GOVERNMENT OF WESTERN AUSTRALIA

Department of **Biodiversity, Conservation and Attractions**

Predator Control Baiting and Monitoring Program, Yarraloola and Red Hill, Pilbara Region, Western Australia. 2019 Annual and Final Report - Year 5.

Version: final

Approved by: Dr. Lesley Gibson

Last Updated: 17 April 2020

Custodian: Russell Palmer

Review date: 17 April 2020

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

2019 Annual and Final Report – Year 5

Russell Palmer, Hannah Anderson and Brooke Richards

Biodiversity and Conservation Science

April 2020

Department of Biodiversity, Conservation and Attractions

Government of Western Australia

Rio Tinto

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

www.dbca.wa.gov.au

This report/document/publication was prepared by Russell Palmer, Hannah Anderson and Brooke Richards

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

The recommended reference for this publication is:
Palmer R, Anderson H, Richards B, (2020). Predator control baiting and monitoring program, Yarraloola and Red Hill, Pilbara region, Western Australia. 2019 Annual report - Year 5. Department of Biodiversity, Conservation and Attractions, Perth.

This document is available in alternative formats on request.

Contents

Appendices

Figures

Tables

Acknowledgments

This study was undertaken as part of a Threatened Species Offset Plan (TSOP) funded by Rio Tinto. The TSOP scope of work for 2019 was developed in liaison with Martin Buck and Martin Salm (Rio Tinto). Martin Salm and Phoebe Sampson facilitated the field work and other project logistics for Pannawonica 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.

We thank Digby, Leanne and Dylan Corker for permission to access Red Hill pastoral lease. Australian Premium Iron (APIM) provided in-kind support for our operations at Red Hill. Phil Davidson, Jacqueline Waapu-Ruawai, Richard Galloway, Frank Hoppe, Vi Saffer, Darren Varcoe and Stefan Woodtli facilitated visits and accommodation at Cardo Camp at Red Hill. The Robe River Kuruma (RRK) people provided access to their traditional lands on Yarraloola and Red Hill pastoral leases.

Ashley Millar, Gary Edwards and Shane Morse of the Parks and Wildlife Service, Western Shield team coordinated the aerial baiting program. Alicia Whittington (DBCA, Pilbara region) managed the aerial baiting notifications and landholder liaisons. Alicia Whittington and Lucy Clausen organised the helicopter tracking sessions of the collared feral cats. We are grateful for the field assistance provided by RRK traditional owners Eden Bobby, Joshua Evans, Eugene Evans, Arnold Bobby and Royce Evans.

We thank honours student Hassan Abdi and volunteers Arlen Hogan-West, Amelia Catterick-Stoll, Ashleigh Johnson and Sam Edwards for their hard work and commitment.

Thank you to DBCA staff that assisted during the year including Neal Birch, Mel Mykytiuk, Kate Rick, Jeff Pinder, Abby Thomas and Zac Simms. We are appreciative of the efforts of Jason Fletcher in teaching us the art of trapping feral cats. Sarah Comer (DBCA) performed the occupancy modelling.

Drafts of this report were reviewed by Lesley Gibson (DBCA), Jason Rossendell (Rio Tinto) and Tessa Elvy (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.

Executive 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 feral cat control at the landscape scale 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 impact on northern quolls and other threatened fauna was a core component of the TSOP.

This report discusses the methods and results for 2019, the final year of the operational broad-scale feral cat control program (TSOP - Phase 2), in the context of results from the previous three years. In contrast to previous years, seasonal conditions were particularly poor in 2019, with well below average rainfall across the region. There were also extensive wildfires on Yarraloola following dry lightning storms over the summer.

Aerial baiting of the Yarraloola LMA took place on the 8-9 July, covering an area of 142,036 ha. The aircraft dropped 70,850 *Eradicat*® in 1417 bait clusters. Monitoring of feral cats exposed to baits revealed a 34% decline in their detection rate on camera traps and a 33% mortality rate of radio-collared adult feral cats. The detection rate of feral cats on Yarraloola following the baiting was very low (~0.5 cats per 100 camera trap nights (CTN)), which equates to approximately one feral cat detection in 250 camera trap nights. This result was consistent with the three previous years, with baiting reducing feral cat populations to similarly low levels. The dry conditions were likely to have enhanced baiting efficacy through improved uptake by younger feral cats and adult females. Notably, several collared females that had survived the previous year's baiting operation, when rodent prey were plentiful, succumbed to baiting in 2019. The relative abundance of feral cats at the Red Hill reference site were consistently higher than that for Yarraloola once baiting commenced. The exception being the first half of 2018, following re-invasion by feral cats of the baited cell.

There was no evidence that feral cat control using *Eradicat*® baiting negatively impacted the co-occurring northern quoll populations. The detection rates of northern quolls immediately prior to and immediately following each baiting program remained stable in all years apart from 2019. The decline in the northern quoll population following the baiting in 2019 was potentially due to increased predation pressure from feral cats due to their dietary shift as rodent populations collapsed. Roughly 20% of cat scats collected at this time on Yarraloola contained northern quoll remains.

The overall capture rate of northern quolls during the annual September trapping program in 2019 were ~30% lower than the previous year. Female quoll capture rates on Red Hill were particularly low, falling to 0.83 individuals per 100 trap nights,

the lowest level during the study. Female quoll numbers (1.59 individuals per 100 trap nights) remained higher under the feral cat control regime on Yarraloola. The annual survival rates of tagged adult female quolls between trapping sessions were higher on Yarraloola for two of the three stages (2016-2017 and 2018-2019). Also of note was the capture of a marked female for the fourth consecutive year in the centre of the baited cell in 2019. This is the oldest known wild female northern quoll. The abundance of male quolls was also higher on Yarraloola from 2017 onwards.

There were strong indications that northern quolls were benefitting indirectly from reduced competition with feral cats on Yarraloola. A marked dietary shift from protein-poor food sources [fruits] to the consumption of more rodents was detected following the implementation of the baiting program. Northern quoll diets on Red Hill remained largely unchanged for the duration of the study.

Finally, we make recommendations regarding the adoption of a strategic feral cat management program better designed to address the future challenge of effectively managing a formerly bait naïve feral cat population to a feral cat population with an increasing number of bait smart adult males.

1 Introduction

1.1 Project background

The Yandicoogina Junction South West and Oxbow Iron Ore Expansion Project located in the central Pilbara region of Western Australia was approved by the State and Commonwealth Governments (Ministerial Statement 914 and *Environment Protection and Biodiversity Conservation Act* 1999 (EPBC Act) Decision Notice 2011/5815, respectively), both of which were subject to a number of offset conditions. The Commonwealth required 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 selected 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 a smaller area of adjoining unallocated crown land (Rio Tinto 2014).

Introduced predator management was the core component of the TSOP (Rio Tinto 2014). The plan 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 outlined by 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 (Algar *et al.* 2007 & 2013; Comer *et al.* 2018; Lohr and Algar 2020). This bait is not currently approved 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, the Kimberley and Northern Territory, and areas throughout the Pilbara of Western Australia (Braithwaite and Griffiths 1994; Cramer *et al.* 2016; Moore *et al.* 2019). In 2005, the northern quoll was listed as an endangered species under the Commonwealth's EPBC Act. Predation by feral cats has 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).

Key threats such as predation by introduced predators, habitat loss and fragmentation, and the likely future invasion of the poisonous cane toad (*Rhinella marina*) have been identified as serious risks to the Pilbara region populations (Cramer *et al.* 2016).

1.2 Introduced Predator Management

The implementation of an introduced predator control program that focused on large-scale deployment of baits to control feral cats was considered the optimal management action to benefit the northern quoll and Pilbara olive python within the Yarraloola LMA (Rio Tinto 2014). Actions under this section of the TSOP program were divided into two parts. In order to identify and resolve any potential non-target bait impacts to northern quolls, an *Eradicat*® baiting field trial was planned for the first year of the study, prior to the commencement of the operational scale predator control program.

1.2.1 Management goal

To enhance northern quoll and Pilbara olive python populations (and populations of other native fauna) and their habitat through a reduction in introduced predators (principally feral cats but also foxes and wild dogs) within the Yarraloola LMA (page 30; Rio Tinto 2014).

1.3 Action 1 – Northern quoll *Eradicat®* feral cat bait uptake and survivorship study 2015

1.3.1 Management objective

To assess the field uptake of feral cat baits Eradicat® by northern quoll and its impact on their survivorship and reproduction, and to subsequently develop an effective introduced predator control strategy that will benefit the northern quoll and other threatened fauna in the Yarraloola LMA (page 30; Rio Tinto 2014).

1.3.2 Background and research undertaken in 2015

According to 1080 dosage rate trials, northern quolls have a moderate tolerance to compound 1080 (LD50 7.5 mg/kg; King *et al*. 1989). Although due to their small body size in the Pilbara (average of 360-600 g), the ingestion of a single *Eradicat®* bait (4.5 mg of 1080) could place them at risk of lethal poisoning. Calver *et al.* (1989) identified that in the laboratory, northern quolls were at risk from accidental poisoning from crackle baits containing 6 mg of 1080 for dingo control. However, there is an extensive literature demonstrating that theoretical risk derived from the above mentioned approaches rarely translates to actual risk faced by free-ranging native carnivores and other non-target species under field situations (King 1989; Körtner *et al*. 2003; Körtner and Watson 2006; Claridge and Mills 2007; Körtner 2007). Hence, these discrepancies between estimated bait toxicity and actual poisoning of quolls require resolution under field conditions (Jones *et al*. 2014).

The precautionary approach was applied here and the recommended pathway of monitoring the fate of individual northern quolls during an actual *Eradicat®* baiting campaign was undertaken in 2015. A full account of this study is found in Morris *et al.* (2015) and Cowan *et al.* (in press).

Briefly, 21 quolls were captured and fitted with radio-collars within a 20,000 ha experimental treatment cell on Yarraloola. This cell was then aerial baited with

Eradicat® in July 2015 and the fate of these quolls was closely monitored. No deaths of radio-collared northern quolls were attributed to 1080 poisoning and females showed no acute effects of sublethal poisoning based on reproductive output. The conclusion being that aerial feral cat baiting programs using *Eradicat*® during winter were unlikely to pose a hazard to free ranging northern quolls (Morris *et al.* 2015; Cowan *et al.* in press).

1.4 Action 2 – Introduced predator control program 2016–19

1.4.1 Management objective

To improve northern quoll and Pilbara olive python habitat within the Yarraloola LMA through a reduction in the abundance of introduced predators (page 35; Rio Tinto 2014).

1.4.2 Operational broad-scale feral cat baiting

Based on the above, the project entered the operational phase and annual winter aerial baiting with *Eradicat*® baits over ~145,000 ha of the Yarraloola LMA commenced in 2016 (Morris and Thomas 2014). Additional safeguards were built into the monitoring program, particularly for northern quolls. Approval was granted by the APVMA to amend the Research Permit (PER14758) to increase the area of the bait cell from 20,000 ha to 163,000 ha for 2016 to 2019. Here, we primarily discuss the methods and results of 2019, with a summary of the findings over the past four years of operational feral cat baiting. Previous information is contained in the annual reports (Palmer *et al.* 2017; Palmer and Anderson 2018; Palmer *et al.* 2019).

1.4.3 Study aims for 2019

The project for 2019 was largely a continuation of the baiting and monitoring programs established in 2016. Due to ongoing concerns regarding the effectiveness of the camera trap monitoring method used to measure change at very low feral cat densities, we continued the cat collaring and radio-tracking component of the study that was introduced in 2018. Radio-telemetry allowed for independent verification of feral cat mortality rates due to winter baiting.

Aims were to:

1) conduct the fourth 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 (Yarraloola - baited) and reference site (Red Hill - unbaited); 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.

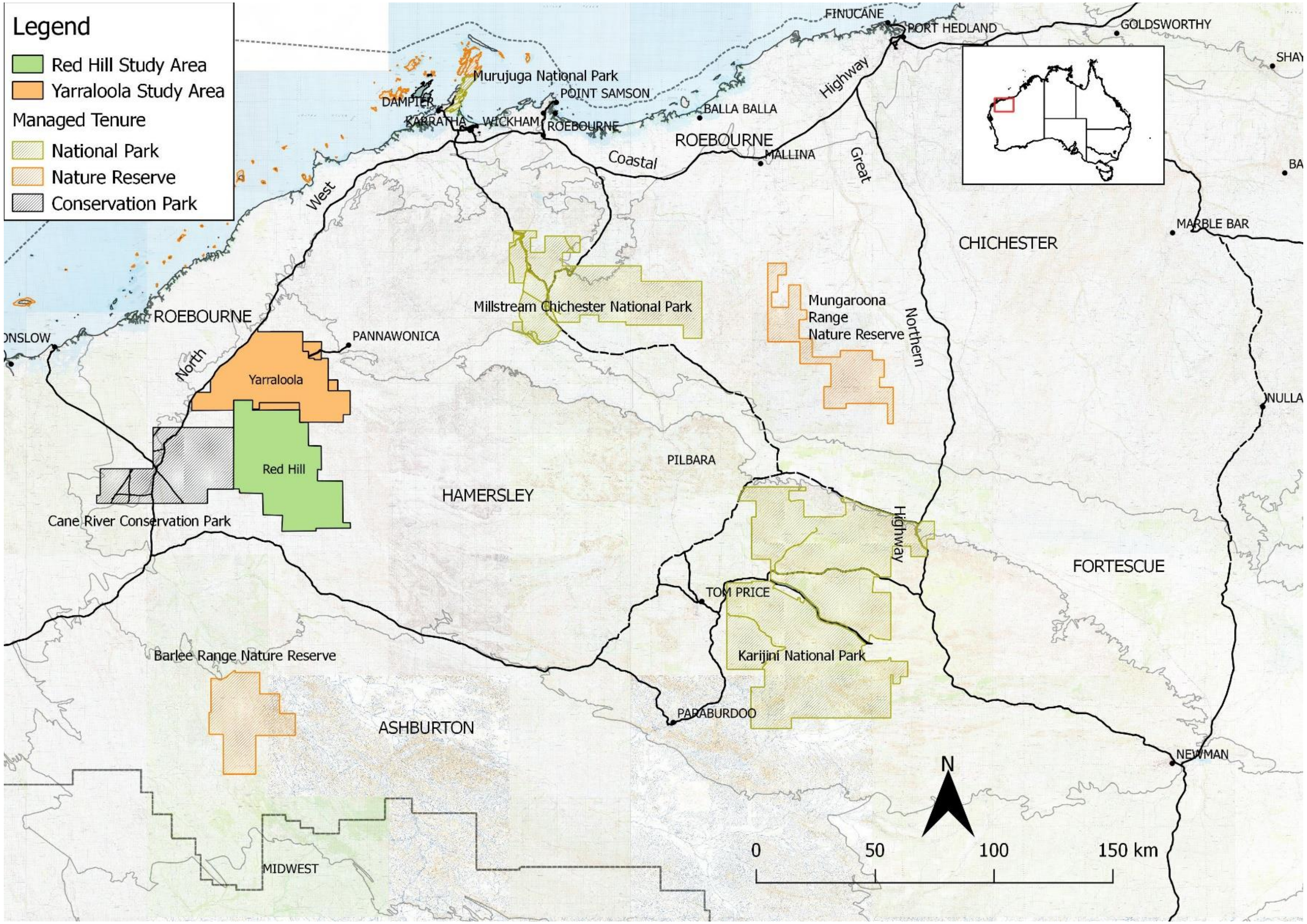


Figure 1. Location of the Yarraloola LMA and Red Hill in the Pilbara region of Western Australia.

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).

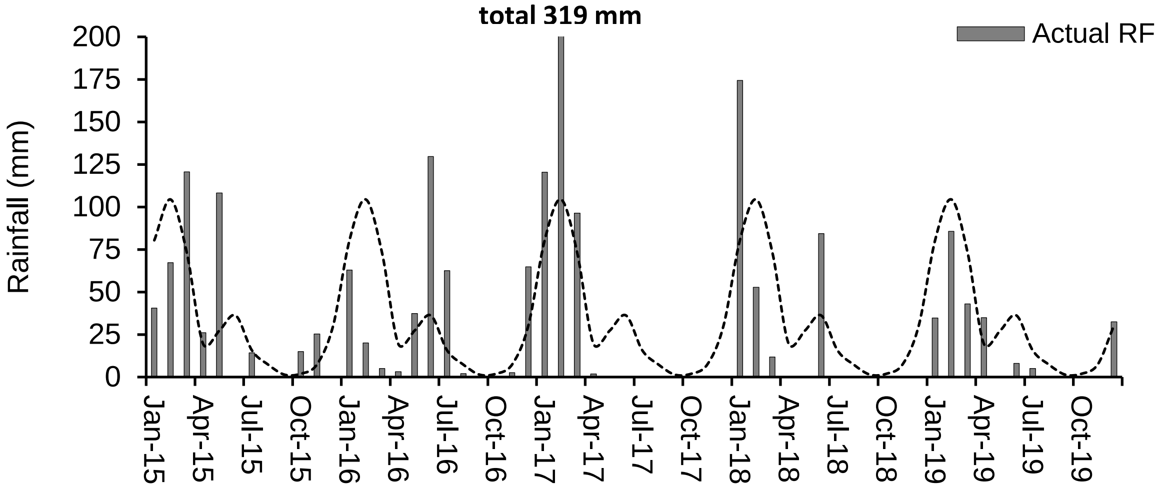
2.1.1 Rainfall

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 (Figure 2).

Average annual rainfall for Pannawonica and Red Hill from 1971, when records commenced for Pannawonica, is ~400 mm (Australian Bureau of Meteorology 2019). The rainfall patterns since the study commenced in 2015 reflects this variability (Figure 2). Annual rainfall totals for 2015 to 2016 were reasonably close to the long-term averages. A tropical low passed over the study area in February 2017 delivering 319 mm to Pannawonica and a yearly total of 538 mm.

