Yandicoogina JSW and Oxbow Project: Threatened Species Offset Plan.

The northern quoll cat bait uptake and survivorship study, Yarraloola Land Management Area, Pilbara Region, WA.

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Cover photograph: Northern quoll *Dasyurus hallucatus*, J Hayward 2010.

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Executive Summary

Predation by feral cats and other introduced predators has been shown to be a significant threatening process for many species of medium-sized mammals, in the Pilbara and elsewhere in Australia. As part of an environmental offset condition, Rio Tinto were required to prepare a Threatened Species Offset Plan (TSOP) that implements management actions to benefit the EPBC Act listed northern quoll and Pilbara olive python. Rio Tinto has defined an area (the Yarraloola Land Management Area, LMA) within which management actions described in the TSOP will be delivered. The LMA encompasses a part of the Yarraloola pastoral lease, as well as smaller parts of adjoining tenure, in the west Pilbara. A central component of the TSOP was the development and implementation of an introduced predator control program. A key aspect of the development of this program was an assessment of the impact of using *Eradicat®* feral cat baits in the presence of northern quolls, as the carnivorous quolls are potentially at risk from toxic bait consumption.

A study examining the survivorship of northern quolls and their uptake of toxic *Eradicat®* baits was undertaken from May – October 2015. The impact of toxic feral cat baiting was primarily assessed by monitoring survivorship of radio-collared northern quolls at the baited site within the LMA and comparing with survivorship at an unbaited site on the adjacent Red Hill pastoral lease. The uptake of *Eradicat®* baits was assessed through examination of the mouth and scats of live quolls for signs of Rhodamine B (RhB) biomarker. Where possible, dead quolls were also examined closely for signs of bait ingestion through evidence of RhB pigmentation. Five of the 21 radio-collared quolls at

Yarraloola died during this study, two of these deaths occurred before baiting. Four deaths were from cat predation and one was unknown. Five of the 20 quolls radio-collared at Red Hill are known to have died during the same period; two of these were from cat predation, and two from canid predation. Another was recovered but its cause of death could not be confirmed. The fate of a further two quolls was unknown as the animals/carcasses were not recovered. Potential sub-lethal impacts of the sodium fluoroacetate toxin (1080) on quoll reproduction were assessed through monitoring the number of pouch young produced as a measure of reproductive output. The average litter size was higher in the cat baited area at Yarraloola compared to the unbaited area at Red Hill, and was within the range reported elsewhere for northern quolls.

Data on movements were also obtained and these showed that males ranged over significantly larger areas than did females during the trial. A composite map of male and female quoll movement areas, and aerial bait drops, and the suspected spread of baits on the ground, indicates that quolls were exposed to feral cat baits during this trial. However, none of the 30 quolls captured at Yarraloola after baiting, or the four recovered quoll carcases showed signs of RhB ingestion.

The conclusion of this study was that *Eradicat®* baiting in the cooler and drier winter months is unlikely to detrimentally impact on the northern quoll population at Yarraloola, but that the current level of predation by feral cats is likely to contribute to the long term decline of this population. Introducing an operational landscape scale feral cat baiting program, with appropriate monitoring, at Yarraloola is most likely to benefit the northern quoll population and this is supported by Population Viability Analysis modelling of the population over time.

1 Background

The Yandicoogina Junction South West (JSW) and Oxbow Iron Ore Expansion Project was approved by the Western Australian Government and the Commonwealth Government (via MS 914 and EPBC Decision Notice 2011/5815 respectively) subject to a number of conditions, including the Commonwealth requirement for submission of a Threatened Species Offset Plan (TSOP) by Rio Tinto (Rio Tinto 2014) to benefit the threatened northern quoll (*Dasyurus hallucatus*) and Pilbara olive python (*Liasis olivaceus barroni*). This was completed in December 2014 and provided details of measures to control and/or manage introduced predators, feral herbivores, unmanaged fires and invasive weeds.

The introduced predator control program (Morris and Thomas 2014) focused on controlling feral cats, given their significant detrimental impact on native fauna, particularly mammals and ground dwelling birds. There are few records of foxes in the TSOP area. In Western Australia (WA), the most effective way of controlling feral cats at the landscape scale is through baiting with the *Eradicat®* cat bait. However this bait was only registered in December 2014 for operational use in WA in areas where potential non-target species, such as northern quolls, do not occur. This study was undertaken under an APVMA research permit to assess the survivorship of northern quolls and their uptake of toxic *Eradicat®* baits before, during and after a toxic cat baiting program. The results of this study will be used to plan an operational cat baiting program across the Yarraloola LMA for the period 2016 - 2019 and beyond.

2 Introduction

Since European settlement, 29 (9.2%) of Australia's terrestrial mammal species have become extinct, and another 57 species (18.3%) have declined significantly and are considered threatened (Woinarski *et al*. 2014). Predations by introduced predators (particularly the European red fox *Vulpes vulpes* and feral cat *Felis catus*) have been identified as significant factors in mammal declines in

Australia. In the 1980 - 90s, predation by foxes was shown to be a significant threatening process for native fauna in WA (Kinnear *et al*. 2002, Morris *et al*. 2003). More recently, feral cat predation has been identified as a major issue for native mammal conservation (Marlow *et al.* 2015, Fisher *et al*. 2014, Wayne *et al*. 2013) and Woinarski *et al*. (2014) regard this as the factor now affecting the largest number of threatened and near threatened mammal taxa. Predation by feral cats is a listed Key Threatening Process under the *Environment Protection and Biodiversity Conservation Act* (EPBC 1999).

Twelve species of terrestrial mammal have become extinct in the Pilbara region of WA in the last 200 years, and another seven species have declined (McKenzie *et al*. 2006). A review of the conservation values, threats and management options for biodiversity conservation in the Pilbara (Carwardine *et al*. 2014) identified effective feral cat control was a key strategy for conserving terrestrial vertebrates of conservation significance. Without cat control it was likely that another five species of terrestrial vertebrate (including the spectacled hare-wallaby and bilby) will become regionally extinct in the Pilbara in the next 20 years, and another 18 species will continue to decline (including the northern quoll).

The northern quoll (*Dasyurus hallucatus*) is one of the seven Pilbara medium-sized mammal species that has persisted in the Pilbara bioregion (McKenzie *et al*. 2006). All of these species, except perhaps the echidna (*Tachyglossus aculeatus*), have declined to some extent in the Pilbara, and three, including the northern quoll, are listed as threatened species under State and Commonwealth legislation. The northern quoll was once distributed widely across northern Australia, from the Pilbara and Kimberley, across the Top End of the Northern Territory, to southern Queensland, but has now contracted to several disjunct populations (Braithwaite and Griffiths 1994, Oakwood 2008). An alarming decrease or complete collapse in once locally abundant populations of the northern quoll has occurred in recent years as a direct result of the invasion of the cane toad, *Rhinella marina* (Woinarski *et al*. 2008; Woinarski *et al*. 2010). Three other factors were also identified as contributing to the decline of northern quolls and other medium-sized mammals across northern Australia: changed habitats through widespread fires, predation by feral cats, and novel disease (Woinarski *et al*. 2011). Due to these declines and threatening processes, the northern quoll is listed as Endangered under both the Commonwealth's EPBC Act (1999) and the Western Australian *Wildlife Conservation Act 1950*.

Baiting using a type of sausage bait with the toxin sodium fluoroacetate (1080) is recognized as the most effective method for controlling feral cats over large areas on mainland WA and large islands (Algar and Burrows 2004; Algar *et al*. 2007; DEWHA 2008; Short *et al*. 1997), where there is limited risk posed to non-target species. The *Eradicat*® bait (Algar and Burrows 2004; Algar *et al*. 2007) has been used under APVMA approved 'research use permits' to demonstrate baiting efficacy at a number of sites across WA, including Dirk Hartog Island, Montebello Islands, Lorna Glen (Matuwa), Cape Arid National Park, Fitzgerald River National Park, Fortescue Marsh and Peron Peninsula. In December 2014, the *Eradicat®* feral cat bait was registered for operational use in areas of WA where there are no non-target risks to fauna. The bait could potentially be used in the Pilbara to reduce feral cat (and fox and dog) densities and improve conservation outcomes for northern quolls and other threatened fauna such as the bilby (*Macrotis lagotis*). However, prior to *Eradicat®* being used operationally in the Pilbara, potential non-target baiting impacts on northern quolls had to be identified and resolved. As a top order native predator, the northern quoll is at potential risk to poisoning after ingestion of the toxic sausage baits. Based on a 1080 LD_{50} of 7.5 mg/kg (King *et al*. 1989), an average size Pilbara northern quoll (380-580 g) would only need to ingest approximately one toxic cat

bait containing 4.5mg of 1080 to be at risk. Calver *et al*. (1989) identified that in the laboratory, the northern quoll was at risk from accidental poisoning from crackle baits containing 6 mg of 1080 for dingo control. However, King (1989) showed that an aerial dingo baiting program did not pose a hazard to free ranging northern quolls.

