Department of **Biodiversity, Conservation and Attractions**

GOVERNMENT OF WESTERN AUSTRALIA

Predator Control Baiting and Monitoring Program, Yarraloola and Red Hill, Pilbara Region, Western Australia. 2017 Annual Report - Year 3.

Version: final

Approved by: Keith Morris

Last Updated: 21 February 2018

Custodian: Russell Palmer

Review date: 15 February 2018

Predator Control Baiting and Monitoring Program, Yarraloola and Red Hill, Pilbara Region, Western Australia

2017 Annual Report – Year 3

Russell Palmer and Hannah Anderson

Biodiversity and Conservation Science

February 2018

GOVERNMENT OF WESTERN AUSTRALIA

Department of **Biodiversity, Conservation and Attractions**

RioTinto

Department of Biodiversity, Conservation and Attractions
Locked Bag 104
Bentley Delivery Centre WA 6983
Phone: (08) 9219 9000
Fax: (08) 9334 0498

www.dbca.wa.gov.au

This report was prepared by Russell Palmer and Hannah Anderson

Questions regarding the use of this material should be directed to:
Russell Palmer
Research Scientist
Biodiversity and Conservation Science
Department of Biodiversity, Conservation and Attractions
Locked Bag 104
Bentley Delivery Centre WA 6983
Phone: 08 9405 5105
Email: russell.palmer@dbca.wa.gov.au

The recommended reference for this publication is:
Palmer R, Anderson, H (2018). Predator control baiting and monitoring program, Yarraloola and Red Hill, Pilbara region, Western Australia. 2017 Annual report - Year 3. Department of Biodiversity, Conservation and Attractions, Perth.

Cover photograph: Brooke Richards (volunteer) releasing a northern quoll at a quoll trapping site on Yarraloola during the September monitoring trip (Photo by Neal Birch DBCA).

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Acknowledgments

This study was undertaken as part of Rio Tinto's Threatened Species Offset Plan (TSOP) to benefit the northern quoll and Pilbara olive python and was funded by Rio Tinto. The TSOP scope of work for 2017 was developed in liaison with Russell Thomas and Brian Dalton (Rio Tinto). Russell Thomas, Brian Dalton, Chris Morris, Martin Salm and Philip Curry (Rio Tinto) facilitated the field work and other project logistics for Pannawonica, Mesa A and the Yarraloola Land Management Area (LMA).

The Department of Biodiversity, Conservation and Attractions (DBCA) Regional Office in Karratha monitored our safety when in the field and provided logistical support. The Rio Tinto Robe Valley emergency response teams were on standby in the event search and rescue services for our field teams were required on site.

We thank Digby and Leanne Corker for permission to access Red Hill pastoral lease. Australian Premium Iron (API) provided in-kind support for our operations at Red Hill. Phil Davidson, Kimberley Flowerdew, Ryan Francis, Stephen Woodtli, Damion Kuret and Darren Varcoe facilitated visits to the Red Hill site. The Kuruma and Marthudunera (KM) Traditional Owners provided access to their traditional lands on Yarraloola and Red Hill pastoral leases.

Gareth Watkins and Rob Brazell of the Parks and Wildlife Service Western Shield team coordinated the aerial baiting program. Alicia Whittington (DBCA, Pilbara region) managed the aerial baiting notifications and landholder liaisons, signage installation [with the KM Rangers] and ground baiting along the Pannawonica road corridor. We are grateful for the field assistance provided by KM traditional owners Brendon and Arnold Bobby, and volunteers Callum Smithyman, Tom Dimaline (Leicester University, UK, intern), Jodie Millar, Sasha Ayton and Brooke Richards. Thank you to casual staff members Neal Birch for assistance in the field, and to Rob Susac for processing the camera image data. PhD student from Charles Darwin University, William Ross assisted greatly during the trapping session in September, which was greatly appreciated. Sarah Comer (DBCA) and Peter Speldewinde (The University of Western Australia) performed the cat occupancy modelling.

Drafts of this report were reviewed by Keith Morris, and Brian Dalton and Martin Salm from Rio Tinto.

The following permits were obtained to conduct this work:

- The predator control baiting and monitoring program study was approved by the Department of Parks and Wildlife Animal Ethics Committee permit AEC 2016/15.
- The Australian Pesticides and Veterinary Medicines Authority issued PER14758Ver2 allowing the use of the *Eradicat*® feral cat bait on the Yarraloola LMA 2016-2019.

Summary

Given the level of threat that feral cats pose to native fauna on the Australian mainland, the development of broad-scale approaches that will deliver effective cat control at landscape levels are both a policy and management priority of government. Broad-scale aerial baiting using the toxic *Eradicat*® cat bait is effective at controlling feral cats at the landscape scale. However, this bait is currently not registered for operational use in the Pilbara or northern Australia where the effects on potential non-target species, such as the carnivorous northern quoll (*Dasyurus hallucatus*), have not been quantified.

As part of the conditions of an environmental offset, Rio Tinto developed a Threatened Species Offset Plan (TSOP) to implement management actions to benefit the endangered northern quoll in the western Pilbara. Controlling feral cats at a landscape scale within the Yarraloola Land Management Area (LMA) to reduce their predation impacts on northern quolls and other native fauna was a core component of the TSOP. This program commenced in 2015 with an experimental *Eradicat*® baiting trial, which demonstrated that northern quolls were not at risk of poisoning from toxic cat baits (Morris *et al*. 2015). The program then moved into an operational phase, the implementation of an annual aerial baiting of cats with *Eradicat*® over ~145 000 ha of the Yarraloola LMA from 2016 to 2019. This report discusses the second year of the broad-scale baiting program undertaken in 2017.

Aerial baiting took place on the 16-17 July, with 73 000 *Eradicat*® baits distributed over 144 638 ha of the Yarraloola LMA. The impact on feral cat numbers was assessed by occupancy modelling and analysis of detection rates using data from camera traps set prior to, and following baiting from 60 sites across each of Yarraloola (baited site) and Red Hill (unbaited reference site). Baiting in 2017 maintained the low densities of cats resulting from the 2016 baiting. Cat detections were 0.4 cats per 100 camera trap nights (CTN). This equates to one cat detected in 250 CTNs and is amongst the lowest reported for studies using similar techniques elsewhere in the country. Monitoring prior to baiting also highlighted that there was little recovery of the cat population following the previous 2016 winter baiting program.

We found no evidence that feral cat control using *Eradicat*® negatively impacts upon co-occurring northern quoll populations. Quoll populations did respond strongly across both Yarraloola and Red Hill to the improved season conditions following high summer rainfall. Capture rates of quolls during the annual September trapping session were higher for both sexes on Yarraloola compared with Red Hill. Other population metrics, such as quoll detection rates on the cat camera traps and annual survival rates of tagged female quolls were also higher on Yarraloola. Furthermore, evidence of indirect benefits for quolls from cat control was detected on Yarraloola in 2017, with quolls shifting from protein–poor food sources [fruits] to eating more rodents. Previously, quolls would have had to compete more directly with cats to access rodents.

While these findings are encouraging it should be noted that this project is still at an early stage in terms of demonstrating the potential benefits of effective cat control on northern quoll populations. We also note that in spite of reduced cat densities on Yarraloola, evidence of a cat or cats seemingly targeting quolls along neighbouring gorge sites (Quoll trap sites N and M) was found in September following the baiting. Five of eight cat scats collected at these two trap sites contained quoll remains and the capture rate of quolls at site M declined sharply from the previous year.

1 Background

The Yandicoogina Junction South West (JSW) and Oxbow Iron Ore Expansion Project was approved by the Western Australian Government and the Commonwealth Government (via MS 914 and *Environment Protection and Biodiversity Conservation Act* 1999 (EPBC Act) Decision Notice 2011/5815, respectively) subject to a number of conditions, including the Commonwealth requirement for Rio Tinto to develop and implement a Threatened Species Offset Plan (TSOP) to benefit the EPBC Act listed northern quoll (*Dasyurus hallucatus*) and Pilbara olive python (*Liasis olivaceus barroni;* Rio Tinto 2014).The defined offset area was the Yarraloola Land Management Area (LMA), which is located approximately 15 km to the southwest of Pannawonica in the western region of the Pilbara (Figure 1). The LMA encompasses the Yarraloola pastoral lease to the west of north west coastal highway and covers approximately 150 000 ha.

The introduced predator control program was the core component of the TSOP (Morris and Thomas 2014). This program focusses on the control of feral cats given their significant threat to Australian fauna. In Western Australia, baiting with the *Eradicat*® bait containing 4.5 mg of the toxin sodium fluoroacetate (1080) is the most effective and efficient method for controlling feral cats at the landscape scale where there is limited risk posed to non-target species (Algar *et al.* 2007; Algar and Burrows 2004; Short *et al.* 1997). However, this bait is not registered for operational use in areas of Western Australia where potential non-target species occur, such as the carnivorous northern quoll, due to the potential risk of toxic bait consumption.

The impact of using *Eradicat*® feral cat baits in the presence of northern quolls in the Pilbara was assessed during an experimental baiting operation over 20 000 ha within the LMA in 2015. This study found that aerial baiting with *Eradicat*® had no observable non-target impact on radio-collared northern quolls (Morris *et al.* 2015). These results were consistent with similar studies [using wild dog baits] on quolls in the Pilbara (King 1989) and several on the spotted-tailed quoll (*Dasyurus maculatus*) in New South Wales (Claridge and Mills 2007; Körtner and Watson 2005).

Given these findings, the project moved into the planned operational phase of broad-scale cat baiting and the measuring of its success in reducing cat numbers. Sixty camera trap monitoring sites for feral cat were established across each of Yarraloola (baited site) and Red Hill (unbaited reference site) to monitor the efficacy of the cat baiting program. *Eradicat*® baits were aerially distributed over 144 100 ha of the Yarraloola LMA in winter 2016. This baiting reduced feral cat populations to low levels on Yarraloola. No mortality of northern quolls was detected due to the baiting and there was no evidence that sub-lethal exposure to 1080 impacted on the reproductive success of quolls within the Yarraloola LMA. Camera trap monitoring of hand laid toxic *Eradicat*® baits showed that while quolls sample some of the baits, their encounters with these baits appeared to be non-lethal. The result of this sub-lethal exposure appears to be the rapid development of bait-shyness by quolls to both toxic and non-toxic *Eradicat*® baits. Quolls apparently learnt from what was probably an unpleasant experience and they then avoid eating any further baits.

2 Introduction

Feral cats (*Felis catus*) rank as one of the most damaging invasive species on the planet. In the wake of their introduction to the Australian mainland and many of its islands after European settlement they have contributed to the demise of many native mammal species and to a lesser degree, other native fauna (Commonwealth of Australia 2015a; 2015b; Woinarski *et al.* 2014; 2015). The Australian Mammal Action Plan 2012 warns that a large proportion of the remaining extant threatened and near threatened mammal taxa are at risk from predation by feral cats and it urges immediate and targeted actions to avoid further extinctions (Woinarski *et al.* 2014; 2015). Consequently, the control of feral cats in Australia has become a policy and management priority of the Threatened Species Strategy for Australia (Commonwealth of Australia 2015b).

Predation by feral cats was listed as a 'Key Threatening Process' under the Commonwealth's EPBC Act (1999) in 2000. The Department of the Environment released the second version of the Threat Abatement Plan (TAP) for Predation by Feral Cats in 2015. This TAP established a national framework to guide and coordinate Australia's response to the impacts of feral cats on biodiversity. It identified the research, management and other actions required to ensure the improved survival of native species and ecological communities affected by predation by feral cats. A key action of the TAP is to "ensure broad-scale toxic baits targeting feral cats are developed, registered and available for use across all of Australia, including northern Australia" (p 11, Commonwealth of Australia 2015a).

The northern quoll is the largest predatory dasyurid remaining in northern Australia (Cramer *et al.* 2016). Its distribution formerly extended across the northern third of Australia but it now only occurs in smaller disjunct populations across this range in Queensland, Kimberley and Northern Territory, and areas throughout the Pilbara of Western Australia (Braithwaite and Griffiths 1994; Cramer *et al.* 2016). In 2005, the northern quoll was listed as an endangered species under the Commonwealth's EPBC Act. Predation by feral cats contributed to their decline and continues to pose a severe threat to mainland quoll populations (Braithwaite and Griffiths 1994; Hill and Ward 2010; Woinarski *et al.* 2014; Woinarski *et al.* 2008). In the Pilbara, less is known about the northern quoll populations compared to other regions. Key threats such as introduced predators, habitat loss and fragmentation, and the likely future invasion of the cane toad have been identified as serious risks to the Pilbara region populations (Cramer *et al.* 2016). A key research priority is to better understand the key threats, including predation by cats, and the interaction of these threats to help conserve and protect northern quolls in the Pilbara.

The aims of this program for 2017 were to:

1) conduct the second annual broad-scale aerial and ground baiting program using *Eradicat®* baits targeting feral cats in the Yarraloola LMA;
2) assess effectiveness of this baiting program to reduce feral cat populations within the baited cell;
3) assess the potential non-target impacts and/or benefits of broad-scale feral cat baiting on northern quoll populations by comparing their abundance, survivorship and demographics over time within a treatment (baited) and reference site (Red Hill); and
4) monitor the potential indirect benefits of reduced feral cat numbers for northern quolls by investigating changes to the ecological niche of northern quolls (dietary and habitat shifts) in the treatment site (cat baited) compared with the reference site.

Plate 1. Feral cat camera trap monitoring site.

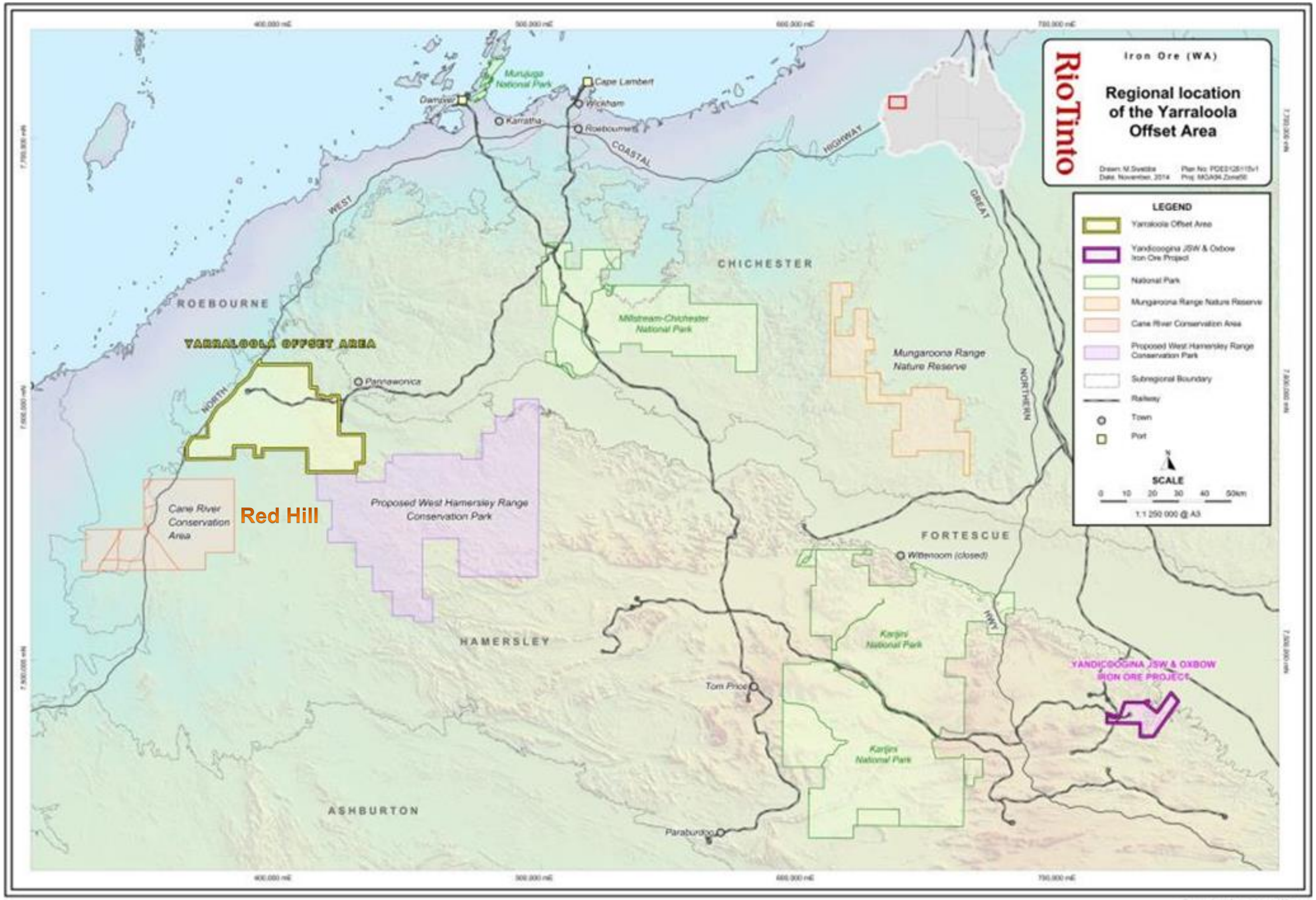


Figure 1. Regional location of the Yarraloola Land Management Area in the western Pilbara region of Western Australia.