Much of the rain that fell in the summer of 2018 was associated with localised thunderstorm activity. A frontal rain system then delivered significant rainfall in early June across the entire study area. However, totals received at the recording stations at Pannawonica (323 mm) and Red Hill (336 mm) were below the annual average (Figure 2). Rainfall for 2019 was well below average across both sites, particularly on Red Hill where it was less than half the annual average.

a) Yarraloola



b) Red Hill

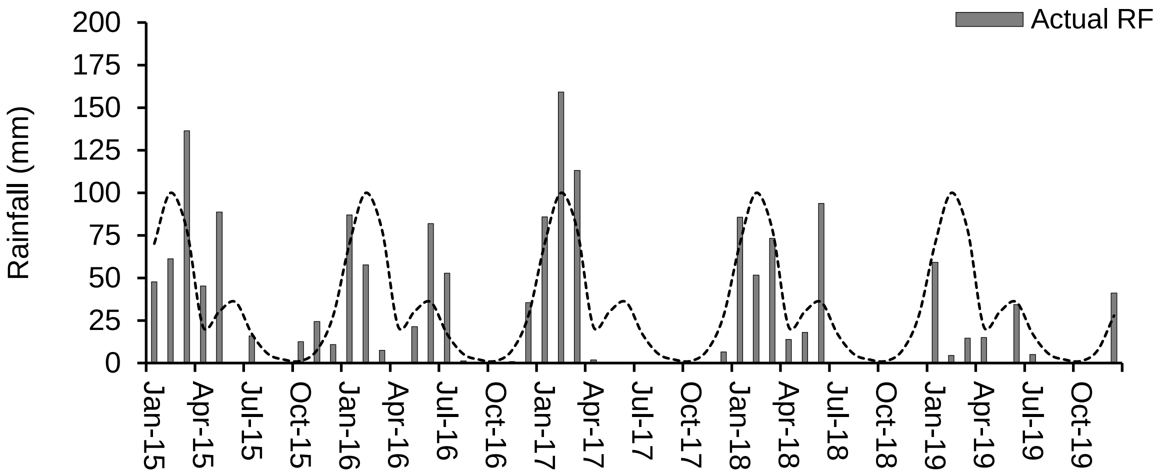


Figure 2. Monthly rainfall (bars) relative to the monthly long-term average (1971 onwards = dotted line) from 2015 to 2018 for a) Pannawonica (mean annual rainfall = 405 mm) and b) Red Hill (mean annual rainfall = 396 mm).

2.1.2 Fire

Fire scars were mapped annually as part of the TSOP project (Chapman and Zdunic 2019a and b). Fire regimes were relatively benign in terms of the areas of northern quoll and Pilbara olive python habitat burnt from 2015 to late in 2018 (Figure 3 and Figure 4). In the last week of December 2018, dry lightning storms over Yarraloola triggered the ignition of numerous fires, resulting in significant areas of northern quoll and Pilbara olive python habitat being burnt. In addition to the data provided in Figure 3, there were further fires on Yarraloola in January/February 2019 that burnt the eastern section of the site along the Robe River, Mesa H and the northern end of the Hamersley Range across to Quoll trap sites J and I. An estimated 5,000 ha of northern quoll and Pilbara olive python habitat was burnt, which equates to roughly 32% of this habitat being severely burnt in hot fires over the summer.

In contrast, wildfires burnt relatively minor areas of northern quoll and Pilbara olive python habitat on Red Hill for the duration of the study (Chapman and Zdunic 2019a).

The quoll trapping sites selected for monitoring in 2015 and 2016 were all unburnt at the time. Fires subsequently impacted the following sites on Yarraloola; December 2016 (Site F partially burnt), January 2017 (Site K entirely burnt): December 2018 (Sites A, P and R completely burnt), and January/February 2019 (Site O mostly burnt, Site J partially burnt, and Site I burned up to the base of the Mesa). Fewer trap lines were impacted by fire on Red Hill, with Sites G and M burnt in December 2016 and Site L burnt in November 2018.

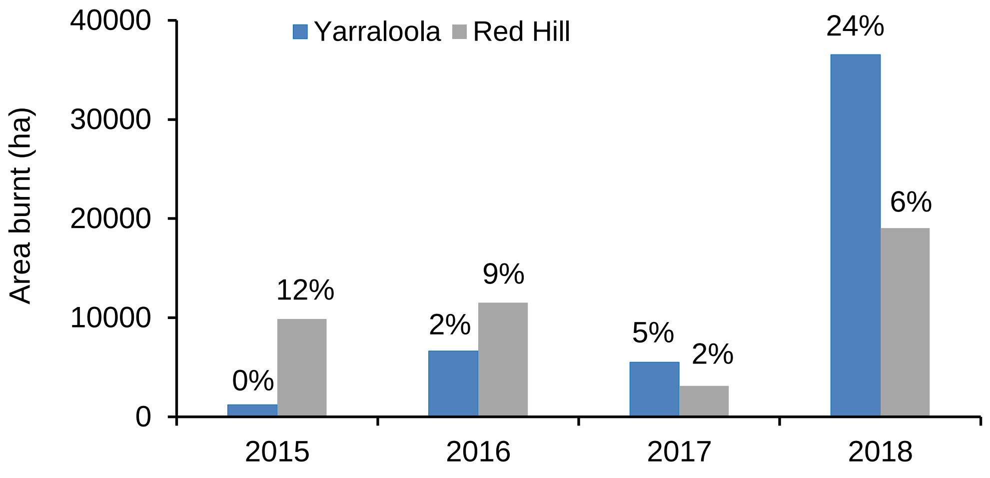


Figure 3. Total area (ha) of the Yarraloola LMA and Red Hill burnt per year from 2015 to 2018. Annotated percentages are the percent of northern quoll and Pilbara olive python habitat burnt. Total area of northern quoll and Pilbara olive python habitat for Yarraloola and Red Hill was estimated to cover 65,665 ha and 53,630 ha, respectively.

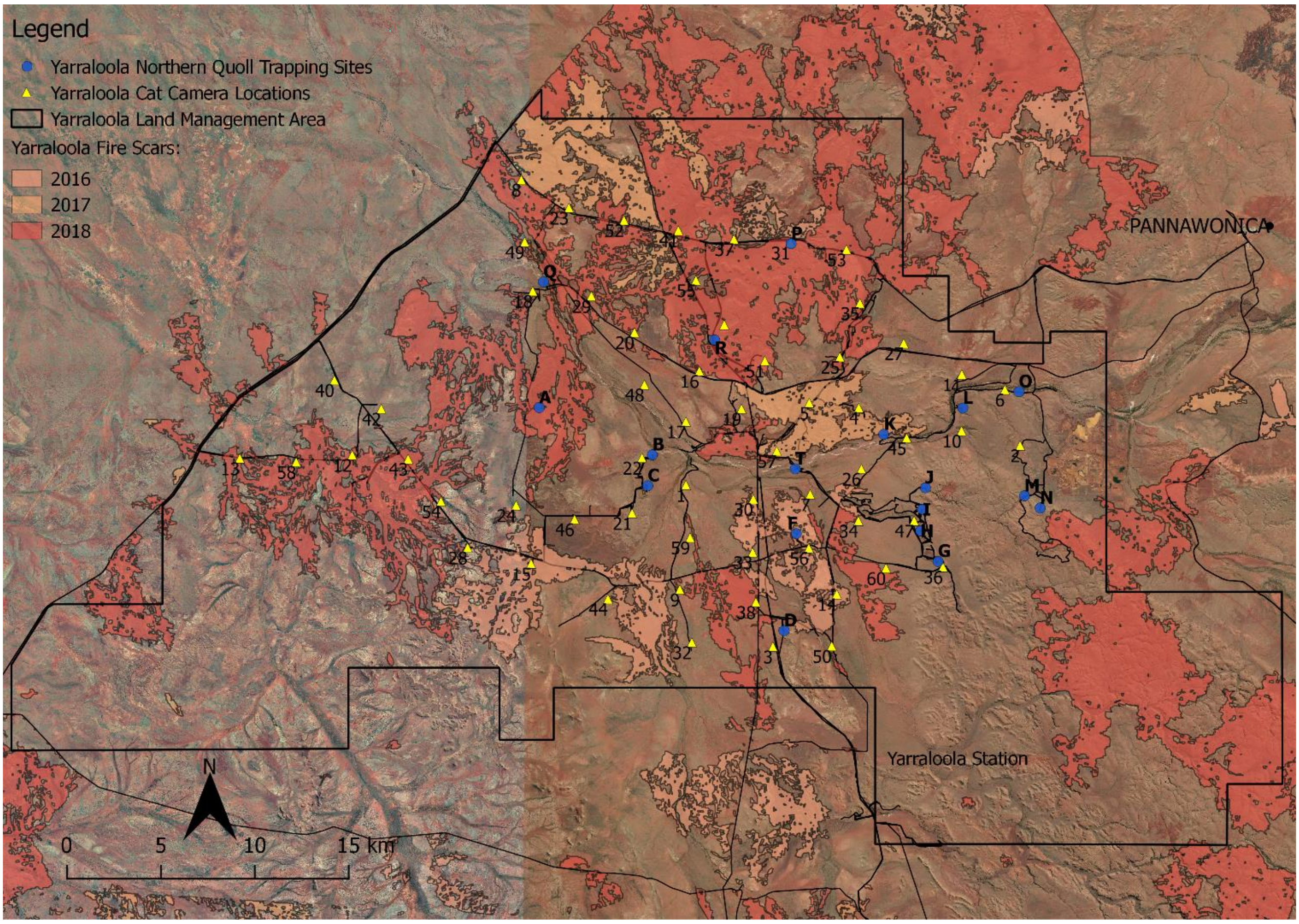


Figure 4. Annual fire scars for 2016 to 2018 within the Yarraloola LMA.

2.2 Study design and timing

This project was designed around the optimal time for baiting of feral cats, which is when they 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, particularly reptiles (Algar and Burrows 2004). Bait degradation due to rainfall, ant attack, and hot weather is also reduced at this time of the year.

Previously, the Pilbara Regional Biosecurity Group aerially baited both stations for dingoes and their hybrids (hereinafter 'dingoes') during their annual Pilbara-wide program implemented in September. This program was discontinued over the study area in 2016. Dingo control was largely undertaken via ground-based methods by the pastoralists as required under the *Biosecurity and Agriculture Management Act 2007*. *Eradicat*® feral cat baits are lethal to canids.

The field work program for 2019 is outlined in Appendix 1.

2.3 Feral cat monitoring

2.3.1 Camera trap design and occupancy modelling

The camera trapping approach of Comer *et al.* (2018) was 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 5 & 6). The layout of the cat camera sites 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.

Cameras were set in mid-June, allowing for 25 nights of monitoring on each camera trap before the baiting commenced on the 8 July. Three weeks following baiting, cat cameras were redeployed (30 July) and then collected during the quoll trapping trip in September. During the period between the two monitoring sessions, cameras and lures were removed to prevent feral 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 feral 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 feral cats and northern quolls. We considered detections as independent when separated by greater than 60 minutes. 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 feral cats to be detected more than once on a camera in a single night. 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.

The impact of the baiting program on the feral cat population was determined by comparing the first 25 CTN 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.

Bayesian occupancy models were run in WinBUGs 1.4, using detection histories from the treatment (baited - Yarraloola) and reference (unbaited - Red Hill) to generate a probability of occupancy at each camera trap site. Occupancy was calculated based on a basic occupancy model with the assumption of constant occupancy and detection probability during the period of camera trapping. Two forms of the model were used. To account for heterogeneity across the site a random effects component was included in one model. A random effects model, which assumes detection probability is not constant, was used to determine site occupancy at both the treatment and reference site. A spatial component was also modelled, which models the potential impact of an individual feral 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 2018/04A and followed standard techniques (Clausen *et al.* 2016). Trapping was undertaken by two teams on Yarraloola from the 21 May – 1 June. No trapping was undertaken on Red Hill in 2019.

Victor 'Soft Catch'® № 1.5 padded leg-hold traps (Woodstream Corp., Lititz, Pa.; U.S.A.) were used, with cat faeces as the attractant. Trap pan tensions were set at 2 pounds (~900 grams) as a precautionary measure to ensure northern quolls were not accidentally captured. Traps were set along similar transects used in 2018 (Figure 5 in Palmer *et al.* 2019), although recently burnt areas were avoided due to the lack of shelter. Additional trap sites were situated in known preferred habitat types of feral cats.

Traps were set in shaded sites along the edge of tracks, 0.5 – 1.0 km apart. Open-ended (walk through) trap sets were used consisting of two traps positioned lengthwise and vegetation used as a barrier along the sides of the trap area. In addition, some 'cubby' trap sets were used consisting of two traps positioned lengthwise inside a natural 'cubby' created in the side of a large spinifex clump. Seventy-six trap pairs were set for approximately 10 nights each.

Trapped feral cats were sedated with an intramuscular injection of 4 mg/kg Zoletil 100® (Virbac, Milperra, Australia). Feral cats were sexed, measured (head length and width), weighed, coat colour noted and DNA tissue samples taken. Each individual over 2,000 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 July – September and four 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 feral cats fitted with radio-collars

Monitoring was conducted from the ground during each field trip and via three sessions of helicopter tracking. Located collared cats were determined to be alive or dead. GPS data was remotely downloaded from each collar if necessary. Helicopter tracking flights were undertaken in summer (19 February) and either side of the baiting program (2 July and 3 September).

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. Calculations for the 95% minimum convex polygons (95% MCP) as an estimation of home range from GPS points collected for each feral cat were undertaken in R 3.6.1 (R Core Team 2019) using the adehabitatHR package (Calenge 2006). The 95% MCP were mapped on 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 feral cats were killed from eating a toxic bait, location data from the GPS collars removed from dead feral 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.

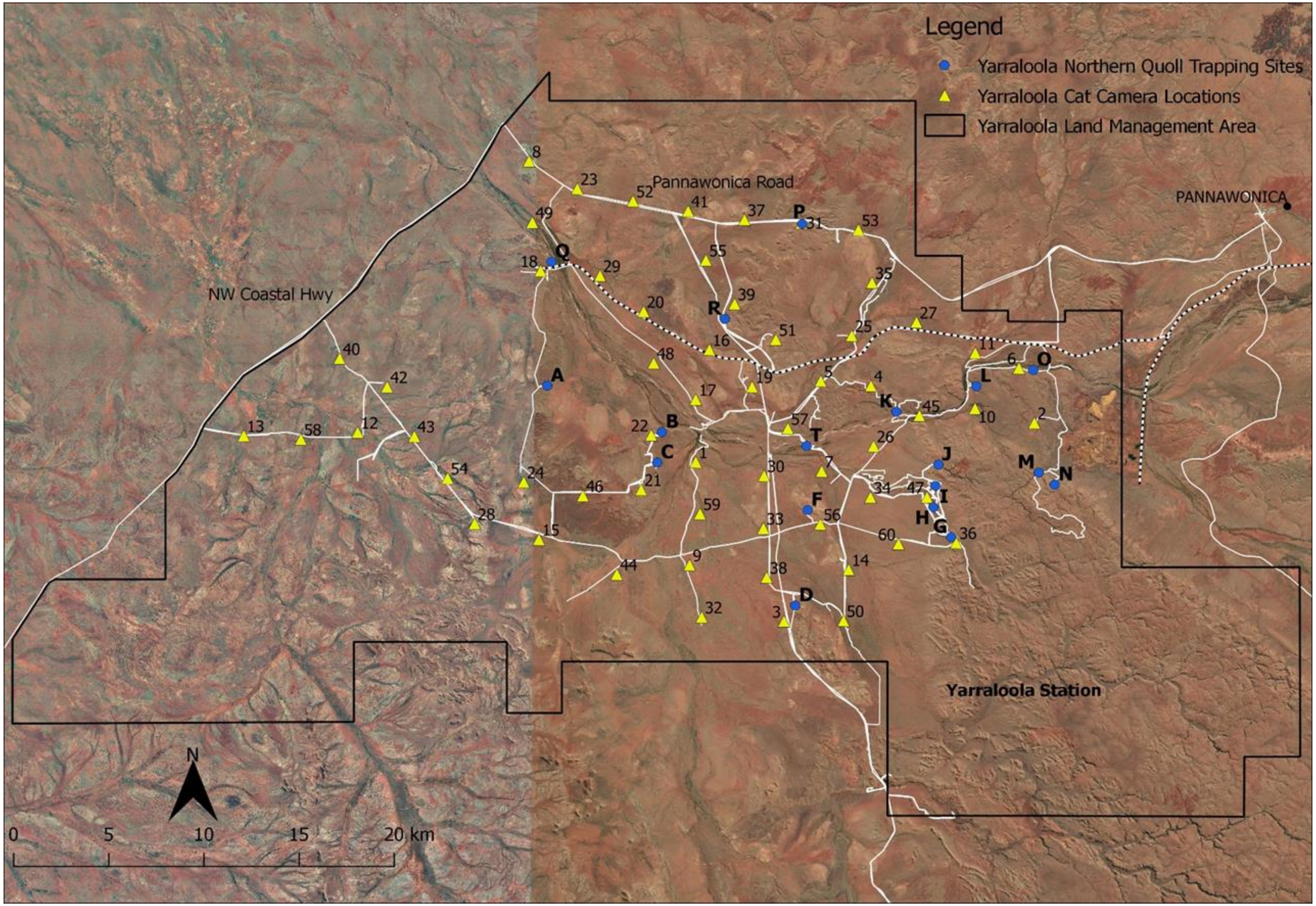


Figure 5. Feral cat camera and northern quoll trapping locations on the Yarraloola LMA baited site.

