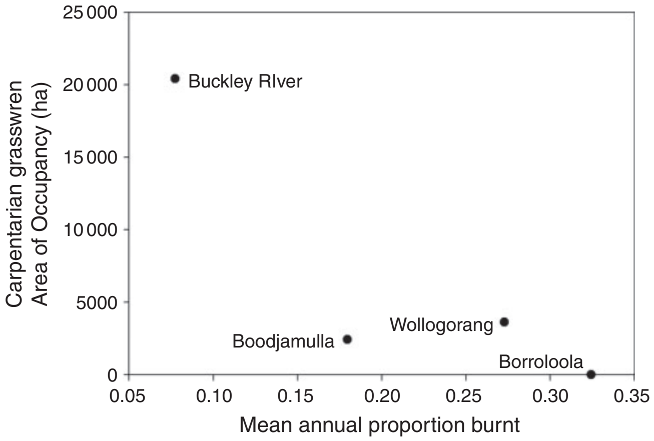

Fig. 2. Relationship between mean annual area burnt (proportion of EOO) and the size of each population's contemporary distribution (based on AOO) for Carpentarian grasswrens.

suggest that for a 0% decline, the detection probability would need to be as low as 0.07. In the absence of empirical field data, it is difficult to assess whether or not this low level of detection is realistic. However, if one applies a 0.07 detection probability to the raw survey results, surveyors could have expected to encounter Carpentarian grasswrens at 443 out of 1001 locations in 2009 (Table 1; other expected results under alternate detection probabilities are also shown in Table 1). Given that this seems to be an unrealistically high number, it is argued that the true detection probability for Carpentarian grasswrens is probably significantly higher than 0.07, thus supporting the notion that Carpentarian grasswrens have indeed disappeared from a substantial proportion of historical sites.

Relationship with prevailing fire patterns

Despite problems relating to detection uncertainty in Carpentarian grasswrens, we argue that the results and analyses outlined above provide convincing evidence to indicate that Carpentarian grasswrens have declined both in terms of range and overall population size. Explaining these patterns in relation to the prevailing fire patterns presents further challenges, relating mainly to small sample size (i.e. $n = 4$ populations). One approach might be to use logistic regression to explain the detection rate at point locations in relation to local fire patterns. However, without a better understanding of detection probability, such an approach is considered beyond reach at this stage. Resolving this using empirical data should be given high priority for future research.

Until such time as more comprehensive and inferential analyses can be undertaken, descriptive analyses of the fire patterns at a population scale nevertheless provide important insights into the relationship between fire and population decline. At one end of the spectrum is Borroloola, where apparent local extinction seems to have been driven by a high frequency of large fires (Fig. 2). Indeed, fire scar analyses based on data from the North Australia Fire Information website (www.firenorth.org.au) shows that, on average, 32% of the EOO for the Borroloola population burnt each year between 2000 and 2014 (Figs 2, 3). At the other end of the spectrum sits Buckley River, where, on average, only 8% burnt in the same period. Seemingly related to this, Buckley River supports the largest contemporary AOO by Carpentarian grasswrens, although the analyses presented here do demonstrate a 28% decline in AOO since 2000. However, with an appropriate level of investment in effective fire management that would see a reduction in the incidence of large-scale single fire events, we suggest that the population at Buckley River might recover.

Intermediate to Borroloola and Buckley River are the Boodjamulla and Wollogorang populations, each with a small and apparently stable AOO, despite relatively frequent, large-scale fire events (Figs 2, 3). It is feasible that these populations may have declined at some point previously, and what we see now is pairs or small groups of birds whose distributions have contracted to small and isolated fire refugia. It is possible that the AOO for these intermediate populations will remain steady for some time. However, it may also be worth considering that these two populations could be currently sitting at advanced stages on an extinction pathway, similar to that already observed at Borroloola, where a once-widespread population contracted to isolated fire refugia, with each suffering progressive declines due to subsequent fires or stochastic events until the entire population went extinct. It seems that the progressive deterioration in fire patterns as one moves northwards (Figs 2, 3) fits with this northward process of population decline, fragmentation and extinction in Carpentarian grasswrens.