3 Methods

3.1 Study sites

The study was undertaken on two pastoral leases, Yarraloola LMA (~150 000 ha) and Red Hill (~190 000 ha), in the western Pilbara region of Western Australia. The Yarraloola LMA is approximately 120 km southwest of Karratha (centroid: 21^{o} 44' 50"S, 116^{o} 08' 31"E; Figure 1). The small mining town of Pannawonica is located 15 km northeast of the LMA. Red Hill abuts the southern boundary of Yarraloola forming the unbaited reference area for the study. No aerial baiting of wild dogs was undertaken in 2017 on the two pastoral leases.

These sites experience a semi-arid climate typical of the Pilbara bioregion. Summers are very hot and winters mild. Rainfall is characteristically extremely variable and follows a loose bi-modal rainfall pattern with the majority of rain falling during January, February and March in association with tropical cyclone and heat trough events. Tropical cyclones typically deliver large falls of rain over extensive areas whereas thunderstorm events associated with heat troughs are more localised. A second, smaller rainfall peak occurs in May and June as a result of southern frontal systems which are at their northern extent of influence over the area. The historic yearly average rainfall for Pannawonica, over 43 years, is 404 mm but yearly rainfall is highly variable (Australian Bureau of Meteorology 2017).

The rainfall received during the study period reflects this variability (Figure 2).

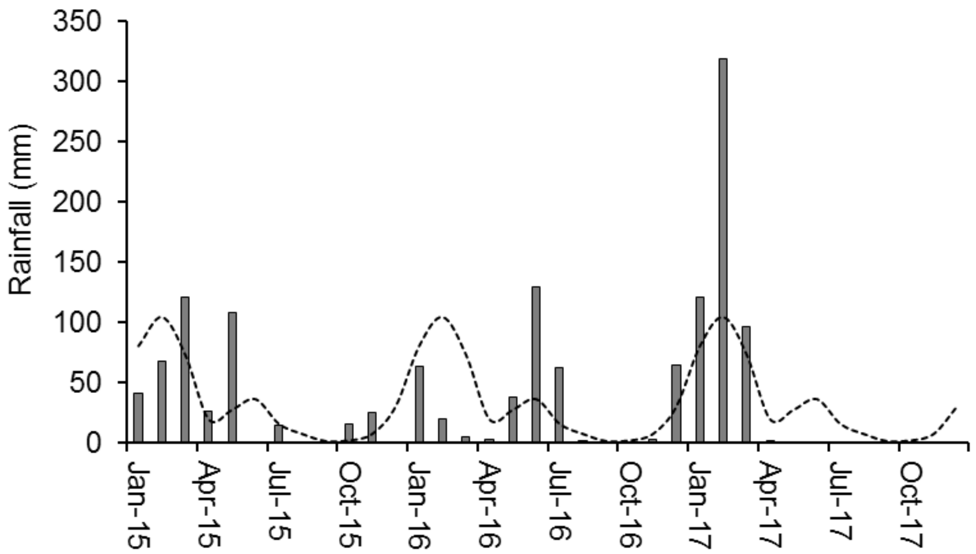


Figure 2. Monthly rainfall (bars) relative to the monthly long-term average (dotted line) during 2015–2017 for Pannawonica (mean annual rainfall = 404 mm).

3.2 Study design and timing

This project was designed around the optimal time for baiting of feral cats, which is when cats are mostly likely to encounter and consume bait. For the Pilbara, this occurs during the coolest period in winter (July) when bait uptake by feral cats is maximised due to the low abundance and activity of prey, in particular reptiles (Algar and Burrows 2004). Bait degradation due to rainfall, ants, and hot weather is also reduced at this time of the year.

3.3 Feral cat monitoring

3.3.1 Background

Monitoring the abundance of highly secretive and cryptic animals such as feral cats is notoriously difficult. In the Pilbara, they are largely nocturnal, have large home ranges and occur at relatively low densities across the landscape (Clausen *et al.* 2016; Hernandez-Santin *et al.* 2016). The availability of affordable and high quality camera traps, however, has allowed for the development of new monitoring techniques for this species that appear to be robust (Comer *et al.* in press).

To determine the impact of the baiting program under the TSOP, Morris and Thomas (2014) recommended the use of the feral cat monitoring methodology developed and widely used by DBCA in Western Australian to measure site occupancy by feral cats before and after baiting (Clausen *et al.* 2016; Comer *et al.* in press).

3.3.2 Camera trap design and occupancy modelling

Camera trap monitoring arrays for feral cats were established and used on both study sites (Yarraloola - baited and Red Hill - unbaited reference) in 2016. Full details can be found in Palmer *et al.* (2017). Briefly, 60 cat camera trap sites were established at each of the study sites in a semi-randomised fashion from the existing road networks. Cameras were situated within walking distance of a road (50 m to 400 m either side) and at least 3 km from the closest neighbouring camera (Figure 3 and 4). The 3 km distance was used to increase camera independence by reducing the chance of individual feral cats appearing on multiple cameras during the same sampling period. For the baited site at Yarraloola, cameras were located at least 2 km inside the bait cell boundary (Figure 7) and there was a buffer of ~14 km between the bait cell and the nearest cat camera on Red Hill.

The layout of cat camera sites is shown in Plate 1, with full details in Palmer *et al.* (2017). Briefly, each camera (Reconyx HyperFire™ PC900) was programmed on ‘Aggressive’ to take five pictures at up to two frames per second upon a trigger. There was no quiet period between triggers. The ‘lure pole’ with visual and olfactory lures for feral cats was set 3 m in front of each camera. The olfactory lure consisted of a 60 ml plastic vial containing 15 ml of ‘Catastrophic’ scent lure in an oil suspension (Outfoxed Pest Control, Victoria), attached to a stake approximately 30 cm from the ground. Also attached to this stake, was a 1.5 m long metal curtain rod with three white turkey feathers taped obliquely at its midpoint and a 30 cm length of silver tinsel secured to the top of the rod. Vegetation was trimmed from the detection zone of the camera to minimize false triggers caused by moving plants.

The cat cameras were set in late May for a minimum of 25 nights leading up to the aerial baiting (16–17 July) and then reset after 2 weeks following the bait drop (31 July–6 August). The cameras were collected during the quoll trapping trip in September. During the period between the two monitoring sessions, cameras and lures were removed to prevent cats from becoming accustomed to them.

All images were downloaded from the camera trap SD cards and uploaded into the photo database program 'CPW Photo Warehouse' (Ivan and Newkirk 2016). Date- and time-stamp information from each image was captured by this program ensuring an accurate time of day for each image. Images of fauna were identified to species level where possible. Accurate identification of some of the smaller fauna groups that are morphologically similar using camera trap imagery is difficult. Some of these groups were pooled as 'small rodents', '*Ctenotus* skink', etc. Experts were consulted to confirm identifications where required.

Interference by inquisitive cattle at our cat camera sites did result in some cameras being knocked over or offline (not pointing at the lure pole) and/or the lure pole being knocked over. The time and date when individual cameras were rendered inoperable was noted (i.e. reduced sampling effort).

CPW Photo Warehouse was used to generate the capture event results for cats and quolls for the occupancy modelling and detection rate analysis. Capture events were quantified on the basis of camera trap nights, which were measured from midday to midday of the next day. A camera trap site was considered 'occupied' if one (or more) detections of the target species were recorded at that site.

Detection rate (number of independent detections or 'events' of an animal on a camera trap divided by the amount of time the camera was operated) was used as a second metric to measure the relative abundance of cats and quolls. For analyses of detection rates, successive images of a species less than 60 minutes apart were classed as one event. Multiple detections or events of quolls on any given night at camera sites in their preferred habitats were common. In contrast, it was extremely rare for cats to be detected more than once on a camera in a single night (Hernandez-Santin *et al.* 2016). Camera trapping effort was standardised due to cattle inference at some sites, with the mean detection rate representing the mean number of events per 100 camera trap nights (100 CTN) per site.

Bayesian occupancy models were run in WinBUGs 1.4, using detection histories from the treatment (baited - Yarraloola and unbaited reference -Red Hill). A random effects model, which assumes detection probability is not constant, was used to determine site occupancy at both the treatment and reference. A spatial component was also modelled for the treatment site, which models the potential impact of an individual cat appearing on more than one camera. All models were run with a burn in of 5,000 iterations before sampling for a further 5,000 iterations (Comer *et al.* in press).

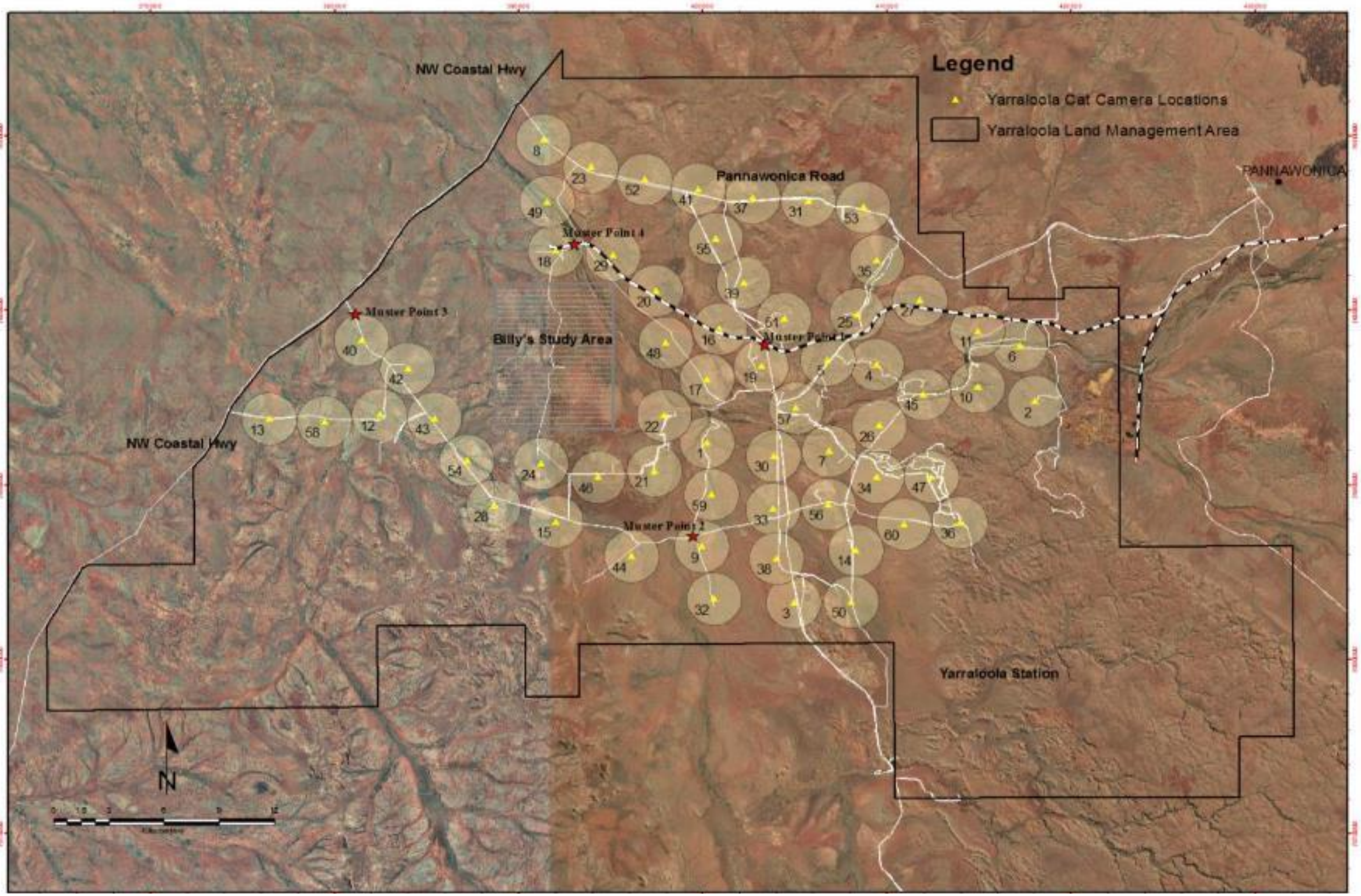


Figure 3 Cat camera locations and buffers on the Yarraloola LMA baited site.

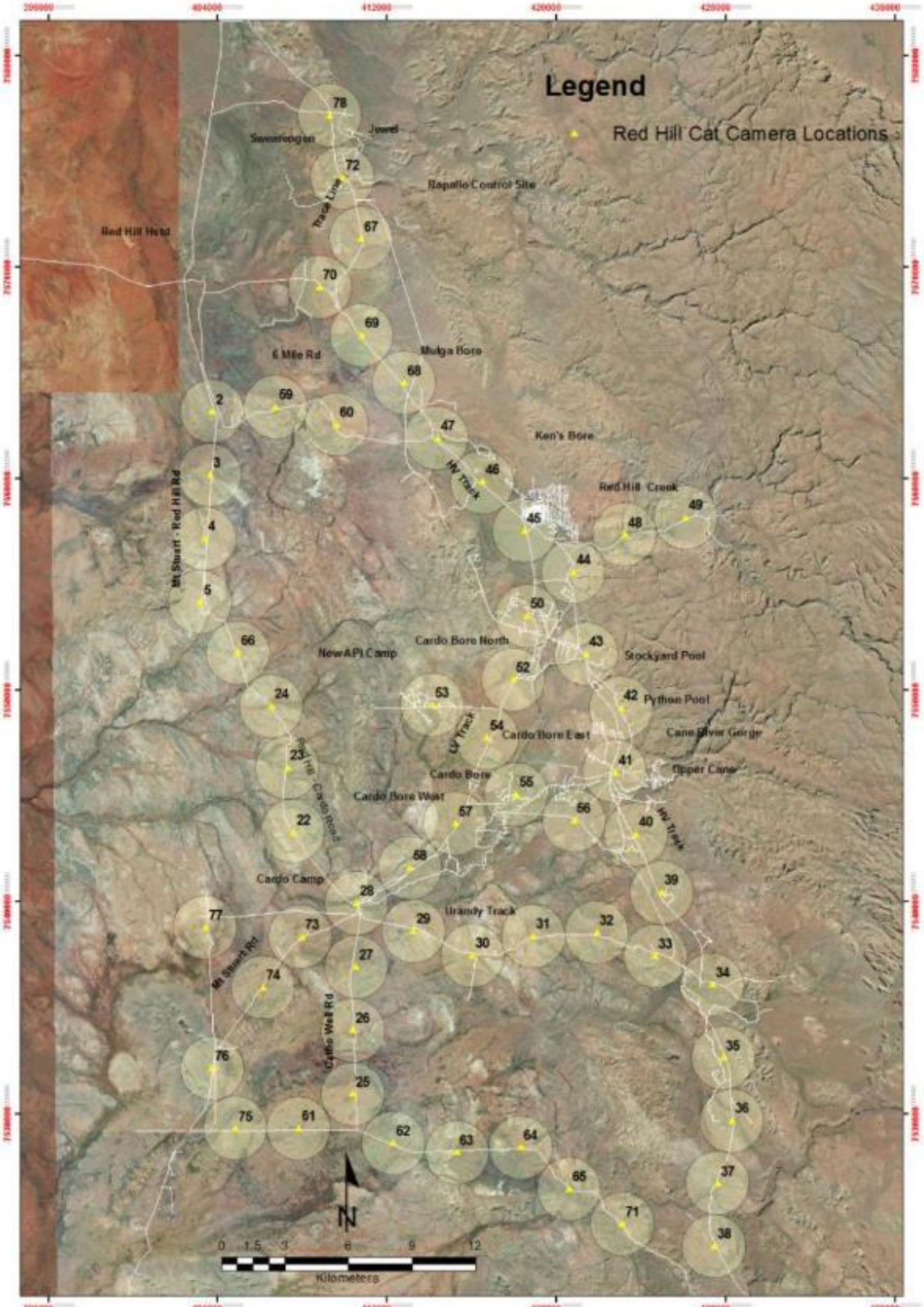


Figure 4 Cat camera locations and buffers on the Red Hill reference site.

