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Predator Control Baiting and Monitoring Program, Yarraloola and Red Hill, Pilbara Region, Western Australia. 2016 Annual Report - Year 2.

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

2016 Annual Report -Year 2

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Science and Conservation Division

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Cover photograph: Northern quoll (Dasyurus hallucatus) captured on camera trap inspecting and then ignoring pinned Eradicat® baits (toxic and non-toxic) during the bait uptake trial.

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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 2016 was developed in liaison with Caitlin O'Neill, Russell Thomas and Melinda Brand (Rio Tinto). Russell Thomas, Brian Dalton and Philip Curry (Rio Tinto) ensured our safety on site and facilitated the field work and other project logistics for Pannawonica and the Yarraloola land management area.

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The Parks and Wildlife Western Shield baiting team coordinated the aerial baiting program for this project. Rob Brazell (Parks and Wildlife) provided the non-toxic baits for the bait uptake trials. Alicia Whittington (Parks and Wildlife, Pilbara region) coordinated the feral cat baiting program and provided assistance with equipment and safety logistics. We are grateful for the field assistance provided by volunteers Susie Stockwell, Andrew Irvine, Talitha Moyle, Merryn Pryor and Annika Baynham. Thank you to Tom Dimaline (UK intern) for help processing camera image data. Dr Colleen Sims provided field assistance and veterinary expertise for collecting whisker and blood samples from quolls. PhD student from Charles Darwin University, William Ross provided an additional pair of hands in the field, which was much appreciated. Sarah Comer (Parks and Wildlife) and Peter Speldewinde (The University of Western Australia) performed the cat occupancy modelling.

Drafts of this report were reviewed by Parks and Wildlife Science and Conservation Division staff and Russell Thomas 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

The recent Australian Mammal Action Plan 2012 warned that a large proportion of the threatened or near-threatened mammal species in Australia are at risk from predation by feral cats. The urgent call for action to prevent further mammal extinctions has led to feral cat control highlighted as both a policy and management priority in the federal government's 2015 Threatened Species Strategy for Australia. Broadscale aerial baiting using the toxic *Eradicat®* bait developed by the Department of Parks and Wildlife is regarded as the most successful technique for controlling feral cats at the landscape scale on the Australian mainland. However, questions remain as to the potential risks of operational baiting programs on native carnivores, such as the endangered northern quoll. Because of these risks, *Eradicat®* is currently not registered for operational use in the Pilbara and other areas of Western Australia where the effects on potential non-target species have not been quantified.

As part of an environmental offset condition for Rio Tinto's Yandicoogina Junction South West and Oxbow Iron Ore Expansion Project, they were required to prepare a Threatened Species Offset Plan (TSOP) that implements management actions to benefit the Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act) listed northern quoll (*Dasyurus hallucatus*) and Pilbara olive python (*Liasis olivaceus barroni*). A key component of the approved TSOP is to control feral cats within the Yarraloola Land Management Area (LMA), a large offset area located in the western Pilbara. Based on the evidence of low risk to northern quolls from the experimental *Eradicat®* baiting trial undertaken at this site in 2015 (Morris *et al*. 2015), a research permit was granted by Australian Pesticides and Veterinary Medicines Authority to aerially bait with *Eradicat®* ~150 000 ha of the Yarraloola LMA 2016-2019.

In the second phase of the project, research has shifted towards the operation of the cat baiting program and measuring its success in reducing cat numbers. Sixty camera trap monitoring sites for feral cat were established across both Yarraloola (baited site) and Red Hill (unbaited site) to monitor the efficacy of the cat baiting program. The probability of occupancy by feral cats was assessed based on data gathered for 25 camera trap-nights at each of the 60 camera sites prior to, and following the baiting in both the treatment and control sites. After several delays due to rain, *Eradicat®* baits were aerially distributed over 144 100 ha of the Yarraloola LMA in late July 2016. A significant decline in the probability of feral cat occupancy was recorded following the baiting, but the magnitude of this decline was greater in the control site (Red Hill) than the treatment site (Yarraloola). A possible explanation for this unexpected finding may be due to the delays to the baiting program, and the subsequent rescheduling of the post-baiting cat monitoring. The timing of this camera trapping session probably coincided with the female cats giving birth and then caring for their young kittens, resulting in reduced mobility and changes to their activity levels. However, very few cats were detected on Yarraloola after the baiting, with only seven cats recorded in ~1500 camera trap-nights.

No mortality of northern quolls was detected due to the baiting and there was no evidence that sub-lethal exposure to 1080 had any impact on reproductive success of quolls inhabiting the Yarraloola LMA. Capture rates of both female and male quolls were similarly low across

the Yarraloola LMA and Red Hill, and these did not differ from the capture rates recorded in 2015. These early results provide strong indications that broadscale feral cat control using *Eradicat*® does not negatively impact upon co-occurring northern quoll populations. This was supported by evidence gathered via the monitoring of toxic *Eradicat*® baits using camera traps under field conditions. Northern quolls were recorded taking some of the toxic baits, but their encounters with these baits appeared to be non-lethal and they learnt rapidly from what was probably an unpleasant experience to then avoid *Eradicat*® baits.

We provide further information on other relevant baseline data gathered during the course of the 2016 field program. We also discuss plans to utilise this data to improve aspects of the feral cat monitoring program and to explore the likely behavioural responses by northern quolls to reduced competition from feral cats within the cat-baited Yarraloola LMA.

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*). This plan provides details of measures to control and/or manage introduced predators, feral herbivores, unmanaged fires and invasive weeds, and monitoring programs to detect changes in abundances of northern quolls and Pilbara olive pythons in the offset area (Rio Tinto 2014). The defined offset area was the Yarraloola Land Management Area (LMA), which covers approximately 150 000 ha and encompasses a large portion of the Yarraloola pastoral lease and a smaller part of adjoining unallocated crown land. The LMA is located approximately 15 km to the southwest of Pannawonica in the western region of the Pilbara.

A core component of the TSOP was the development and implementation of an introduced predator control program (Morris and Thomas 2014). This program focusses on the control of feral cats given their significant detrimental impact on native fauna, in particular on mammals. 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 and Burrows 2004; Algar *et al*. 2007; Short *et al*. 1997). However, this bait is not registered for operational use in areas of Western Australia where potential non-target species, such as the carnivorous quolls occur, due to the potential risk of toxic bait consumption.

To assess the impact of using feral cat baits in the presence of northern quolls in the Pilbara, a study examining the survivorship of northern quolls and their uptake of toxic *Eradicat*® baits was undertaken from May–October 2015 in the LMA. The impact of toxic feral cat baiting was assessed by monitoring the survivorship of radio-collared northern quolls at an experimental baited site (20 000 ha) within the LMA and comparing this with quoll survivorship at an unbaited site on the adjacent Red Hill pastoral lease.

Ten deaths were confirmed amongst the 41 radio-collared quolls across the baited cell and control site on Red Hill, but none were attributed to 1080 poisoning (Morris *et al*. 2015). The finding that aerial baiting using meat-based baits containing the compound 1080 for controlling feral cats has no observable impact on local radio-collared quoll populations, is consistent with similar studies [using wild dog baits] on northern 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).

Morris *et al*. (2015) reported that predation by feral cats was the major cause of mortality amongst the radio-collared quolls. They concluded that baiting with *Eradicat*® in winter for feral cats is unlikely to have a detrimental impact on northern quolls in the Yarraloola LMA, but predation by feral cats is likely to contribute to the long-term decline of this population. They recommended expanding the feral cat baiting program to an operational landscape scale of 150 000 ha as proposed by Morris and Thomas (2014).

2 Introduction

Feral domestic 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 and b; Woinarski *et al*. 2014; 2015). The recent 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 under the recently released 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 establishes a national framework to guide and coordinate Australia's response to the impacts of feral cats on biodiversity. It identifies 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" (page 11, Commonwealth of Australia 2015a).

However, prior to *Eradicat*® being registered for operational use in the Pilbara, further research and monitoring is required to redress deficiencies surrounding the potential non-target impact of 1080 poison baiting for feral cats on a range of native mammals, particularly at-risk carnivores such as the northern quoll. This carnivorous marsupial is the largest predatory dasyurid remaining in northern Australia (Cramer *et al*. 2016). The distribution of the northern quoll formerly extended across the northern third of Australia. Now it occurs in smaller disjunct populations across this range in Queensland, Kimberley and Northern Territory, and areas throughout the Pilbara of Western Australia (Braithwaite et al. 1994; Cramer *et al*. 2016). In 2005, the northern quoll was listed as an endangered species under the Commonwealth's EPBC Act. This was due to the decrease in its range and population size. Predation by feral cats contributed to their decline and continues to pose a severe threat to mainland quoll populations (Braithwaite *et. al*. 1994; Hill and Ward, 2010; Woinarski *et al*. 2008; Woinarski *et al*. 2014). 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 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.

While 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) suggests they would only need to ingest a single toxic cat bait containing 4.5 mg of 1080 to be at risk. Calver *et al*. (1989) identified that in the laboratory, the northern quoll was at risk from accidental poisoning from crackle baits containing 6 mg of 1080 for dingo control. However, King (1989) and Morris *et al*. (2015) both showed that aerial baiting programs did not pose a hazard to free ranging northern quolls. Such discrepancies between estimated bait toxicity and actual poisoning of quolls require further resolution under field conditions (Jones *et al*. 2014).

The aims of this program for 2016 were to:

1) conduct broadscale aerial and ground baiting using *Eradicat*® bait 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 of broadscale feral cat baiting on northern quoll populations by comparing their abundance and demographics over time within a treatment (baited) and control site (Red Hill); and
4) investigate the mechanism/s that allows northern quolls to routinely survive aerial baiting programs in the Pilbara.

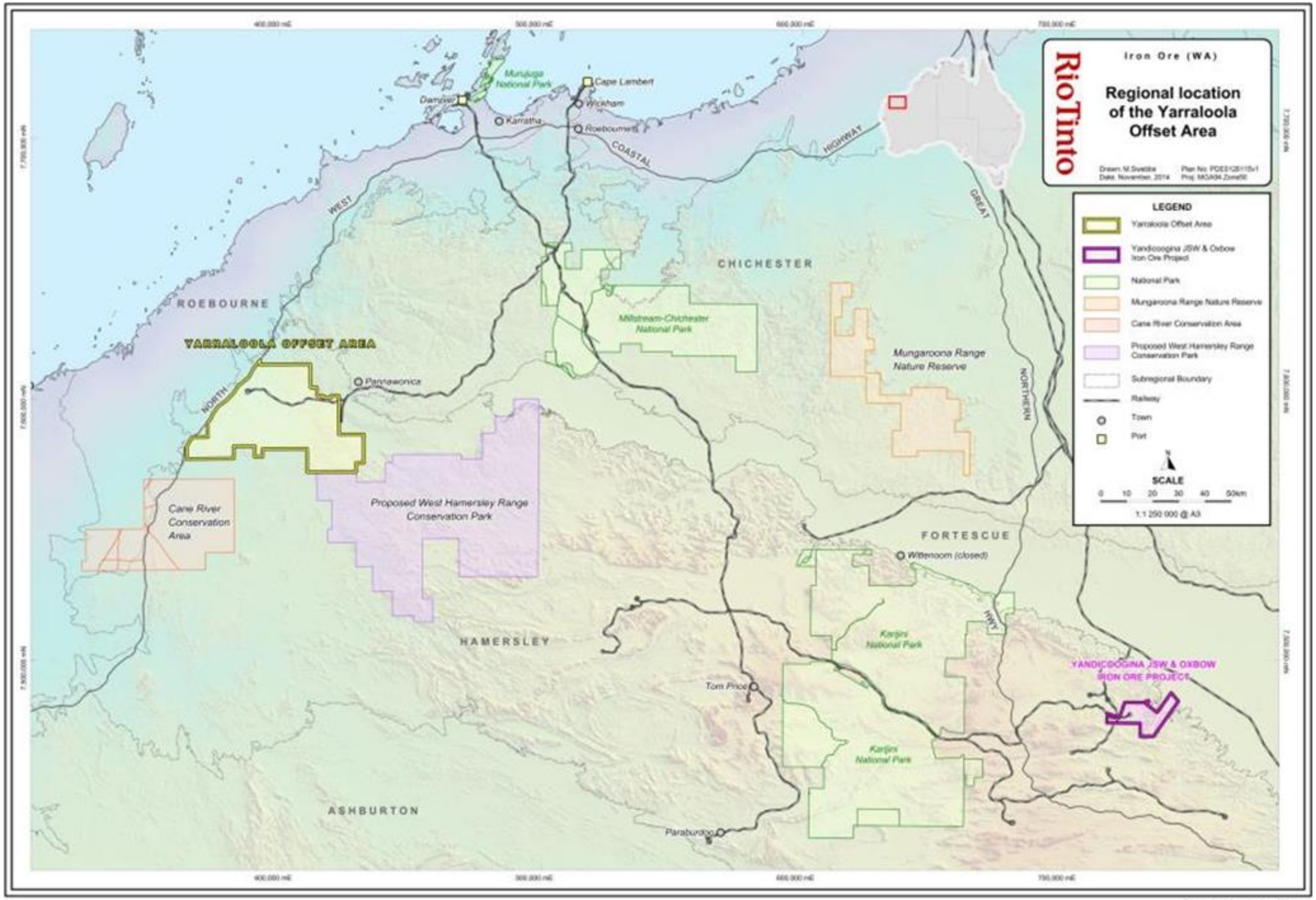


Figure 1 Regional location of the Yarraloola Land Management Area in the western Pilbara region of Western Australia.

3 Methods

3.1 Study sites

The study was undertaken on the Yarraloola LMA (~150 000 ha) and Red Hill (~190 000 ha) pastoral lease in the western Pilbara region of Western Australia. The Yarraloola LMA is approximately 120 km southwest of Karratha and 75 km east of Onslow near the Pilbara coast (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 and was used as a control (no cat baiting treatment) site for Yarraloola.

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).

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 western 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 prep).

To determine the impact of the baiting program under the TSOP, Morris and Thomas (2014) recommended the use of the feral cat monitoring methods Parks and Wildlife have developed and used for the past five years to measure site occupancy pre- and post-baiting in the Fortescue Marsh feral cat baiting program (Comer *et al*. in prep).

