GOVERNMENT OF WESTERN AUSTRALIA

Department of **Biodiversity, Conservation and Attractions**

Predator Control Baiting and Monitoring Program, Yarraloola and Red Hill, Pilbara Region, Western Australia. 2018 Annual Report - Year 4.

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

2018 Annual Report – Year 4

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Biodiversity and Conservation Science

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GOVERNMENT OF WESTERN AUSTRALIA

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Cover photograph: Kuruma and Marthudunera traditional owner Joshua Evans releasing a northern quoll at a trap site on Yarraloola (Photo by Neil 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 2018 was developed in liaison with Brian Dalton (Rio Tinto). Brian Dalton and Martin Salm (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 services team were on standby in the event search and rescue services for our field teams were required on site.

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Drafts of this report were reviewed by Keith Morris (DBCA), and Martin Buck and Martin Salm from Rio Tinto.

The following permits were obtained to conduct this work:

- Department of Biodiversity, Conservation and Attractions Animal Ethics Committee permits AEC 2015/16 and 2018/04.
- 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

Predation by feral cats continues to pose a major threat to native wildlife on the Australian mainland. Stemming the damage they cause remains an ongoing challenge for conservation practitioners. Accordingly, development of approaches aimed at delivering effective cat control at landscape scales are both a policy and management priority of governments. 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 (*Dasyurus hallucatus*) in the western Pilbara. Controlling feral cats at a landscape scale within the Yarraloola Land Management Area (LMA) to reduce their impacts on northern quolls and other native fauna was a core component of the TSOP.

Following a successful experimental phase in 2015, which demonstrated northern quolls were not at risk of poisoning from the toxic *Eradicat*® feral cat bait (Morris *et al.* 2015), the project entered a four-year operational phase, involving the annual baiting of cats each winter over ~145 000 ha of the Yarraloola LMA. Here we report on the third year of operational cat baiting for the TSOP project undertaken in 2018.

Monitoring showed that the first two winter baiting programs in 2016-2017 greatly depressed cat populations, but a substantial recovery was detected during the cat trapping and collaring program undertaken in late April-May 2018, with 15 cats trapped inside the bait cell. Subsequent camera monitoring revealed 1.7 cats per 100 camera trap nights (100 CTN^{-1}) in June 2018, up from a low of 0.4 cats 100 CTN^{-1} in September 2017. Reduced competition for resources is likely to have stimulated the dispersal of cats from adjoining high-density areas. Limited intraspecific competition is also expected to have promoted increased recruitment/survival of kittens born to cats that had survived baiting programs.

Aerial baiting took place on the 9-10 July 2018, with 71 000 *Eradicat*® baits distributed over 141 594 ha of the Yarraloola LMA. The impact on feral cat numbers was assessed using data from camera traps set prior to, and following baiting, and the analysis of mortality rate of radio-collared cats exposed to baits. Camera trapping demonstrated baiting had a significant impact on the cat population reducing its abundance by 57% to 0.7 cats 100 CTN^{-1}. Mortality of two of eight radio-collared cats present in the bait cell was attributed to bait consumption (25%). The discrepancy between these two independent measures of bait efficacy was probably caused by a bias toward the radio-collaring of adult cats. Experienced cats fitted with collars were probably less likely to consume baits compared with the general cat population present on Yarraloola when it was baited. We expect that the recovering cat population consisted largely of bait naïve younger cats, hence the higher knockdown detected by camera traps better reflected the level achieved by baiting.

We found no evidence that feral cat control using *Eradicat*® negatively impacts upon co-occurring northern quoll populations. With below average rainfall for 2018, quoll populations did not continue their upward population trajectory as found in the previous wetter year. Capture rates of female quolls during the annual September trapping session remained stable on Yarraloola and captures of both sexes were

relatively unchanged on Red Hill. Capture rates of male quolls continued to increase on Yarraloola, suggesting males benefitted more strongly from cat control than females in 2018. However, the average body mass of both male and female quolls was lower on Yarraloola in 2018, potentially indicating that conditions were harsher despite cat control. Population turnover in males was complete with no known marked (PIT tagged) individuals surviving beyond their second breeding season. This suggests that cat baiting may increase the longevity of males in the die-off period following the mating season (late July-August) but it is not known for how long or what is driving this response (i.e. reduced levels of cat predation, increased availability or access to prey resources and so on).

The annual survival rate of tagged female quolls was lower on Yarraloola in 2018 and similar to that on Red Hill. Evidence that quolls benefit indirectly from cat control through shifting from protein–poor food sources [fruits] to eating more rodents continued to strengthen, with rodent prey now present in 41% of quoll scats on Yarraloola compared with 5% prior to the commencement of operational baiting in 2015 or ~20% occurrence for quolls on Red Hill. The above findings continue the encouraging trends in terms of demonstrating the potential benefits of effective cat control to the endangered northern quoll. We are hopeful that the data gathered in 2019 will allow us to tease apart further the interactions between rainfall and cat control on the population dynamics of quolls across the Yarraloola LMA (cat baited) and Red Hill (reference) sites.

1 Introduction

1.1 Project 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) in the western region of the Pilbara (Figure 1). The LMA encompasses the Yarraloola pastoral lease to the east of northwest 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 focuses on the control of feral cats given their significant threat to Australian fauna (Woinarski *et al.* 2014; 2015) and is consistent with the policy and management priorities of the Threat Abatement Plan for Predation by Feral Cats and the Threatened Species Strategy for Australia (Commonwealth of Australia 2015a & b). 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 (Short *et al.* 1997; Algar *et al.* 2007 & 2013). 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 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). 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 impact of using *Eradicat*® feral cat baits in the presence of northern quolls was assessed during an experimental baiting operation over 20 000 ha within the

Yarraloola 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 (*D. maculatus*) in New South Wales (Claridge and Mills 2007; Körtner and Watson 2005).

1.2 Operational broad-scale cat baiting 2016–19

Following the above-mentioned findings, the project entered the operational phase and annual winter aerial baiting with *Eradicat®* baits over ~144 100 ha of the Yarraloola LMA commenced in 2016 (Morris and Thomas 2014). Additional safeguards were built into the monitoring program, particularly for northern quolls. Added research involving the use of camera traps to monitor the fate of individual toxic *Eradicat®* baits was covered by Palmer *et al.* (2017).

1.2.1 Study aims

The project for 2018 was largely a continuation of the baiting and monitoring programs established in 2016. In response to concerns over the robustness of the camera trap monitoring to measure the effectiveness of baiting at very low cat densities we incorporated the collaring and radio-tracking of cats to allow for independent verification of cat mortality rates due to winter baiting.

Aims were to:

1) conduct the third annual broad-scale aerial 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 through camera trap monitoring and radio-telemetry;
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.

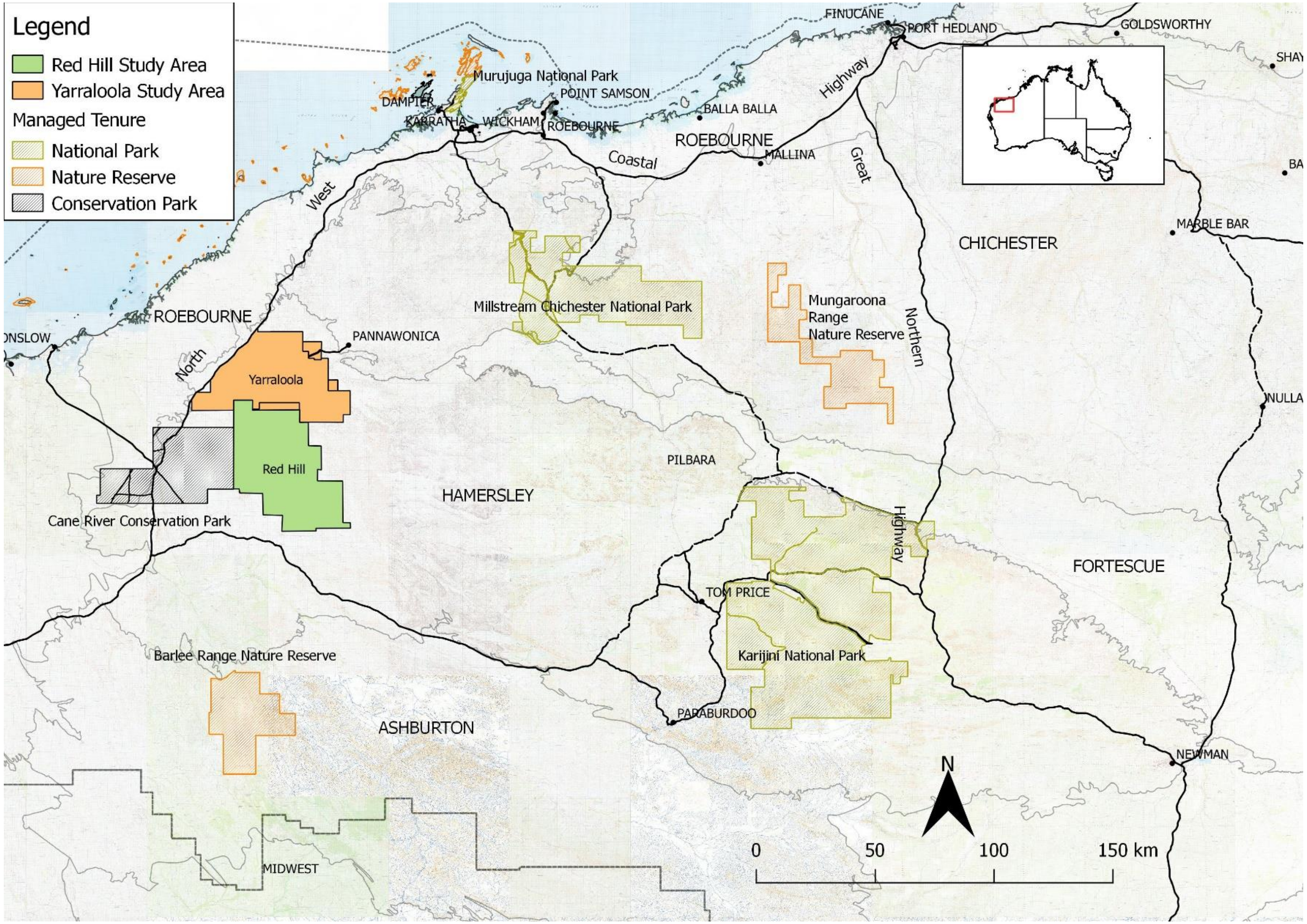


Figure 1. Location of the Yarraloola LMA and Red Hill in the western Pilbara region of Western Australia.

2 Methods

2.1 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 (Figure 1).

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 most of the 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.

Average annual rainfall for Pannawonica and Red Hill from 1971, when records commenced for Pannawonica, is ~400 mm (Australian Bureau of Meteorology 2018). The rainfall received across the study sites since the study commenced in 2015 reflects this variability (Figure 2). Annual rainfall totals for the study period to date have been reasonably close to the long-term averages. The exception was 2017 for Pannawonica, when 319 mm fell in February 2017 following the passage of a tropical low. The total was 538 mm for the year.

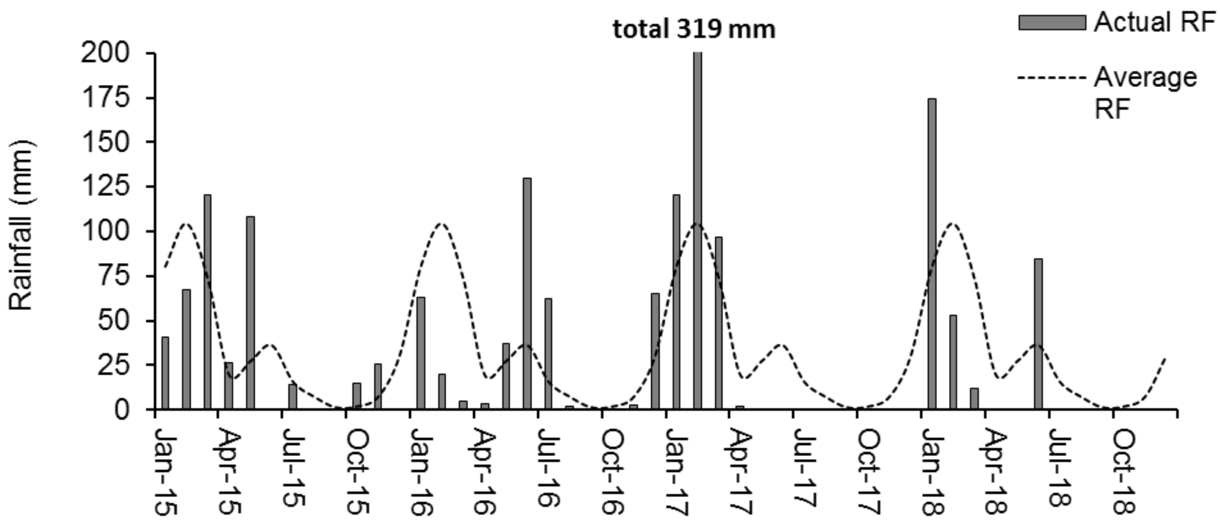
2.2 Study design and timing

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, ant attack, and hot weather is also reduced at this time of the year.

There was no aerial baiting of wild dogs undertaken in 2018 on the two pastoral leases.

The field work program for 2018 is outlined in Appendix 1.

a) Pannawonica



b) *Red Hill*

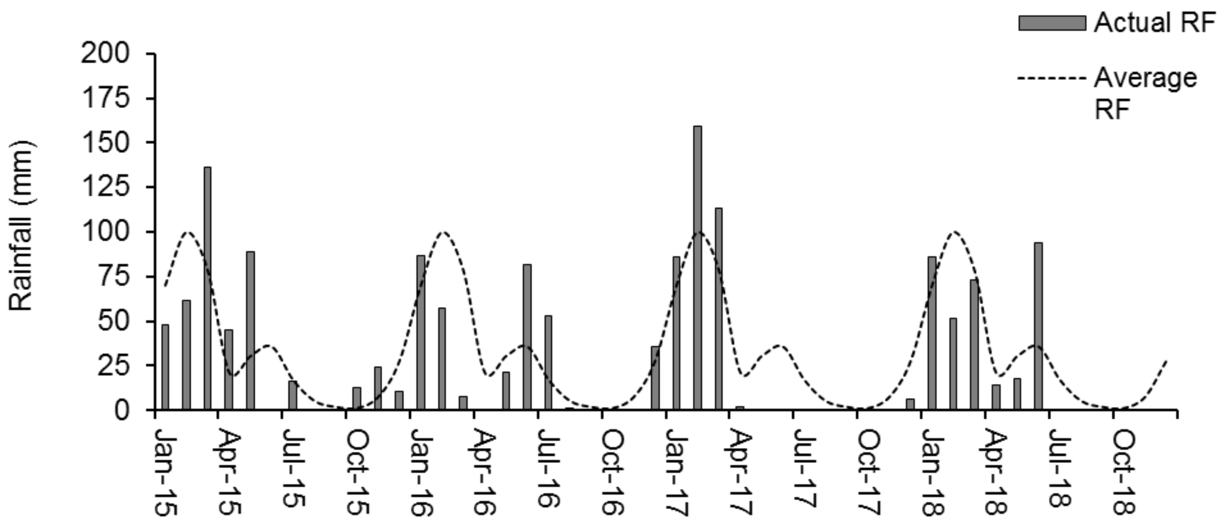


Figure 2. Monthly rainfall (bars) relative to the monthly long-term average (1971 onwards = dotted line) from 2015 to 2018 for a) Pannawonica (mean annual rainfall = 405 mm) and b) Red Hill (mean annual rainfall = 396 mm).