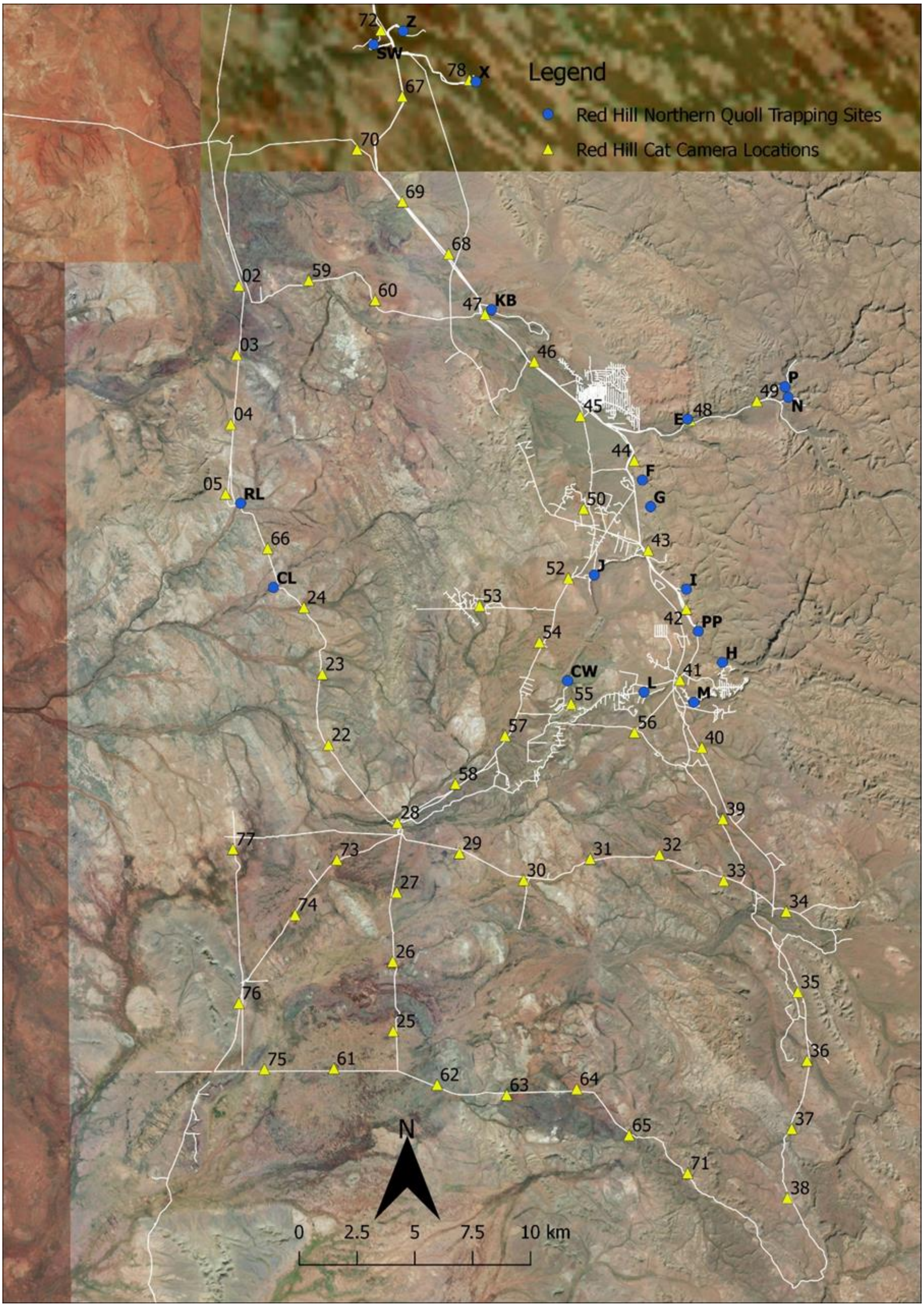


Figure 6. Feral cat camera and northern quoll trapping locations on the Red Hill reference site.

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). It also adhered to the 'Code of Practice on the Use and Management of 1080' (Health Department, Western Australia) and was approved under the DBCA '1080 Baiting Risk Assessment and Approval' process.

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

To further minimise the risk of any aerially spread baits falling near permanent water bodies along the Robe River and other drainage lines the exclusion zones around these sites were made larger (Figure 7).

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. Additional 1080 warning signs were erected on the new gates along the fence either side of the rail line and replacement signs placed on access roads on Yarraloola LMA to notify the public who may be bringing in pets/dogs. The Robe River Kuruma 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 feral cats.

Aerial baiting of the Yarraloola LMA took place on 8-9 July 2019. 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 150-160 knots and 500-1500 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

The annual September cage trapping program was continued across the 18 sites on both Yarraloola and Red Hill to monitor northern quoll populations (Figure 5 & 6). Details of the trapping design can be found in Morris *et al.* (2016) and Palmer *et al.* (2017). Trapping generally coincided with the birth of quoll pouch young and hence allowed for the collection of this key demographic information. This timing is less suited to males, as post-mating mortality (die-off) of males begins in late July-August. As such, capture data for female and male quolls will be presented separately.

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 top of and around the sides of traps for stability and to 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, sexed, and two small tissue samples were taken from an ear for DNA analysis. For females, reproductive condition was assessed and if present, pouch young were counted and measured. 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 2016-2019 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. The mean number of pouch young for all years for Yarraloola and Red Hill was compared using a Welch two sample t-test. Analyses and box plots were performed in the R software (ver. 3.6.1 https://www.R-project.org/). Error bars presented on graphs are standard errors unless otherwise stated.

2.6 Predator diets

Northern quoll scats were collected from cage traps (first capture night to avoid contamination from bait consumption) and from around lures used for camera trapping as they actively mark (defecate) these places. Dingo and feral cat scats were collected during targeted searches of roadsides and cattle watering points. In addition, a quadbike was used on Yarraloola over three days in July to search minor station tracks and drill lines on Mesa G for feral cat and dingo scats. Predator scats encountered opportunistically were also collected.

Scats were analysed by G. 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 undertook opportunistic searches to locate the threatened Pilbara olive python where possible. Opportunistic bird records were kept on each field trip by Hannah Anderson and Brooke Richards.

3 Results

3.1 Feral cat baiting

Aerial baiting took place on the 8-9 July covering an area of 142,036 ha. The aircraft dropped 70,850 baits in 1417 bait clusters (Figure 7). This equates to an average application rate over the entire bait cell of 50 baits km^{-2}, which is consistent with the baiting protocol. No ground baiting of the Pannawonica road corridor took place in 2019 as many parts had been extensively burnt. Thirty ground baits were laid along drill pad lines on Mesa G. These baits were monitored using camera traps and there was one confirmed take by a feral cat.

There was 5 mm of rain on the 5th July prior to the baiting operation and no subsequent rain in the months that followed (Figure 2).

3.1.1 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 early-mid July, early August or September.

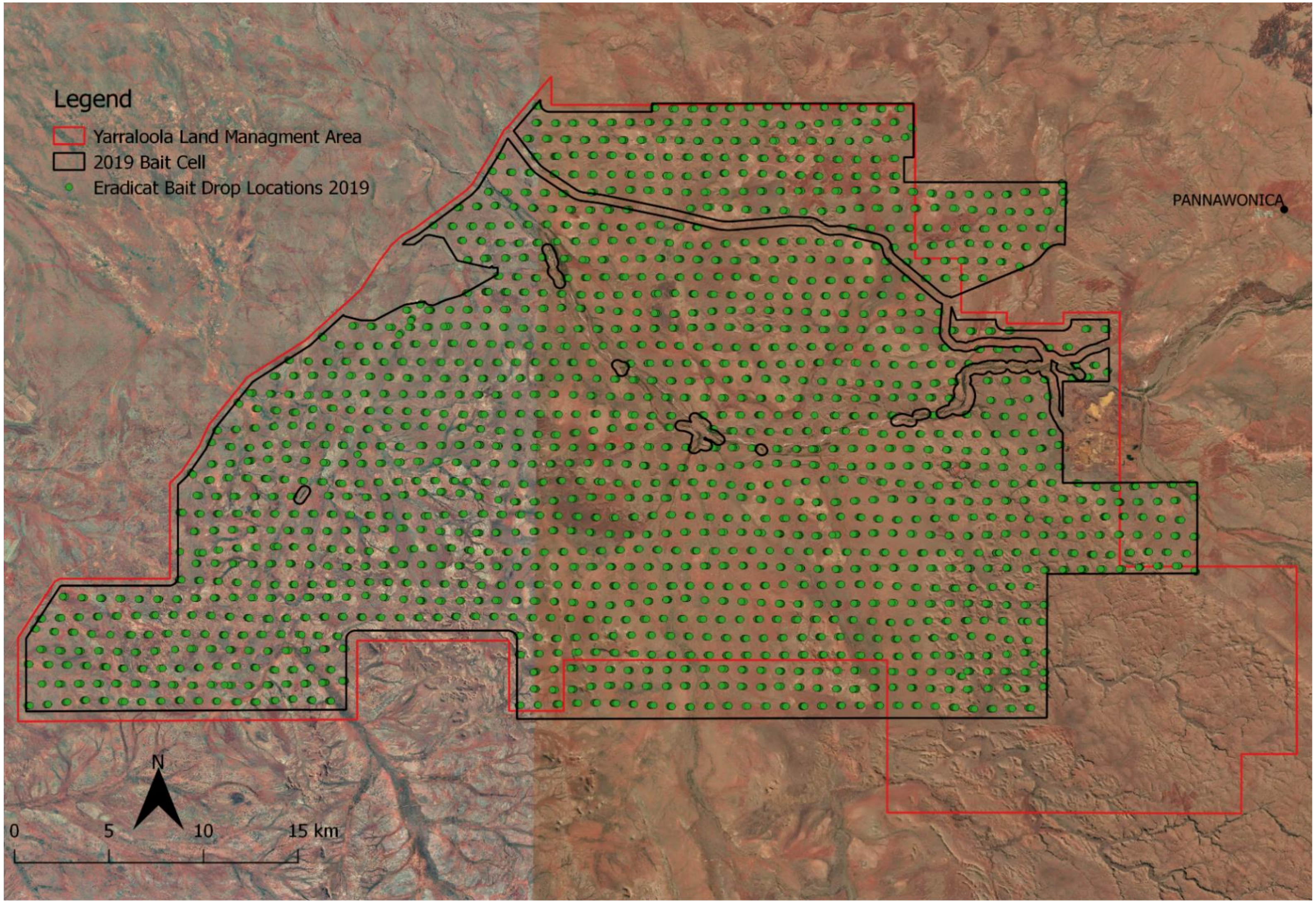


Figure 7. The Yarraloola LMA bait cell (black bold line) for 2019 and the distribution of baits on the 8 and 9 July. The bait exclusion areas within the LMA are bounded by a bold black line. The outer red line is the Yarraloola LMA boundary.

3.2 Camera trap monitoring

The camera trapping data for 2019 are summarized in Table 1. No monitoring session achieved the maximum of 1500 CTN, although the lengths of time that individual cameras were inoperable were relatively short (Table 1).

The number of camera trap sites with feral cat detections on Yarraloola remained low in 2019. Northern quoll visits to camera trap sites displayed the opposite trend, particularly during the pre-bait monitoring session with animals being detected on 27 of the 60 cameras on Yarraloola (Table 1). These patterns were the reverse on Red Hill, where there were higher detections of feral cats and fewer detections of quolls in 2019.

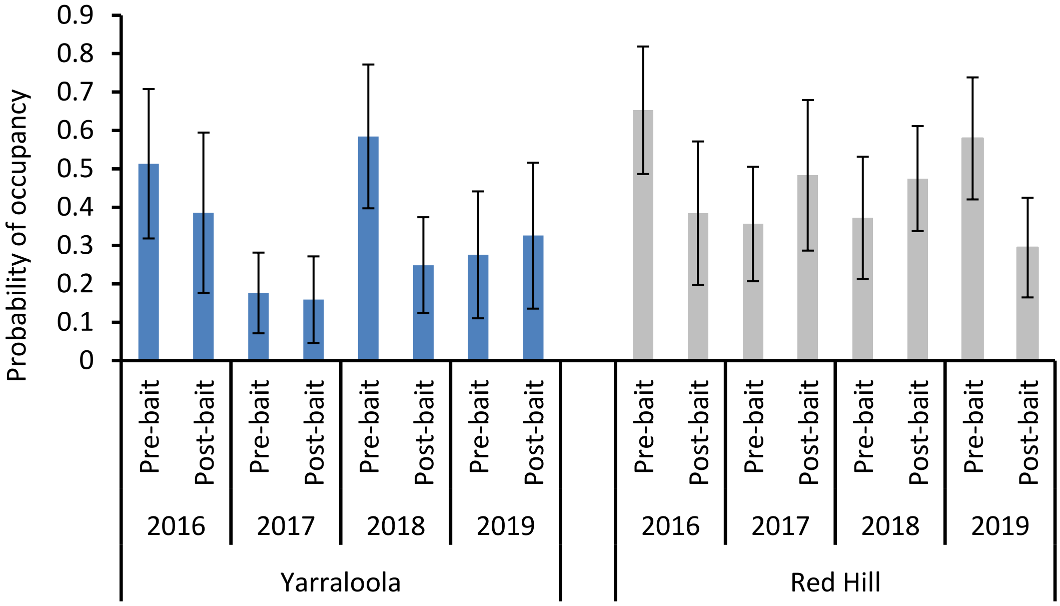
Table 1. Summary of camera trap sessions before and after baiting in 2019.

	Yarraloola		**Red Hill**	
	Pre-bait	Post-bait	Pre-bait	Post-bait
Number of camera sites with feral cats	7	6	16	7
Number of camera sites with northern quolls	27	16	6	3
Camera trapping effort				
Total camera trap nights	1474	1472	1431	1434

3.2.1 Site occupancy of feral cats

A similar pattern in changes in site occupancy of feral cats between pre- and post-baiting at both treatment and non-treatment sites was observed using either the random effects model or spatial model (Figure 8). At the treatment site, a decline in occupancy post-baiting was observed in the first three years, being most profound in 2018 (t-test, $p<0.00001$), however an increase was observed in 2019. This increase was significant for the spatial component model (t-test, $p=0.015$) but not for the random effects model (t-test, $p=0.063$). A variable response across years was observed at the non-treatment site. The probability of feral cat occupancy for both models decreased significantly in the post-bait monitoring session on Red Hill in 2019 (t-test, $p<0.00001$). This was also the case for this site in 2016.

a) Random effects



b) Spatial component

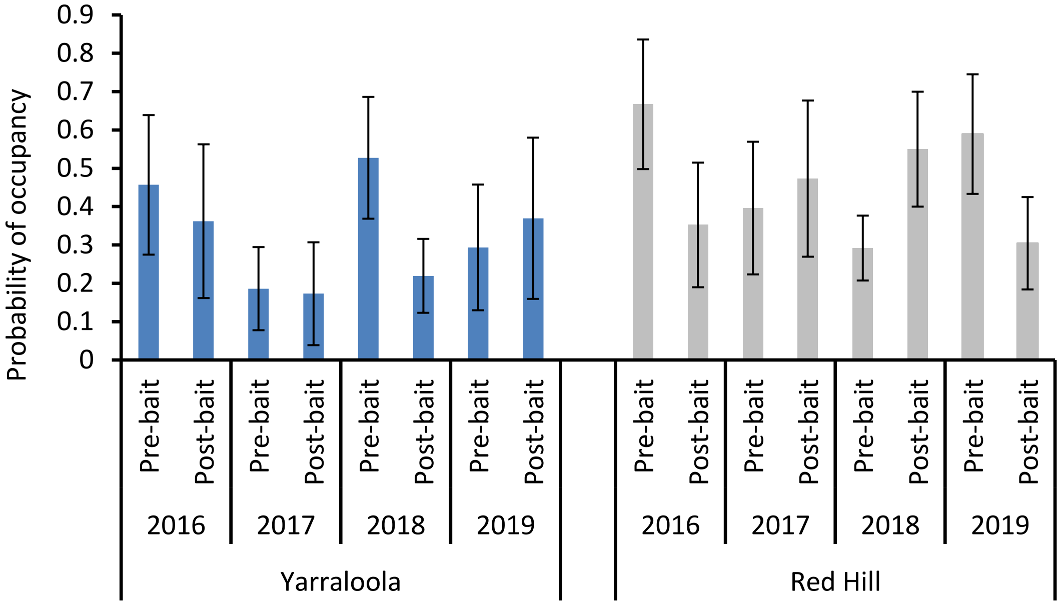


Figure 8. Modelled proportion of sites occupied (mean ± SD) by feral cats before and after baiting in treatment (Yarraloola) and reference (Red Hill) sites for 2016 to 2019 with (a) random effects and (b) spatial component.

3.2.2 Detection rates of feral cats and northern quolls

The detection rates of feral cats prior to baiting in 2019 across both sites were almost identical to those recorded following the baiting program in the previous year (Figure 9). The decline in the detection rate following baiting was relatively low at 34% (0.71 to 0.47 feral cats per 100 CTN) on Yarraloola. However, this trend was also matched (35% decline) on Red Hill without baiting (1.59 to 1.03 feral cats per 100 CTN between the two monitoring sessions).

For 2019, detection rates of quolls were particularly high and variable on Yarraloola prior to the baiting, as opposed to Red Hill where the rate was significantly lower. This year both populations suffered a sharp decline in detection rates in the monitoring session following the baiting (Figure 9). The overall trends in the detection rates of northern quolls were broadly similar to previous years across both study areas, whereby they were consistently higher on Yarraloola following the initial baiting program in July 2016 (Figure 9). The magnitude of the decline in quoll detections on Red Hill in the post-bait monitoring sessions were always greater. The onset of the post-breeding die-off in male quolls provides a partial explanation for this decline each year, particularly on Red Hill. Baiting of feral cats on Yarraloola could potentially be reducing the predation risk faced by male quolls seeking out mating opportunities and/or prolong their lifespan during the die-off phase every though they may be in poor health.

3.2.3 Feral cat and northern quoll detections at the camera trap site level from 2016 to 2019

The cat camera trap dataset compiled over the past four years is now approximating 24,000 camera trap nights (25 camera trap nights across eight sessions for all 120 sites). At the camera site level on Yarraloola, quolls have been recorded at more sites than feral cats for seven out of the eight sessions, all of which follow the first broad-scale baiting program in July 2016 (Figure 10). In contrast, quolls were never detected at more camera sites than feral cats for any of the sessions on Red Hill.

The number of new camera sites on which quolls were detected increased every year on Yarraloola. They have now been recorded at 63% of the camera trap sites (38 of 60). On Red Hill, the cumulative number of camera sites at which quolls were detected plateaued in 2018, with only three sites being added in the four subsequent monitoring sessions (28 camera sites; Figure 10). The cumulative number of camera sites on which feral cats were detected has continued to rise across both stations (Figure 10).

3.2.4 Opportunistic detections of dingoes on camera traps for 2019

Dingoes on were detected at comparatively few camera trap sites on Yarraloola, with three detections before baiting and seven detections at five different cameras after baiting (T45, T53, T6 pre-baiting and T35, T49, T25, T6 and T29 post-baiting). There was a noticeable increase in the detection of dingoes on Red Hill in 2019, with seven detections across seven different cameras in the pre-bait session (C5, C54, C74, C77, C49, C48, C63), increasing to 15 detections on 12 cameras (C37, C49, C75,

C48, C61, C76, C77, C40, C47, C2, C26, C45) in the post-bait session. No foxes were recorded.

