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Understanding and managing the threats to Night Parrots in south-western Queensland

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ABSTRACT

South-western Queensland supports a suite of threatened native species, including Night Parrots. We investigated why this species has persisted in the region and discovered low prevalence of the typical factors that are thought to explain fauna attrition elsewhere in central Australia. Foxes appear to be completely absent. Feral cats were recorded relatively infrequently and showed a significant preference for habitats less commonly used by Night Parrots, a partition that may be driven by the presence of dogs that were detected twice as frequently as cats. Our study area has had a long history of moderate grazing pressure, which is concentrated mostly in productive alluvial habitats. We detected very few herbivores, and dog scat analyses suggest that macropod populations are regulated by predation. Archival imagery shows that large fires are not a feature of this landscape, resulting in the long-term, stable availability of patchy *Triodia* habitats separated by natural no-fuel areas. Based on these empirical data, we postulate that low non-native predator pressure, long-term stable availability of *Triodia* cover and a productive landscape that has had only moderate grazing pressure are the interacting factors that may explain why Night Parrots have persisted in south-western Queensland. We present practical management actions that could enhance the suitability of this landscape for Night Parrots.

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Introduction

Night Parrots (*Pezoporus occidentalis*) are small (~100 g; Murphy *et al.* 2017b), nocturnal parrots that were once found across Australia's vast arid zone. Specimens have been collected from an area spanning more than 1.2 million km^2 and there is some evidence to suggest that the species was relatively common at least at some places throughout this range. For example, 21 of the 28 museum skins known to exist were collected between 1871 and 1881 at a single location (the Gawler Ranges) in South Australia (Black 2012). At Alice Springs Telegraph Station in 1892 pet cats killed enough Night Parrots for their owner to make several mounted wall features from their wings and tails (Ashby 1924).

Despite their previously vast range and apparent abundance at some times and places, irrefutable Night Parrot records were absent for most of the 20th century. The last intentionally collected specimen was taken in 1912 in the Gascoyne region of Western Australia (Wilson 1937). It was 78 years before the next indisputable record surfaced when museum ornithologists found a desiccated body by a roadside in south-western Queensland (Boles *et al.* 1994). Sixteen years after that record, a Queensland Parks Service ranger found another dead bird in south-western Queensland (Cupitt and Cupitt 2008; McDougall *et al.* 2009) and in 2013 the first photographs of a live bird were obtained in roughly the same area (Dooley 2013). Since then, field research in south-western Queensland has started to build a better understanding of this enigmatic species, including aspects of breeding (Murphy *et al.* 2017a), home range and habitat use (Murphy *et al.* 2017b), vocalisations and diet.

The apparent precipitous decline of Night Parrots in central Australia was not an isolated phenomenon. Bush Stone-Curlews (*Burhinus grallarius*), for example, went from being 'seldom absent from the many localities visited during the expedition [to Central Australia]' (Whitlock 1924, p. 256) to being absent or extremely rarely reported from central Australia in contemporary times (Reid and Fleming 1992; Baxter and Paton 1998). Although there are similar examples involving declines in other bird species or groups (e.g. Grasswrens (*Amytornis* spp.) (Skroblin and Murphy

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2013) and Plains Wanderers (*Pedionomus torquatus*); Bennett 1983) it is the rapid declines of native mammals that have most dramatically underscored the severity of ecosystem dysfunction in this region. Ten arid zone mammal species are wholly extinct, and a further 21 taxa that are either regionally extinct or have experienced severe range contractions (*Environment Protection and Biodiversity Conservation Act 1999*, terrestrial mammal list, February 2017).

While the primary cause of this profound ecological perturbation is still debated, most ecologists agree that it was likely to involve interacting factors rather than a sole threatening process (Morton 1990; Dickman 1996; Johnson and Isaac 2009; Morton *et al.* 2011). In a recent review McKenzie *et al.* (2007) found that six factors interacted to cause fauna attrition across Australia's mainland bioregions. Four were intrinsic characteristics: phylogenetic similarity, body weight, distribution, area, and tendency for burrowing. The other two were environmental variables, namely rainfall (as a surrogate for regional productivity) and the extent of ecological change since European settlement, which included vegetation clearing, grazing pressure, predation by introduced mammals and changed fire regimes. Of the six interacting factors identified by McKenzie *et al.* (2007) it is the suite related to ecological change since European settlement that can be manipulated by conservation managers in central Australia and is therefore the focus of this paper.