2.3 Feral cat monitoring

2.3.1 Camera trap design and occupancy modelling

The camera trapping approach of Comer *et al.* (2018) were broadly followed to monitor feral cats on both study sites (Yarraloola - baited and Red Hill - unbaited reference) before and after the July baiting operation (full details in Palmer *et al.* 2017; Palmer and Anderson 2018). 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). An example of the layout use at each cat camera site can be seen in Plate 1.

Each camera (Reconyx HyperFire™ PC900) was programmed on 'Aggressive' to take five pictures at up to two frames per second upon a trigger. A '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 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.

Generally, cameras are set for 25 nights leading up to the aerial baiting but widespread rainfall in early June delayed the setting in 2018. Cameras were set in mid-June, allowing for 20 to 23 nights of monitoring on each camera trap before the baiting commenced on the 9 July. Three weeks following baiting, cat cameras were redeployed (2-9 August) and then collected during the quoll trapping trip in August–September. During the period between the two monitoring sessions, cameras and lures were removed to prevent cats from becoming accustomed to them.

All images from the camera traps were uploaded into the 'CPW Photo Warehouse' program for processing and fauna species were identified (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. Interference from inquisitive cattle and crows resulted in some cameras being rendered inoperable for parts of survey periods. Sampling effort was adjusted in the analysis according to the date and time-stamp data.

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 based on 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 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 interference by cattle or crows 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.* 2018).

2.3.2 Trapping and collaring methods

Feral cat trapping was conducted under ethics approval AEC 2018/04 and followed standard techniques (Clausen *et al.* 2016). Trapping was undertaken by two teams on Yarraloola from the 24 April to 4 May and by a single team on Red Hill between 8–17 May.

We used Victor 'Soft Catch'® № 1.5 padded leg-hold traps (Woodstream Corp., Lititz, Pa.; U.S.A.), with cat faeces as the attractant. Locations of trap sites were selected based on habitat types where we had previously recorded higher detection rates of cats on camera traps and few northern quolls. All traps were situated more than 500 m from preferred quoll habitat (e.g. mesa, rocky areas, riverine/gorge systems) to further reduce the likelihood quolls would encounter trap sites. Traps were set in shaded sites along the edge of tracks, 0.5 – 1.0 km apart. Open-ended trap sets were used consisting of two traps positioned lengthwise and vegetation used as a barrier along the sides of the trap area. Seventy-six trap locations were set on Yarraloola and 78 trapping locations on Red Hill. The cat trapping transects for Yarraloola and Red Hill are presented in Figure 5.

Trapped cats were sedated with an intramuscular injection of 4 mg/kg Zoletil 100® (Virbac, Milperra, Australia). Cats were sexed, measured (head length and width), weighed, coat colour noted and DNA tissue samples taken. Each cat over 1700 g was fitted with a GPS/VHF radio-telemetry collar with mortality signal (ATS, Minnesota, USA). Collars were programmed to take 24 GPS fixes per day between June and September and six GPS fixes per day for the remaining months. The collars were programmed to go into mortality mode following 12 hours of inactivity.

2.3.3 Monitoring and mortality rates of cats fitted with radio-collars

Monitoring of collars was conducted by ground and helicopter tracking. Two helicopter flights, one prior to baiting (8 July) and one after baiting (7 September), were conducted to locate collared cats (alive or dead) and to remotely download the GPS data from the collar. Before and in between both helicopter flights, opportunistic ground tracking was conducted to locate cats and download GPS data where possible.

GPS data obtained from the collars was converted using the ATS fixes program and Microsoft Excel to remove failed/blank GPS fixes and remove points after the collar went into mortality mode (i.e. motionless) before importing into QGIS 2.18.16. Cat home ranges were calculated using Minimum Convex Polygon (MCP) method via the plugin Animove in QGIS. This method creates a convex polygon around the smallest polygon that includes a specific proportion of GPS fixes for that animal, we used 95% of the GPS points, excluding the furthest 5% of data points from the sample mean (White and Garrott 1990).

To determine if cats were killed from eating a toxic bait, location data from the GPS collars removed from dead cats was merged with bait drop data in QGIS. We investigated hourly movements leading up to when the collar showed inactivity to determine the likelihood of intersection with a cluster of baits. Time to death following the bait drop was then estimated.

Plate 1. Feral cat camera trap monitoring site.

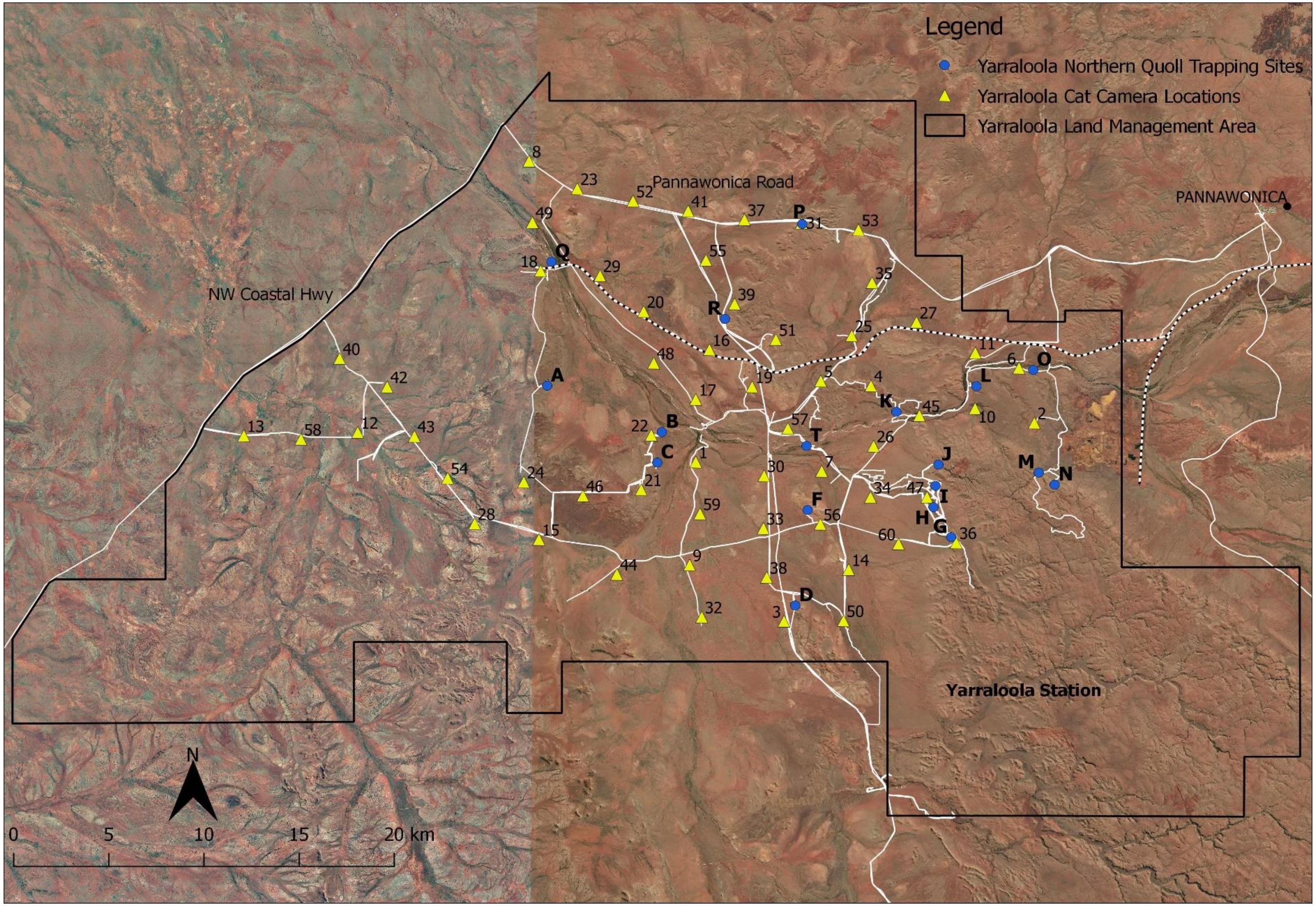


Figure 3. Cat camera and quoll trapping locations on the Yarraloola LMA baited site.

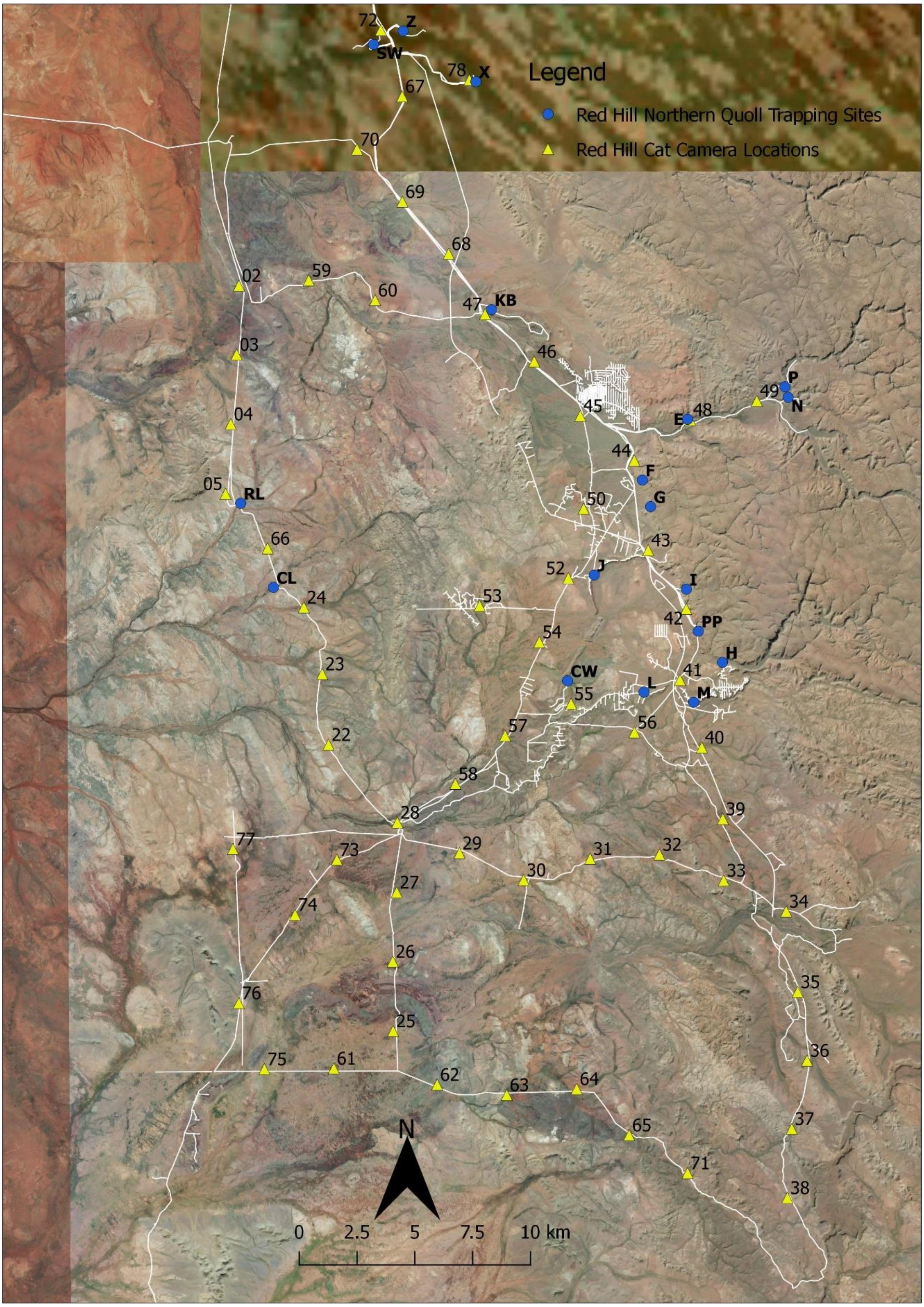


Figure 4. Cat camera and quoll trapping locations on the Red Hill reference site.

2.4 Baits and baiting

2.4.1 *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 via injection in the manufacturing process at a rate of 4.5 mg per bait.

2.4.2 Bait cell modifications

The heat map analysis based on camera trap detections of cats from 2016 to 2017 and other general observations highlighted that cats tend to avoid extensive area of rugged hills and ridges supporting hard spinifex grasslands (not presented). In contrast, we found cats showed a strong preference for the stony alluvial plains supporting snakewood shrublands with patchy tussock grasses and soft spinifex grasslands (Sherlock Land System) and the sandy alluvial plains and drainage lines supporting shrubby soft spinifex grasslands (Urandy Land System). Based on this analysis, we excluded a large area of the Hamersley Ranges (Newman Land System) from the bait cell (UCL in the southeast of the Yarraloola LMA) and added three smaller parcels of cat-preferred Sherlock and Urandy plains habitat to the bait cell (Figure 6). These extra buffer zone areas positioned on the margin of the 2016-17 bait cell, included one in the south and two along the eastern boundary.

2.4.3 On ground coordination and notifications

Landholders surrounding the Yarraloola LMA were informed by email and letter of the pending baiting operation. Feral cat baiting notification posters were erected around the Pannawonica town site to alert community members and visitors to the operation. The Kuruma Marthudunera Aboriginal Corporation was informed and provided with the notification poster so they could pass this information on to traditional owners.

2.4.4 Aerial baiting

The baiting operation was coordinated from the Mt Minnie Station airstrip located 50 km to the southwest of Yarraloola. Frozen *Eradicat®* baits were unloaded from the truck and placed in direct sunlight on purpose–built drying racks to thaw and then sweat. This 'sweating' process causes the oils and lipid-soluble digest material to exude from the surface of the bait. The baits were sprayed 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 9-10 July 2018. This was conducted by Shine Aviation Services, Western Australia, under the DBCA Western Shield aerial baiting contract. 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^2 were distributed through a carousel to give an approximate 200 m long by 40 m wide bait swathe.

2.5 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 3 and 4. Trapping is generally timed to coincide with the birth of quoll pouch young in September to allow for the collection of this key demographic information. 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. Due to logistical reasons this year however, the annual trapping session on Red Hill was moved forward by one week, commencing on the 28 August.

2.5.1 Trapping methods

At each trapping site, 20 small Sheffield cage traps 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 the sides of 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 an existing 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.

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.

2.5.2 Statistical analysis of quoll data

A two-way analysis of variance (ANOVA) was performed on quoll body weights of male and female quolls between treatments and years. Only 2016-2018 data was included in this analysis as fewer sites were trapped in 2015. 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 and box plots were performed in the R software (ver. 3.4.2 https://www.R-project.org/).

2.6 Predator diets

Northern quoll scats were collected from cage traps (first capture night to avoid contamination from bait consumption). Quolls also mark (defecate) the area around lures used for camera trap monitoring. Dingo and cat scats were collected during targeted searches of road sides and cattle watering points. A quadbike was utilised this year [7-9 September] to extensively search the sides of various tracks on Yarraloola for dingo and cat scats. Predator scats encountered opportunistically were also 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.

2.7 Other incidental/opportunistic 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 and Brooke Richards.

2.7.1 Tissue collection possums

There is some uncertainty over the sub-species status of the common brushtail possum (*Trichosurus vulpecula*) in the Pilbara. Possums were first detected during this study on a camera trap set on the edge of the Robe River near Cat Camera 49 (Figure 3) on 16 September 2016 (Palmer *et al.* 2017). This initial detection was followed by numerous detections of possums on Cat Camera 49 in 2017 (Palmer and Anderson 2018). Eight medium-sized cage traps baited with green apples and peanut butter were set for three nights in June 2018 in this general location with the aim of capturing possums for tissue collection for an Australia wide genetics investigation lead by Professor Stephen Donnellan, South Australian Museum.

