Caught out: Using camera traps to assess the effectiveness of feral cat baiting in north-western Australia.

Ashleigh Johnson

Supervised by Russell Palmer[a], Harry Moore[b,c], Philip Withers[c]

[a] *Department of Biodiversity, Conservation and Attractions, Bentley Delivery Centre, Locked Bag 104, Perth, Western Australia, Australia.*

[b] *Institute for Land, Water and Society, School of Environmental Science, Charles Sturt University, Albury, 2640, New South Wales, Australia.*

[c] *School of Biological Sciences, University of Western Australia, Crawley 6009, Western Australia, Australia.*

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Abstract

Camera traps are increasingly used across the world for many different wildlife monitoring programs, and are useful passive monitoring tools for the detection of species in remote areas. In Australia, and worldwide, feral cats (*Felis catus*) are major predators and competitors for native species, and effective monitoring and management of feral cats is a vital component in global conservation. As part of ongoing efforts to mitigate the impacts of feral cats in Western Australia, in 2016, the Department of Biodiversity, Conservation and Attractions began a four-year landscape scale cat control program in the southwest Pilbara, with annual aerial baiting using the *Eradicat*® feral cat bait. Remote sensing camera traps were deployed at two sites (one baited site and one control site) to determining the effectiveness of the baiting program. The objective of this study was to measure changes in feral cat 1) Detectability, 2) Abundance, and 3) Behaviour (cat activity) as a result from feral cat baiting. Feral cat detectability and abundance followed similar trends, with a reduction in the number of detections and minimum number of animals alive in post-baiting and post-control monitoring sessions. It was also observed that feral cat activity had changed at the control site between the pre- and post-monitoring sessions, but had little change at the baited site. Considering the results found in my study, I have identified a few potential future research directions, such as long-term monitoring, optimising individual identification, using different lure attractants, and observing seasonal and weather impacts throughout monitoring programs.

Contents

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1. Introduction

Feral cats threaten biodiversity globally (Doherty et al., 2016; McGregor et al., 2015; Medina et al., 2011), predominantly due to predation; but also through competition (Doherty et al., 2016). In Australia, feral cats were a causal factor in the recent extinctions of at least 20 native mammal species, including the desert bandicoot (*Perameles eremiana*) (Woinarski et al., 2014). Managing and mitigating the impacts of feral cats on native populations is essential for the global conservation of threatened species (Doherty and Algar, 2015).

Effective feral cat management relies on a foundation of reliable ecological monitoring. To manage feral cats effectively, the success of various management techniques needs to be monitored, such as the efficacy of lethal baiting to reduce feral cat populations. Monitoring feral cats can be difficult due to their cryptic nature and low densities, with detection levels often very low (McGregor et al., 2015; Rees et al., 2019). However, camera traps can provide information on animal activity without human interaction, by supplying image-based data (Foster and Harmes, 2012), that can be used to observe species population changes.

For species that have markings unique to the individual, camera traps can also be used to identify individual animals to estimate species density and/or abundance, which has been applied by many studies on a variety of different animal taxa, such as the perentie (*Varanus giganteus*; Moore et al., 2020a). Recent studies have used camera trap images to estimate population densities by individually identifying feral cats using spatially explicit mark-recapture methods (McGregor et al., 2015; Rees et al., 2019). Camera trapping provides a method of gauging the success of bait uptake and can provide a robust and repeatable measure that improves the detectability of introduced predators before and after baiting programs (Comer et al., 2018). Once set up, camera traps can be left for weeks at a time to record changes in feral cat densities, with less maintenance and effort than regularly checking cage or leg-hold traps (Lohr and Algar, 2020). The ability to identify individual feral cats from camera trap images can potentially enable us to improve the monitoring of cats, and therefore assess the effectiveness of lethal baiting programs, which are very time-consuming and expensive. Few studies have tested the applicability of camera traps for this purpose in Australia.

In 2016, a feral cat monitoring program was established by the Department of Biodiversity, Conservation and Attractions (DBCA) at two adjacent sites, Yarraloola and Red Hill, in the Pilbara bioregion of Western Australia, to monitor changes in feral cat populations in response to *Eradicat*® baiting. These baits were specifically designed for the control of feral cats in Australia, containing 4.5 mg of the toxin '1080' (sodium monofluoroacetate, a metabolic poison) injected in a 'chipolata' shaped bait comprised of 70% kangaroo mince, 20% chicken fat and 10% digest and flavour enhancers (Algar et al., 2007). Yarraloola was aerially baited with *Eradicat*® every winter from 2016 to 2019, whereas the adjacent Red Hill site was not baited and used as a "control" (Fig. 1; Palmer et al., 2020). To analyse the effectiveness of *Eradicat*® baiting at reducing the feral cat population, a camera trap based monitoring program was adopted from a study, also in the Pilbara bioregion (Comer et al., 2018), to utilise camera traps to estimate changes in feral cat occupancy before and after aerial baiting. This analysis used camera site level presence/absence data and did not rely on individually identifying each cat, as this was considered too laborious and time-consuming by Lohr and Algar (2020).

However, there are a range of advantages to be gained by individually identifying feral cats. This allows comparison of the number of cats before and after a baiting session at the baited site, reflecting the survivability of individual cats within the population. It can also reveal common traits of surviving cats, such as sex or age, which would improve current knowledge of feral cat control measures (Lohr and Algar, 2020). Individually identifying feral cats can also test the assumption of site occupancy models, which assume feral cats are not detected at more than one independent camera trap site (Comer et al., 2018).

Here, I use camera trap imagery collected as part of the DBCA Pilbara predator control baiting and monitoring program in its entirety, to further investigate the effectiveness of feral cat baiting in the Pilbara bioregion through individual identification. The objective of this study was to measure changes in feral cat:

- Detectability.
- Abundance.
- Behaviour (cat activity) as a result of feral cat baiting.

Firstly, the raw camera trap images were used to analyse changes in detection rates pre- and post-baiting sessions at Yarraloola, and also pre- and post-control sessions at Red Hill. The same images were then used to individually identify feral cats. This was utilised to detect changes in the number of individual cats, to see if this improves the result of the analysis using raw detections. Lastly, the dataset was examined if baiting influenced cat behaviour, which was analysed through two methods: temporal activity (when cats are most active), and lure interaction time. Recent research has shown apex predator activity could alter mesopredator activity (Brooke et al., 2012; Fancourt et al., 2019). As *Eradicat*® is also lethal to dingoes (*Canis lupus dingo*), cats that survive baiting at the baited site (Yarraloola) may change their temporal activity if there were fewer apex predators present. Improved understanding of cat behavioural shifts arising as a result from baiting or previous encounters with camera traps could optimise future design of camera trap monitoring programs for feral cats.

2. Materials and methods

2.1. Study area

My study sites were two cattle station pastoral leases, Yarraloola (~150 000 ha) and Red Hill (~190 000 ha) located in the southwest of the Pilbara bioregion in Western Australia (Fig. 1; Palmer et al., 2020). The climate is semi-arid, with mean summer temperatures averaging 40ºC, and winter temperatures 27ºC (Charles et al., 2015). Approximately 60% of annual rainfall occurs during summer (January to March), frequently linked to cyclonic events, with little rainfall in winter (Charles et al., 2015). The average yearly rainfall for Red Hill is ~361 mm and Yarraloola ~301mm (Australian Bureau of Meteorology, 2020). The sites are dominated by mesa formations within the Hammersley IBRA (Interim Biogeographic Regionalisation for Australia) subregion (Charles et al., 2015). The open stony plains of the study sites have various spinifex hummock grasslands (*Triodia spp.*) and *Acacia* species (van Vreeswyk et al., 2004). Due to the adjacent location of the two sites and their similar habitat and climatic conditions, the two sites can be treated as spatial replicates (bait/no bait).

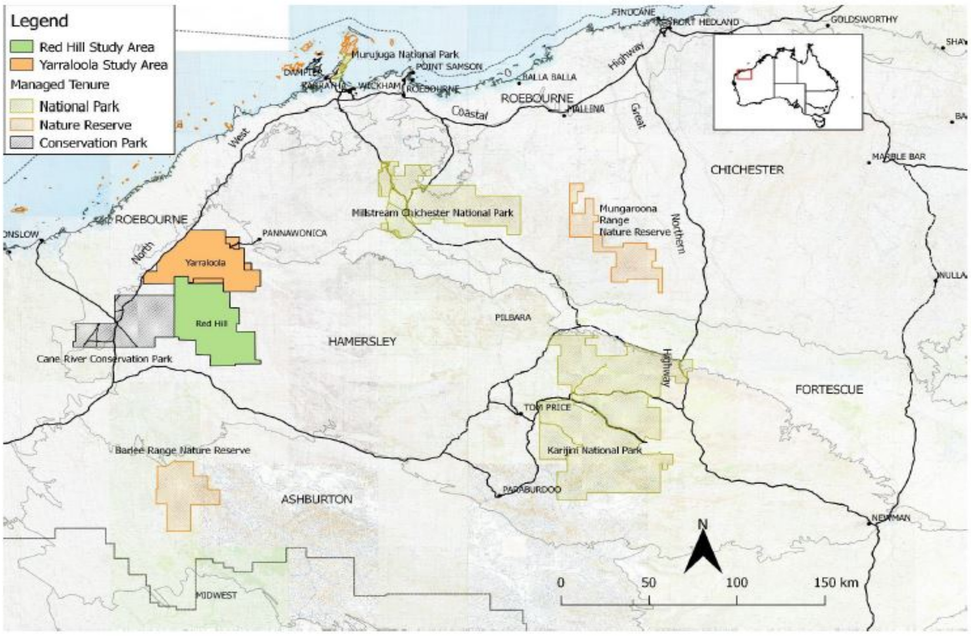

Fig. 1. Location of the Yarraloola and Red Hill in the southwestern Pilbara bioregion of Western Australia (Palmer et al., 2020).