3.4 Baits and baiting

3.4.1 *Eradicat®* baits

The feral cat baiting program on the Yarraloola LMA was conducted under a research permit (Permit No. PER14758 Version 2) issued by the Australian Pesticides and Veterinary Medicines Authority (APVMA) and governed by the 'Code of Practice on the Use and Management of 1080' (Health Department, Western Australia) and associated '1080 Baiting Risk Assessment'.

The *Eradicat®* feral cat baits were manufactured at the Department's bait facility located in Harvey, WA. This bait is similar to a chipolata sausage in appearance, approximately 20 g wet-weight, dried to 15 g, blanched and then frozen. It is composed of 70% kangaroo meat mince, 20% chicken fat and 10% digest and flavour enhancers (Patent No. AU781829). The toxicant sodium fluoroacetate (compound 1080) was added at a rate of 4.5 mg per bait.

3.4.2 On ground coordination and notifications

Landholders surrounding the Yarraloola LMA were informed by letter of the pending baiting operation. Cat baiting posters were placed around Pannawonica. Additional 1080 baiting signage was installed on tracks leading off Pannawonica Road into the Yarraloola LMA with the help of KM Rangers on the 23rd May. Alicia Whittington (DBCA) checked bait signage and visited the popular camping site at Yerra Bluff on the Robe River [baiting exclusion zone] to warn campers of the pending aerial baiting program on the 15th July. Two of the notified campers had their pet dogs with them and decided they would move on before the aerial baiting commenced.

3.4.3 Aerial and ground baiting

The baiting operation was coordinated from the Mt Minnie Station airstrip located 50 km to the southwest of Yarraloola. The Western Shield ground crew unloaded the frozen *Eradicat®* baits from the truck and thawed them in direct sunlight on the purpose–built drying racks. This 'sweating' process causes the oils and lipid-soluble digest material to exude from the surface of the bait. The baits were sprayed, during the sweating process, with the ant deterrent compound Coopex®. Excluding ants from deployed baits enhances their acceptance by cats.

Aerial baiting of the Yarraloola LMA took place on 16–17 July 2017. This was conducted under the DBCA Western Shield aerial baiting contract by Shine Aviation Services, Western Australia. A Beechcraft Baron B58 twin-engine aircraft fitted with computerised GPS-linked equipment was used to deploy the baits to ensure accurate application along previously designated flight lines covering the entire baiting cell. The baiting aircraft flew at 150 knots and 500 feet above ground level. A series of panel lights indicated to the bombardier when to release the baits, with a GPS-linked mechanism used to prevent the application of bait outside the programmed bait cell on the Yarraloola LMA. The location of the aircraft was logged each time baits were released. Fifty baits per km^2were distributed through a carousel to give an approximate 200 m long by 40 m wide bait swathe.

3.4.4 Ground baiting

The 500 m wide aerial baiting exclusion zone along the Pannawonica road was hand baited on either side of the road from an all-terrain vehicle by DBCA staff from Karratha (Daniel Wingett and Alicia Whittington). Baits were laid at a rate of one bait per every 100 m. All baits were placed more than 50 m from the road edge.

3.4.5 Monitoring for non-target species deaths

The monitoring and reporting conditions of the APVMA permit required that all observed non-target mortalities be recorded and that a reasoned deduction to the likely cause of death be provided. Project staff members were present on site two weeks after the baiting [31 July – 6 August] and then for an extended period between 5–19 September (See Appendix 1 for fieldwork activities undertaken). During these trips field teams travelled in vehicles on the extensive track networks throughout the baited area of the Yarraloola LMA and to a lesser degree, by foot. This coverage included multiple visits to all cat camera sites and at least five visits to each of the quoll trapping sites (Figures 3–6).

3.5 Northern quoll monitoring

An annual trapping program is used to monitor northern quoll populations on Yarraloola and Red Hill. Details pertaining to the trapping design can be found in Morris *et al.*(2016) and Palmer *et al.*(2017). The locations for the quoll trapping sites are presented in Figure 5 and 6. Trapping occurs in September to allow for the collection of key demographic information from females, namely counts of pouch young. For monitoring of males however, this timing is less than ideal as many die-off after the mating season in late July–August. As such, capture data for female and male quolls will be presented separately.

3.5.1 Trapping methods

At each trapping site, 20 small Sheffield cage traps (Sheffield Wire Products, Welshpool, WA) baited with peanut butter, oats and sardines, were set in a linear transect (500 m) to trap quolls. Trap lines usually followed a landscape feature, such as a mesa edge or side, timbered riverine system or a drainage line in a gorge. Traps were placed in sheltered, shady locations and covered with a hessian bag and other vegetation, providing protection from heat and potential harassment from other animals. Rocks were placed on and around traps to stabilize each trap and provide additional cover.

All trapped quolls were transferred into a capture bag and then scanned for the presence of a passive integrated transponder (PIT) implant. Each animal was then weighed, measured and sexed, and two small tissue samples were taken from an ear for DNA analysis. For females, reproductive condition was assessed and pouch young were counted and measured, if present. Each new quoll was implanted with a unique PIT (Allflex® 12 mm FD-X transponder; Allflex Australia) to enable individuals to be identified. Upon first capture in 2017, individual quolls were also given a unique alphanumeric ear tag (National Brand and Tag Company, USA). Females were tagged on the right ear and males on the left with the view that ear tags would aid their identification on camera traps via spot pattern recognition.

Other species captured were recorded. Tissue samples were taken from *Pseudantechinus* sp. as there is uncertainty over the identity of this species. After processing, animals were released immediately at the site of capture. All trapping data was entered into the Yarraloola Project MS Access database.

3.5.2 Statistical analysis of quoll data

A two-way analysis of variance (ANOVA) was performed on quoll litter sizes and body weights of male and female quolls between treatments and years. A 'Shapiro-Wilks' normality test and a 'Bartlett's test' for homogeneity of variance were used to ensure the data satisfied the test assumptions. Analyses were performed in the R software (ver. 3.4.2 https://www.R-project.org/).

3.6 Predator diets and incidental/opportunistic records

3.6.1 Predator scats

The collection and analysis of predator scats offers a relatively cheap and non-invasive method to gain a broad range of information to better understand predator-prey relationships, the likelihood of interactions between predators themselves, and to build a clearer picture of ecosystem dynamics. Palmer *et al.* (2017) summarised the existing information from the 180 quoll, 13 feral cat and 50 dingo scats collected in previous years.

Northern quoll scats were collected from cage traps (usually only from the first capture night to avoid contamination from bait consumption). Quolls also mark (defecate) the area around tuna tins used as lures for camera trap monitoring. Up to a maximum of six quoll scat samples were collected from quoll camera trap sites. Dingo and cat scats were collected during targeted searches of road sides. This year dingo scats were also collected on Red Hill, particularly near stock watering points. Predator scats encountered opportunistically were collected as well.

Scats were analysed by Georgeanna Story of Scats About (www.scatsabout.com.au). Diet was described by the frequency of occurrence (the proportion of scats in a given sample that contained a particular prey group) and/or percentage volume of each prey group, which was estimated visually and expressed as a mean percentage volume for a given sample of scats. In general, the percentage volume method provides a measure of the relative importance of a prey type/group in the diet and the frequency of occurrence method shows how often it is eaten.

3.7 Other records

Field teams investigated opportunities to locate the threatened Pilbara olive python where possible. Opportunistic bird records were kept on each field trip by Hannah Anderson.

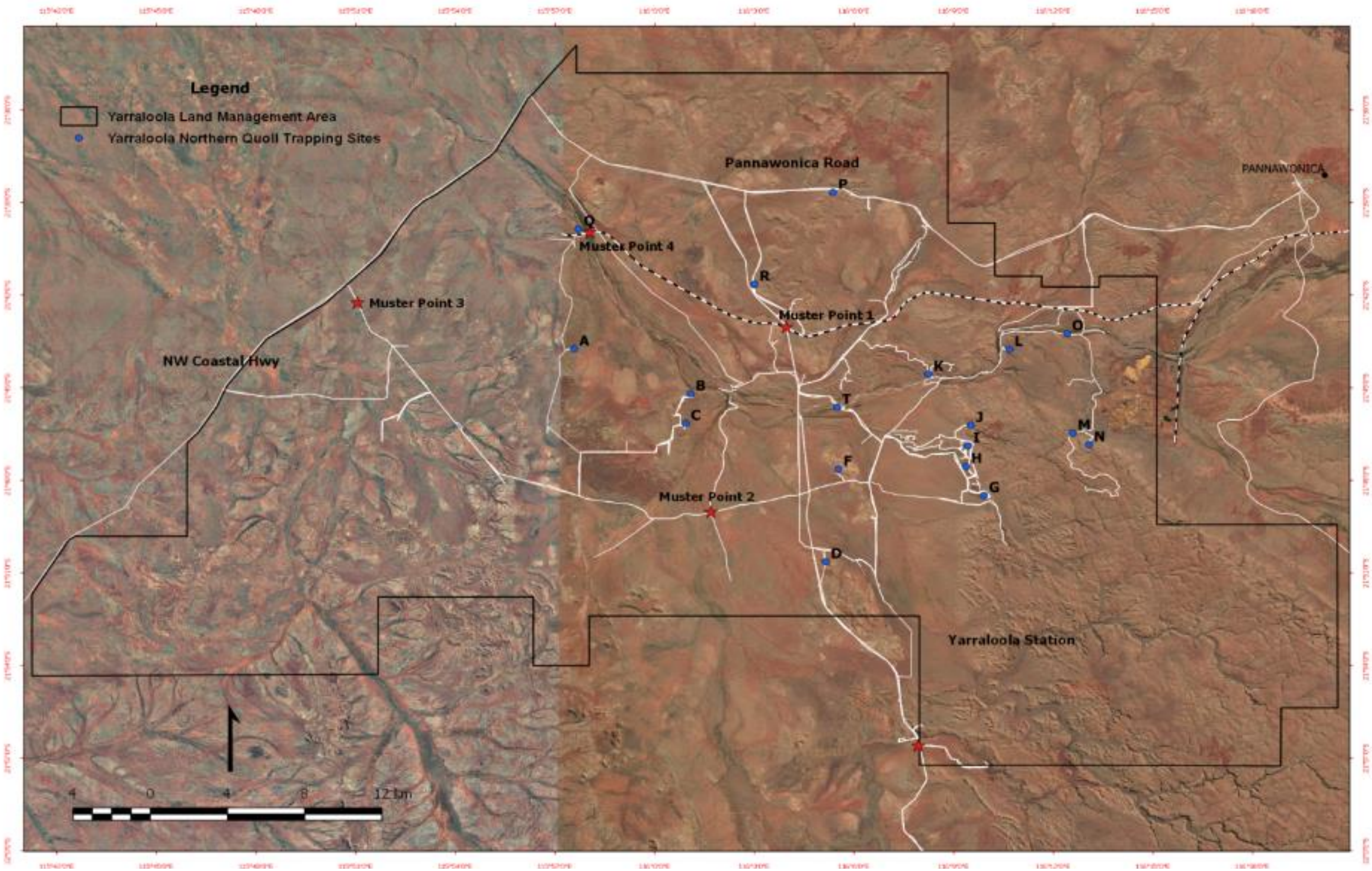


Figure 5. Locations of northern quoll trapping sites on the Yarraloola LMA. Only 11 sites (A, B, C, F, D, J, I, H, G, L and K) were monitored in 2015.

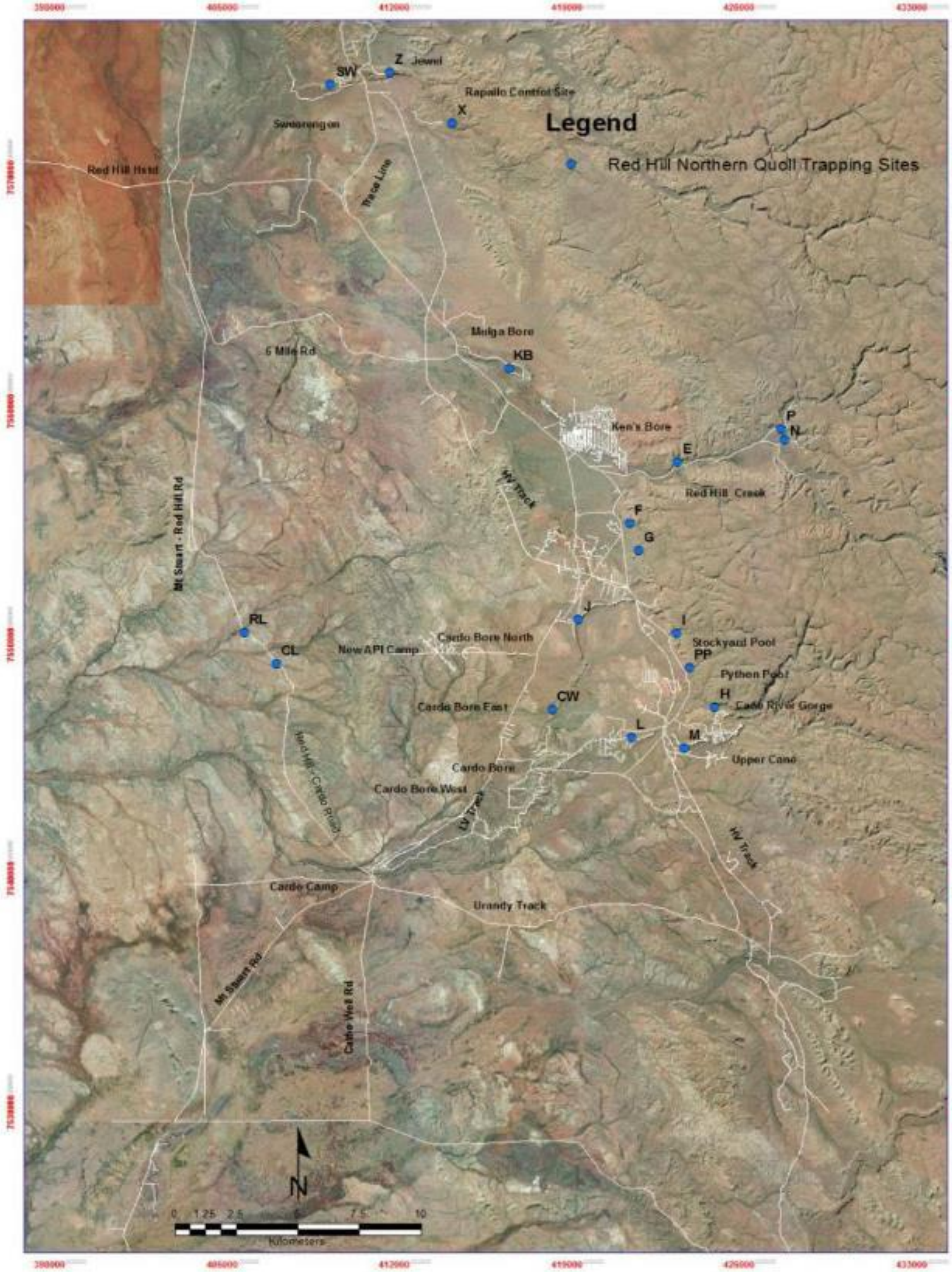


Figure 6 Locations of northern quoll trapping sites on Red Hill. Only 10 sites (M, L, H, I, G, F, E, P, N and J) were monitored in 2015.

4 Results

4.1 Rainfall and seasonal conditions

Tropical lows over summer delivered a substantial wet season with over 300 mm received at Pannawonica in February 2017 (Figure 2). Little to no rain fell over the Yarraloola LMA following March 2017 so there was no interference to the winter baiting program due to wet weather. The above average wet season rains and the previous high early winter rainfall in 2016 meant that seasonal conditions were good across both sites during 2017.

4.2 Feral cat baiting

Delayed notification of the landholders regarding the aerial baiting dates resulted in a date clash between planned aerial mustering and baiting. As such the baiting program was shifted from early July to mid-July (16–17th). Once the aerial baiting conditions under the code of practice were imposed on the Yarraloola LMA, the final area of the bait cell was 144 638 ha [118 138 ha Yarraloola pastoral lease and 25 500 ha unallocated Crown land] (Figure 7). Key exclusion areas were the mine sites at Mesa A and J, public roads and waterholes along the Robe River.

The Parks and Wildlife ground crew at Mt Minnie reported that 73 000 *Eradicat®* cat baits were dropped by the aircraft over the two days. The GPS logging indicated good coverage was achieved and the average application rate over the entire bait cell was as per the baiting protocol at 50.1 baits km^{-2} (Figure 7).

