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The effect of cat baiting on foraging and antipredator behaviour of the northern quoll in the Pilbara, Western Australia

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Cover image: Northern quoll. Image: Department of Parks and Wildlife WA.

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Executive summary

There is an urgent need to develop approaches to mitigating the impact of predation by cats on Australian wildlife. In arid and semi-arid Australia, broad-scale cat baiting programs have been shown to effectively reduce cat populations and, as a result, lead to an increase in the abundance of small native mammals. Understanding how native wildlife respond to a reduction in the abundance of cats, and/or the predation pressure they exert, is critical to evaluating the cost-effectiveness of cat management programs.

We have made use of a 4-year feral cat baiting program, being undertaken by the Western Australian Department of Biodiversity, Conservation and Attractions, on Yarraloola station in the Pilbara region of Western Australia (2016–2019), in order to understand the effects of a reduction in cat abundance on the foraging behaviour of the EPBC Act-listed (Endangered) northern quoll (*Dasyurus hallucatus*). We analysed quoll survey data to assess differences in the daily patterns of quoll activity between the baited property and an unbaited property nearby. We also conducted a 'giving-up density' (GUD) experiment to understand how perceived predation risk varies between the baited and unbaited properties and in relation to habitat features.

Despite earlier, published evidence that the cat baiting program has led to an increase in the abundance of the northern quoll between 2016 and 2019, we found no clear evidence that cat baiting led to a shift in the daily patterns of quoll activity, nor perceived predation risk. However, there was clear evidence that broad habitat types (mesa vs. riverine), and microhabitat within these (open vs. sheltered), affect perceived predation risk. There was a greater propensity to visit feeding trays in the riverine habitat, and within sheltered areas. There was evidence that more food was consumed from feeding trays in sheltered areas.

Our results highlight the importance of both broad- and fine-scale habitat features on predation risk of the northern quoll, and other small mammals. They are consistent with the notion that habitat management, to maintain and enhance the structural complexity and density of understorey vegetation (e.g. by reducing grazing by exotic herbivores, reducing fire frequency, extent and intensity) can help to mitigate the impacts of cats on small mammals. Further research is required to evaluate the feasibility, and cost-effectiveness, of such an approach in the Pilbara.

Quoll habitat in semi-arid nothern Western Australia. Image: Scott Carver/UTAS

Introduction

Australia has experienced more mammal extinctions in the last 250 years than any other continent on Earth. Twenty-nine, or >10%, of Australia's 273 endemic terrestrial mammal species have been lost since European colonisation (Woinarski et al. 2015). Australian mammal extinctions have occurred in most regions, and most habitat types (Woinarski et al. 2014; Woinarski et al. 2015). However, among Australian mammals, there are some clear ecological and morphological correlates of extinction, with highest rates of loss associated with species in the 'critical weight range' (CWR): species with body weight between 35 and 5 500 g (Burbidge and McKenzie 1989). Species in the CWR are historically and currently particularly extinction prone (Johnson and Isaac 2009), especially in arid and semi-arid areas which have less ground vegetation cover resulting in higher predation risk (Morton 1990).

The cat (*Felis catus*) is a voracious predator which has been present in Australia for at least 200 years, had colonised the majority of the continent by 1890 (Abbott 2002) and now occupies 98% of Australia’s landmass (Legge et al. 2017). It has been identified as the primary driver of the extinction of the majority of the thirty Australian native mammal species lost since European colonisation (Woinarski et al. 2014; Woinarski et al. 2019) and is recognised as a key threatening process under Australia's Environmental Protection and Biodiversity Conservation Act (1999) with a Threat Abatement Plan published in 2008 and revised in 2015.

The destructive impact of feral cats on Australia’s biodiversity was first noted in the early 20th Century in parts of inland Australia (Abbott 2002) and as their proliferation became more obvious, the first small-scale control measures (namely trapping and shooting) began to be implemented in the 1950s and 1960s, however these control measures were rudimentary and inefficient. This ad hoc process of instigating small-scale control of cats continued up until the 21st Century and, even then, the number of broad-scale control programs being implemented remains limited (Denny and Dickman 2010). Over the past two decades, broad-scale poison baiting of cats has emerged as the control method of greatest potential over much of arid and semi-arid Australia, with protocols being refined and bait types developed which minimise the risk to non-target species.