2.2 Feral cat baiting program

Feral cat baiting was conducted on Yarraloola station from 2016 to 2019. *Eradicat*® feral cat baits were deployed aerially (via fixed wing aircraft) at a density of 50 baits km^{-2} (Palmer et al., 2020), on an annual basis during the winter months of each year (26–27 July 2016; 16-17 July 2017; 9-10 July 2018; 8-9 July 2019) when prey activity (such as small rodents, birds and reptiles) was at its lowest (Palmer et al., 2020). This timing was selected to increase the likelihood of bait uptake by feral cats and decrease bait degradation from rainfall, insects, and hot weather (Palmer et al., 2020). Red Hill station was left unbaited as a control site. There was a 5 km wide buffer zone between the two sites (following Comer et al., 2018), to reduce the likelihood of feral cats from Red Hill accessing baits deployed on Yarraloola.

2.3. Study design

Camera trapping was conducted before and after the baiting periods of 2016-2019, to monitor the impact of baiting on the feral cat populations at Yarraloola, and at Red Hill to observe any potential temporal impacts to the camera trapping results. The same pre- and post-monitoring sessions were used for the control site but without baiting. Each site had 60 camera traps (Reconyx HyperFire™ PC900) programmed on 'Aggressive' mode, to take five pictures at up to two frames per second upon a trigger (Palmer et al., 2020). They were each placed at least 3 km apart (Figs. 2, 3) to avoid spatial autocorrelation, given the average home range of cats in a similar arid area (3.5 km^2 for males and 1.2 km^2 for females; McGregor et al., 2015). A 'lure pole' with visual (tinsel, feathers) and olfactory scent ('Catastrophic'; Outfoxed Pest Control, Victoria) lures was set 3 m in front of each camera and was refreshed for each pre- and post-monitoring period throughout the project.

To account for differences in camera operation time, camera data collected after 25 nights of deployment was excluded for statistical analysis. All images were catalogued and stored in the 'CPW Photo Warehouse', a database designed to process identified fauna species in Microsoft Access (Ivan and Newkirk, 2016). Camera images were interpreted as independent detection events, if they occurred >10 minutes after the last series of images on the same camera, unless cats were able to be reliably identified as two separate individuals (Fancourt et al., 2019).

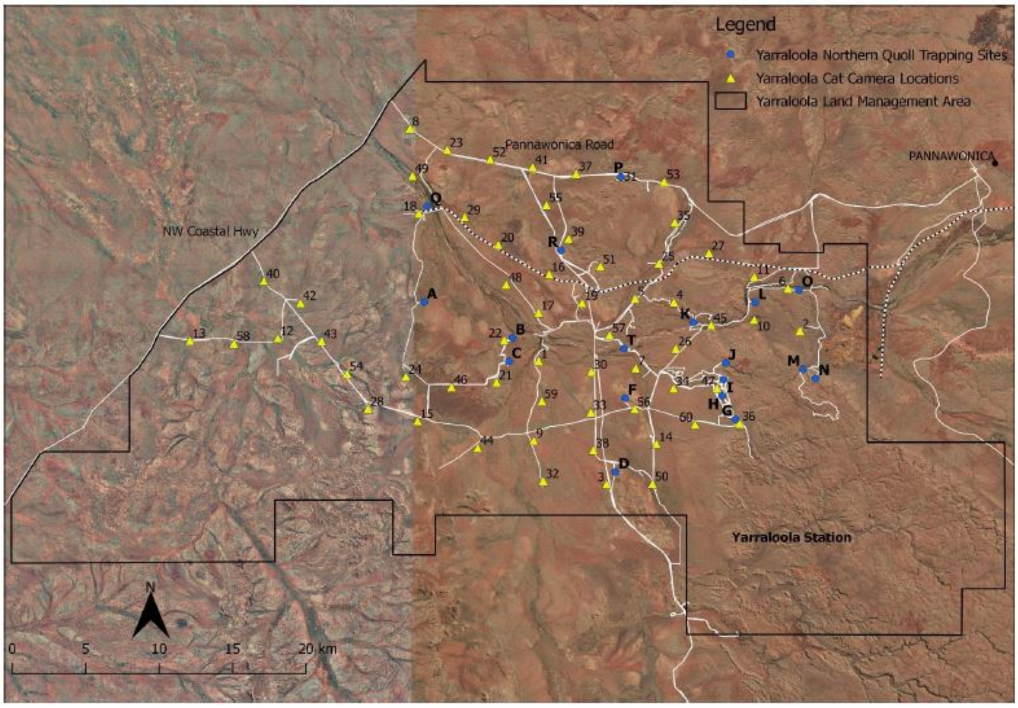

Fig. 2. Cat camera locations (yellow triangles) at the Yarraloola baited site (Palmer et al., 2020).

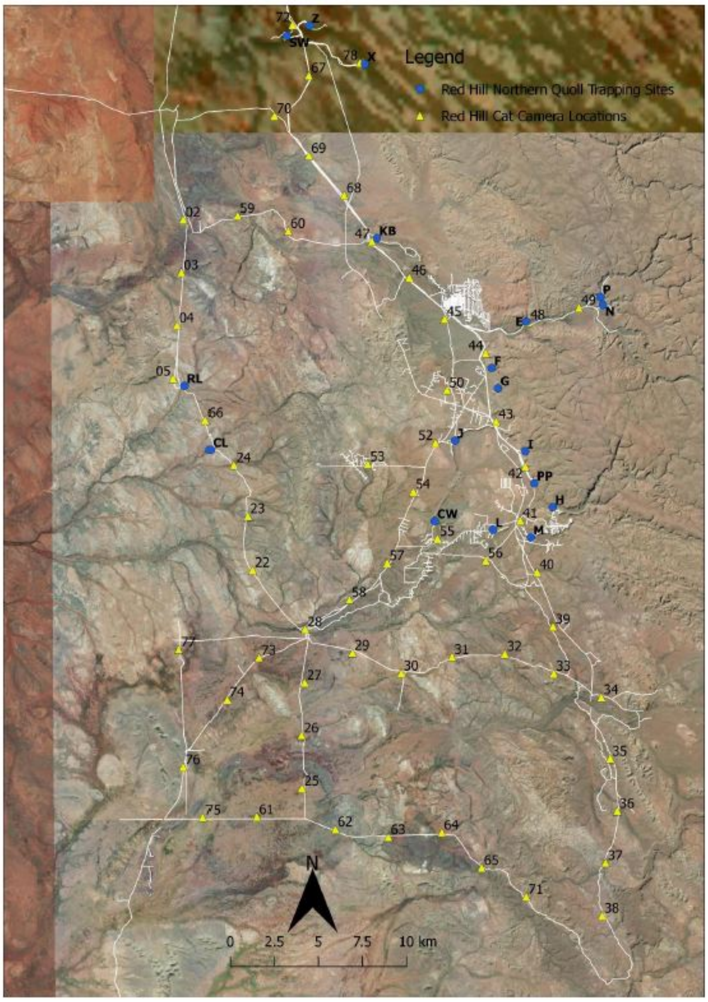

Fig. 3. Cat camera locations (yellow triangles) at the Red Hill control site (Palmer et al., 2020).

2.4. Individual identification

Individual feral cats were identified from camera trap detection events by examining morphological features (Table 1). Variations of coat colour and body/leg markings were the most distinguishable features used for identification (predominantly stripes and spots for tabby cats), as they were unique for each individual. The tail markings on the feral cats were also effective when side markings were not completely visible. Sex, tail shape and body build were also used to distinguish individuals where possible (McGregor et al., 2015; Rees et al., 2019).

Images showing these features were collected and placed together on PowerPoint slides with the identified cats' identity (e.g. Tabby cat 1), similar to McGregor et al. (2015) and Rees et al. (2019). Each cat detection image was then compared to the PowerPoint 'library' to classify it as a recapture, a new individual, or ‘unidentifiable’. All the information for the identified and unidentified individuals was stored on a master datasheet using Excel. To account for potential misidentifications, all the slides showing individual cats were shown to two other independent observers following Johansson et al. (2020). For an individual cat to be considered identified, the slides had to be agreed upon by all three reviewers (including myself), and any individuals that were potentially recaptures or unable to be confirmed by all reviewers, were instead marked as unidentifiable. Where possible, the sex of cats was also determined for interpretation of detections and/or behavioural responses. Total number of useful images captured was typically high for recaptured individuals when compared to individuals captured only once. As such, the sex of recaptured individuals was successfully determined more often.

It is important to note that the camera trap deployment used here was designed as part of a broader research program, aimed primarily at detecting changes in cat occupancy over a large area. As such, cameras were spaced at large distances from one another, limiting total number of recaptures, and precluding the use of spatially explicit mark-recapture techniques, commonly used to estimate changes in feral cat density. To overcome this issue, the minimum number of animals known to be alive (MNA) at each site was calculated (Krebs 1989); MNA is a abundance metric commonly used in ecology when more sophisticated measures are not available (Baker et al., 2017; Onodera et al., 2017). MNA was calculated by summing the number of individual animals detected at each site in both pre- and post-baiting/control monitoring sessions.

Table 1. Morphological features used for individual identification.