The national recovery plan for the northern quoll (Hill and Ward 2010) contains objectives to reduce the impact of feral predators on northern quolls, and to implement efforts to protect key northern quoll populations from the impacts of feral predators. This study assessed the risk of toxic cat baiting to a free-ranging northern quoll population, and the results will contribute to the achievement of these recovery plan objectives in the Yarraloola LMA, and elsewhere in the Pilbara. Assessing the impact of toxic baiting to control feral cats on northern quolls is an important component in the development of landscape scale programs to control introduced predators and reduce the extinction risk for quolls and other medium-sized mammals in the Pilbara. This trial did not assess the efficacy of *Eradicat*® baiting in controlling feral cats as it was only undertaken on a relatively small area. However, elsewhere in the Pilbara, at Fortescue Marsh, cat baiting efficacy over areas >100,000 ha has been as high as 85% (D. Algar *pers com*).

3 Study sites

This study was undertaken at two sites in the western Pilbara region of WA. The trial cat baiting program was undertaken over a 20,000 ha area, within the 163,213 ha Yarraloola LMA (Figure 1). This site is approximately 120 km south west of Karratha and 60 km east of Onslow near the Pilbara coast (centroid: 21^{o} 44’ 50”S, 116^{o} 08’ 31”E). The small mining town of Pannawonica is located 10 km north east of the LMA. An unbaited area on the adjacent Red Hill pastoral lease, approximately 65 km south of the Yarraloola baited site, was used as a control for this study.

These sites experience a semi-arid climate typical of the Pilbara bioregion. Summers are hot and winters mild. Rainfall is characteristically extremely variable and follows a loose bi-modal rainfall pattern with the majority of rainfall occurring 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 much 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, interacting with moist tropical air from the north-west. The historic yearly average rainfall for Pannawonica, over 43 years, is 404 mm but yearly rainfall is highly variable (Bureau of Meteorology).

Since the 1980’s, the WA Department of Agriculture and Food (DAFWA) has been controlling wild dog/dingo hybrids (*Canis familiaris / lupus*) via 1080 baiting on the Yarraloola pastoral lease; aerially baiting along the length of the Robe River (incorporating part of the Mullewa – De Grey stock route), southern half of Warramboo Creek and numerous other ephemeral water points within the LMA. In addition, *ad hoc* hand-baiting for dingoes / dogs has been undertaken by the Yarraloola pastoral managers around artificial water points and other areas of high dog activity including areas within the LMA. This baiting continued during this program as part of the ongoing pastoral management of Yarraloola Station. There is some evidence that *Eradicat*® baiting programs reduces dingo/dog abundance by ca. 25% at Matuwa (Lorna Glen) in the northern Goldfields (M Wysong, unpublished data).

The European red fox does occur in the Pilbara region (King and Smith 1985), however most records are along the coast and few are in the rocky areas of the inland Pilbara. Foxes may penetrate the inland Pilbara along river systems such as the Robe River. Berry *et al*. (2012) have demonstrated that baiting with *Eradicat*® baits in the rangelands significantly reduced fox densities and it is likely that aerial cat baiting would also reduce fox abundances at Yarraloola if they were present.

4 Methods

4.1 Cat baiting

4.1.1 Feral cat baits

The *Eradicat*® feral cat baits used in the Yarraloola trial baiting program were manufactured at the Department of Parks and Wildlife's (Parks and Wildlife) Bait Manufacturing Facility at Harvey, WA. The bait is similar to a chipolata sausage in appearance, approximately 20 g wet-weight, dried to 15 g, blanched and then frozen. This bait is composed of 70% kangaroo meat mince, 20% chicken fat and 10% digest and flavour enhancers (Patent No. AU781829). Toxic feral cat baits are dosed at 4.5 mg of 1080 per bait. Prior to bait application, feral cat baits were thawed at the Auski Roadhouse airstrip, adjacent to the Great Northern Highway near Wittenoom, and placed in direct sunlight on-site. This 'sweating' process causes the oils and lipid-soluble digest material to exude from the surface of the bait. All feral cat baits were sprayed, during the sweating process, with an ant deterrent compound (Coopex®) at a concentration of 12.5 g/L as per the manufacturer's instructions. This process is aimed at preventing bait degradation by ant attack and enhancing acceptance of baits by cats by limiting the physical presence of ants on and around the bait medium. For this trial, the toxic baits were also impregnated with the non-toxic biomarker RhodamineB (RhB) to confirm if northern quolls had ingested cat baits.

4.1.2 Cat baiting risk assessment

A "1080 Baiting Application and Risk Assessment" as required by the *Code of Practice for Safe Use and Management of 1080 in Western Australia (August 2010)* was completed prior to undertaking the cat baiting program at Yarraloola. This is standard practice for any 1080 baiting undertaken by Parks and Wildlife and this process examines the potential risks of 1080 baiting to non-target native animals and human health. An assessment of species potentially at risk is shown in the draft operational introduced predator control program for the Yarraloola LMA (Morris and Thomas 2014), and this concluded that there was little potential risk to any other native species, apart from the northern quoll. Similarly, Algar *et al*. (2011) evaluated the risk of cat baiting to native mammal species at Fortescue Marsh, in the east Pilbara and concluded that the northern quoll was the species most at risk from a toxic cat baiting trial.

The risk to people operating in the baited area was also assessed as part of the risk assessment process. The 20,000 ha baited cell was located away from public use areas such as roads, railways, town sites and mine sites. Neighbours were notified by Pilbara Region Parks and Wildlife staff and 1080 baiting warning signs were erected at appropriate locations. Briefings were provided to the Kuruma and Marthudunera traditional owners on the potential risks of 1080 baiting to their use of the baited areas within the Yarraloola LMA. A site visit to the Yarraloola LMA by representatives of the Kuruma and Marthudunera Traditional Owners was also facilitated by Parks and Wildlife prior to finalising the area to be baited. The greatest risk for traditional owner groups was the potential for poisoning of domestic dogs if they were taken into the cat baited area. Domestic dogs, like cats and foxes have a low tolerance to 1080 (McIlroy 1981, McIlroy 1986), and would only need to consume 1-2 baits to receive a lethal dose. There were no reports of domestic dogs in the baited cell during this study or of any accidental deaths during the baiting trial.

4.1.3 Cat baiting operations

Cat baiting operations for this study were conducted under a research use permit issued by the APVMA in December 2014, and valid from the 9 December 2014 to 30 November 2016. Toxic cat baiting is also governed by the '*Code of Practice on the Use and Management of 1080' (Health Department, Western Australia)* and associated '*1080 Baiting Risk Assessment'* (see above).

Baiting at Yarraloola took place on 6 July 2015 and followed Parks and Wildlife cat baiting prescriptions. This was the coolest and driest period for the Yarraloola area when bait uptake by feral cats is maximised due to the low abundance and activity of prey items, in particular reptiles and small mammals (Algar and Burrows 2004). Bait degradation due to rainfall, ants, and hot weather is also significantly reduced at this time. No rainfall was recorded at Pannawonica or Red Hill station in June, August or September. At both sites, 1.2 mm of rain was recorded on 12 July, six days after baiting, and at Pannawonica another 14.2 mm was recorded on 22 July (14.8 mm at Red Hill), 16 days after baiting (Bureau of Meteorology). The *Eradicat*® cat bait remains palatable to feral cats, and most likely other non-target fauna with single rainfall events of up to 25mm.

After being loaded into the aircraft at the Auski Roadhouse airstrip near the Great Northern Highway, cat baits were aerially delivered over the 20,000ha trial cat baited area (Figures 2 and 3). The baiting program was conducted under the Parks and Wildlife Western Shield Aerial Baiting Contract with baits deployed in batches of 50 at one kilometre (50 baits / km^2) intervals along previously designated baiting flight lines. Flight lines were one kilometre apart and covered the entire baiting cell. The baiting aircraft flew at 150 knots and 500 feet above ground level. A GPS point was recorded on the flight plan each time baits left the aircraft (Figure 3). Previous trials have shown that under these flight conditions, the ground spread of the 50 baits will be approximately 250 x 50 m (Algar *et al*. 2011).