The northern quoll (*Dasyurus hallucatus*) is a threatened native mammal that can benefit from a reduction in predation pressure from cats. The northern quoll's range has contracted severely to six disjunct populations scattered from far northern Queensland across the Northern Territory to the Pilbara in northern Western Australia (Braithwaite and Griffiths 1994; Hill and Ward 2010). A large part of this decline may be attributed to the spread of the invasive cane toad (*Rhinella marina*), an easily accessible toxic prey species, that once ingested kills its consumer (Burnett 1997; Shine and Wiens 2010). However, population declines of the northern quoll were observed in several regions prior to the arrival of the cane toad, these were most notable along the drier periphery of their range in the eastern and southwestern Kimberley (McKenzie 1981; Woinarski 1992; Start et al. 2012), in the eastern Pilbara (Morton and Baynes 1985; Baynes and McDowell 2010) and southern parts of Kakadu and Arnhem Land (Braithwaite and Griffiths 1994). This suggests that the probable drivers of these declines are similar to those of small- to medium-sized mammals of inland and northern Australia: the synergistic threats of fire, grazing and predation. As foxes are absent from the vast majority of the northern quoll’s range, this predatory impact can almost certainly be ascribed to feral cats; given the right circumstances, cats can have a significant negative impact on quoll populations (Woinarski et al. 2014). The situation of the northern quoll within this predator–prey interaction framework is particularly interesting as it is also a mesopredator that is both a prey species of feral cats (Oakwood 2000a; 2002; Morris et al. 2015) and a competitor for some of the same food (e.g. small vertebrates) and habitat resources (e.g. denning sites and foraging areas). Therefore, it lends itself as a unique study species to investigate how other native predators and prey species may respond to dedicated predator control and whether there is a predator abundance threshold below which particular groups of species can survive and possibly recover.

We have made use of a 4-year feral cat baiting program undertaken on Yarraloola station in the Pilbara region of Western Australia (2016–2019), in order to understand the effects of a reduction in cat abundance on the foraging behaviour of the northern quoll. There is compelling evidence that the cat baiting program, despite running for just four years, led to a significant reduction in the cat population and, as a result, a significant increase in the abundance of the northern quoll on Yarraloola (Palmer et al. 2021). Hence, we might expect that the cat baiting program has led to northern quolls having a reduced level of predator vigilance, in response to a perceived reduction in predation pressure from cats.

We used quoll activity data collected by the Western Australian Department of Biodiversity, Conservation and Attractions (WA DBCA) (described by Palmer et al. 2021) to assess differences in the daily pattern of quoll activity between the baited property and an unbaited property nearby. We hypothesised that quoll activity would be less temporally constrained on the baited property, given the relaxation of predation pressure from cats.

We also conducted a 'giving-up density' (GUD) experiment to understand how perceived predation risk varies between the baited and unbaited properties and in relation to habitat features. The GUD approach is widely used to assess variation in predation pressure perceived by a prey species, and how this impacts foraging efficiency. The GUD approach involves allowing animals to search a depleting food patch (a set amount of food reward mixed into an inedible matrix) until the decreasing rewards are outweighed by the effort of continued searching and the cost of perceived predation risk (Bedoya-Perez et al. 2013). The remaining food is measured as the GUD and all else being equal, the GUD will be higher in patches where foragers perceive greater risks. The GUD reflects the harvest rate that is not acceptable to justify the predation risk.

We used our GUD experiment to address the questions:

(1) does perceived predation risk differ between habitat types and the inherent cover they provide?

(2) within these habitat types, is perceived predation risk greater in more exposed microhabitats?

(3) does reduced cat abundance lead to a reduction in perceived predation risk?

Northern quoll at the Pilbara study site. Image: Nicolas Rakotopare

Methods

Study site

The study was conducted on two neighbouring cattle stations (Yarraloola and Red Hill) in the west Pilbara, Western Australia (Fig. 1). The cattle stations are part of an existing research project run by WA DBCA examining the efficacy of feral cat baiting (e.g. Palmer et al. 2021). WA DBCA's research program complements a 5-year cat-baiting program, which formed the core part of a Threatened Species Offset Plan (TSOP) developed and implemented by Rio Tinto to benefit the EPBC Act listed northern quoll and Pilbara olive python (*Liasis olivaceus barroni*). The TSOP was required by the Commonwealth for the approval of Rio Tinto's Yandicoogina Junction South West and Oxbow Iron Ore Expansion Project.