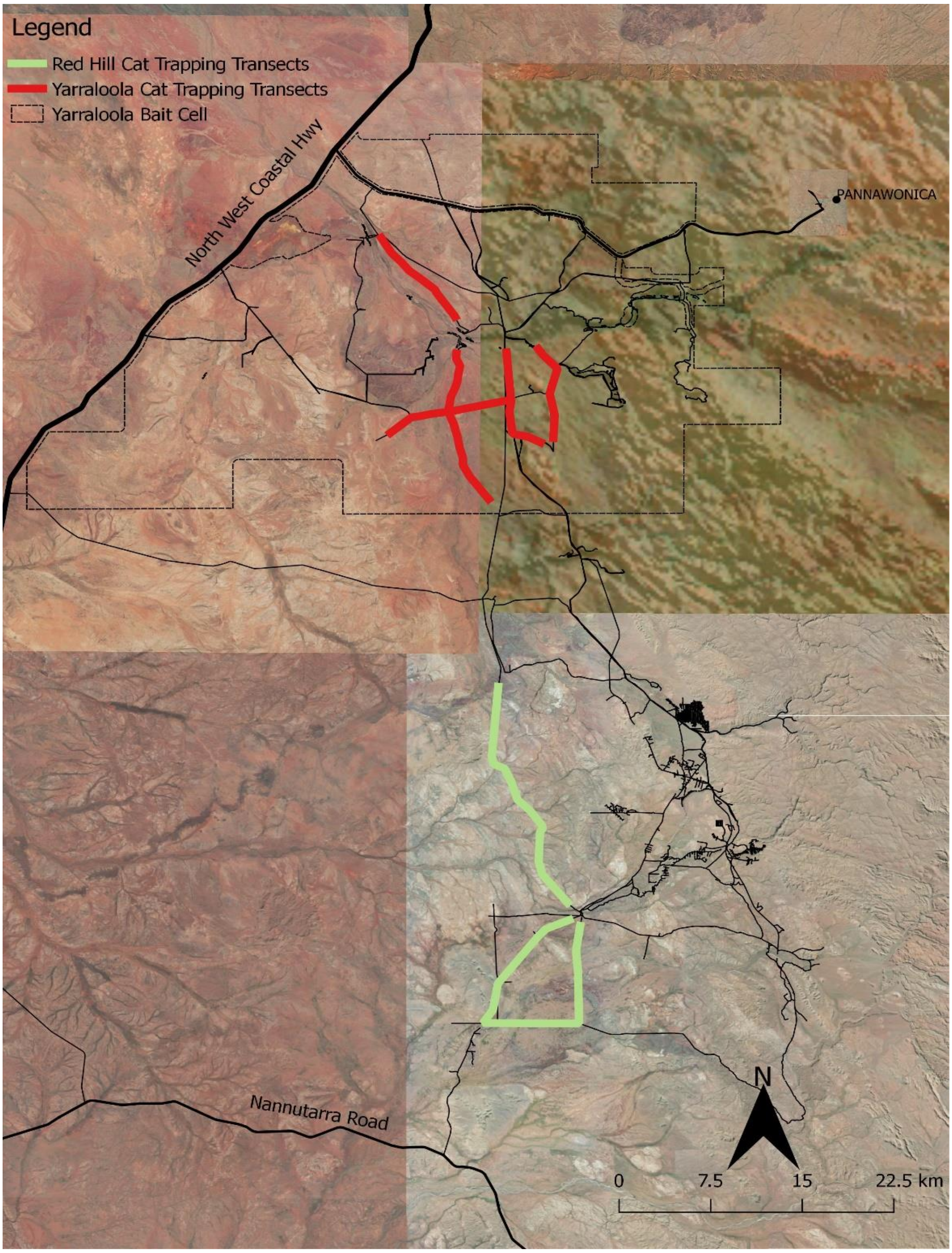


Figure 5. Cat trapping transects set on the baited (Yarraloola) and unbaited (Red Hill) site in 2018.

3 Results

3.1 Rainfall and seasonal conditions

Leading into 2018, there was little to no rain in the second half of 2017. A number of cyclones and tropical lows passed over parts of the Pilbara during the wet season, but these activities brought little rain to the study area. Much of the rain that fell in summer was associated with localised thunderstorm activity and totals received at the recording stations at Pannawonica (323 mm) and Red Hill (336 mm) were below the annual average (pers. comm. Leanne Corker). A late frontal rain system delivered significant rainfall in early June across the entire study area (Figure 2). No further rainfall was recorded for the remainder of 2018.

Examination of rainfall patterns over the past six years indicates that while there has been only one dry year (2014), summer rainfall has been below average every year apart from 2017. Annual rainfall totals were boosted by higher than average falls being received from April to July in 2013, 2015, 2016 and 2018.

3.2 Feral cat baiting

Aerial baiting took place on the 9-10 July covering an area of 141 594 ha (Figure 6). A total of 71 000 *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 6).

No ground baiting of the Pannawonica road corridor took place in 2018.

3.2.1 Detection of non-target species deaths

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

3.3 Feral cat and quoll detections on cat camera traps

The impact of the baiting program on the feral cat population was determined by comparing 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 camera trapping results are summarized in Table 1. The total number of camera nights per session was lower than the maximum (1500 CTN) during the pre-bait period because wet weather delayed the setting of camera traps (Table 1). Relatively few camera trap nights were lost due to interference by cattle/crows.

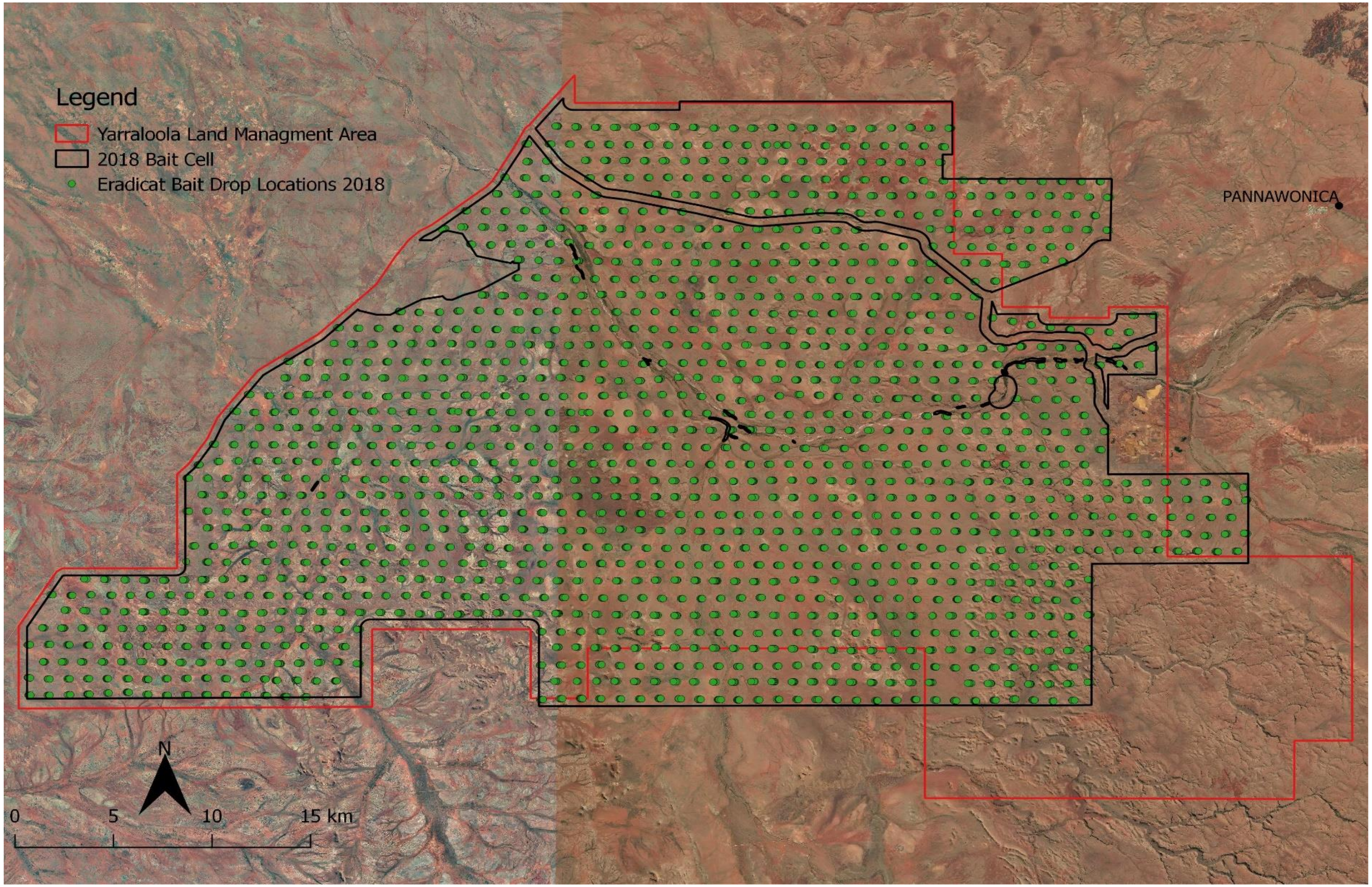


Figure 6. The Yarraloola LMA bait cell (black bold line) for 2018 and the distribution of baits on the 9 and 10 July. The bait exclusion areas within the LMA are bounded by a bold black line. The outer red line is the Yarraloola LMA boundary.

Table 1. Summary of cat camera trap sessions before and after baiting.

	Yarraloola		Red Hill	
	Pre-bait	Post-bait	Pre-bait	Post-bait
Cat detections				
Total number of nightly detections	22	11	19	25
Total number of camera sites with cats	15	7	11	16
Quolls detections				
Total number of nightly detections	63	50	31	16
Total number of camera sites with quolls	18	15	11	12
Camera trapping effort				
Total camera trap nights	1270	1485	1278	1495

Total cat detections were higher in 2018 compared with previous years, with cats being recorded on multiple nights at individual camera sites during both monitoring sessions for Yarraloola and Red Hill. In some instances, cats were detected on three to four different nights during the pre-baiting session on Yarraloola and during both sessions on Red Hill (cats on 4 different nights at C38 Yarraloola, 4 nights C58 Red Hill, 3 nights C75 Red Hill; Figures 3 and 4).

While quolls are not the target species of these cameras, their detection rates on Yarraloola were higher than the target species, cats (Table 1). For Yarraloola, quolls were found on 63 nights at 18 cameras before baiting and 50 nights at 15 cameras after baiting. On Red Hill, it was 31 nights at 11 cameras before and 16 nights at 12 cameras after.

Very few dingoes were detected on the cat cameras. On Yarraloola, there were no records before the baiting and only four records at three different cameras after baiting (C15, 25 Aug; C18, 15 and 25 Aug; C60, 17 Aug). Likewise, Red Hill had four detections at three different cameras, two detections (C47, 28 June; C3, 8 July) before baiting and two after (C3, 18 Aug; C31, 6 Aug). No foxes were recorded.

3.3.1 Site occupancy of cats

Cat occupancy in the treatment area was high during the pre-bait monitoring session (Figure 7). The probability of feral cat occupancy in both models (random effects and spatial component) showed a significant decrease following the baiting on Yarraloola (t-test, p 0.00001). There was a significant increase in cat occupancy in the reference site for both models in the post-bait monitoring session (T-test, p 0.0001; Figure 7).

(a) *Modelled random effects* (b) *Modelled spatial component*

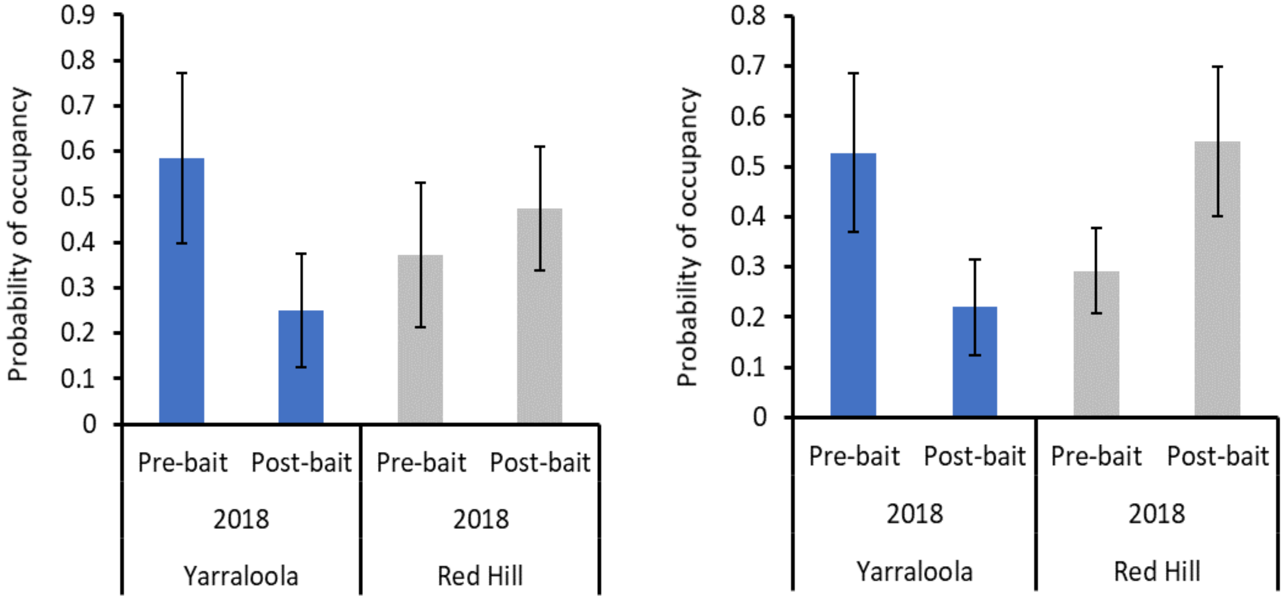


Figure 7. Site occupancy (mean ± SD) before and after baiting in treatment (Yarraloola) and reference (Red Hill) sites for 2018 with (a) random effects and (b) spatial component.

3.3.2 Detection rates of cats and quolls

Feral cat populations increased substantially prior to baiting in 2018 (Figure 8a, b). On Yarraloola, there was a three-fold rise in the mean detection rate of cats from a low of 0.4 cats per 100 CTN following last year's baiting program to 1.7 cats per 100 CTN prior to baiting in 2018. The increase in cat abundance on Red Hill was of a lesser magnitude.

Baiting had a significant impact reducing the cat abundance by 57% to 0.7 cats per 100 CTN. This knockdown was not as low as previously measured following baiting in 2016 or 2017 (Figure 8a). On Red Hill, there was a slight increase in cat detections after the scheduled baiting program on Yarraloola, with the rate being equivalent to that on Yarraloola prior to baiting in 2018 (Figure 8b).

Detection rates of northern quolls on Yarraloola showed no evidence of a significant decline following each of the baiting programs (Figure 8c). Quoll detection rates on the Red Hill cameras were consistently lower and were lower during the post-bait monitoring session in each year (Figure 8d). The high detection rates of quolls recorded on Yarraloola in 2017 were maintained into 2018.