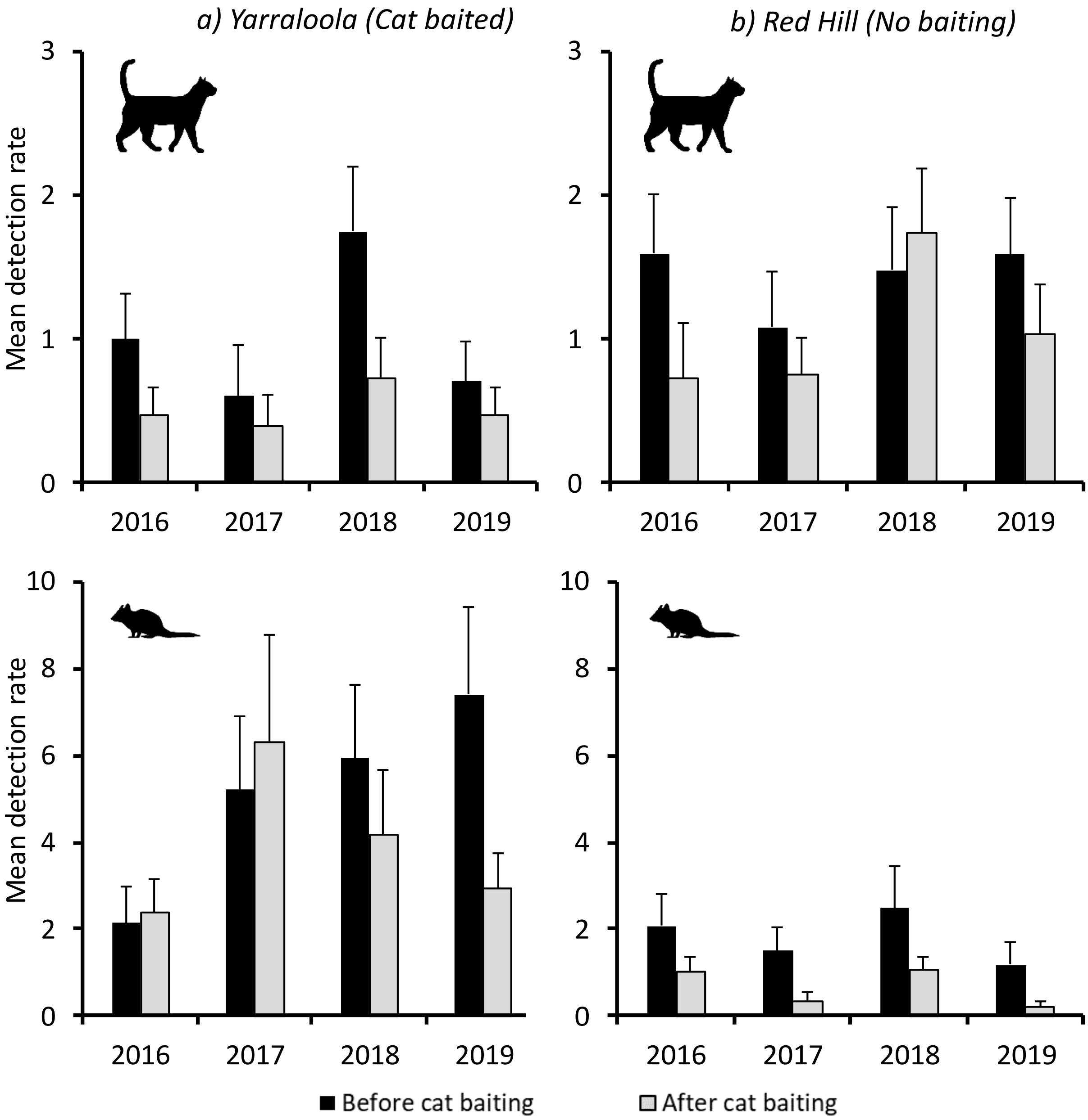


Figure 9. Mean detection rate (mean number of events per 100 camera trap nights per camera trap site) of feral cats and northern quolls on Yarraloola (a) and Red Hill (b) prior to and after the winter baiting program on Yarraloola from 2016 to 2019.

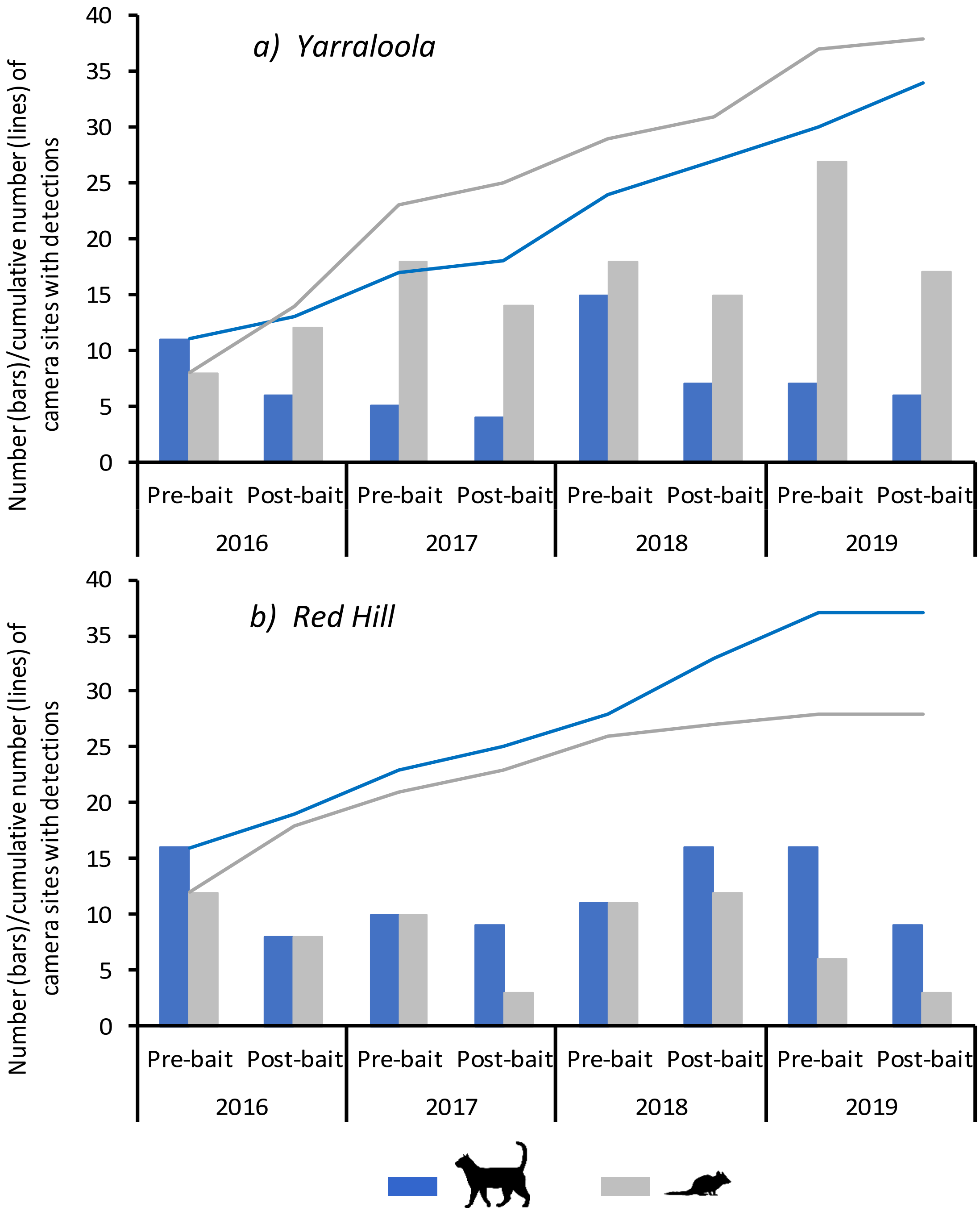


Figure 10. Number and cumulative number of cat camera sites with feral cat and northern quoll detections on Yarraloola (a) and Red Hill (b) for each pre- and post-bait monitoring session from 2016 to 2019.

3.3 Feral cat trapping and collaring

3.3.1 Trapping and radio-collaring

A total of 697 trap nights were conducted on Yarraloola in 2019. Five feral cats (2 F, 3 M) were trapped giving a capture success rate of 0.7%. The mean mass (± SE) of females was 3485 ± 555 g and males 4267 ± 138 g (Table 2). All five feral cats were fitted with GPS/VHF radio-collars.

3.3.2 Fate of surviving feral cats collared in 2018

Nine collared feral cats were detected alive during the post-bait helicopter tracking session on 7 September 2018 on Yarraloola and three were present on Red Hill. One of the males on Yarraloola (YM04) was subsequently found in mortality mode in 2019. The cause of death was unclear as there were few remains left. The GPS data downloaded from its collar showed that it died on 9 September 2018. The remaining eight collared feral cats on Yarraloola and the three on Red Hill were all alive leading into the baiting program in July 2019 (Table 2).

3.3.3 Monitoring and mortality of collared feral cats

During the pre-bait helicopter flight on 2 July over Yarraloola, four (2 F, 2 M) of the five newly collared cats were detected, along with the eight (3 F, 5 M) collared in the previous year (Table 2). A male cat (YM12) collared in late May 2019 not located.

Following baiting, a sub-adult female (YF06, collared 2019) was found dead on 31 July via ground tracking. Her carcass and collar were retrieved. This female passed through a bait cluster two days after baiting in the early hours of the 11 July and stopped moving around midday. A further three cats were found in mortality mode from the helicopter on the 3 September. The male cat (YM10, collared 2019) passed through a bait cluster during the early morning on 16 July and died in the mid-morning, seven days after baiting. An adult female cat (YF04, collared 2018) moved through a bait cluster at night on 15 July, dying early the following morning on 16 July, seven days after baiting. The other female cat (YF03, collared 2018) was within range of a bait cluster early in the morning on 26 July and died around midday, 17 days after baiting (Table 2).

The other eight collared feral cats (2 F, 6 M) known to be present inside the bait cell just prior to baiting were all alive in September 2019. As were the three collared feral cats on Red Hill. The fate of the missing collared cat remains unknown.

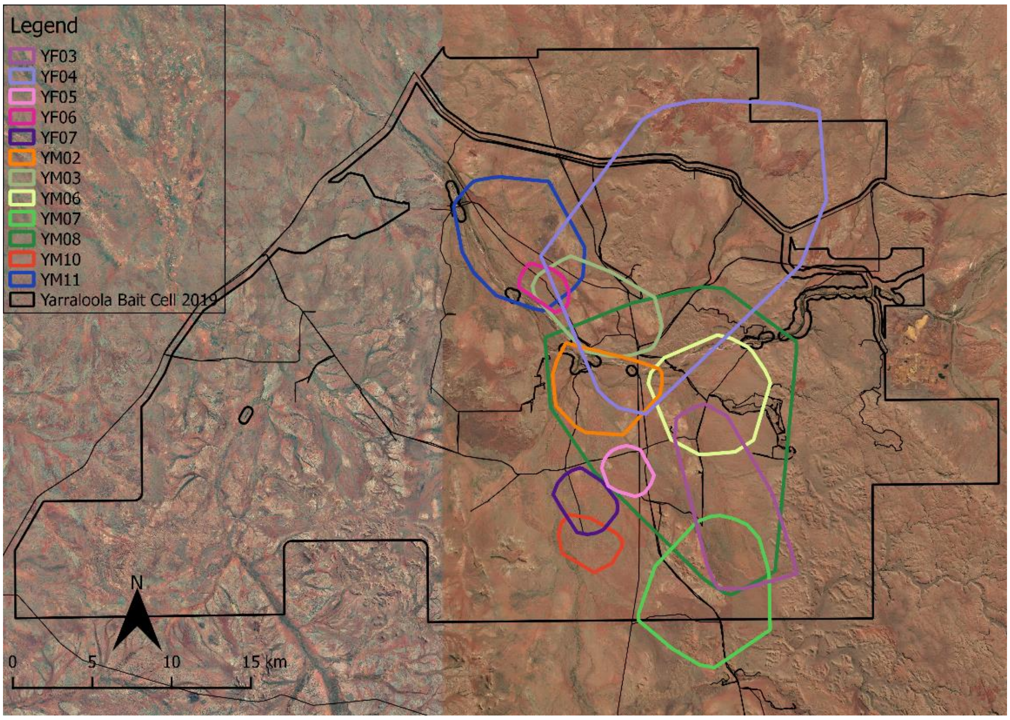
In total, four out of 12 collared feral cats died from baiting (33.3% mortality rate). Only two of the eight collared feral cats that survived baiting in 2018 died following baiting in 2019 (25%), both were females. The survivors were five large males and one female. Of the four feral cats collared in 2019, the two lighter individuals died (50%; 1 F, 1 M) and the two larger animals survived (1 F, 1 M). Analysis of the movement patterns of these survivors suggests they all had multiple opportunities to encounter bait clusters.

3.3.4 Home range analysis

Sufficient data was available from 15 collared feral cats from 2018 to 2019 (5 F, 7 M, Yarraloola; 2 F, 1 M, Red Hill) to calculate the 95% MCP home range size (Table 2; Figure 11a & b). On Yarraloola, male home ranges varied in area from 986 ha (YM10 – died from baiting) to 20,897 ha (YM08) (Table 2). Female home ranges varied from 624 ha (YF06 – died from baiting) to 5351 ha (YF03– died from baiting) (Table 2). One female (YF04) was considered an outlier as she undertook numerous exploratory walks before she settled in one general area along the Drum Road on Yarraloola. Her resulting home range was enormous (22,904 ha; Figure 11a).

Mean home range size of males was 6153 ± 742 ha and females 1962 ± 1134 ha on Yarraloola (excludes YF04). Mean home range size for females on Red Hill was 395 ± 55 ha and the sole male collared has a range size of 2007 ha (Table 2, Figure 11).

a) Yarraloola



b) Red Hill

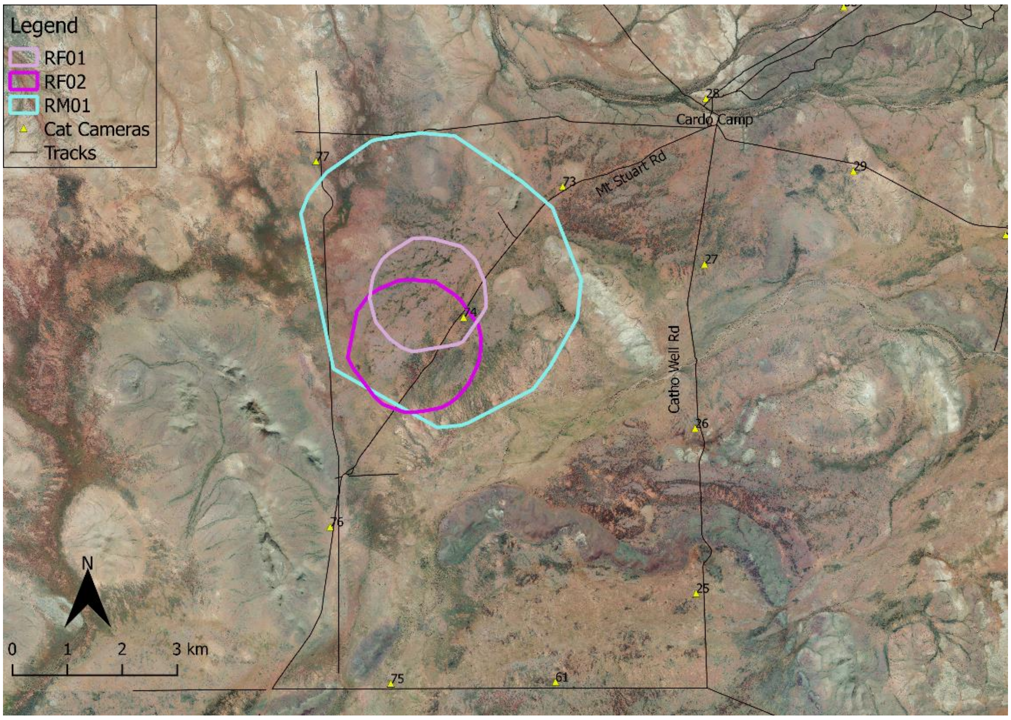


Figure 11. Feral cat minimum convex polygons (MCP) showing 95% home range area on a) Yarraloola and b) Red Hill. Each cat was assigned a code name/number, 'M' indicates male and 'F' female.

Table 2. Capture date, demographics, home range size and status of feral cats trapped on Yarraloola and Red Hill 2018-19. Grey highlights indicate cats captured in 2019. Underlining highlights the feral cats present in the bait cell during the 2019 aerial baiting operation.

Identifier	Site	Capture date	Sex	Mass (g)	Coat colour	Age	Total No of fixes	MCP95 (ha)	Status
YF01	Yarraloola	25-Apr-18	♀	2400	Tabby	Adult	No data	-	Missing
YF02	Yarraloola	26-Apr-18	♀	1700	Tabby	Juvenile	657	557	**Died from baiting** (0300 hrs 12/07/18)
YF03	Yarraloola	26-Apr-18	♀	3390	Tabby	Adult	3413	5351	**Died from baiting** (1300 hrs on 26/07/19)
YM01	Yarraloola	27-Apr-18	♂	3200	Ginger	Sub-adult	1	-	Killed by Wedge-tailed Eagle 27/04/18
<u>YM02</u>	Yarraloola	<u>27-Apr-18</u>	♂	4170	Tabby	Adult	2636	2860	Alive on 3/09/19
<u>YM03</u>	Yarraloola	<u>28-Apr-18</u>	♂	4200	Tabby	Adult	2429	3361	Alive on 3/09/19
YM04	Yarraloola	28-Apr-18	♂	5000	Tabby	Adult	2063	3329	**Died** on 9/09/18, cause unknown
<u>YF04</u>	Yarraloola	<u>28-Apr-18</u>	♀	3120	Tabby	Adult	3489	22904	**Died from baiting** (0800 hrs 16/07/19)
<u>YF05</u>	Yarraloola	<u>30-Apr-18</u>	♀	2630	Tortoiseshell	Adult	2514	750	Alive on 3/09/19
<u>YF06</u>	Yarraloola	<u>23-May-19</u>	♀	2930	Tabby	Adult	406	624	**Died from baiting** (1300 hrs, 11/07/19)
<u>YF07</u>	Yarraloola	<u>28-May-19</u>	♀	4040	Tabby	Adult	1671	1125	Alive on 3/09/19
YM05	Yarraloola	01-May-18	♂	2050	Tabby	Juvenile	289	10449	**Died** before baiting (1300 hrs 28/06/18)
<u>YM06</u>	Yarraloola	<u>01-May-18</u>	♂	4630	Black	Adult	2540	4203	Alive on 3/09/19
<u>YM07</u>	Yarraloola	<u>01-May-18</u>	♂	5620	Tabby	Adult	2312	5658	Alive on 3/09/19
<u>YM08</u>	Yarraloola	<u>02-May-18</u>	♂	3080	Tabby	Sub-adult	2298	20897	Alive on 3/09/19
YM09	Yarraloola	04-May-18	♂	4400	Tabby	Adult	1013	2000	**Died from baiting** (0800 hrs 28/07/18)
<u>YM10</u>	Yarraloola	<u>25-May-19</u>	♂	4075	Tabby	Adult	515	986	**Died from baiting** (1000 hrs, 16/07/19)
<u>YM11</u>	Yarraloola	<u>28-May-19</u>	♂	4535	Black	Adult	1675	5105	Alive on 3/09/19
YM12	Yarraloola	29-May-19	♂	4190	Black	Adult	No data	-	Missing since collaring
RM01	Red Hill	13-May-18	♂	5100	Tabby	Adult	1880	2007	Alive on 10/09/19
RF01	Red Hill	14-May-18	♀	3000	Tabby	Adult	2834	340	Alive on 10/09/19
RF02	Red Hill	16-May-18	♀	2900	Tabby	Adult	4679	451	Alive on 4/09/19

3.4 Northern quoll monitoring (trapping)

3.4.1 Quoll trapping, number of individuals captured and survivorship

Trapping effort for the annual September northern quoll monitoring program was consistent with the previous three years for Red Hill (1440 trap nights at 18 sites). For Yarraloola, the trapping effort was 1360 trap nights at 17 sites. Trap site R was abandoned after the setting of eight traps on the first night. There was not enough cover present for trapping as the area had been severely burnt. It is notable however, two quolls were captured in these eight traps (data not included in abundance estimates; Appendix 2).