Ground baiting of the Pannawonica road corridor took place on the 19th July.

4.2.1 Detection of non-target species deaths

No carcasses of feral cats or non-target species were observed following the baiting on the two field trips undertaken by project staff members in late July–early August or September.

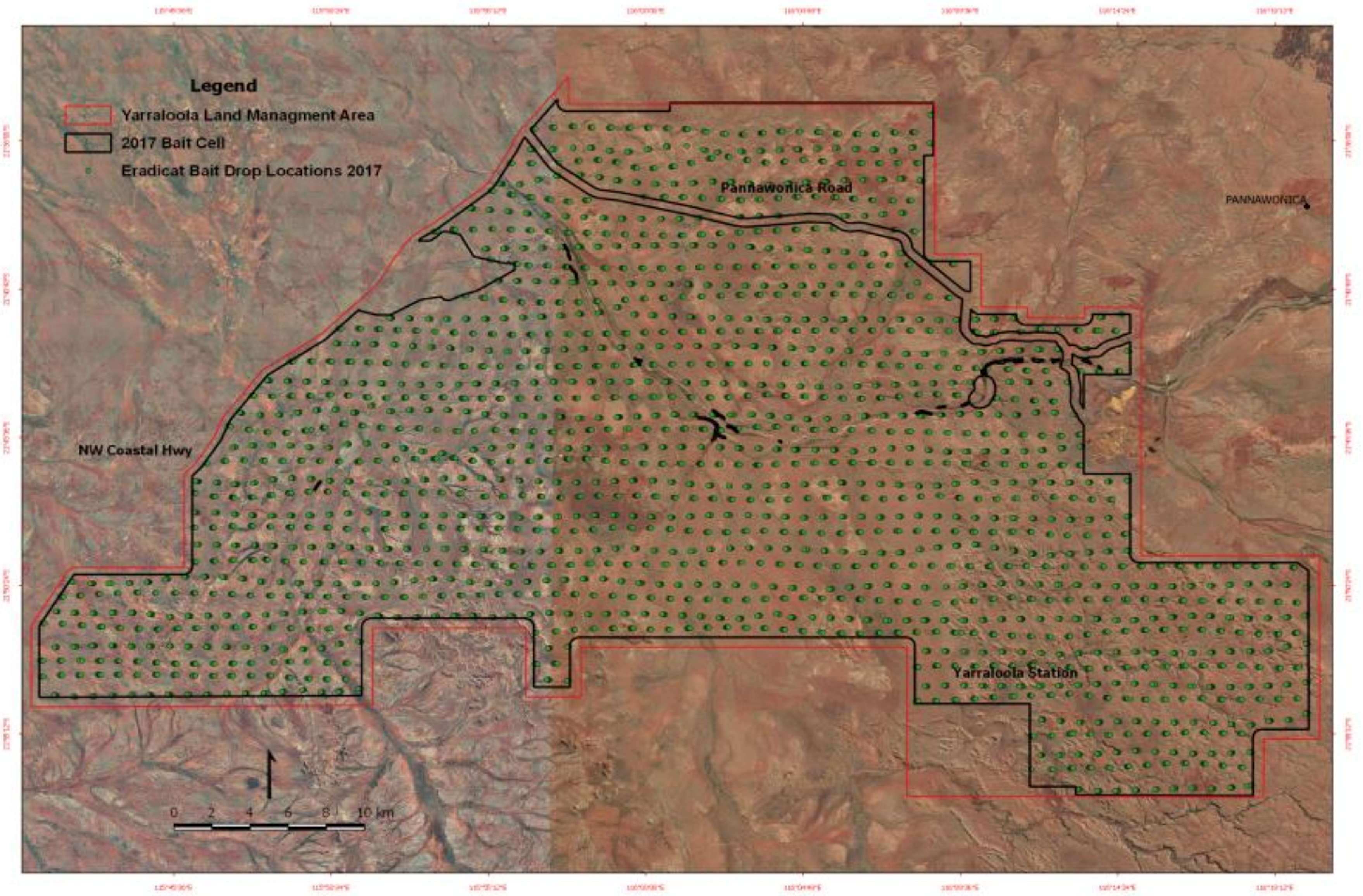


Figure 7. The Yarraloola LMA bait cell (black bold line) for 2017 and the distribution of baits on the 16 and 17 July. The bait exclusion areas within the LMA are bounded by a bold black line. The outer red line is the Yarraloola LMA boundary.

4.3 Feral cat and quoll monitoring on cat camera traps

To determine the impact of the baiting program on the feral cat population we used the first 25 camera trap nights from the pre- and post-bait monitoring sessions in both the treatment and reference sites to calculate detection rates and occupancy before and after baiting. The possible camera trapping effort was 1500 camera trap nights per session and location, which was achieved for the pre-bait session on Yarraloola. Cattle interference reduced sampling effort slightly during the other sessions; Red Hill pre-bait (5 cameras affected – corrected total of 1431 CTN) and post-bait (6 cameras – 1412 CTN) and Yarraloola post-bait (4 cameras – 1469 CTN).

The camera sites where cats and/or quolls were recorded for both camera trapping sessions on Yarraloola and Red Hill are shown in Figures 8 and 9.

On Yarraloola, cats were detected on 9 nights at 5 different camera traps before the baiting and then on 6 nights at 4 cameras after baiting. For Red Hill, cats were detected on 16 nights at 10 cameras before baiting and then on 11 nights at 9 cameras after baiting. Detections of cats across multiple nights at a camera site during a session were uncommon. There were several instances of cats being detected on three or more different nights, but only during the pre-baiting sessions (cats on 5 different nights at C38 Yarraloola, 4 nights C58 Red Hill, 3 nights C75 Red Hill; Figures 8 and 9).

Quolls were also attracted by the cat lures. For Yarraloola, quolls were found on 59 nights at 18 cameras before baiting and 64 nights at 14 cameras after baiting. On Red Hill, it was 21 nights at 10 cameras before and 5 nights at 3 cameras after.

Very few dingoes were detected on the cat cameras. On Yarraloola, there was one record before the baiting (C36, 16 June) and one after on the same camera (10 Aug). Likewise, Red Hill had one detection (C64, 5 June) before and one after (C58, 13 Aug). No foxes were recorded.

Spatial overlap according to camera detections of the predator species present (dingoes/cats/quolls) was not common. There was only one camera on Yarraloola that both cats and quolls were recorded. This was at Camera 22 located on Mesa F and it was the first recorded visit by a cat to a camera site located in rugged rocky habitat. Located in core quoll habitat, quolls were commonly detected by this camera, with two quoll visits on the same night as the cat. Dingoes were only found on Camera 36 on Yarraloola, which was also visited by quolls. Overlap between cats and quolls on Red Hill was found at four camera sites (Figure 9). On Camera 58 on Red Hill, both species were recorded on the same night twice, which were two nights apart. On the first night, the quoll was detected early in the night and the cat in the morning but on the second night the visits were only several hours apart. A dingo was also detected on this camera but not on the same night as either of these other species. For the other three cameras, visits between the cats and quolls were on different nights. A cat was detected on the second camera (C64) visited by a dingo on Red Hill.

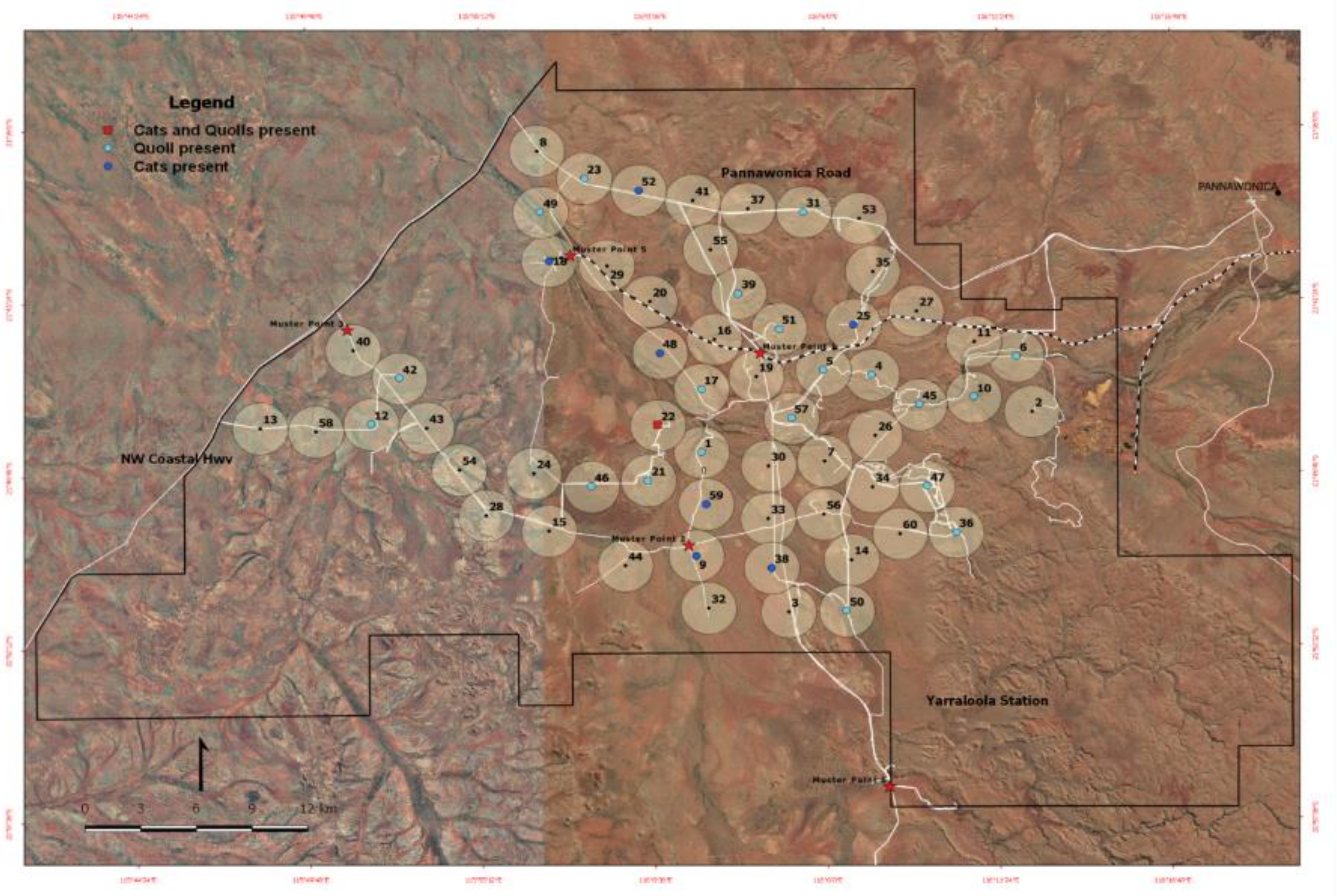


Figure 8. Locations of feral cat and northern quoll record for camera traps (pre- and post-bait survey sessions combined) within the Yarraloola LMA.

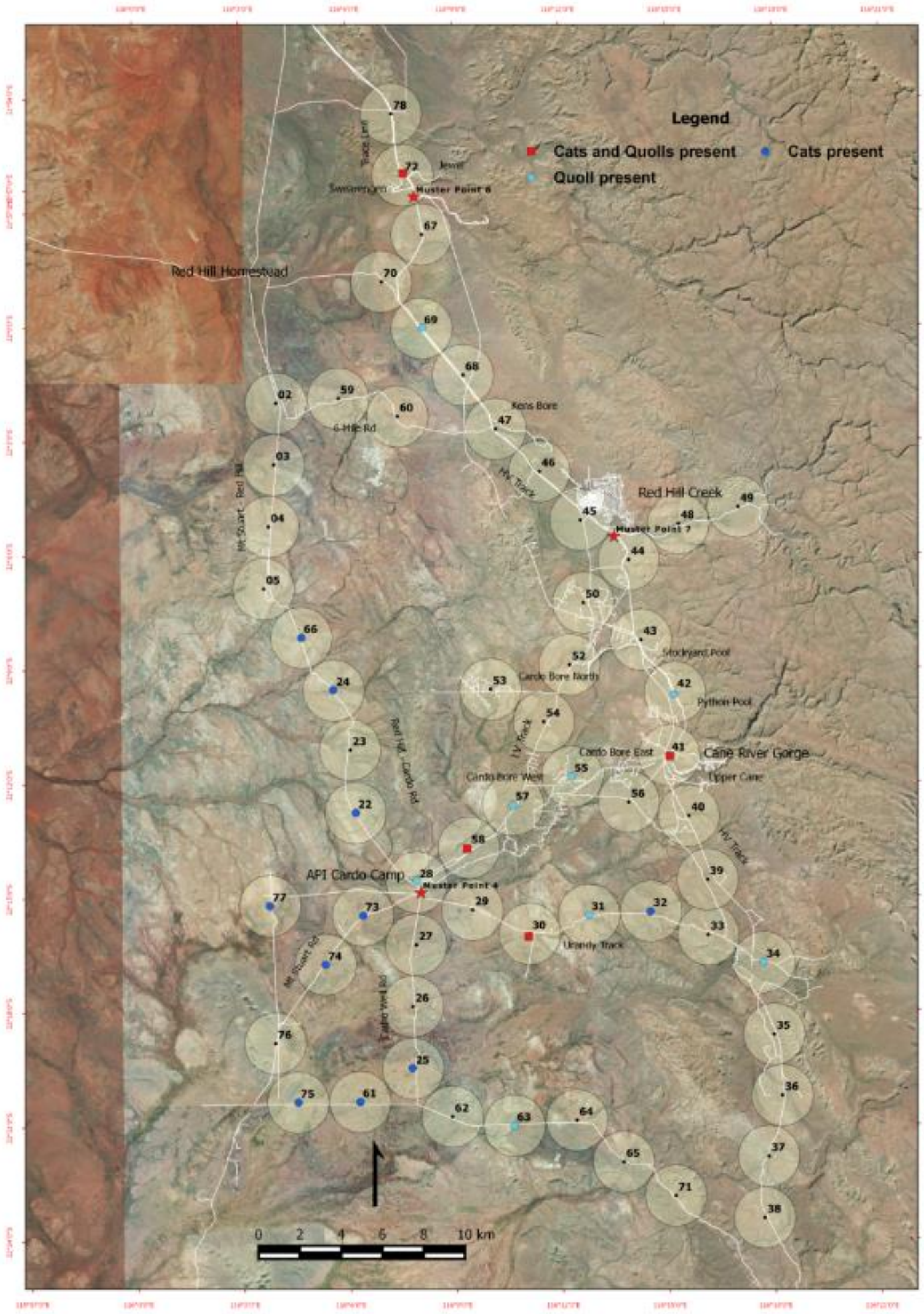


Figure 9. Locations of feral cat and northern quoll record for camera traps (pre- and post-bait survey sessions combined) on Red Hill.

4.3.1 Site occupancy of cats

The detection probability for cats within the treatment area was extremely low but this was not the case for the Red Hill reference site (Figure 10). The probability of feral cat occupancy in both models did not decrease significantly following the baiting on Yarraloola. There was a slight increase in cat activity in the reference site for both models in the post-bait monitoring session (Figure 10).

a) Modelled random effects (b) Modelled spatial component

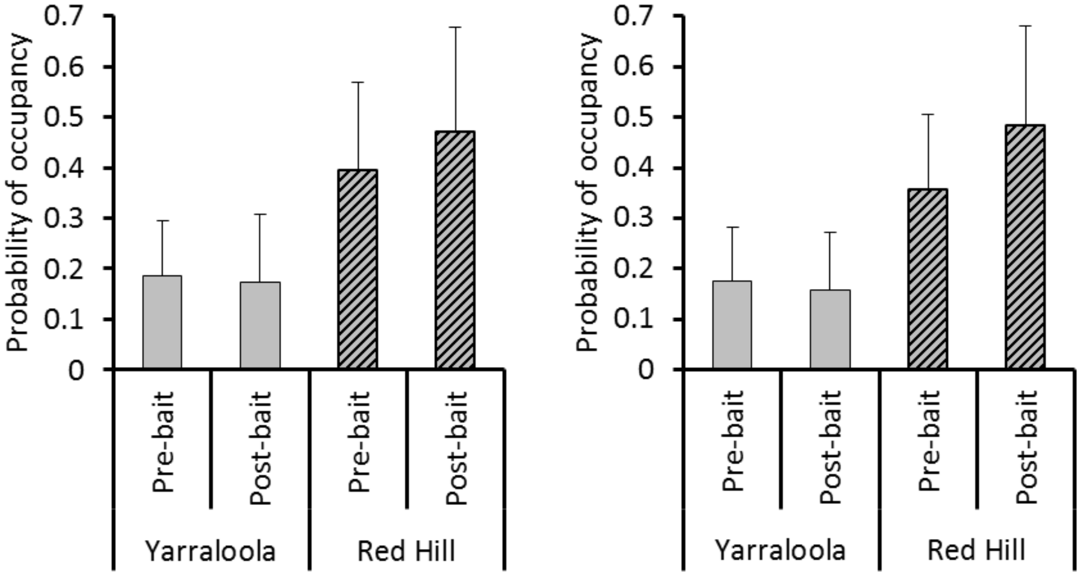


Figure 10. Site occupancy (mean + SD) before and after baiting in treatment (Yarraloola) and reference (Red Hill) sites with (a) random effects and (b) spatial component

4.3.2 Detection rates of cats and quolls

The mean detection rate of cats (mean number of events per 100 camera trap nights per camera trap site) was highest on both sites prior to the commencement of broad-scale baiting in 2016 (Figure 11a, b). Following baiting in 2016 there was sharp decline in the detection rate of cats in both the baited and unbaited sites (see Palmer *et al.* 2017 for potential explanation). Prior to baiting in 2017, cat detection rates on Yarraloola remained low and were similar to the detection rate recorded after baiting in the previous year (Figure 11a). Baiting in 2017 maintained feral cats at low densities and the detection rate declined further to a low of 0.4 cats per 100 CTN per site. On Red Hill there was a slight increase in cat detections before the scheduled baiting program on Yarraloola in 2017, but the rate remained lower than the previous peak prior to the baiting in 2016 (Figure 11b). The detection rate was 0.7 cats per 100 CTN for the post-bait monitoring session on Red Hill.