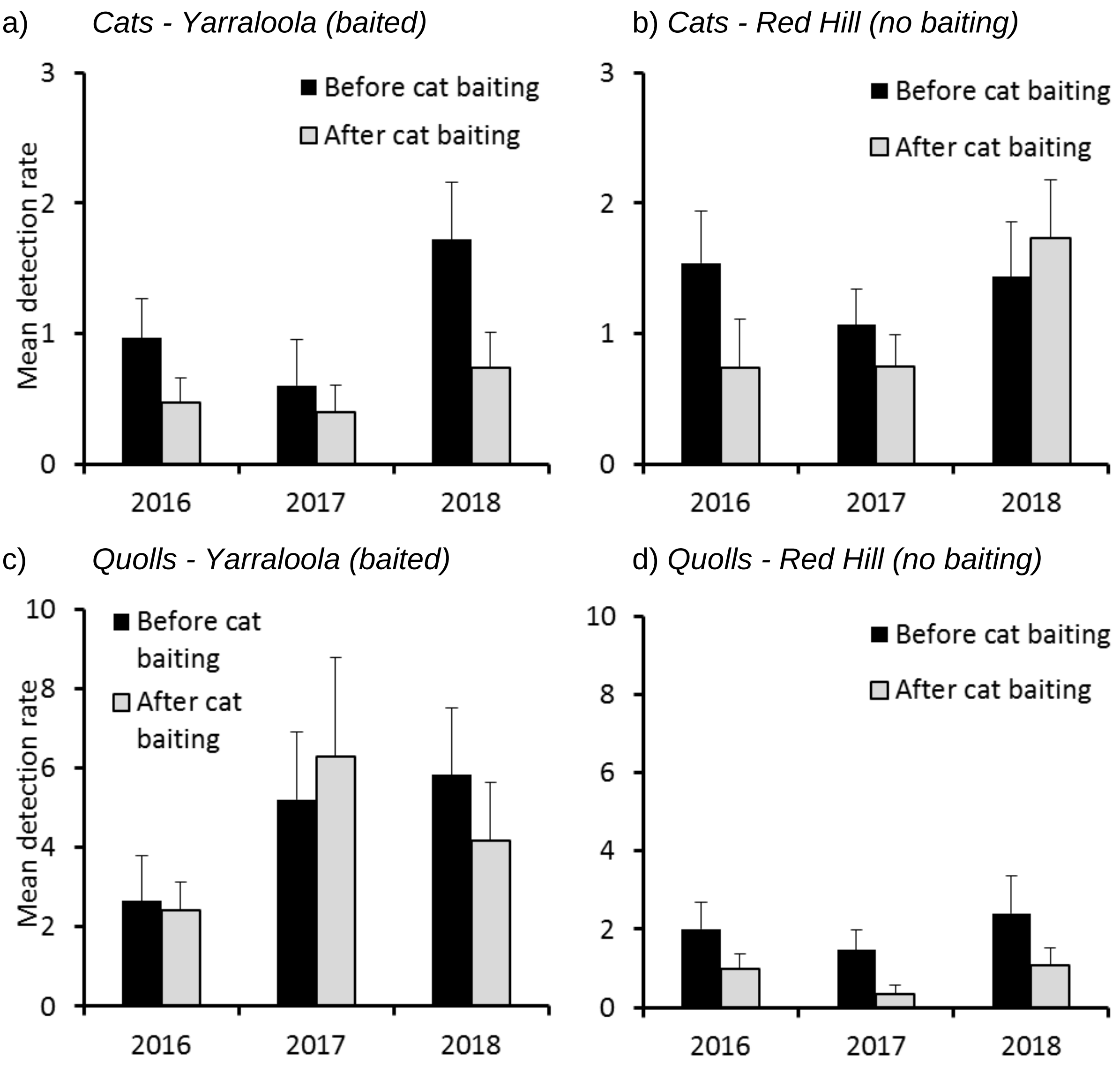


Figure 8. Mean detection rate (mean number of events per 100 camera trap nights per camera trap site) of cats on Yarraloola (a) and Red Hill (b) and northern quolls on Yarraloola (c) and Red Hill (d) prior to and after winter cat baiting on Yarraloola from 2016 to 2018.

3.4 Feral cat trapping and collaring

3.4.1 Trapping and radio-collaring

A total of 533 trap nights were conducted on Yarraloola and 431 nights on Red Hill. Fifteen cats (6 F, 9 M) were trapped on Yarraloola giving a capture success rate of 2.8%, compared to seven cats (5 F, 1 M, 1 unknown) on Red Hill at a capture rate of 1.6%. On Yarraloola, the mean mass (± SE) of females was 2465 ± 302 g and males 4039 ± 363 g (Table 2). For Red Hill the mass of females was lighter at 1960 ± 420 g and only one male was trapped weighing 5100 g. Fourteen cats (5 F, 9 M) were fitted with GPS/VHF radio-collars (93% collared) on Yarraloola, whereas only three cats (2 F, 1 M) large enough to collared on Red Hill (42% collared). Individuals not collared were all juveniles weighing <1800 g (Table 2). Juvenile cats were released following capture on Red Hill (i.e. reference site) and shot on Yarraloola.

A small number of non-target species were captured on Yarraloola and Red Hill. Six wild dogs (*Canis familiaris*) were euthanised as required under the *Biosecurity and Agriculture Management Act 2007* for pastoral lands. Two varanids were released unharmed and a third varanid died in the trap.

3.4.2 Monitoring and mortality of collared cats

A sub-adult male cat (YM01) was killed by a wedge-tailed eagle in the hours after it was released on the day it was collared. The collar and carcass were retrieved several days later not far from the release site. This cat may have still been recovering from the effects of the sedative.

During the pre-bait helicopter flight on the 8 July, 12 of the collared cats on Yarraloola were found and data downloaded. One female cat (YF01) was not found and it remains missing. The collar of the juvenile male cat (YM05) was in mortality mode. A later ground search resulted in its mummified carcass being found and the collar was retrieved (Figure 9). There were no clear signs of the cause of death. The three collared cats on Red Hill were accounted for during the pre-bait period.

Eight out of twelve collared cats on Yarraloola were located and data downloaded during the helicopter tracking session two months following the baiting on the 7 September. Two cats (YM09, YF02) were in mortality mode, both collars and carcasses were recovered. Subsequent analysis of the movement data confirmed likely bait deaths for both cats. The female cat (YF02) was approximately 26 m from a bait cluster when she stopped moving, which was two days after baiting on 12 July (Figure 10, Table 2). The male cat YM09 passed through a bait cluster on 27 July and died early the following morning. All three cats on Red Hill were accounted for during the post-bait period.

Four cats (YM07, YM08, YF01, YF03,) were not located during September. Two individuals, YM08 and YF03, were heard alive inside the bait cell from the ground on 7 and 8 August 2018, respectively. No data downloads were possible so access to toxic baits was not able to be confirmed. The male cat YM07 was outside of the bait cell a day before the bait drop (8 July 2018) and has not been located since. This means that two out of eight collared cats died from baiting, giving a 25% mortality rate of collared cats.

Preliminary analysis of some cats that survived baiting suggests they potentially had multiple opportunities to encounter toxic baits as they passed through bait clusters. An example is presented in Figure 10 for three cats in the south of Yarraloola. The adult male (YM04, 5000 g) and adult female (YF05, 2630 g) survived baiting, but a juvenile (when captured) female (YF02, 1700 g) succumbed to baiting (Figure 10).

3.4.3 Home range analysis

Sufficient data was available from 14 collared cats (three weeks of data for 24 fixes/day) to calculate home range size (11 cats Yarraloola and 3 cats Red Hill, Figure 11). The juvenile male (YM05) went on a large exploratory journey after it was captured on the 1 May. It initially followed the Robe River and left the study site on 14 May and travelled west to the coast south of Weld Island, before returning to the bait cell on 23 May (Figure 9). It then appeared to settle into a range in the north-west of the Yarraloola LMA but died on the 28 June 2018. This animal was excluded from the home range analysis.

Home range analysis using MCP 95% was conducted on four female and seven male cats on Yarraloola (Figure 11a) and two females and one male on Red Hill (Figure 11b). On Yarraloola, male home ranges varied in area from 856 ha (YM08) to 4490 ha (YM06) (Table 2). Female home ranges varied from 557 ha (YF02 – died from baiting) to 2829 ha (YF03) (Table 2). Of note, female YF04 had an enormous home range (23643 ha) due to several exploratory walks across the landscape (Figure 11a).

Mean home range size of males was 2900 ± 445 ha and female 1428 ± 707 ha on Yarraloola (YF04 was excluded from this calculation). Mean home range size for females on Red Hill was 319 ± 17 ha and the sole male collared has a range size of 1954 ha (Table 2, Figure 11b). There was extensive range overlap between males on Yarraloola, YM09 (died from baiting), YM04 and YM02 all overlap, as well as YM03, YM08 and YM02 (Figure 11a). Male YM02 home range polygon overlaps with four other male cats (Figure 11a). None of the female cats overlap with each other on Yarraloola. The two females on Red Hill do partially overlap and the male cat's home range encompasses both female ranges (Figure 11b).

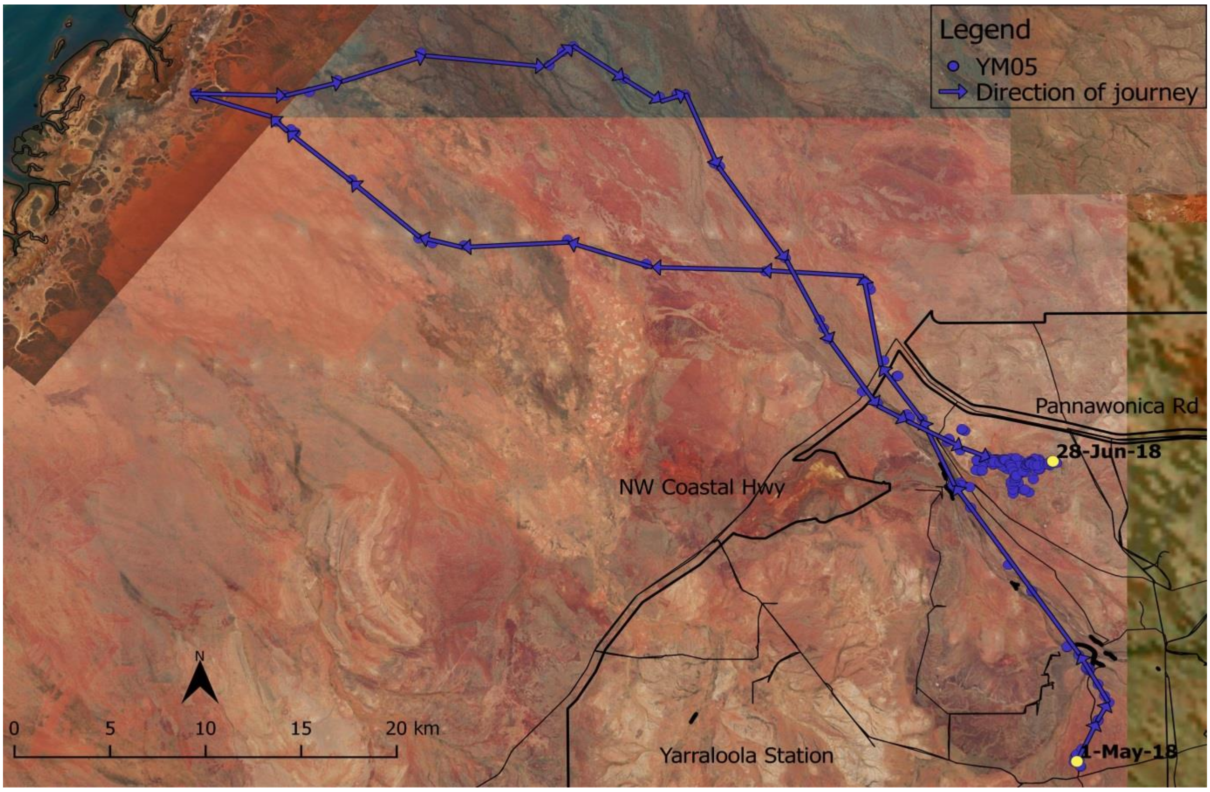


Figure 9. Movements of juvenile male (YM05) from capture 1 May to death 28 June 2018.

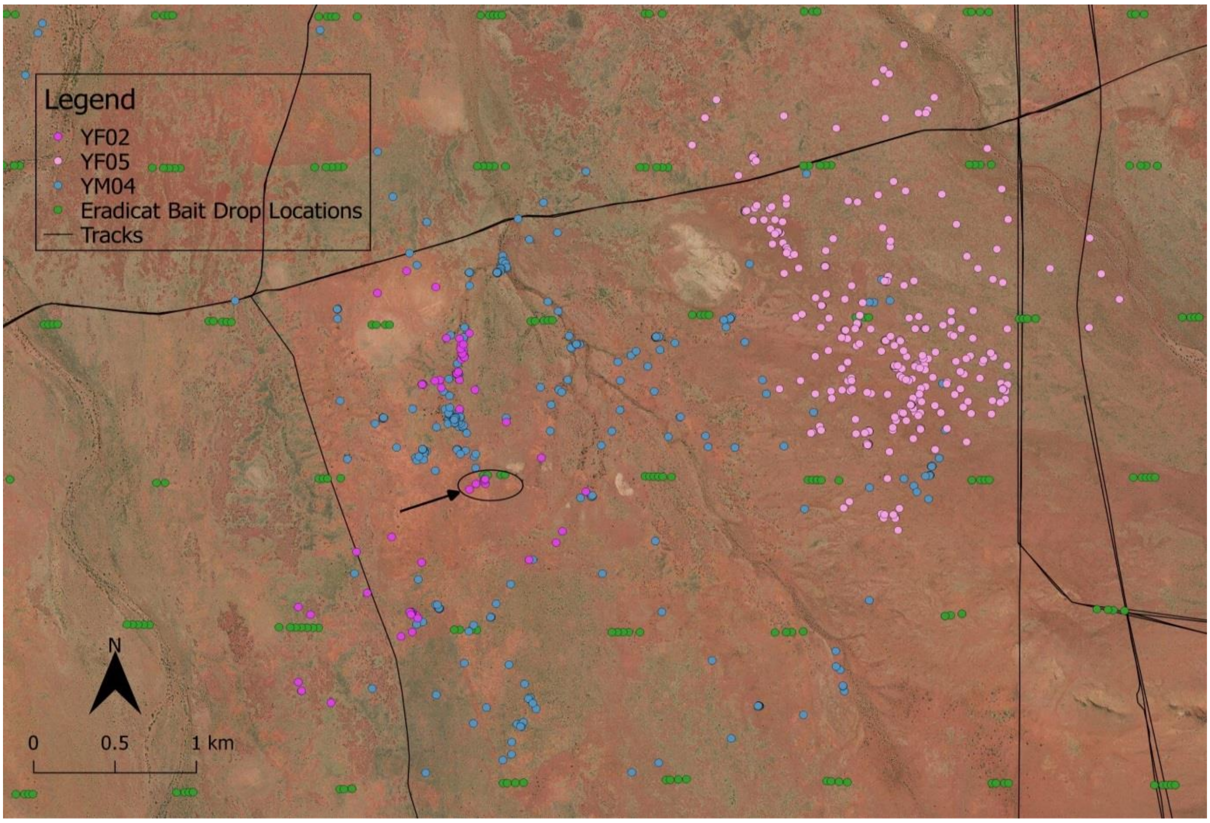
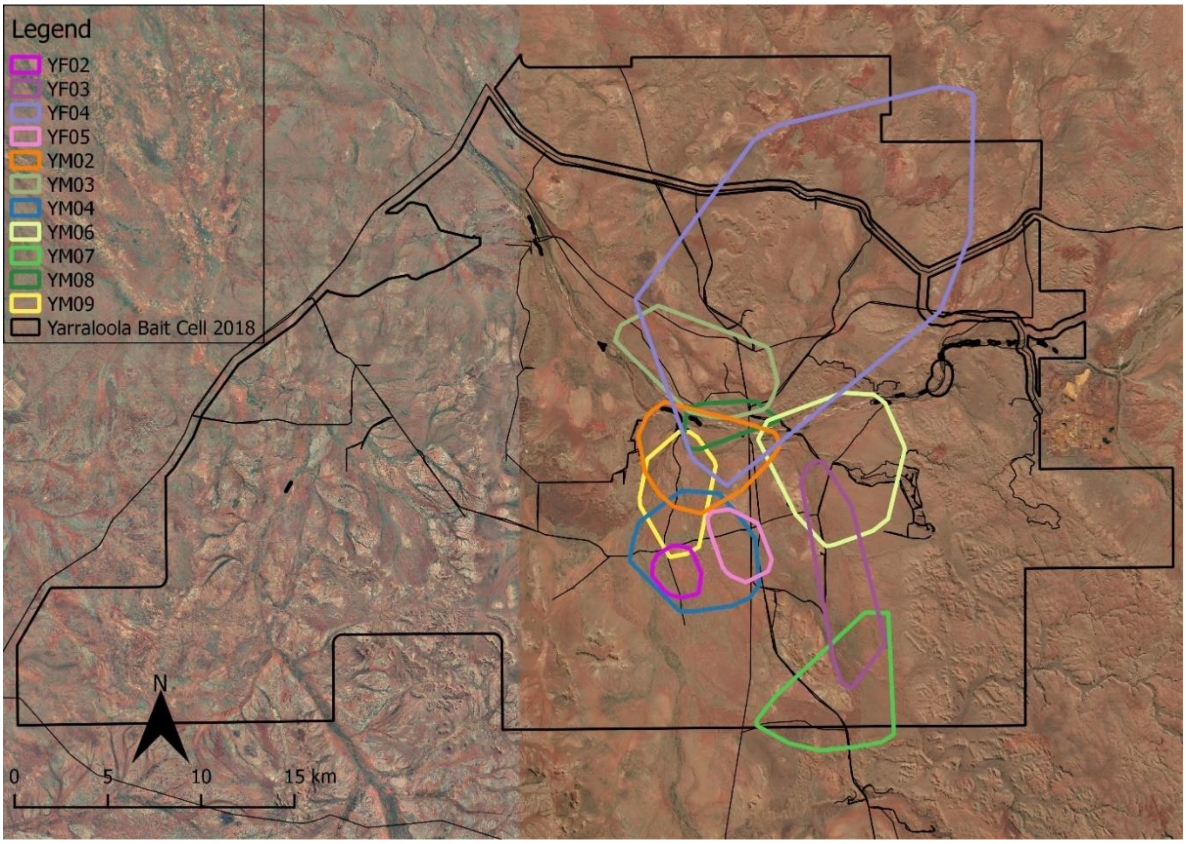