Apart from some relatively small areas associated with mining and horticulture, large-scale vegetation clearing has not occurred in central Australia and is therefore not considered further here. However, Australia has more land area under managed grazing than any other country, with much of central Australia used for cattle and sheep grazing; the latter mostly confined to the eastern and southern portions (Asner *et al.* 2004). Adding to total grazing pressure, large macropods (*Macropus* spp.) occur across the area, most abundantly in semi-arid regions (Pople and Grigg 1999), often alongside high densities of Feral Goats (*Capra hircus*; Pople and Froese 2012). European Rabbits (*Oryctolagus cuniculus*) no longer irrupt at the plague densities they once did thanks to the introduction of *myxomatosis* and *calici* viruses in the 1950s and 1990s, and this has led to dramatic increases in the range and abundance of formerly rare desert mammals in some areas (Pedler *et al.* 2016). Nonetheless, they do remain at high densities in places (Scanlan *et al.* 2006). One-humped Camels (*Camelus dromedaries*) roam the central deserts (Saalfeld and Edwards 2010) while Feral Horses (*Equus callabus*), Donkeys (*E. asinus*) and Pigs (*Sus scrofa*) occur patchily (Edwards *et al.* 2004). These domestic, feral and native herbivores contribute to elevated total grazing pressure throughout inland Australia, which historically supported relatively low densities of native macropods since the extinction of the Pleistocene megafauna ~45 000 years ago (Johnson 2006; Fensham and Fairfax 2008). While the mechanisms and magnitude of ecological change wrought by livestock production remain debated (Gill 2005; Silcock *et al.* 2013), it is clear that the past 150 years of altered land management practices have modified many regions, including places that once supported Night Parrot populations such as the Gawler Ranges (Andrews 1883; Department for Environment and Heritage 2006).

Feral Cats (*Felis catus*) inhabit the entire Australian continent in virtually all habitat types (Legge *et al.* 2017). Cat predation has contributed to 28 mammal extinctions (Woinarski *et al.* 2014) and continues to threaten a further 70 mammals, 40 birds, 21 reptiles and 4 amphibians (Commonwealth of Australia 2015). European Foxes (*Vulpes vulpes*) occur mostly across the southern two-thirds of Australia (Atlas of Living Australia (ALA), accessed 9 January 2017) and are listed as a threat to 14 species of bird, 48 mammals, 12 reptiles and 2 amphibians (DEWHA 2008). Although mammals are the most frequently eaten prey, 20–30% of fox scats from arid areas have been found to contain birds (Palmer 1995; Paltridge 2002; Cupples *et al.* 2011), and ground-nesting birds are thought to be particularly vulnerable to fox predation (DEWHA 2008).

Dogs (treated here as including Dingoes (*Canis lupus dingo*), Feral Dogs (*Canis familiaris*) and their hybrids) are a third potential mammalian predator that may have contributed to fauna attrition in central Australia, being known predators of threatened species such as Greater Bilbies (*Macrotis lagotis*) (Newsome *et al.* 2014), Centralian Brush-tail Possums (*Trichosurus vulpecula*) (Kerle *et al.* 1992), some rodents (Allen and Leung 2012) and possibly even Night Parrots (G. A. Keartland 1894 in Ashby 1924). Notwithstanding the potential for dogs to prey on fauna, several studies have shown that dogs can also benefit native species via their regulatory effects on cats and foxes (Newsome *et al.* 2001; Kennedy *et al.* 2012; Moseby *et al.* 2012). Evidence supporting this 'mesopredator regulation' effect is variable, which has recently fuelled a lively debate in the literature about the scale at which it occurs and whether sufficient evidence exists for managers to maintain dogs in landscapes to achieve conservation objectives (Allen *et al.*

2013, 2014; Hayward and Marlow 2014; Nimmo *et al.* 2015).