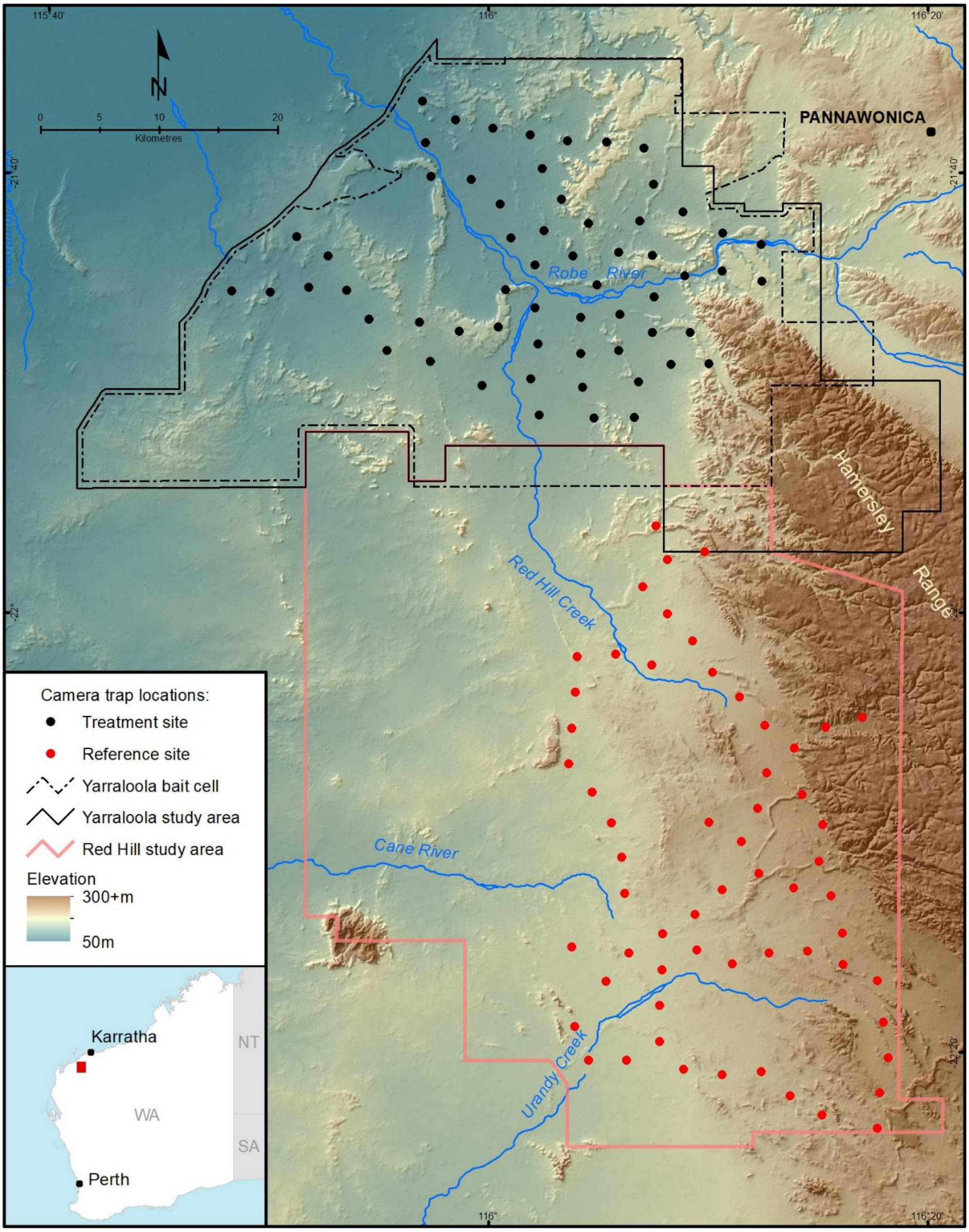

Figure 1. Location of Yarraloola (black outline) and Red Hill (pink outline) stations within the Pilbara region of Western Australia. The black and red dots (on Yarraloola and Red Hill stations, respectively), are the quoll monitoring sites of Palmer et al. (2021). The map is from Palmer et al. (2021).

Yarraloola station covers an area of 160 000 ha and was the baited treatment site. Neighbouring Red Hill station covers an area of 180 000 ha and was the unbaited reference site. Both stations have similar topography and vegetation: extensive lowland areas of *Acacia* low open woodlands and spinifex (*Triodia* spp.) grasslands, interspersed with Channel Iron Deposits or Robe Pisolite forming flat topped 'mesas' (Geoscience Australia and Australian Stratigraphy Commission 2017). The lowlands are dissected by riverine systems, with relatively dense vegetation. The region has a hot, semi-arid climate, with high interannual rainfall variability. Monthly rainfall is typically highest from January–March. Mean annual rainfall across the two cattle stations is about 300–400 mm (Yarraloola weather station: 298 mm; Red Hill weather station: 362; Pannawonica weather station: 404 mm; Australian Bureau of Meteorology 2021)

Aerial baiting for cats was carried out on Yarraloola station annually in July (the beginning of the driest part of the year, when cats are most likely to consume baits) for four years (2016–2019). Eradicat® baits (sausage-style baits, each containing 4.5 mg of the toxin sodium fluoroacetate, or 1080) were deployed at a rate of 50 km^{-2}. Approximately 71 500 baits were dropped in 1 430 bait clusters each year at Yarraloola. No baiting was carried out on Red Hill station. For full details of the baiting program, see Palmer et al. (2021). Over the four years of baiting, annual rainfall was slightly (about 10%) below the long-term average. The year 2019 had rainfall well below average (about 45% below the long-term average), 2018 was 15% below, 2016 was 5% below, and 2017 was 15% above.

Daily patterns of quoll activity

We used the quoll survey data of Palmer et al. (2021) to evaluate whether daily patterns of quoll activity were affected by cat baiting. The quoll survey data was collected using motion-activated cameras, deployed at 60 sites on Yarraloola and 60 sites on Red Hill (Fig. 1). One camera (HyperFire PC900; Reconyx, Holmen, Wisconsin USA) was deployed at each site, and baited with both visual and olfactory lures. The visual lure consisted of a 'lure pole' set 3 m in front of each camera. The olfactory lure consisted of a plastic vial containing 15–20 mL of 'Catastrophic' scent lure. Camera traps were set for a minimum of 25 nights prior to the July baiting operation each year and then re-set three weeks afterwards for a further 25 nights. This occurred in each of the four years of baiting (2016–2019, inclusive).

We compared daily patterns of quoll activity, expressed as number of detections throughout the day, before and after the baiting period, on the baited (Yarraloola) and unbaited (Red Hill) properties. We used the R package 'activity' to assess the extent to which the daily pattern of activity of quolls differed between the baited and unbaited properties.