Feature	Sources of variation
Coat colour	• tabby (mackerel or spotted mackerel) • swirled/marbled tabby • black • ginger
Sex	• male, female, unknown • genitals visible
Body markings	• colour of fur • marking patterns (Stripes/broken stripes/spots) • position of markings on body • unique markings • scars, ear tears
Leg markings	• colour and patterning on leg markings • stripes/broken stripes on legs • white socks on paws/legs
Tail markings **(Tabby and Swirled Tabby)**	• number and thickness of black bar markings on tail • thickness of black tip on tail
Tail shape	• length of tail relative to body • thickness of tail (bushy/thin) relative to tail length • broken or kinked tail
Head/face shape	• wide/narrow face shape • patterning of face markings where possible
Body size/build	• thin/wider body shape • longer/shorter body • pregnant female
Tracking collar	• no collar • tracking collar (some were fitted in 2018 and 2019)

2.5. Behavioural responses

Behavioural responses of each feral cat were also observed. Interactions of feral cats with the olfactory lures and the total seconds present at a camera trap (interaction time) were noted for each individual to analyse potential behavioural changes over time and any influence from baiting. If a cat was interested in the lure and walked up to it to either sniff or spray, then this was classified as a lure interaction. If a cat did not acknowledge the presence of the lure and walked past, this was classified as no lure interaction. Changes could be a result of baiting, seasonal changes between the pre- and post-monitoring session, or a loss of interest in lures (habituation) within a monitoring session.

2.6. STATISTICAL ANALYSIS

All statistical analyses used R version 4.0.2 (R Development Core Team, 2020). To account for differences in camera operation time, camera data collected after 25 nights of deployment was excluded for statistical analysis. When appropriate, paired t-tests were used to compare statistical differences between the treatment (control/baited site) and monitoring session (pre/post).

2.6.1. Detectability

The effect of treatment (control/baited site) and monitoring session (pre/post) on the number of detections was examined using a generalised linear mixed effects model (GLMM) fitted with a binomial distribution following Moore et al. (2020b). This measures how the response variable, the proportion of nights that feral cats were detected at a site, is predicted to change in proportion to the fixed effects treatment (baited/control site), monitoring session (pre/post) and year. To account for non-independence between camera trap sites, the model included the camera trap site number as a random effect. Models were fit using the package lme4 version 1.1-23 (Bates et al., 2015). Models were fit for all combinations of fixed effects using the dredge function in the package MuMIn (Bartoń, 2020). Models were ranked according to model fit using AIC_c, and models with delta $AIC_c < 2$ were considered useful (Burnham and Anderson, 2002). Fixed effects were regarded as having an importance effect if 95% confidence intervals (CIs) did not overlap zero.

To incorporate the influence of site (baited or control) on detectability, the post-monitoring detections at the control and baited site were separately normalised, for each year, relative to the pre-monitoring detections (i.e. calculated as post-monitoring/pre-monitoring). These normalised post-monitoring feral cat detectability values were then compared for the baited and control sites using a paired t-test (paired for year) to determine if baiting had a significantly different effect on post-monitoring detectability at Yarraloola compared to Red Hill.

2.6.2. Abundance

Changes in cat abundance, measured by MNA in response to monitoring session (pre/post) and treatment (control/baited site), were modelled using a GLMM fit with a Poisson distribution. Similar to models described in the previous sections, camera trap site number was fit as a random effect, and all combinations of fixed effects were ranked according to AIC_c. Fixed effects were regarded as having an importance effect if 95% CIs did not overlap zero. The post-monitoring MNA at the control and baited site were also separately normalised, relative to the pre-monitoring MNA, to determine if baited had significantly different effect on post-monitoring MNA at the baited site compared to the control site with no baiting. As camera trap sites were spaced similarly and covered similar areas, the total area of land at the Yarraloola and Red Hill stations were not likely to influence the number of individual cats.

2.6.3. Temporal activity

Changes in feral cat temporal activity in response to the treatment (control/baited site) and monitoring session (pre/post) was measured using the 'overlap' package version 0.3.3 (Ridout and Linkie, 2009), following Fancourt et al. (2019). An overlap coefficient, Δ (Fancourt et al., 2019), was used to quantify the total temporal overlap, ranging from 0 (no overlap, complete separation) to 1 (complete overlap, no separation). $\Delta 4$ ($n \geq 75$) was used for analysis from three overlap coefficients ($\Delta 1$, $\Delta 4$ and $\Delta 5$), following Fancourt et al. (2019) and Ridout and Linkie (2009). CIs between the two sites and monitoring sessions were obtained from 10,000 bootstrap samples (Fancourt et al., 2019; Ridout and Linkie, 2009). Temporal activity between dingoes and feral cats was also analysed to examine if apex predator (dingo) presence could have influenced mesopredator (feral cat) activity.

2.6.4. Behaviour

To test whether feral cat baiting could potentially influence cat behaviour, we examined behavioural responses such as lure interaction and interaction time, using GLMMs. The fixed effects; sex, treatment (baited/control site), monitoring session (pre/post), days camera trap was active, and the capture number (number of times a cat had been caught on a camera trap), were modelled as influencing factors for two response variables; interaction time with the lure, and lure interaction. To account for non-independence between camera trap sites, the model included the camera trap site number as a random effect. Models were fit using the package lme4 version 1.1-23 (Bates et al., 2015). Models were fit for all combinations of fixed effects using the dredge function in the package MuMIn (Bartoń, 2020). Models were ranked according to model fit using AIC_c, and models with $AIC_c < 2$ were considered useful (Burnham and Anderson, 2002). Fixed effects were regarded as having an importance effect if 95% CIs did not overlap zero.

3. Results

3.1. Detections and individual identification

In total, there were 3568 images of feral cats from 300 detection events from the whole dataset. A total of 142 different cats were identified from 226 of the detection events, which were agreed upon by all three reviewers: 88 individuals at the control site (Red Hill) and 54 at the baited site (Yarraloola). The remaining 74 detections could not be identified due to poor image quality or lack of unique markings. Tabby coat colouring (mackerel/spotted mackerel and swirled/marbled) was very common amongst 89% of individual cats (Table 2). Only 11% of individuals with less unique coat colour markings (black) or coat colours which appear white with the infrared flash (ginger/tortoiseshell), were identified over the four years. There was an average of 22 new cats identified each year at the control site and 13 at the baited site. A paired t-test showed there was nearly significance ($t_3 = 2.87$; $P = 0.064$) between the number of new cats identified each year between the two sites, which is notable given that there was only four years of data (Table A1). 53 of the identified cats were re-detected (recaptured) again in later trapping sessions (36 at Red Hill and 17 at Yarraloola), but there was no significant difference between the percent of recaptured individuals between the sites (t_3 = 0.76; P = 0.503) (Table A2). On one occasion at Red Hill, there were two different cats (male and female) captured together on the same detection. This was treated as two detections as each cat could be identified.

Table 2. Coat colour of identified individuals at the control (Red Hill) and baited site (Yarraloola).

COAT COLOUR	CONTROL	BAITED	TOTAL
Tabby (mackerel or spotted mackerel)	74	41	115
Swirled/Marbled tabby	8	3	11
Black	5	8	13
Ginger	1	1	2
Tortoiseshell	0	1	1

Over the four years, three males and two females at the both the control and baited site (ten individual cats in total) were captured at different nearby camera trap sites, all of which were immediately adjacent to the first camera trap. Each cat was only detected once at a different camera trap site, except for one male who was detected twice at different sites. Only two individuals were detected at more than one camera trap site in the same monitoring session (both at the baited site). There were six individual cats detected (3 M; 3 F) before and after a baiting period at the baited site (Table 3). One female was known to survive the first baiting session in 2016, two (1 M; 1F) survived the second in 2017, three males survived the third in 2018 and two (1 M; 1 F) survived the last baiting session in 2019. Two males survived consecutive baiting sessions, one male in 2017 and 2018, the other male in 2018 and 2019. At the control site, fifteen cats (8 M; 5 F; 1 unknown sex) were detected in pre- and post-control monitoring sessions, with a clear male dominance (Tables 4).

Table 3. Individual feral cats known to survive a baiting session at Yarraloola.

FERAL CAT ID	SEX	SURVIVED BAITING SESSIONS
Tabby Cat 22	F	2016
Swirled Tabby Cat 3	F	2017
Tabby Cat 60	M	2017, 2018
Black Cat 8	M	2018, 2019
Tabby Cat 90	M	2018
Black Cat 11	F	2019

Table 4. Individual feral cats detected at the control site (Red Hill) before and after a baiting session at the baited site (Yarraloola).

FERAL CAT ID	SEX	SURVIVED 'BAITING' SESSIONS
Swirled Tabby Cat 2	M	2017
Swirled Tabby Cat 7	M	2018
Tabby Cat 11	F	2016
Tabby Cat 12	M	2016
Tabby Cat 13	M	2016, 2017, 2018
Tabby Cat 15	Unknown sex	2016, 2017
Tabby Cat 17	M	2017, 2018
Tabby Cat 41	F	2017, 2018, 2019
Tabby Cat 42	M	2017, 2018, 2019
Tabby Cat 46	M	2017, 2018
Tabby Cat 48	F	2017
Tabby Cat 53	F	2018
Tabby Cat 72	M	2018, 2019
Tabby Cat 76	M	2018, 2019
Tabby Cat 106	F	2019

Only 52% of feral cats identified were able to be sexed. As such, no formal analysis was used to measure sex-specific trends from feral cat detections and abundance. Overall, there were generally more males than females observed at each trapping session (Table 5). The number of males detected in the post-control session at Red Hill was observed to have dropped slightly each year (except for 2016), whereas the number of males seen after the baiting period at the baited site did not decrease (except for 2016). The number of females fluctuated at both sites throughout pre- and post-monitoring.

Table 5. Number of individually identified males, females, and sex unknown cats observed (excluding recaptured individuals in same trapping session and unidentifiable cats) for unbaited (Red Hill) and baited (Yarraloola) sites.