Figure 10. Hourly GPS locational data for three cats (YF02,YF05, and YM04) for two weeks following baiting. Each series of green dots is a cluster of Eradicat® baits (n=50). Black arrow indicates the location where YF02 died from baiting.

Table 2. Capture date, demographics, home range size and status of feral cats trapped on Yarraloola and Red Hill.

Identifier	Site	Capture date	Sex	Mass (g)	Coat colour	Age	Duration of filtered data	Total No of fixes	MCP95 (ha)	Status
YF01	Yarraloola	25-Apr-18	♀	2400	Tabby	Adult	No data	No data	No data	Missing
YF02	Yarraloola	26-Apr-18	♀	1700	Tabby	Juvenile	24 June–12 July	437	557	Died after baiting (0300 hrs 12 July)
YF03	Yarraloola	26-Apr-18	♀	3390	Tabby	Adult	24 June–8 July	345	2829	Alive 8 Aug (missing Sept)
YM01	Yarraloola	27-Apr-18	♂	3200	Ginger	Sub-adult	-	-	-	Killed by Wedge-tailed Eagle
YM02	Yarraloola	27-Apr-18	♂	4170	Tabby	Adult	24 June–7 Sept	1802	2998	Alive 7 Sept
YM03	Yarraloola	28-Apr-18	♂	4200	Tabby	Adult	24 June–7 Sept	1790	3262	Alive 7 Sept
YM04	Yarraloola	28-Apr-18	♂	5000	Tabby	Adult	24 June–7 Sept	1803	3329	Alive 7 Sept
YF04	Yarraloola	28-Apr-18	♀	3120	Tabby	Adult	24 June–7 Sept	1810	23643	Alive 7 Sept
-	Yarraloola	29-Apr-18	♀	1550	Tortoiseshell	Juvenile	-	-	-	Shot
YF05	Yarraloola	30-Apr-18	♀	2630	Tortoiseshell	Adult	24 June–7 Sept	1805	899	Alive 7 Sept
YM05	Yarraloola	01-May-18	♂	2050	Tabby	Juvenile	24–28 June	94	-	Died before baiting (1300 hrs on 28 June)
YM06	Yarraloola	01-May-18	♂	4630	Black	Adult	24 June–7 Sept	1809	4490	Alive 7 Sept
YM07	Yarraloola	01-May-18	♂	5620	Tabby	Adult	24 June–8 July	357	3459	Alive 8 July (missing Sept)
YM08	Yarraloola	02-May-18	♂	3080	Tabby	Sub-adult	24 June–8 July	345	856	Alive 7 Aug (missing Sept)
YM09	Yarraloola	04-May-18	♂	4400	Tabby	Adult	24 June–28 July	829	1909	Died after baiting (0800 hrs 28 July)
-	Red Hill	09-May-18	♀	1700	Tabby	Juvenile	-	-	-	Released; too small
-	Red Hill	11-May-18	-	-	Tabby	Juvenile	-	-	-	Released; too small
RM01	Red Hill	13-May-18	♂	5100	Tabby	Adult	24 June–3 Sept	1717	1954	Alive 3 Sept
RF01	Red Hill	14-May-18	♀	3000	Tabby	Adult	24 June–4 Sept	1735	303	Alive 4 Sept
-	Red Hill	15-May-18	♀	<1000	Tabby	Juvenile	-	-	-	Released; too small
RF02	Red Hill	16-May-18	♀	2900	Tabby	Adult	24 June–4 Sept	1738	337	Alive 4 Sept
-	Red Hill	17-May-18	♀	1200	Tabby	Juvenile	-	-	-	Died (reaction to sedative?)

a) *Yarraloola*



b) *Red Hill*

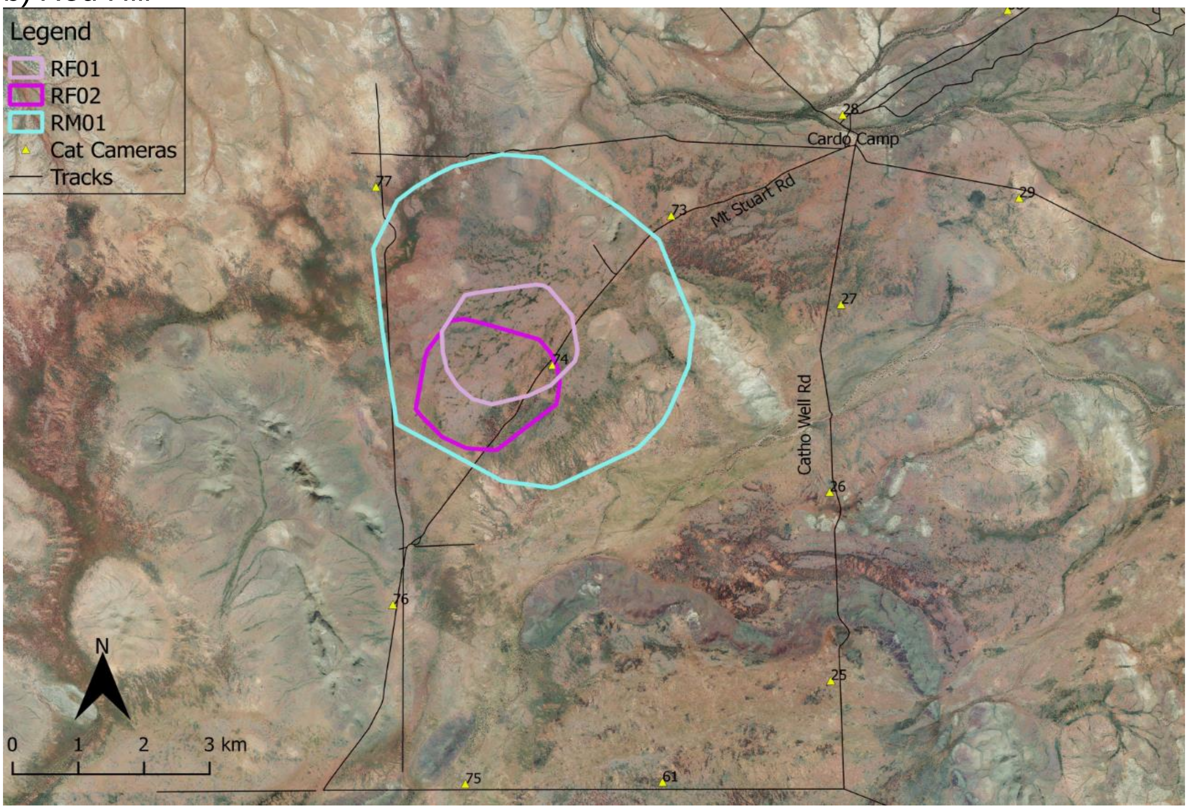


Figure 11. Feral cat minimum convex polygons (MCP) showing 95% home range area on a) Yarraloola and b) Red Hill. Each cat was assigned a code name/number, 'M' indicates male and 'F' female.

3.5 Northern quoll monitoring

3.5.1 Quoll trapping, number of individuals captured and survivorship

Trapping effort for the annual September quoll monitoring program was consistent with the previous two years (1440 trap nights at 18 sites on both Yarraloola and Red Hill). There was a further increase in the total number of individual quolls captured on Yarraloola, due this time to a large rise in the capture of males (33 M in 2017 to 47 M in 2018; Figure 13a). The number of individual quolls captured on Red Hill remained largely unchanged (Figure 13b).

A strong female capture bias is expected as trapping commences following the onset of the male die-off following breeding in August. The boost in male captures on Yarraloola however, saw more males being caught than females for the first time in this study. Capture data for individual sites and other capture rate metrics can be found in Appendix 2.

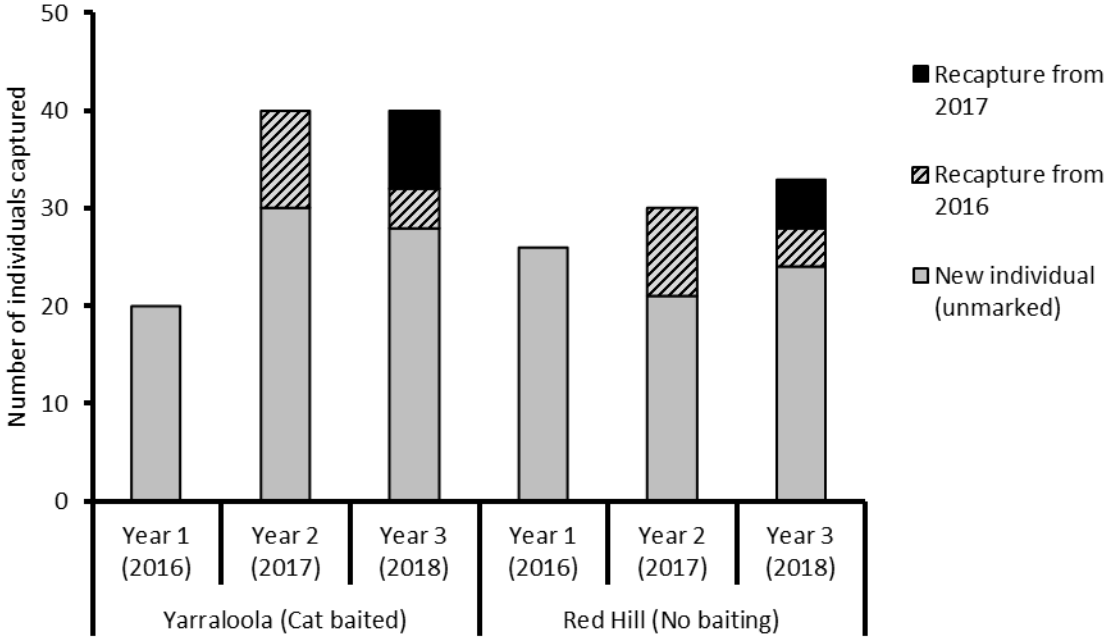
The survival rate of tagged females from September 2017 to this year's trapping session was 30% for both sites (12 of 40 Yarraloola; 9 of 30 Red Hill; Figure 13a). As relatively high proportions (~40%) of these tagged survivors in 2018 were originally captured in 2016 the survival rates of females captured for the first time in 2017 were only between 15 and 20% (Figure 13a). None of the 54 marked males across both sites from the previous year were recaptured in 2018 (Figure 13b).

We detected long distance movements in males across sites, with one male moving 5.3 km over three nights from Line J to L on Yarraloola. Two different males moved distances of ~one km each between trap lines, N to P and SW to Z, on Red Hill (Appendix 2).

3.5.2 Capture rates of quolls

Quoll trapping commenced in 2015 to obtain baseline capture rates prior to the introduction of broad-scale cat baiting. As fewer trap sites were used in 2015, we converted quoll capture data into mean number of individuals captured per trap line to enable comparison between all trapping sessions (Figure 14). This longer time series of capture data highlights the strong population response by quolls on Yarraloola from September 2016 to September 2017. Quoll populations responded to a lesser magnitude over the same time period on Red Hill. There was little change in the capture rates of quolls from the 2017 trapping session to 2018 at this reference site. Male capture rates on Yarraloola increased further on 2017 levels but captures per site ranged from none to ten individuals, hence the large error bar (Figure 14; Appendix 2). The highest number of males captured on a single line on Red Hill was four.

a) *Female quolls*



b) *Male quolls*

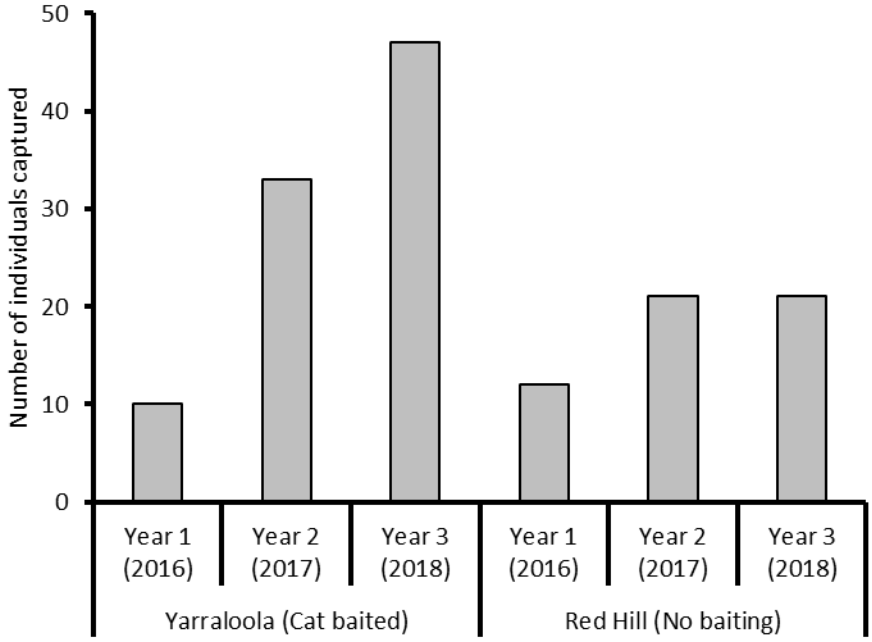


Figure 12. Total number and capture history of individual female (a) and male (b) quolls captured per 18 trap sites (1440 trap nights) on Yarraloola (cat baited) and Red Hill (reference) from 2016 to 2018. Note no tagged males were recorded to have survived from one trapping session to the next.