This cat baiting operation occurred at a time when northern quolls, particularly males, were very mobile as they looked for mates. Normally at this time also, first year quolls would be becoming reproductively active and females would be gaining weight in readiness for pregnancy and suckling pouch young (Dunlop *pers com*). The recorded times for breeding activity for female Pilbara northern quolls in the Pilbara varies slightly with those from the Northern Territory and Kimberley (Table 1).

4.2 Northern quoll survivorship

The impact of feral cat baiting on northern quolls was assessed, using a Before-After-Control-Impact (BACI) experimental design, by comparing quoll survivorship at the Yarraloola (cat baited) and Red Hill (unbaited) sites, before and after cat baiting at Yarraloola. Survivorship was primarily determined by monitoring radio-collared individuals at each site. A supplementary trial of quoll detections on a camera array at Yarraloola was also undertaken. The health of captured quolls and evidence of reproductive success in females was also assessed as measures of the impact of cat baiting.

The dates of field activities at Yarraloola and Red Hill are shown in Table 2. At each site, quolls were trapped using linear transects of up to 50 small Sheffield cage traps (Sheffield Wire Company, Welshpool, WA) baited with a mixture of peanut butter, oats and sardines. This is similar to the methodology used by the northern quoll regional monitoring project (Dunlop *et al.* 2014); however for the trapping undertaken to fit and retrieve radio-collars, the trapping intensity varied depending on the quoll trap success rates. During the course of this study, it was determined that trapping effort for the monitoring phase of this project (2015-2019) could be reduced to 20 traps at 25 m spacing at each site, instead of 50 traps at 50m spacing, as currently used in the regional quoll monitoring program. At Yarraloola quolls were at low densities and this reduced trapping effort was shown to be as effective at trapping all the quolls in the immediate area, but with less effort. Traps were placed in sheltered, shady locations and covered with a hessian bag for protection of any trapped animals from

the heat. Trap lines ran along rocky breakaways and mesas, as well as in and around gorges where quolls were known (based on preliminary surveys), or thought likely to occur. All trapped quolls were weighed, measured and sexed, and a small tissue sample taken from each ear for DNA analysis. Each animal was individually marked with a passive implant transponder (PIT) tag inserted subcutaneously between the shoulder blades. Other species captured were also recorded and tissue samples taken. All trapping data were entered into an MS Excel spreadsheet and later an MS Access database.

Adult quolls weighing between 300 and 790 g were fitted with VHF neck-mounted radio-transmitters equipped with mortality mode (Sirtrack, Havelock North, NZ; 12-13 g) (Table 4). These radio-collars were initially tasked with operating only during daylight hours to prolong battery life to six months. Night time operation was later invoked by delaying radio-collar start times by up to three hours as radio-tracking at night when quolls were active was found to be more efficient. Ten females and 11 males at Yarraloola, and 10 females and 10 males at Red Hill were fitted with radio-collars and released at their site of capture at least 15 days prior to the baiting at Yarraloola (Table 3). Quolls were re-trapped between August and October to remove radio-collars. Trapping in September/October was also used to assess whether breeding was occurring (presence and persistence of pouch young), and was also undertaken as the initial baseline monitoring session for quolls. Additional trapping was periodically undertaken post-baiting to attempt to confirm the survival of individuals when radio-tracking had been unsuccessful.

Ground and aerial radio-tracking was undertaken in the four week period prior to cat baiting and during the twelve week period post-cat baiting to determine survivorship of the radio-collared quolls (Table 2). If dead quolls were detected through the mortality signal, carcasses were retrieved where possible and examined to determine cause of death. In particular, remains were examined closely for the presence of the RhB biomarker. If predation was thought to be the cause of death, the retrieved radio-collars were placed in plastic bags and kept in a freezer prior to DNA analysis (Helix Molecular Solutions, The University of Western Australia) to determine the most likely predator responsible for death (Berry *et al.* 2012). Radio-tracked quolls also provided information on habitat usage, home range and movement areas. Home range was estimated using the convex hull method (Worton 1995).

A 6 x 6 grid of digital infrared camera traps (Reconyx Hyperfire PC900) was set at 400m x 300m spacing to trial this non-invasive methodology for monitoring the impact of cat baiting on northern quolls. Each camera was attached to a peg and set approximately 40cm above the ground. A non-reward food lure (peanut butter, sardines and oats) was placed 2m in front of the camera. Lures were activated when the cameras were set up, and reinvigorated immediately after cat baiting on 6 July 2015. Cameras were operated for 13 days before baiting, and 15 days after baiting. Images were downloaded just prior to baiting occurring, and again when the cameras were collected at the end of the camera trial. Images were sorted by species, and the number of quoll detections recorded. A change in the camera detection rate of quolls before and after baiting may provide an immediate indication of quoll response to the baiting. The location of the camera grid in relation to the trial cat baiting cell is shown in Figure 4. The GPS locations of the camera grid corners were: NW 116.14175, -21.78305; SW 116.14167, -21.79660; SE 116.16101, -21.79670; and NE 116.16109, -21.78315.

4.3 Northern quoll bait uptake

All northern quolls trapped, and those recovered dead, at Yarraloola after the cat baiting on 6 July were examined for purple / pink signs of the biomarker RhB. In particular, the mouth and lips were closely inspected. Scats from trap captures were also examined for any purple / pink colouration.

The baiting coordinates recorded from the baiting aircraft were overlaid with movement areas of the radio-collared quolls to determine whether quolls would have had the opportunity to encounter cat baits (Figures 5, 6).

4.4 Northern quoll Population Viability Analysis (PVA)

Prior to the baiting program, Program VORTEX was used to predict the risk of northern quoll population decline and extinction and this allowed an understanding of what level of quoll mortality could be tolerated before the population declined. Empirical data such as demographic structure, mortality and survival rates and reproductive rates were obtained from the Pilbara regional quoll monitoring program (Dunlop *pers com.*) and from published northern quoll demographic studies across Australia (e.g. Braithwaite and Griffiths 1994, Oakwood 2000). The risk of the cat baiting to the survival of the northern quoll population was determined by examining quoll population trends provided by the PVA under certain mortality scenarios. Six scenarios were simulated:

1. No cat baiting (baseline or current scenario).
2. Increase initial population size of northern quoll – resident population sizes of 40, 60 and 80 were modelled.
3. Impact of cat bait-related mortality on adult northern quoll – adult mortality rates of 5%, 10%, 15% and 20% were modelled.
4. Impact of cat bait-related mortality on juvenile northern quoll – juvenile mortalities of 5%, 10%, 15% and 20% were modelled.
5. Increased adult survivorship as a result of reduced cat predation (due to baiting) – adult mortality rates decreased by 5%, 10%, 15% and 20% were modelled.
6. Increased juvenile survivorship as a result of reduced cat predation (due to baiting) – juvenile mortality rates decreased by 5%, 10%, 15% and 20% were modelled.

5 Results

5.1 Cat baiting

The feral cat baiting program occurred as scheduled on 6 July, 2015 and all baits were delivered as planned. A total of 9,750 *Eradicat*® baits were delivered at an application rate of 48.75 baits/km^2, slightly less than the prescribed 50 baits/km^2. A plan showing where baits were dropped from the aircraft is shown in Figure 3.

5.2 Northern quoll survivorship

At Yarraloola, trapping for northern quolls suitable to fit radio-collars was undertaken from 20 May to 25 June. A total of 1860 trap nights occurred across 21 sites with 166 quoll captures (8.9% trap success rate) of 39 (18 females, 21 males) individuals. Ten females and 11 males were selected and fitted with a radio-collar. A minimum bodyweight of 300g was selected so that the radio-collar weight was no more than 3-5% of the body weight (Table 3). Two of the radio-collared quolls (one male, one female) died prior to the baiting. Both deaths were believed to be from feral cat predations. At Red

Hill, there were 137 captures of 39 (17 females, 22 males) individuals in 1739 trap nights (7.9% trap success rate) across 12 sites. Ten females and 10 males were selected and fitted with radio-collars (Table 3).