3.3.2 Camera trap design and occupancy modelling

Camera trap monitoring arrays were established using and adapting the methods of Clausen *et al*. (2016). Cameras (HyperFire™ PC900; Reconyx, Wisconsin, USA) were set horizontally, attached to a plastic peg approximately 30 cm above the ground and oriented to face south, away from direct sun. They were programmed on ‘Aggressive’ to take five pictures at up to two frames per second upon a trigger. There was no quiet period between triggers. A ‘lure pole’ with visual and olfactory lures for feral cats was set 3 m in front of each camera. The lure pole 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 bamboo cane with three white turkey feathers taped obliquely at its midpoint and a 30 cm length of silver tinsel secured to the top of the cane (Plate 1). Vegetation was trimmed from the detection zone of the camera to minimize false triggers caused by moving vegetation.

The Fortescue Marsh cat study occurs on a flat and open landscape (Clausen *et al*. 2016), which contrasts greatly with our western Pilbara sites featuring rugged mesas and ranges. As such, it was not feasible to replicate the grid formation placement of camera traps used in that study. Instead, we set cat cameras from the existing road networks, which enabled broader coverage of the Yarraloola LMA (baited) and Red Hill (control) sites. GIS mapping tools (ArcMap and QGIS) were used to generate semi-randomised camera points that were situated within walking distance of roads (50 m to 400 m either side) and at least 3 km from the closest neighbouring camera (Figure 2 & 3). 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 and there was a buffer of ~14 km between the bait cell and the nearest cat camera on Red Hill. It was possible to place 60 cat camera traps from the roads on both Yarraloola and Red Hill (Figure 2 & 3).

Cat camera trap sites were set-up on both Yarraloola and Red Hill stations between 24–28 May for the pre-baiting period. An attempt was made to collect these cameras between 20–22 June, but heavy rains only allowed for the collection of 45 and 20 cameras from Red Hill and Yarraloola, respectively. The remaining cameras were collected in late July coinciding with the aerial baiting. For the post-baiting monitoring, the cameras were reset on Red Hill between 9–12 August and 16–19 August for Yarraloola. Cameras were then collected between 8–17 September on the quoll monitoring trip. During the period between the two monitoring sessions, cameras and lures were removed to prevent cats from becoming accustomed to them. Note that most of the cameras on Yarraloola were in place for an additional month prior to the baiting.

Bayesian occupancy models were run in WinBUGs 1.4, using detections histories from the treatment (Yarraloola) and control (Red Hill). A random effects model, which assumes detection probability is not constant, was used to determine site occupancy at both the treatment and control. 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 prep).

All images were downloaded from the camera trap SD cards and uploaded into the photo database program ‘CPW Photo Warehouse’ (Ivan and Newkirk 2015). 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’, ‘small *Ctenotus* skinks’, ‘large *Ctenotus* skinks’, etc. Experts were consulted to confirm the identification of some bird species. CPW Photo Warehouse was used to manage this data and to generate the capture event results for cats for the occupancy modelling. We quantified capture events 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.

Interference at our cat camera sites by inquisitive cattle was a problem during the pre-baiting monitoring session. Cattle knocked over numerous cameras and/or lure poles when the ground was wet after the heavy rains. The time and date when individual cameras were rendered inoperable was noted (i.e. reduced sampling effort). To minimise further data loss, we reinforced our cat camera trap sites for the post-baiting monitoring session. The bamboo canes were replaced with metal curtain rods and extra pegs were used to strengthen mountings (Plate 1).

Plate 1 Feral cat camera trap monitoring site

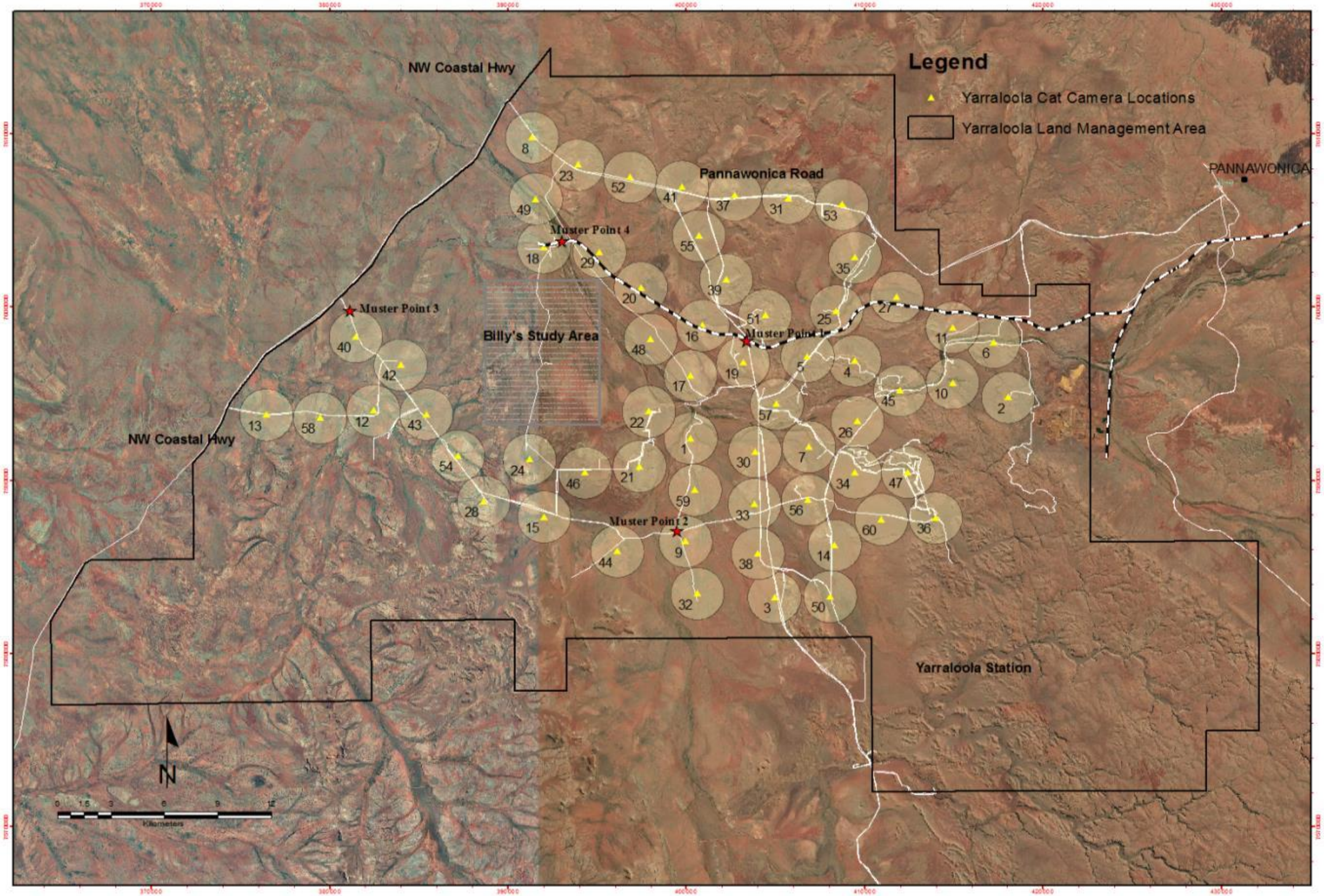


Figure 2 Cat camera locations and buffers on the Yarraloola LMA baited site.

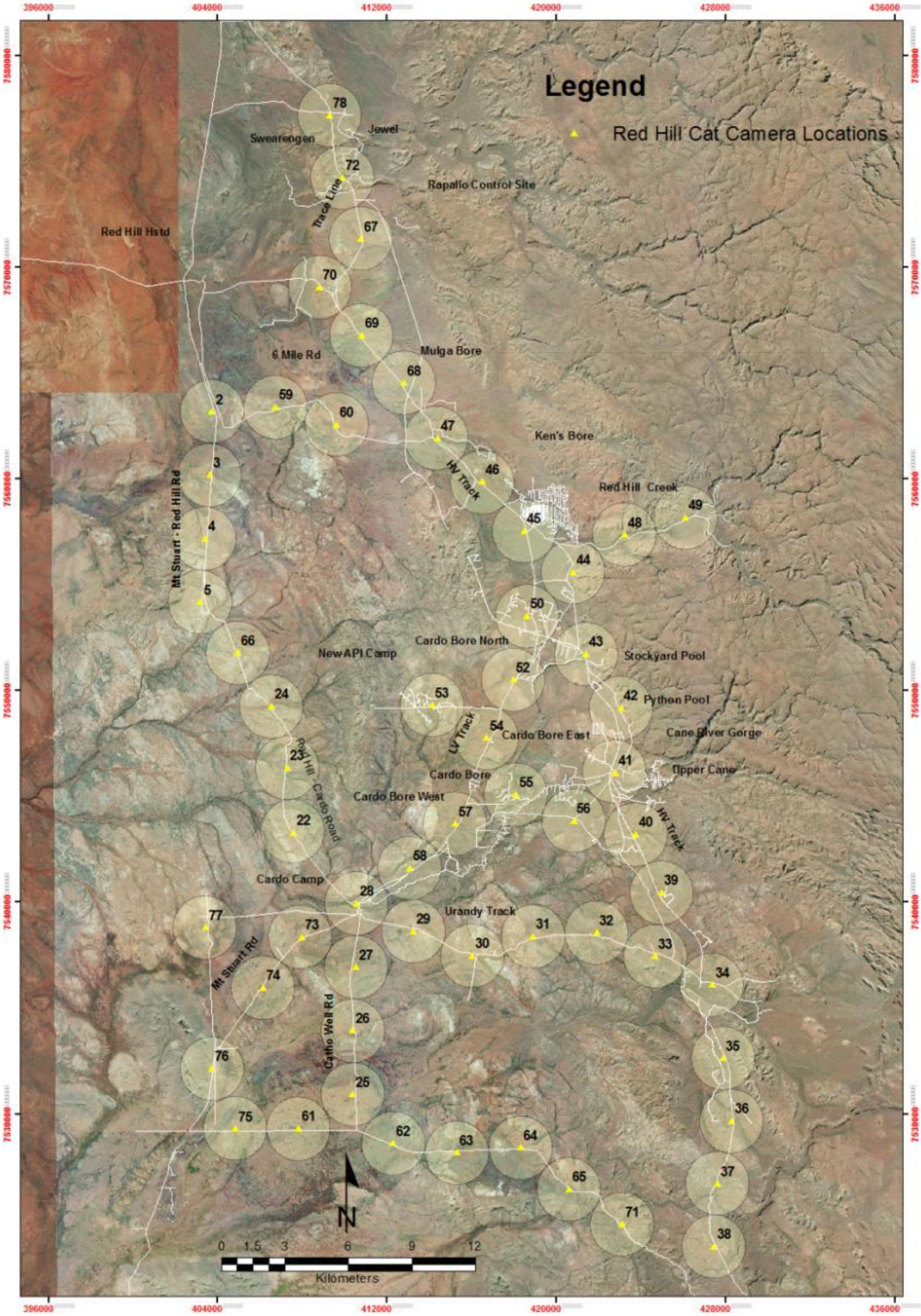


Figure 3 Cat camera locations and buffers on the Red Hill control (un-baited) site.

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 APVMA permit was issued on the 29 June 2016 and is valid until 30 November 2019.

The *Eradicat®* feral cat baits were manufactured at the Parks and Wildlife 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 Biomarker

In addition, the baits used at Yarraloola were also impregnated with the non-toxic biomarker rhodamine B at a dosage rate of 350 ml to 150 kg of sausage mix. Rhodamine B is a widely used systemic biomarker that has proved effective as an indicator of bait consumption in other quoll species (Claridge *et al*. 2006; de Tores *et al*. 2011). Once rhodamine B is consumed, the dye enters the animal's bloodstream and is incorporated into growing tissue, hairs and whiskers. Its presence is detected by staining, usually as bands of fluorescence, in hair and whiskers of mammals. Detection in most species and individuals requires the use of ultraviolet (UV) illumination or a fluorescence microscope. The period between ingestion and the first detection of the marker in whiskers pulled from mammals ranges from < 40 hr to 2 months (Fisher 1998).

The purpose of adding rhodamine B to *Eradicat®* baits in this study was to determine if individual northern quolls living in the bait cell (Yarraloola LMA) were consuming the bait (or part thereof) and then surviving to be captured during the quoll monitoring program in September.

3.4.3 Bait preparation and aerial baiting

The baiting operation was coordinated from the Mt Minnie Station airstrip located 50 km to the southwest of Yarraloola. On the 26th July, after numerous delays due to wet weather, the baits were unloaded from the truck and thawed in direct sunlight on 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 an ant deterrent compound (Coopex®) at a concentration of 12.5 g/L as per the manufacturer's instructions. Coopex® prevents bait degradation by ant attack and therefore enhances acceptance of baits by cats through limiting the physical presence of ants on and around the bait medium.

Aerial baiting of the Yarraloola LMA took place on 26–27 July 2016. This was conducted under the Parks and Wildlife Western Shield aerial baiting contract by Thunderbird Aero Service, 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 baits 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^2 were distributed through a carousel to give an approximate 200 m long by 40 m wide bait swathe.

3.4.4 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 during the aerial baiting and immediately after [26–30 July], then again two weeks later [15–20 August] and then for an extended period between 5–19 September (See Appendix 1 for fieldwork activities undertaken). During these three 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 2–5).

3.5 Northern quoll monitoring

3.5.1 Trapping design and selection of additional sites

As part of the research program undertaken in 2015, a trapping protocol was developed to monitor the relative abundance of northern quoll populations on Yarraloola and Red Hill (Morris *et al*. 2016). Because quolls were found to occur in low densities in areas of core habitat across these sites, modifications to the recommended standardised quoll monitoring procedures for the Pilbara (Dunlop *et al.* 2014) were deemed necessary. Instead of using 50 cage traps at 50 m spacing, Morris *et al*. (2016) recommended using 20 traps at 25 m spacing for four nights. This reduced trapping effort was shown to be as effective at trapping all the quolls in the immediate area, but with less effort. The presence of radio-telemetered quolls in the vicinity of trapping lines further reinforced the modification of the trapping protocol to suit the local conditions.