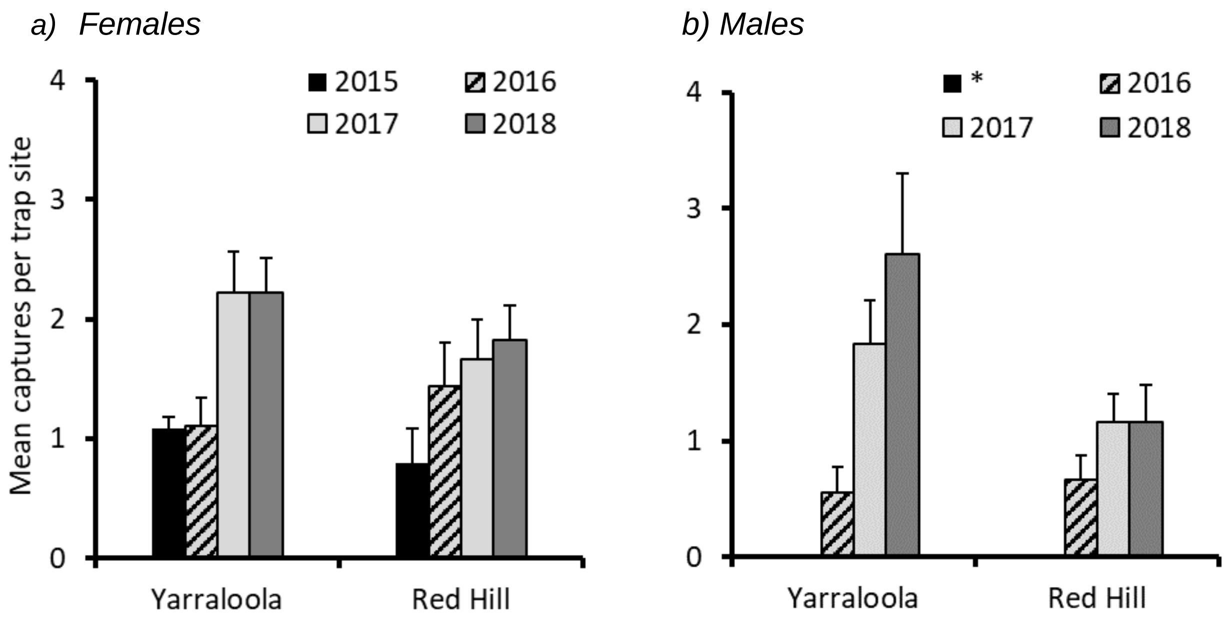


*Figure 13. Mean (+ SE) number of individual female (a) and male (b) quolls captured per trap site (20 traps set for 4 consecutive nights) at Yarraloola and Red Hill from 2015 to 2018. For 2016-18 there were 18 sites trapped at each site in September. For 2015 trapping was spread from August to October (Yarraloola 11 trap sites, Red Hill 10 trap sites). * Males excluded as some sites were trapped in August before the male die-off.*

3.5.3 Quoll body mass and litter size

The mean body mass of captured females and males across the sites decreased in 2018 following the higher masses recorded in 2017 (Figure 15). The mean body mass of both males and females was slightly less on Yarraloola than on Red Hill in 2018 (Figure 15). The two-way ANOVA revealed a significant site effect ($F_{1,182}$ = 4.50, p = 0.035) and year effect ($F_{2,182}$ = 16.98, p = 0.000) on female weights, as well as a significant site by year interaction effect ($F_{2,182}$ = 3.06, p = 0.049). However, a two-way ANOVA carried out on male quoll weights indicated no significant site effect alone but a significant year effect ($F_{2,137}$ = 27.71, p = 0.000) and site by year interaction ($F_{2,137}$ = 5.96, p = 0.003) effect.

Pouch young were only present in eight of the 40 individual female quolls (20%) from Yarraloola with a mean ± SE number of 7.37 ± 0.26 and mean ± SE crown rump size of 6.06 ± 1.19. Female quolls on Red Hill bore the signs and scars of recent mating activity but none of the 33 individuals had given birth yet. Given the small sample size for Yarraloola and lack of pouch young on Red Hill no comparable analysis was performed.

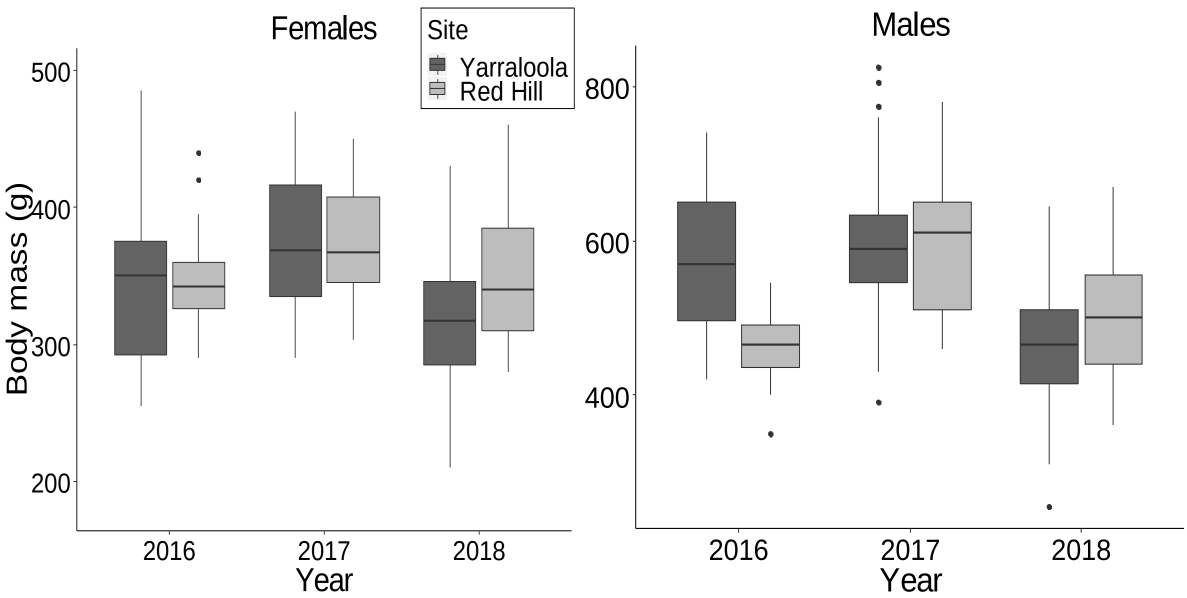


Figure 14. Body mass (g) of female and male northern quolls captured at monitoring sites from 2016 to 2018 at Yarraloola and Red Hill. Band inside the box represents the median value, box boundaries the 25th and 75th percentiles, whiskers the 10th and 90th percentiles and filled circles represent outliers.

3.5.4 Non-target captures in quoll traps

The most common non-target species captured was the common rock-rat (*Zyzomys argurus*) with 266 captures at Yarraloola and 240 captures at Red Hill. The mean number of common rock-rats captured per trap line across both sites increased dramatically this year compared to previous years (Figure 16). The other species of by-catch included five *Pseudantechinus* sp., and small numbers of skinks (*Egernia* sp. and *Ctenotus* sp.) and goannas (*Varanus acanthurus*, *V. giganteus and Varanus* sp.). On Red Hill only, four Rothschild's rock wallabies (*Petrogale rothschildi*) were captured.

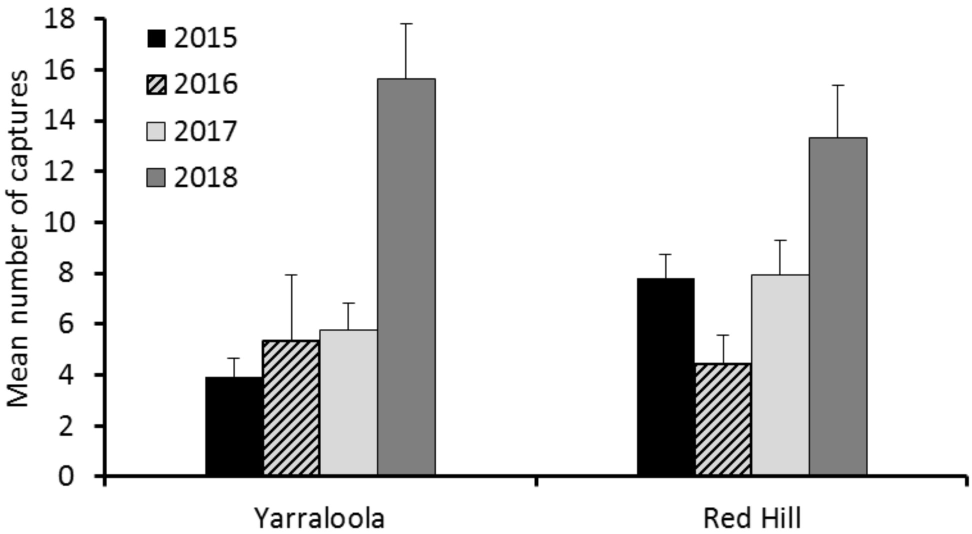


Figure 15. Mean (+ SE) number of common rock-rats captured per quoll monitoring site at Yarraloola and Red Hill for 2015 to 2018.

3.6 Predator diets

3.6.1 Overall comparison of dingoes, feral cats and northern quolls

In total, 161 quoll, 60 feral cat and 105 dingo scats were collected during 2018. These results were combined with previous data and the relative volume of food groups is shown in Figure 16.

The diets of the three predators show strong separation according to their body mass. Dingoes ate mostly kangaroos, which were largely euros and a smaller proportion of red kangaroos. The next most important prey group in terms of dietary volume were other large mammals, which consisted mostly of the gut contents of large herbivores (probably kangaroos or cattle). These scats lacked hair or other diagnostic features so it was not possible to identify the source. Minor prey items were cattle, echidnas, emus and grasshoppers.

Common rock rats comprised almost 45% of the diet of cats by volume. Other prey were mostly small vertebrates including other rodent species, dasyurids and birds. Quolls had the most varied diet, consuming mostly arthropods and to a lesser degree fruits, rodents and other small vertebrates.

There was some evidence of intraguild predation where one predator species consumed another. Out of the 48 dingo scats from Red Hill, one contained cat remains and a second, quoll remains. One of the 57 dingo scats from Yarraloola contained cat remains. Quoll was found in one of the 56 cat scats from Yarraloola. There were several accounts of cannibalism in both dingoes and quolls.

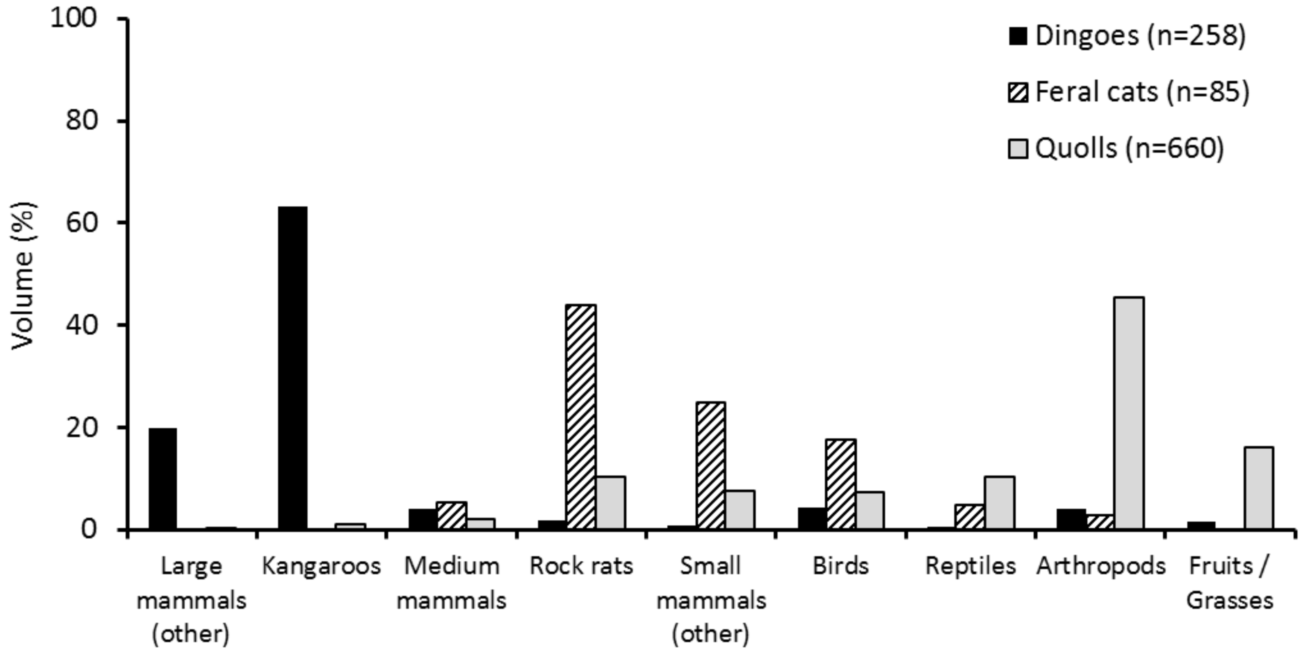


Figure 16. Relative volume of food groups in the diets of dingoes, feral cats and northern quolls for 2015 to 2018. Parentheses show sample sizes.

3.6.2 Feral cats

Feral cat scats have proved difficult to find in previous years with only 25 having been collected over the past three years. Two days of quad bike searches along road sides on Yarraloola in September resulted in the collection of ~50 cat scats. Cats were found to defecate on the top of weathered spinifex mounts pushed aside by the blade of the grader/loader.

The detection of apparent localised predation on quolls by cats at Quoll trapline N and M on Yarraloola in September/October 2017 (Palmer and Anderson 2018) raised concerns that reinvading cats may take a heavy toll on the high quoll population on Yarraloola in 2018. Only one cat scat of 55 collected contained quoll remains (Figure 17). Instead, cats were found to prey on their preferred prey of rodents, particularly common rock rats. Birds were also a common prey but did not contribute that much to the diet in terms of prey volume (Figure 17).