Foraging behaviour (giving-up density) experiment

We used plastic trays (41 cm [length] × 8.8 cm [height] × 31.2 cm [width]) as foraging trays. Each foraging tray contained 100 food items (Schmackos™ dog treats, cut into 1 cm strips) distributed in an inedible matrix (sand). The number of food items taken from each tray were counted each morning and remaining food was collected to minimise interference by non-target diurnal species. Food items were replenished daily in the afternoon.

We used motion-activated cameras (XR6 Ultrafire Covert Camera; Reconyx, Holmen, Wisconsin USA) to confirm foraging species identification and record duration of foraging (e.g. Fig. 2). A camera was deployed 2 m from each feeding station, attached to a plastic stake at a height of 40 cm. Cameras were set to take 10 photos when triggered, with no post-trigger delay.

Figure 2. *An example of a photo of a northern quoll eating from a feeding tray. The photos were used to confirm the identity of the species consuming the food, and to estimate the amount of time spent feeding.*

Ten sites were established at each of the baited (Yarraloola) and unbaited (Red Hill) properties. At each property, five sites were located on mesas and five in riparian vegetation to investigate how foraging differs with varying habitat characteristics and whether cat baiting leads to a reduced behavioural response in different habitat types (suggesting that quolls are less fearful). Each site had two foraging trays, one in an exposed microhabitat (e.g. in the middle of a sandy washout) and one in a sheltered microhabitat (e.g. in the mouth of a deep cave system or amongst dense vegetation). Finally, a cat odour treatment was assigned to either the exposed or sheltered tray at four out of five sites. Cat odour treatment consisted of three cotton balls wired to the ground soaked with 15 mL of 'Catastrophic' scent lure (Outfoxed Pest Control, Victoria), a commercially available liquid containing cat anal gland and cat faeces, re-soaked daily. This gave a total sample size of 20 feeding trays at each of the two properties (Fig. 3), which were monitored for 4 nights. The same experiment was repeated in October 2017 and 2018, and the data pooled.

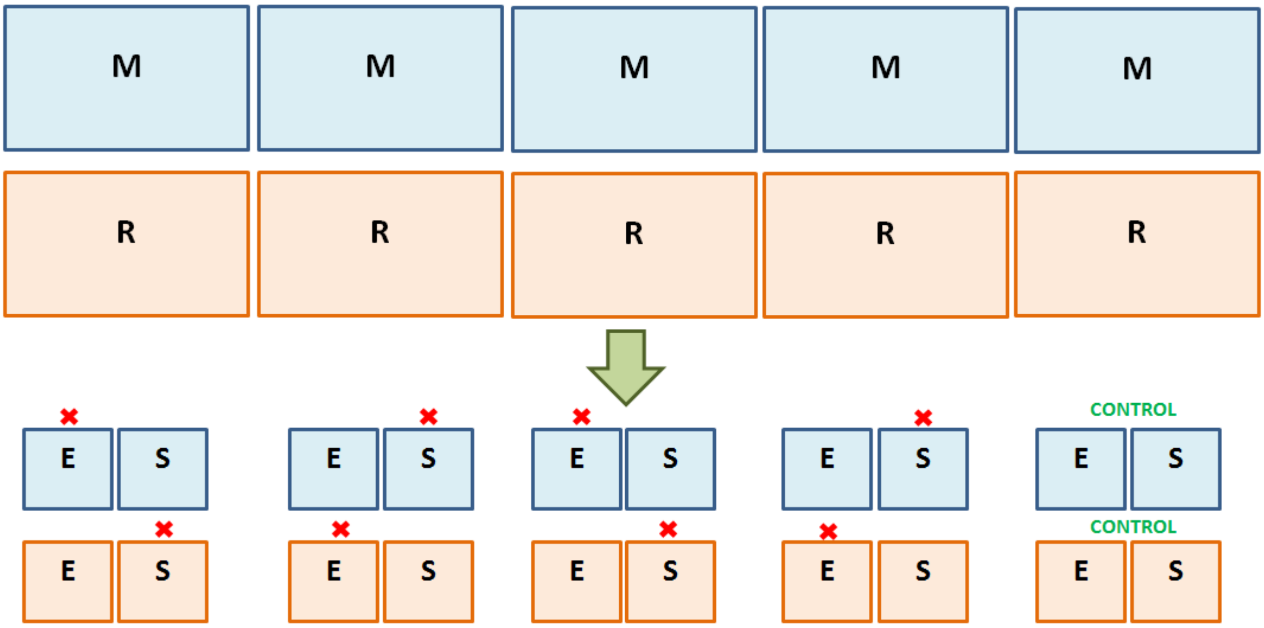

Figure 3. *Schematic representation of the experimental design of the quoll foraging behaviour study. 'M' and 'R' denote mesa and riparian sites, respectively. 'E' and 'S' denote paired exposed and sheltered feeding stations, respectively. The red symbol 'x' denotes feeding stations where cat odour was applied. The 'control' feedings trays had no cat odour applied.*

Each feeding tray was treated as a single replicate, and we pooled data across all 4 nights of observation. We analysed three response variables: (1) whether or not a tray was visited by a quoll over the 4 nights; (2) the number of times a tray was visited by a quoll over the 4 nights; and (3) the number of food pieces taken by quolls over the 4 nights (excluding trays that were not visited).