Body weights of males were significantly higher than females at both sites (Table 5) and within the range of body weights recorded for other Pilbara northern quoll populations (for example, Dunlop *et al.* 2015). Male body weights were lower at both sites in October compared to May, most likely due to a loss of condition just prior to the annual male die off, a demographic characteristic of this species (Oakwood *et al.* 2000). This difference was significant only for the Yarraloola males ($t_{(7)} = 4.36$, $p = 0.003$).

Reproductive success was assessed through the production of pouch young in female quolls. Pouch young first appeared in late August at Yarraloola and early September at Red Hill. At Yarraloola, 18 female quolls were trapped from early August to October. Fourteen of these had pouch young and the average litter size was 6.8 $\pm$ 0.3 (s.e.) pouch young. In the same period, 13 female quolls were trapped at Red Hill and nine of these had pouch young. The average litter size at Red Hill was 5.3 $\pm$ 0.5 (s.e.) pouch young and this was significantly less than the average litter size at Yarraloola ($t_{19} = 2.44$, $p = 0.029$).

At the time of baiting, nine female and 10 male northern quolls with radio-collars were known to be alive at Yarraloola, and all 20 collared quolls were alive at Red Hill. After baiting at Yarraloola, in the period July - October another three collared (two females, one male) quolls died, two were confirmed to be due to cat predation from DNA analyses and one was believed to be a cat predation based on teeth marks on the collar (but no DNA evidence). At Red Hill, five of the 20 radio-collared quolls are known to have died; two of these due to cat predation and two were due to canid predation. The DNA on another of the retrieved collars, which was suspected to be a predation, was too weak to amplify to get any confirmed predator results. The radio-collars of another two quolls went into mortality mode and may have died, however the radio-collars and / or quolls (alive or dead) were not recovered (Tables 1, 2).

Northern quolls, including those fitted with radio-transmitters were regularly detected on the camera grid prior to cat baiting at Yarraloola (Figure 5). However, following baiting, no quolls were detected, despite the continued known persistence of the radio-collared quolls in this area. This anomaly is believed to be due to the use of a non-reward lure and that the quolls no longer came within range of the cameras once they learnt that a food reward was not available. The value of using remote camera arrays for monitoring quolls will be discussed in the report on the baseline monitoring currently in preparation.

5.3 Northern quoll bait uptake

There were 108 captures of 30 individual quolls (17 males, 13 females) at Yarraloola after the baiting, between July and October. These captures included radio-collared and new, un-collared quolls. All were inspected for evidence of cat bait ingestion by searching for purple / pink colouration (consistent with RhB exposure) around the mouth and lips, and in scats found in traps. No such evidence was observed, and none showed any sign of 1080 poisoning.

Male quolls at Yarraloola and Red Hill exhibited significantly larger mean home range areas and longer linear movements than females (Table 5). At Yarraloola, male home ranges overlapped with an average of 8.5 $\pm$ 1.8 (s.e.) baiting locations and male quolls would most likely have been exposed

to many cat baits as they moved around their home ranges (Figure 6). Females had significantly smaller home ranges and shorter linear movements and on average only intersected 0.6 ± 0.2 (s.e.) baiting locations. However, the average linear movement for females at Yarraloola was 1031 m, greater than the one kilometer baiting interval and at least 50 % of the females where home ranges were calculated (YF02, YF03, YF09 and YF12) were most likely to have been exposed to some bait drop sites (Figure 7). Only one of these (YF12) died during this trial, and this was most likely due to cat predation, although this was not confirmed by DNA analysis. At Yarraloola, male home ranges were estimated from an average of 15 radio-fixes per quoll, and female home ranges were estimated from an average of 13 radio-fixes per quoll.

5.4 Northern Quoll Population Viability Analysis

The results of the PVA were prepared in a separate report (Moro 2015). In summary, in the absence of cat baiting (current situation), northern quolls persist but there is a small but steady decline in population over time (up to 10% population decline in 20 years). Improving adult or juvenile survivorship above current levels (i.e. reducing mortalities due to cat predation) improved numbers in the population over 20 years, reducing the risk of a local extinction event. Simulations were most sensitive to perturbations in adult mortality above 10% or juvenile mortality above 5% of current (baseline) levels, leading to dramatic declines in the numbers of quoll in an area. Importantly, improved juvenile survivorship above current levels (for example, due to reduced predation by feral cats) reduces the risks of decline in the quoll population by up to 54%.

6 Discussion

This study has been the first to examine the potential impact of using *Eradicat*® cat baits on the survivorship of northern quolls in the Pilbara region of Western Australia, or elsewhere. It has also identified the level of impact that feral cat predation has on a northern quoll population and highlighted the importance of managing feral cats in the Pilbara to prevent further threatened fauna declines. In doing so, it has contributed significantly to achieving some of the objectives of the national recovery plan for the northern quoll (Hill and Ward 2010).

Despite potential exposure to aerially distributed toxic *Eradicat*® cat baits deployed following the Parks and Wildlife cat baiting prescription, there was no evidence that quolls consumed baits, or died as a result of the trial baiting program. Previous studies have predicted that northern quolls would be at risk if they ingested 1080 baits (Calver *et al*. 1989, King *et al*. 1989), and the lack of deaths attributed to bait ingestion at Yarraloola suggests that quolls did not ingest any cat baits they may have encountered. The same numbers of confirmed quoll deaths were recorded at both Yarraloola and the un-baited site at Red Hill, all due to predation by either feral cats or canids. The closely related chuditch, or western quoll (*Dasyurus geoffroii*) was also considered to be at risk from 1080 baiting programs in the south-west of WA (King *et al.* 1989, Soderquist and Serena 1993). However, subsequent field trials using toxic fox baits were shown to benefit chuditch populations rather than pose a risk to them (Morris *et al.* 2003).

Sub-lethal doses of 1080 can still be harmful to populations. Toxins passed through milk can kill the pouch young of northern quolls, as well as other marsupials such as tammar wallabies and brushtail possums (McIlroy 1981). Sub-lethal doses of 1080 can also potentially cause sterility in males as has been demonstrated in rats (Sullivan *et al.* 1979). The litter size for quolls at Yarraloola where 1080 cat baiting had occurred was not significantly different to that recorded for quolls at Kakadu, Northern Territory (7.3 ± 0.3 py/female; Oakwood 2000) and it is unlikely that sub-lethal ingestion of 1080 impacted on litter size during this study.

We now have available empirical data from this study site on the cat / canid predation rate on northern quolls. At least 20% of the radio-collared quoll were predated by either feral cats or canids over a period of six months, and this was the most significant cause of mortality for the radio-collared adult quolls. While this mortality rate was slightly less than that modelled in the PVA (Scenario 1, annual adult mortality between 56% for females and 98% for males) the modelled data considered all types of mortality (including natural deaths and predation from native predators). Therefore, any reduction to the loss of adults and / or juveniles in the local population will improve numbers over time and reduce the risk of local extinction (Moro 2015). Feral cat predation was a significant part of this mortality, highlighting the value of implementing landscape scale feral cat control programs in the Pilbara. Ongoing canid control would probably also benefit quolls in this situation.

Many of the dead quolls were recovered from drainage lines suggesting that quolls face considerable predation risk when they use these corridors to traverse open landscapes between rocky areas. In the rangelands at Matuwa (Lorna Glen) preliminary observations from a GPS radio-collar trial show that dingoes do use drainage lines, and that there is some spatial separation of dingo and cat activity in this area (M. Wysong *pers com*).

It is possible that cane toads will penetrate into the Pilbara from the Kimberley using artificial water points and permanent water holes to access a largely waterless landscape (Tingley *et al.* 2012). Flooding due to cyclonic rainfall could exacerbate the spread of cane toads into the Pilbara. Additional mortality, over and above that currently occurring at Yarraloola primarily due to cat and canid predation, particularly to the juvenile age cohort, is possible in the future if cane toads become established in and near river systems such as the Robe River. This suggests that where the cause of mortality can be managed such as by effective feral cat control, this should be undertaken to ensure the longer term conservation of northern quolls in the Pilbara.