There was an overall decrease in the total number of individual northern quolls captured on Yarraloola and Red Hill, with fewer captured on Red Hill compared to Yarraloola (36 quolls compared to 59 quolls; Appendix 2). Slightly more males were caught than females on both Yarraloola (31 M, 27 F) and Red Hill (21 M, 15 F). Capture data for individual sites and other capture rate metrics can be found in Appendix 2).

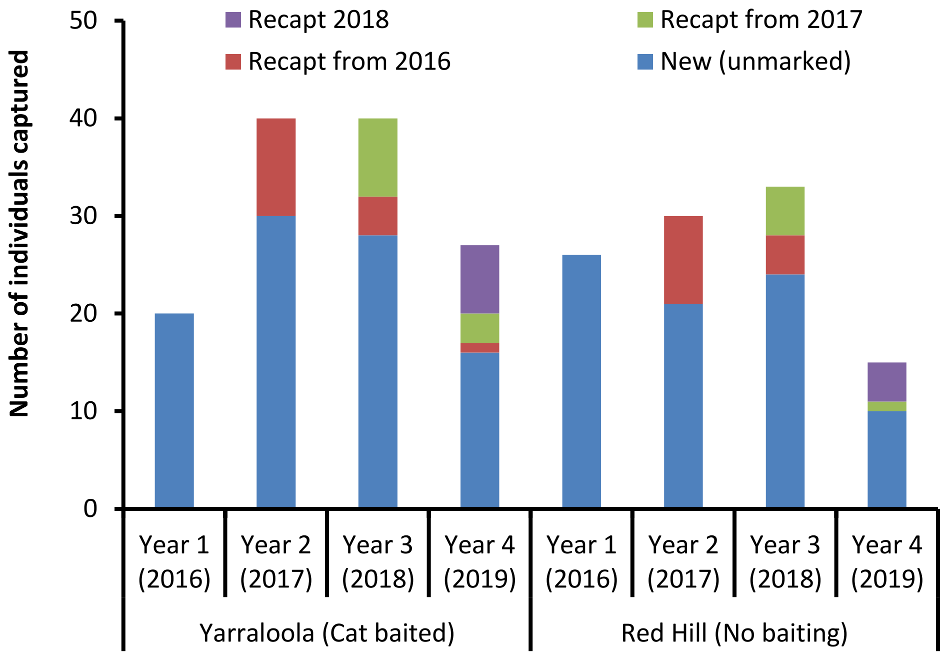
The survival rate of tagged females from September 2018 to this year’s trapping session was 29% for Yarraloola (11 of 38; adjusted for Site R not being trapped) and 15% for Red Hill (5 of 33; Figure 12a). The proportion of unmarked female northern quolls captured across the stations each year from 2017 (Year 2) to 2019 (year 4) were relatively consistent, ranging from 67% to 75% in most cases. There was a slight deviation from this trend during the last year on Yarraloola, where marked females comprised 40% of trapped animals. Further detailed analysis of the survival rates of female quolls is required but this suggests that cat control may promote increased survival of adult females. Interestingly, one of the females (PIT 918017) recaptured at Site K on the edge of Mesa G along the Robe River was first captured in 2016, which means she was probably born in 2015. This female was at least four years old. None of the 89 marked males across both sites from the previous year were recaptured in 2019 (Figure 12b).

Long distance movements of several males were evident. One male on Yarraloola moved ~1 km each night for four nights as it travelled back and forth from Line M to N twice. Another male on Red Hill was caught at three different trap lines. It moved 9.13 km over five nights, starting at Line L, moving to PP and it was finally caught at Line J (Appendix 2).

3.4.2 Capture rates of northern quolls

To enable the comparison of quoll captures between all trapping sessions, data was converted to the mean number of individuals captured per trap line (Figure 13). Capture rates of both males and females declined on Yarraloola from their previous peaks in 2018. The magnitude of the decline for females was not as great as that experienced on Red Hill, where capture rate fell by 55%. The capture rate of males on Red Hill remained lower than Yarraloola but unchanged from the previous two years. Male capture rates at the trap site level were highly variable across both areas ranging from none to seven individuals. Although no males were caught at over half the trapping sites on Red Hill (Figure 13; Appendix 2).

a) Female quolls



b) Male quolls

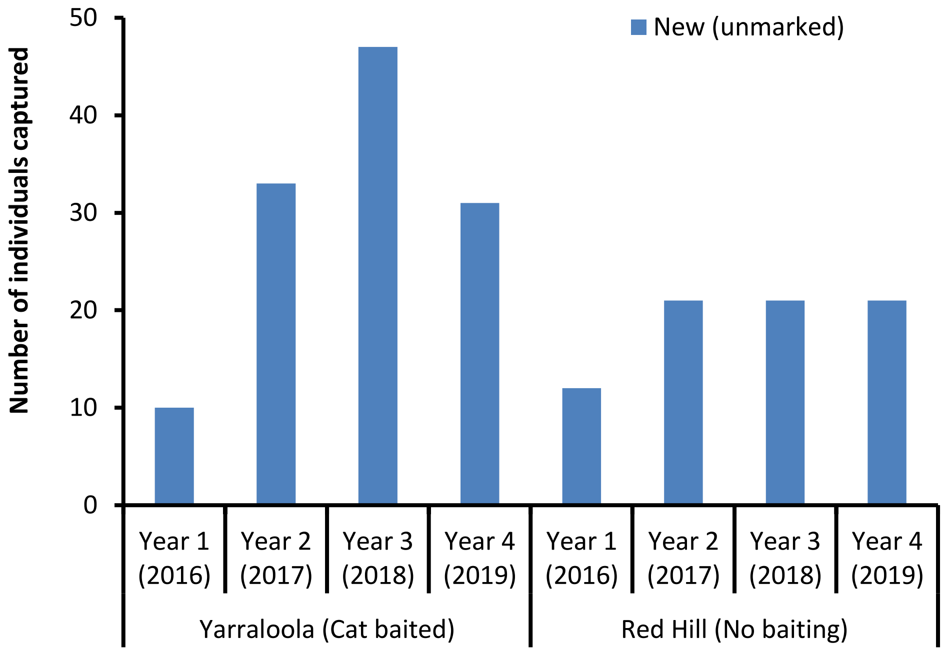


*Figure 12. Total number and capture history of individual female (a) and male (b) northern quolls captured per 18 trap sites (1440 trap nights) on Yarraloola (baited) and Red Hill (reference) from 2016 to 2019. * For 2019, Site R on Yarraloola was not trapped (17 trap sites and 1360 trap nights).*

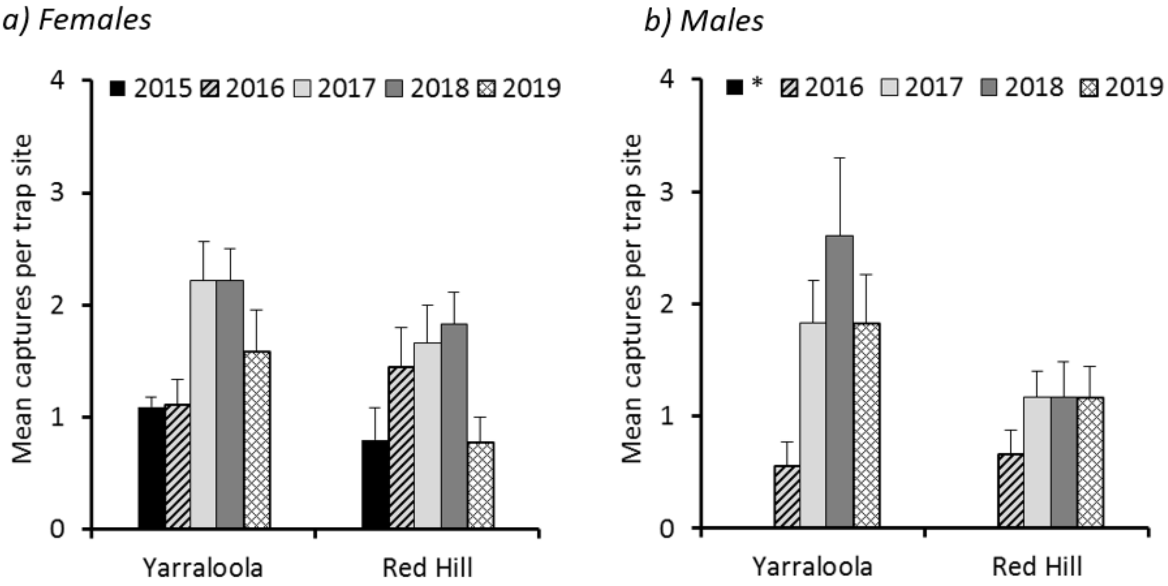


*Figure 13. Mean (+ SE) number of individual female (a) and male (b) northern quolls captured per trap site (20 traps set for 4 consecutive nights) at Yarraloola and Red Hill from 2015 to 2019. For 2016-19 there were 18 sites trapped at each site in September, apart from Yarraloola 2019 when there were 17 sites trapped. For 2015, trapping was spread from August to October (Yarraloola 11 trap sites, Red Hill 10 trap sites). * Males for 2015 were excluded as some sites were trapped in early August before the male die-off.*

3.4.3 Northern quoll body mass and litter size

The mean body mass of captured females and males across the sites remained largely unchanged from 2018 (Figure 14). The two-way ANOVA revealed no significant effect for site or a site by year interaction but there was a significant year effect ($F_{3,222}$ = 8.99, p = 0.000) on female body mass. Females were heaviest in 2017 when there was above average rainfall and lighter in years of average or below average rainfall (2016, 2018, 2019). The mean body mass for males was relatively low for 2019 (dry conditions). For males, there was no significant site effect alone but a significant year effect ($F_{3,187}$ = 25.12, p = 0.000) and site by year interaction ($F_{3,187}$ = 4.47, p = 0.005) effect. Like females, the males were also heaviest in 2017 when it was wetter. The site by year interaction resulted from the significant difference between the body masses of quolls captured in 2016. The onset of male die-off was potentially earlier that year and there were relatively few males captured at either site. Only twelve males were captured on Red Hill, most of which were in a particularly poor state. In contrast, several the ten males captured on Yarraloola were surprisingly healthy.

Births were delayed this year as only one female from each site was recorded to have pouch young (n = 28 Yarraloola; n = 15 Red Hill). Both females had eight pouch young, no larger than 8 mm. In previous years, the average litter size on Yarraloola was highest in 2018 with 7.4 ± 0.3 pouch young (PY) per litter (range 6–8, n = 8), similar to 2017 (7.2 ± 0.2 PY, range 3–8, n = 32) and 2015 (7.2 + 0.3 PY, range 5–8, n = 10), but greater than 2016 (6.8 ± 0.4 PY, range 2–8, n = 16). Mean litter sizes were consistently lower on Red Hill, 2017 (6.4 ± 0.3 PY, range 3–8, n = 22), 2016 (6.6 ± 0.4 PY, range 3–8, n = 11) and 2015 (5.3 ± 0.6 PY, range 3–8, n = 8). No pouch young were recorded on Red Hill in 2018 but trapping started a week earlier due to logistical reasons. Overall, the number of pouch young was significantly lower on Red Hill than Yarraloola for all years combined ($t_{80} = 3.20$, $P = 0.001$).

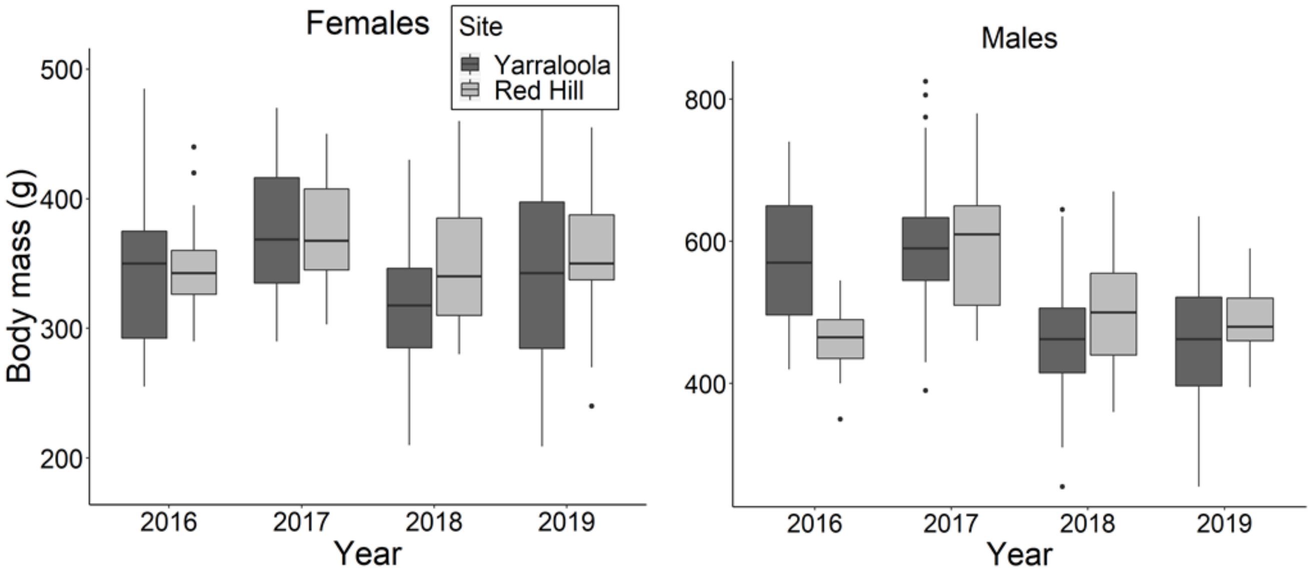


Figure 14. Body mass (g) of female and male northern quolls captured at monitoring sites from 2016 to 2019 at Yarraloola and Red Hill. Band inside the box represents the median value, box boundaries the 25th and 75th percentiles, whiskers the 10th and 90th percentiles and filled circles represent outliers.

3.4.4 Non-target captures in quoll traps

Capture rates of non-target species were low in 2019. Common rock-rats (*Zyzomys argurus*) were the most frequently encountered species, with 58 captures at Yarraloola and 77 captures at Red Hill. The mean number of common rock-rats captured per trap line across both sites collapsed following the peak reached in September 2018 (Figure 15).

The other species of by-catch included four *Pseudantechinus* sp., two *Dasykaluta rosamondae*, a sub-adult Rothschild's rock wallaby (*Petrogale rothschildi*), several skinks (*Egernia* sp. and *Ctenotus* sp.) and a juvenile goanna (*Varanus* sp.).

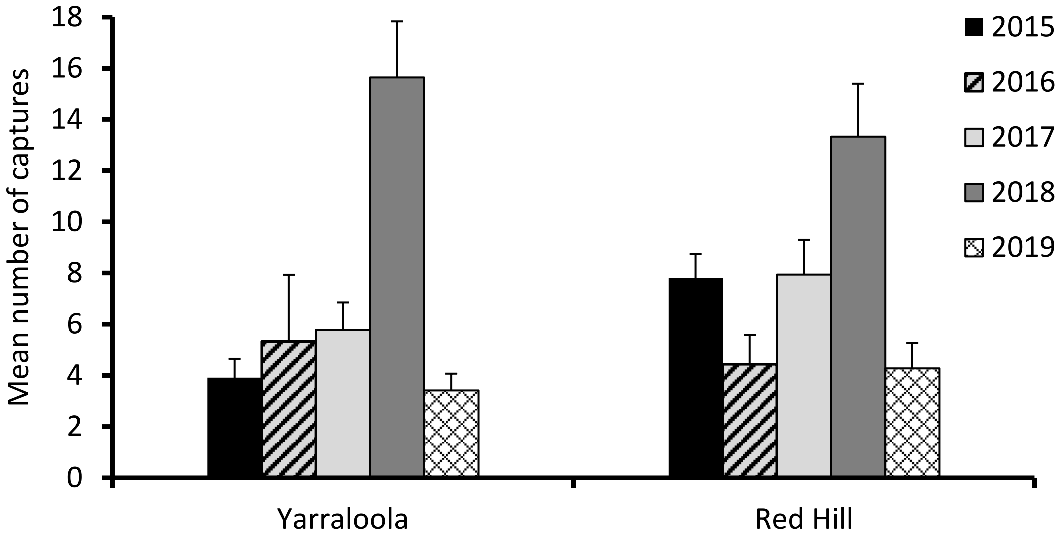


Figure 15. Mean (+ SE) number of common rock-rats captured per quoll monitoring site at Yarraloola and Red Hill for 2015 to 2019.

3.5 Predator diets

3.5.1 Overall dietary comparison for dingoes, feral cats and northern quolls

In total, 322 northern quoll, 50 feral cat and 135 dingo scats were collected during 2019. 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. Cattle were the other important source of food. Minor prey items were echidnas, emus and grasshoppers (Figure 16).

Common rock-rats comprised almost 44% of the diet of feral cats by volume. Other prey were mostly small vertebrates including other rodent species, dasyurids and birds. Northern quolls had the most varied diet, consuming mostly arthropods and to a lesser degree fruits, rodents and other small vertebrates.

Evidence for dingoes preying on subordinate predators was relatively weak across the entire collection of 395 scats from across the four-year study. Only seven scats contained feral cat remains (1.8% frequency of occurrence; FOO) and three quoll remains (0.8% FOO). Four of the feral cat detections were from Yarraloola in 2019 (6.2% FOO; n=65 scats). In contrast, 17 of the 135 feral cat scats collected across the entire study contained quoll remains (12.6% FOO), indicating feral cats were a more important predator of quolls. One of the feral cat scats collected at Quoll trap Line M on Red Hill in September 2019 contained a northern quoll PIT tag. There were several accounts of cannibalism in both dingoes and northern quolls.