Conservation status

In this paper, we have attempted to make the best use of a relatively hard-won dataset to draw some conclusions about the population trajectories of Carpentarian grasswrens. While we are the first to admit that there is more work to be done in relation to developing quantitative models of detection probability that will enable more robust population monitoring, we believe there is sufficient reliable evidence now to elevate the species to Vulnerable status at the Federal and State (Queensland) level. Together with colleagues from Birdlife Australia, the Queensland government and CSIRO, we have submitted nominations accordingly, but the outcome of these assessments are unknown at the time of writing. Of course, even if Carpentarian grasswrens are listed as Vulnerable, this alone will do little to reverse the declines reported here and secure the remaining populations. Doing this will rely on a long-term commitment by State and Federal governments, working together with Traditional Owners, graziers and other stakeholders, to develop an effective fire-management program using early dry season burning to reduce the homogenising effects of frequent, large-scale single-fire events. There are at least two examples of such programs in similarly remote and flammable landscapes elsewhere in northern Australia (Legge *et al.* 2011; Price *et al.* 2012). Unless these sorts of successes are replicated within the range of the Carpentarian grasswren, we predict (at least) that the populations at Wollogorang and Boodjamulla will probably follow the Borroloola population into extinction in the short-to-medium term.

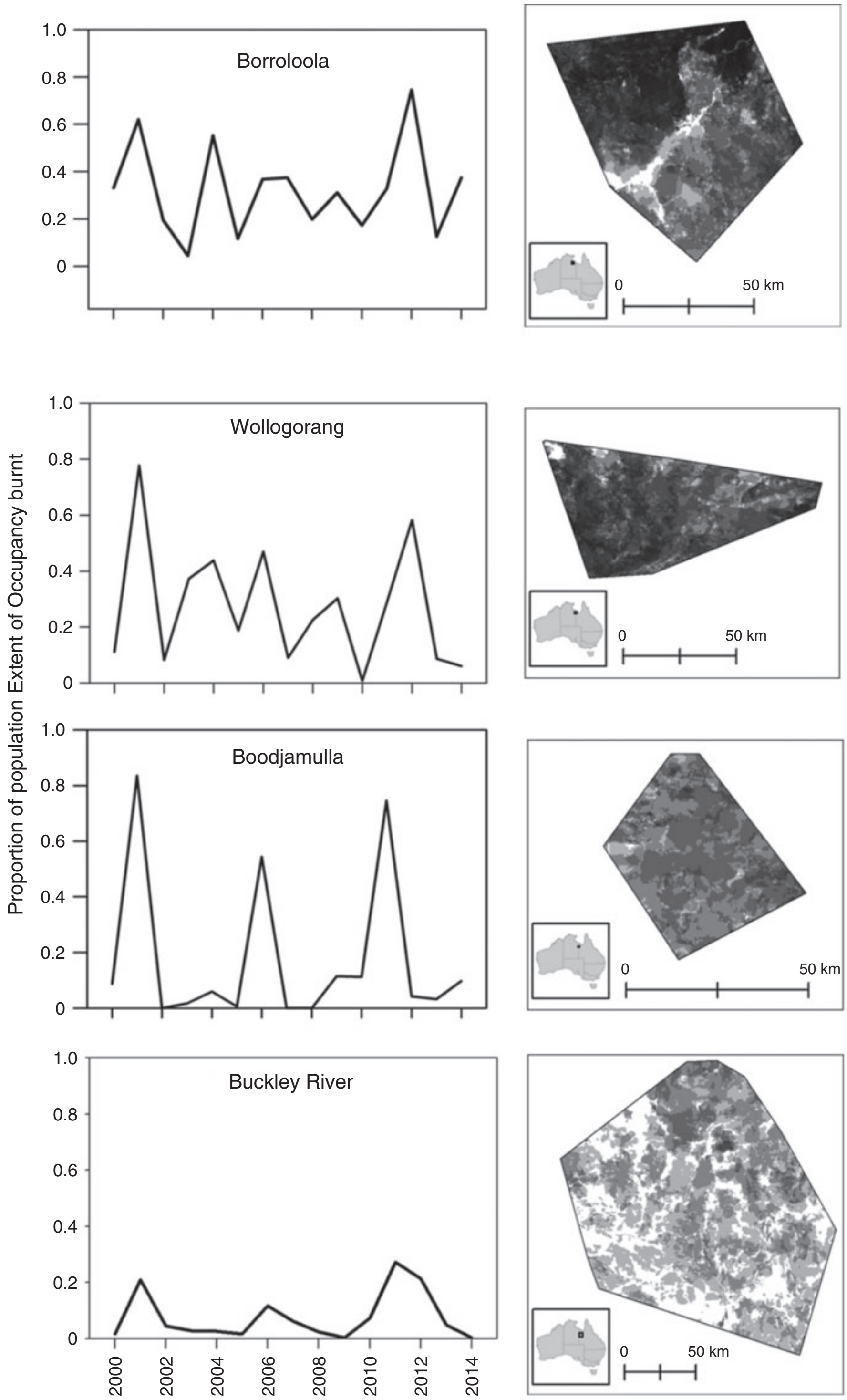

Fig. 3. History of fire activity within the Extents of Occupancy (EOO) for the four Carpentarian grasswren populations. The graphs show the proportion of EOO burnt in each year from 2000 to 2014. The maps on the right-hand side correspond to the adjacent graphs and show the actual fire scar data displayed using 70% transparency. As such, the darker the area, the more frequently it was burnt. Fire scar data were derived from www.firenorth.org.au

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References

Allan, G., and Baker, L. (1990). Uluru (Ayers Rock – Mt. Olga) National Park: an assessment of a fire management programme. *Proceedings of the Ecological Society of Australia* **16**, 217–220.