This study has identified some issues with the effectiveness of the aerial VHF radio-tracking operations in iron-rich, rocky environments such as at Yarraloola and Red Hill. This was due initially to the receiver equipment on the aircraft not operating at maximum efficiency and requiring further checking. There were also issues with receiving signals from quolls located in day-time refuges within rock piles and mesas. Signals were often weak, intermittent, highly directional and exceptionally short range, making it difficult to accurately locate quolls, particularly during the day. However, the aerial radio-tracking did allow several of the quolls, particularly males, to be located after they had travelled several kilometres from their last known locations, and outside the range of hand-held aerials. In the later stages of the program, ground radio-tracking was hampered by the loss of most of the whip aerials fitted to the neck-mounted transmitters. This was most likely due to quolls pushing between rocks when moving to and from day-time refuges, and continually flexing the base of the whip aerial. The effectiveness of radio-tracking from the ground improved once night time operations were undertaken.

With the demonstration that GPS telemetry can be used on northern quolls in the Pilbara (Henderson 2015), it is recommended that a research study using this technology, instead of VHF telemetry, would provide better information on the temporal and spatial use of habitat by both northern quolls and feral cats and allow an assessment of the extent to which they may overlap and encounter each other. If undertaken before and after a cat baiting program it would also provide additional evidence for the effectiveness of Eradicat® baiting to reduce cat abundance in the Pilbara, and impact, if any, on the northern quoll population.

The results of this study indicated that using *Eradicat*® baits in the cooler, drier months to reduce cat abundance at a landscape scale should not pose a risk to northern quoll populations, and that this management action would likely benefit them and other threatened fauna in the Pilbara. It is recommended that any further *Eradicat*® baiting at landscape scales in areas where northern quolls are known to exist adopt an adaptive management approach and monitor both northern quoll and feral cat abundances. This monitoring for quolls should include a regular trapping program with the power to detect significant changes in quoll abundances and the use of the RhB biomarker to assess any bait uptake. The use of a biomarker to detect bait ingestion would be particularly important if baiting was undertaken at any other time of the year when non-target species may be more active, or at a time when young northern quolls may be exposed to toxic baits.

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Tables

	Apr	May	Jun	Jul	Aug	Sep	Oct
PILBARA							
No development							
Pouch developed							
Pouch young present							
Teats regressed							
NORTHERN TERRITORY							
No development							
Pouch developed							
Pouch young present							
Teats regressed							

Table 1. Recorded times of breeding for female Pilbara and Northern Territory northern quolls. (Pilbara data sourced from Dunlop *pers com*, Northern Territory data sourced from Begg 1981)

Field Trip #	Date(s)	Field Activity
1	18 May – 5 June	Northern quoll trapping at Yarraloola and Red Hill to fit radio-collars.
	14 June	Fit and tested aircraft tracking aerials on C172
	22 June	Aerial radio-tracking at Red Hill and Yarraloola.
2	13 – 26 June	Ground radio-tracking at Yarraloola and Red Hill: pre-bait monitoring. Set up quoll monitoring camera grid at Yarraloola.
	6 July	Aerial cat baiting at Yarraloola.
	6 - 7 July	Aerial radio-tracking at Red Hill and Yarraloola.
	13 - 14 July	Aerial radio-tracking at Red Hill and Yarraloola.
3	6 - 19 July	Ground radio-tracking at Yarraloola and Red Hill; post-bait monitoring. Close down quoll monitoring camera grid at Yarraloola.
4	27 July – 7 August	Ground radio-tracking at Yarraloola and Red Hill; post-bait monitoring.
	28 – 29 July	Aerial radio-tracking at Yarraloola and Red Hill. Final aerial tracking.
5	17 – 28 August	Ground radio-tracking at Yarraloola and Red Hill; post-bait monitoring. Trapping to commence removal of male radio-collars. Quoll baseline monitoring.
6	7 – 18 September	Ground radio-tracking at Yarraloola and Red Hill; post-bait monitoring, trapping to remove male radio-collars.
7	5 – 16 October	Ground radio-tracking at Yarraloola and Red Hill; post-bait monitoring, trapping to remove female radio-collars. Final field trip, return field equipment to Perth.

Table 2. Dates of field activity at Yarraloola and Red Hill.

	Yarraloola (cat baited)		Red Hill (unbaited)	
	Males	**Females**	**Males**	**Females**
# quolls trapped	21	18	22	17
# fitted with radio-collar	11	10	10	10
# confirmed dead	2	3	2	3
Cat predation	2	2	1	1
Canid predation	0	0	1	1
Unconfirmed cause of death	0	1*	0	1*
Carcass not recovered	0	0	1	1
# collars removed	10	10	8	10

Table 3. Number of northern quolls trapped, fitted with radio-collars and their survivorship: June – October 2015. (* insufficient DNA, but believed to be a cat predation from teeth marks on collar)

Quoll ID (Y = Yarraloola, R = Red Hill, M = male, F = female)	Body Weight (g)	Date fitted with radio-collar	Date recorded dead	Cause of death	# days post-bait	Date radio-collar removed
YM04	790	27/05/15				23/08/2015
YM05	630	29/05/15				25/08/2015
YM06	510	29/05/15				22/08/2015
YM07	715	01/06/15				21/08/2015
YM08	690	02/06/15				23/08/2015
YM11	580	14/06/15	28/07/2015	Cat predation	22	
YM13	715	18/06/15				23/08/2015
YM14	685	18/06/15				16/10/2015
YM15	705	19/06/15	last alive date 03/08/15	Fate unknown, collar not retrieved	ca. 43	.
YM16	630	22/06/15	6/07/2015	Cat predation	0	
YM17	788	23/06/15				25/08/2015
YF01	310	20/05/15	18/06/2015	Cat predation	Died before baiting	
YF02	590	25/05/15				14/10/2015
YF03	270	27/05/15				8/10/2015
YF09	300	03/06/15				25/08/2015
YF10	350	04/06/15				10/10/2015
YF12	408	14/06/15	17/09/2015	Assumed cat predation, no DNA analysis	74	
YF18	310	23/06/15				7/10/2015
YF19	320	24/06/15				7/10/2015
YF20	395	24/06/15	8/07/2015	Cat predation	2	
YF21	340	25/06/15				11/10/2015
RM01	620	20/05/15	20/08/2015	Fate unknown, collar not retrieved		
RM02	640	20/05/15				9/09/2015
RM08	550	27/05/15				24/08/2015
RM09	440	29/05/15		Fate unknown, collar not retrieved		
RM11	925	29/05/15	10/09/2015	Canid predation		
RM12	685	29/05/15		Fate unknown, collar not		

				retrieved		
RM14	695	31/05/15				24/08/2015
RM16	595	31/05/15	5/08/2015	Assumed cat predation, no DNA analysis		
RM18	725	02/06/15				22/08/2015
RM20	540	04/06/15				20/08/2015
RF03	340	22/05/15				9/09/2015
RF04	490	19/05/15	9/09/2015	Cat predation		
RF05	310	25/05/15	2/06/2015	Fate unknown, collar not retrieved		
RF06	470	25/05/15				9/09/2015
RF07	350	27/05/15	3/06/2015	Cat predation		
RF10	300	29/05/15				17/09/2015
RF13	390	30/05/15				14/09/2015
RF15	320	31/05/15				14/09/2015
RF17	330	31/05/15				8/10/2015
RF19	576	03/06/15	8/07/2015	Canid predation		

Table 4. Timelines for the fitting of radio-collars on northern quolls at Yarraloola and Red Hill, and their fate.

	Yarraloola		Red Hill	
	Males (n = 8) (mean ± SE)	**Females (n = 7) (mean + SE)**	**Males (n = 6) (mean + SE)**	**Females (n = 9) (mean + SE)**
Pre-bait: May 2015 (g)	690.4 ± 31.9	342.8 ± 44.5	628.3 ± 27.8	365.0 ± 21.0
Post-bait: October 2015 (g)	567.6 ± 28.1	352.0 ± 23.1	604.2 ± 46.2	363.3 ± 18.1

Table 5. Body weights of radio-collared northern quolls at Yarraloola and Red Hill.

	Yarraloola		Red Hill	
	Males (mean ± SE)	**Females (mean ± SE)**	**Males (mean ± SE)**	**Females (mean ± SE)**
Home range (ha)	931.1 ± 259.9	32.5 ± 10.7	301.4 ± 108.9	13.8 ± 6.6
Linear movements (m)	6689.3 ± 1833.7	1031.4 ± 136.1	3330.0 ± 613.2	844.4 ± 132.5

Table 6. Home range size (convex hull) and linear movement lengths for northern quolls at Yarraloola and Red Hill.