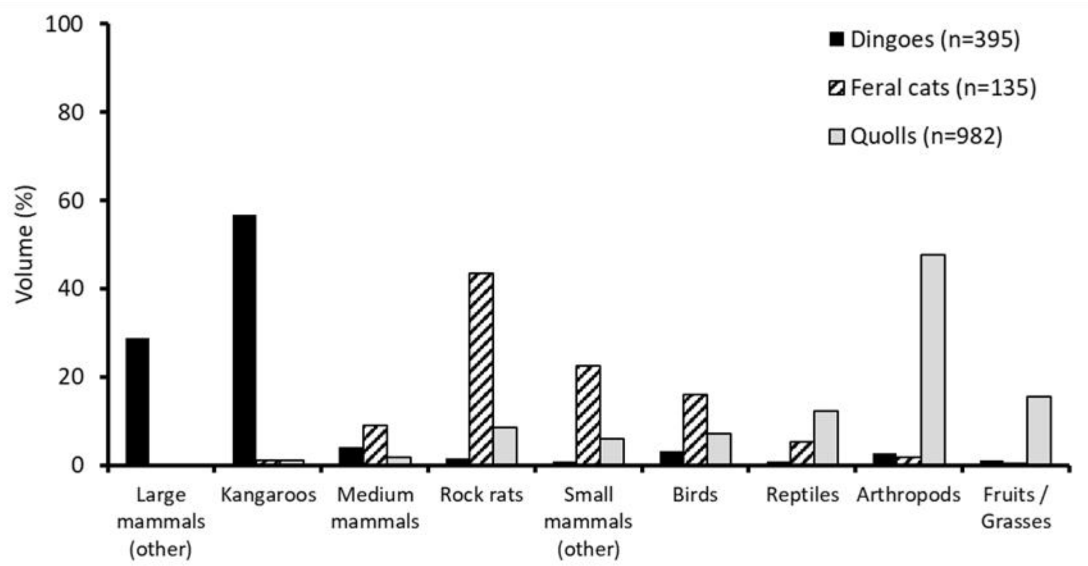


Figure 16. Relative volume of food groups in the diets of dingoes, feral cats and northern quolls for 2015 to 2019. Parentheses show sample sizes.

3.5.2 Feral cat diets

The use of a quad bike on Yarraloola aided the collection of feral cat scats, with 47 found compared with only three for Red Hill (no quad bike surveys). Many of the feral cat scats were from the drill pad lines on Mesa G. The common rock-rat remained the most important prey on Yarraloola in 2019 (Figure 17). The frequency at which quolls were detected increased to 21.3% FOO and the relative volume of this species was 14.8%. Most of the scats containing quoll remains (8 of 11) were collected from Mesa G. There was a previous event of high occurrence of quolls in feral cat scats in 2017, where five of eight cat scats found in two neighbouring gorges at Quoll trapline N and M on Yarraloola contained quoll remains (Palmer and Anderson 2018). Birds were also a common prey (53.2% FOO) of feral cats in 2019 but they contributed less in terms of relative dietary volume (Figure 17). Two feral cat scats from Mesa G also contained Rothchild’s rock wallaby, which was the first record of this prey for the study.

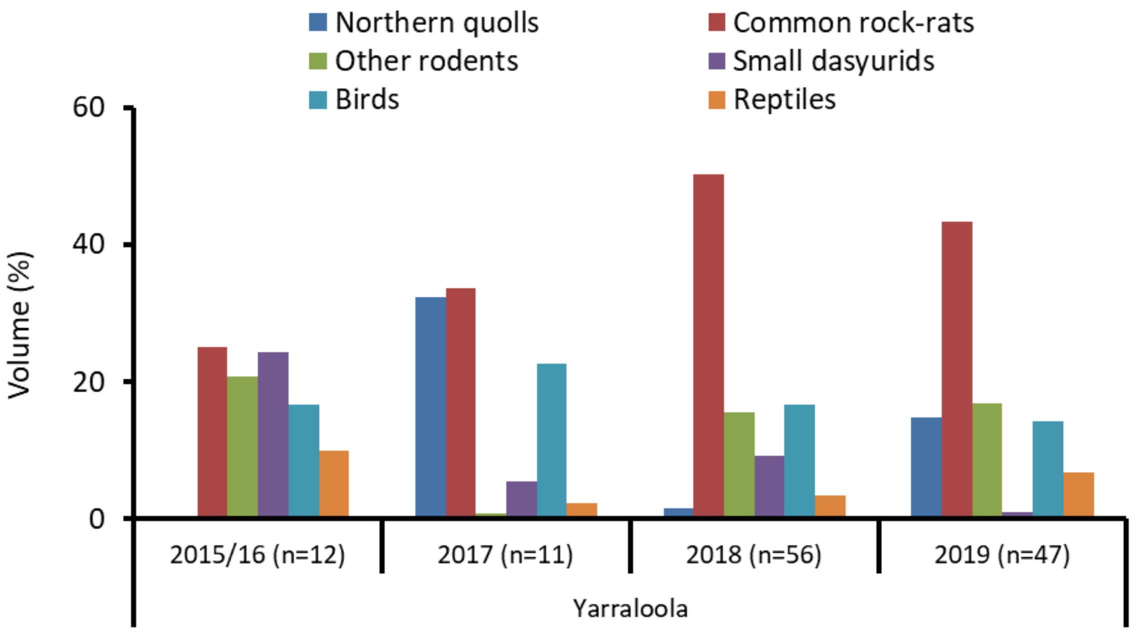


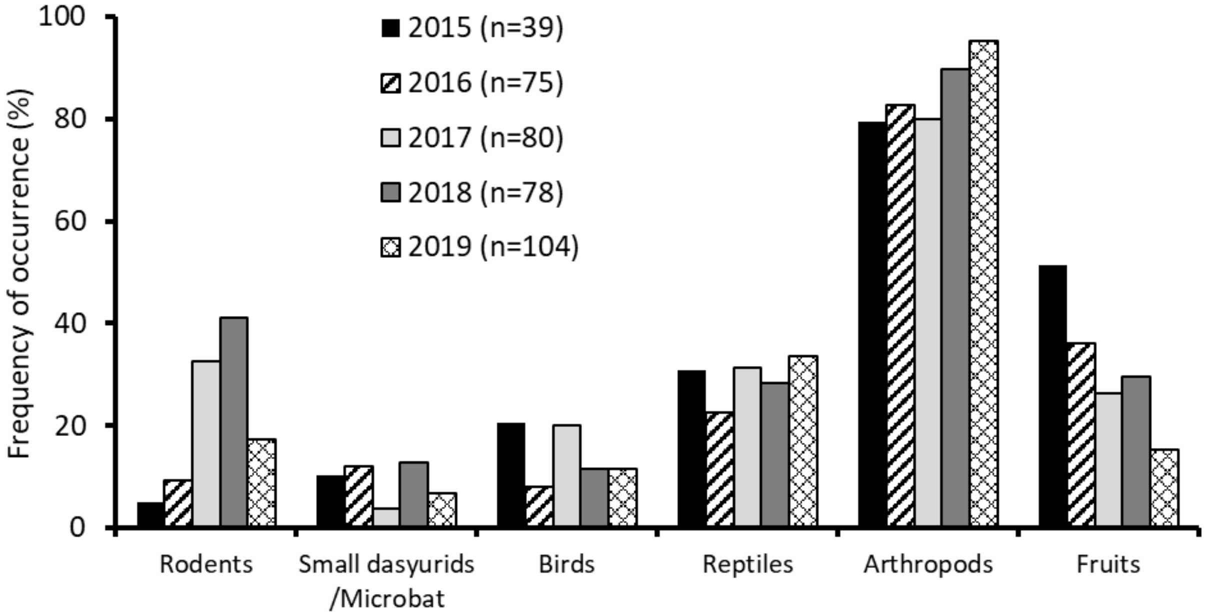
Figure 17. Comparative diet of feral cats on Yarraloola from 2016 to 2019. Diets are shown in terms of relative volume of each food group in the scats. Parentheses show sample sizes.

3.5.3 Northern quoll diets

Northern quolls on Yarraloola appear to have changed their dietary niche since feral cat control commenced (Figure 18). Prior to broad-scale baiting and during the first year of the baiting program, fruits featured as the second most eaten food group. The prevalence of fruit in their diet subsequently declined as quolls increased their intake of rodents in 2017 and 2018. Under the dry conditions in 2019, the frequency of rodents in the diet of quolls across the two stations declined, but it remained higher for quolls on Yarraloola (17.3% FOO) compared to Red Hill (6.2% FOO). The frequency of fruits eaten by quolls on Red Hill was higher in 2018-19, whereas quolls on Yarraloola preyed more heavily on invertebrates in these years.

The orange fur of a microbat, probably the threatened Pilbara leaf-nosed bat (*Rhinonicteris aurantia*) was recovered from a quoll scat collected in the Cane River gorge on Red Hill.

a) Yarraloola



b) Red Hill

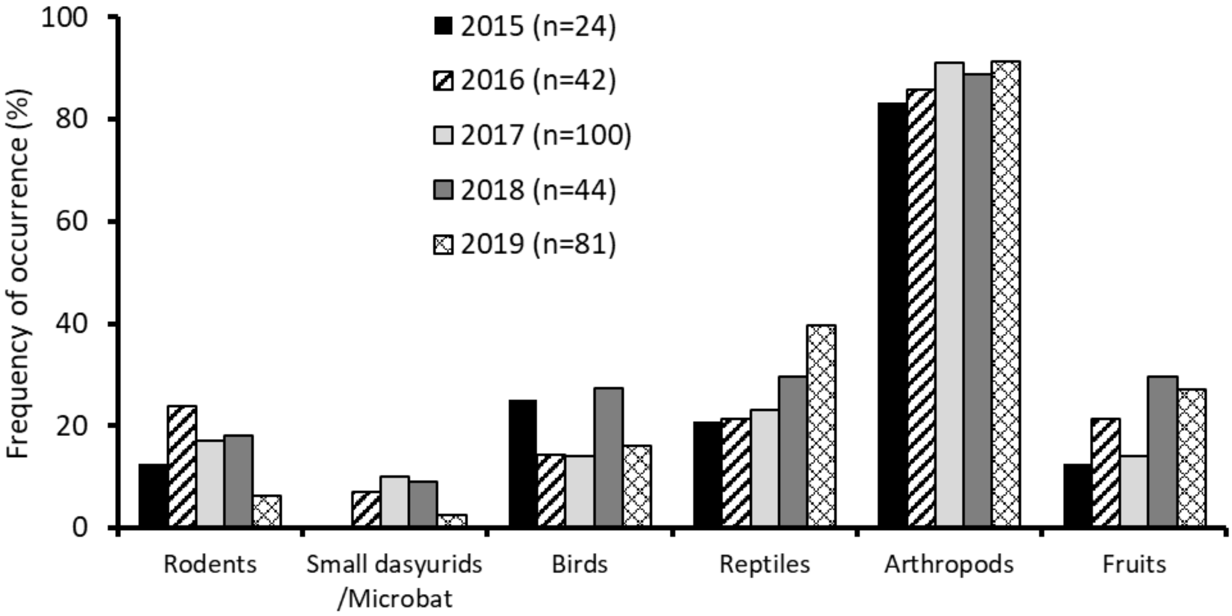


Figure 18. Comparative diets of northern quolls for (a) Red Hill and (b) Yarraloola (2015-2019). Diets are shown in terms of frequency of occurrence of each food group in the scats. Parentheses show sample sizes.

3.5.4 Dingo diets

From 2016 to 2018, dingoes on Yarraloola largely preyed on kangaroos (euros and red kangaroos), with relatively little change between years in their dietary composition (Figure 19). Likewise, dingo diets on Red Hill from 2017 to 2018 were reasonably consistent between these years. Compared with Yarraloola, kangaroos were eaten in lesser quantities, and cattle and grasshoppers (2017) were consumed in greater volumes.

There was a major shift in dingo diets on Yarraloola in 2019, with cattle becoming the main food source and kangaroos the second most important prey. There was an increase in the amount of cattle eaten on Red Hill in 2019 but kangaroos remained the primary prey.

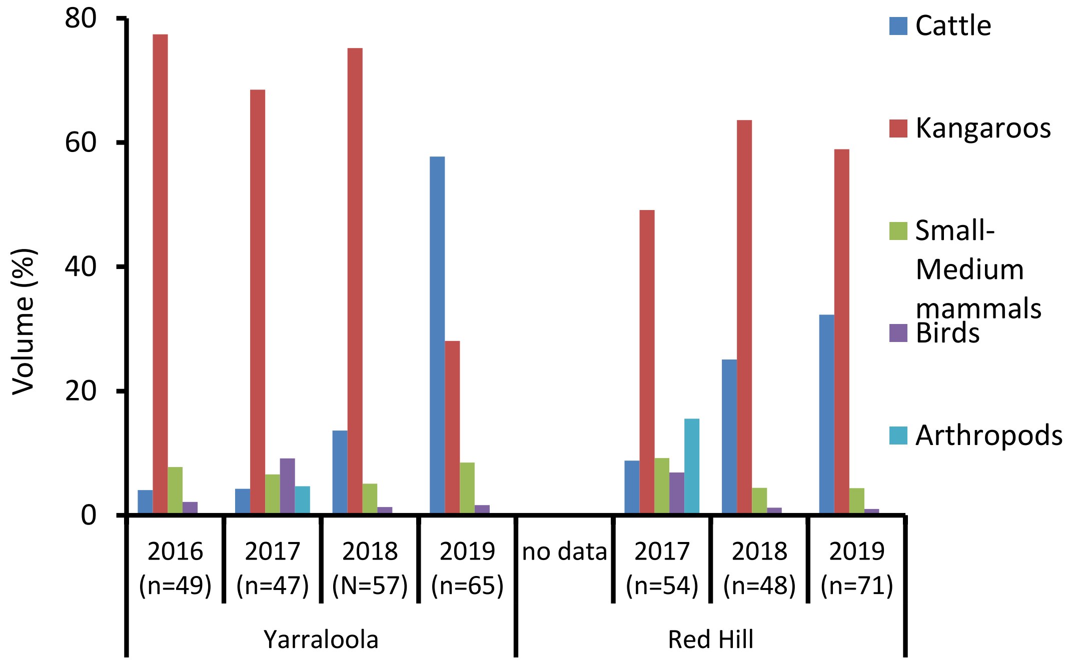


Figure 19. Relative volume of food groups in the diets of dingoes for Yarraloola (2016-2019) and Red Hill (2017-2019). Parentheses show sample sizes. Reptiles and Fruits/Grasses were excluded as these groups were rarely eaten.

3.6 Other incidental/opportunistic records

Two Pilbara olive pythons (*Liasis olivaceus barroni*) were found in 2019, both on Red Hill. The first was detected in early August under a cattle watering trough commonly used by the pythons, situated near Cardo Camp. The second was seen during September at Cardo camp itself (Appendix 3).

No common brush-tail possums (*Trichosurus vulpecula*) were recorded Cat Camera 49 this year. One was recorded in new location on Mesa C, appearing on two quoll camera traps set for the first time (Appendix 3).

4 Discussion

4.1 Winter baiting program

As no rain fell following the baiting program on the 8-9 July 2019, there were no issues related to baits getting wet, which can impact on bait toxicity or palatability (Algar *et al.* 2013). In total, 70,850 *Eradicat*® feral cat baits were delivered by air over the 142,036 ha bait cell at the rate of 49.9 baits km^{-2}, which is consistent with the baiting protocol. No carcasses of non-target species were observed after the baiting program.

The timing of the deaths of the four collared feral cats indicate baits were taken on day two, seven (two cats) and seventeen following the baiting. These results are consistent with the 2018 Yarraloola baiting program (Palmer *et al.* 2019) and those from Fortescue Marsh (Comer *et al*. 2018), indicating surface laid baits in the Pilbara remain available and palatable to feral cats for at least three weeks.

4.2 Effectiveness of *Eradicat*® baiting

4.2.1 Feral cat numbers leading into the 2019 baiting program

The relative abundance of feral cats prior to the baiting program remained similar to that recorded after the winter baiting program in the previous year on Yarraloola. Hence, there was little evidence of a recovery in this population over the summer due to natal recruitment and/or immigration of animals from outside the baited cell. There was evidence that breeding did occur in spring 2018 with some obvious younger cats detected on camera traps across both stations in June 2019. The lack of any substantial recovery in the feral cat population within the bait cell up to 11 months following the previous baiting program contrasts with other similar broad-scale cat baiting projects at Fortescue Marsh in the eastern Pilbara and Matuwa Indigenous Protected Area (IPA) in the southern rangelands (Algar *et al.* 2013; Comer *et al.* 2018; Lohr and Algar 2020). This finding is discussed further below.

4.2.2 Baiting efficacy

Two independent approaches, camera trap monitoring and the tracking of mortality rates of radio-collared feral cats exposed to baits, were used to monitor baiting efficacy in 2019. Two measures of the relative abundance of feral cats were generated from the camera trapping data (site occupancy and detection rate) immediately prior to and immediately following the baiting program. Previously, there was general agreement between these two metrics, albeit the mortality rate of collared feral cats exposed to baits was lower in 2018 (Palmer *et al.* 2019). For 2019, the probability of site occupancy of feral cats according to both models (random and spatial effects) in the baited cell increased after the baiting program but fell by a significant magnitude in the reference site over the same period. In contrast, the detection rate of feral cats declined following baiting on Yarraloola (34%), but it also fell on Red Hill (35%) where there was no baiting.

There was no mortality amongst the three collared feral cats present on Red Hill. Whereas, four of the twelve (33%) collared feral cats present within the bait cell died within 17 days of the bait drop. Hence, the mortality rate of feral cats was reflected in the decline in detections on Yarraloola following baiting, but site occupancy increased. The reason for this inconsistency is not clear. It is possible that the low number of feral cat detections pre- and post-baiting meant that the power to detect a change in occupancy was compromised. Repeat feral cat detections at individual camera sites was also low on Yarraloola, with only one camera site occupied by cats during both monitoring sessions. Site fidelity was stronger on Red Hill with most (6 of 7) of the camera sites with feral cats in the post-bait session also recording them during the pre-bait session.

The reasons to why feral cat occupancy/detection rates fell sharply between the monitoring sessions on Red Hill in both 2016 and 2019 in the absence of any control action is unknown. This highlights the importance of long-term monitoring to better understand natural variation in abundance over time. Factors that influence the mobility and activity levels of feral cats have the potential to impact site occupancy rates. For instance, the increasing day length after the winter solstice usually triggers the onset of breeding in female cats. Activity levels and movement may therefore decline after baiting as females give birth to kittens. Decreased movements due to the maternal care of kittens may have been responsible for the pattern observed in August 2016 (Palmer *et al.* 2017). Although it does not explain the decline in 2019 as most females probably did not breed due to the dry conditions.