	2016			**2017**			**2018**			**2019**		
	M	**F**	**U**	**M**	**F**	**U**	**M**	**F**	**U**	**M**	**F**	**U**
RED HILL (PRE-CONTROL)	6	6	6	10	6	4	6	2	4	4	3	7
RED HILL (POST-CONTROL)	8	2	1	8	3	4	5	3	9	3	4	3
YARRALOOLA (PRE-BAIT)	5	5	4	3	1	1	4	3	8	1	0	6
YARRALOOLA (POST-BAIT)	0	3	1	3	3	1	4	1	3	1	2	1

3.2. STATISTICAL ANALYSIS

3.2.1. Detectability

The control site had a significantly higher number of feral cat detections each year compared to the baited site (t_3 = 4.65, P = 0.019; Fig. 4). Cat detections decreased following each annual winter baiting operation on Yarraloola (Table 6). However, decreases in cat detections post-control at Red Hill were also evident each year, except for 2018 where cat detections peaked. There was no significant difference between the normalised post-baiting and post-control detections between the sites (t_3 = 1.21, P = 0.313), however, the mean post-baiting detections at Yarraloola (0.59) was lower than the post-control detections at Red hill (0.86). The best supported GLMM model (Table B3) included both treatment (control/baited site) and monitoring session (pre/post) as predictors, both of which were statistically significant (Table 7; Fig. 5). Baiting treatment had a significant negative effect on detectability (coefficient = -0.46, CI = -0.70 to -0.22; coefficient = -0.44, CI = -0.67 to -0.21).

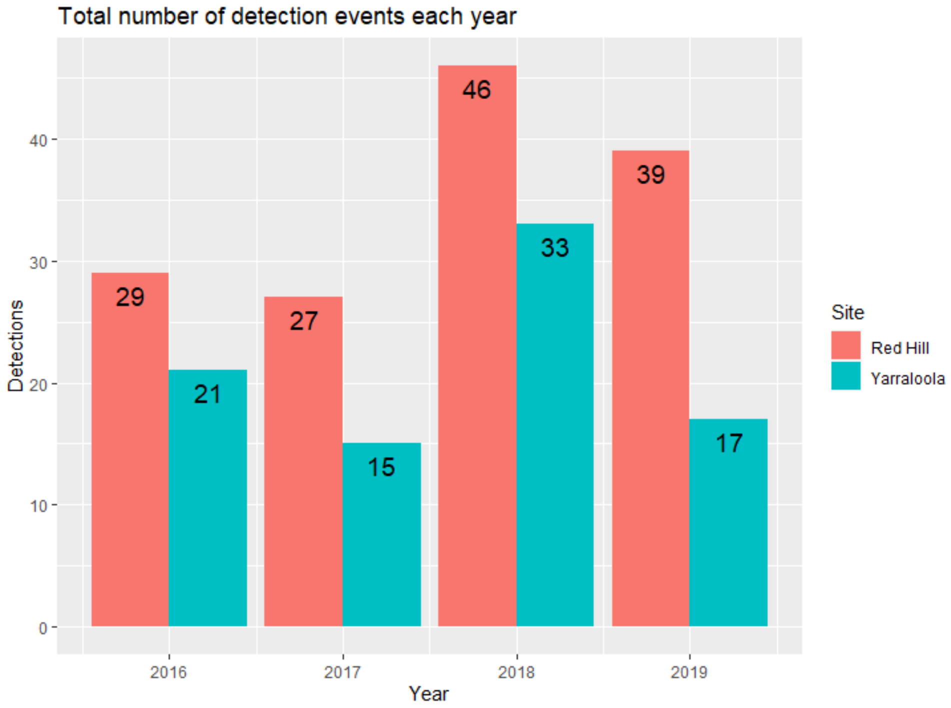

Fig. 4. The total number of yearly cat detection events for both the control (Red Hill) and the baited site (Yarraloola).

Table 6. Number of cat detections (number of camera trap nights) at the control (Red Hill) and baited site (Yarraloola).

	RED HILL (PRE-CONTROL)	RED HILL (POST-CONTROL)	CHANGE IN DETECTIONS (RELATIVE TO PRE-CONTROL)	YARRALOOLA (PRE-BAIT)	YARRALOOLA (POST-BAIT)	CHANGE IN DETECTIONS (RELATIVE TO PRE-BAIT)
2016	18 (1255)	11 (1472)	↓ 47%	14 (1301)	7 (1485)	↓ 56%
2017	16 (1427)	11 (1408)	↓ 30%	9 (1301)	6 (1469)	↓ 32%
2018	19 (1274)	27 (1495)	↑ 21%	22 (1268)	11 (1485)	↓ 57%
2019	23 (1424)	16 (1432)	↓ 31%	10 (1474)	7 (1472)	↓ 30%

Table 7. The coefficient, standard error, Z-value and 95% CIs for detectability in response to the fixed effects of baiting and site.

Fixed effect	Coef	SE	Lower 95% CI	Upper 95% CI
Intercept	-4.2379	0.0921	-4.42	-4.48
Monitoring Session (Post-bait / Post-control)	-0.4395	0.1192	-0.67	-0.21
Treatment (baited: Yarraloola)	-0.4567	0.1210	-0.70	-0.22

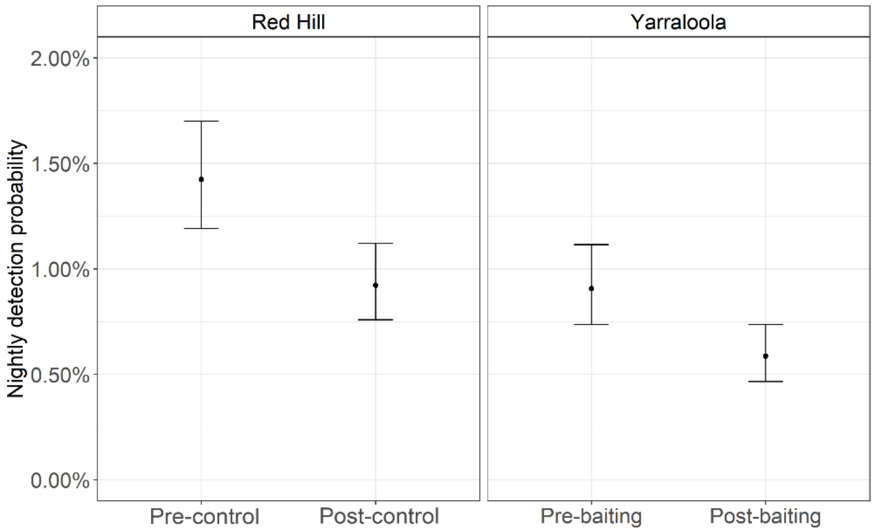

Fig. 5. The probability of feral cat nightly detections between pre- and post-monitoring sessions at the control (Red Hill) and baited site (Yarraloola) with 95% CI error bars.

3.2.2. Abundance

The control site had a significantly higher abundance of feral cats each year compared to the baited site (t_3 = 8.17, P = 0.004; Fig. 6). There was a steady reduction in feral cat abundance (MNA) each year at the baited site (except for 2017 with no change) (Table C1). The control site also had a decrease in feral cat abundance in the post-baiting sessions, except for 2018 with an increase in feral cat abundance post-baiting that year. There was no significant difference in the MNA between the normalised post-baiting session at Yarraloola and post-control session at Red Hill (t_3 = 0.68, P = 0.544), however, the mean post-baiting detections at Yarraloola (0.54) was lower than the post-control detections at Red Hill (0.75). The best supported GLMM model included both treatment (control/baited site) and monitoring session (pre/post) as predictors, both of which were statistically significant (Table 8; Fig. 7). Baiting treatment had a significant negative effect on cat abundance (coefficient = -0.5863, CI = -0.96 to -0.22), as did the monitoring session (coefficient = -0.4931, CI = -0.83 to -0.17).

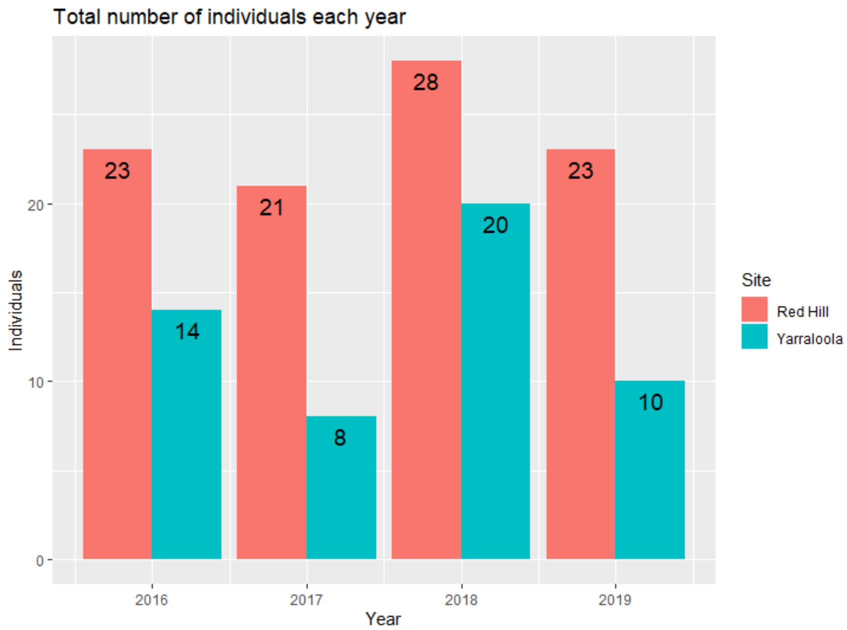

Fig. 6. The total number of individual feral cats identified early at the control (Red Hill) and the baited site (Yarraloola).

Table 8. The coefficient, standard error, Z-value and 95% CIs for abundance in response to the fixed effects of baiting and site.