There has been dramatic spatial and temporal change in contemporary fire patterns in central Australia, with a shift from the continuous small-scale use of fire under traditional Aboriginal management towards less frequent and much larger single-fire events that typically follow years of above-average rainfall (Burrows *et al.* 2006; Edwards *et al.* 2008). Contemporary fire patterns homogenise the landscape and periodically remove cover over large areas (Edwards *et al.* 2008). Such homogenisation can alter vegetation structure and floristics, promote the spread of weeds, increase grazing pressure and make conditions favourable for hunting by introduced predators (Kutt and Woinarski 2007; Edwards *et al.* 2008; Miller *et al.* 2010; McGregor *et al.* 2015). As such, changes to fire patterns have been mooted as a potentially significant mechanism explaining faunal collapse in central Australia (Garnett *et al.* 2011; Woinarski *et al.* 2014). It is important to note, however, that there is little evidence of changed fire regimes in the eastern parts of central Australia (Silcock *et al.* 2013; Kimber and Friedel 2015).

It is within this context that we considered the persistence and management of Night Parrots in south-western Queensland. Tracking studies (Murphy *et al.* 2017b) and long-term acoustic monitoring (S. Murphy unpub. data) suggest that at least some of the population is sedentary and this provides a clear imperative to maintain the population by understanding and managing the threats to it. In this paper, we focus on the potential impacts of mammalian predators, herbivores and fire on Night Parrots in south-western Queensland and in doing so present a conceptual model that may explain why Night Parrots may have persisted in the region. We also discuss the key conservation management options being implemented to enhance the inherent resilience that exists in this system.

Methods

Study area

The study was undertaken on Pullen-Pullen Reserve and Mt Windsor Station in south-western Queensland. Pullen-Pullen is 56 000 ha and was part of Brighton Downs beef cattle station prior to its subdivision and acquisition by the conservation charity Bush Heritage Australia in 2016. The reserve sits within the Goneaway Tableland subregion of the Channel Country biogeographic region (Thackway and Cresswell 1995). Habitats include sandstone plateaus vegetated with Spinifex (*Triodia longiceps*) and Lancewood (*Acacia shirleyi*), extensive open ironstone plains dotted with vegetated run-on areas, relatively wooded watercourses dominated by *A. aneura* and *A. cambagei*, and productive open floodplains of the outer Diamantina River. Detailed descriptions of habitats and their use by Night Parrots appear in Murphy *et al.* (2017b).

The region is hot and arid with mean maximum temperatures of 39°C in January and 23°C in July. Annual rainfall is highly unpredictable, with dry periods punctuated by occasional wet years. Median annual rainfall at Brighton Downs is 240 mm and on average 65% of the rainfall occurs between December and March (Bureau of Meteorology station number 37,007). Rainfall was collected at the study site using a tipping bucket gauge between 12 November 2013 and 27 April 2016. The years 2013 and 2015 were very dry, while rainfall in 2014 was slightly above average due to large events in February and December, and 2016 was an extremely wet year, with regular falls including 155 mm in March.

Mammalian predators

Photographs from 205 camera trap (Reconyx HC600) locations were examined to determine the presence of mammalian predators including feral cats, dogs and foxes. Most locations were in the Mayne Range where Night Parrot activity was concentrated (determined by long-term acoustic data; S. Murphy unpub. data), with a smaller number of locations sampled in the Nisbet Range. Both lured (dried meat) and lureless cameras were positioned on trees, fence-posts and on star-pickets in all the major habitats in the study area. Cameras were set for several reasons as part of the broader study (e.g. testing as a survey method for Night Parrots) and so some were not positioned optimally to detect predators (Read *et al.* 2015a). However, this did not affect the simple assessment of predator presence or absence (although it was taken into account when calculating detection rates and for inferential analyses – see below). Cameras were set to ‘rapid fire’ mode without delay, capturing five photographs per trigger. For inferential analyses and calculations of relative detection rates (for herbivores – see below), individual events were defined as those that occurred more than 1 h after the last event (of the same type) on each camera. Counts of individuals were not included in analyses. The average deployment period was 120 nights at each location.