The development of more advanced analytical techniques for camera-trap data suggests that it is now feasible to derive robust population density estimates for cryptic and wide-ranging species based on individual identification (Forsyth *et al.* 2019; Rees *et al.* 2019). Camera traps can be placed in grid formation in a landscape to systematically sample areas of interest, then the resulting history of detections can be used to estimate the abundance of a species using a spatially explicit capture-recapture (SECR) framework. These models consider both the distribution and movement of individuals across the landscape in relation to the placement of detection devices, and account for imperfect detection (Royle *et al.* 2013).

A Masters student from the University of Western Australia is currently exploring the potential to use the SECR framework for deriving feral cat densities in future camera trapping programs in the Pilbara. This project will make use of current camera trapping data to investigate the likelihood of individually identifying feral cats from unique coat markings. A shift to this approach may avoid some of the issues surrounding the use of the current camera trap abundance metrics. Other changes may include using white-flash camera traps to improve the quality of images of feral cats and manipulating lures (olfactory, visual, audio, food cues) to maintain curiosity levels of individual feral cats so that they continue visiting camera trap sites.

While some of the apparent anomalies in the camera monitoring over the past four years are not easily explained, the trends in feral cat abundances between the baited and unbaited sites were clear. Following the first large-scale bait drop in 2016, feral cat abundance (detection rates in Figure 9) and camera sites with cat detections (Figure 10) were all lower on Yarraloola compared with Red Hill apart from June 2018 (pre-bait) when there was a re-invasion of the bait cell. The winter baiting greatly reduced (2016 and 2018) or lowered (2017 and 2019) feral cat abundance on Yarraloola to very low detection rates. In three of the four years, the detection rate of feral cats on Yarraloola following baiting was below 0.5 cats per 100 CTN, which is the equivalent of one cat detected in 250 camera trap nights. Such levels are very low compared to other camera trapping studies from arid and northern regions of Australia (Brook *et al.* 2012; Hernandez-Santin *et al*. 2016; Read *et al*. 2015; Stokeld *et al*. 2016). The only period where the post-bait level was greater (0.73 cats per 100 CTN) was in 2018. In that year, there was a feral cat re-invasion of Yarraloola between September 2017 and May 2018. The detection rate of feral cats prior to baiting in June 2018 peaked at 1.7 cats per 100 CTN.

The recent addition of camera trap monitoring to the 16-year long feral cat control program on the Matuwa IPA suggested that aerial baiting alone no longer suppressed the feral cat population to the levels currently achieved in this ‘early stage’ Yarraloola study. A decline in efficacy of baiting had resulted from the long-term control approach selectively altering the demographics of the feral cat population towards one dominated by older and larger sized males that avoid taking baits. An intensive large-scale leg-hold trapping program was implemented with 159 feral cats trapped from September 2018 to May 2019. This removal process essentially had the effect of re-setting the feral cat population to one that was now largely bait naïve. The subsequent aerial baiting program in winter 2019 reduced the detection rate of feral cats to levels well below that achieved at Yarraloola (Lohr and Algar 2020).

Although annual aerial baiting remains effective at Yarraloola, there is evidence that individual adult male cats (radio-collared males YM02-03 and YM06-08; Table 2) have survived multiple winter baiting programs. Other uncollared large males were also identified from camera trap images from inside the bait cell recorded over multiple years. The resulting male bias in the adult feral cat population will eventually reduce the efficacy of baiting (Lohr and Algar 2020). An integrated feral cat management approach is recommended for arid zone systems with the implementation of intensive trapping programs at least every 10 years.

A key factor in the efficacy of the baiting program in 2019 was the dry conditions. It is well documented that baiting is more effective when prey supplies are low during dry times (Algar and Burrows 2004; Algar *et al.* 2013). In this study, when common rock-rat numbers were at their highest in 2018, only two of the eleven feral cats with collars exposed to baiting died (18.2% mortality *cf.* 33.3% mortality in 2019 under dry conditions). However, while none of the five large radio-collared males exposed to baiting in 2018 when prey supplies were plentiful took baits, they also survived following the baiting in 2019. Although, two (YF03-04) of the three surviving females from 2018 were killed during the baiting program in 2019 under changed conditions. The surviving adult males may have learnt to avoid baits from their previous encounters, or they had become proficient hunters of preferred live-prey and were not interested in eating baits (Algar *et al.* 2007).

Another factor to note is that survival rates of adult feral cats in the study area were high. Of the 17 collared adults that remained in the study sites, only one large male (YM04, 5.0 kg) died from unknown causes (Table 2). This death occurred two months following the baiting in 2019, which suggests it was unlikely to have taken a bait. The other five deaths of collared adult feral cats were attributed to baiting. The remaining eleven collared adults were still alive in September 2019. Only two of the juvenile cats captured were large enough to collar. Both died in 2018, one from baiting and the other from natural causes.

Limiting re-invasion of cat-managed areas surrounded by open-system populations of feral cats remains an ongoing challenge for landscape scale control programs (Comer *et al.* 2018). The Fortescue Marsh site was re-invaded each year from 2013 to 2016. Furthermore, in relation to the long-term Matuwa IPA cat control program, Lohr and Algar (2020) indicate that reinvasion following feral cat control is inevitable. Yet our monitoring has only identified a single reinvasion event of Yarraloola in the three years that followed the initial baiting program in 2016. Breeding and recruitment patterns of cats in the Pilbara are unknown, making it difficult to speculate why there was no recovery in the cat population on Yarraloola in 2017 and 2019. Cat reinvasion is believed to occur in the summer and autumn periods preceding baiting, driven by both natal recruitment and immigration of younger animals from outside the baited area (Algar *et al.* 2013). The recovery of the feral cat population on Yarraloola in 2018 was probably triggered by high recruitment following the increases in prey populations driven by the tropical low that delivered widespread summer rainfall in February 2017 (Palmer *et al*. 2019). Populations of invertebrates and nomadic birds were high in 2017, followed by common rock-rats in 2018.

The more topographically rich landscapes of the west Pilbara may be more restrictive on feral cat movement compared with these other studies (Fortescue Marsh and Matuwa IPA) done in largely flat landscapes (Hohnen *et al*. 2016). 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 feral cat re-invasion rates (Recio *et al.* 2015).

4.3 Response by northern quolls to feral cat control

4.3.1 Population response by northern quolls to feral cat control

The overall capture rate of northern quolls during the September 2019 trapping session declined for the first time since large-scale baiting commenced in 2016. These declines were ~30% lower from the peaks reached in the previous year across both sites. Quoll capture rates remained higher on Yarraloola, with 4.26 individuals captured per 100 trap nights (TN) down from 6.04 individuals 100 TN^{-1} in 2018. The tally for Red Hill was ~40% lower than Yarraloola at 2.50 individuals 100 TN^{-1} (*cf.* 3.75 individuals 100 TN^{-1} in 2018).

Captures of females remained higher within the feral cat baited treatment compared with the reference site. They also suffered a lower rate of decline (28%) from the previous year, with the female capture rate falling by 55% from September 2018 to 2019 on Red Hill. The number of individual males captured on Yarraloola declined by 16% but remained higher than on Red Hill where there was no change from the 2017-18 capture rates.

Summer rainfall patterns are a key driver of population fluctuations in northern quolls as this short-lived species is highly dependent on annual juvenile recruitment (Moro et al 2019). For this four-year study there was only one year of high summer rainfall, which was in 2017. Hence, there was a strong population increase detected from 2016 to 2017, particularly on Yarraloola where quoll captures doubled (Figure 12 & 13). Quoll body masses were also heavier in this wetter year. There were good late autumn and early winter falls of rain in 2016 and 2018 but this was well after the period critical for newly weaned quolls in early summer.

Rainfall for 2019 was well below average and the wet season was poor, particularly on Red Hill. Poor juvenile recruitment across both sites was likely to be a factor in the general decline in northern quoll populations. Disentangling the influences of feral cat control and differing rainfall patterns on quoll populations across the study areas is not straightforward. For instance, the dry conditions experienced in 2019 lead to a considerable delay in the birth of young, with only 2 of the 43 females examined having pouch young. In fact, some of the small females were yet to mate. This delay may have also caused a lag in male die-off in 2019, which could explain why the capture rates of males remained seemingly high despite the dry conditions. However, even with the well below average rainfall in 2019, quoll numbers were still higher on Yarraloola compared to Red Hill, indicating that they did benefit from feral cat control.

Recaptures of marked quolls (PIT tags) also indicate that survival rates of adult females were higher with feral cat control for two of the three annual periods between trapping sessions. The annual survival rate of females on Yarraloola was higher for 2016-17 (50% *cf.* RH 35%) and 2018-19 (29% *cf.* RH 15%). For 2017-18 it was 30% for both sites (Figure 12). Additionally, we captured the oldest known wild female quoll at Site K on the Robe River on Yarraloola in 2019. This female was captured 12 times from September 2016 to 2019 (maximum opportunity to be trapped was 16 times). She was most likely four years of age when last captured. Given how 'trap happy' this female was and the fact that Site K was trapped on a number of occasions in 2015, we believe she was born in September 2015. Three-years is the previous maximum reported survivorship for a female (Moro *et al.* 2019). Also, of note is that Site K was burnt in January 2017 (Figure 4). As per previous years, none of the marked males from former trapping sessions were captured again.

Wildfire is another factor that potentially dampened the response by northern quolls to feral cat baiting in 2019. Fire mapping for 2019 is yet to be completed but it is estimated that ~32% of northern quoll habitat was burnt on Yarraloola by hot summer fires between the 2018 and 2019 quoll trapping sessions. Up to six quoll trapping sites on Yarraloola were impacted by fire. Trapping at Site R was abandoned due to the lack of cover. In contrast, there were few summer wildfires on

Red Hill that impacted on quoll habitat and only one site was burnt. Further analysis/research is required on the effects of fire on quoll populations as it is widely reported that feral cats respond to fire scars in northern Australia, where they can take a heavy toll on fauna populations in burnt sites that lack adequate cover to protect them from predation (Leahy *et al.* 2016). Interestingly, Site P on the southern side of the Pannawonica road was severely burnt in late December 2018, but then four female and four male quolls were captured there in September 2019. Likewise, only eight traps were set at Site R for a single night and two quolls were captured. Clearly this species is well adapted to fire.

4.3.2 Northern quoll abundance before and after *Eradicat®* baiting

Laboratory testing showed northern quolls have a moderate tolerance to compound 1080 (LD50 7.5 mg/kg; King *et al.* 1989). Previously, it was speculated that their relatively small body mass in the Pilbara (360-600 g) may place northern quolls at risk if they ingested a single toxic feral cat bait containing 4.5 mg of 1080. Yet King (1989) and this project (Cowan *et al*. in press) show that aerial baiting programs targeting wild dogs or feral cats do not pose a hazard to co-occurring free ranging northern quolls in the Pilbara. These studies confirm that the estimated bait toxicity derived from laboratory settings applying 1080 in a liquid dosage form and actual poisoning of quolls under field conditions when the 1080 is presented in a meat bait are not comparable (Jones *et al.* 2014).

Here, we extend this evidence by presenting data on the relative abundance of northern quolls immediately prior to and immediately following four winter *Eradicat®* baiting programs (Figure 9). If northern quolls were susceptible to 1080 poisoning from meat baits, we would expect to detect a collapse in quoll numbers following each baiting program. Quoll detection rates only declined by a significant level following the baiting on one occasion on Yarraloola, which was in 2019. In contrast, quoll detection rates declined significantly in the post-bait monitoring session in all years on Red Hill in the absence of baiting.

It was not possible to sex the northern quolls visiting these camera traps, although many appeared larger. Given the cameras were also set in the lead-up to and during the quoll breeding season and there was an olfactory lure present, we suspect most individuals detected were males. The sharp decline in quoll detections in the post-bait session each year on Red Hill is likely to be due to a combination of decreased mating activity in the second half of August and the onset of male die-off. Higher feral cat densities on Red Hill may also mean a greater proportion of these weakened male quolls were taken by cats. In 2019, the dry conditions delayed the onset of breeding and the subsequent male die-off process. However, there were significant declines in the detection rates of northern quolls on both Yarraloola and Red Hill during the post-bait monitoring session. Both quoll populations were likely to have been heavily impacted by feral cat predation in this period as ~20% of cat scats collected at this time contained quoll remains.

4.4 Predator interactions and potential indirect benefits to quolls from feral 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, Cowan *et al* in press). Effective control of feral cats should therefore enhance the fitness of the northern quoll population on Yarraloola.

The monitoring of northern quoll diets from 2015 to 2019 across both sites has demonstrated a dietary shift by quolls on Yarraloola away from fruits to rodent prey (Figure 18). In contrast, quoll diets were stable across years on Red Hill regardless of the differing rainfall patterns and changes in common rock-rat numbers. Dunlop *et al.* (2017) hypothesised 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 feral cats on Yarraloola benefits quoll populations indirectly by improving their access to richer prey sources in high-risk open habitats. The occurrence of rodent prey in the diet of quolls at both sites did fall under the dry conditions in 2019, coinciding with the collapse in the capture rates of common rock-rats. Capture rates of this key prey species were at their lowest across both sites in 2019.

According to Hernandez-Santin *et al*. (2016) introduced predators influence the use of landscapes by northern quolls at both local and larger scales in the northern Pilbara, with quolls avoiding the flat and open habitats more frequently used by feral cats. They suggest that predator avoidance was a key reason for the contraction of the distribution of northern quolls to rocky areas across northern Australia. Over the past four years in this study, feral cats and quolls have occasionally been detected at the same camera sites on both study areas in a range of different habitat types. The most compelling images captured that demonstrate the risk to northern quolls moving through lowland habitats was that of a northern quoll being followed by a feral cat at 11 pm on the 7 July 2019 at Camera Site 57 on Red Hill.

We are yet to investigate how landscape/habitat differences across camera trap sites influences levels of spatial overlap/segregation between feral cats and quolls. On Yarraloola where feral cat baiting has reduced their numbers, northern quolls should be less likely to encounter feral cats compared with those in the unbaited reference site of Red Hill. Visits by quolls to camera traps located in lowland sites on Yarraloola has increased every year since baiting commenced (Figure 10). Northern quolls are now known to have visited 38 of the 60 cat cameras on Yarraloola, although not all of these camera sites were in lowland habitats. In contrast, northern quolls have been detected at 28 camera sites on Red Hill, with few new sites added since 2017. Furthermore, after the initial baiting program, northern quolls have been detected at more camera sites than feral cats during all seven monitoring sessions, whilst this has never occurred on Red Hill.

4.4.1 Intraguild predation

Evidence of intraguild predation based on the analysis of predator scat collections was mixed. Dingoes rarely ate northern quolls (<1% frequency in diet) and feral cats were infrequent prey (7 in 395 scats). An increase in consumption of feral cats by dingoes (6.2% FOO) was detected under the drier conditions for Yarraloola in 2019 but not on Red Hill. Increased levels of intraguild predation were expected under the harsher conditions but it is unclear why no feral cat remains were found in the 71 dingo scats examined from Red Hill. Whether this increase related to dingoes scavenging the carcasses of poisoned feral cats or if they were using the large fire scars as hunting grounds on Yarraloola. Pilbara olive pythons were also confirmed to prey on northern quolls, with two of eight scats examined containing quolls and a further two Rothchild’s rock wallaby.

Feral cats were the predominate predator of northern quolls in this region, but predation was patchy between years. In 2017, we detected a localised predation event whereby an individual feral cat/s were targeting quolls in two neighbouring gorges connected by drainage lines to the south of Mesa J (Quoll Traplines M and N). Five of eight feral cat scats collected in this area in September/October contained the remains of quolls. Only one other feral cat scat collected from 2016 and 2018 (n=68) contained northern quoll remains. Northern quolls then became a significant prey item for feral cats under the dry conditions in 2019. One of the feral cat scats from Red Hill even contained the PIT of a previously trapped quoll, which unfortunately was damaged and could not be read by the scanner. The collapse of rodent populations due to the dry conditions in 2019 was the key driver of this dietary shift by feral cats. Even though feral cat densities on Yarraloola were reduced by the baiting program, those feral cats remaining placed heavy predation pressure on the northern quoll population. The extensive networks of drill pad tracks within the ranges/mesas on Yarraloola were likely to have facilitated access for feral cats to hunt prey in these rocky refuge sites. Many of the feral cat scats containing northern quoll remains were collected from Mesa G in 2019, which was recently subject to further exploration activity resulting in the addition of numerous tracks.

4.5 Future directions: strategic feral cat management

The future challenge is how to transition from the management of a bait naïve feral cat population to a feral cat population with an increasing number of bait smart adult males. A more strategic adaptive management approach that accounts for the unpredictable behaviour of feral cats is needed (Lohr and Algar 2020). A combination of aerial and targeted ground-baiting by hand may be more effective than uniform aerial baiting across the entire LMA. Creating feral cat “sinks” in areas less critical to threatened species, and in areas where feral cats prefer, such as lowland plains areas, could be achieved by targeted aerial baiting. Additionally, ground baiting in high density feral cat prey locations, such as along waterways, may increase exposure of feral cats to the baits. Complementing baiting with leg-hold trapping is required to remove bait-shy individuals (Lohr and Algar 2020). A cost-saving option may be to avoid baiting altogether after high-rainfall periods as prey abundance will be high (e.g. influx of nomadic ground nesting birds) and feral cats are less likely to take baits. New audio and other types of prey cues designed to attract feral cats from further distances into areas with control devices could also be tested.

References

Algar DA, Burrows ND (2004) A review of Western Shield: feral cat control research. *Conservation Science Western Australia*. **5**, 131–163.

Algar DA, Angus GJ, Williams MR, Mellican AE (2007) Influence of bait type, weather and prey abundance on bait uptake by feral cats (*Felis catus*) on Peron Peninsula, Western Australia. *Conservation Science Western Australia*. **6**, 109–149.

Algar DA, Onus M, Hamilton N (2013) Feral cat control as part of *Rangelands Restoration* at Lorna Glen (Matuwa), Western Australia: the first seven years. *Conservation Science Western Australia*. **8**, 367–381.

Australian Bureau of Meteorology (2019) Climate Data Online. Available at http://www.bom.gov.au/climate/data/index.shtml [accessed 31 Dec 2019].

Braithwaite RW, Griffiths AD (1994) Demographic variation and range contraction in the northern quoll *Dasyurus hallucatus* (Marsupialia: Dasyuridae). *Wildlife Research*. **21**, 203–217.

Brook LA, Johnson CN, Ritchie EG (2012) Effects of predator control on behaviour of an apex predator and indirect consequences for mesopredator suppression. *Journal of Applied Ecology*. **49**, 1278–1286.