All analyses were done using the statistical program R (R Development Core Team 2013). Response (1), above, was binary (whether or not a tray was visited), and hence was analysed using generalized linear models (GLMs) with binomial error family. Responses (2) and (3), above were counts but were zero-inflated and overdispersed. To account for this, we used zero-inflated GLMs with a negative binomial distribution, using the 'pscl' package (Jackman et al. 2015). This type of model explicitly deals with two distinct processes within the response variable: (1) the probability of the response being zero vs. non-zero (i.e. the response is 0 or $\geq$1); and (2) if non-zero, the value of the response (i.e. 1 to ∞). We assumed the first part of the model (the probability of the response being zero) was constant, and explanatory variables only affected the second part of the model.

We constructed a candidate set of models, representing all 16 combinations of the four binary explanatory variables (broad habitat class [mesa/riverine], microhabitat class [open/sheltered], cat odour [present/absent], property [Yarraloola/Red Hill]). Model selection was based on Akaike's Information Criterion (AIC) (Burnham and Anderson 2002).

Findings

Daily patterns of quoll activity

Despite an apparent increase in the abundance of the northern quoll on the baited property over the course of the 4-year baiting program (2016–2019), as recent described by Palmer et al. (2021), there was little evidence that the daily patterns of quoll activity differed between the baited or unbaited properties (Fig. 4). This suggests that, if a reduction in predation pressure is allowing quoll populations to increase on Yarraloola, quolls have not responded by broadening or shifting the times of day at which they are most active.