No foxes were detected on cameras or during hundreds of spotlighting hours, nor were any fox tracks or scats found in the area, and so further presentation of methods excludes them. We were interested in whether the variation in where cats were detected could be explained by habitat type and/or the presence of dogs. Using a subset of cameras that were positioned optimally (Read *et al.* 2015a) to detect predators without meat lures (hereafter termed the 'focal dataset'), we expressed cat and dog detections in two ways. First, we calculated a continuous response variable – detections per 100 trap nights – that accounted for variable sample effort. Second, we converted detections into a categorical variable (yes/no). This was valid because there was no significant relationship between these categorical expressions and sample effort (cats: $F_{1,44} = 0.38$, $p = 0.541$; dogs: $F_{1,44} = 1.06$, $p = 0.31$) and therefore variable sample effort could be ignored. To examine the relationship between cat and dog detections, we used linear regression for continuous data and contingency tables with chi-square tests for categorical data. To examine the effect of habitat on cat and dog detections, the focal dataset was attributed according to whether they occurred in open or wooded habitats, based on habitat descriptions of the most suitable Regional Ecosystem (RE; Neldner *et al.* 2012) polygon at or nearby each point (there are one or more descriptions, each assigned a percentage, for every RE polygon). Regional Ecosystems 5.3.21, 5.3.21c, 5.7.15, 5.7.10x1, 5.9.3x3 and 5.9.5 were classed 'open', while REs 5.3.10, 5.7.2, 5.7.3, 5.7.5, 5.7.6 and 5.9.2x1 were classed 'wooded' (Queensland Herbarium 2016). We examined the relationship between habitat type and cat detections using analysis of variance for continuous detection data, and chi-square tests for categorical detection data.

Scat analysis

Predator scats were examined for evidence of mesopredator regulation and predation on Night Parrots. No fox scats were found and only one cat scat collected, so analyses were limited to dogs. Sixty dog scats were analysed, mostly collected along vehicle tracks throughout the 56 000 ha study area between April 2015 and October 2016. Dog scats were identified based on size, smell, shape and colour (Triggs 1996). A single scat sample was defined as one or more faecal pellets that appeared to have been deposited together in one defecation event. Scat samples were placed into individual nylon bags, soaked in water for 24 h before being washed through a domestic washing machine set on regular cycle. Samples were air-dried in the sun prior to microscopic analysis. Undigested fragments of prey (hair, teeth, claws, feathers, scales, exoskeletons) were initially examined under a dissecting microscope (20–40 × magnification) and compared with reference material from species known or expected to be in the area. Prey were identified to the most specific taxonomic level possible. Hair from each sample was further examined through whole-mount and cross-section under compound microscope (100–400 × magnification) following the methods of Brunner and Triggs (2002). Scat analyses were conducted by R.P. but a representative hair sample of all mammal species identified was confirmed by a second hair analyst (B. Triggs unpub. data).

Herbivores

Images from all cameras (irrespective of their position) were used to detect medium-large herbivores in the study area (Cattle (*Bos taurus* × *indicus*), horses, donkeys, goats, camels, pigs (included here as herbivores although we acknowledge also their omnivorous habits) and rabbits). The macropods Common Wallaroo (*Macropus robustus*) and Red Kangaroo (*M. rufus*) were collectively termed 'macropod'. To obtain a measure of their abundance, the relative detection rates of large herbivores was calculated using the focal dataset as described above, expressed as detections per 100 camera-trap nights.

Fire history

Given the role that altered fire regimes have played in changing ecosystems in central Australia (Edwards *et al.* 2008) and its recurring role in the decline of a diverse range of birds (Garnett *et al.* 2011), we examined the fire history of the Pullen-Pullen–Mt Windsor site at a scale that is relevant to Night Parrot biology (i.e. their use of habitat patches that can be less than 100 m wide; Murphy *et al.* 2017b). We used the automatically mapped Landsat-based time series for Queensland for 1988–2015 that has 30 m resolution (Goodwin and Collett 2014). This dataset is prone to both commission and omission errors, which can vary in time and space (Goodwin and Collett 2014). To assess its reliability we manually compared putative automatically derived fire scars to Landsat TM, ETM+ and OLI images for 1987–2016 for the scene that covers the Pullen-Pullen–Mt Windsor area (scene 097–076). These were processed as false colour images, where fire scars were highlighted at 30 m resolution using a combination of bands RGB: 7/5, 4, 3 (TM and ETM+) or 7/6, 5, 4 (OLI) with pixel value stretching using ERDAS ER Mapper 2011

(Hexagon Geospatial, GA, USA). False colour images were inspected manually for all putative fire scars within the study area. In addition, we selected 108 random points within putative fire scars for the entire Landsat scene and manually inspected our false colour image library for evidence of fires, scoring each point as fire = yes/no. We ignored commission errors that were obviously related to Landsat 7 Scan Line Corrector instrument failure, which were easily identified by their striped appearance. We extended the Landsat-based fire history with archival air photographs from 1951 and 1971 over the Mayne Range and that part of the Nisbet Range that occurs on Pullen-Pullen. Digitised images were georeferenced using DigitalGlobe imagery (www.digitalglobe.com) and manually inspected for evidence of past fires.