Calenge C (2006) The package adehabitat for the R software: a tool for the analysis of space and habitat use by animals. *Ecological Modelling* **197**, 516–519.

Calver MC, McIlroy JC, King DR, Bradley JS, Gardner JL (1989) Assessment of an approximate lethal dose technique for determining the relative susceptibility of non-target species to 1080-toxin. *Wildlife Research* **16**, 33–40.

Chapman J, Zdunic K (2019a) Red Hill annual desktop fire regime monitoring, 2018. Department of Biodiversity, Conservation and Attractions, Kensington, WA.

Chapman J, Zdunic K (2019b) Yarraloola annual desktop fire regime monitoring, 2018. Department of Biodiversity, Conservation and Attractions, Kensington, WA.

Claridge AW, Mills DJ (2007) Aerial baiting for wild dogs has no observable impact on spotted-tailed quolls (*Dasyurus maculatus*) in a rainshadow woodland. *Wildlife Research*. **34**, 116–124.

Clausen L, Cowen S, Pinder J, Danks A, Thomas A, Bell L, Speldewinde P, Comer S, Algar DA (2016) *Fortescue Marsh feral cat baiting program (Christmas Creek Water Management Scheme) Year 5 Annual Report.* Department of Parks and Wildlife, Western Australia.

Comer S, Speldewinde P, Tiller C, Clausen L, Pinder J, Cowen S, Algar DA (2018) Evaluating the efficacy of a landscape scale feral cat control program using camera traps and occupancy models. *Scientific Reports* **8**, 5335.

Commonwealth of Australia (2015a) *Threat abatement plan for predation by feral cats*. Department of Environment and Energy, Canberra.

Commonwealth of Australia (2015b) *Threatened species strategy*. Department of Environment and Energy, Canberra.

Cowan M, Moro D, Anderson H, Garretson S, Angus J. Morris K (in press). Aerial baiting for feral cats is unlikely to affect survivorship of northern quolls in the Pilbara region of Western Australia. *Wildlife Research*.

Cramer VA, Dunlop J, Davis R, Ellis R, Barnett B, Cook A, Morris K, van Leeuwen S (2016) Research priorities for the northern quoll (*Dasyurus hallucatus*) in the Pilbara region of Western Australia. *Australian Mammalogy*. **38**, 135–148.

Dunlop JA, Rayner K, Doherty TS (2017) Dietary flexibility in small carnivores: a case study on the endangered northern quoll, Dasyurus hallucatus. *Journal of Mammalogy*. **98**, 858–866.

Forsyth DM, Ramsey DS, Woodford LP (2019) Estimating abundances, densities, and interspecific associations in a carnivore community. *The Journal of Wildlife Management* **83**, 1090–1102.

Hernandez-Santin L, Goldizen AW, Fisher DO (2016) Introduced predators and habitat structure influence range contraction of an endangered native predator, the northern quoll. *Biological Conservation*. **203**, 160–167.

Hohnen R, Tuft K, McGregor HW, Legge S, Radford IJ, Johnson CN (2016) Occupancy of the invasive feral cat varies with habitat complexity. *PLoS One*, **11**, e0152520.

Hill BM, Ward SJ (2010) *National recovery plan for the northern quoll Dasyurus hallucatus*. Department of Natural Resources, Environment, The Arts and Sport, Darwin.

Ivan JS, Newkirk ES (2016) CPW Photo Warehouse: a custom database to facilitate archiving, identifying, summarizing and managing photo data collected from camera traps. *Methods in Ecology and Evolution*. **7**, 499–504.

Jones ME, Burnett S, Claridge AW, Fancourt B, Körtner G, Morris K, Peacock D, Troy S, Woinarski JCZ (2014). Australia's surviving marsupial carnivores: threats and conservation. In 'Carnivores of Australia: Past, Present and Future'. (eds AS Glen and CR Dickman.) pp. 197–240. CSIRO Publishing, Melbourne.

King DR (1989) An assessment of the hazard posed to northern quolls (*Dasyurus hallucatus*) by aerial baiting with 1080 to control dingoes. *Australian Wildlife Research* **16**, 569–574.

King DR, Twigg LE, Gardner JL (1989). Tolerance to sodium monofluoroacetate in dasyurids from Western Australia. *Australian Wildlife Research* **6**,131–140.

Körtner G, Gresser S, Harden B (2003) Does fox baiting threaten the spotted-tailed quoll, *Dasyurus maculatus*? *Wildlife Research* **30**, 111–118.

Körtner G, Watson P (2006). The immediate impact of 1080 aerial baiting to control wild dogs on a spotted-tailed quoll population. *Wildlife Research* **32**, 673–680.

Körtner G (2007) 1080 aerial baiting for the control of wild dogs and its impact on spotted-tailed quoll (*Dasyurus maculatus*) populations in eastern Australia. *Wildlife Research* **34**, 48–53.

Lohr CA, Algar D (2020) Managing feral cats through an adaptive framework in an arid landscape. *Science of the Total Environment* **137631**.

Leahy L, Legge SM, Tuft K, McGregor HW, Barmuta LA, Jones ME, Johnson CN (2016) Amplified predation after fire suppresses rodent populations in Australia's tropical savannas. *Wildlife Research* **42**, 705–716.

Molsher R, Newsome AE, Newsome TM, Dickman CR (2017) Mesopredator management: effects of red fox control on the abundance, diet and use of space by feral cats. *PLOS ONE*. **12**, e0168460.

Moore HA, Dunlop JA, Valentine LE, Woinarski JC, Ritchie EG, Watson DM, Nimmo DG (2019) Topographic ruggedness and rainfall mediate geographic range contraction of a threatened marsupial predator. *Diversity and Distributions* **25**, 1818–1831.

Moro D, Dunlop J, Williams MR (2019). Northern quoll persistence is most sensitive to survivorship of juveniles*. Wildlife Research* **46**, 165–175.

Morris K, Thomas N (2014) *Operational introduced predator control program – Yarraloola Offset Area, Pilbara Region, WA 2015-2019.* Department of Parks and Wildlife, Perth.

Morris K, Cowan M, Angus GJ, Anderson H, Garretson S, Algar DA, Moro D, Williams M (2015) *The northern quoll cat bait uptake and survivorship study, Yarraloola Land Management Area, Pilbara Region WA*. Department of Parks and Wildlife, Perth.

Morris K, Cowan M, Angus GJ, Anderson H, Garretson S, Palmer R, Williams M, Pearson D (2016) *Baseline monitoring for northern quoll and Rothschild's rock-wallaby at Eradicat® baited and unbaited sites, Pilbara Region WA*. Department of Parks and Wildlife, Perth.

Palmer R, Anderson H, Angus GJ, Garretson S, Morris K (2017) *Predator Control Baiting and Monitoring Program, Yarraloola and Red Hill, Pilbara Region, Western Australia. 2016 Annual Report - Year 2*. Department of Parks and Wildlife, Perth, Western Australia.

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, Western Australia.

Palmer R, Anderson H, Richards B (2019). *Predator control baiting and monitoring program, Yarraloola and Red Hill, Pilbara region, Western Australia: 2018 annual report, year 4.* Department of Biodiversity, Conservation and Attractions, Woodvale, WA. 59 p

R Core Team (2019). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Read JL, Bengsen AJ, Meek PD, Moseby KE (2015) How to snap your cat: optimum lures and their placement for attracting mammalian predators in arid Australia. *Wildlife Research*. **42**, 1–12.

Recio MR, Seddon PJ, Moore AB (2015) Niche and movement models identify corridors of introduced feral cats infringing ecologically sensitive areas in New Zealand. *Biological Conservation*. **192**, 48–56.

Rees MW, Pascoe JH, Wintle BA, Le Pla M, Birnbaum EK, Hradsky BA (2019) Unexpectedly high densities of feral cats in a rugged temperate forest. *Biological Conservation* **239**, 108287.

Rio Tinto (2014) *Yandicoogina JSW and Oxbow Project, EPBC 2011/5815 Condition 14: Threatened Species Offset Plan*. Hamersley Iron Pty Ltd, Perth.

Royle JA, Chandler RB, Sollmann R, Gardner B (2013) *Spatial capture-recapture*. Academic Press.

Stokeld D, Frank ASK, Hill B, Choy JL, Mahney T, Stevens A, Young S, Rangers D, Rangers W, Gillespie GR (2016) Multiple cameras required to reliably detect feral cats in northern Australian tropical savanna: an evaluation of sampling design when using camera traps. *Wildlife Research*. **42**, 642–649.

White GC, Garrott RA (1990) *Analysis of wildlife radio-tracking data*. Harcourt Brace Jovanovich, New York.

Woinarski J, Burbidge A, Harrison P (2014) *Action Plan for Australian Mammals 2012*. CSIRO Publishing, Melbourne.

Woinarski JCZ, Burbidge AA, Harrison PL (2015) Ongoing unraveling of a continental fauna: Decline and extinction of Australian mammals since European settlement. *Proceedings of the National Academy of Sciences*. **112**, 4531–4540.

Appendices

Appendix 1 Field work program for 2019

Trip	Date(s)	Field Activity
1	18 - 20 Feb Yarra	Helicopter radio-tracking for radio-collared cats. Alicia Whittington undertook the tracking.
2	3 – 15 Apr Yarra	Trials were undertaken to investigate methods to optimise the use of leg-hold traps for the capture of cats while excluding non-target species, particularly northern quolls. These experiments formed part of an Honours project for Hassan Abdi (Curtin University). Forty passive cat cameras were set and trialled as a possible alternative to lured cat cameras for monitoring in the future. RRK ranger involvement. (2 teams)
3	29 Apr– 3 May Yarra/Red Hill	Quoll cameras were set along trap lines and teams radio-tracked for collared cats. RRK rangers and a volunteer assisted. (2 teams)
4	21 May – 2 June Yarra	Cat trapping and collaring using ~84 cat trap sets. Five cats were trapped and collared. No non-target species were accidently captured. DBCA expert cat trapper Jason Fletcher supervised the trapping. Honours student Hassan Abdi assisted. Quoll cameras were collected from trap lines and quoll scats collected for diet study. All passive cat cameras were collected charged.
5	10 – 14 June Yarra/Red Hill	Setting of 120 camera traps for the monitoring of feral cats prior to baiting. RRK rangers assisted. Radio-tracking and downloading data from collared cats. (2 teams)
6	1 – 2 July Yarra	Heli-tracking of collared cats with help from Alicia Whittington from DBCA Karratha.
	1 – 12 July Yarra/Red Hill	*Eradicat* ® bait uptake experiment. Small radio transmitters were inserted into each bait. Baits laid in front of a camera. Individual baits were tracked each day to determine the fate of removed the baits and whether these baits were consumed. 120 cat cameras were collected and extra 1080 signage was installed. Predator scat surveys were undertaken on a quad bike on Yarraloola.
	8 – 9 July Yarra	Aerial baiting of *Eradicat* ® on Yarraloola Station. Western Shield baiting team and Shine aviation from Mt. Minnie. Alicia Whittington coordinated the operation.
7	29 July – 2 Aug Yarra/Red Hill	Setting of 120 camera traps for the monitoring feral cats after the baiting. RRK rangers assisted. Radio-tracking feral cats and locating any dead cats. (2 teams)
8	1 - 16 Sept Yarra.	Quoll monitoring at 18 sites, trapped for four nights each. Collected sixty cat cameras. Predator scat surveys conducted. RRK rangers involved. (3 teams)
	3 Sept Yarra	Heli-tracking of collared cats with help from Alicia Whittington from DBCA Karratha. Dead cats retrieved.
	2 - 12 Sept Red Hill	Quoll monitoring at 18 sites, trapped for four nights each. Collected sixty cat cameras. Cats radio tracked. Predator scat collection. (3 teams)

Appendix 2. Northern quoll capture results for 2019

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	1	0	1	1.25	1.25
B	4	1	9	11.25	6.25
C	2	7	14	17.50	11.25
D	3	1	7	8.75	5.00
F	2	1	4	5.00	3.75
G	0	0	0	0	0
H	0	0	0	0	0
I	2	1	5	6.25	3.75
J	0	4	6	7.50	5.00
K	4	0	7	8.75	5.00
L	2	0	4	5.00	2.50
M	2	4*	11	13.75	7.50
N	1	3*	11	13.75	5.00
O	0	5	8	10.00	6.25
P	4	4	13	16.25	10.00
Q	0	0	0	0	0
R	#(1)	#(1)	-	-	-
T	0	0	0	0	0
Totals	**27**	**31**	**100**	**-**	**-**
Means	**1.59**	**1.82**	**5.88**	**7.35**	**4.26**

*Male (PIT 287571) was first captured at Line M Trap 12 (13/9), then moved to Line N Trap 1 (14/9), back to Line M Trap 6 (15/9) and then returned to Line N Trap 2 (16/9).

Line R was burnt by a hot fire in late December 2018. Eight traps were set for a single night resulting in the capture of one unmarked female and one unmarked male. The site was abandoned due to the lack of protective shelter for which to place traps. These captures were not included in the analysis.

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

Trap site	Females	Males	Total captures (includes	Overall trap success rate (%)	Individuals captured per 100 trap nights
CL	0	0	0	0	0
CW	0	0	0	0	0
E	0	0	0	0	0
F	2	1	9	11.25	3.75
G	0	0	0	0	0
H	0	0	0	0	0
I	1	0	2	2.50	1.25
J	2	2*	7	8.75	5.00
KB	0	1	1	1.25	1.25
L	0	1	1	1.25	1.25
M	0	0	0	0	0
N	2	7	18	22.50	11.25
P	1	1	6	7.50	2.50
PP	3	0*	9	11.25	3.75
RL	0	0	0	0	0
SW	1	0	1	1.25	1.25
X	1	2	5	6.25	3.75
Z	2	6	9	11.25	10.00
Total	**15**	**21**	**68**	**-**	**-**
Means	**0.83**	**1.17**	**3.78**	**4.72**	**2.50**

*Male (PIT 289748) was first captured at Line L Trap 16 (4/9), then moved to Line PP Trap 11 (5/9) and a few days later was caught at Line J Trap 2 (8/9).

Appendix 3 Incidental and opportunistic records

From top then left to right for other panels: a) Pilbara olive python, b) Rothschild's rock wallaby, c) *Egernia formosa*, d) Kaluta, e) Brush-tail possum

Appendix 4 Volunteer engagement 2019

Name	Dates	Hours	Description
Amelia Catterick-Stoll	29 Apr – 3 May	54.5	Quoll camera trap setting, Yarraloola
Arlen Hogan-West	8 – 12 July	53.5	Cat camera collection, Yarraloola
Sam Edwards	2 – 12 Sept	94	Northern quoll cage trapping, Red Hill
Kate Rick	2 – 12 Sept	90	Northern quoll cage trapping, Red Hill
Ashleigh Johnson	2 – 16 Sept	130	Northern quoll cage trapping, Yarraloola

Appendix 5 TSOP outputs and engagement summary

Robe River Kuruma engagement

Table 3. Robe River Kuruma field staff involvement according to year and number of days worked during the TSOP. The number of field trips per year in parentheses.

Name	Year of TSOP Project			Total
	2017	2018	2019	
Arnold Bobby	5	3	9 (2)	17
Brendon Bobby	5	-	-	5
Eden Bobby	-	-	11 (2)	11
Eugene Evans	-	-	15 (3)	15
Joshua Evans	-	26 (3)	5	31
Nathan Evans	-	7 (2)	-	7
Royce Evans	-	-	4	4
Chaylean Sampi	-	6	-	6
John Shaw	-	15	-	15

Publications

<u>*Action 1 – Northern quoll Eradicat® cat bait uptake and survivorship study (2015)*</u>

Annual Reports

Morris K, Cowan M, Angus GJ, Anderson H, Garretson S, Algar DA, Moro D, Williams M (2015). *The northern quoll cat bait uptake and survivorship study, Yarraloola Land Management Area, Pilbara Region WA*. Department of Parks and Wildlife, Perth.

Morris K, Cowan M, Angus GJ, Anderson H, Garretson S, Palmer R, Williams M, Pearson D (2016). *Baseline monitoring for northern quoll and Rothschild's rock-wallaby at Eradicat® baited and unbaited sites, Pilbara Region WA*. Department of Parks and Wildlife, Perth.

Scientific Papers

Moro D, Dunlop J, Williams MR (2019). Northern quoll persistence is most sensitive to survivorship of juveniles*. Wildlife Research* **46**, 165–175.

Cowan M, Moro D, Anderson H, Angus J, Garretson S, Morris K (in press). Aerial baiting for feral cats is unlikely to affect survivorship of northern quolls in the Pilbara region of Western Australia. *Wildlife Research*.

Action 2 – Introduced predator control program (2016–19)

Annual Reports

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

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.

Palmer R, Anderson H, Richards B, (2019). Predator control baiting and monitoring program, Yarraloola and Red Hill, Pilbara region, Western Australia. 2018 Annual report - Year 4. Department of Biodiversity, Conservation and Attractions, Perth.

*Scientific Papers (*Review papers that include data on feral cat diets from this study)

Woinarski JCZ, Murphy BP, Legge SM, Garnett ST, Lawes MJ, Comer S, Dickman CR, Doherty TS, Edwards G, Nankivell A, Paton D, Palmer R, Woolley LA (2017). How many birds are killed by cats in Australia? *Biological Conservation* **214**, 76–87.

Woinarski JCZ, Woolley LA, Garnett ST, Legge SM, Murphy BP, Lawes MJ, *et al*. [Palmer R] (2017). Compilation and traits of Australian bird species killed by cats. *Biological Conservation* **216**, 1–9.

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.

Murphy BP, Woolley LA, Geyle HM, Legge SM, Palmer R, Dickman CR *et al.* (2019). Introduced cats (*Felis catus*) eating a continental fauna: the number of mammals killed in Australia. *Biological Conservation* **237**, 28–40.

Woolley LA, Geyle HM, Murphy BP, Legge SM, Palmer R, *et al.* (2019). Introduced cats (*Felis catus*) eating a continental mammal fauna: inventory and traits of species killed. *Mammal Review* **49**, 354–368.

Woinarski JCZ, Legge SM, Woolley LA, Palmer R, Dickman CR *et al.* (in press). Predation by introduced cats *Felis catus* on Australian frogs: compilation of species' records and estimation of numbers killed. *Wildlife Research.*

Woolley LA, Murphy BP, Geyle HM, Legge SM, Palmer R, *et al.* (in press). Introduced cats eating a continental fauna: invertebrate consumption by feral cats *Felis catus* in Australia. *Wildlife Research.*

Popular magazine articles

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

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.

Student thesis

Abdi HA (2019). Excluding bycatch of endangered northern quoll from feral cat leg-hold traps. Honours thesis. Curtin University, Perth.