The low numbers of individual quolls (mean of 1.0 female and 1.9 males) recorded at each monitoring site in 2015 meant that additional sites were required to provide sufficient power to detect significant changes in the quoll populations. An additional seven sites at Yarraloola and eight sites at Red Hill were recommended so that a total of 18 sites in each area could be used for northern quoll monitoring from 2016–2019. Timing is a key issue for monitoring quoll populations as the pronounced movement behavior of males at certain times of the year may have a strong influence on capture rates and most males also die-off after mating. September was identified as the most suitable month for trapping in terms of maximising the collection of demographic information from females and it is just prior to the annual male die off (Morris *et al*. 2016).

Eleven of the existing trapping sites on Yarraloola and ten on Red Hill were deemed suitable for continued use, which meant seven and eight additional sites, on the respective properties had to be chosen. A reconnaissance trip of the area was undertaken in April 2016 whereby two camera traps, baited with a punctured tin of tuna, were placed along potential new quoll trapping lines on both properties. These cameras were collected after ~30 days and the new sites were selected according to the levels of quoll activity, the mix of core quoll habitat types (i.e. riverine, rocky mesa habitat, gorge systems, etc.) and the distribution of sites across the study areas. On Yarraloola, the new monitoring sites selected were Q, P, R, T, M, N and O (Figure 4). For Red Hill, the new sites were SW, Z, X, KB, PP, CL, RL and CW (Figure 5). Monitoring for northern quolls at these sites will continue each year until at least 2019.

3.5.2 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 linear transects (500 m) to trap quolls. Traps were placed in sheltered, shady locations and covered with a hessian bag for additional protection from the heat and harassment from other animals. All trapped quolls were weighed, measured and sexed, and a small tissue sample taken from each ear for DNA analysis. Each new quoll was implanted with a unique Passive Integrated Transponder (PIT); Allflex® 12 mm FD-X transponder (Allflex Australia, QLD, Australia) to recognise individuals. For females, reproductive condition was assessed and pouch young were counted and described, if present. Other species captured were also recorded, weighed, measured and temporarily marked, either by trimming a small patch of fur or using a non-toxic marker pen. Tissue samples were taken from *Pseudantechinus* sp. as there is uncertainty over the identity of this species. After examination, animals were released immediately at the site of capture. All trapping data was entered into the Yarraloola Project MS Access database.

3.5.3 Whisker and blood sampling of northern quolls

During the trapping a sub-sample of captured quolls from both sites were anaesthetised in the field with isoflurane gas, administered via a face-mask, and up to eight whiskers were removed from each individual and put into appropriately labelled zip-lock bags (Claridge *et al*. 2006; de Tores *et al*. 2011). This process was undertaken by registered veterinary surgeon and Parks and Wildlife staff member Dr Colleen Sims. Whiskers were also taken from quolls outside the baited cell on Red Hill to test for naturally occurring background levels of fluorescence (de Tores *et al.* 2011).

While quolls were anaesthetised, a sample of up to 1 ml of blood was taken with a small syringe inserted into the quolls' tail vein. Samples were spun using a centrifuge and stored in a freezer. This component was done in collaboration with PhD student William Ross of Charles Darwin University.

Whisker samples were processed in the laboratory at Woodvale by John Angus and Hannah Anderson in December 2016. Each whisker was washed in 100% ethanol and then distilled water to remove any dirt or debris and left to air dry. Samples were then mounted onto glass slides ready for microscope analysis. Fluorescence microscopy, as described in Fisher (1998), was used to detect rhodamine B marking in the quoll whiskers.

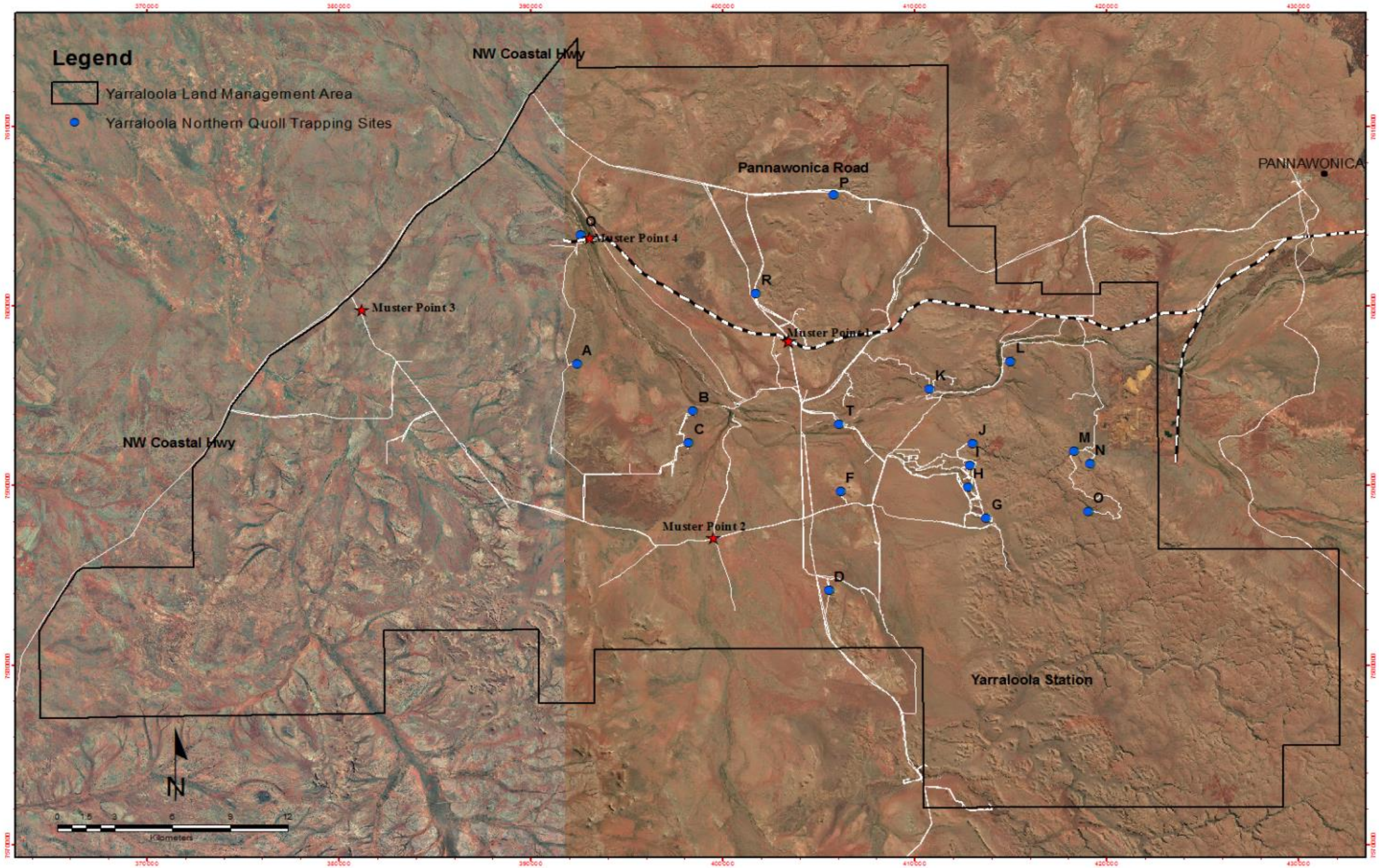


Figure 4 Locations of northern quoll trapping sites on the Yarraloola LMA, sites Q, P, R, T, M, N and O were only monitored in 2016, the rest were surveyed in 2015 and 2016.

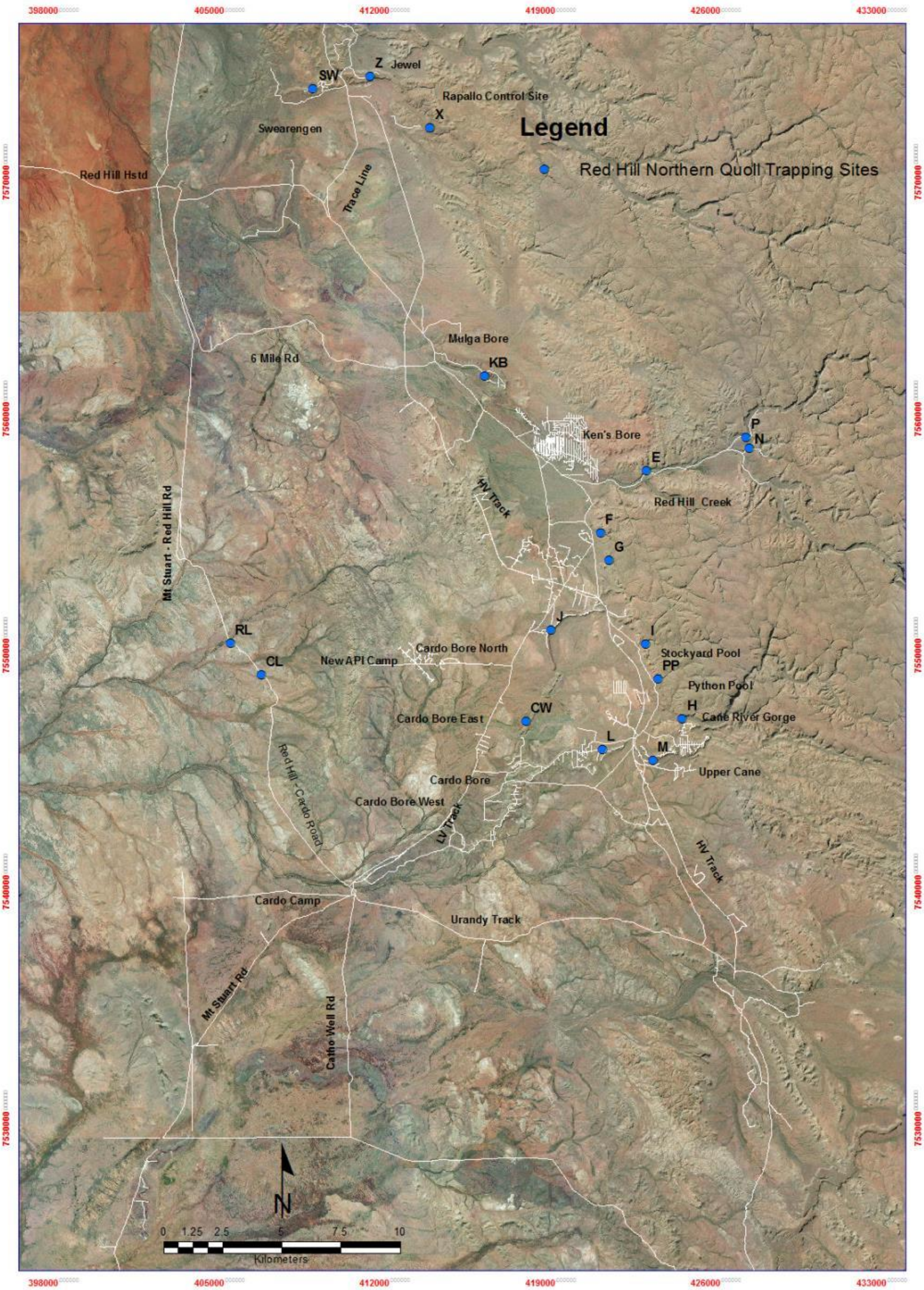


Figure 5 Locations of northern quoll trapping sites on the Red Hill control site, sites SW, Z, X, KB, PP, CL, RL and CW were only monitored in 2016, the rest were surveyed in 2015 and 2016.

3.6 *Eradicat®* bait uptake trails

3.6.1 Background

As mentioned in Section 2, laboratory trials and desktop risk assessments potentially place northern quolls at risk of accidental poisoning if they consume a single *Eradicat®* or 1080 wild dog meat bait. Yet there is no evidence that northern quolls succumb to aerial baiting campaigns targeting wild dogs or feral cats in the Pilbara. The actual mechanism by which quolls routinely survive these 1080 poisoning programs in the Pilbara remains uncertain (King 1989; Morris *et al*. 2015). Studies suggest there are several potential mechanisms that reduce the risk of quolls from being exposed to a lethal dose of 1080 when presented with toxic baits. These mechanisms include;

- Some species of dasyurids are known to reduce food uptake when presented with 1080-laced baits (Sinclair and Bird 1984).
- Quolls may consume a single *Eradicat®* bait, develop symptoms of poisoning, but survive. They may then avoid eating any further toxic baits they encounter. Note: *Eradicat®* baits are dropped in clusters of 50, so once a quoll encounters one bait then the likelihood of them encountering more baits is high.
- Carnivores are known to regurgitate 1080-laced baits (McIlroy 1981).

A pilot bait uptake trial in June 2016 on Yarraloola using non-toxic *Eradicat®* baits demonstrated that northern quolls were keen scavengers and they readily located and consumed these non-toxic meat baits. Whatever the mechanism that allows quolls to survive toxic baiting programs, it appears likely that individuals will stop eating baits once they have attempted to consume one or more toxic *Eradicat®* baits. In contrast, individuals exposed to non-toxic versions of the bait will continue to consume baits as they encounter them. This experiment also allowed us to monitor bait uptake by the target species [feral cats] and other non-target species.

3.6.2 Bait uptake experiment

Three exclusion zones (1.7 km^2) covering mesa sites were added to the aerial baiting cell for Yarraloola. Instead of receiving aerially dropped baits, 20 toxic baits were pinned to the ground by hand (cover photograph) over a similar area (200 m by 40 m) that the aerial baits [usually 50] would have fallen. Camera traps were set to monitor each bait using the same settings as for the cat monitoring cameras. Toxic cat baits were handled by 1080 trained personnel. At the Red Hill control site, we established a single “drop site” of 20 non-toxic baits and camera traps in similar mesa habitat. This experiment was set-up on the days the aerial baiting occurred (26-27 July 2016; Trial 1 in Table 1).

When triggered, cameras recorded a series of five photographs that were used to identify the species and their interactions with the pinned bait. Anchoring baits slowed their removal by animals and increased the number of camera trigger events allowing better interpretation of each interaction. Where possible, images of quoll spot patterns were used to identify individuals according to their unique spot patterns.