Figures

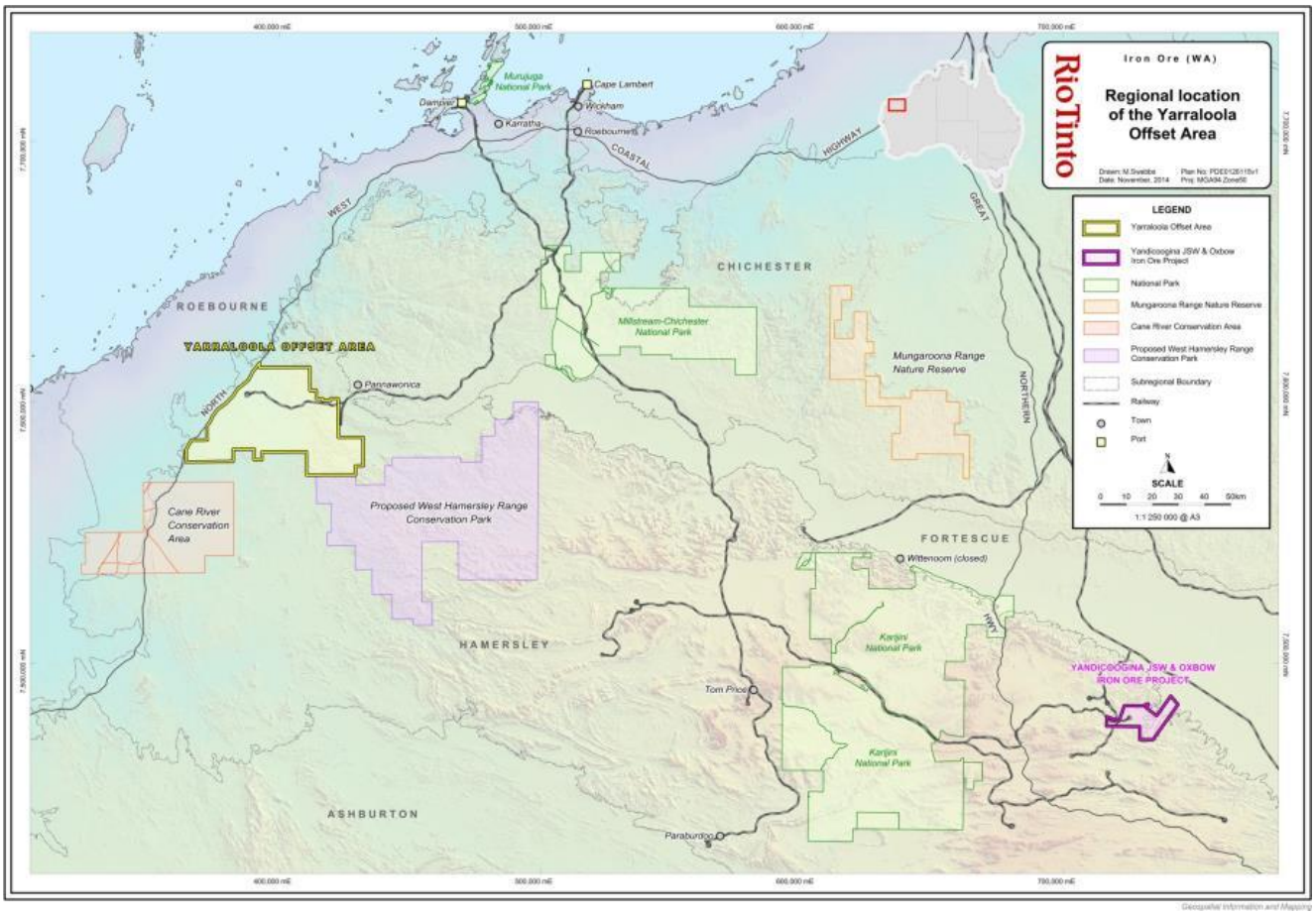

Figure 1. Regional location of the Yarraloola Land Management Area (LMA) in the west Pilbara region of Western Australia.

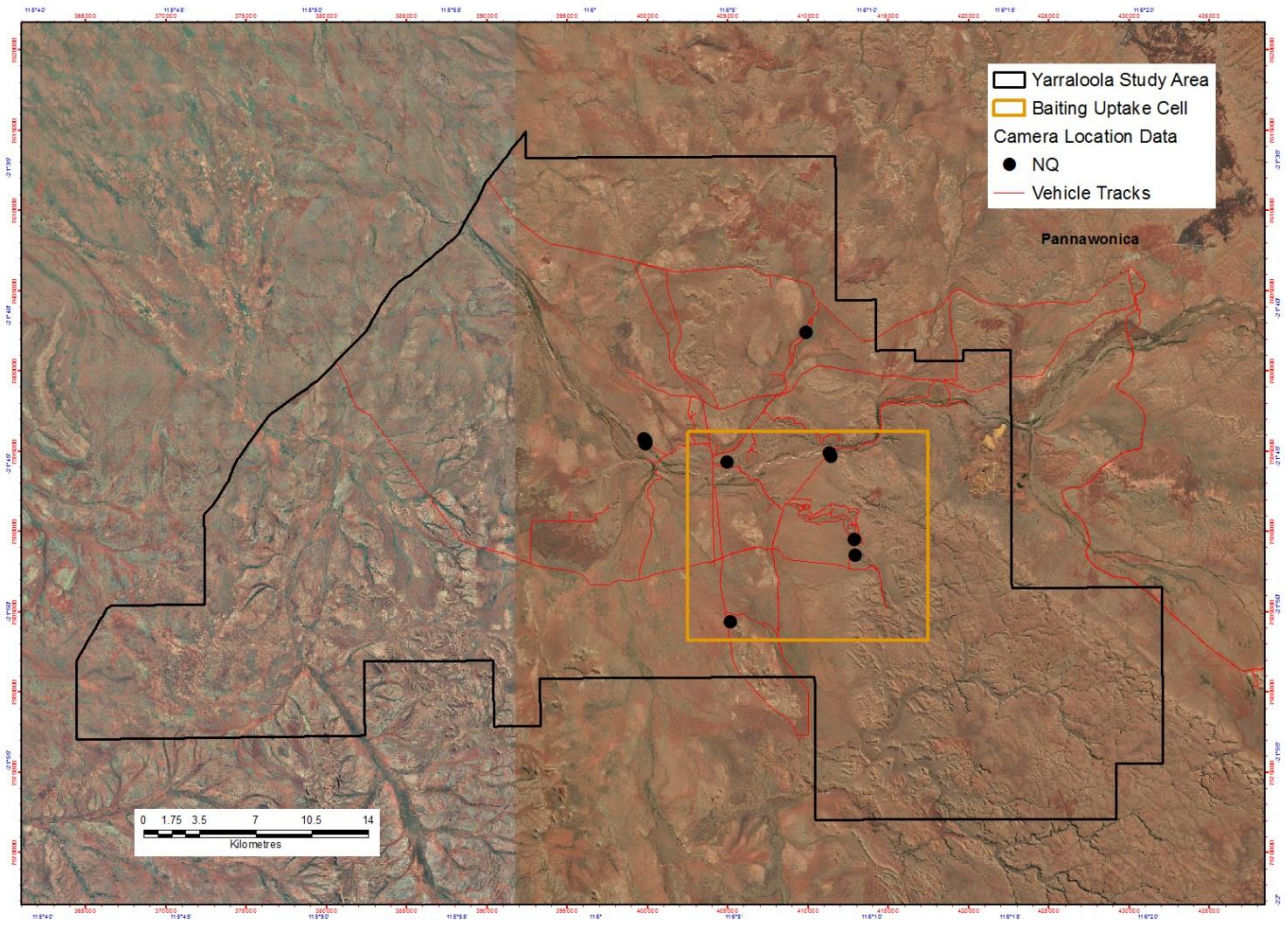

Figure 2. Location of the trial cat baiting cell (20,000 ha) within the Yarraloola LMA.