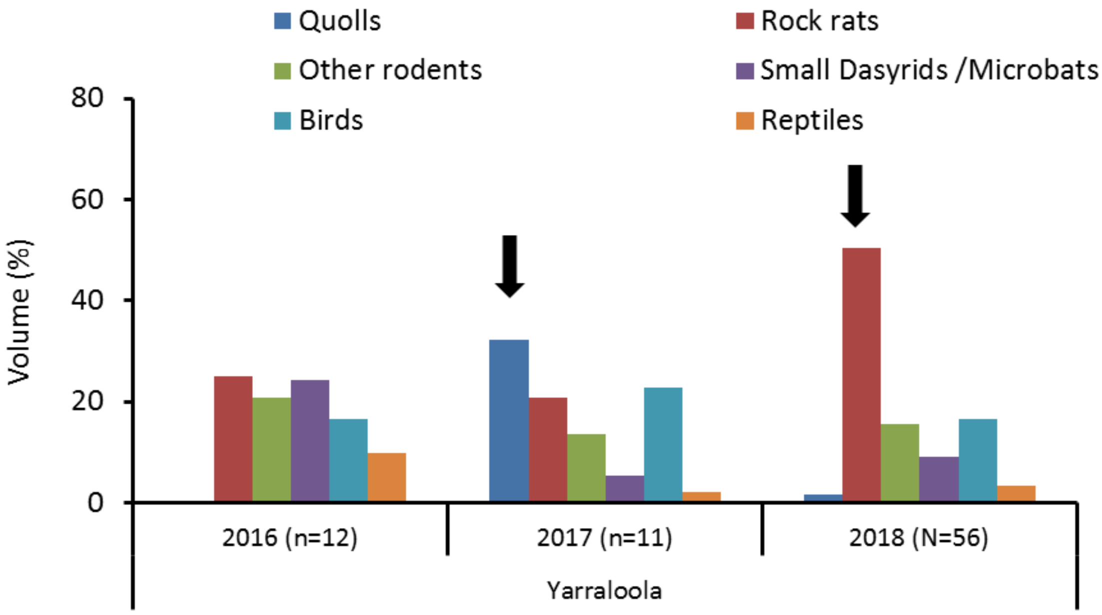


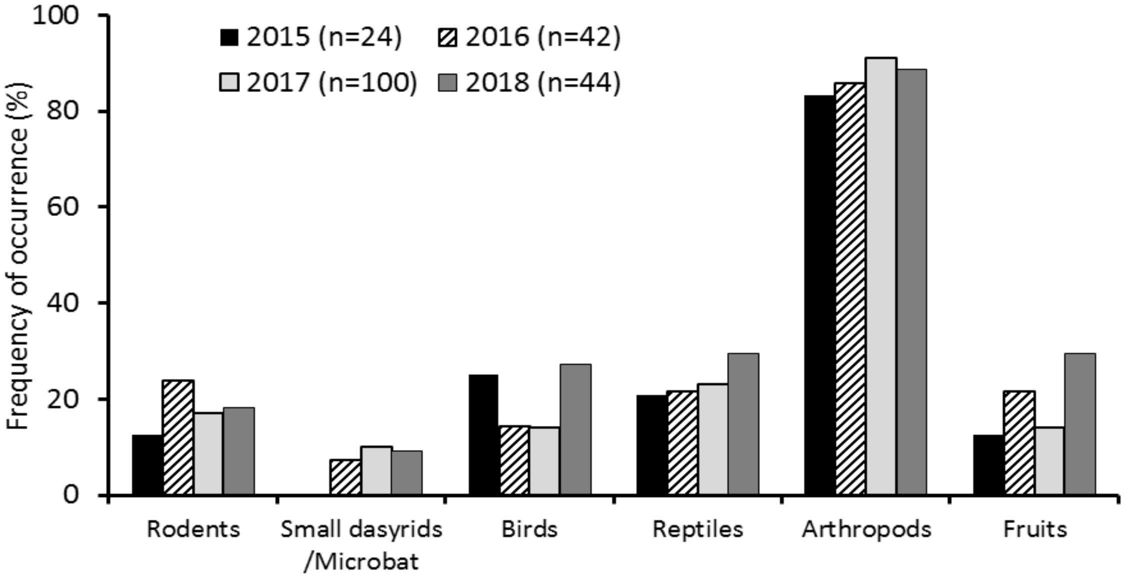
Figure 17. Comparative diet of feral cats on Yarraloola from 2016 to 2018. Diets are shown in terms of relative volume of each food group in the scats. Arrows indicate the quoll predation event of 2017 and the increased intake of preferred rock rat prey in 2018. Parentheses show sample sizes.

3.6.3 Quoll diets – 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 cat and quoll diets overlap across the small vertebrate prey groups (Figure 16). Palmer *et al.* (2017) predicted that quolls would gradually 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.

As predicted, quolls on Yarraloola have shown a strong dietary response to cat control, increasing their take of rodents over time and decreasing their reliance on fruits. Over the same period there has been little change in the diet of quolls on Red Hill (Figure 18).

a) Red Hill



b) Yarraloola

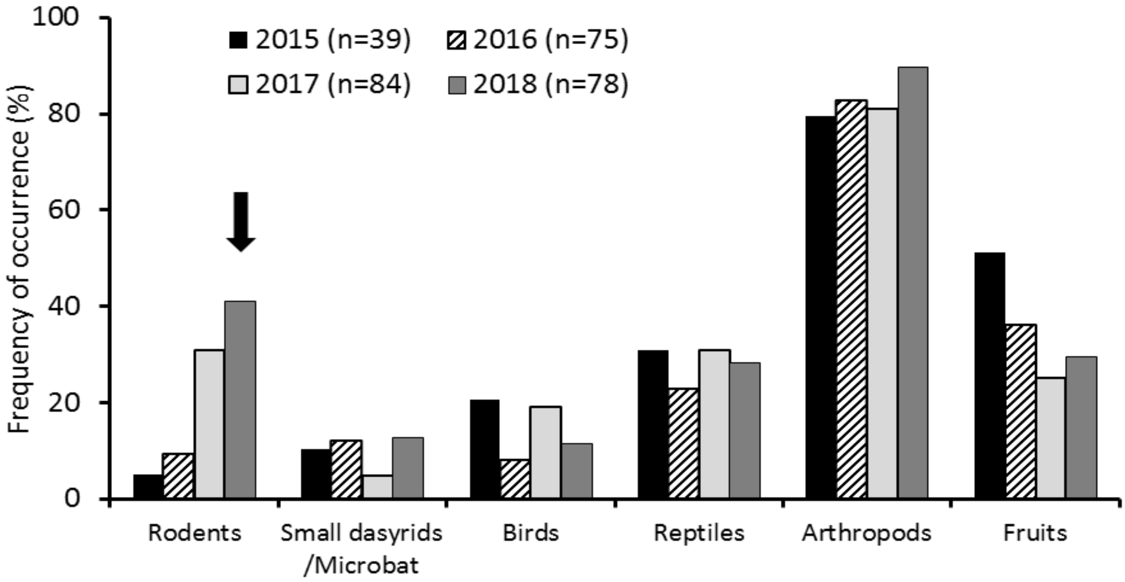


Figure 18 Comparative diets of northern quolls for (a) Red Hill and (b) Yarraloola (2015-2018). Diets are shown in terms of frequency of occurrence of each food group in the scats. Parentheses show sample sizes.

3.6.4 Dingoes

Dingoes on Yarraloola largely preyed on kangaroos (euros and red kangaroos) and there has been little change in their diets between 2016 and 2018 (Figure 19). On Red Hill, kangaroos were eaten in lesser quantities, with cattle and grasshoppers (2017) being consumed in greater volumes.

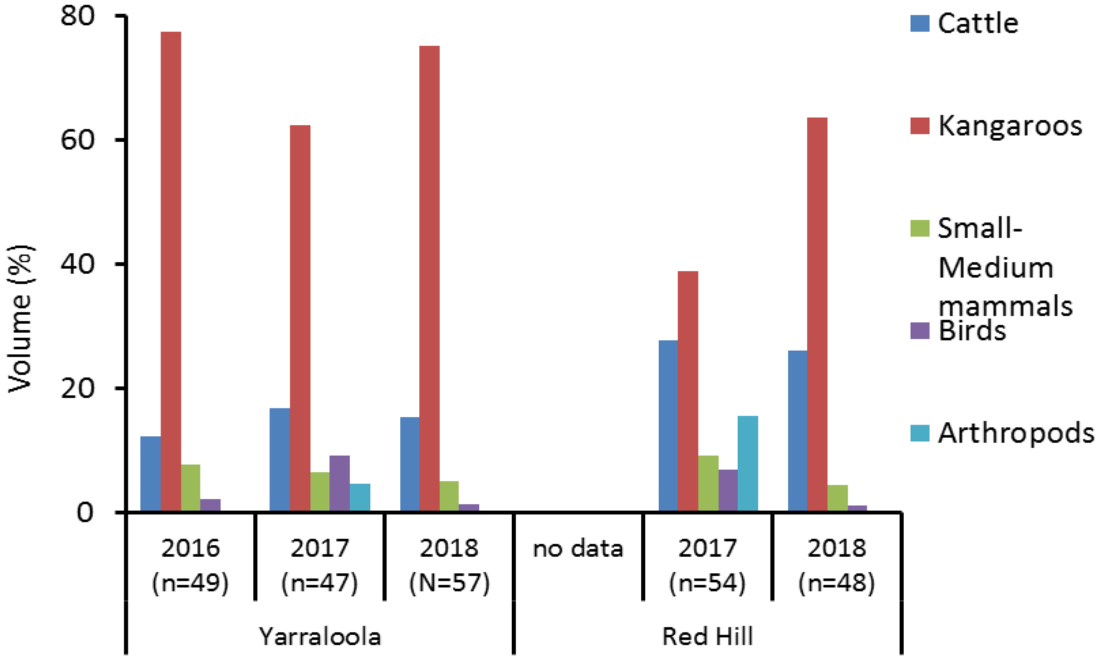


Figure 19. Relative volume of food groups in the diets of dingoes for Yarraloola (2016-2018) and Red Hill (2017-2018). Parentheses show sample sizes. Reptiles and Fruits/Grasses were excluded as these groups were rarely eaten.

3.7 Other incidental/opportunistic records

3.7.1 Pilbara olive python records

Seven olive pythons were detected in 2018. For Red Hill there were records for Python Pool, the water trough at Cardo Camp in May (Plate 2) and a cave entrance in Red Hill Creek. Billy Ross saw a large python at Quoll trapping site L in April on Yarraloola. A further three were detected by camera traps on Yarraloola, one on the 12 January at the rock hole on Mesa F near Quoll Trap site C (Plate 2) and two on different Quoll Cameras on 3 May at Quoll Trap site H and 7 May on Mesa G.

3.7.2 Possum trapping

Two possums were trapped on the 22 June 2018 (1 adult male, 1675 g and adult female with a small pouch young, 1900 g) near Cat Camera 49 on the Robe River. A small piece of ear tissue was collected from both individuals and sent to the South Australian Museum.

4 Discussion

4.1 Winter baiting program and conditions

Timing of cat baiting programs in relation to rainfall is critical as significant rains immediately following bait delivery has the potential to reduce bait toxicity and palatability (Algar *et al.* 2013). While there was a large rainfall event in the first week of June over the entire study area, little further rain was received, and weather conditions were favourable when the winter baiting occurred on the 9-10 July. In total, 71 000 *Eradicat*® cat baits were delivered by air over the 141 594 ha bait cell at the recommended rate of 50.1 baits km^{-2}.

4.2 Effectiveness of *Eradicat*® baiting

4.2.1 Feral cats re-invade the Yarraloola LMA

As previously mentioned by Palmer and Anderson (2018), the lack of re-invasion by cats of the Yarraloola LMA following the baiting in July 2016 was surprising compared with other similar broad-scale cat baiting projects at Fortescue Marsh in the eastern Pilbara and Matuwa (Lorna Glen) in the southern rangelands (Algar *et al.* 2013; Comer *et al.* 2018). Limiting re-invasion of cat–managed areas surrounded by open-system populations of feral cats remains an ongoing challenge for landscape scale cat control programs (Comer *et al.* 2018). Palmer and Anderson (2018) speculated that the more topographically rich landscapes of the east Pilbara may be more restrictive on feral cat movement compared with these other studies done in largely flat landscapes (Hohnen *et al*. 2016). They suggested that topographic barriers surrounding the Yarraloola LMA, such as the rugged Hamersley range that line the eastern margin of the bait cell and other mesa formations that mark parts of the northern and southern boundaries may form natural obstacles, slowing cat re-invasion rates (Recio *et al.* 2015).

Regrettably the 'honeymoon period' of very low cat numbers on Yarraloola in 2017 appears to have been short–lived as there was extensive cat re-invasion following the post-baiting low (0.4 cats 100 CTN^{-1}) in August 2017 to a new peak of 1.7 cats 100 CTN^{-1} in June 2018. The moderately high capture rate of cats (2.8 cats per 100 leg-hold trap nights) recorded during the April-May 2018 trapping session on Yarraloola supports the camera trap monitoring. As there was no systematic monitoring of cats between September 2017 and May 2018, the pattern of re-invasion is not known. However, there were signs of increased cat activity detected in September/October 2017. Numerous sets of cat tracks were observed, and eight cat scats discovered at Quoll Trap sites N and M, which is close to the eastern margin of the Yarraloola bait cell. Five of these scats contained quoll remains raising concerns over cat reinvasion and the localised impacts of cats in gorge systems (Palmer and Anderson 2018).

More intensive monitoring of cats at Matuwa by Algar *et al.* (2013) revealed that cat activity did not increase in the six-month period preceding baiting. Suggesting that resident animals that survived baiting do not take over vacated territories left by baited cats. Reinvasion was instead linked to later events driven by natal recruitment and immigration of younger animals from outside the baited area (Algar *et al.* 2013). In this study, nine of the twenty-two cats trapped in April-May 2018, were either juveniles or sub-adults, suggesting strong recruitment from the recent spring/early summer breeding season. Noticeably small cats were also detected on the camera traps during the pre-bait monitoring session.

Younger adult cats (i.e. second year cohort from the previous breeding season) were also likely to have emigrated into Yarraloola at some stage following the 2017 baiting program from neighbouring unbaited areas (Comer *et al.* 2018). Drier conditions experienced to the west of the Yarraloola LMA in late 2017/early 2018 (pers. comm. Leanne Corker), may have been the trigger for cats to move into the bait cell where conditions were more favourable due to localised summer storms. Interestingly, a juvenile male (YM05) fitted with a collar left the Yarraloola LMA in mid-May and moved through this area out to the coast before returning nine days later. Apart from the fact that this cat returned to the Yarraloola LMA to settle, this journey also highlights the movement capability of cats, with this small 2.1 kg male moving over 120 km in 22 days (Figure 9).

4.2.2 Baiting efficacy

Two independent approaches were used to monitor baiting efficacy in 2018. We continued the use of systematic camera trap monitoring within the Yarraloola LMA and on the unbaited Red Hill reference site and radio-telemetry was used for the first time to monitor mortality of cats due to bait consumption.

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. Modelling incorporating random and spatial effects showed a significant decrease in the occupancy of camera sites by cats within the Yarraloola LMA. There was a 57% decline recorded in cat detection rates and the proportion of camera sites occupied by cats across the treatment cell also decreased by approximately 57% using both occupancy models.

In contrast, the bait efficacy rate based on the mortality of radio-collared cats attributed to bait consumption was lower at 25%, with two of eight collared cats dying. The six surviving collared cats remained inside the bait cell for at least eight weeks after the baiting. A further two cats were heard alive inside the bait cell approximately four weeks after the baiting. However, they were not relocated during the helicopter tracking session in September and no data was downloaded from these individuals following baiting, so their fates remain unknown.

While there was a discrepancy between these two independent measures (camera traps and radio-telemetry) of bait efficacy, camera trap monitoring was considered to better reflect the level of knockdown achieved. A high proportion of cats present in the Yarraloola LMA prior to baiting in July 2018 were likely to have been naive individuals as population recovery following the last baiting program was driven by immigration and natal recruitment. Bait mortality amongst this first and second year cohort of cats is expected to be greater than older and experienced adult cats (Algar *et al.* 2013; Comer *et al.* 2018).