To determine if individual quolls exposed to toxic *Eradicat®* baits learnt to not eat the bait or avoid the toxin (1080 in the bait), we then re-exposed quolls to new non-toxic baits (Trial 2 in

Table 1). At Yarra 3, the ten uneaten toxic baits left from Trial 1 were removed and disposed, whereas the remaining toxic baits were left *in situ* at the Yarra 1 and 2 sites. The second trial was monitored using camera traps for a further 4 weeks (mid-August to mid-September).

Here we only present the data for instances where 'bait take' was confirmed by the camera trap. Bait take was defined as an animal consuming all of the bait or being captured on camera taking bait out of the field of view of the camera. Analysis of the 'nil take' data, animal detected by the camera at or in the vicinity of the bait but there were no images to show the animal interacted with the bait or they only nibbled at the bait, is yet to be completed. This nil take data will be included the publication of this bait uptake experiment.

Table 1 Experimental design for the two bait uptake experiments undertaken from July to September

Site	Trial 1	Dates exposed	Trial 2	Days exposed
Yarra 1	20 toxic baits	24 (26/7-19/8)	20 non-toxic baits added (20 toxic baits left *in situ*)	28 (19/8-16/9)
Yarra 2	20 toxic baits	25 (26/7-20/8)	20 non-toxic baits added (17 toxic baits left *in situ*)	26 (20/8-15/9)
Yarra 3	20 toxic baits	24 (26/7-19/8)	20 non-toxic baits added (toxic baits removed)	27 (19/8-15/9)
Red Hill	20 non-toxic baits	22 (27/7-18/8)	20 non-toxic baits added	30 (18/8-17/9)

3.7 Predator diets and incidental/opportunistic records

3.7.1 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. Northern quoll scats were collected from traps during the 2015 field work. We continued to collect northern quoll scats from traps and extended our search effort to include quoll scats found at camera sites in 2016. Targeted roadside searches were used for the collection of dingo and cat scats. Additionally, predator scats encountered opportunistically while undertaking field work were collected. 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.

3.7.2 Other records

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

4 Results

4.1 Feral cat baiting

Once the aerial baiting conditions under the code of practice were imposed on the overall Yarraloola LMA, the final area of the bait cell was 144 100 ha [118 600 ha Yarraloola pastoral lease and 25 500 ha unallocated Crown land] (Figure 6). Key exclusion areas were the mine sites at Mesa A and J, public roads and waterholes along the Robe River. The three additional aerial bait exclusion areas (black circles) in Figure 6 were used for the bait-uptake experiment.

The Pilbara experienced a dry summer in 2016. However, there were widespread and unseasonal rains in the lead-up to the initial planned baiting date in early July, with Pannawonica receiving 130 mm and 63 mm of rain in June and the first half of July, respectively (Australian Bureau of Meteorology 2017). Most of the July rain fell on the first six days of the month and the ground surface was dry enough by the 26–27 July for baiting. There was no further rain in July after the baiting and only two minor falls of 0.8 mm and 1.2 mm were recorded on different days in August (Australian Bureau of Meteorology 2017).

The Parks and Wildlife ground crew at Mt Minnie reported that 61 000 *Eradicat*® cat baits were dropped by the aircraft over the two days. This was far fewer than the estimated 72 000 baits required to cover the aerial bait cell at the prescribed rate of 50 baits km^{-2}. On downloading the GPS data from the baiting equipment in the aircraft, the Western Shield baiting coordinator confirmed that the aerial baiting contractor had flown the correct baiting flight lines within the bait cell but the baits were not applied at the required rate (Figure 6). Baits were dropped at the majority of the 1 km spaced sites to be baited, however it was evident from the number of dots mapped that the rates were variable at these drop sites [one dot indicates ~10 baits passed through the baiting chute. The average application rate over the entire bait cell was 41 baits km^{-2}.

Due to the numerous weather enforced changes to the planned baiting dates, ground baiting for cats within the aerial baiting exclusion zone (250 m wide either side) along the Pannawonica road was abandoned.

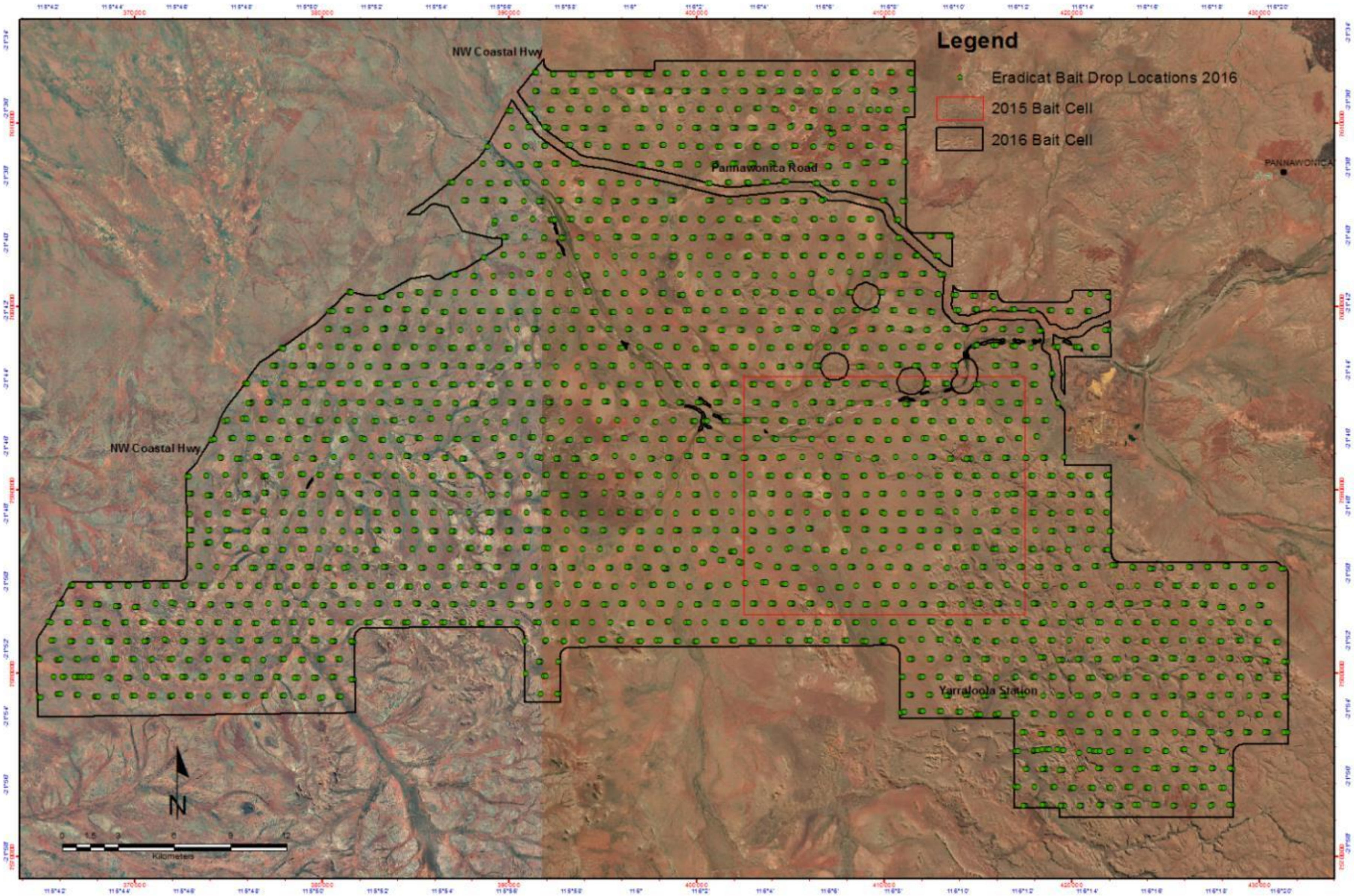


Figure 6 The Yarraloola LMA bait cell for 2016 and the distribution of baits on the 26 and 27 July. The bait exclusion areas within the LMA are bounded by a bold black line. The 20 000 ha trial bait cell used in 2015 has the red boundary.

4.1.1 Detection of non-target species deaths

No carcasses of non-target species were observed following the baiting on the three field trips undertaken by project staff members in July, August or September. A single feral cat carcass was located on the 6th September in a creek line at the start of the quoll monitoring line J (21.7706ºS 116.1577ºE) (Plate 2). We were unable to confirm how the cat died but the stage of decomposition of the carcass suggested that it could have taken a toxic bait.

Plate 2 Dead cat found on the Yarraloola LMA

4.1.2 Biomarker detection in quoll whiskers

Whiskers were extracted from 11 females and 6 males captured inside the bait cell on Yarraloola and 6 females and 2 males from Red Hill (no baiting). No distinctive banding of rhodamine B was observed in any of northern quoll whisker samples. Both observers (JA and HA) detected rhodamine B banding in the reference samples from an eastern quoll and common brushtail possum.

4.2 Feral cat monitoring

Due to disruptions of the field schedule caused by the wet weather, many of the camera traps used for the feral cat monitoring prior to and after the baiting program within the treatment (Yarraloola LMA) and control (Red Hill) cells were operational for longer than required. 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 control sites to calculate occupancy before and after baiting.

The possible camera trapping effort was 1500 camera trap nights per session and location. For the pre-bait session, cattle interference at approximately 15 camera sites on both Yarraloola and Red Hill reduced effort to 1292 and 1267 camera trap nights, respectively.

Reinforcing camera sites and limited rain saw only 15 nights on Yarraloola and 28 nights on Red Hill being lost for the monitoring session after the baiting. The camera sites where cats and/or quolls were recorded for both camera trapping sessions on Yarraloola and Red Hill are shown in Figures 7 & 8.

On Yarraloola, cats were detected on 14 nights at 11 different camera traps before the baiting and then on 7 nights at 6 cameras after baiting. For Red Hill, cats were detected on 20 nights at 16 cameras before baiting and then on 11 nights at 8 cameras after baiting. Few of the cameras detected cats on multiple nights and there was only one instance where a camera detected cats on three different nights (C63 Red Hill post-bait session; Figure 8).

Quolls were also attracted by the 'Catastrophic' and visual lures. They were generally detected on more nights than cats but visited fewer cameras. For Yarraloola, quolls were found on 23 nights at 7 cameras before baiting and 29 nights at 11 cameras after baiting. On Red Hill, it was 25 nights at 12 cameras before and 15 nights at 8 cameras after. Occupancy rates of camera sites by quolls tended to be higher than for cats, with quolls being recorded on up to 6–7 nights out of the 25 on some cameras. Examination of the quoll images suggests that a large proportion of these visits were by males in the lead up to or during the breeding season. Whether or not these data will be informative in terms of site occupancy modelling requires further examination.

Very few dingoes were detected on the cat cameras. On Yarraloola, there was one record before the baiting (C55, 7 June) and one after (C29, 1 Sept; Figure 7). For Red Hill, there were three detections (C24, 29 May; C45, 27 May; C46, 11 June) before and one after (C24, 12 Sept; Figure 8). No foxes were recorded.

Spatial overlap according to camera detections of the predator species present (dingoes/cats/quolls) was not common. Both cats and quolls were detected at a single camera site on Yarraloola and at four camera sites on Red Hill (Figure 7 & 8). On Red Hill a cat and quoll were recorded on the same night several hours apart on camera 30. Dingoes overlapped with cats on Yarraloola C29 and Red Hill C24 and with quolls at Red Hill C45 and C46.

Numerous other species of mammals, birds and reptiles were also detected by the camera traps. Currently only the birds have been identified to species level, with 33 species being detected on Red Hill and 22 on Yarraloola (Appendix 3 for complete list). One of the unusual mammal records was the detection of brushtail possums (details in Appendix 3).

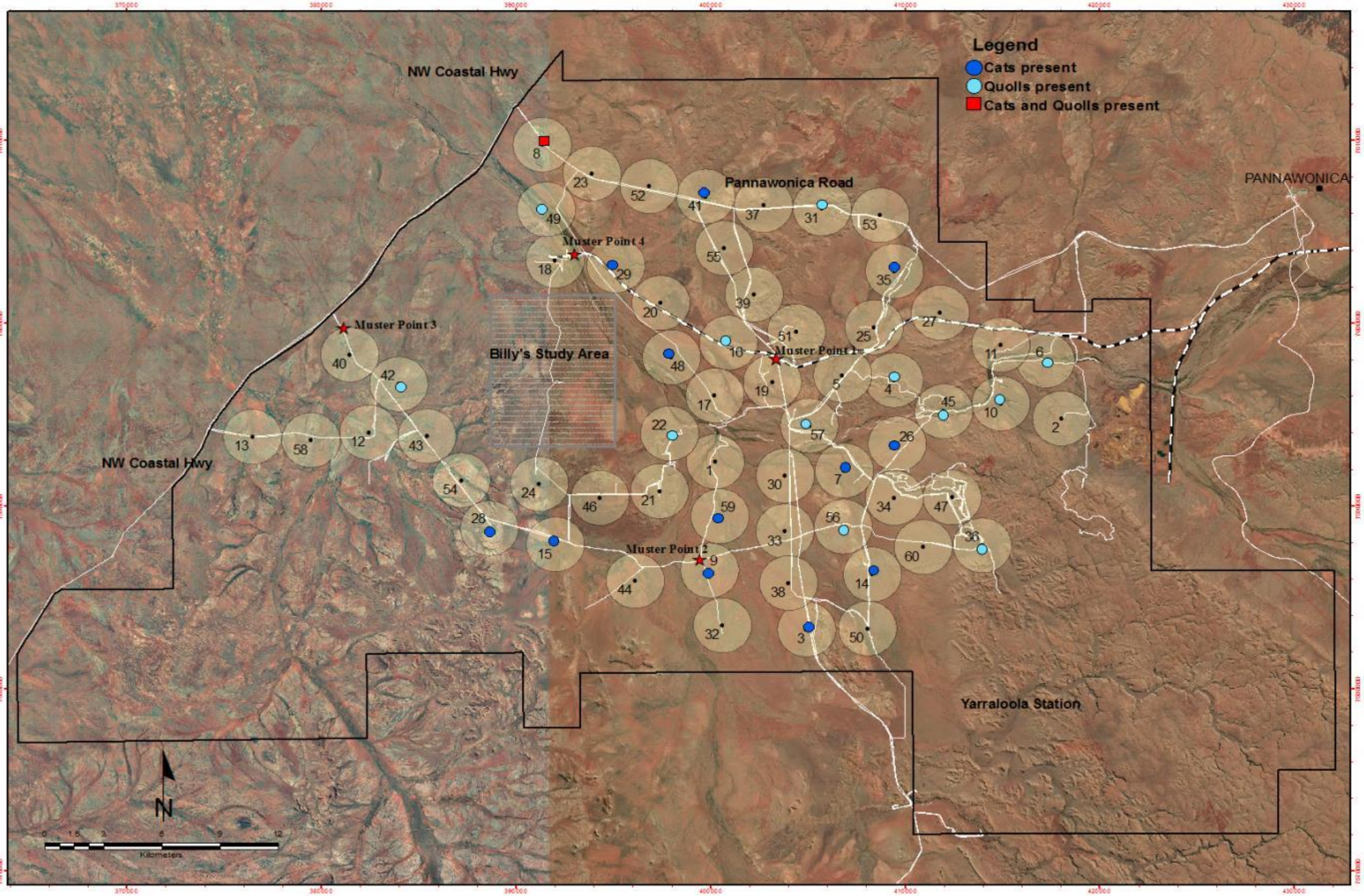


Figure 7 Location of feral cats and northern quolls recorded at camera-traps for both pre- and post-bait surveys on the baited Yarraloola LMA.