Fixed effect	**Coef**	**SE**	**Lower 95% CI**	**Upper 95% CI**
Intercept	-1.6195	0.1730	-1.98	-1.30
Site (Yarraloola)	-0.5863	0.1870	-0.96	-0.22
Baiting (Post-Baiting)	-0.4931	0.1687	-0.83	-0.17

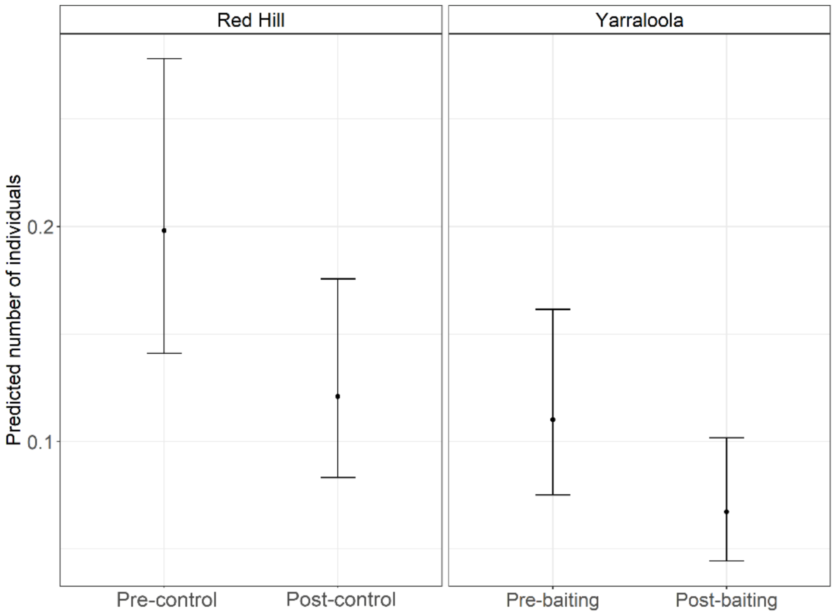

Fig. 7. The predicted number of individuals based on the MNA alive pre- and post-monitoring at the control (Red Hill) and baited site (Yarraloola) with 95% CI error bars.

3.2.3. Temporal activity

Camera trap detections indicated that cats were largely nocturnal, with 82% of total detections captured after sunset and before sunrise (~6pm to ~6am). Feral cats were active throughout the night for 76% of detections at the control site and 92% at the baited site. There was no change in feral cat activity before and after baiting operations at the baited site over the four year period ($\Delta4 = 0.87$ (95% CI: 0.65–0.92); Fig. 8A). At the control site, there was less overlap, suggesting a slightly greater change in activity between the monitoring sessions in the absence of baiting ($\Delta4 = 0.81$ (95% CI: 0.68–0.88); Fig. 8B). Cats were active for a shorter amount of time throughout the day in the post-control session and were most active around dusk and dawn.

There was a greater difference in cat activity in the pre-monitoring sessions ($\Delta4 = 0.75$ (95% CI: 0.66–0.87); Fig. 9A) compared to the post-monitoring sessions ($\Delta4 = 0.90$ (95% CI: 0.73–0.92); Fig. 9B). Feral cats were active for longer at the control site in the pre-control session, compared to the pre-baited session at the baited site. There was a large overlap between the activity in the post-monitoring session between the two sites, with little change in activity as a result from baiting.

There was little evidence that cat activity was influenced by dingoes, with a 77% marked overlap between both species ($\Delta4 = 0.77$ (95% CI: 0.7–0.85); Fig. 10). The overlap showed that both feral cats and dingos were active around similar times (between 6pm to 6am) but does not consider spatial activity. Both species could have been present at the same time but in different areas.

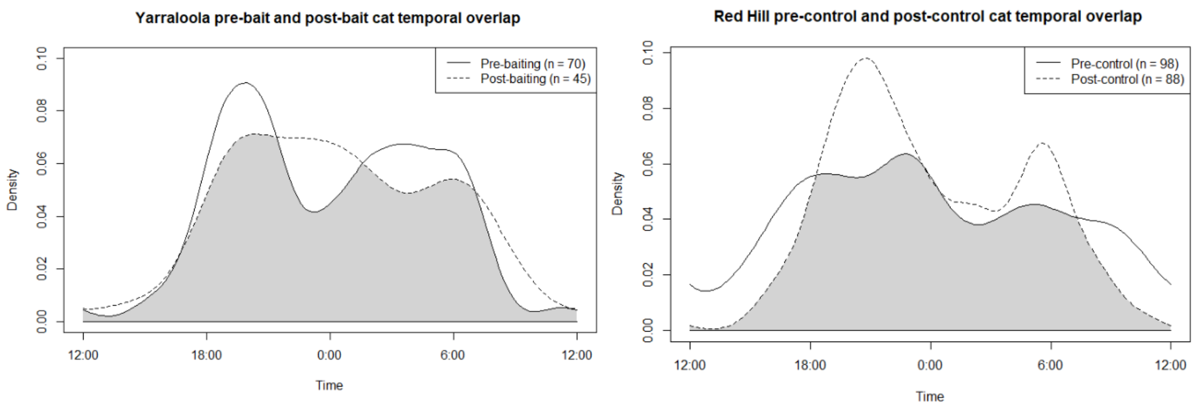

Fig. 8. Overlap analysis of feral cat temporal activity pre- and post-monitoring.
A: Yarraloola (baited site). B: Red Hill (control site).

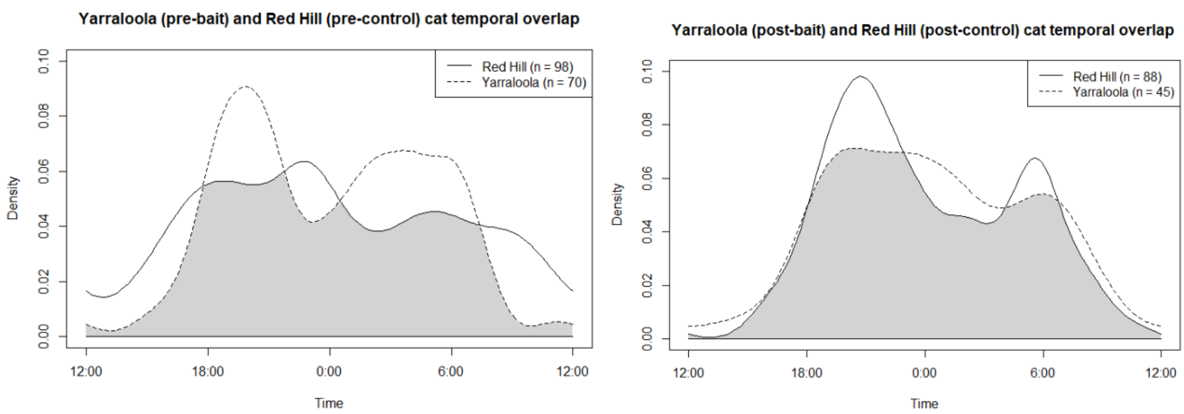

Fig. 9. Overlap analysis of feral cat temporal activity between the control and baited sites.
A: Pre-monitoring. B: Post-monitoring.

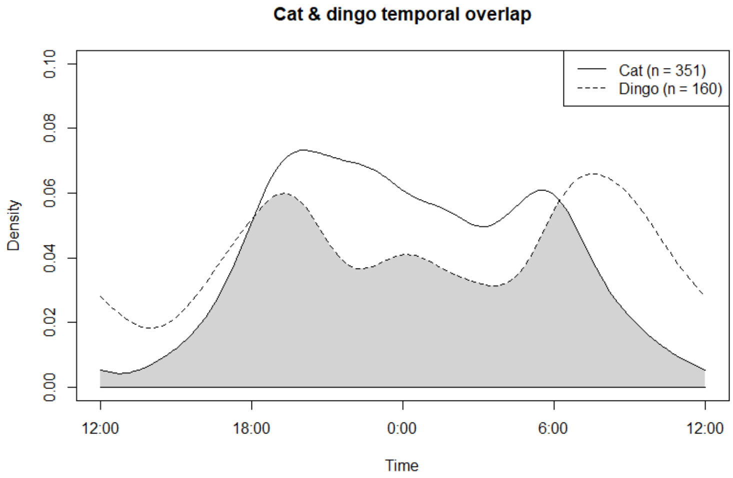

Fig. 10. Overlap analysis of feral cat and dingo temporal activity.

3.2.4. Behaviour

The best model used to predict the probability of feral cats interacting with a lure only included days since camera was deployed as a predictor (Table 9; D1). Time since camera deployment had a significant negative effect on the probability of lures being interacted with (coefficient = -0.06, CI = -0.11 to -0.02). The longer a camera had been active for, the less chance a cat would interact with the lure (Fig. 11).

Table 9. The coefficient, standard error, Z-value and 95% CIs for lure interaction in response to the fixed effect of time since camera deployment.

Fixed effect	Coef	SE	Lower 95% CI	Upper 95% CI
Intercept	1.0677	0.3195	0.4860	1.7819
Time since camera deployment	-0.0626	0.0233	-0.1140	-0.0198

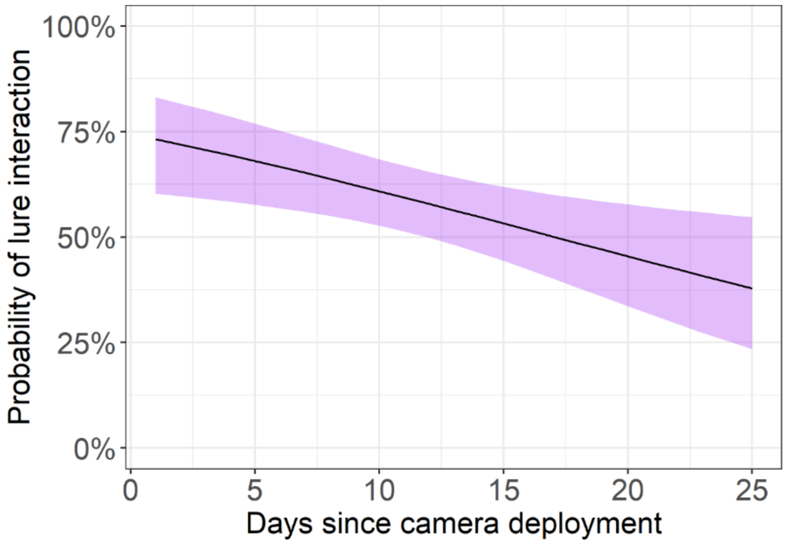

Fig. 11. Probability of lure interaction over time since days of camera deployment, with 95% CI shown in purple.