Andersen, A. N., Cook, G. D., Corbett, L. K., Douglas, M. M., Eager, R. W., Russell-Smith, J., Setterfield, S., Williams, R., and Woinarski, J. (2005). Fire frequency and biodiversity conservation in Australian tropical savannas: implications from the Kapalga fire experiment. *Austral Ecology* **30**, 155–167. doi:10.1111/J.1442-9993.2005.01441.X

Barrett, G., Silcocks, A., Barry, S., Cunningham, R., and Poulter, R. (2003). 'The New Atlas of Australian Birds.' (Birds Australia: Melbourne.)

Blakers, M., Reilly, P., and Davies, S. (1984). 'The Atlas of Australian Birds.' (Royal Australasian Ornithologists' Union & Melbourne University Press: Melbourne.)

Gaston, K. J., and Fuller, R. A. (2009). The sizes of species' geographic ranges. *Journal of Applied Ecology* **46**, 1–9. doi:10.1111/J.1365-2664.2008.01596.X

Harris, P. (1992). A further Queensland record of the Carpentarian grasswren. *Sunbird: Journal of the Queensland Ornithological Society* **22**, 23–24.

Higgins, P., Peter, J., and Steele, W. (2001). 'Handbook of Australian, New Zealand and Antarctic birds. Volume 5: tyrant-flycatchers to chats.' (Oxford University Press: Melbourne.)

Hill, G. (1913). Ornithological notes, Barclay Expedition. *Emu* **12**, 238–262. doi:10.1071/MU912238

IUCN (2001). 'IUCN red list categories and criteria: version 3.1.' (IUCN Species Survival Commission: Gland, Switzerland.)

IUCN (2006). 'Guidelines for using the IUCN red list categories and criteria: version 6.1. Standards and Petitions Working Group.' (Gland, Switzerland, & Cambridge, UK.)

IUCN (2015). The IUCN Red List of Threatened Species – *Amytornis dorotheae*. IUCN. Available at: http://www.iucnredlist.org/details/22703786/0 [accessed 7 June 2015].

Legge, S., Murphy, S., Kingswood, R., Maher, B., and Swan, D. (2011). EcoFire: restoring the biodiversity values of the Kimberley region by managing fire. *Ecological Management & Restoration* **12**, 84–92. doi:10.1111/J.1442-8903.2011.00595.X

NT Department of Land Resource Management (2015). Threatened Species List. Northern Territory Government. Available at: http://www.lrm.nt.gov.au/plants-and-animals/threatened-species/specieslist#birds [accessed 15 May 2015].

Perry, J., Fisher, A., and Palmer, C. (2011). Status and habitat of the Carpentarian grasswren (*Amytornis dorotheae*) in the Northern Territory. *Emu* **111**, 155–161. doi:10.1071/MU10013

Price, O. F., Russell-Smith, J., and Watt, F. (2012). The influence of prescribed fire on the extent of wildfire in savanna landscapes of western Arnhem Land, Australia. *International Journal of Wildland Fire* **21**, 297–305. doi:10.1071/WF10079

Russell-Smith, J. (2002). Pre-contact Aboriginal, and contemporary fire regimes of the savanna landscapes of northern Australia: patterns, changes and ecological processes. In 'Australian Fire Regimes: Contemporary Patterns (April 1998 – March 2000) and Changes since European Settlement. Australia State of the Environment Second Technical Paper Series (Biodiversity)'. (Eds J. Russell-Smith, R. Craig, A. M. Gill, R. Smith and J. Williams.) pp. 1–31. (Department of the Environment and Heritage: Canberra.)

Russell-Smith, J., Yates, C., Edwards, A., Allan, G. E., Cook, G. D., Cooke, P., Craig, R., Heath, B., and Smith, R. (2003). Contemporary fire regimes of northern Australia, 1997–2001: change since Aboriginal occupancy, challenges for sustainable management. *International Journal of Wildland Fire* **12**, 283–297. doi:10.1071/WF03015