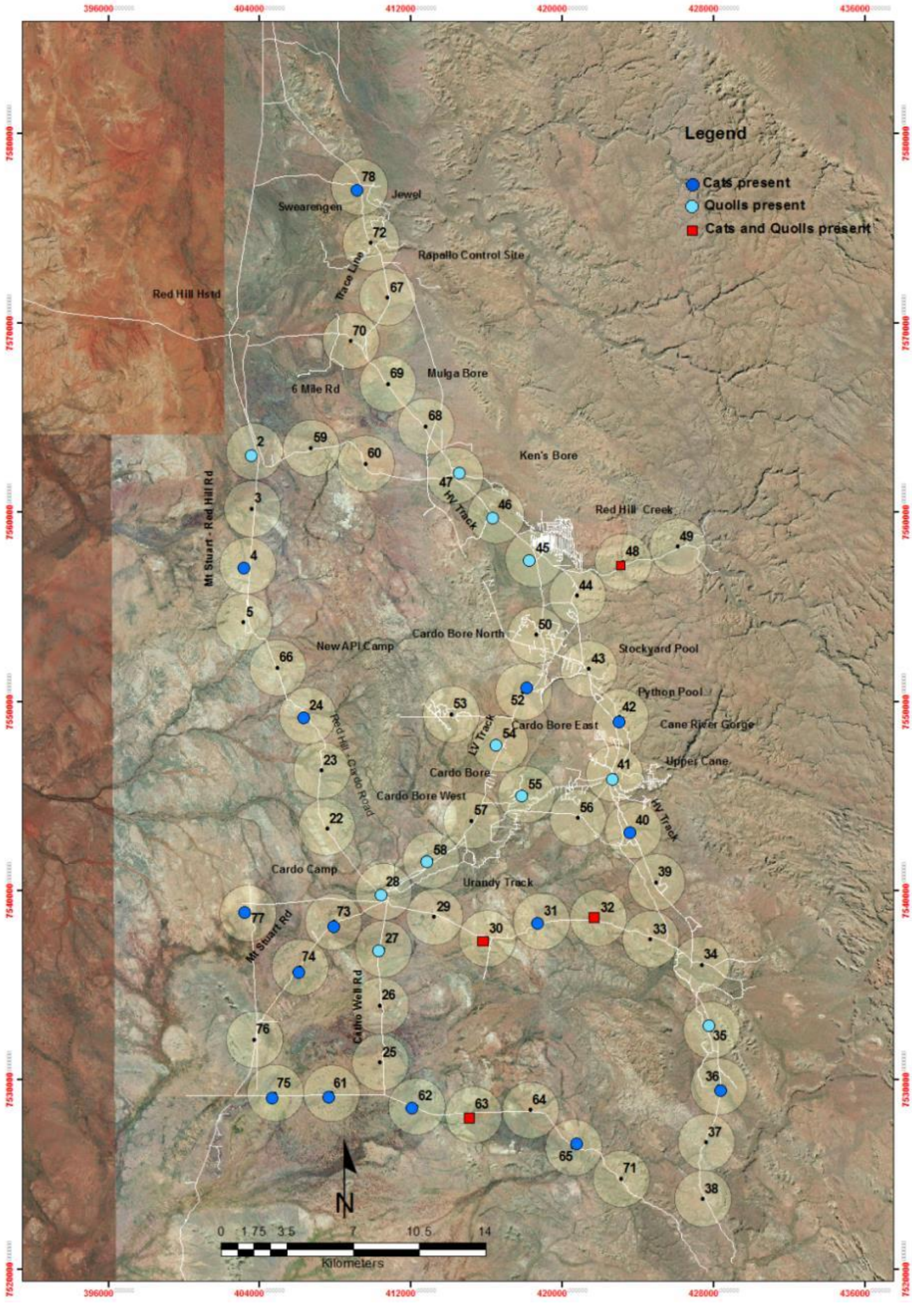
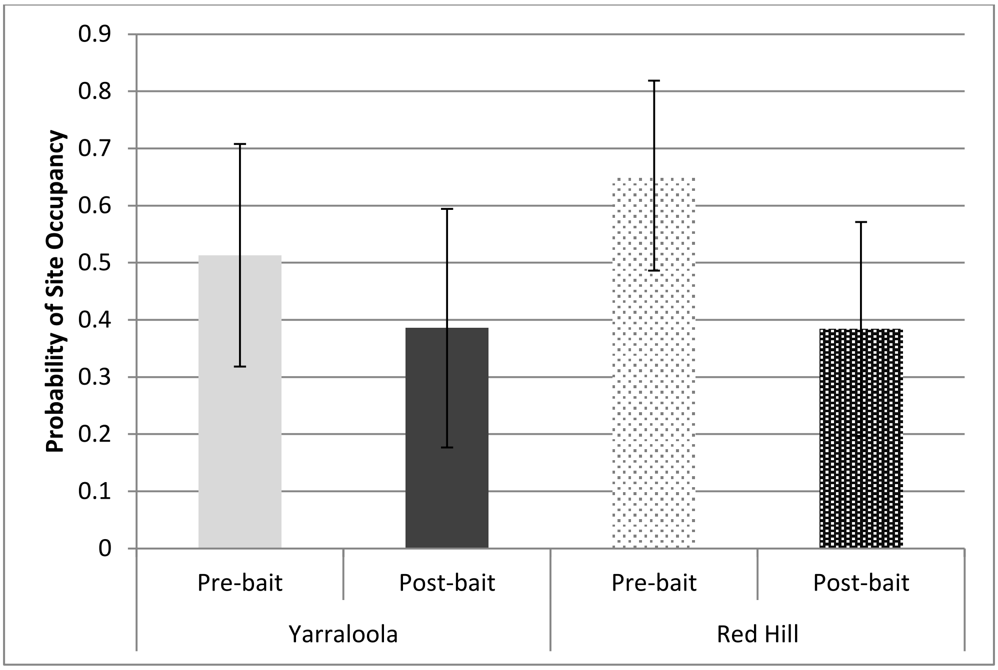


Figure 8 Location of feral cats and northern quolls recorded at camera-traps for both pre- and post-bait surveys on the control site of Red Hill.

a) modelled random effects



b) modelled spatial component

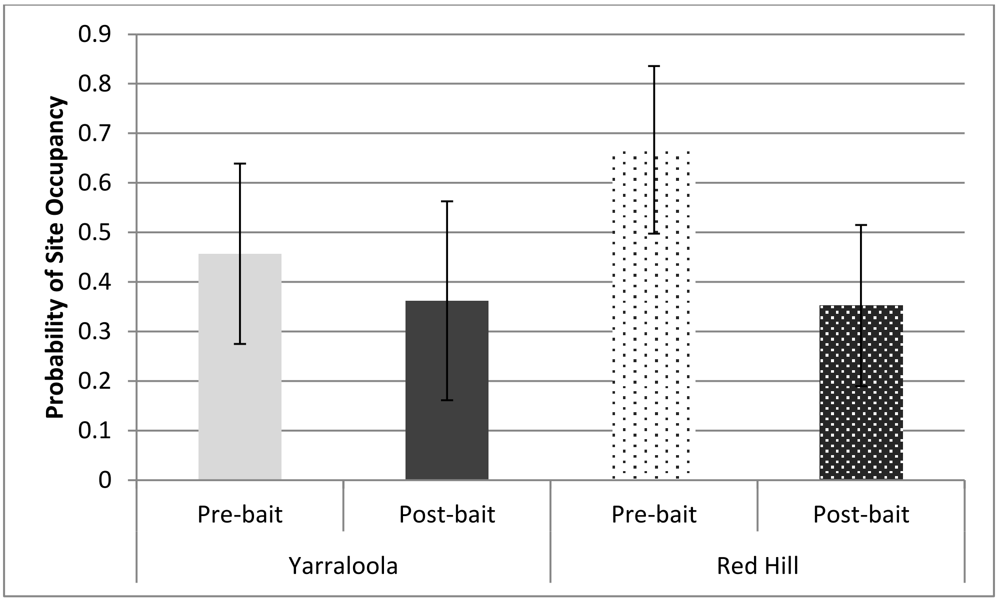


Figure 9 Site occupancy (mean ± SE) pre- and post-baiting in treatment (Yarraloola) and control (Red Hill) with (a) random effects and (b) spatial component

4.2.1 Site occupancy

The random effects model showed a significant decrease in the probability of feral cat occupancy in both treatment and control (t-test, $p<0.05$), with the decline greater in the control (55%) than the treatment (41%) (Figure 9). The results of the spatial model were also significant (t-test, $p<0.01$) in the Yarraloola treatment and control, with a decrease of around 20% in the probability of site occupancy post-baiting in the treatment area compared with 47% in the control (Figure 9).

4.3 Northern quoll monitoring

4.3.1 Quoll trapping

The trapping effort for the September quoll monitoring was 1440 trap nights across the 18 lines on both Yarraloola and Red Hill. Captures were low with 30 individuals (20 females, 10 males) and 38 individuals (26 females, 12 males) trapped on Yarraloola and Red Hill, respectively (see Appendix 2 for raw data and different capture rate metrics). Although more females were captured, the sex ratio did not differ from parity at Yarraloola, but the difference was significant at Red Hill ($X_{2(1)} = 5.16$, $p = 0.023$).

The mean number of individual females and males captured per monitoring line were similarly low between Yarraloola and Red Hill (Figure 10). There are no differences in the capture rates of females or males between the baited and unbaited treatments. For comparative purposes, the corresponding capture rates of females and males for 2015 are presented in Figure 10a. There were no within–site differences in the capture rates of either sex from 2015 to 2016. Visually the mean capture rate of males appears to have declined sharply from 2015 to 2016, but the standard error was large for 2015 as the number of males captured per line was highly variable (range 0 – 9).

Two of the females captured at each location were recaptures of individuals first pit-tagged in 2015. The recapture rate of females caught in 2015 was 17% (2 out of 12) and 25% (2 of 8) for Yarraloola and Red Hill, respectively. None of the 43 males captured and pit-tagged during the 2015 studies were recaptured in 2016.

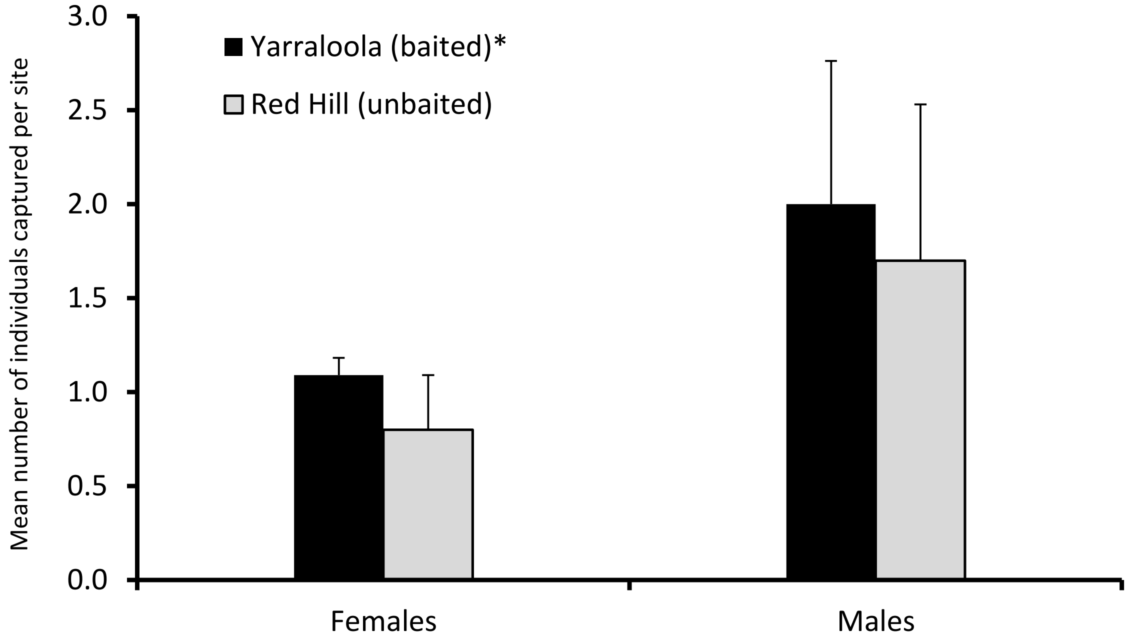
Litter sizes were similar across the baited and unbaited treatments. Sixteen females on Yarraloola had pouch young (mean litter size 6.8 ± 0.4) and 13 females on Red Hill averaged litter size of 5.9 ± 0.4 young.

Female body masses were similar across sites and years, although they were slightly lighter in 2016 (Table 2). Males on Red Hill were significantly lighter than the males on Yarraloola in 2016 ($t_{(20)} = 3.13$, $p = 0.005$). These males were also lighter than individuals captured at Red Hill in the previous year ($t_{(26)} = 3.09$, $p = 0.005$; Table 2).