The best model used to predict lure interaction time included sex and treatment as fixed effects, both of which had a significant effect (Table 10; D2). Male had a negative effect compared to females (coefficient = -1.53, CI = -1.72 to -1.32). The baited site (Yarraloola) also had a negative effect on interaction time compared to the control site (Red Hill) (coefficient = -0.61, CI = -1.22 to -0.01). Interaction time was higher for females at the control site, compared to females at the baited site (Fig. 12). Males spent little time in front of the camera at both sites.

Table 10. The coefficient, standard error, Z-value and 95% CIs for interaction time in response to the fixed effects of site and sex.

Fixed effect	Coef	SE	Lower 95% CI	Upper 95% CI
Intercept	4.3087	0.2063	3.90	4.72
Site (Yarraloola)	-0.6124	0.3023	-1.22	-0.01
Sex (Male)	-1.5263	0.0977	-1.72	-1.34

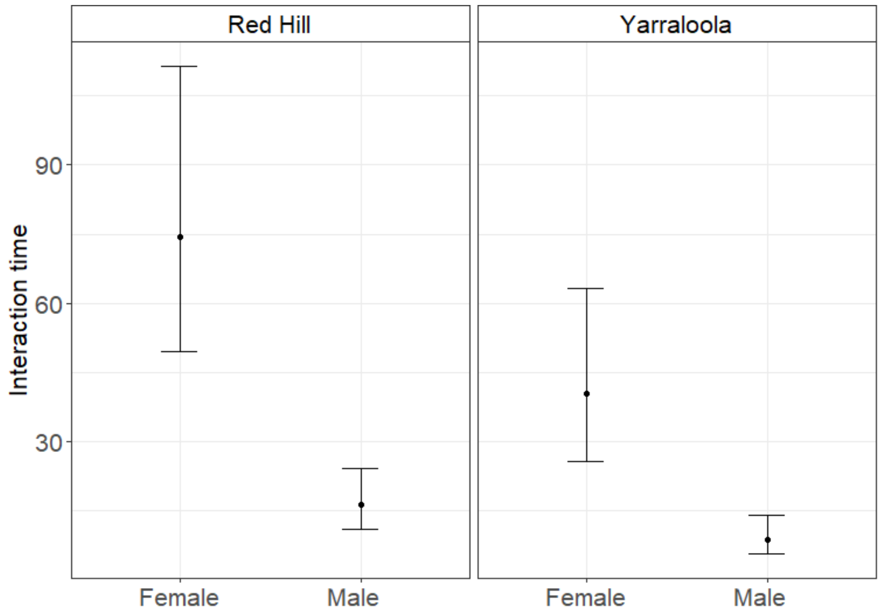

Fig. 12. Predicted interaction time for female and male feral cats at the control (Red Hill) and baited site (Yarraloola) with 95% confidence interval error bars.

4. Discussion

Accurate and reliable data is vital when assessing management efforts for controlling feral cat populations. To evaluate the effectiveness of *Eradicat*® baiting at reducing feral cat populations, camera trapping provides a straightforward and cost-effective method (Foster and Harmes, 2012). Reliable camera trapping monitoring data is essential for understanding the effects that baiting has on feral cat populations and whether it is a viable and effective form of management. The camera trap data used in this study indicated that changes were occurring in baited (Yarraloola) and non-baited (Red Hill) feral cat populations. My study examines changes in feral cat detectability, abundance, and behaviour in response to *Eradicat*® baiting.

4.1. Detectability

The GLMM analysis showed that detectability was significantly influenced by both the treatment (control/baited site) and monitoring session (pre/post), with the baited site (Yarraloola) and post-monitoring session both having reduced detectability. Furthermore, there was higher statistical difference between the pre- and post-baiting sessions at the baited site compared to the pre- and post-control sessions at the control site, suggesting influence by *Eradicat*® baiting at Yarraloola (Tables B1, B2). Although the normalised post-monitoring detections did show a significant difference between the control and baited site, the mean post-baiting detections at Yarraloola was lower than the post-control detections at Red Hill, suggesting a small baiting influence, but four years of data may not be sufficient to detect a statistical difference as a result from feral cat baiting. The year was not a significant predictor of detectability. As detectability at the control site decreased ~30% in the same years that the baited site dropped ~31% (Table 6), it is likely that factors other than baiting, such as breeding, weather and reinvasion events played a role in the reduction of detections. Similar results were observed by Comer et al. (2020), where cat detections also decreased in some of the post-monitoring sessions at the control site, which was not baited.

Pre-monitoring sessions occurred throughout May-June, with baiting taking place in July and post-monitoring sessions in August-September. When air temperature is similar to the body temperature of a feral cat (38.7ºC), the thermal senses for camera traps may not detect a cat walking past (Hilmer et al., 2010). Slight variations in air temperature between the pre- and post-monitoring sessions could have impacted detectability, however, the mean monthly maximum temperature did not exceed 35ºC between May and September, and therefore unlikely to have a significant effect on detectability (Australian Bureau of Meteorology, 2020). Other seasonal impacts, such as breeding, could lead to fewer cat detections post-monitoring at both the control and baited site (Algar et al., 2013). The reproductive cycle of females means they were most likely to have kittens during the post-monitoring session and are less likely to venture far from their young, which reduces their detectability (Algar et al., 2013). The curiosity of younger cats present in the pre-monitoring session, when establishing their home range, leads to higher lure interaction events due to their inquisitive nature and often an increase in camera detections (Lohr and Algar, 2020).

4.2. Individual identification and recaptures

From the 300 feral cat detection events recorded as part of this study, individuals were able to be identified in 75% of cases. Similar studies have found higher success rates of cat identification; however, this is potentially due to the further distance separating the camera traps in my study resulting in far fewer recaptures (McGregor et al., 2015; Rees et al., 2019). Poor image quality and lack of unique markings, particularly for black cats, prevented individual identification of a further 25% of detection events. Although individual identification of feral cats is possible, the proportion of unidentified cat's and misclassification errors could lead to less reliable conclusions. Improving the likelihood of identification is strongly suggested for accurate feral cat population and behavioural trends, such as using a variety of lures or a dual-camera trap set up with two camera traps facing a lure (Bengsen et al., 2011).

A large number (63%) of the 142 individually identified cats were not detected again at a later trapping session (60% at the control and 69% at the baited site). Further analysis showed no statistical difference between the two sites and the percent of recaptured individuals each year. The number of recaptures may be higher if camera trap sites were closer together and designed for an intensive-style study, rather than a landscape-style study designed for occupancy analysis (McGregor et al., 2015; Rees et al., 2019).

Being able to identify individual feral cats before and after baiting, I could then determine and compare how many and which cats were still present after a baiting session at Yarraloola, and without baiting at Red Hill. I did not find that a large proportion of cats survived baiting sessions, so more research (both camera trapping effort and more sophisticated techniques) is needed to document survivorship, in order to target survivors for more effective baiting. Over the four year monitoring program, only six cats were known to have survived baiting at Yarraloola, compared to more than double at the control site (Red Hill) in the same monitoring sessions (Tables 3, 4). Only two of the surviving cats at Yarraloola from 2018 and 2019 were seen alive after the final baiting session in 2019.

4.3. Abundance

Feral cat abundance, using the MNA, followed a similar trend to the detectability analysis, with post-monitoring abundance often lower than the pre-monitoring sessions for both the control and baited sites. The GLMM analysis also revealed both the treatment (control/baited site) and monitoring session (pre/post) influenced feral cat abundance, however, the treatment was the greatest influence. Similar to the detectability analysis, the year was also not a good predictor and did not influence abundance. Neither abundance nor detectability declined consistently through time, suggesting little effectiveness of cat baiting over the four years. The baited site (Yarraloola) and post-monitoring session negatively affected feral cat abundance. There was no statistical difference between the normalised post-baiting and post-control MNA between the sites, however, the mean post-baiting MNA at Yarraloola was lower than the post-control detections at Red Hill. This suggests there could have been a minor effect from baiting but monitoring over a longer period of time might be needed to detect any statistical difference as a result from feral cat baiting.

Other environmental impacts, such as rainfall, has previously been shown to have a strong impact on feral cat populations (Algar et al., 2013; Lohr and Algar, 2020), with one to two year lags after high rainfall to an increase in cat abundance. Higher rainfall typically promotes reinvasion by new individuals and breeding success for resident individuals, as the increase in vegetation and prey availability ensures a higher chance of survival for younger cats (Algar et al., 2013; Lohr and Algar, 2020; Wysong et al., 2020). Many cats from neighbouring areas may be drawn to habitats with abundant prey resources. The large increase in individuals at the baited site in 2018 (Table C1) is likely to be a result from repopulation via natal recruitment and/or dispersal of young adults from outside the baited area, following the high rainfall event in February 2017 (Palmer et al., 2020; Lohr and Algar, 2020). With many younger cats surviving after high rainfall, the behaviour and interest in the lures used for camera trapping could potentially change, as young cats are often more curious and likely to interact with a lure (Lohr and Algar, 2020).