Results

Mammalian predators

No foxes were detected in 19 108 camera-trap nights at 205 locations. There were 51 and 111 cat and dog detections, respectively. It was difficult to determine exactly how many individual cats were involved; six coat colours and patterns were recorded (light tabby, dark tabby, spotted tabby, medium tabby, ginger and pied). In one area of about 200 ha, five of the six colours were recorded. Given this diversity, and the distances between some detections of cats with the same coat colours (e.g. 11 km, 54 km) we suggest that the 51 encounters involved at least nine individuals, and probably more. Given the observed uniformity in dog coat colours over a wide area (i.e. sandy with white points) it was even more difficult to determine exactly how many dogs were involved in the 111 detections, although both singletons and packs of up to four dogs were recorded.

A total of 6206 camera-trap nights from 46 locations were included in the focal dataset for detection rate calculations and inferential analyses. Detection rates for cats and dogs are shown in Table 1. Variation in cat detection was not explained by the presence of dogs for either continuous or categorical expressions of the data ($F_{1,44} = 0.92$, $p = 0.34$; $X_1^2 = 0.18$, $p = 0.67$; n(cats) = 26; n(dogs) = 52). Similarly, variation in our continuous expression of cat detection was not explained by habitat type (open vs. wooded; $F_{1,44} = 1.6$, $p = 0.2$). In contrast, using the categorical expression of cat detections, cats were significantly more likely to be detected in wooded habitats than open habitats ($X_1^2 = 4.7$, $p = 0.03$).

Table 1. Relative detection rates of mammalian predators and large herbivores (all based on 6206 camera-trap nights at 46 locations, except for macropods that involved 4259 camera-trap nights at 26 locations).

Species	Detection rate (events/100 nights)
Cats	0.42
Dogs	0.84
Macropods	4.60
Cattle	0.73
One-humped Camels	0.05
Horses	0.05

Scat analysis

Analysis of 60 dog scats revealed a diet dominated by macropods (82% of scats) including both Red Kangaroos and Common Wallaroos. Size of claws or teeth in 16 samples indicated juveniles and adults were eaten in similar proportions. Cat remains were found in one dog scat (<2%), cattle hair in 15% of scats, but no sign of foxes was recorded. Rodents were infrequently recorded (5% of samples). Evidence of birds occurred in three scats. Two could not be identified (but were not parrots), whereas one sample contained parrot feathers but the blue, green and yellow feathers were identified as an Australian Ringneck (*Barnadius zonarius*). The presence of fly larvae in this sample indicated the bird was consumed as carrion.

Herbivore detections

The medium-large herbivore assemblage in the study area, based on 19 108 camera-trap nights at 205 locations, included macropods (Common Wallaroos and Red Kangaroos), cattle (managed as opposed to wild), camels (wild), horses (wild) and rabbits. No pigs, goats or donkeys were detected, despite infrequent incidental sightings of the former two. Detection rates are shown in Table 1. Only two rabbits were detected at locations that were not included in the focal dataset (hence do not appear in Table 1).

Fire history at Pullen-Pullen

We could find no evidence of any fire activity within the Pullen-Pullen–Mt Windsor study area in either the Landsat archive or air photograph sequence dating back to 1951. Beyond this area we did detect fire scars in the remainder of the Landsat scene, but incorrect assignment remained common; 78% of 108 points within putative scars appeared to be commission errors mainly associated with watercourses and ephemeral alluvial habitats that experience large change in ground cover over short periods. All correctly assigned scars occurred in the north-east of the scene, which is supported by incidental field observations of fire scars in this region (S. Murphy pers. obs.). We were unsure about fire activity at three points, which we conservatively scored as being correct.

Discussion

With only one confirmed record in the late 20th century amidst a handful of unconfirmed sightings (Boles *et al.* 1994; S. Murphy unpub. data), many people thought Night Parrots were following the fate of so many Australian arid-zone mammals into extinction. Dramatically, and in keeping with the species' mysterious aura, Night Parrots were recently found alive in south-western Queensland and at a second, widely separated, undisclosed location in Western Australia. An empirical assessment of actual or potential threats operating at each of these two populations, and their similarities or differences, is the critical first step in implementing practical conservation management actions for Night Parrots. At the time of writing the Western Australian population had only recently been discovered and research into this new population was yet to commence. By contrast, Night Parrots in south-western Queensland have been studied intensively for about 4 years and a reasonable understanding of the threatening processes in that region is beginning to emerge. The analyses presented above suggest that several of the main threats typically associated with historical and ongoing fauna attrition elsewhere in central Australia are absent or occur only at low levels at the south-western Queensland site.