4.3.2 Quoll blood sampling

Blood samples were taken from the 25 quolls that were anaesthetised for whisker extraction. Samples were transported to Murdoch University for storage and will be screened for the presence of cat transmitted diseases such as toxoplasmosis at a later date.

a) 2015



b) 2016

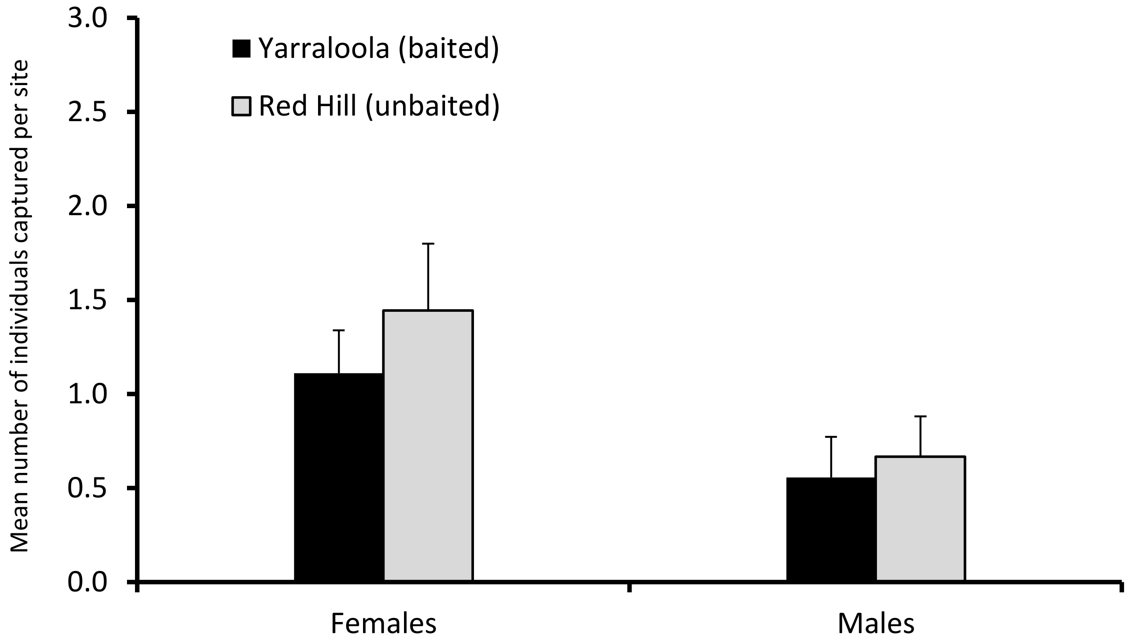


Figure 10 Mean (+ SE) number of individual female and male quolls captured per monitoring site at Yarraloola and Red Hill for (a) 2015 and (b) 2016. Each monitoring site consisted of 20 traps set for 4 consecutive nights. In 2015, there were 11 sites on Yarraloola.

Table 2 Body mass (g, mean ± s.e.) of northern quolls captured at monitoring sites in 2015 and 2016 at Yarraloola and Red Hill.

Yarraloola		**Red Hill**	
Year 2015			
Females (n = 12)	Males (n = 15)	Females (n = 7)	Males (n = 16)
360.8 ± 14.0	598.4 ± 33.4	385.7 ± 12.7	546.9 ± 20.2
Year 2016			
Females (n = 19)	Males (n = 10)	Females (n = 26)	Males (n = 12)
344.5 ± 13.4	573.0 ± 33.4	349.4 ± 6.8	462.0 ± 16.6*

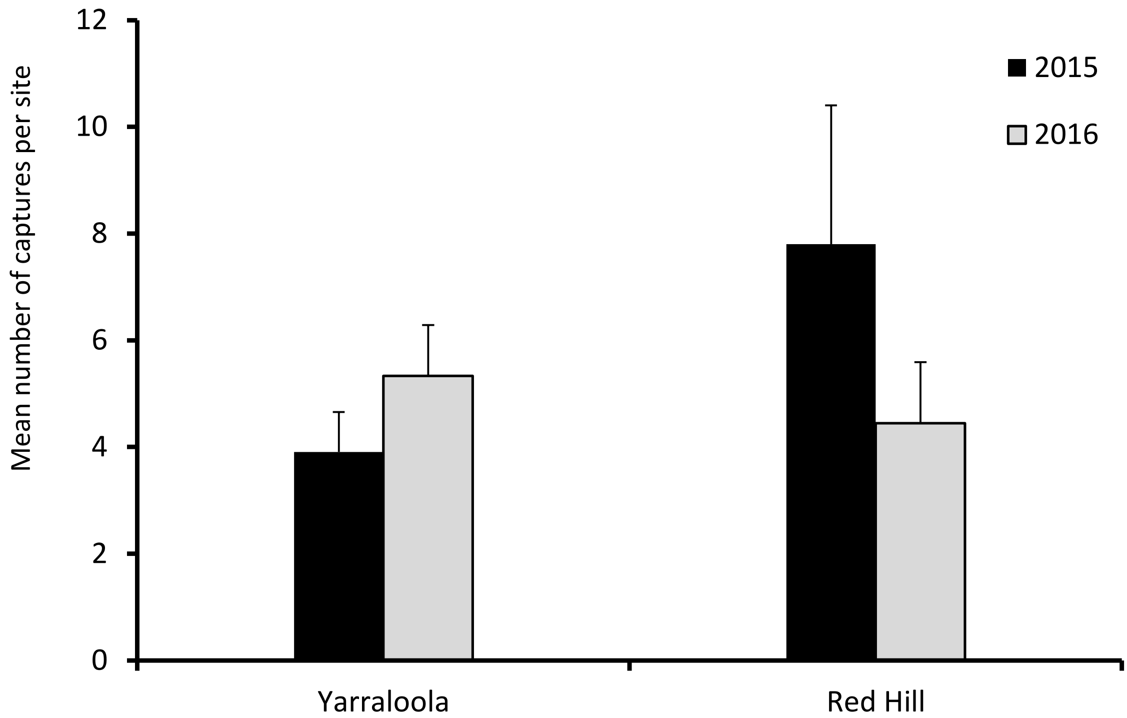


Figure 11 Mean (+ SE) number of common rock rats captured per quoll monitoring site at Yarraloola and Red Hill for 2015 and 2016.

4.3.3 Non-target captures in quoll traps

The most common non-target species captured were the common rock rat with 176 total captures. The mean number of common rock rats captured per trap line was similar across sites and years (Figure 11). Other non-target species captures were uncommon with three *Pseudantechinus* sp. trapped and several young varanids and large skinks (*Ctenotus grandis*, *Egernia formosa* and *E. pilbarensis*) also caught. Novel incidental captures included an echidna, white-plumed honeyeater and two striated grasswrens.

4.4 *Eradicat®* bait monitoring trails

No feral cats were detected by camera traps at any of the 80 monitored bait sites. The total camera trapping effort across the two trials for this experiment was ~50 camera trap-nights per bait site.

Only 13 of 60 toxic baits were completely removed from in front of the cameras during Trial 1 (Table 3). None of the 27 toxic baits left *in situ* (>24 days old) at the Yarra 1 & 2 sites for Trial 2 were taken. Cameras provided confirmation of the species that took 7 out of the 13 toxic baits, with quolls taking four and common rock rats three. A varanid took one and rock rats 11 of the non-toxic baits in the second trial at the Yarraloola sites (Table 3). None of the quolls present at the Yarra 1 and 2 sites took any of the baits during the second trial period. At Yarra 3, all eight baits taken in the second period were by the same female quoll. For the toxic baits, quolls visited the three Yarra bait grids on an average of seven out of the 23/24 nights of Trial 1. In other words, quolls were present but few took the toxic baits.

At Red Hill, where there were no toxic baits used, all 20 baits disappeared during each trial. Cameras confirmed that quolls took 10 baits during the first trial and 12 during the second trial. Known individual quolls took multiple non-toxic baits. For Trial 1, quolls were detected on 13 out of the 22 nights on the experimental grid.

In addition to the total removal of baits, the cameras also showed that common rock rats frequently sampled (nibbled) toxic baits. Many other species of mammals, birds and reptiles were detected by cameras near the baits but there was no evidence to show they consumed the bait. This data, when fully analysed, will to provide further insight into the limited risk *Eradicat®* baits pose to non-target species.

Table 3 Bait uptake of toxic and non-toxic Eradicat® *baits by non-target species based on camera trap monitoring.*

Sites	Type of bait	Total number of baits taken	Number of confirmed bait takes by species		
			Northern quolls	Common rock rats	Varanids
Trial 1					
Yarra 1	Toxic	0	0	0	0
Yarra 2	Toxic	3	2	0	0
Yarra 3	Toxic	10	2	3	0
Red Hill	Non-toxic	20	10	0	0
Trial 2					
Yarra 1	Non-toxic[a]	6	0	2	1
Yarra 2	Non-toxic[b]	12	0	5	0
Yarra 3	Non-toxic[c]	20	8	4	0
Red Hill	Non-toxic	20	12	0	0

[a] new non-toxic baits placed alongside the 20 remaining toxic baits from Trial 1.
[b] new non-toxic baits placed alongside the 17 remaining toxic baits from Trial 1.
[c] remaining toxic baits were removed.

4.4.1 Toxic baits taken by quolls

Quolls took the two baits at the Yarra 3 site on the 29 July at 12:35 am and 12:53 am, respectively. The images captured by the two cameras were overexposed and the spot patterns were obscured. It is probable this was the same animal but this could not be confirmed.

The cameras at the Yarra 2 site provided a clearer sequence of events, with the same female taking two toxic baits on the same night of the 31 July (Table 4). It would appear that this quoll ingested the bait at Camera YP068 and then regurgitated at least part of it back up. Minutes later she removed another bait from Camera YP075 but it is not known if she ate this bait. However, it was clear that she survived this experience as she was detected almost a month later at Camera 078. On this occasion she did not eat or remove the non-toxic bait. Bare patches detected on each hip indicated she had recently mated.

Table 4 Details of known female quoll taking toxic Eradicat® *baits captured by camera traps*

Date	Time	Camera #	Activities in relation to baits
30/7	~4:00am	YP075	Quoll removed the end of the bait (~20%). Walks out of view.
31/7	4:15-17am	YP068	Quoll eats part of bait, walks off, returns and removes remaining bait. Appeared to consume it with back to camera.
31/7	4:20am	YP068	3 minute gap – two piles of regurgitated bait visible and quoll walks away.
31/7	4:27am	YP075	Quoll returned to this bait [previous night], removes remaining bait. Walked out of view with bait in its mouth.
31/7	12:00pm	YP068	Time lapse image during the day shows two small pink (rhodamine B) piles of regurgitated bait.
26/8	9:20pm	078	Same female identified with bare patches on hips due to recent mating. Inspects a non-toxic bait and ignores it.

4.4.2 Removal rate of *Eradicat®* baits Trial 1

The rate at which non-toxic baits were removed at the Red Hill control site was rapid with all baits gone by the sixth day (Figure 12). Quolls were confirmed to have removed at least ten of these baits at Red Hill. In comparison, the removal rate of toxic baits was slow. No baits were taken at Yarra 1. Quolls removed several baits at Yarra 2 and 3 towards the start of the trial and common rock rats appear to have been responsible for the removal of the latter baits (Figure 12; Table 3).

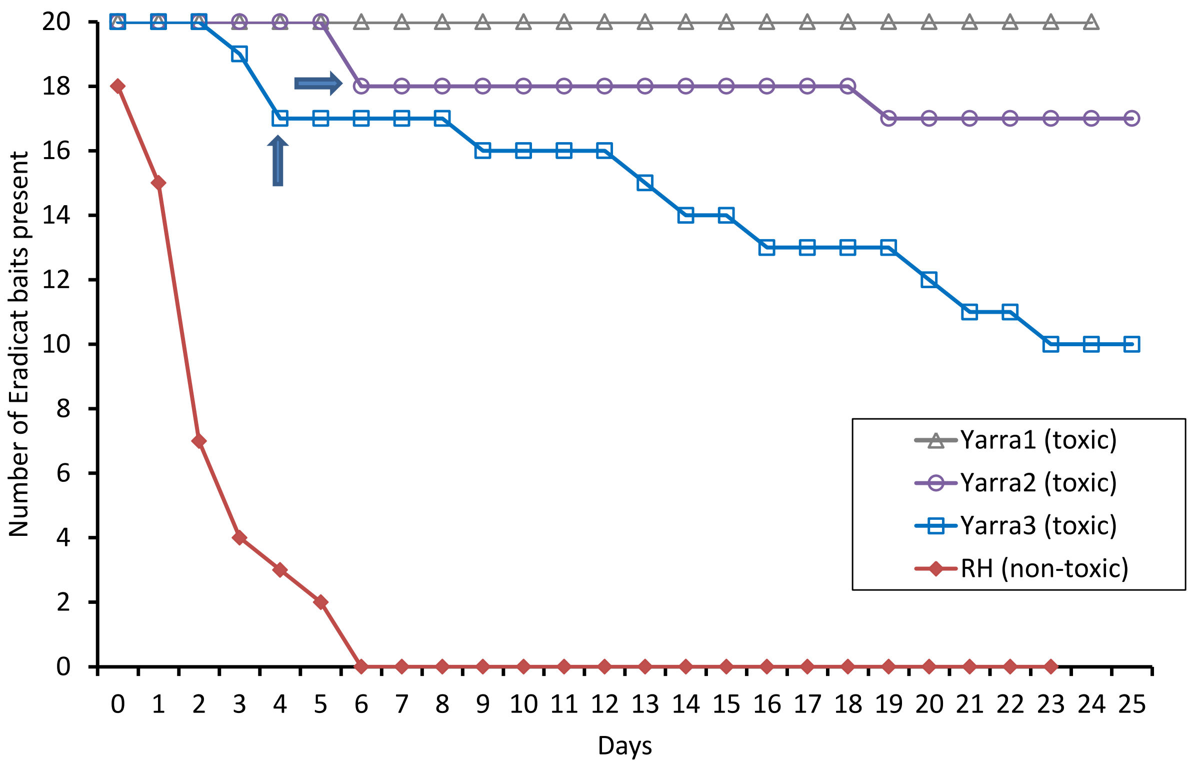


Figure 12 Removal rate of toxic Eradicat® baits per day from the three bait uptake sites within the baited cell on Yarraloola compared with the removal rate of non-toxic Eradicat® baits on the unbaited Red Hill site. Blue arrows indicate when confirmed takes of baits by northern quolls occurred.