4.4. Behaviour and temporal activity

Temporal overlap analysis of feral cat activity between pre- and post-baiting sessions demonstrated little effect from baiting, with 87% overlap at the baited site and 81% overlap at the control site (Figs. 8A, 8B). There was no evidence that the presence of dingoes influenced cat activity, as cats and dingoes were active around similar times (Fig. 10). Spatial activity was not investigated in my study, but it is unlikely that cats avoided dingoes based on conclusions from Fancourt et al. (2019) and Hernandez-Santin et al. (2016), showing little spatial avoidance.

The GLMM analysis suggested that baiting did not influence feral cat behaviour. Interaction time was only influenced by sex and site, with no change between years or from *Eradicat*® baiting. The probability of a feral cat interacting with a lure was primarily influenced by the length of time in which a camera trap had been deployed, as there was less chance a cat would interact with the lure the longer a camera had been active for. Leaving a camera trap and lure for a longer time-period may not necessarily be beneficial, as the likelihood of a lure attracting a cat declines over time (Fig. 11). Using the same lure attractant for each trapping session could also have had detrimental effects to the number of detections, as relatively few cats were recaptured. Those cats that were recaptured showed little interest in the olfactory scent lure compared to new cats investigating it for the first time. The majority of recaptured cats did not show any interest in the lure and simply walked past a camera trap.

The decrease in interest after investigating the lures could lead to challenges when relying on recaptured cats on a landscape-scale study, as the chance of a cat walking past a camera trap is understandably reduced when there was generally only one camera per cat home range. There is also potential for some cats to become more wary from human-scented cameras and lures (Comer et al., 2018). The deaths of younger and more curious cats due to baiting could lead to a reduction in lure interaction in post-baiting sessions, as older and wiser cats could persist after baiting, which were less likely to interact with a lure (Comer et al., 2018; Lohr and Algar, 2020). Using a different lure attractant post-monitoring could potentially increase the chance of attracting a cat and could help lead to a more accurate representation on how many and which cats are surviving an *Eradicat*® baiting session.

4.5. Caveats

It is important to acknowledge that there were caveats associated with this study that may have influenced results. One caveat could be that feral cat's activity avoided camera traps, thus evading detection. For example, Meek et al. (2014) showed that cats could detect camera traps more than other animals. Errors are also common when attempting to individually identify feral cats. Photographic captures of the same individual from different detection events can be split into two different individuals, and vice versa where two different individuals can be classified as the same individual (9.9% probability; Johansson et al., 2020). Another error is the misclassification of unidentified individuals, which are usually excluded from a dataset (8.7% probability; Johansson et al., 2020). This study has aimed to anticipate and account for these potential errors as far as practicable, with individual feral cat identification confirmed through the use of three reviewers (two being experts), all of whom were shown the same images and unless a consensus was reached on the individuality of a feral cat, it was instead placed into the unidentified category (McGregor et al., 2015).

4.6. Future research

The future potential research directions that arise from the findings of this study include; optimising individual identification, use different lure attractants, monitor seasonal and weather impacts throughout monitoring programs, and long term management is essential to show significant success of cat baiting. Optimising individual identification through camera trapping can lead to a better analysis of the extent of cat baiting success. Identifying how many cats are seen over more than one year can represent the proportion of surviving cats in a population following baiting. As 22% of total detections were unidentifiable, this could have misrepresented data collected through individual cat identification. Potentially far more cats could have survived baiting sessions throughout the study. An intensive-style approach would be more successful than landscape-style when aiming to individually identify feral cats. Using paired cameras at each site would greatly increase the chance of identification by observing a cat from different angles, but doubling the number of camera traps would be impractical as it would be very expensive and time-consuming to set up (Bengsen et al., 2011). Instead, the camera trap sites with no cat detections could be dropped and the excess cameras could be used to improve detection at areas with previously seen high numbers of cat detections. As many of the unidentified cats spent a noticeably short amount of time in front of the camera, increasing the interaction time by using a variety of different lures could improve identification (Bengsen et al., 2011).

The lure had the same chance of attracting a cat whether it was female or male, pre- or post-monitoring. Interest in the lure decreased over time since camera trap deployment. The attractiveness was also reduced after a cat already investigated a lure, which was observed by the decrease in lure interactions with recaptured cats compared to new cats. The loss in interest when using the same lure could have resulted in fewer recaptures. By using a different lure in the post-monitoring session, it could appeal to different subsets of the population and increase the chance of detections for both new and old cats in the post-monitoring sessions (Bengsen et al., 2011). To avoid breeding affects, leaving a camera trap and lure for a longer time-period may not necessarily be beneficial, as the likelihood of a lure attracting a cat declines over time. Instead, setting up the post-monitoring session after the breeding season could increase female detection events. Other monitoring sessions (e.g. at the start of the year before the pre-monitoring session, and again at the end of the year after the post-monitoring session) could be utilised to further study trends in feral cat abundance throughout the year. More evaluation is needed however, as an increase in fires throughout summer months might prohibit this.

The results from this study point to strong adaptive management when using camera trapping techniques to monitor animal populations. Other variables, such as breeding season and weather impacts, need to be accounted for when structuring a monitoring program and analysing the data collected. Rainfall has been shown to greatly impact feral cat abundance (Lohr and Algar, 2020) therefore high rainfall can be used to predict future increases in feral cat abundance. Increasing baiting effort in the year following high rainfall might reduce the severity of an upcoming reinvasion event. The constant fluctuations of cat detections every second year at the baited site and no statistical difference between post-control and post-baiting sessions further enhances the need for long-term baiting. Lohr and Algar (2020) demonstrated the importance of long-term monitoring by detecting an overall significant decrease in feral cat detections as a result from *Eradicat*® baiting, however the effectiveness of baiting varied over the sixteen years of cat control.

4.7. Conclusion

By measuring the changes in feral cat detections and abundance using GLMM analysis, it is likely that *Eradicat*® baiting had reduced feral cat populations at Yarraloola, however, neither abundance nor detectability declined consistently through time, suggesting little effectiveness of cat baiting over the four years. It is likely that baiting had a minor effect, as normalised post-monitoring detections and MNA were lower at the baited site compared to the control site, however, no statistical difference was detected to show a strong impact from baiting. The true extent of baiting success is unknown, as other potential variables, such as breeding season and loss of interest in the lure, could have also influenced detectability and abundance. The need for long-term monitoring is essential for detecting changes in cat populations as a result from baiting, as four years of monitoring may not be sufficient. Considering the results found in my study, I have identified a few potential future research directions, such as long-term cat control monitoring, optimising individual identification, using different lure attractants, and observing seasonal and weather impacts throughout monitoring programs. By modifying camera trapping techniques used for monitoring feral cat populations in response to *Eradicat*® baiting, we will be able to gain more accurate data to reflect population changes over time. This will greatly help conservation, as enhancing current knowledge on feral cat baiting is essential for the survival of many threatened species.

References

Anderson, D., Burnham, K.P., 2002. Avoiding pitfalls when using information-theoretic methods. The Journal of Wildlife Management 66 (3), 912-918. https://doi.org/10.2307/3803155

Algar, D., Angus, G., Williams, M., Mellican, A., 2007. Influence of bait type, weather and prey abundance on bait uptake by feral cats (*Felis catus*) on Peron Peninsula, Western Australia. Conservation Science Western Australia 6 (1), 109-149.

Algar, D., Onus, M., Hamilton, N., 2013. Feral cat control as part of rangelands restoration at Lorna Glen (Matuwa), Western Australia: the first seven years. Conservation Science Western Australia 8 (3), 367-381.

Australian Bureau of Meteorology, 2020. Climate Data Online. Available at http://www.bom.gov.au/climate/data/index.shtml, Accessed date: 20 September 2020.

Baker, C.M., Armsworth, P.R., Lenhart, S.M., 2017. Handling overheads: optimal multi-method invasive species control. Theoretical Ecology 10 (4), 493-501. https://doi.org/10.1007/s12080-017-0344-1

Bartoń, K., 2020. MuMIn: Multi-model inference. R package 1.43.17. Available at https://cran.r-project.org/package=MuMIn

Bates, D., Maechler, M., Bolker, B., Walker, S., 2015. Fitting linear mixed-effects models using lme4. Journal of Statistical Software 67 (1), 1-48. http://doi.org/10.18637/jss.v067.i01

Bengsen, A., Butler, J., Masters, P., 2011. Estimating and indexing feral cat population abundances using camera traps. Wildlife Research 38 (8), 732-739. http://doi.org/10.1071/wr11134

Brook, L.A., Johnson, C.N., Ritchie, E.G., 2012. Effects of predator control on behaviour of an apex predator and indirect consequences for mesopredator suppression. Journal of Applied Ecology 49 (6), 1278-1286. https://doi.org/10.1111/j.1365-2664.2012.02207.x

Charles, S., Fu, G., McFarlane, D., Hodgson, G., Teng, J., Barron, O., Aryal, S., Dawes, W., 2015. Hydroclimate of the Pilbara: past, present and future. A report to the Government of Western Australia and industry partners from the CSIRO Pilbara Water Resource Assessment. CSIRO Land and Water, Australia. Available at https://publications.csiro.au/rpr/download?pid=csiro:EP157752&dsid=DS2

Comer, S., Speldewinde, P., Tiller, C., Clausen, L., Pinder, J., Cowen, S., Algar, D., 2018. Evaluating the efficacy of a landscape scale feral cat control program using camera traps and occupancy models. Scientific Reports 8, 1-9. https://doi.org/10.1038/s41598-018-23495-z

Comer, S., Clausen, L., Cowen, S., Pinder, J., Thomas, A., Burbidge, A.H., Tiller, C., Algar, D., Speldewinde, P., 2020. Integrating feral cat (*Felis catus*) control into landscape-scale introduced predator management to improve conservation prospects for threatened fauna: a case study from the south coast of Western Australia. Wildlife Research. http://doi.org/10.1071/WR19217