By chance, cats captured in leg-hold traps were potentially unrepresentative of the re-invading population, as seven of the eight radio-collared cats monitored before and after the baiting on Yarraloola were adults (two females >2.6 kg and five males > 4.2 kg). The two individuals that died were a juvenile female (1.7 kg) and a younger adult male (4.4 kg). The survivors were all adults that may have been resident animals with previous exposure to cat baiting programs and therefore they could have learnt to avoid baits. Alternatively, these experienced cats were proficient hunters of preferred live-prey and were not interested in eating baits under the conditions at the time they potentially encountered baits in July or August 2018 (Figure 11; Algar *et al.* 2007). For example, rodents were presumably common during the winter bait period as they featured prominently in the diets of cats in 2018 (Figure 18) and capture rates of common rock rats were high in September (Figure 16). If these collared cats continue to reside in the bait cell, we are hoping to monitor them through the 2019 winter baiting program as a change in seasonal conditions may increase their likelihood of taking baits (Algar *et al.* 2007).

The level to which the cat population was reduced by baiting in 2018 was not as low as the two previous winter baiting programs. Although the post-bait level of 0.73 cats per 100 CTN on Yarraloola was comparatively low relative to cat populations elsewhere (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 137 camera trap nights.

The land owner/manager of both pastoral leases actively controls dingoes/wild dogs to reduce their impacts on cattle herds. Wild dogs were not common on these pastoral leases in 2018, with only a small number detected by camera traps. The influence of cat baiting on their numbers could not be determined.

4.2.3 Home ranges and spatial ecology of cats

The high-quality movement data obtained from the GPS collars on cats in this project is somewhat of an added bonus and presents new opportunities to investigate and develop more strategic control approaches for feral cats at this site into the future (Recio *et al.* 2015). Opportunities for a PhD student to take on this challenge under the supervision of a specialist spatial analyst at Murdoch University are currently being investigated. As such, only preliminary analysis of cat home ranges has been undertaken.

Feral cat home ranges vary with the rate of productivity and the number of other cats in the landscape (Bengsen *et al.* 2015). The mean home range size for males was 2900 ± 445 ha (n=7) for Yarraloola, which were similar to that reported for the nearby Karijini National Park (2382 ± 522 ha, n=5; Johnson *et al.* 2013) and within the highly variable mix of mean home range sizes reported for male cats from 2014 to 2016 for Fortescue Marsh (Comer *et al.* 2018). Females have smaller home ranges than males. The mean home ranges for females (1428 ± 707 ha, n=3) on Yarraloola were comparatively large (Bengsen *et al.* 2015; Comer *et al.* 2018). Only two females were collared on Red Hill and their home range size was relatively small (319 ± 17 ha) for a semi-arid region. The overlap of home ranges for male cats and no overlap for female cats on Yarraloola was similar to what other studies have reported (McGregor *et al.* 2015).

In more productive areas the smaller the distance cats have to travel to look for prey/food, so their home ranges are smaller (Bengsen *et al.* 2015). This might suggest that cats on Yarraloola require larger areas to obtain food so the landscape is potentially less productive. Alternatively, regular control operations may cause disruptions to the social structures resulting in cats occupying larger areas due to the lack of territorial pressures. Perhaps, the enormous home range of 23643 ha of female (YF04) is an indicator that large spaces are available, or home ranges are not clearly defined in areas of this bait altered landscape (Figure 11a).

4.3 Response by northern quoll populations to cat control

The capture rate of quolls on Yarraloola increased further to 6.04 individuals per 100 trap nights during the September trapping session (*cf.* 5.07 individuals 100 TN^{-1} in 2017). The tally for Red Hill was lower at 3.75 individuals 100 TN^{-1}, which was only marginally higher than the 2017 level of 3.54 individuals 100 TN^{-1}. The increase on Yarraloola was driven entirely by the capture of more males as female captures remained unchanged on the previous year.

Captures of females remained higher within the cat baited treatment compared with the reference site. The lack of any substantial change in female abundance across sites from 2017 to 2018 contrasts with the strong population increase previously detected from 2016 to 2017, particularly on Yarraloola where quoll captures doubled (Figure 12 & 13). These two periods experienced contrasting patterns of summer precipitation, with widespread, well above average, falls received in 2017 and patchy, below average, localised storm rain received in 2018 (Figure 2). Disentangling the influences of cat control and differing rainfall patterns on female quoll populations across the study areas is not straightforward. Female quolls on Yarraloola appeared to benefit strongly from the combined influence of high summer rainfall and cat control in 2017 with strong recruitment and high survivorship of adult females (50%).

The widespread frontal rains in June 2018 boosted the annual rainfall total and triggered extensive vegetation growth, but these winter rains appeared to be less influential in terms of benefitting female quoll populations. Female mean body masses were lower than previous years, particularly on Yarraloola (Figure 14) and the birth of pouch young was delayed by one to two weeks. The annual survival rate of marked females between trapping sessions also declined on Yarraloola (50% 2016-17 *cf.* 30% for 2017-18) and was similar to that recorded on Red Hill for both periods (~25-30%; Figure 12).

Palmer *et al.* (2017) speculated that male quolls may respond more strongly to cat baiting as they undertake more risky behaviours when searching for females and hence have a higher level of exposure to cat predation. Movement by adult males increases leading up to and during the mating season in late July and August (Morris *et al*. 2015). Quoll visits to our cat camera sites (June to August) in open habitats tend to also be by large–sized individuals suggesting many were males. Interestingly, in the past two trapping sessions in September we have also recorded males moving considerable distances between trap sites. The longest distance travelled by a male in 2018 was 5.3 km over three nights. In contrast, adult female quolls seem to be more risk adverse, with radio-telemetry data suggesting they are sedentary and rarely venture far from refuge habitats into 'high-risk' open areas favoured by cats (Henderson 2015, Hernandez-Sanin *et al.* 2016, Morris *et al*. 2015). Only one female has been recorded to move between trap sites in September (Palmer *et al.* 2017).

Following from the above, base line capture rates of males across both sites were low several months after the first broad-scale aerial baiting operation on Yarraloola in 2016 (10 individuals, Yarraloola and 12, Red Hill). On Yarraloola, their numbers increased to 33 individuals in 2017, which was due in part to high summer rainfall as outlined above, and the fact that there was also a jump in captures on Red Hill to 20 individuals (Palmer and Anderson 2018). However, the capture of males continued climbing on Yarraloola to 47 individuals in 2018, while their numbers remained stable on Red Hill at 20 individuals.

Monitoring of tagged males indicates this change is not driven by substantial changes in their longevity as no tagged individuals from 2017 (n=54) were recaptured during the 2018 trapping session. Male northern quolls rarely survive into a second mating season (Spencer *et al*. 2017). Rather it would appear that in the cat baited area, post-mating mortality of males (die-off) was delayed. Whether some of these males will now recover and survive to breed again remains to be seen. The high number of males present on Yarraloola also suggests there were increased levels of recruitment of males born in September 2017 and/or survivorship of those males through to September 2018 compared to Red Hill.

Increased survival of males to this late stage in the year, however, may not necessarily have overall benefits to the quoll population on Yarraloola as females carrying pouch young or newly independent young could face increased competition from older males. The spike in male numbers may be relatively short–lived as many of those trapped in September were in poor condition, some barely alive, so they are likely to suffer high mortality rates before the young become independent in January 2019.

4.4 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.

The ongoing monitoring of quoll diets provided further evidence of a diet shift by quolls 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 strong support that baiting of cats on Yarraloola benefits quoll populations indirectly by improving their access to richer prey sources in high-risk open habitats.

We are yet to investigate spatial responses by quolls in detail, but visits by quolls to cat camera traps located in open habitats on Yarraloola has continued to increase. Quolls are now known to have visited 31 of the 60 cat cameras on Yarraloola. Habitat shifts by quolls in response to cat baiting however may increase their vulnerability to predation by cats recolonising these vacant territories on Yarraloola. Interestingly, we found no strong evidence this was occurring, with only one cat scat out of 56 collected in 2018 containing quoll remains. The high availability of rodents in the bait cell, particularly common rock rats, appears to have deflected cat predation pressure away from northern quolls and other species in this instance.

Now that an effective method for locating cat scats has been established, systematic surveys (May and September) along fixed tracks on Yarraloola and Red Hill will be introduced to the study in 2019. This will allow for a greater understanding of the prey buffering/deflecting role common rock rats may play. Furthermore, if cat baiting is promoting the recovery of common rock rat populations on Yarraloola, it is possible this species may be elevated (or re-established) to a position of a keystone native prey species in the ecosystem. Under a regime of cat baiting, it may be better able to maintain their numbers, and therefore influence the abundance of other threatened predators (northern quolls, ghost bats and juvenile olive pythons) present in these systems.

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Appendices

Appendix 1 Field work program for 2018

Field Trip #	Date(s)	Field Activity
1	23 April – 6 May Yarraloola Two teams	Cat trapping and collaring using ~75 cat trap sets, yielding a total of 14 collared cats with help from DBCA Exmouth expert cat trappers. KMaC rangers involved. Quoll cameras were set along trap lines.
	7 – 18 May Red Hill Single team	Cat trapping and collaring using ~50 cat trap sets, yielding a total of 3 collared cats. Quoll cameras were set along trap lines.
2	15 – 22 June Yarraloola/Red Hill Two teams	Establishment of 60 camera traps for the monitoring of feral cats for the pre-baiting period. Radio-tracking and downloading data from collared cats on Yarraloola with KMaC Rangers. Quoll cameras were collected from quoll trapping sites, and quoll scats were collected for diet study.
3	8 July Yarraloola/Red Hill	Helicopter flight to track and download GPS data from collared cats.
	9 – 14 July Yarraloola/Red Hill Two teams	Cat camera demobilisation on both sites and set-up bait trial experiment to monitor *Eradicat*® baits on Yarraloola with KMaC Rangers.
	9 - 10 July	Aerial Baiting, Yarraloola.
4	1 – 10 August Yarraloola/Red Hill Single team	Sixty camera traps were set for the post-baiting monitoring of feral cats on Yarraloola and Red Hill. Cameras were collected from bait trial experiment to monitor *Eradicat*® baits. Radio-tracking of collared cats.
5	27 August – 6 September Red Hill Three teams	Quoll monitoring at 18 sites, trapped for four nights each. Sixty cat cameras were collected. Radio-tracking and downloading GPS data from collared cats. Predator scat collection over the duration of the trip.
	3 – 17 September Yarraloola Two teams	Quoll monitoring at 18 sites, trapped for four nights each. Sixty cat cameras were collected. Predator scat collection over the duration of the trip. KMaC Rangers involved. Two days of Quad bike searching for cat scats.
	7 September Yarraloola	Helicopter flight to track and download GPS data from collared cats.

Appendix 2 Quoll capture results for each trap site in 2018

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	2	0	6	7.5	2.5
B	5	10	28	35	18.75
C	1	1	6	7.5	2.5
D	3	4	13	16.25	8.75
F	0	6	7	8.75	7.5
G	3	0	4*	5	3.75
H	2	1	7	8.75	3.75
I	1	0	3	3.75	1.25
J	1	4^	10	12.5	6.25
K	4	3	21	26.25	8.75
L	4	3	21^	26.25	8.75
M	2	8	18	22.5	12.5
N	2	0	5*	6.25	2.5
O	2	0	3	3.75	2.5
P	2	1	5	6.25	3.75
Q	2	2	8*	10	5
R	2	1	3	3.75	3.75
T	2	3	8	10	6.25
Totals	**40**	**47**	**176**		
Means	**2.22**	**2.61**	**9.78**	**12.22**	**6.04**

* Captured quoll of unknown sex escaped (Trap G14 6/09/2018; Trap N12 10/09/2018; Trap Q17 15/09/2018). We assumed these individuals were recaptured on subsequent trap nights. ^ Male quoll captured first from line J and then recaptured four times on line L (Trap J4 6/09/2018; Trap L5 9/09/2018; Trap L4 10/09/2018, Trap L6 11/09/2018, Trap L8 12/09/2018).

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	1	0	2	2.50	1.25
CW	1	1	5	6.25	2.50
E	2	1	10	12.50	3.75
F	4	0	14	17.50	5.00
G	2	0	4	5.00	2.50
H	3	0	12	15.00	3.75
I	3	4	9	11.25	8.75
J	3	2	10	12.50	6.25
KB	2	0	7	8.75	2.50
L	1	4	11	13.75	6.25
M	2	2	10	12.50	5.00
N	0	2*	5	6.25	2.50
P	1	0	2*	2.50	1.25
PP	4	2	9	11.25	7.50
RL	0	0	0	0.00	0.00
SW	2	2*	7	8.75	5.00
X	1	1	7	8.75	2.50
Z	1	0	4*	5.00	1.25
Total	**33**	**21**	**128**		
Means	**1.83**	**1.17**	**7.11**	**8.89**	**3.75**

* Male quoll captured first from line N and then recaptured once from line P (Trap N14 30/08/2018; Trap N16 31/08/2018; Trap P6 1/09/2018); another male quoll captured first from line SW and then recaptured on line Z three times (Trap SW14 2/09/2018; Trap Z20 3/09/2018; Trap Z19 4/09/2018, Trap Z15 5/09/2018).

Appendix 3 Incidental and opportunistic records

Plate 2. Pilbara olive python records for 2018: top photo of python in water trough at Cardo Camp on Red Hill (Photo credit: Neal Birch); bottom photo of python detected on a camera trap on Yarraloola.

Appendix 4 Outputs and Engagement

Kuruma Marthudunera Traditional Owners

Kuruma Marthudunera Aboriginal Corporation presentations

- 20 March Karratha KMaC Office – Review of 2017 project results and 2018 program for ranger involvement.
- 7 November Karratha KMaC Office – Review of 2018 project results and discussion of 2019 program for ranger involvement.

Fieldwork

- Arnold Bobby (29 Apr – 1 May) and Nathan Evans (29 Apr – 3 May) – Cat trapping and cat radio-tracking, Yarraloola.
- Joshua Evans (18–22 June) and Nathan Evans (18–19 June) – Cat camera trap setting, collecting of quoll camera traps and radio-tracking of cats, Yarraloola.
- Joshua Evans and Chaylean Sampi – (9–14 July) – Collecting cat camera traps and radio-tracking of cats, Yarraloola and Red Hill.
- Joshua Evans and John Shaw (3–17 Sept) - Quoll trapping Yarraloola.

Volunteer involvement in fieldwork

- Arlen Hogan-West: 27 Aug – 7 Sept, 105 hrs, Quoll trapping trip Red Hill
- Taylah Drechsler: 3 – 18 Sept, 132 hrs, Quoll trapping trip Yarraloola
- Leanne Kelman: 8 – 18 Sept, 89 hrs, Quoll trapping trip Yarraloola
- Diana Virkki: 4 – 8, 46 hrs, Quoll trapping trip Yarraloola

Publications

Annual Report

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, Kensington, WA. 56 p.

Popular magazine

Anderson H, Palmer R, (2018). No laughing matter: camera trap snaps a Laughing Dove on Yarraloola Station, SW Pilbara. *Western Australian Bird Notes* **168**, 35–36.

Scientific Papers

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

Cat diet data from this project was used in a meta-analysis of ~100 cat dietary studies from across Australia.

Woinarski JCZ, Murphy BP, Palmer R, Legge SM, Dickman CR, Doherty TS, Edwards G, Nankivell A, Stokeld, H (2018). How many reptiles are killed by cats in Australia? *Wildlife Research* **45**, 247–266.

Woolley LA, Geyle HM, Murphy BP, Legge SM, Palmer R, et al. (submitted). Introduced cats (*Felis catus*) eating a continental mammal fauna: inventory and traits of species killed. *Mammal Review.*

Murphy BP, Woolley LA, Geyle HM, Legge SM, Palmer R, et al. (submitted). Australian mammals killed by cats (*Felis catus*): where and how many? *Biological Conservation.*