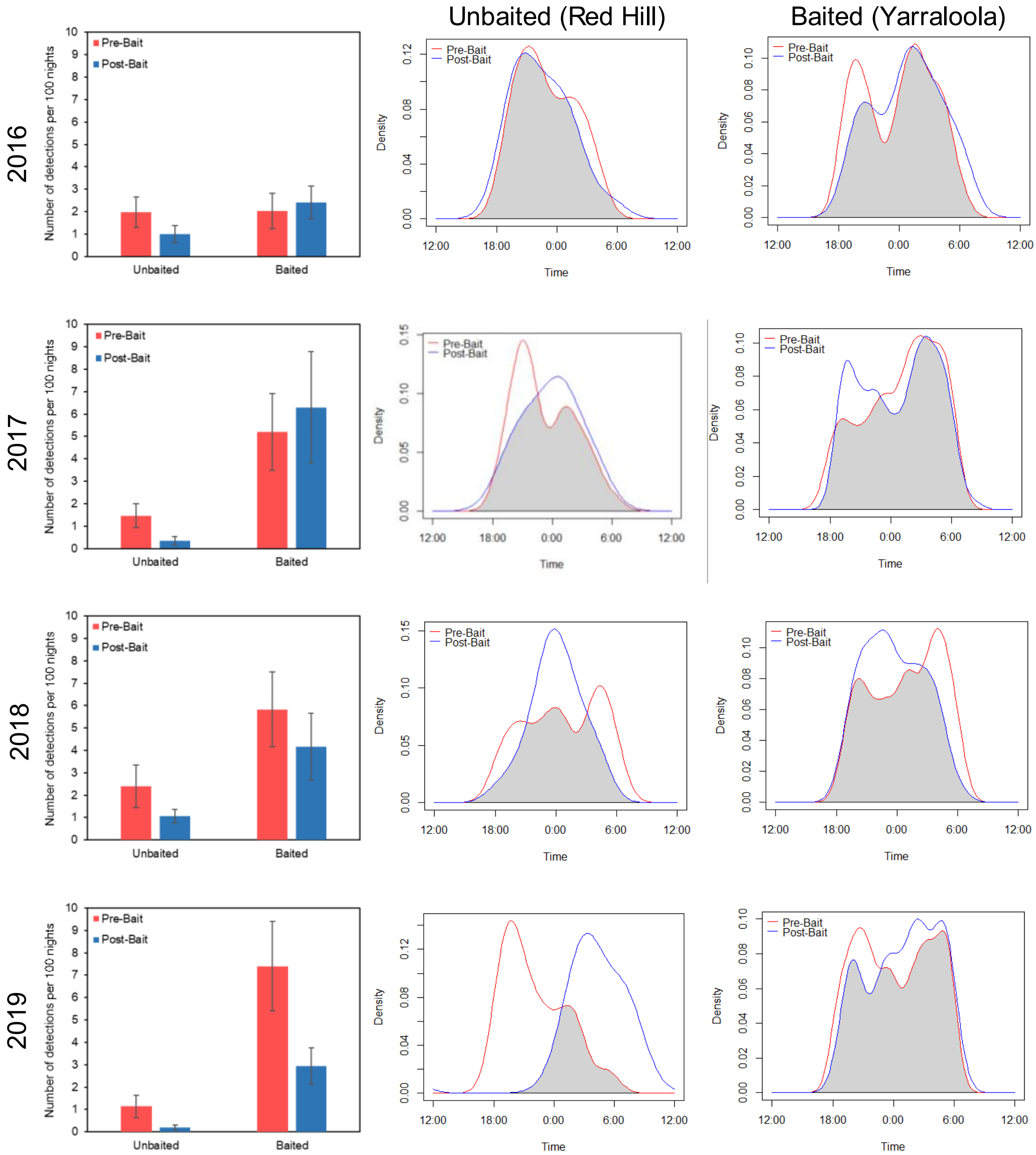

Figure 4. *Changes in the abundance (left-most column) and daily activity patterns right two columns) over the course of the 4-year baiting program (2016–2019). The quoll abundance and daily activity data were kindly provided by the Western Australia Department of Biodiversity, Conservation and Attractions (Palmer et al. 2021).*

Foraging behaviour

There was clear evidence of differences in the propensity of quolls to visit feeding trays, depending on the location of the tray. Broad habitat class (i.e. mesa or riverine) and microhabitat class (i.e. open of sheltered) were clear predictors of the probability of quolls visiting a tray and the number of times the tray was visited. Broad habitat class and microhabitat class both appeared in all well-supported models (i.e. ΔAIC $\leq$2) of these responses (Table 1a–b). Quolls were much more likely to visit a feeding tray (Fig. 5a), and visit it more often (Fig. 6a), if it was located in riparian rather than mesa habitat. Likewise, they were much more likely to visit a feeding tray (Fig. 5b), and visit it more often (Fig. 6b), if it was located in a sheltered location at the site.

There was some evidence that microhabitat class was a predictor of the number of food pieces taken by quolls. Although this variable did not appear in all well-supported models (i.e. ΔAIC $\leq$2), it was statistically significant ($p < 0.05$) within the best model. It appeared that more food pieces tended to be taken from feeding trays in sheltered locations (Fig. 7).

Neither the cat odour treatment nor the property (Yarraloola [baited] or Red Hill [unbaited]) were clear predictors of any of the three response variables. Neither of these variables consistently appeared in the well-supported models (Table 1), nor had significant model terms in the best-supported model.

Table 1. *Model ranking table for the three response variables examined: (a) whether or not a tray was visited by a quoll over the 4 nights; (b) the number of times a tray was visited by a quoll over the 4 nights; and (c) the number of food pieces taken by quolls over the 4 nights (excluding trays that were not visited). Models were ranked according to ΔAIC (the difference between a model's AIC value and the minimum AIC value in the set of candidate models). w_i is the Akaike weight, equivalent to the probability of that model being the best in the candidate set. The set of candidate models included all combinations of the explanatory variables, but only the models with ΔAIC $\leq$5 are shown.*

	Explanatory variables					
Response	Habitat	Microhabitat	Cat odour	Property	ΔAIC	w_i
(a) Probability visit	+	+			0.0	0.37
	+	+	+		1.2	0.20
	+	+		+	1.8	0.15
	+	+	+	+	3.0	0.08
		+			3.6	0.06
		+	+		4.9	0.03
(b) Number of visits	+	+	+	+	0.0	0.31
	+	+		+	0.4	0.26
	+	+	+		1.0	0.20
	+	+			1.5	0.15
		+	+		5.0	0.03
(c) Number of food pieces taken		+	+		0.0	0.15
		+			0.1	0.14
	+	+			1.0	0.09
					1.0	0.09
	+	+	+		1.3	0.08
			+		1.8	0.06
		+	+	+	1.9	0.06
		+		+	2.1	0.05
	+				2.1	0.05
	+	+	+	+	2.6	0.04
	+	+		+	2.7	0.04
	+		+		2.9	0.04
				+	3.0	0.03
			+	+	3.8	0.02
	+			+	4.1	0.02
	+		+	+	4.8	0.01