Doherty, T.S., Algar, D., 2015. Response of feral cats to a track-based baiting programme using *Eradicat*® baits. Ecological Management & Restoration 16 (2), 124-130. https://doi.org/10.1111/emr.12158

Doherty, T.S., Glen, A.S., Nimmo, D.G., Ritchie, E.G., Dickman, C.R., 2016. Invasive predators and global biodiversity loss. Proceedings of the National Academy of Sciences 113 (40), 11261-11265. https://doi.org/10.1073/pnas.1602480113

Fancourt, B.A., Cremasco, P., Wilson, C., Gentle, M.N., 2019. Do introduced apex predators suppress introduced mesopredators? A multiscale spatiotemporal study of dingoes and feral cats in Australia suggests not. Journal of Applied Ecology 56 (12), 2584-2595. https://doi.org/10.1111/1365-2664.13514

Foster, R.J., Harmsen, B.J., 2012. A critique of density estimation from camera-trap data. The Journal of Wildlife Management 76 (2), 224-236. https://doi.org/10.1002/jwmg.275

Glen, A.S., Cockburn, S., Nichols, M., Ekanayake, J., Warburton, B., 2013. Optimising camera traps for monitoring small mammals. PLoS ONE 8 (6), e67940. https://doi.org/10.1371/journal.pone.0067940

Hernandez-Santin, L., Goldizen, A.W., Fisher, D.O., 2016. Introduced predators and habitat structure influence range contraction of an endangered native predator, the northern quoll. Biological Conservation 203, 160-167. https://doi.org/10.1016/j.biocon.2016.09.023

Hilmer, S., Algar, D., Neck, D., Schleucher, E., 2010. Remote sensing of physiological data: Impact of long term captivity on body temperature variation of the feral cat (*Felis catus*) in Australia, recorded via Thermochron iButtons. Journal of Thermal Biology 35 (5), 205-210. https://doi.org/10.1016/j.jtherbio.2010.05.002

Ivan, J.S., Newkirk, E.S., 2016. CPW Photo Warehouse: a custom database to facilitate archiving, identifying, summarizing and managing photo data collected from camera traps. Methods in Ecology and Evolution 7, 499-504. https://doi.org/10.1111/2041-210X.12503

Johansson, Ö., Samelius, G., Wikberg, E., Chapron, G., Mishra, C., Low, M., 2020. Identification errors in camera-trap studies result in systematic population overestimation. Scientific Reports 10, 1-10. https://doi.org/10.1038/s41598-020-63367-z

Krebs, C. J., 1989. Ecological methodology. Harper & Row, New York, USA.

Lohr, C.A., Algar, D., 2020. Managing feral cats through an adaptive framework in an arid landscape. Science of The Total Environment 720, 137631. https://doi.org/10.1016/j.scitotenv.2020.137631

McGregor, H.W., Legge, S., Potts, J., Jones, M.E., Johnson, C.N., 2015. Density and home range of feral cats in north-western Australia. Wildlife Research 42 (3), 223-231. https://doi.org/10.1071/WR14180

Medina, F.M., Bonnaud, E., Vidal, E., Tershy, B.R., Zavaleta, E.S., Donlan, C.J., Keitt, B.S., Le Corre, M., Horwath, S.V., Nogales, M., 2011. A global review of the impacts of invasive cats on island endangered vertebrates. Global Change Biology 17 (11), https://doi.org/10.1111/j.1365-2486.2011.02464.x

Meek, P.D., Ballard, G.A., Fleming, P.J., Schaefer, M., Williams, W., Falzon, G., 2014. Camera traps can be heard and seen by animals. PLoS ONE (10), e110832. https://doi.org/10.1371/journal.pone.0110832

Moore, H.A., Champney, J.L, Dunlop, J.A., Valentine, L.E., Nimmo, D.G., 2020a. Spot on: using camera traps to individually monitor one of the world's largest lizards. Wildlife Research 47 (4), 326-337. http://doi.org/10.1071/WR19159

Moore, H.A., Valentine, L.E., Dunlop, J.A., Nimmo, D.G., 2020b. The effect of camera orientation on the detectability of wildlife: a case study from north-western Australia. Remote Sensing in Ecology and Conservation. https://doi.org/10.1002/rse2.158

Onodera, R., Akimoto, Y., Shimada, T., Saitoh, T., 2017. Different population responses of three sympatric rodent species to acorn masting – the role of tannin tolerance. Population Ecology 59 (1), 29-43. https://doi.org/10.1007/s10144-017-0570-9

Palmer, R., Anderson, H., Richards, B., 2020. Predator control baiting and monitoring program, Yarraloola and Red Hill, Pilbara region, Western Australia. Department of Biodiversity, Conservation and Attractions, Perth. Available at http://scholar.google.com

R Core Team, 2020. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. Available at http://www.r-project.org/

Rees, M., Pascoe, J., Wintle, B., Le Pla, M., Birnbaum, E., Hradsky, B., 2019. Unexpectedly high densities of feral cats in a rugged temperate forest. Biological Conservation 239, 108287. https://doi.org/10.1016/j.biocon.2019.108287

Ridout, M., Linkie, M., 2009. Estimating overlap of daily activity patterns from camera trap data. Journal of Agricultural, Biological, and Environmental Statistics 14 (3), 322-337. https://doi.org/10.1198/jabes.2009.08038

Van Vreeswyk, A., Leighton, K., Payne, A., Hennig, P., 2004. An inventory and condition survey of the Pilbara region, Western Australia. Department of Agriculture and Food, Western Australia, Perth. Technical Bulletin 92.

Woinarski, J.C., Burbidge, A.A., Harrison, P.L., 2014. The action plan for Australian mammals 2012. CSIRO publishing, Collingwood, Australia. Available at http://publish.csiro.au/book/7010

Wysong, M.L., Iacona, G.D., Valentine, L.E., Morris, K., Ritchie, E.G., 2020. On the right track: placement of camera traps on roads improves detection of predators and shows non-target impacts of feral cat baiting. Wildlife Research. https://doi.org/10.1071/WR19175

Appendix A (Individual identification)

Table A1. Number new cats identified each year at the control (Red Hill) and baited site (Yarraloola).

	2016	2017	2018	2019	AVERAGE
CONTROL	25	27	22	14	22
BAITED	17	10	18	9	13.5

Table A2. Percent of recaptured identified individuals each year at the control (Red Hill) and baited site (Yarraloola).

	2016	2017	2018	2019	AVERAGE
CONTROL	24.0%	25.0%	9.3%	10.2%	17.1%
BAITED	11.8%	18.5%	13.6%	12.8%	12.8%

Appendix B (Detectability)

Table B1. The coefficient, standard error, Z-value and 95% CIs for detectability in response to the fixed effects of monitoring session (pre/post) at the **baited site (Yarraloola)**

Fixed effect	Coef	SE	Lower 95% CI	Upper 95% CI
Intercept	-4.6480	0.1210	-4.89	-4.42
Post-Baiting	-0.5547	0.1936	-0.94	-0.18

Table B2. The coefficient, standard error, Z-value and 95% CIs for detectability in response to the fixed effects of monitoring session (pre/post) at the **control site (Red Hill)**

Fixed effect	Coef	SE	Lower 95% CI	Upper 95% CI
Intercept	-4.2703	0.1028	-4.48	-4.08
Post-Control	-0.3676	0.1517	-0.67	-0.07

Table B3. Detectability GLMM model selection table showing the top three models with delta $AIC_c < 2$, with session (pre/post), treatment (control/baited site) and year as fixed effects.

Model	df	AIC_c	Delta AIC	AIC_{wt}
Detectability ~ Session + Treatment	3	1421.56	0.00	0.42
Detectability ~ Session + Treatment + Year	4	1422.53	0.97	0.25
Detectability ~ Session * Treatment + Year	4	1422.99	1.43	0.20

Appendix C (Abundance)

Table C1. MNA pre- and post-monitoring for the control (Red Hill) and baited site (Yarraloola).

	RED HILL (PRE-CONTROL)	RED HILL (POST-CONTROL)	CHANGE IN MNA	YARRALOOLA (PRE-BAIT)	YARRALOOLA (POST-BAIT)	CHANGE IN MNA
2016	15	8	↓ 47 %	10	4	↓ 60%
2017	14	7	↓ 50%	4	4	0%
2018	12	16	↑ 33%	15	5	↓ 67%
2019	14	9	↓ 36%	7	3	↓ 57%

Appendix D (Behaviour)

Table D1. Lure interaction GLMM model selection table showing the top models with delta AIC_c < 2, with session (pre/post), treatment (control/baited site) and year as fixed effects.

Model	df	AIC_c	Delta AIC	AIC_{wt}
Lure interaction ~ Time since deployment	3	153.8	0.00	0.17
Lure interaction ~ Treatment	3	154.1	0.37	0.14
Lure interaction ~ no predictors	2	154.7	1.00	0.10
Lure interaction ~ Sex + Time since deployment	4	154.8	1.04	0.10
Lure interaction ~ Sex	3	154.8	1.09	0.10
Lure interaction ~ Sex + Treatment	4	154.9	1.15	0.10
Lure interaction ~ Sex + Treatment + Time since deployment	5	155.2	1.42	0.08

Table D2. Visit length GLMM model selection table showing the top three models with delta AIC_c < 2, with session (pre/post), treatment (control/baited site) and year as fixed effects.

Model	df	AIC_c	Delta AIC	AIC_{wt}
Visit length ~ Sex + Treatment	4	1254.4	0.00	0.34
Visit length ~ Sex + Treatment + Year	5	1255.8	1.34	0.18
Visit length ~ Sex	3	1256.2	1.77	0.14