The absence of large, single fires

Our analyses of both air photographs and Landsat imagery show that the large single-fire events that characterise contemporary fire patterns elsewhere in central Australia do not occur in south-western Queensland (a pattern also presented by Kimber and Friedel 2015). Field observations show that ignitions do occur (mostly by lightning; S. Murphy pers. obs.) but fire spread is limited by bare surfaces that are naturally devoid of fuel. Given a run of wet years it is possible that some of these bare interstitial areas could support combustible vegetation (most likely annuals or short-lived perennials, especially among *Triodia* hummocks near plateau margins), thus potentially fuelling larger fires (Nano *et al.* 2012). It is likely that that this scenario happens on much longer time scales than can be captured by the 60+ year imagery archive that we analysed. In some areas around the plateau margins, short burnt stumps of small trees (presumably *Acacia shirleyi* or *A. aneura*) provide evidence of previous fire. However, aggregations of these charcoaled stumps occur infrequently through the study area and do not provide evidence of the very large fires that occur in *Triodia*-dominated systems elsewhere. From the parrot's perspective, this pattern of relatively small and very infrequent fires has meant that *Triodia* cover has been constantly available within a relatively small area, providing critical breeding (Murphy *et al.* 2017a), roosting (Murphy *et al.* 2017b) and feeding (S. Murphy unpub. data) habitat.

From a management perspective there is no justification for the application of an extensive prescribed burning programme of the kind implemented in many other parts of central Australia (Edwards *et al.* 2008). Instead, we recommend that fuels loads be monitored to ensure that currently isolated areas of *Triodia* do not become linked by vegetation following stock removal and/or significantly wet periods. Similarly, Buffel Grass (*Cenchrus ciliaris*) incursions should be removed before they establish in bare interstitial areas which would increase fire sizes and potentially act as wicks into critical Night Parrot habitat. Buffel Grass currently occurs as small, isolated outbreaks mostly along drainage lines but has the potential to invade large areas and significantly affect fire behaviour (Miller *et al.* 2010). Observations on neighbouring Diamantina National Park suggest it has spread over the past decade, and continues to do so (C. Mitchell pers. comm.). We recommend baseline mapping of Buffel Grass in the study area so that spread can be monitored over time, and encourage targeted control of Buffel in adjacent regions and corridors leading to the Night Parrot habitat.

The absence of foxes

Despite our large survey effort, we failed to detect foxes at the site – a premise supported by the absence of records within the ALA (accessed 9 January 2017) and from hundreds of hours of unpublished spotlighting data amassed by bilby researchers in the same region over the past two decades (P. McRae pers. comm.). Although there are no empirical data suggesting that foxes prey upon Night Parrots, in southern Australia, they are known to impact other ground-dwelling threatened birds such as Plains Wanderers (Llewellyn 1975) and Bush Stone-Curlews (Carter 2010). It seems likely that the absence of foxes has contributed to the persistence of these species, Night Parrots and other threatened species such as Greater Bilbies and Kowaris (*Dasyuroides byrnei*) in this region.

The absence of foxes from this part of Queensland is poorly understood. Distribution records (ALA) show that foxes occur north, south, east and west of the study area thereby indicating that physiological constraints related to climate alone do not explain their absence. While dogs are known to kill foxes (Moseby *et al.* 2012), given that both species coexist elsewhere in central Australia (R. Paltridge unpub. data) it seems improbable that foxes are being excluded from the region solely because of pressure exerted by dogs, although we assume that predation efficacy of dingoes on foxes would be higher in this region than in habitats with many subterranean fox refuges such as rabbit warrens. Lack of preferred prey may also be a contributing factor to fox absence with very few rabbits, possibly due to extensive rocky substrates that prevent burrowing (this study; ALA, accessed 17 April 2017) and normally low populations of small mammals (between irruptions), as demonstrated by the very low frequency of small mammals in the dog scats that we examined. However, their catholic diet (Paltridge 2002) suggests that it is unlikely that foxes are absent solely due to lack of food. Another untested hypothesis to explain their absence is poisoning by naturally occurring toxic compounds that become systemic in the food web (Peacock *et al.* 2011; Read *et al.* 2015b). Given that the fox-free status of this region could be a major driver explaining the persistence of Night Parrots and other threatened species, and is potentially useful to replicate elsewhere for conservation management, we argue that it is an issue that warrants further research.