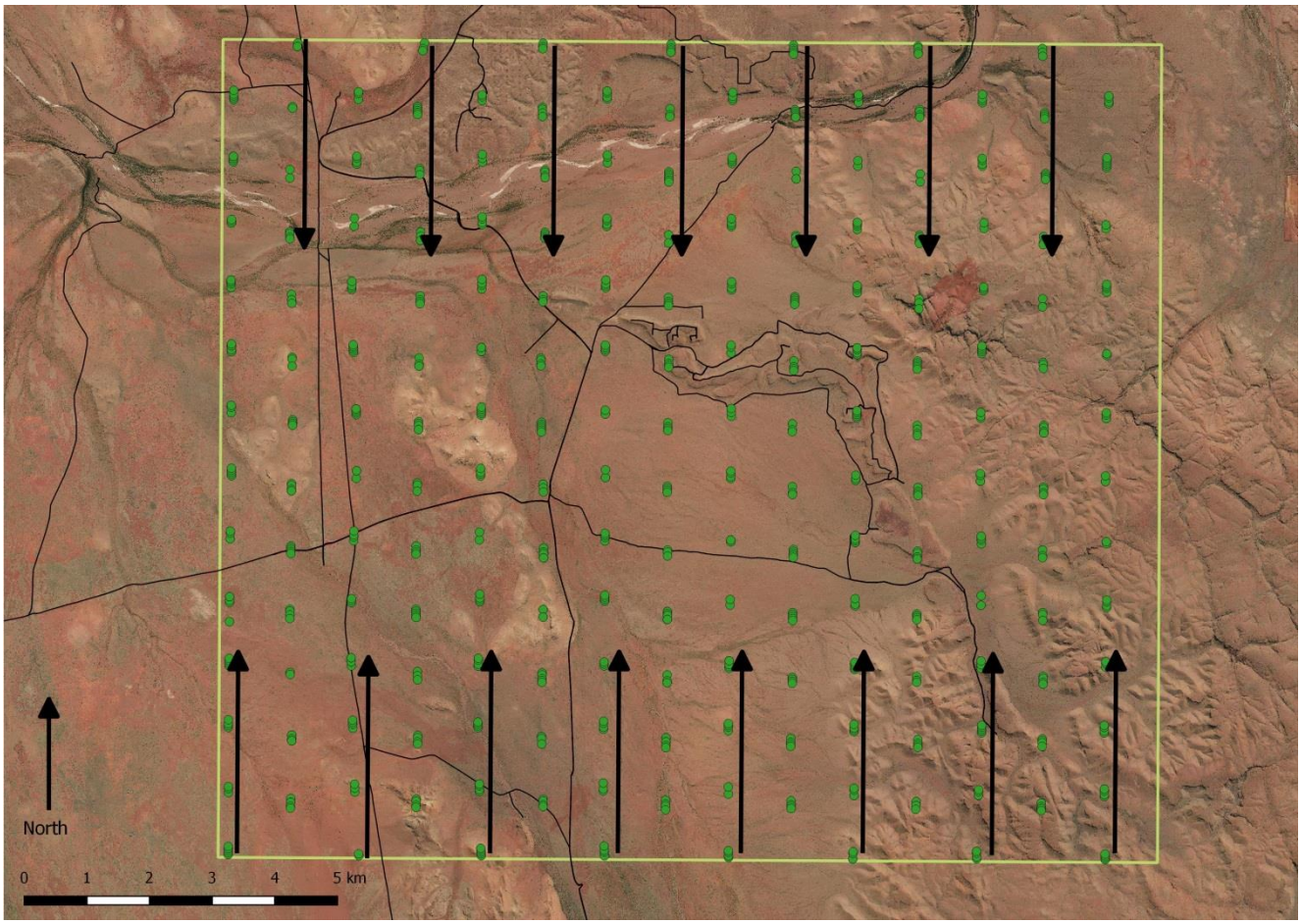

Figure 3. Locations of where *Eradicat*® baits were dropped from an aircraft over the trial cat bait site at the Yarraloola LMA, July 2015. Fifty baits were dropped from 500 feet a.g.l at each of the clumped green dots. Arrows indicate the flight direction of the baiting aircraft.

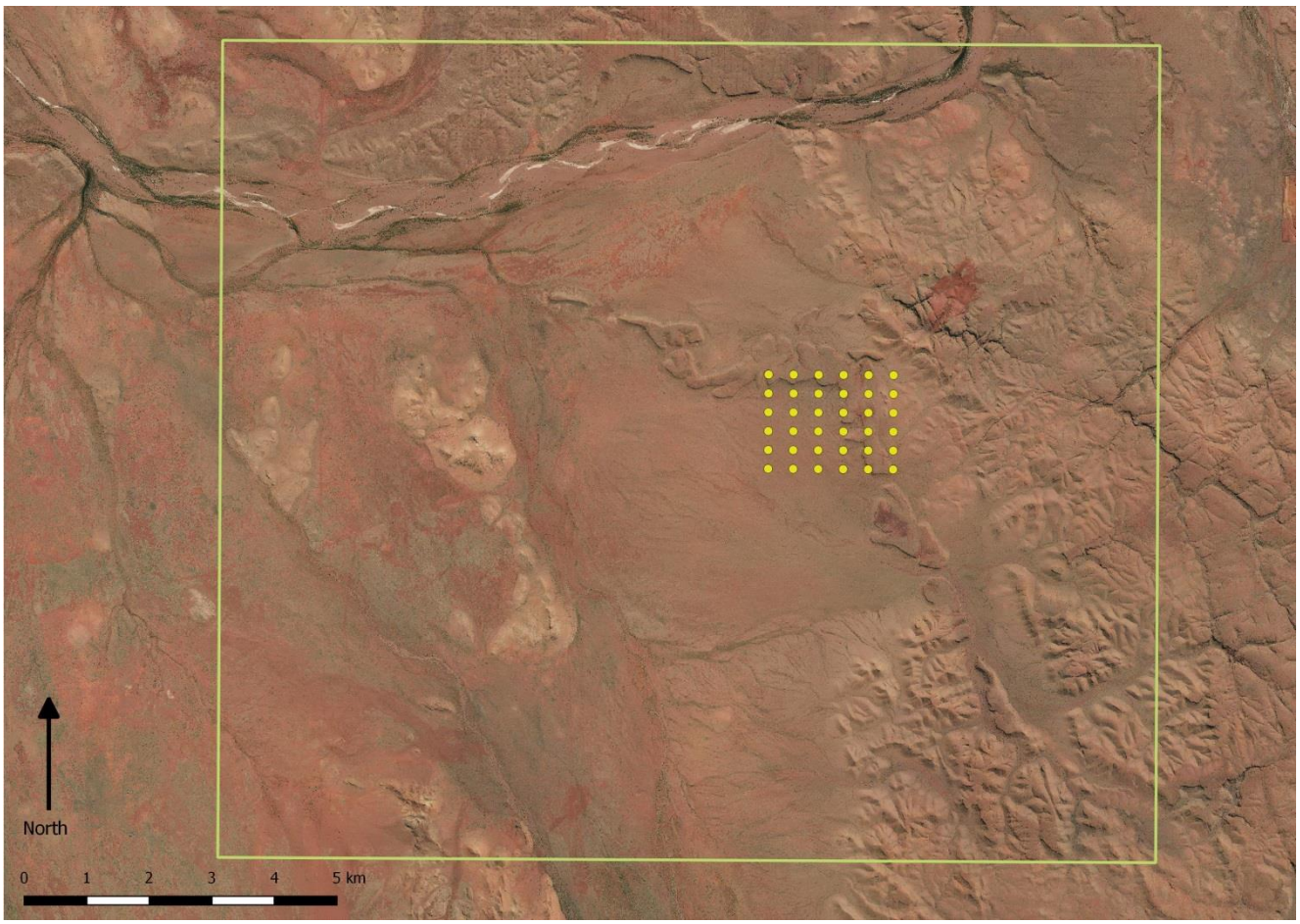

Figure 4. Location of 6 x 6 remote camera grid within the trial cat baited area in the Yarraloola LMA.

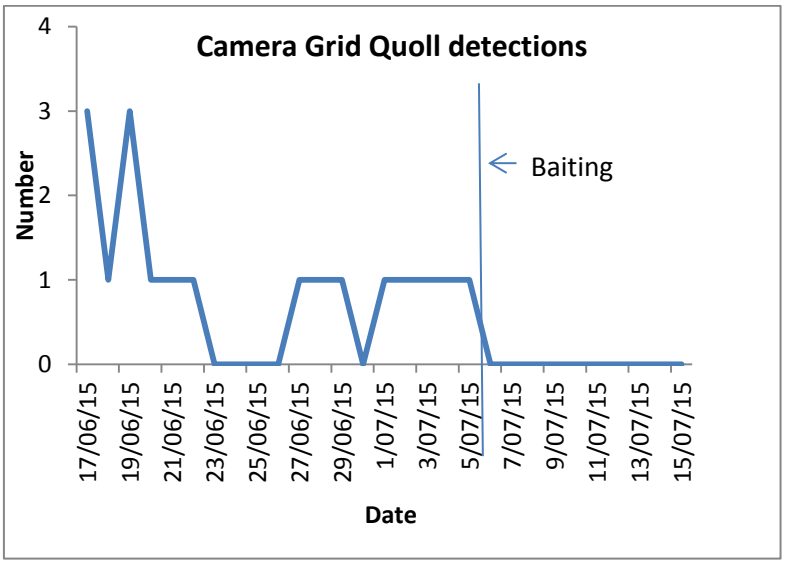

Figure 5. Number of northern quolls detected by remote cameras before and after cat baiting at Yarraloola.