Detection rates of northern quolls on Yarraloola showed no sign of decline following each of the baiting programs (Figure 11c). They also showed a considerable increase between the years, although the error bars are large due to the large increase in detections of quolls at a number of camera sites located in or near to the Robe River (Cameras 6, 10, 22, 45 and 49). Quoll detection rates on the Red Hill cameras were consistently low and were lower during the post-bait monitoring session in each year (Figure 11d).

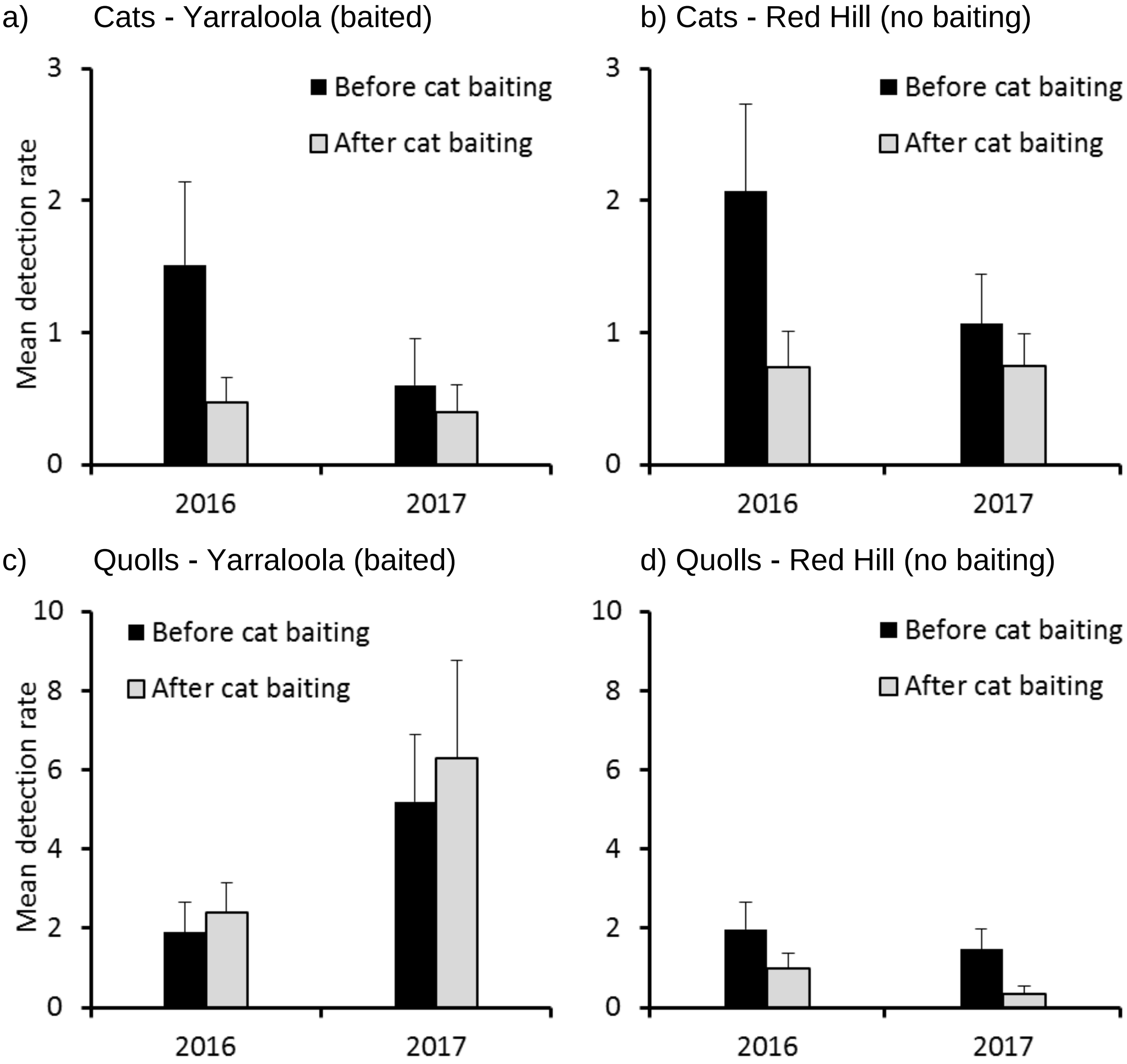


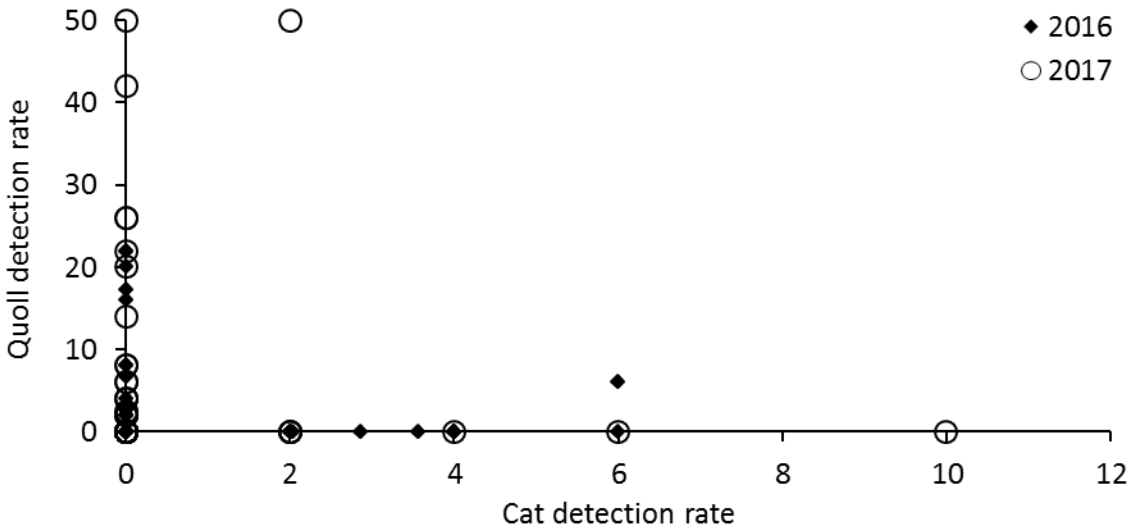
Figure 11. Mean detection rate (mean number of events per 100 camera trap nights per camera trap site) of cats on Yarraloola (a) and Red Hill (b) and northern quolls on Yarraloola (c) and Red Hill (d) prior to and after winter cat baiting on Yarraloola for 2016 and 2017.

4.3.3 Cat–quoll spatial overlap based on detections at camera sites

The detection rate of cats on Red Hill was higher than at Yarraloola and they have been recorded at more camera trap sites (n=19 in 2016, 14 in 2017) compared with Yarraloola (13 in 2016, 8 in 2017). Quolls were found on 18 cameras in 2016 and then 12 in 2017 on Red Hill. For Yarraloola, quolls were present on 14 cameras in 2016, increasing to 21 in 2017.

Overlap between cats and quolls at the same camera site was however uncommon. This suggests that quolls as the subordinate species, reduce predation risk from cats by avoiding them in space (Hernandez-Santin *et al.* 2016). This relationship was explored by plotting cat detection rates against that of quolls for all individual cameras sites across treatments and years (Figure 12). Any data points not located on either axis represent a camera site where both cats and quolls were recorded in that year (combined pre and post baiting monitoring sessions). Co-occurrence of cats and quolls at the same camera site was more frequent at Red Hill (no baiting; Figure 12b). Quolls were also recorded at seven of the 14 camera sites that had higher cat detection rates (≥ 4 cats 100 CTN) on the unbaited site (Red Hill).

a) Yarraloola (baited)



b) Red Hill (no baiting)

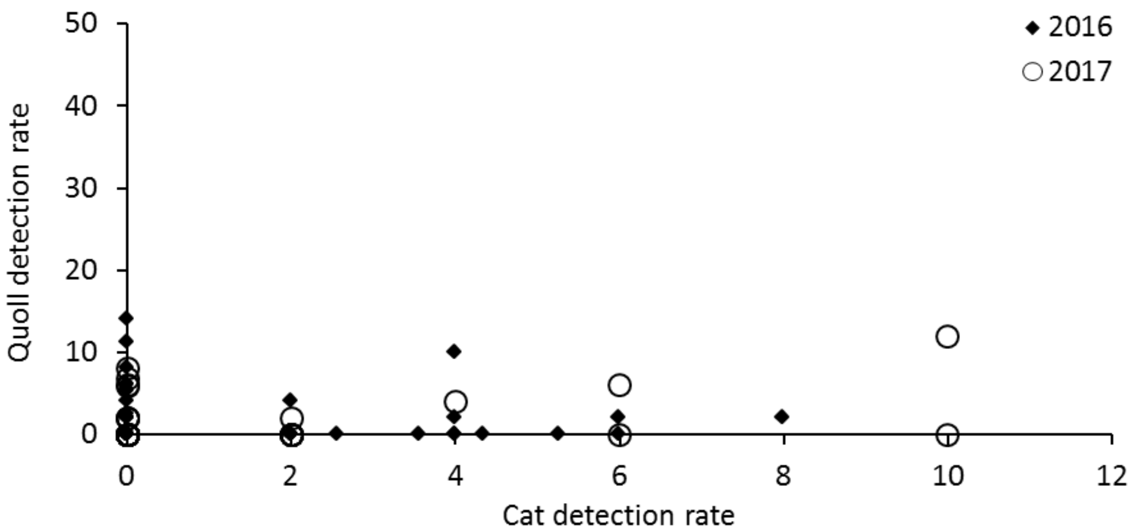


Figure 12 Cat and quoll detection rates (animals per 100 CTN) at cat camera trap sites (n=60) for a) Yarraloola (cat baited) and b) Red Hill (reference) for 2016 and 2017. The two camera trapping sessions per year (before and after the baiting program) were pooled (maximum effort of 50 CTN per camera site).

4.4 Northern quoll monitoring

4.4.1 Quoll trapping and survivorship

The trapping effort for the September quoll monitoring was 1440 trap nights across the 18 sites at each of Yarraloola and Red Hill. The number of individual quolls captured more than doubled on Yarraloola, increasing from 30 in 2016 (20 females,10 males) to 73 (40 F, 33 M) in 2017. For Red Hill, the overall increase in the number of quolls captured was of a lesser magnitude, rising from 38 individuals (26 F, 12 M) in 2016 to 51 (30 F, 21 M) this year. Although more females were at each site, sex ratios did not differ from parity. Capture data for individual sites and other capture rate metrics can be found in Appendix 2.

One of the original 12 females pit-tagged on Yarraloola in 2015 was recaptured in 2017. This female was first captured at Site I in June 2015 and fitted with a radio-collar for the baiting experiment (Morris *et al.* 2015). She was also recaptured in 2016 at this site. None of the eight original females from 2015 on Red Hill were caught this year. The recapture rate of females caught and tagged in September 2016 was high this year, with 53% (10 out of 19 females) and 35% (9 of 26) for Yarraloola and Red Hill, respectively. None of the 22 marked males across both sites from the previous year were recaptured in 2017.

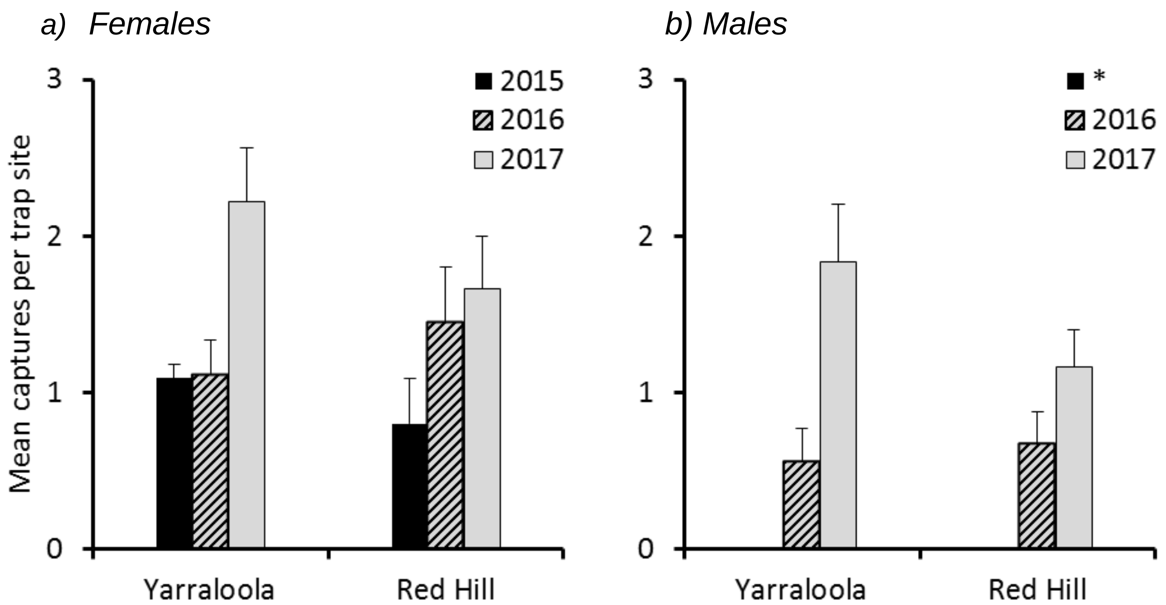


*Figure 13. Mean (+ SE) number of individual female (a) and male (b) quolls captured per trap site (20 traps set for 4 consecutive nights) at Yarraloola and Red Hill from 2015 to 2017. For 2016-17 there were 18 sites trapped at each site in September. For 2015 trapping was spread from August to October (Yarraloola 11 trap sites, Red Hill 10 trap sites). * Capture rates for males in 2015 were excluded as the trapping period also included sites with high male capture rates before the male die-off in August.*

4.4.2 Capture rates of quolls

The mean number of individual females and males captured per trap line increased considerably from 2016 to 2017 on Yarraloola (Figure 13). The magnitude of the increase in capture rates was much lower on Red Hill for both sexes (Figure 13). More males survived the male die-off, or at least survived longer into the die-off period to be captured in September this year compared with the previous year.