Cats in the presence of dogs

Low levels of cats and dogs were detected on cameras throughout the study area. Camera trapping remains a relatively recent technique for surveying predators in Australia and so there are few published and relevant datasets that permit comparison of our detection rates. Two that are somewhat relevant both reported considerably higher detection rates of both predators (6.1 cats and 2.3 dogs per 100 camera-trap nights across 25 cameras deployed continuously for 2 years in the Simpson Desert (Greenville *et al.* 2014), and 4 cats and 7.5 dogs per 100 camera-trap nights on 18 pastoral properties across northern and central Australia; Brook *et al.* 2012). Confounding effects in these studies that make comparisons with our data questionable are that Greenville *et al.* (2014) was conducted during a rodent irruption while Brook *et al.* (2012) included a more productive biome and used lures to attract predators, rather than the passive technique we used to calculate detection rates. A third unpublished study generated more comparative data (R. Paltridge unpub. data): 3 years of continuous monitoring in *Triodia* grasslands in the Tanami Desert revealed detection rates for cats that were similar to our study area (0.7 detections per 100 camera-trap nights). This work was conducted during a period of average climatic conditions and included equal numbers of baited cameras set along roads (1.1 cats/100 camera-trap nights), and unbaited cameras set off roads at burrows of key prey species (0.3 cats/100 camera-trap nights). This suggests cat densities in our study area in south-western Queensland may not be substantially different from other parts of central Australia during typical seasonal conditions.

The presence of cat remains in one dog scat provided some evidence of intraguild predation although the extent to which this regulates cats is uncertain. In most parts of Australia cats form only a minor part of dog diet; 0.63% reported by Allen *et al.* (2014). However, higher levels of cat remains in dog scats have been found in other *Triodia* habitats (R. Paltridge unpub. data) and dogs are also known to kill cats and foxes without eating them (Moseby *et al.* 2012). We found no relationship between dog and cat presence, but cats were more likely to be detected in wooded habitats possibly because trees provide effective refuges from dog predation. Given that Night Parrots preferentially use open habitats with a very low density of trees and shrubs (Murphy *et al.* 2017b), this spatial separation suggests there is reduced probability that cats will encounter Night Parrots and that this might be driven by the presence of dogs. Our results suggest that birds are not a common part of dog diets in this area. Elsewhere, birds are eaten opportunistically by dogs, generally occurring in 2–20% of scats (Corbett 2001).

More research is required to examine predator–prey and predator–predator interactions, and habitat preferences of cats during small mammal irruptions. This may help to determine trigger points for instigating cat control (for example, as small mammals decline so as to mitigate prey switching), to inform the most efficient placement of baits, find refuge areas to target during dry periods, and improve our understanding of how dogs might regulate cats. While cats are notoriously difficult to control with traps, baits and shooting, dogs can be manipulated more easily through management decisions about control efforts, opening or closing watering points and potentially the provision of carrion to help channel their activity to critical habitat areas. However, management tools that manipulate dog activity by carrion provisioning must first examine the likelihood of perverse outcomes (for example, increased dog predation, unintended increases in feral cats or increases in varanid populations near Night Parrot breeding habitat).

Low levels of herbivory in a resilient system

Given the close proximity of the 2006 Night Parrot specimen to our study area (McDougall *et al.* 2009), it seems likely that Night Parrots and cattle have coexisted on Brighton Downs for at least 11 years and probably much longer. Prior to its purchase by the Britton family in 2013, Brighton Downs had been owned by the Australian Agricultural Company for over 60 years, during which time grazing pressure was moderated by conservative stocking rates (P. Britton pers. comm.). Furthermore, herbivory by macropods is likely to have been regulated to some extent by dogs, which have escaped intensive control measures partly because of the rugged terrain and partly due to a long history of targeted, as opposed to wholesale, dog control measures in the study area (W. Campbell pers. comm.).