4.5 Predator diets and other records

4.5.1 Pilbara olive python records

Three Pilbara olive pythons were recorded on Yarraloola. One was detected on a camera trap accidently left in the field for the 2015/16 summer and collected in April 2016. This camera recorded images of an olive python on the 26th October 2015. A fresh road killed olive python was found on the Pannawonica road near the Northwest Coastal highway 25 May 2016 (21.6151ºS, 115.955ºE). This animal was collected and lodged with the Western Australian Museum (Registration No. R175765). A third individual was found in an ambush position in a rock hole on the end of the quoll monitoring line C on the 18 September 2016 (21.7724ºS, 116.0150ºE). This individual weighed 1835 grams and was 201 cm in length (snout to vent 171 cm; tail 30 cm). A scale clip was taken for DNA analysis.

Two unconfirmed olive python scats were found. One contained the remains of a northern quoll and the other a bird.

4.5.2 Dietary analysis

In total, 180 quoll, 13 feral cat and 50 dingo scats were collected and analysed. The bulk of the cat and dingo scats were from Yarraloola. Quoll scat collections were more comprehensive across sites and years, with 114 from Yarraloola (39 in 2015; 85 in 2016) and 66 from Red Hill (24; 42). The diets of all three predators showed strong separation according to their body mass (Figure 13). Dingoes ate almost entirely large macropods (euros and red kangaroos). Minor prey items were echidna, cattle and emu. Small mammals (rodents and dasyurids) were the primary prey of feral cats. Quolls had the most varied diet, consuming arthropods, fruits, small reptiles and other small vertebrates. There was no evidence of intraguild predation whereby one predator species consumed another, although there was potential evidence of cannibalism in quolls.

The overall diets of quolls across the two study sites were similar for both dietary measures, relative volume of prey remains and frequency of occurrence (Figure 14). Quolls on Yarraloola consumed slightly more fruit and the Red Hill quolls more rodents. The presence of quoll hair was more prevalent in Red Hill scats, although this was probably due to a greater proportion of these scats being recovered from animals caught in traps. Trapped animals tend to accidently ingest their own hair.

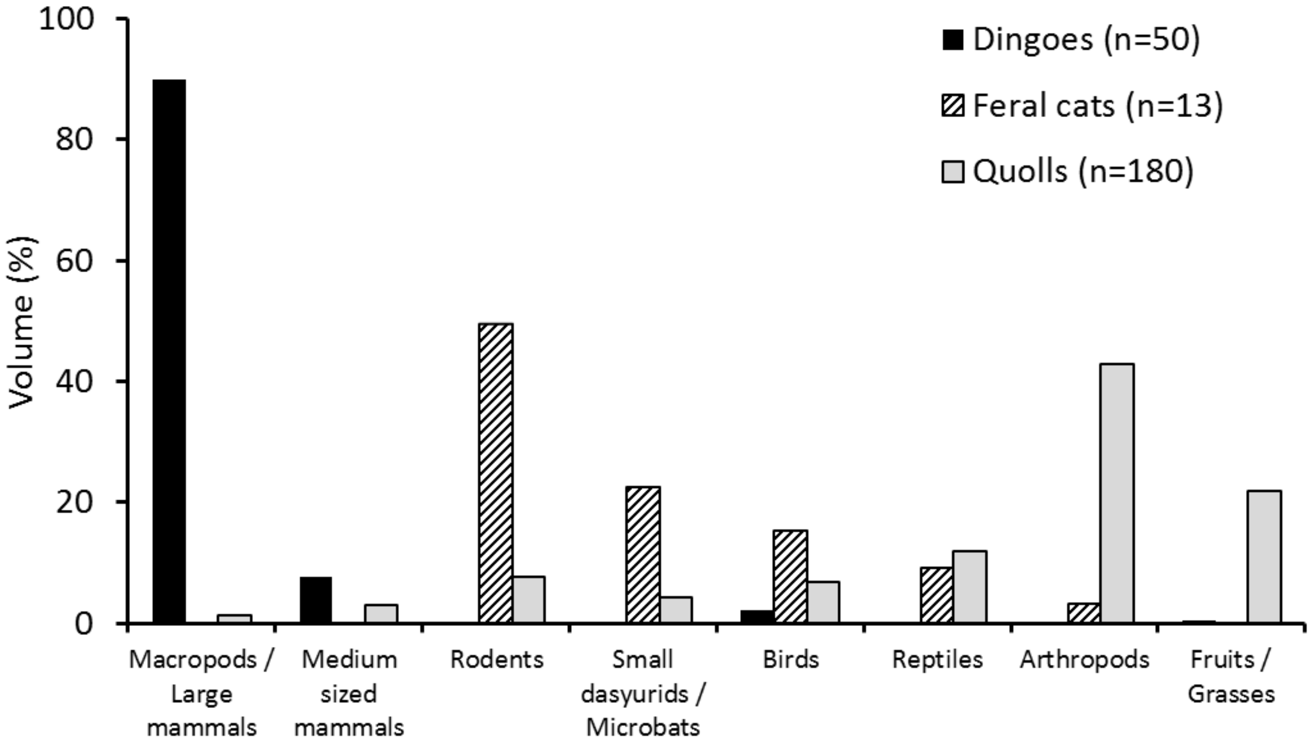


Figure 13 Relative volume of food categories in the diets of dingoes, feral cats and northern quolls from Yarraloola and Red Hill. Parentheses show sample sizes.

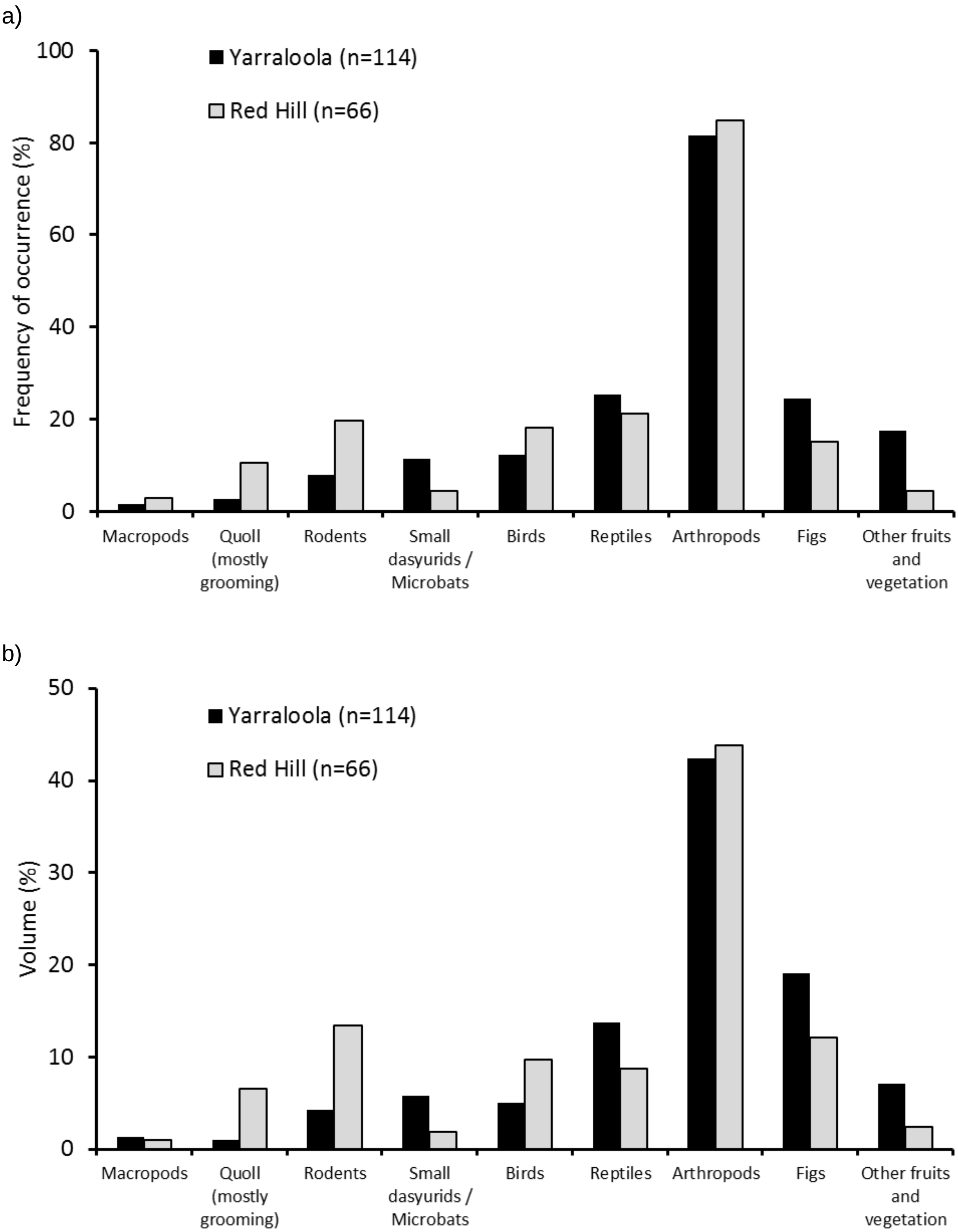


Figure 14 Comparative diets of northern quolls for Yarraloola and Red Hill (2015-2016). Diets are shown in terms of (a) frequency of occurrence, and (b) relative volume of each food category in the scats. Parentheses show sample sizes.

5 Discussion

5.1 Feral cat monitoring and baiting

The higher than normal rainfall (~200 mm) that fell in June and early July delayed the planned aerial baiting program from the start of July to almost the end of July. Although this timing was still considered optimal for feral cat baiting due to the cooler weather and associated low activity levels of key prey groups of cats, the change may have influenced the cat camera trap monitoring program. The random effects and spatial site occupancy models using the camera trap data both showed significant decreases in feral cat occupancy following the baiting, however, the magnitude of the declines were greater on Red Hill (control) than it was on the baited Yarraloola LMA. A significant decline in cat occupancy over such a large area in the absence of any management action was unexpected. Nonetheless, this finding was not restricted to Red Hill, as a similar pattern was also recorded for the first time in five years of monitoring within the control site of the Fortescue Marsh Cat Baiting Program in 2016. In that case however, a greater order of magnitude decrease occurred in the treatment (baited) site following the baiting program (Clausen *et al*. 2016).

Factors that influence the behaviour of feral cats, resulting in changes to their mobility and activity levels have the potential to influence site occupancy rates in the absence of cat control. The increasing day length after the winter solstice generally triggers the onset of breeding in female cats. We suspect that activity levels and movement declined in female cats across Red Hill and the Yarraloola LMA during post-bait monitoring session as they probably gave birth to kittens during this period. Regardless of the potential influence breeding may have had on the occupancy modelling, Clausen *et al*. (2016) reported a 82% baiting efficacy rate, with 9 out of 11 radio-collared cats being killed by the baiting at Fortescue Marsh. This second independent measure clearly demonstrated that the aerial baiting program was highly effective in 2016 (Clausen *et al*. 2016). The fact that only seven cats were detected in ~1500 camera trap-nights after the baiting on the Yarraloola LMA suggests that cat numbers were very low after the baiting program.

The lower than prescribed application rate of baits, averaged 41 baits km^{-2} instead of 50 km^{-2}, may not have reduced the effectiveness of the baiting program, as the Fortescue Marsh site suffered the same fate and recorded a high baiting efficacy. There are plans to trap and radio-collar feral cats prior to the baiting at Yarraloola in 2017, and monitor survivorship after the cat baiting. This will be undertaken in partnership with William Ross (CDU).

The combined detection rate of cats in our study were low, with 0.008 and 0.011 cats per trap-night on Yarraloola (21 cats in 2777 camera trap nights) and Red Hill (31 cats in 2759 camera trap nights), respectively. Hernandez-Santin *et al*. (2015) detected considerably higher rates with baited (punctured tuna tins) cameras at two other sites in the Pilbara (69 cats in 2761 trap nights; 0.025 cats per trap-night). Although our results were consistent with other camera trap studies in the tropical savanna (0.006 cats per trap-night; 18 cats in 3200 nights; Stokeld *et al*. 2015) and South Australian arid zone (0.015 cats per trap-night; 43 cats in 2788 nights; Read *et al*. 2015).

The detection rates of feral cats on cameras were considerable higher at Fortescue Marsh compared with our sites for 2016 (Clausen *et al*. 2016). In terms of combined camera sites, they detected cats on ~50% of cameras (45 of 95 camera sites) compared with ~25% (32 of 120 camera sites) for Yarraloola and Red Hill. These study areas differ vastly in terms of topography, habitat types and productivity. Yarraloola and Red Hill have substantial areas of rocky habitat that cats tend to avoid but quolls prefer (Hernandez-Santin *et al*. 2015). Current camera trap data indicates cats mostly occupy the flatter landscapes between the mesas and ranges (Figure 7 & 8). The scheduled radio-telemetry study of cats in 2017 will provide additional insight into their habitat use patterns. Such data may allow for the development of detection probabilities for cats that relate to topography, which could improve the occupancy modelling approach when it is applied to variable landscapes.

Further investigations of the nature of habitat separation patterns between feral cats and quolls are planned, as partitioning of rocky habitat may also allow for the development of a more strategic and targeted cat baiting program for the Yarraloola LMA.

Dingoes were very scarce on both pastoral leases presumably due to effective existing control programs to reduce their impacts on cattle herds. Only one dingo was detected by cameras before the cat baiting and one after, hence we were unable to determine if the cat baiting reduced dingo numbers.

5.2 Northern quoll populations

The capture rates of female quolls were consistently low across Yarraloola and Red Hill, averaging between 1 and 1.5 individuals per trapping site. These capture rates were similar to the previous year's trapping program (Morris *et al*. 2016). Importantly there was no decline evident in the capture rates of females within the baited Yarraloola LMA, which would be expected if northern quolls were susceptible to 1080 poisoning. Mean capture rates of males were lower in 2016 compared with 2015. However, there was considerable variability in the capture rates of males in 2015 as high numbers of males were captured at sites in August prior to the male die-off. There was no difference in the capture rates of males between the baited and unbaited treatments in 2016.