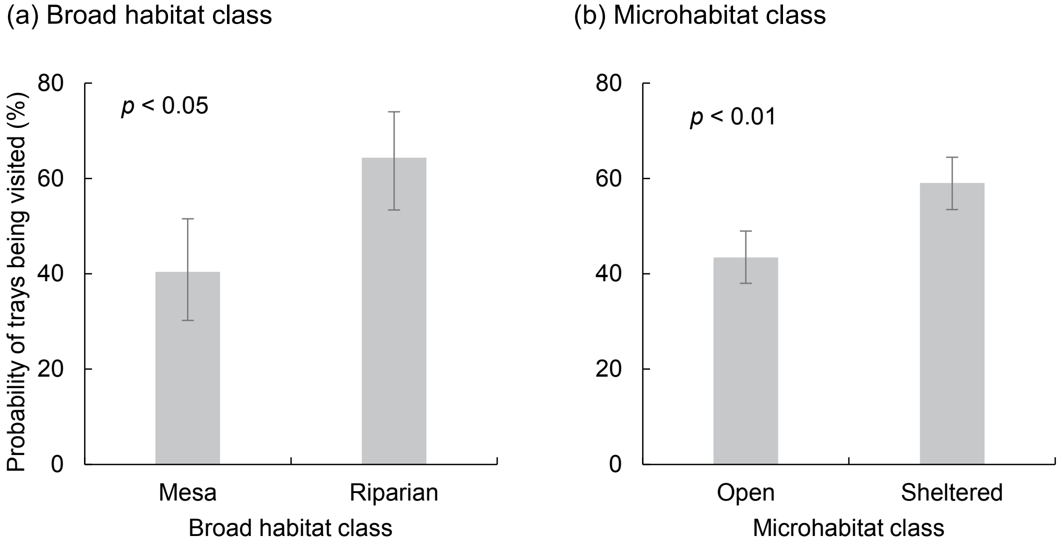

Figure 5. *The modelled effect of (a) broad habitat class (i.e. mesa or riverine) and (b) microhabitat class (i.e. open of sheltered) on the probability of a feeding tray being visited by a quoll over a 4-night period. The model predictions are based on multi-model averaging of the entire candidate set of 16 models. The error bars indicate standard errors. The p-values refer to the difference between the two classes, from the best-supported model in the candidate set.*

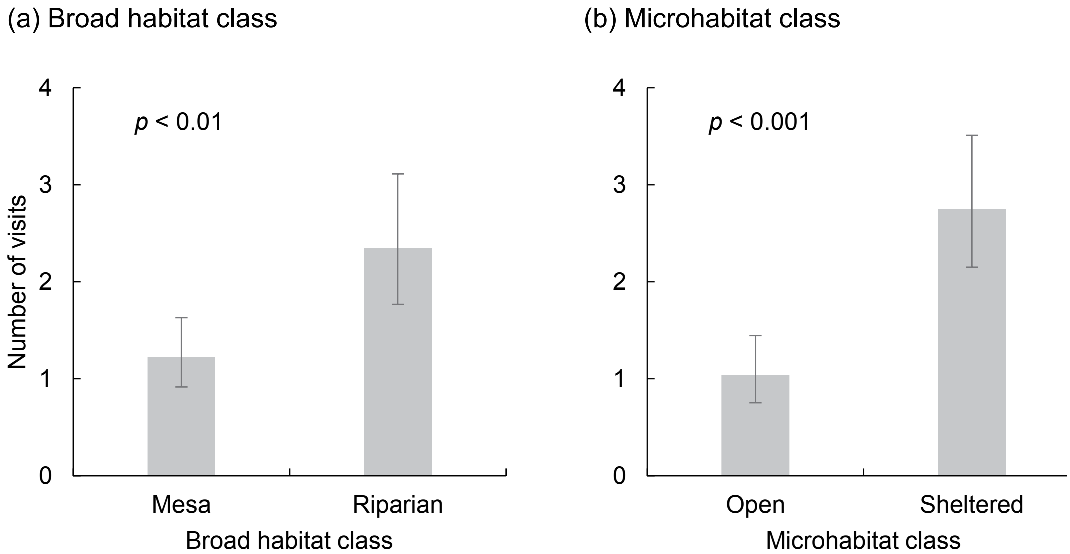

Figure 6. *The modelled effect of (a) broad habitat class (i.e. mesa or riverine) and (b) microhabitat class (i.e. open of sheltered) on the number of times a feeding tray was visited by quolls over a 4-night period. The model predictions are based on multi-model averaging of the entire candidate set of 16 models. The error bars indicate standard errors. The p-values refer to the difference between the two classes, from the best-supported model in the candidate set.*

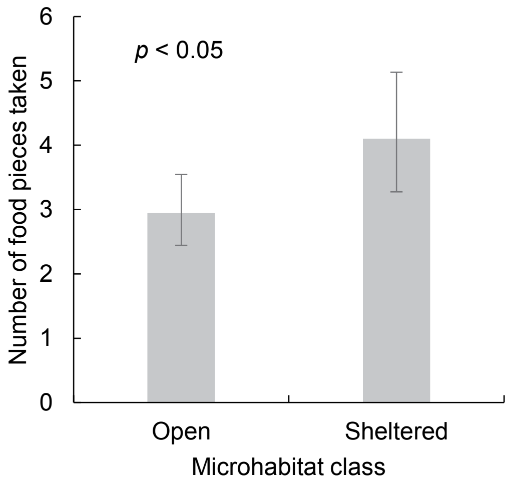

Figure 7. *The modelled effect of microhabitat class (i.e. open of sheltered) on the number of food pieces taken by quolls over a 4-night period. The model predictions are based on multi-model averaging of the entire candidate set of 16 models. The error bars indicate standard errors. The p-values refer to the difference between the two classes, from the best-supported model in the candidate set.*

Discussion

Palmer et al. (2021) have recently demonstrated that the 4-year (2016–2019) feral cat baiting program at Yarraloola has had positive benefits on the abundance of the northern quoll on the large (160 000 ha) property. Within a month of baiting on Yarraloola, mortality of feral cats was in the order of 18–33%. Palmer et al. (2021) demonstrated that, over four years, there was a steady increase in quoll detection rates (on motion-activated cameras) on Yarraloola, but not neighbouring Red Hill, which was unbaited. Despite this, we found no evidence of systematic differences between Yarraloola and Red Hill in terms of daily patterns of quoll activity, and the propensity of quolls to take food from bait stations. This might reflect that predators (including cats) remain abundant enough on Yarraloola to maintain high levels of anti-predator vigilance in quolls.