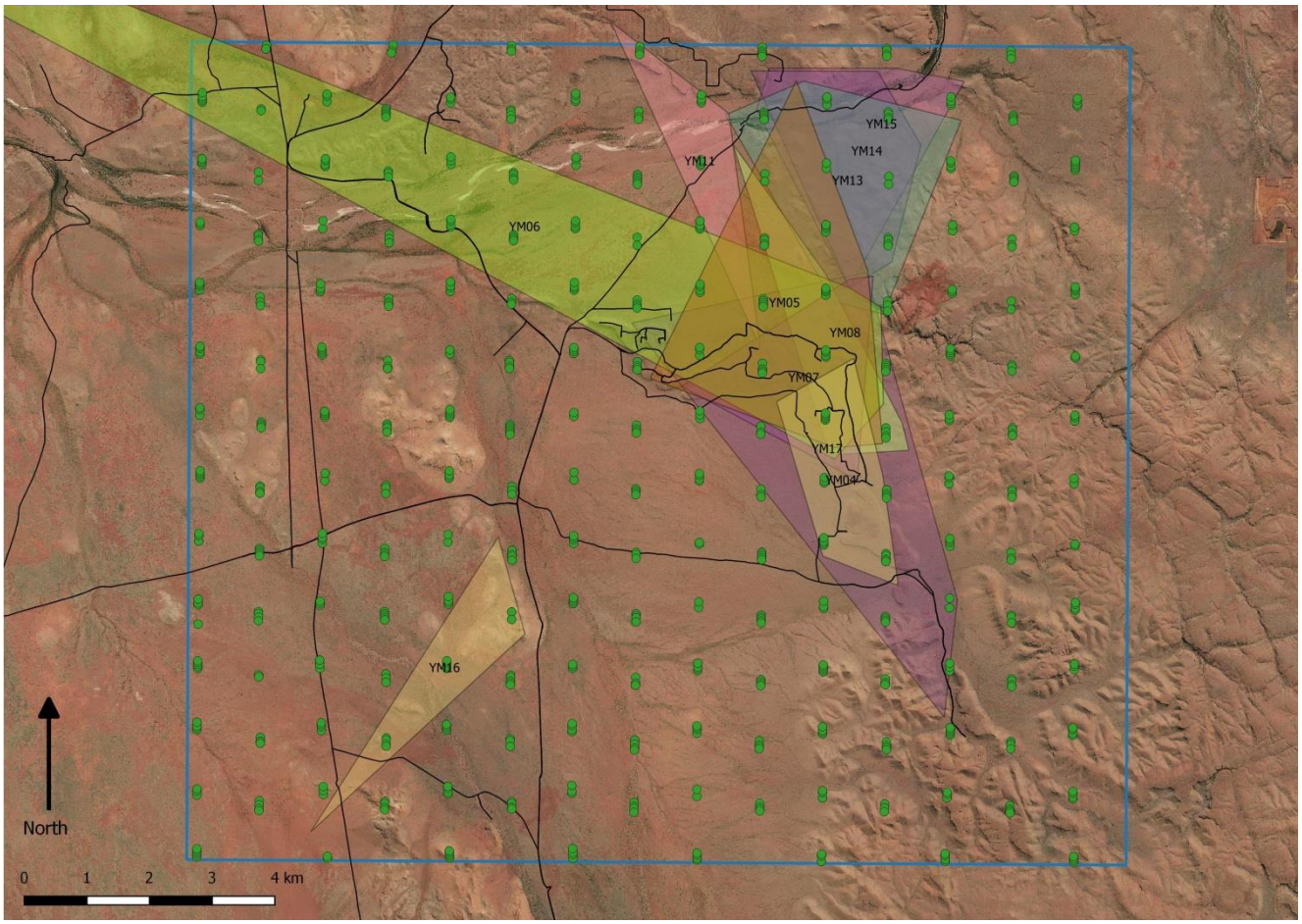

Figure 6. Home range movements of male northern quolls at Yarraloola in relation to the cat bait drop sites.

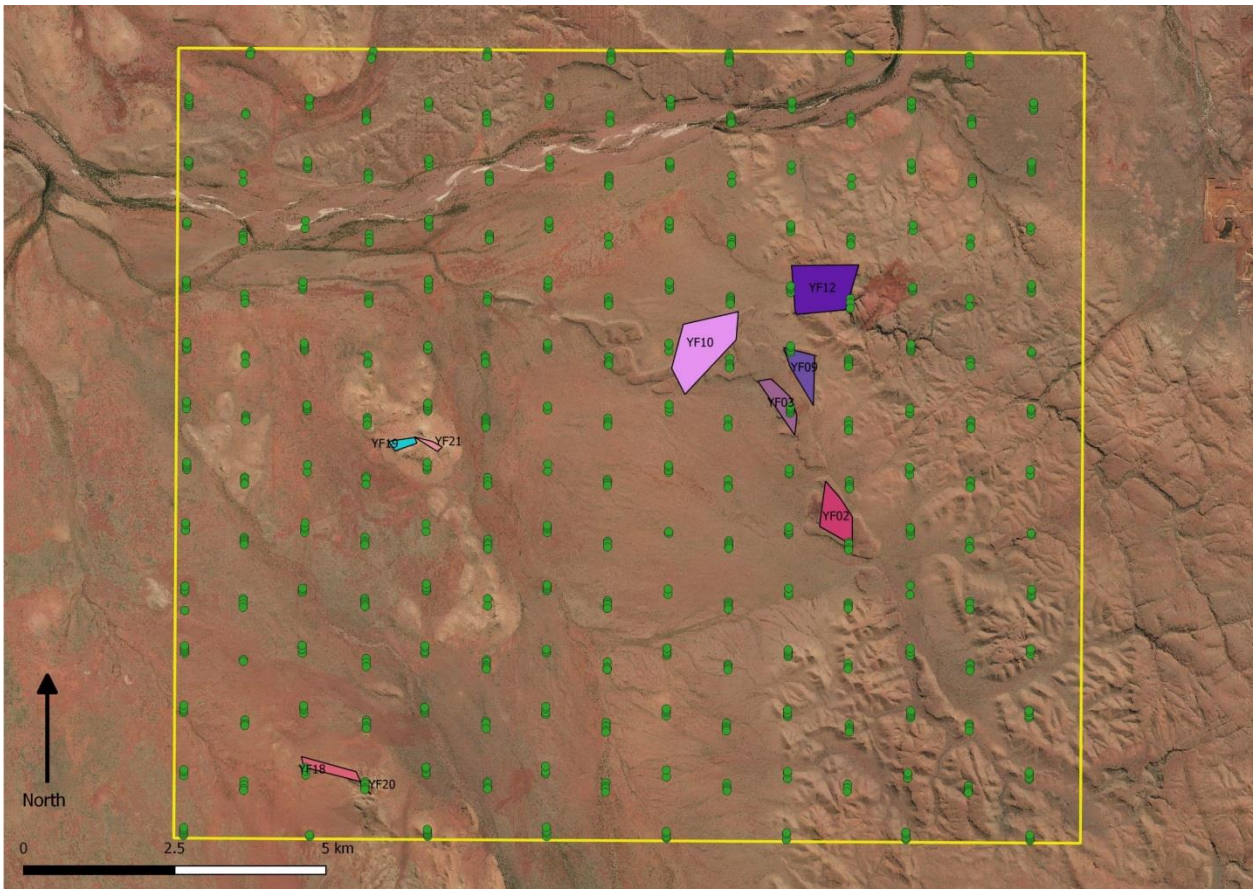

Figure 7. Home range movements of female northern quolls at Yarraloola in relation to cat bait drop sites.