4.4.3 Capture rates of quolls in riverine/rocky habitats

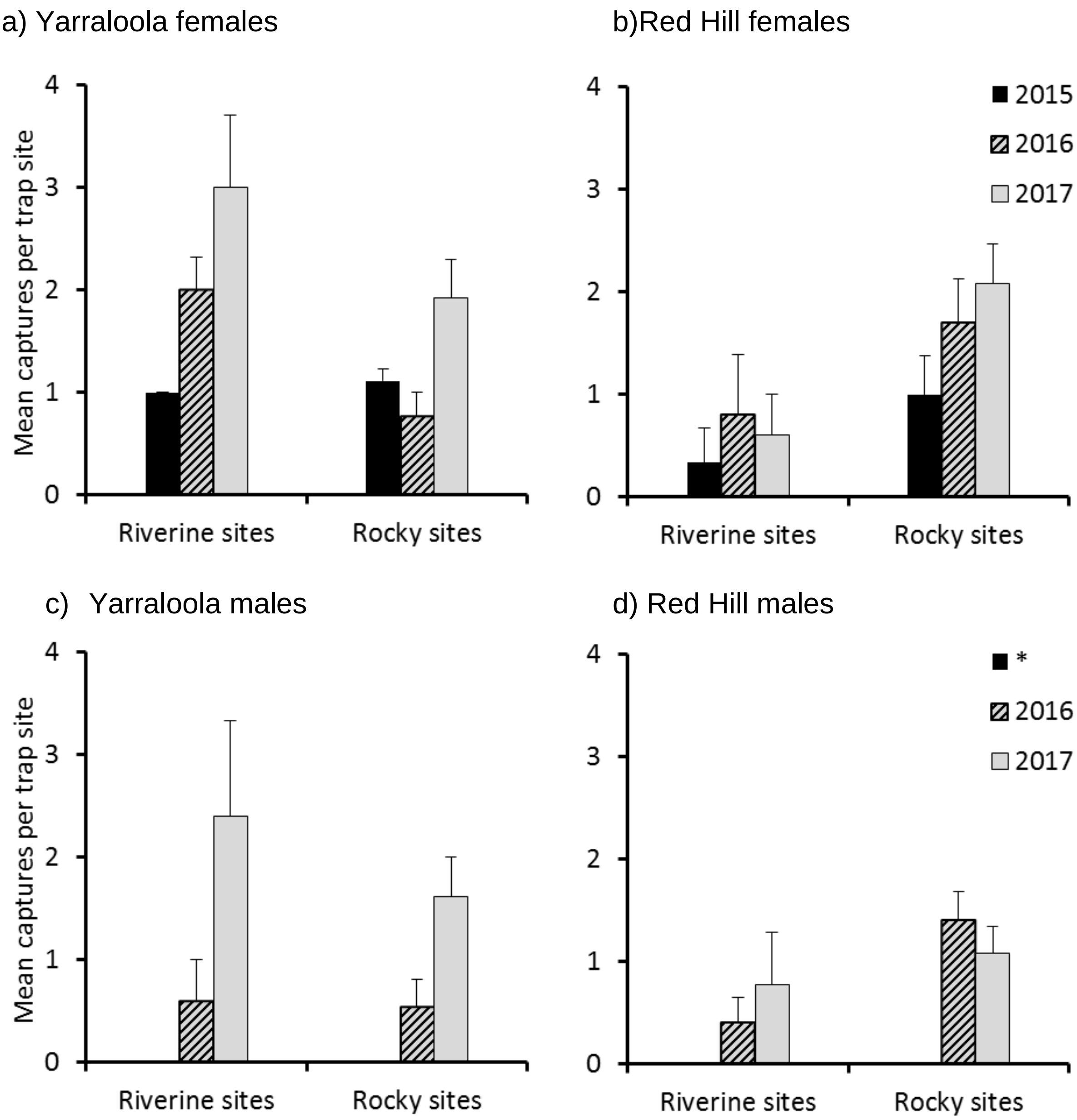


*Figure 14. Mean (+ SE) number of individual female (a and b) and male (c and d) quolls captured per trap site according to riverine and rocky habitats on Yarraloola and Red Hill from 2015 to 2017. There were 2 riverine and 9 rocky sites surveyed on Yarraloola and 3 riverine and 7 rocky on Red Hill in 2015. * Male capture rates are not presented for 2015. For 2016-17 there were 5 riverine and 13 rocky sites surveyed at each site.*

As mentioned above, a large increase in the detection rates of quolls was recorded at camera sites associated with the Robe River on Yarraloola. To explore this pattern further, we divided the quoll trap lines on both sites into those associated with the major drainage lines (riverine habitats) and those that were purely in rocky refuge habitats (mesa formations, rocky gorge systems, and ranges). On Yarraloola there were five trap lines (O, L, K, T, and Q) along the Robe River that were either in riverine habitat or rocky habitats abutting the river. Drainage systems on Red Hill are not as large as the Robe River, but there were five broadly similar sites (CL, E, N, P and RL) along Red Hill creek and another creekline.

This preliminary graphic comparison of capture rates of female and male quolls from 2015 to 2017 across treatments (baited and unbaited) and according to the habitat type of trapping sites, indicates a stronger population response by quolls associated with the Robe River in the baited Yarraloola LMA (Figure 14). Quoll capture rates in riverine sites on Red Hill have remained consistently low for all years. In rocky refuge habitats capture rates of quolls appear to have been similar across treatments suggesting that there was limited change due to baiting at this early stage of the project in these habitats.

4.4.4 Quoll body mass and litter size

The mean body mass of captured females across the sites increased in 2017 following the lower masses recorded in 2016 (Figure 15). The two-way ANOVA revealed a significant year effect ($F_{2,128}$ = 5.04, p = 0.008) on female weights but no site effect or site by year interaction. Likewise, captured males were heavier in 2017, particularly on Red Hill where males were considerably lighter in 2016 (Figure 15). A two-way ANOVA carried out on male quoll weights indicated both site ($F_{1,100}$ = 4.92, p = 0.029) and year ($F_{2,100}$ = 6.73, p = 0.002) effects. The site by year interaction was close to being significant ($F_{2,100}$ = 2.94, p = 0.057).

The two-way ANOVA indicated a significant site effect ($F_{1,97}$ = 8.70, p = 0.004) on litter size but no year effect or site by year interaction. For Yarraloola, the average litter size was highest in 2017 with 7.2 ± 0.2 pouch young (PY) per litter (range 3–8, n = 32), which was slightly above the previous years of 2016 (6.8 ± 0.4 PY, range 2–8, n = 16) and 2015 (6.9 ± 0.4 PY, range 5–8, n = 14). Mean litter sizes were consistently lower on Red Hill across years, 2017 (6.4 ± 0.3 PY, range 3–8, n = 22), 2016 (6.6 ± 0.4 PY, range 3–8, n = 11) and 2015 (5.3 ± 0.6 PY, range 3–8, n = 8).

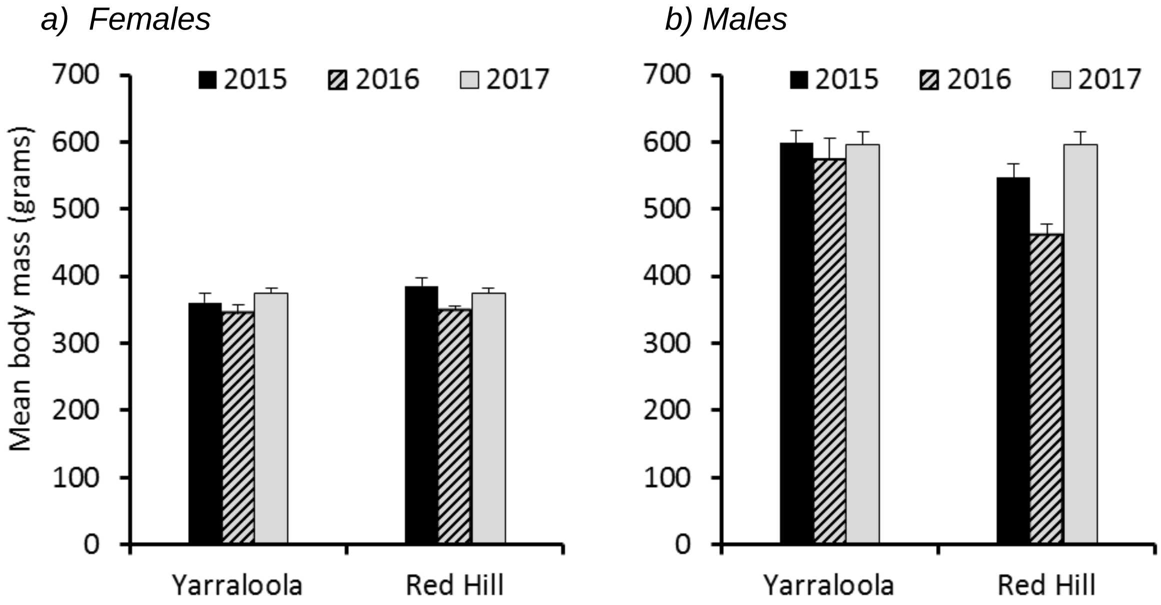


Figure 15. Mean body mass (+ SE) of female (a) and male (b) northern quolls captured at monitoring sites from 2015 to 2017 at Yarraloola and Red Hill.

4.4.5 Non-target captures in quoll traps

The most common non-target species captured was the common rock-rat (*Zyzomys argurus*) with 247 total captures. The mean number of common rock-rats captured per trap line was similar across sites and years (Figure 16). The other non-target species captured were eight *Pseudantechinus* sp., and small numbers of crevice skinks (*Egernia formosa* and *E. pilbarensis*) and goannas (*Varanus acanthurus* and *V. panoptes*). Novel incidental captures included an echidna, house mouse, grey butcher bird and five king brown snakes (*Pseudechis australis*).

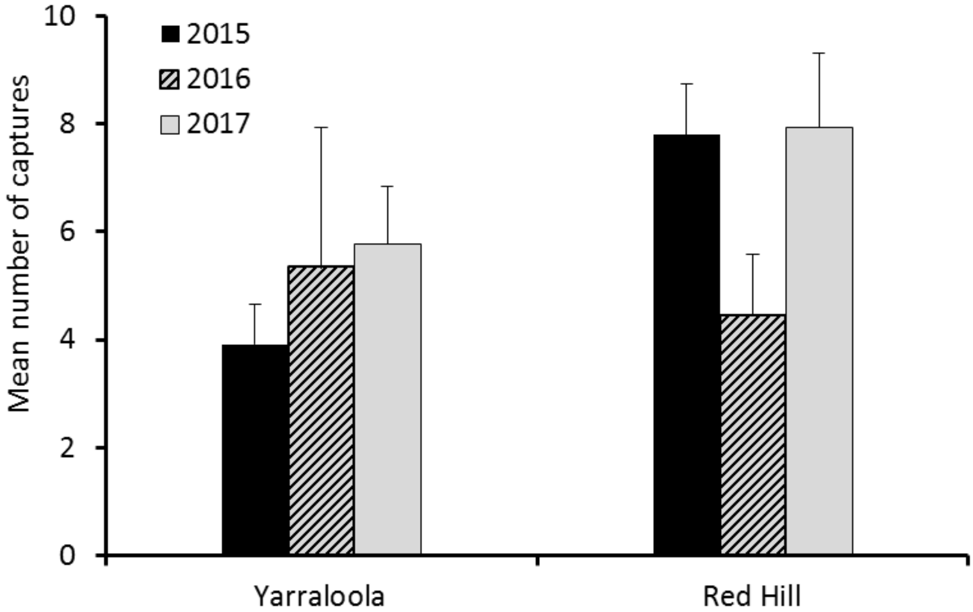


Figure 16. Mean (+ SE) number of common rock-rats captured per quoll monitoring site at Yarraloola and Red Hill for 2015 to 2017.

4.5 Predator diets and other records

4.5.1 Overall comparison of dingoes, feral cats and northern quolls

Predator scats from 2017 (294 quoll, 12 feral cat, 103 dingo) were combined with previous data and the relative volume of food groups is shown in Figure 17. The diets of the three predators show strong separation according to their body mass. Dingoes ate almost entirely large macropods (euros and red kangaroos). Minor prey items were cattle, echidna, emu and grasshoppers. Small mammals (rodents and dasyurids) were the primary prey of feral cats. Quolls had the most varied diet, consuming arthropods, fruits, rodents and other small vertebrates.

There was evidence in 2017 of intraguild predation where one predator species consumed another. Out of the 54 dingo scats from Red Hill, one contained cat remains and a second, quoll remains. Five cat scats collected in September and October from Quoll trapline N and M on Yarraloola contained quolls. There was evidence of cannibalism in both dingoes and quolls.

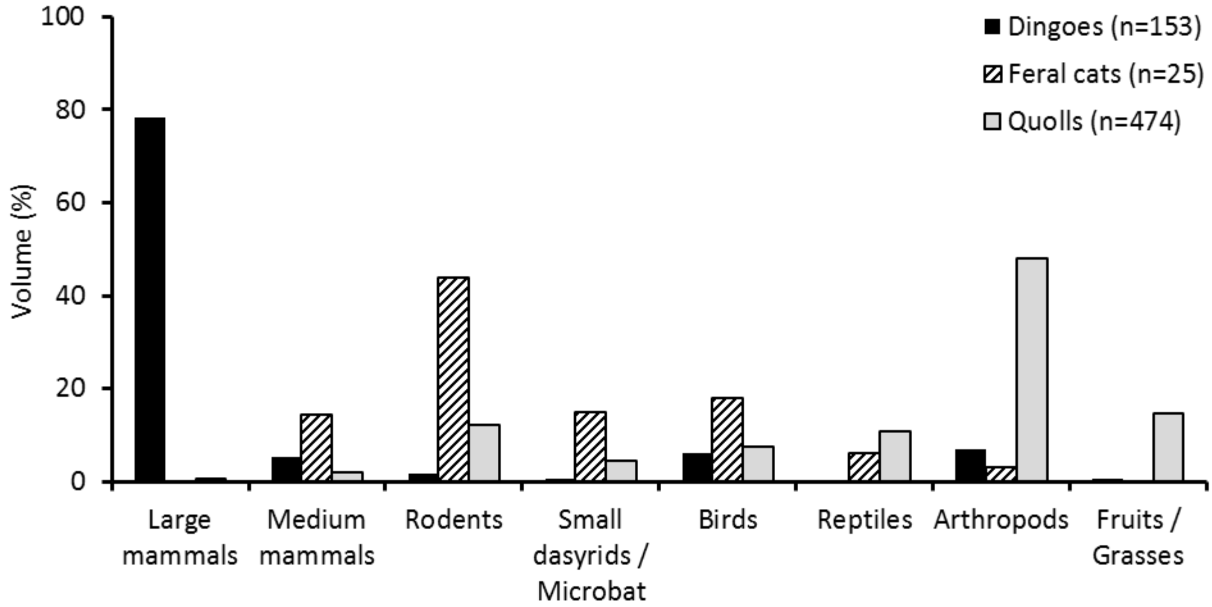


Figure 17. Relative volume of food groups in the diets of dingoes, feral cats and northern quolls from Yarraloola and Red Hill for 2015 to 2017. Parentheses show sample sizes.

4.5.2 Potential dietary shift by quolls in response to cat control

Dunlop *et al.* (2017) hypothesized that small vertebrates were the high-value and preferred prey of northern quolls across the Pilbara, but diet-switching to fruits common in rocky habitat, was a sign that feral cats were excluding quolls from less rocky habitats where availability of small vertebrate prey was higher. At our sites feral cats and quolls diets overlap considerably across the small vertebrate prey groups (Figure 17). Palmer *et al.* (2017) predicted that quolls would change their dietary niche in response to cat control on Yarraloola by including more vertebrate prey in their diets. The temporal changes in quoll diets can be assessed in Figure 18.

Quoll diets on Red Hill over the three years were highly consistent and relatively similar to quoll diets on Yarraloola, although there were differences in the rodent and fruit prey groups (Figure 18). Quolls on Red Hill consumed higher numbers of rodents in 2015–16 and lower numbers of fruits in all years. In contrast, fruit consumption by quolls was at its highest in 2015 on Yarraloola and then it declined in subsequent years. Over the same period, rodent intake by quolls on Yarraloola increased from a low level to reach a peak of 34% (frequency of occurrence) in 2017. Little change occurred in the consumption of other small vertebrate groups.