GPS tracking data presented in Murphy *et al.* (2017b) identify spatial overlap between productive cattle grazing areas and key Night Parrot feeding areas. Furthermore, ongoing diet studies (S. Murphy unpub. data) show that Night Parrots rely on a suite of plants including some grasses that are preferred by cattle such as *Astrebla* spp. and *Uranthoecium truncatum*. Previous studies have failed to demonstrate a negative effect of grazing on floristic diversity in such habitats (Phelps *et al.* 2007; Silcock and Fensham 2012) and this may explain why Night Parrots have been able to coexist with cattle grazing. In addition, these common feeding areas are somewhat buffered from the impacts of localised droughts because they occur along a mid-section of a hydrological catchment that extends northwards into much higher rainfall zones (Geoscience Australia 2011; Bureau of Meteorology 2015). Hence, reliable monsoon-driven distant rainfall events trigger localised flooding and pulses of the resources that both cattle and parrots require.

Despite the evidence that cattle and Night Parrots can coexist and that cattle grazing does not lead to floristic change in these systems, it remains a possibility that grazing could impact phenology resulting in less food for Night Parrots. A similar situation was demonstrated in Golden-shouldered Parrots (*Psephotus chrysopterygius*) where even moderate levels of grazing lead to reduced seed availability in the key food plant *Alloteropsis semialata* (Crowley and Garnett 2001). Given this possibility, a stock fence was completed along the eastern boundary of Pullen-Pullen in 2016. Recently collected data from ongoing research show there is already a significant difference in total seed abundance in some habitats either side of the fence (J. Silcock, R. Fairfax, and N. Leseberg unpub. data). An independent review of the risks (to Night Parrots colliding with the fence) and benefits of destocking Pullen-Pullen concluded that, with appropriate modifications (i.e. plain-top wire and high visibility broad tape, cf. three-strand barbed wire), the benefits from fencing outweighed risks (Smales 2016). Other internal, and now redundant, fences have been removed and the new fence is being monitored for its effectiveness in stock exclusion and bird collision (not limited to Night Parrots).

Watch or act? Enhancing ecological resilience through adaptive management

Our conceptual model that explains the persistence of Night Parrots at the study area includes that:

- The naturally patchy distribution of vegetation (predominately *Triodia*) limits the size of wildfires, which has resulted in the long-term stable availability of *Triodia* that is critical for breeding, roosting, feeding and escaping predators.
- The absence of foxes reduces total predation pressure, which is potentially also suppressed by the regulation of cats by dogs. There is evidence that Night Parrots and cats are spatially separated because of their different habitats preferences, and it is possible that the presence of dogs maintains this separation.
- The impacts of grazing by introduced and native herbivores on Night Parrot habitats have been limited historically through relatively low stocking rates, few artificial water points, long-term stable dog populations potentially regulating macropod numbers and very low densities of feral herbivores. Grazing also occurs mainly in a subset of Night Parrot habitats (alluvial plains and run-on areas) that are inherently resistant to herbivory-mediated floristic change and are somewhat buffered from the effects of localised drought due to ephemeral inflows from distant, higher rainfall areas.

Opportunities exist for management to enhance the inherent ecological resilience that occurs in the study area, rather than simply to rely upon it for maintaining Night Parrot populations. We acknowledge that some management actions may involve risk (such as maintaining or manipulating the ranging behaviour of dogs and removing livestock) but that this risk can be understood and mitigated by following the principles of adaptive management (Salafsky *et al.* 2002). Similarly, grooming traps that target feral cats without affecting dogs or their ecological roles are also being trialled at Pullen-Pullen (Read *et al.* 2014). Meanwhile, the prevalence of more idiosyncratic threats, such as nest predation by native predators (Murphy *et al.* 2017a), is currently being investigated and the threat of disturbance by uncontrolled (and potentially illegal) human activity is being managed by legal instruments, patrolling and education. As new ecological information about Night Parrots emerges, so too do opportunities that can increase the efficacy of management. For example, recent water budget modelling by Kearney *et al.* (2016) suggests that Night Parrots need access to water during summer (as opposed to relying on dietary water), which may expose them to increased risk of predation by cats at artificial water points. This risk could be lowered by targeted cat control at water points, especially leading into summer. Such ecological insights like this, coupled with strategic management actions, will form the basis of ongoing conservation of Night Parrots in south-western Queensland and elsewhere.

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