Our results suggest that quolls perceive greater danger from predators in open areas. This is unsurprising given that feral cats prefer to hunt in open areas, where they have greater hunting success (McGregor et al. 2014; 2015; 2016), and this likely applies to other predators of quolls, such as the dingoes. For example, Oakwood (2000b) concluded that a major source of mortality of the northern quoll in Kakadu National Park was predation by dingoes, especially in open areas. There is a growing body of evidence that disturbance regimes that increase the openness of the understorey (e.g. frequent high-intensity fire, high densities of feral herbivores) can increase the abundance and hunting efficiency of feral cats (Legge et al. 2019; Davies et al. 2020; Stobo-Wilson et al. 2020b) and, as a result, decrease the abundance of small mammals such as the northern quoll (Stobo-Wilson et al. 2020a).

Application of research

Our results serve to emphasise that while direct control of cats (e.g. using poison baiting) does seem to benefit small mammals such as the northern quoll in the Pilbara region (e.g. Palmer et al. 2021), it may not be the only (or most cost-effective) way to mitigate cat impacts. An approach that is receiving increasing attention, especially in monsoonal northern Australia where cats tend to be more difficult to control using baiting, is to moderate disturbance regimes to help maintain a dense and structurally complex understorey, thereby providing shelter for small mammals and making it more difficult for cats to hunt. Disturbance regimes are typically moderated by reducing the frequency of high-intensity fires, and reducing the abundance of feral herbivores. Such an approach is used extensively by the Australian Wildlife Conservancy in the Kimberley region, with marked reported success (Legge et al. 2011a; Legge et al. 2011b; Legge et al. 2019).

While this approach to mitigating cat impacts has not been used extensively in the Pilbara region, there may be scope to do so. For example, properties such as Yarraloola and Red Hill are active cattle operations; destocking parts of these properties, especially areas of important quoll habitat such as the riverine systems, may further benefit quolls. Fire is much more difficult to manage in a semi-arid region such as the Pilbara, because fire activity is very strongly linked to high interannual rainfall variability.

Future research priorities

Future research should focus on identifying whether there is scope to moderate disturbance regimes (e.g. grazing by exotic herbivores, fire) in the Pilbara, and other semi-arid regions, and whether this leads to:

(1) increased habitat structural complexity and understorey density;

(2) reduced abundance and/or hunting efficiency of feral cats and native predators;

(3) increased abundance of small native mammals.

Such research could be complemented by a cost–benefit analysis of different approaches (cat control vs. habitat management), and how the cost–benefit trade-off might vary across regions (e.g. semi-arid Pilbara vs. monsoonal Kimberley), especially given that there already seems to be implicit recognition that cat control is the preferred approach in the arid zone (e.g. Lohr and Algar 2020; Palmer et al. 2021), while habitat management is the preferred approach in the monsoon tropics (e.g. Legge et al. 2011a; Legge et al. 2011b; Legge et al. 2019).

Data sets

The dataset generated by this work is currently being written up by a Charles Darwin University PhD student. It will be not be publicly available until his thesis has been accepted by the University, and published on the University library's website (the dataset will be available as an appendix to the thesis).

Acknowledgements

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Ethics statement

This project was approved by the Charles Darwin University Animal Ethics Committee (approval A16014).

One of the Pilbara field work sites. Image: Nicolas Rakotopare

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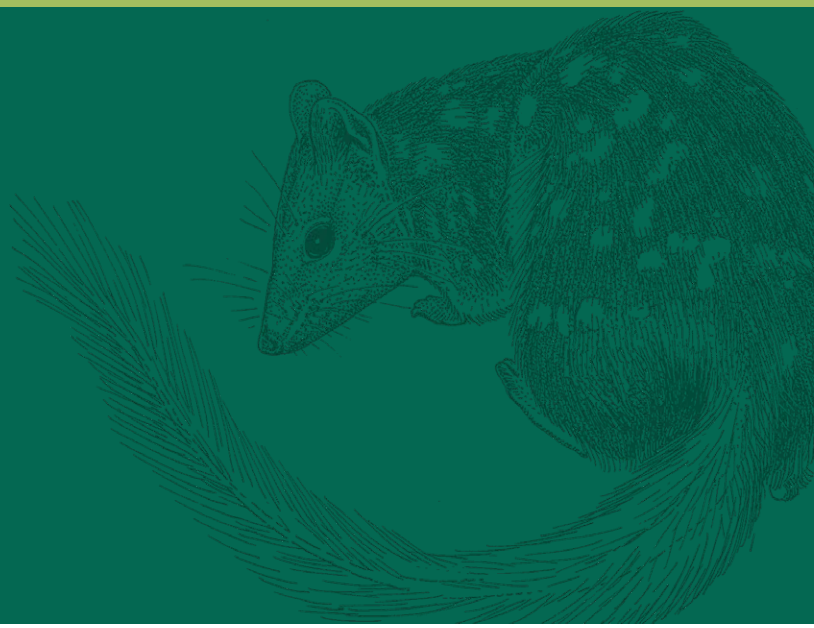

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