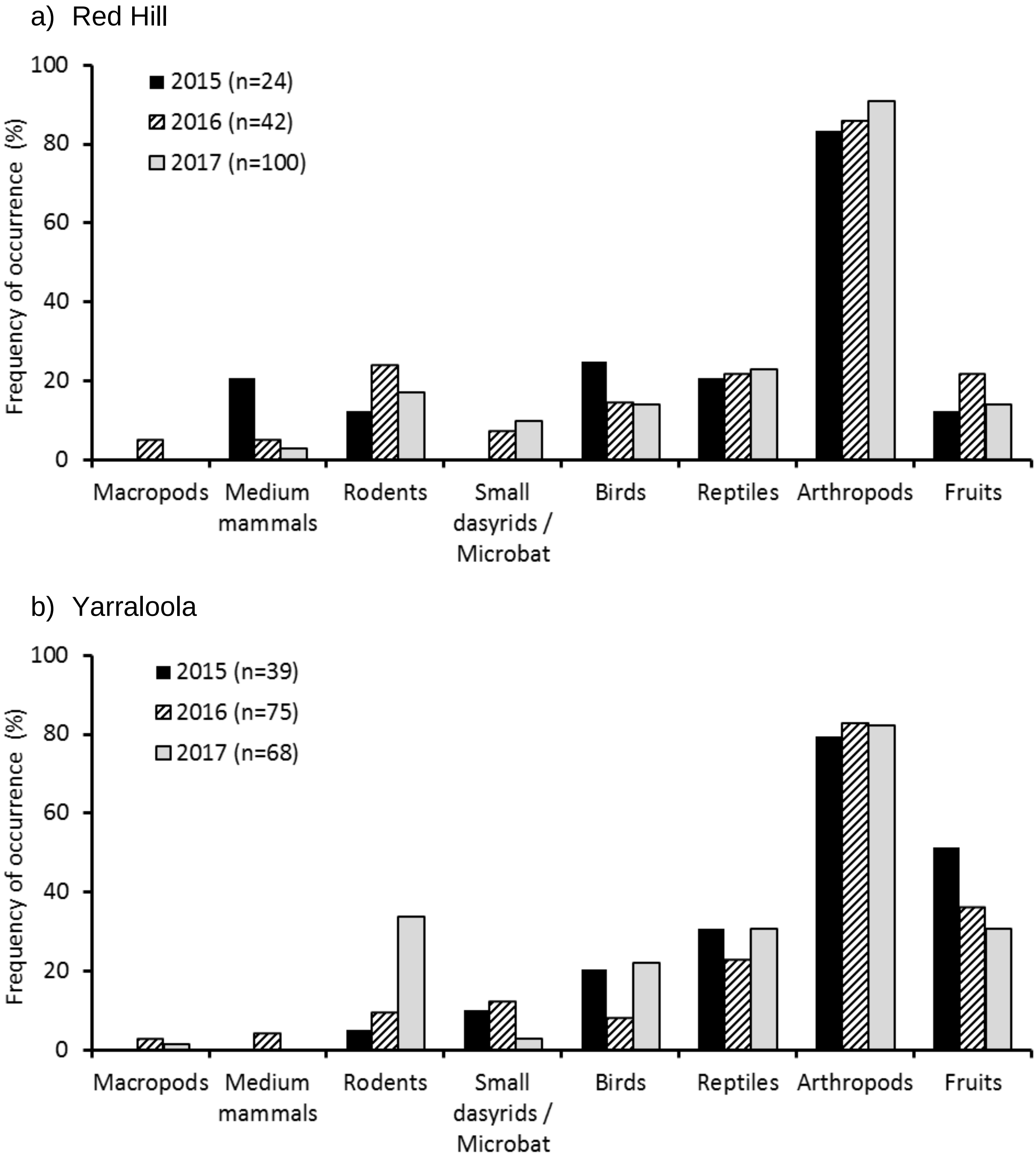


Figure 18. Comparative diets of northern quolls for (a) Red Hill and (b) Yarraloola (2015-2017). Diets are shown in terms of frequency of occurrence of each food group in the scats. Parentheses show sample sizes.

4.5.3 Dingoes

Dingoes on Yarraloola largely focussed on kangaroos (euros and red kangaroos) and there has been little change in their diets between 2016 and 2017 (Figure 19). On Red Hill, kangaroos were eaten in lesser quantities, with cattle, grasshoppers and dingo being consumed in slightly greater volumes.

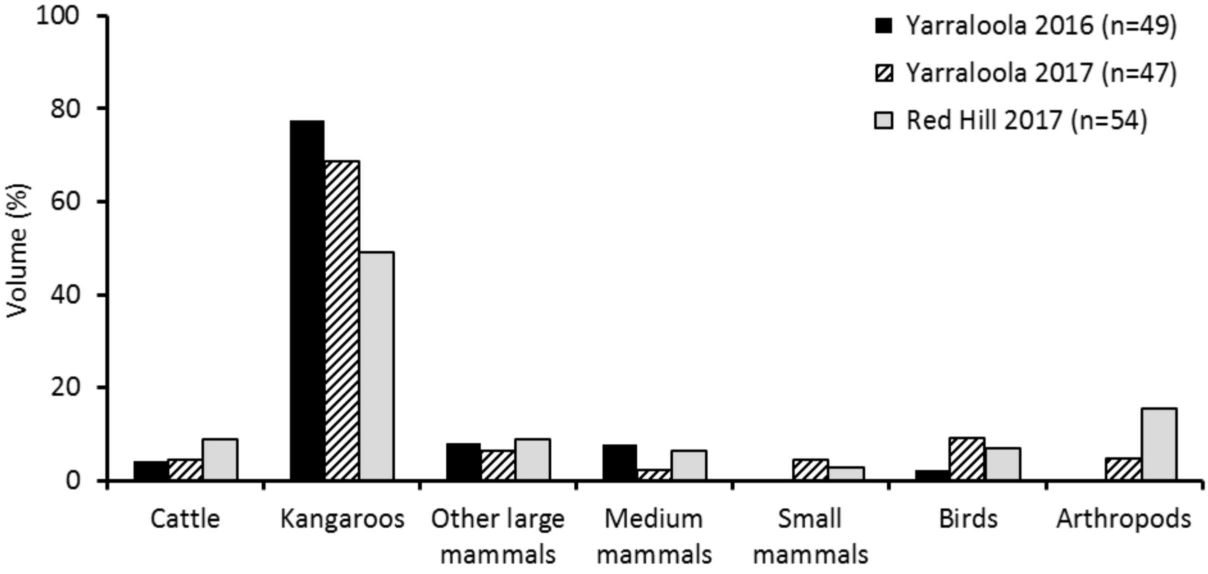


Figure 19. Relative volume of food groups in the diets of dingoes for Yarraloola (2016-2017) and Red Hill (2017). Parentheses show sample sizes. Reptiles and Fruits/Grasses were rarely eaten by dingoes so these groups were excluded.

4.6 Other records

4.6.1 Pilbara olive python records

An olive python, approximately 4m in length, was seen along a fence line at Cardo Camp on 25 May 2017 (22.2477°S, 116.1334°E). No olive pythons were detected by camera traps in 2017.

4.6.2 Other species

A broad range of fauna were detected as incidental records on the feral cat monitoring cameras this year. This included a mother and young brushtail possum (*Trichosurus vulpecula*) along the Robe River on Yarraloola at Camera 49 (Plate 2). In total, six species of reptile and nine species of mammal were detected by cameras this year compared to five reptile species and ten mammal species in 2016 (Appendix 3).

There were 45 species of bird, 11 more than 2016 (Appendix 3). Four species (emu, Horsfield's bronze cuckoo, pallid cuckoo and budgerigar) were recorded on Yarraloola but not on Red Hill and 9 native species (bush stone-curlew, pheasant coucal, tawny frogmouth, spiny-cheeked honeyeater, white-plumed honeyeater, western chestnut quail-thrush, hooded robin, brown songlark and Australian pipit) were detected on Red Hill but not on Yarraloola. Red Hill had a more diverse range of bird species than Yarraloola but this could be due to differences in habitat around each cat camera site. Habitat assessments at each cat camera site will be undertaken in 2018 to further investigate these differences in the present of avifauna.

There was a notable increase in the number of ground-dwelling, seed eating birds (e.g. brown quail, little button-quail, diamond and peaceful doves) recorded on cameras this year compared to 2016. This could be due to the good summer rainfall the Pilbara had. Of particular note, the introduced laughing turtle-dove was detected at cat Camera 32 on Yarraloola, this is the first record of this species at the study site and it is well out of its normal northern range.

Plate 2. A brushtail possum mother and young detected on cat camera 49 in the Robe River on Yarraloola.

5 Discussion

5.1 Feral cat monitoring and baiting

5.1.1 No recovery of cat population

Camera trap monitoring on Yarraloola prior to the 2017 baiting operation revealed that cat numbers had remained low following the baiting in July 2016. The failure of this population to increase significantly from August 2016 (0.47 cats 100 CTN^{-1}) to June 2017 (0.6 cats 100 CTN^{-1}) is not reflected in other similar broad-scale cat aerial baiting programs where cat population monitoring was undertaken (Algar *et al.* 2013; Clausen *et al.* 2016). Cats generally breed in late spring/early summer so there is a tendency for their numbers to be boosted by recruitment prior to the next annual winter baiting program (Algar *et al.* 2013). Re-invasion from neighbouring unbaited areas can also be rapid in some locations (Clausen *et al.* 2016). There was evidence that cats were breeding on Yarraloola, with William Ross (CDU PhD student) observing a young cat in April 2017 and several sub-adult cats were detected on camera traps in April-May.

It is unclear whether the first broad-scale baiting operation of this largely bait naïve cat population within the Yarraloola LMA in 2016 was particularly effective and/or re-invasion rates of cats were slower than those recorded other Pilbara sites like the Fortescue Marsh (Clausen *et al.* 2016). A potential advantage of the Yarraloola LMA bait cell is that it is relatively large and reasonably square in shape. Re-invasion pressure may therefore be slower due to less boundary area and the greater distances that cats would be required to move to reach the central parts of the Yarraloola LMA.

The topography of the Yarraloola LMA may also play a role in the movement patterns of feral cats. Rugged rocky terrain lines the eastern margin of the site (Hamersley range) and other mesa formations mark parts of the northern and southern boundaries. Results from our camera traps support research in New Zealand that suggest feral cats avoid such areas, which could potentially form natural barriers to cat re-invasion (Recio *et al.* 2015). Furthermore, these landscape obstacles could force cats moving from outside source locations to use certain corridors to access a cat–managed area (Recio *et al.* 2015). If such corridors can be identified it may be possible to implement cat control measures more strategically to protect ecologically sensitive areas. These ideas are worthy of further investigation in rocky landscapes like the Pilbara. The planned GPS collaring of cats in this project for 2018 should provide further insights into the above.

5.1.2 Baiting efficacy

Camera trapping is being increasingly used as a tool for monitoring the relative abundance of mammal populations over large spatial scales. Here we generated two measures of the relative abundance of cats using camera trapping (site occupancy and detection rate) immediately prior to and immediately following the baiting program. Both metrics indicated that there has been no significant effect on the cat population due to the baiting in 2017. However, this monitoring demonstrated that the winter baiting program reduced the cat population to its lowest level yet for this project. Only on one occasion in five years of baiting at the Fortescue Marsh did baiting reduce cat abundance to a similarly low probability of occupancy, which was in 2012. This was the first year of baiting for that project (Clausen *et al.* 2016). In terms of other large-scale cat monitoring projects undertaken on the Australian mainland using “lured” camera traps for cat detection, 0.40 cats per 100 CTN reported for the post-bait monitoring session on Yarraloola is amongst the lowest (Brook *et al.* 2012; Hernandez-Santin *et al.* 2016; Read *et al.* 2015; Stokeld *et al.* 2016). This detection rate is the equivalent of 1 cat detected in 250 camera trap nights.

A potential concern of such low detection probabilities of cats on our camera traps within the baited cell is the robustness of this analysis. There were plans to trap and radio-collar feral cats within the Yarraloola LMA prior to the baiting in 2017 to provide an independent verification of the efficacy of the baiting by monitoring mortality rates. This aspect of the project was delayed and will instead be undertaken in 2018 using downloadable GPS collars on cats. GPS-tracking data will provide insights into the movement patterns of cats in relation to bait drop sites and our camera traps. It may also help identify movement corridors used by cats and types of landscape features that act as barriers to cat movement (Recio *et al.* 2015). Furthermore, analysis of the GPS-tracking combined with cat detection data from camera traps will provide insight into high-use areas (preferred habitats) that offer key prey resources and shelter for cats. Improving our understanding of the spatial ecology of cats in these landscapes should enable us to develop a more strategic cat baiting program for this site and potentially other Pilbara sites with similar topographical features. It is also envisaged that we can build-on the occupancy modelling approach used for monitoring cat populations in this study by linking the above information with habitat surveys of our camera trap sites to add meaningful habitat covariates to this analysis.

The land owner/manager of both pastoral leases actively controls dingoes/wild dogs to reduce their impacts on cattle herds, as required by the *Biosecurity and Agriculture Management Act 2007*. Dingoes were scarce on both pastoral leases in 2017, with only one dingo detected by cameras before the cat baiting and one after, hence we were unable to determine if the cat baiting reduced dingo numbers. We only collected ~50 dingo scats from each station, mostly from the sides of roads over five field trips, further indicating their numbers were low.

5.2 Northern quoll populations

Quoll populations responded strongly to the favourable seasonal conditions across the two study areas in 2017. On Yarraloola, the capture rates of females doubled (1.1 to 2.2 individuals per trapping site) and males tripled (0.6 to 1.8) from the previous year (Palmer *et al.* 2017). The increases detected at Red Hill were more moderate, with females increasing from 1.4 to 1.7 individuals per trapping site, and males from 0.7 to 1.2. Females across both sites benefited from the better conditions as they were significantly heavier in 2017 compared with 2016. The annual survival rate of females between trapping sessions was also higher, with a marked improvement for females in the baited area (Yarraloola 53% for 2016-17 *cf.* 17% for 2015-16 and 35% *cf.* 25% for Red Hill, respectively).

Increased female body mass did not translate to universal increases in their litter sizes from 2016 to 2017. For Yarraloola, there was an increase from 6.8 to 7.2 pouch young per litter and a slight decline from 6.6 to 6.4 on Red Hill (Palmer *et al.* 2017). Sub-lethal exposure to 1080 can result in toxins being passed through milk, potentially killing the pouch young of marsupials (McIlroy 1981). If this was the case in this study, females exposed to *Eradicat®* baiting over the past two years on Yarraloola may be expected to have smaller litter sizes. Instead we found that quolls on Yarraloola had significantly larger litters. A number of factors are likely to result in low exposure of pouch young to 1080 in cat baits on Yarraloola. Firstly, baits are distributed in July and most of the young were born in the last week of August through into September. Secondly, camera trap monitoring of non-toxic *Eradicat®* baits within the bait cell in August showed that most quolls would not ingest baits by that stage, following earlier sub-lethal exporure to toxic baits during the aerial baiting program in July (Palmer *et al.* 2017). In other words, most individual females were bait-shy by the time they gave birth and even if they encountered a dried out *Eradicat®* bait still present from the winter baiting program they would not eat it.

The higher capture rate of males across the two sites in 2017 meant that the respective sex ratios of 55% and 59% female, for Yarraloola and Red Hill were more even during the September trapping session compared with that of the previous year (~67% female for each). This indicates that the post-mating mortality of males (die-off) during or immediately after the breeding period (late July-August) was less complete or delayed due to the better seasonal conditions. Males were also significantly heavier in 2017 compared with 2016. The 12 males captured on Red Hill during the 2016 trapping session were in particularly poor condition with large patches of hair missing and they only weighed between 405 to 545 grams. Under the good seasonal conditions in 2017, a number of relatively healthy large male quolls (>750 grams) were captured. Males of this weight were not captured during the previous years (2015-16) following the male die-off. Evidence of males surviving into their second mating season is rare in the literature (Spencer *et al.* 2017). None of the heavier males captured in 2017 had been tagged in the previous year so we were unable to confirm if they were second year animals. Palmer *et al.* (2017) speculated that cat baiting could improve the survival of males as they undertake risky behaviours during the mating season, which increases their exposure to cat predation. The above indicates that separating the potential benefits of cat control and/or improved seasonal conditions on the fitness of male quolls may take some time to tease apart.

Various quoll monitoring metrics, capture rates of females and males in traps (Figure 14), survivorship of females between trapping sessions and their detection rates on cat camera traps (Figure 11), were all higher within the cat baited area this year, which suggests quolls have responded favourably to the current low densities of feral cats on Yarraloola (Figure 13). However, this project is still at an early stage as there has only been one quoll recruitment phase following the commencement of broad-scale cat baiting (two consecutive winter programs) and additional monitoring is required to determine the nature of this trend. For example, separating the quoll trap sites according to those located in “riverine” (plus riverine/rocky) and “rocky” (without major drainage lines) habitats indicates that quolls in the former habitats have benefitted more from cat control compared with those occupying the latter (Figure 14).

5.3 No evidence *Eradicat*® harms northern quolls

Laboratory testing showed northern quolls have a moderate tolerance to compound 1080 (LD50 7.5 mg/kg; King *et al.* 1989). Their relatively small average body mass in the Pilbara (360-600 g) however, suggests northern quolls would only need to ingest a single toxic cat bait containing 4.5 mg of 1080 to be at risk. Yet King (1989) and this project (Morris *et al.* 2015; Morris *et al.* 2016; Palmer *et al.* 2017) show that aerial baiting programs targeting wild dogs or feral cats do not pose a hazard to co-occurring free ranging northern quolls in the Pilbara, confirming that estimated bait toxicity in laboratory settings and actual poisoning of quolls requires resolution under field conditions (Jones *et al.* 2014).