Sub-lethal doses of 1080 can still be harmful to populations. Toxins passed through milk could potentially kill the pouch young of marsupials, such as northern quolls (McIlroy 1981). The mean litter size for quolls at Yarraloola where 1080 cat baiting had occurred was not significantly different to that recorded for quolls on Red Hill, indicating any sub-lethal ingestion of 1080 had no impact on reproductive success of quolls.

The change to a shorter intensive trapping program with four concurrent trapping teams operating in September 2016 avoided the ambiguities associated with having the trapping session spanning different phases of the male die-off process. This timing allowed for pouch young counts as females give birth in late August to early September. However there are few males left in the population by this stage and our capture rate information for adult male quolls is potentially less informative compared with that for females. That said, cat control may result in greater survivorship amongst risk-taking males during the breeding season on Yarraloola. A potential outcome being increased longevity amongst older and heavier males, which could explain why males captured on Yarraloola were significantly heavier than those from Red Hill during September 2016 (547 g *cf.* 462 g; Table 2).

In a broader context, mean quoll capture rates were lower at the 12 Pilbara regional trapping sites in 2016 compared with the two previous years (Dunlop *et al*. 2016; Judy Dunlop pers. comm.). The average capture rates of quolls at Yarraloola and Red Hill were within the range for these sites, but relatively few males were captured at these regional sites even though that trapping program was completed before the onset of the male die-off. It is possible that the failed 2015/16 wet season across the Pilbara resulted in lower recruitment of young from the 2015 breeding season in many areas. If true, quoll numbers may be expected to be higher in 2017 following the recent good summer rains.

5.3 Little evidence *Eradicat®* harms northern quolls

Camera traps do have limitations when monitoring bait uptake by animals under field conditions (Ballard *et al*. 2014). To maximise our chances of detecting animals eating baits in front of cameras we anchored baits to the ground, which may introduce other types of bias compared with baits dropped from an aircraft. We also took a conservative approach to scoring bait take and only assigned a positive take to a species if it was detected by the camera with the bait in its mouth and all of the bait was taken. This meant that we assigned the fate of ~50% of baits taken to a species.

These preliminary findings from the bait uptake experiments confirm that northern quolls are prolific scavengers and they readily find and consume non-toxic *Eradicat®* baits. Our evidence in relation to toxic *Eradicat®* baits is more limited, but we found that a female quoll took and at least partly consumed two baits on the same night. She regurgitated at least part of one of these baits in front of a camera. This quoll was detected again 26 days later and on this occasion she ignored the non-toxic bait present.

Once exposed to toxic baits, northern quolls tend to ignore both non-toxic and toxic *Eradicat®* baits when they are re-presented with such baits. This would suggest they learn to avoid the bait rather than the 1080 toxin within the bait. After the aerial baiting, a single female quoll was confirmed to take eight non-toxic baits at the Yarra 3 site within the baited cell. It is likely that this individual had previously not encountered a toxic bait, as the other quolls detected by cameras at the three Yarra bait sites during the second trial all ignored the baits.

In this study no rhodamine B staining was found in the 17 sets of northern quoll whiskers collected from the Yarraloola LMA; however this does not confirm that quolls did not encounter and consume *Eradicat®* baits. Previously, rhodamine B bands in the whiskers of spotted-tailed quolls exposed to toxic wild dog baits in NSW were reported to show weak fluorescence only, when compared with samples obtained from animals during non-toxic bait trials (Claridge *et al*. 2006; Claridge and Mills 2007). These findings were similar to that of Kortner and Watson (2005), who suggested spotted-tailed quolls only partially consumed toxic baits and/or ate less of the bait when compared to the animals in the non-toxic bait trials. Alternatively, spotted-tailed quolls can regurgitate toxic baits and hence limit the opportunity for the biomarker to enter the animal's bloodstream and subsequently growing tissues (Claridge and Mills 2007). Although our evidence is limited, the latter process potentially explains why rhodamine B staining was lacking from the northern quoll whiskers we examined. According to the images recorded by Camera YP068, the northern quoll regurgitated the bait in under three minutes after ingestion (Table 4). The amount of rhodamine B absorbed by the quoll under these circumstances was probably too low to stain the whiskers of northern quolls.

Based on the above, our working theory is that northern quolls readily locate and sample toxic *Eradicat®* baits in the field. However, their encounters with these toxic baits are non-lethal providing them the opportunity to learn from what is likely to have been an unpleasant experience and discourages them from consuming subsequent baits. The mechanism by which quolls avoid fatal poisoning seems to be that they regurgitate the bait soon after ingestion. Monitoring of baits via small radio-transmitters inserted into each bait may further allow confirmation of this process.

5.4 Predators interactions and what might change with cat control on Yarraloola

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; Morris *et al*. 2015). Effective control of feral cats should therefore enhance the fitness of the northern quoll population on Yarraloola. The potential effects of competition from feral cats on northern quolls should become clearer over time as we continue to monitor the abundance, diet and habitat use patterns of quolls across Yarraloola (cat baited) and Red Hill (no cat baiting). Analysis of predator scats will be used to explore their diets and to investigate evidence of intraguild predation.

Visits by northern quolls to our 120 feral cat camera trap sites across our study areas will enable us to investigate changes in habitat use by quolls over time. If cats are competing with quolls for space we would expect quolls to start making greater use of more open landscapes preferred by feral cats, once the baiting takes effect on Yarraloola. Some quolls did visit cat camera traps located in open landscapes, particularly on Red Hill (Figure 8). Records of spatial overlap between cats and quolls on these cameras were higher than reported by Hernandez-Santin *et al*. (2016), which may explain the high predation rates suffered by radio-collared quolls in 2015 (Morris *et al*. 2015).

Collections of dingo, cat and Pilbara olive python scats from 2016 provided little indication of intraguild predation, with only one event being found of a Pilbara olive python eating a northern quoll. The lack of fox, cat and quoll remains in the fifty dingo scats investigated suggest that intraguild predation events involving the killing and consumption of these other predators by this apex predator were uncommon. This finding is consistent with Thomson (1992), who recorded only one fox and one cat in 403 dingo stomachs/scats examined from the Fortescue and Robe river valleys from 1977-84. In terms of the diet of dingoes, there has been no change from this earlier study to now, with euros and red kangaroos remaining the staple prey. By taking large prey, the diet of dingoes did not overlap with co-occurring feral cats and quolls.

Collections of northern quoll scats from 2015 and 2016 (n = 180; Figure 14) provide an important dietary baseline for quolls across the two sites. Quolls on Yarraloola and Red Hill were also highly omnivorous, consuming mostly arthropods and fruits, as well as a range of small vertebrates (mammals, birds and reptiles), which is consistent with their diet elsewhere in the Pilbara (Dunlop *et al*. in press). The diets of feral cats and quolls overlap across these small vertebrate prey groups (Figure 13). Dunlop *et al*. (in press) 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. We are well placed to test this hypothesis and expect that northern quolls will begin to expand their dietary niche in response to cat control on Yarraloola by including more vertebrate prey in their diets.

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Appendices

Appendix 1 Field work program for 2016

Field Trip #	Date(s)	Field Activity
1	19 – 26 April	Reconnaissance trip of the Yarraloola area to show Russell Palmer (New Project Leader) and Billy Ross (PhD student) the existing 11 northern quoll trapping sites and to select a further 7 new sites in suitable quoll habitat. Two camera traps were set at the 11 existing sites and 9 potential new sites for detection of northern quolls. All roads with Cat Camera points were checked and logged on the GPS. Twelve camera traps were set on tethered non-toxic *Eradicat*® baits next to determine if northern quolls eat the bait.
	19 – 24 April	Objectives as above for Red Hill. Camera traps were set at the 10 existing quoll trapping sites. A further 8 new sites were selected and camera traps set. The condition of roads and access to Cat Camera points was reviewed.
2	18 – 29 May	Establishment of 60 camera traps for the monitoring of feral cats for the pre-baiting period on Yarraloola and Red Hill. On Yarraloola a collection of camera traps were set on non-toxic *Eradicat*® baits.
3	20 – 23 June	Cat camera demobilisation on Yarraloola and Red Hill. Due to heavy rain the trip was abandoned until the next field trip.
	26 – 27 July	Aerial Baiting, Yarraloola.
4	25 – 30 July	Completion of cat camera demobilisation on Yarraloola and Red Hill. Three bait uptake cells were established on Yarraloola and 1 control cell on Red Hill.
5	8 – 13 August	Sixty camera traps were set for the post-baiting monitoring of feral cats on Red Hill.
	15 – 20 August	Sixty camera traps were set for the post-baiting monitoring of feral cats on Yarraloola. Bait uptake sites were checked and serviced.
6	5 – 19 September	The quoll baseline monitoring was completed at Yarraloola, with all 18 sites trapped for 4 nights each. Cat camera demobilisation on Yarraloola.
	7 – 22 September	The quoll baseline monitoring was completed at Red Hill, with 18 sites trapped for 4 nights each. Cat camera demobilisation on Red Hill.
	7 – 17 September	Whisker extraction was undertaken on 25 quolls (17 from Yarraloola and 8 from Red Hill) for biomarker presence. Blood samples were also taken from the quolls for screening of cat transmitted diseases.

Appendix 2 Quoll capture results for each trap site

Capture data and capture metric summaries for northern quolls per trapping site on the Yarraloola Land Management Area.

Trap site	Females	Males	Total captures (includes recaptures)	Overall trap success rate (%)	Individuals captured per 100 trap nights
A	1	1	2	2.50	2.50
B	2	0	5	6.25	2.50
C	0	3	4	5.00	3.75
D	0	0	0	0	0
F	0	0	0	0	0
G	0	0	0	0	0
H	1	0	1	1.25	1.25
I	2	0	3	3.75	2.50
J	0	0	0	0	0
K	3	0	5	6.25	3.75
L	2	0	7	8.75	2.50
M	2	2	4	5.00	5.00
N	1	1	5	6.25	2.50
O	1	0	1	1.25	1.25
P	0	0	0	0	0
Q	2	1	4	5.00	3.75
R	1	0	1	1.25	1.25
T	2	2	5	6.25	5.00
Totals	**20**	**10**	**47**		
Means	**1.11**	**0.56**	**2.61**	**3.26**	**2.08**

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
CC	0	0	0	0	0
CW	0	0	0	0	0
E	3	1	6	7.50	5.00
F	1	2	7	8.75	3.75
G	0	0	0	0	0
H	2	0	2	2.50	2.50
I	2	0	2	2.50	2.50
J	5	1	6	7.50	7.50
KB	0	2	2	2.50	2.50
L	4	1	8	10	6.25
M	1	1	2	2.50	2.50
N	0	0	0	0	0
P	1	0	1	1.25	1.25
PP	1	3	10	12.50	5.00
R	0	1	1	1.25	1.25
SW	2	0	4	5.00	2.50
X	1	0	2	2.50	1.25
Z	3	0	4	5.00	3.75
Total	**26**	**12**	**57**		
Means	**1.44**	**0.67**	**3.17**	**3.96**	**2.64**

Appendix 3 Incidental and opportunistic records

A broad range of fauna species were detected as incidental records on the feral cat monitoring cameras, including brushtail possums (see below). At the time this report was completed only the identity of the birds had been confirmed. Camera traps recorded 33 bird species on Red Hill and 22 on Yarraloola.

List of birds captured on cat camera traps on Red Hill and Yarraloola (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	-
Haliastur sphenurus	Whistling Kite	Y	-
Turnix velox	Little Button-quail	Y	Y
Burhinus grallarius	Bush Stone-curlew	Y	-
Phaps chalcoptera	Common Bronzewing	Y	Y
Ocyphaps lophotes	Crested Pigeon	Y	Y
Geophaps plumifera	Spinifex Pigeon	Y	Y
Geopelia cuneata	Diamond Dove	Y	Y
Geopelia striata	Peaceful Dove	Y	-
Eurostopodus argus	Spotted Nightjar	Y	-
Cacatua roseicapilla	Galah	Y	Y
Cacatua sanguinea	Little Corella	Y	Y
Ptilonorhynchus maculatus	Western Bowerbird	Y	Y
Malurus lamberti	Variegated Fairy-wren	Y	-
Amytornis striatus	Striated Grasswren	Y	-
Epthianura tricolor	Crimson Chat	Y	-
Manorina flavigula	Yellow-throated Miner	Y	Y
Gavicalis virescens	Singing Honeyeater	Y	Y
Ptilotula penicillata	White-plumed Honeyeater	Y	-
Pomatostomus temporalis	Grey-crowned Babbler	Y	Y
Cinclosoma clarum	Western Chestnut Quail-thrush	Y	-
Artamus cinereus	Black-faced Woodswallow	Y	Y
Cracticus nigrogularis	Pied Butcherbird	Y	-
Cracticus tibicen	Australian Magpie	Y	Y
Oreoica gutturalis	Crested Bellbird	Y	Y
Colluricincla harmonica	Grey Shrike-thrush	Y	Y
Rhipidura leucophrys	Willie Wagtail	Y	Y
Corvus sp.	Crow/Raven	Y	Y
Grallina cyanoleuca	Magpie-lark	Y	Y
Megalurus mathewsi	Rufous Songlark	Y	-
Taeniopygia guttata	Zebra Finch	Y	Y
Anthus australis	Australian Pipit	Y	Y

Brushtail possum detections

A camera trap set on an outer channel of the Robe River near Cat Camera #49 detected a brushtail possum on the 16th September 2016 (21.64413ºS, 115.95831ºE). This is the first confirmed record of this species on Yarraloola since 2002, when a road killed individual was collected at Mesa J.

A brushtail possum was also recorded on Red Hill at Cat Camera #63 (Plate 3). This camera was also visited by cats and quolls. Possums has been detected on a few occasions in the past five years on Red Hill (Phil Davidson, pers. comm.).

Plate 3 Brushtail possum on Red Hill at Cat Camera #63 (Figure 8) on the 26 June 2016.