Here we extend this evidence by presenting data on the relative abundance of northern quolls immediately prior to and immediately following two winter *Eradicat*® baiting programs (Figure 11c, d). The abundance metric used was the mean number of quoll detection events per 100 CTN, based on visitation events to camera traps set for feral cat monitoring in 2016 and 2017. Like cats, northern quolls were also attracted to the ‘Catastrophic’ scent lure. Given these cameras were set in the lead-up to and during the quoll breeding season there was a bias towards male quoll visitations. There was no evidence that quoll detection rates declined following the baiting program in either year in the baited area. A decline in quoll detection rates did occur in the unbaited Red Hill site in both years where there were more cats present.

5.4 Predator interactions and potential indirect benefits to quolls from cat control

Top down processes exerted by higher order predators, such as feral cats, can strongly influence the abundance, spatial distribution and behaviour of smaller terrestrial predators like northern quolls through both competition and intraguild predation (Molsher *et al.* 2017). Radio-telemetry demonstrated that northern quolls suffered high levels of mortality due to intraguild predation by feral cats and to a lesser degree canid predators (either dingoes or foxes) in 2015 (Morris *et al.* 2015). Effective control of feral cats should therefore enhance the fitness of the northern quoll population on Yarraloola.

Evidence of intraguild predation based on the analysis of predator scat collections from 2016 was limited to a single record of quoll remains contained in an olive python scat (Palmer *et al.* 2017). A larger sample of 103 dingo scats were collected in 2017, cat and quoll remains were found in a single dingo scats each, both from Red Hill. A large python scat (likely olive python) found at Python Pool on Red Hill in October contained quoll fur. Likewise, an old goanna scat from near Cat Camera 38 on Yarraloola also contained quoll remains. This latter site is in the flat sand plains where we are yet to detect quolls. Given that quolls are locally common in favourable habitats on both stations it was not surprising they were preyed upon or scavenged by larger vertebrate predators.

A more concerning find was that five out of eight cat scats collected from quoll trap lines M and N on Yarraloola in September and October contained the remains of quolls. No other cat scats (n=17) collected over the duration of this study have contained this species (Figure 17). Quoll trap sites M and N follow two nearby gorge systems that stretch up into a rocky range. The drainage lines that flow from each are interconnected on the lower slopes, potentially providing cats with a protected pathway to roam between sites, and up and down each gorge. Four camera traps set following the completion of the quoll trapping in September detected the presence of a large male cat on a single camera.

Based on the recent review by Moseby *et al.* (2015), we speculate that the cat/s operating in this area was a ‘specialist hunter’ predating the northern quolls. Although we trapped two female (recaptured from last year) and three new male quolls at site N (8 total captures with recaptures; Appendix 2), we only captured a single new female on a single night at site M. In contrast, site M was the most successful trap line of the 18 sites on Yarraloola in 2016, with two females and two males captured. This year it was amongst the lowest with one capture and it was the only site in 2017 where the quoll capture rate declined from the previous year.

Specialist hunters or rogue cats are less likely to be killed by broad-scale baiting due to their specific hunting preferences, their size, age or wariness and experience (Moseby *et al.* 2015). They are also thought to be repeat offenders when hunting, either due to their experience or access to hunt in areas where the prey species is susceptible, this could explain why four of the five cat scats containing quolls were from Site M. The gorge at this site has a wider and open sandy floor, lacking the level of cover present in the narrower and steep sided gorge at site N.

Alternatively, male quolls that died following mating may have been scavenged by cats. Cats are not noted scavengers and none of the six dingo scats collected at these trap sites contain quoll remains, suggesting this is an unlikely explanation. Further camera trap and scat surveys will be undertaken in this area in early 2018 and targeted cat control implemented if required.

According to Hernandez-Santin*et al*. (2016) introduced predators influence the use of landscapes by northern quolls at both local and larger scales in the northern Pilbara, with quolls avoiding the flat and open habitats more frequently used by cats. They suggest that predator avoidance was a key reason for the contraction of the distribution of northern quolls to rocky areas across northern Australia. In contrast , we have detected cats and quolls at the same camera sites on both study areas. Overlap between both species on the same night at individual camera trap sites was also recorded on Red Hill. While these records were not common, our initial examination of spatial segregation between cats and quolls from camera trap detections over the past two years indicates quolls do not selectively avoid camera trap sites with higher detection rates of cats on Red Hill (Figure 12).

We are yet to investigate how landscape/habitat differences across camera trap sites influences levels of spatial overlap/segregation between cats and quolls. On Yarraloola where cat baiting has reduced cat numbers, the camera trap data presented in Figure 12 indicates that quolls were less likely to encounter cats compared with those in the unbaited reference site of Red Hill.

Palmer *et al.* (2017) predicted that if cat control was effective on Yarraloola, quolls would respond by making greater use of the open land systems preferred by cats. We are yet to investigate the spatial response by quolls in detail, although there was a strong seasonal response by quoll populations in 2017. Quoll detection rates increased markedly on cat cameras located in both rocky and riverine habitats on Yarraloola (Figure 11). We also detected them for the first time on four additional cat camera traps (C1, C11, C39, and C50; Figure 8) located in open habitats on Yarraloola, which cats might be expected to typically occupy. There were signs of a diet shift by quoll on Yarraloola away from fruits to rodent prey (Figure 18). Dunlop *et al.* (2017) hypothesized that small vertebrates were the high-value and preferred prey of northern quolls, but diet-switching to fruits common in rocky habitat, was a sign that feral cats were excluding quolls from the spinifex grasslands where availability of small vertebrate prey was higher. The above evidence provides some support that baiting of cats on Yarraloola is also benefiting quolls indirectly by improving their access to richer prey sources in high-risk open habitats.

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Appendices

Appendix 1 Field work program for 2017

Field Trip #	Date(s)	Field Activity
1	22 – 29 May Yarraloola	Establishment of 60 camera traps for the monitoring of feral cats for the pre-baiting period. Quoll camera traps set by Billy Ross were collected from quoll trapping sites, and quoll scats were collected for diet study. Fifteen pairs of camera traps were set in recently burnt quoll habitat.
	22 – 28 May Red Hill	Establishment of 60 camera traps for the monitoring of feral cats for the pre-baiting period. Quoll camera traps set by Billy Ross were collected from quoll trapping sites, and quoll scats were collected for diet study.
2	27 June – 6 July Yarraloola/Red Hill	Cat camera demobilisation on both sites. Collected camera traps set on burnt quoll habitat on Yarraloola.
	16 – 17 July	Aerial Baiting, Yarraloola.
3	31 July – 6 August Yarraloola/Red Hill	Sixty camera traps were set for the post-baiting monitoring of feral cats on Yarraloola and Red Hill. Non-toxic bait monitoring camera traps were set on Yarraloola.
4	4 – 19 September Yarraloola	The quoll monitoring was completed with all 18 sites trapped for 4 nights each. Sixty cat cameras collected. Quoll cameras reset on trap lines and fire scars.
	11 – 25 September Red Hill	The quoll monitoring was completed with 18 sites trapped for 4 nights each. Cat camera collected. Quoll cameras reset on trap lines.
5	23 – 27 October Yarraloola/Red Hill	Quoll camera collection on Yarraloola and Red Hill with Kuruma Marthudunera Traditional Owners.

Appendix 2 Quoll capture results for each trap site in 2017

Capture data and capture metric summaries for northern quolls per trapping site on the Yarraloola LMA

Trap site	Females	Males	Total captures (includes recaptures)	Overall trap success rate (%)	Individuals captured per 100 trap nights
A	0	2	3	3.75	2.50
B	2	3	15*	18.75	6.25
C	3	1	6	7.5	5.00
D	3	0	4	5.00	3.75
F	0	0	0	0	0
G	1	2	5	6.25	3.75
H	2	1	8	10.00	3.75
I	2	2	6	7.50	5.00
J	5	3	12	15.00	10.00
K	4	2	18	22.50	7.50
L	5	1	10*	12.50	7.50
M	1	0	1	1.25	1.25
N	2	3	8	10.00	6.25
O	1	1	3	3.75	2.50
P	2	4	8	10.00	7.50
Q	3	6	21	26.25	11.25
R	2	0	2	2.50	2.50
T	2	2	10	12.50	5.00
Totals	**40**	**33**	**140**		
Means	**2.22**	**1.83**	**7.78**	**9.72**	**5.07**

* Captured quoll of unknown sex escaped from the bag while handling on the first trap night (Trap B3 6/09/2017; Trap L9 15/09/2017). We assumed these individuals were recaptured on subsequent trap nights.

Capture data and capture metric summaries for northern quolls per trapping site on Red Hill.

Trap site	Females	Males	Total captures (includes recaptures)	Overall trap success rate (%)	Individuals captured per 100 trap nights
CL	0	1	2	2.50	1.25
CW	1	1	5	6.25	2.50
E	2	3	12	15.00	6.25
F	2	3	13	16.25	6.25
G	0	1	2	2.50	1.25
H	3	1	10	12.50	5.00
I	2	0	7	8.75	2.50
J	4	2	8	10.00	7.50
KB	1	0	1	1.25	1.25
L	2	1	3	3.75	3.75
M	3	0	3	3.75	3.75
N	0	2	4	5.00	2.50
P	1	0	2	2.50	1.25
PP	1	1	3	3.75	2.50
RL	0	1	2	2.50	1.25
SW	1	0	2	2.50	1.25
X	2	2	9	11.25	5.00
Z	5	2	11	13.75	8.75
Total	**30**	**21**	**99**		
Means	**1.67**	**1.17**	**5.50**	**6.88**	**3.54**

Appendix 3 Incidental and opportunistic records

Birds captured by cat camera traps in 2017 (Y = yes for recorded).

Species Name	Common Name	Red Hill	Yarraloola
Dromaius novaehollandiae	Emu	-	Y
Coturnix ypsilophora	Brown Quail	Y	Y
Accipiter fasciatus	Brown Goshawk	Y	Y
Ardeotis australis	Australian Bustard	Y	Y
Turnixvelox	Little Button-quail	Y	Y
Burhinusgrallarius	Bush Stone-curlew	Y	-
**Streptopeliasenegalensis*	Laughing Turtle-Dove	-	Y
Phapschalcoptera	Common Bronzewing	Y	Y
Ocyphapslophotes	Crested Pigeon	Y	Y
Geophapsplumifera	Spinifex Pigeon	Y	Y
Geopeliacuneata	Diamond Dove	Y	Y
Geopeliastriata	Peaceful Dove	Y	Y
Centropusphasianinus	Pheasant Coucal	Y	-
Chrysococcyx basalis	Horsfield's Bronze Cuckoo	-	Y
Cacomantispallidus	Pallid Cuckoo	-	Y
Ninox boobook	Southern Boobook	Y	Y
Podargusstrigoides	Tawny Frogmouth	Y	-
Eurostopodusargus	Spotted Nightjar	Y	Y
*Eurostopodus*sp.	Unidentified nightjar	Y	-
Falco berigora	Brown Falcon	Y	Y
Cacatuaroseicapilla	Galah	Y	Y
Cacatuasanguinea	Little Corella	Y	Y
Melopsittacusundulatus	Budgerigar	-	Y
Ptilonorhynchusmaculatus	Western Bowerbird	Y	Y
Amytornisstriatus	Striated Grasswren	Y	Y
Epthianura tricolor	Crimson Chat	Y	Y
Acanthagenysrufogularis	Spiny-cheeked Honeyeater	Y	-
Manorinaflavigula	Yellow-throated Miner	Y	Y
Gavicalisvirescens	Singing Honeyeater	Y	Y
Ptilotula penicillata	White-plumed Honeyeater	Y	-
Cinclosomaclarum	Western Chestnut Quail-thrush	Y	-
Artamuscinereus	Black-faced Woodswallow	Y	Y
Cracticusnigrogularis	Pied Butcherbird	Y	Y
Cracticustibicen	Australian Magpie	Y	Y
Oreoicagutturalis	Crested Bellbird	Y	Y
Colluricincla harmonica	Grey Shrike-thrush	Y	Y
Rhipiduraleucophrys	Willie Wagtail	Y	Y
Corvus sp.	Crow	Y	Y
Grallinacyanoleuca	Magpie-lark	Y	Y
Melanodryas cucullata	Hooded Robin	Y	-
Megalurusmathewsi	Rufous Songlark	Y	Y
Megaluruscruralis	Brown Songlark	Y	-
Eremiornis carteri	Spinifexbird	Y	Y
Emblemapictum	Painted Finch	Y	Y
Taeniopygiaguttata	Zebra Finch	Y	Y
Anthus australis	Australian Pipit	Y	-

*introduced, range extension

List of mammals (excluding both target species: Northern Quoll and feral cat) captured on cat camera traps on Red Hill and Yarraloola in 2017 (Y = yes for recorded).

Species Name	Common Name	Red Hill	Yarraloola	Comments
Tachyglossus aculeatus	Short-beaked Echidna	-	Y	
Dasykaluta rosamondae	Kaluta	Y	Y	WA endemic
Trichosurus vulpecula hypoleucus	Brushtail Possum	Y	Y	Likely to be koomal
Osphranter robustus	Euro	Y	Y	
Osphranter rufus	Red Kangaroo, Marlu	Y	Y	
Petrogale rothschildi	Rothschild's Rock-wallaby	Y	Y	WA endemic
Notomys alexis	Spinifex Hopping-mouse	Y	Y	
Zyzomys argurus	Common Rock-rat	Y	Y	
Canis dingo	Dingo	Y	Y	

List of reptiles captured on cat camera traps on Red Hill and Yarraloola (Y = yes for recorded).

Species Name	Common Name	Red Hill		Yarraloola	
		2016	2017	2016	2017
Nephrurus wheeleri	Knob tailed Gecko	-	Y	-	-
Pogona minor	Bearded Dragon	-	-	Y	-
Ctenophorus reticulatus	Western Netted Dragon	Y	-	-	-
Tiliqua multifasciata	Central Blue-tongue	Y	Y	Y	Y
Ctenotus pantherinus	Leopard Ctenotus	-	Y	-	-
Varanus panoptes	Yellow-spotted Goanna	Y	Y	Y	Y
Varanus giganteus	Perentie	Y	Y	Y	Y
Varanus acanthurus	Spiny-tailed Goanna	-	Y	-	-

Appendix 4 Outputs and Engagement

Volunteers

- Tom Dimaline: 22-29 May, 86 hrs – Quoll and cat camera setting Yarraloola.
- CallumSmithyman: 31 July-4 August, 54 hrs – Cat camera setting Red Hill.
- Brooke Richards: 4-19 September, 136 hrs – Quoll trapping trip Yarraloola.
- Jodie Millar: 11-25 September, 128 hrs – Quoll trapping trip Red Hill.
- Sasha Ayton: 11-25 September, 128 hrs – Quoll trapping trip Red Hill.

Kuruma Marthudunera Traditional Owners

- Arnold Bobby and Brendon Bobby: 23-27 October – Quoll camera collection Yarraloola and Red Hill.
- Brendon Bobby and Joshua Evans: 23 May – Instillation of 1080 signage with Alicia Whittington.

Media

Russell Palmer (DBCA), William Ross (PhD student CDU) and Russell Thomas (RIO) interviewed by Kendell O'Connor (ABC North West WA) at Yarraloola 27-28 April 2017. Story titled "WA's northern quolls learning to avoid toxic feral cat baits" by Kendall O'Connor posted on the ABC News website 14 May 2017 http://www.abc.net.au/news/2017-05-14/northern-quolls-may-be-learning-to-avoid-toxic-baits/8524890

The story aired on the Western Australian Sunday night ABC News on the 14 May 2017 https://www.facebook.com/abcnorthwestwa/videos/10154417561676811/.

Publications

Annual Report

Palmer R, Anderson H, Angus J, Garretson S, Morris K (2017). Predator control baiting and monitoring program, Yarraloola and Red Hill, Pilbara region, Western Australia: 2016 annual report, year 2. Department of Parks and Wildlife, Woodvale, WA.53 p.

Popular magazine

Palmer R, Anderson H, Angus J, Thomas R (2017). Who takes the bait? *Landscope* **32**, 39–44.

Scientific Papers

Moro D, Dunlop J, Williams, M R (in review) Juvenile survivorship is critical to northern quoll population viability. *Wildlife Research*.

Cat diet data from this project was used in a meta-analysis of 85 cat dietary studies from across Australia to help model, map and estimate the number of birds and reptiles killed by feral cats.

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