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Annual report 2017

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Pilbara Northern Quoll Research Program

2017 Annual Report

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April 2018

GOVERNMENT OF WESTERN AUSTRALIA

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Cover image: KJ Martu Rangers searching for sign of northern quolls in Karlamilyi National Park.
Image credit: Judy Dunlop

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Summary

Pilbara northern quolls have high conservation priority due to their separation from other northern populations, distinct genetics, occupancy of a unique habitat niche and are exposed to different threatening processes to other northern quoll populations across Australia. Northern quolls are listed as Endangered under the *EPBC Act* and IUCN Red List, and Specially Protected Fauna in Western Australia under the Wildlife Conservation (Specially Protected Fauna) Notice 2016 (EPBC, 1999; The IUCN Red List of Threatened Species, 2016). A research plan guiding the implementation of priority future actions for the northern quoll in the Pilbara was developed in 2010 and updated in 2013, following consultation between industry, researchers, and state and federal government agencies (McGrath and van Leeuwen, 2011). The Western Australian Department of Biodiversity, Conservation and Attractions (DBCA) has been undertaking research on Pilbara northern quolls as per the key directions determined by the research plan, and at a follow-up workshop held by the DBCA in 2013 (Cramer *et al.*, 2016). This progress update is structured against the themes of the five key research priorities for northern quoll in the Pilbara determined at this workshop.

This document reports on progress of the Pilbara northern quoll research program during 2017 including the fourth year of annual monitoring. To date, the Pilbara Northern Quoll research project has made substantial gains in understanding the status and ecology of this species in the Pilbara region. This project has greatly enhanced the species records available on NatureMap, through searches for northern quolls in previously unsurveyed areas, and collating additional records from the grey literature. We have used this enhanced spatial dataset to provide the most accurate species distribution model available for the species (Molloy *et al.*, 2017). Dietary analysis of northern quolls across the Pilbara region revealed a flexible, opportunistic omnivorous habit, including 23 vertebrate species and a surprising level of vegetation intake (Dunlop *et al.*, 2017). Sequencing has been completed for approximately 1800 tissue samples collected as part of this project to answer questions about patterns of dispersal, relatedness and life history. Female quolls were found to have very high levels of promiscuity, with pouch young having up to eight fathers within a litter of eight (Chan, 2017). Female northern quolls from island populations are exerting sexual selection pressure on males, and preferentially breeding with smaller males (Chan, 2017). A significant volume of presence records collected via camera and cage trapping is being analysed for detection probabilities and assessment of the efficacy of northern quoll survey methods. We have successfully trialled downward-facing cameras for the purpose of individual identification and population estimation. Currently, a key priority is to examine the impact introduced predators (including feral cats, red foxes and wild dogs) have on northern quoll population densities and habitat use.

Introduction

Once common across the majority of northern Australia, northern quolls (*Dasyurus hallucatus*) have suffered significant range contractions and population fragmentation since European settlement (Braithwaite and Griffiths, 1994; Hill and Ward, 2010). Northern quolls inhabit complex rocky habitats, including ranges, escarpments, gorges and boulder fields, and utilise trees and hollows along major drainage and creek lines (Woinarski *et al.*, 2014). Threats to this small (240–1120g; Oakwood, 2008), omnivorous marsupial include predation by feral cats (*Felis catus*) and the red fox (*Vulpes vulpes*), habitat loss or fragmentation through altered fire regimes, overgrazing, weed invasion and mining and infrastructure developments (Woinarski *et al.*, 2014). The primary cause of decline in this species across northern Australia has been death from predation attempts on the toxic introduced cane toad (*Rhinella marina*), resulting in complete collapse of some northern quoll populations in Queensland and the Northern Territory. Cane toads have not yet reached the Pilbara, but are projected to naturally colonise the Pilbara mainland (and potentially its offshore islands) between 2026–2064 (Kearney *et al.*, 2008; Tingley *et al.*, 2013).

Eradication of cane toads appears to be unfeasible, and prevention of their continued colonisation of suitable country unlikely. This has driven the need to look at novel approaches of manipulating vulnerable taxa's behavior in an effort to increase their resilience to the cane toad invasion (Cremona *et al.*, 2017b; Jolly *et al.*, 2017). The northern quoll has shown the ability to survive a toad invasion, as evidenced by some remnant populations persisting in toad-infested areas. Northern quolls co-existing with cane toads do not show an increase in resistance to the toad's toxin, thereby inferring that individuals have adapted their behaviour to avoid toads and become 'toad smart' (Kelly and Phillips, 2017).

Conditioned taste aversion (CTA) training on quolls (using a thiabendazole-laced sausage or non-lethal juvenile toad) has been shown to enhance this behaviour change prior to the arrival of live toads, allowing for long term female survival who have been able to successfully breed young with toad aversion behaviour (Cremona *et al.*, 2017a). Trials have shown that using a thiabendazole-laced sausage bait can change quoll behaviour, with results determining that sausage treated individuals spend significantly less time interacting with toads.An estimated 41-68% of quolls consumed a bait in the field and were successfully trained to avoid cane toads(Cremona *et al.*, 2017a; Indigo *et al.*, 2018). However this behaviour would have to be reinforced if there is no continuous presence of toads and the longevity of this effect, as well as the ability to translate it to a broad-scale management option requires further investigation (Indigo *et al.*, 2018; Jolly *et al.*, 2017).

The Pilbara population of northern quolls has been identified as genetically distinct, with differing conservation priorities from other northern quoll population across northern Australia (Hill and Ward, 2010). They are present in the hard rocky habitats of the Pilbara that provide denning habitat and safety from predators and fire (Hill and Ward, 2010; Turpin and Bamford, 2014). The physical separation from the nearest Kimberley population by approximately 500km of arid Great Sandy Desert has resulted in distinctive genetics with no evidence of gene flow between the populations (How *et al.*, 2009; Spencer *et al.*, 2013; Westerman and Woolley, 2015). In addition to the threats imposed on most of Australia's critical weight range mammals, the Pilbara population is also recognised to be under specific threat from mining and infrastructure development (McKenzie *et al.*, 2007). As a consequence of these attributes, the Pilbara population is listed as Endangered under the *EPBC Act* and IUCN Red List, and Specially

Protected Fauna in Western Australia under the Wildlife Conservation (Specially Protected Fauna) Notice 2016 (EPBC, 1999; The IUCN Red List of Threatened Species, 2016).

Although the ecology of northern quolls has been studied in the Northern Territory (Begg, 1981; Braithwaite and Griffiths, 1994; Oakwood, 2000; Oakwood, 2002; Cremona *et al.*, 2014) Kimberley (Schmitt *et al.*, 1989; Start *et al.*, 2007; Radford, 2012) and to some extent in Queensland (Pollock, 1999; Burnett, 1997; Burnett and Zwar, 2009), little research has been undertaken in the Pilbara. Conservation of Pilbara northern quolls is restricted by limited information on the species ecology, distribution and differences from other northern quoll populations in more northern and tropical bioregions. Key directions for northern quoll research were determined at a workshop held by DBCA in 2013 (Cramer *et al.*, 2016), wherein the research priorities for northern quoll in the Pilbara were identified to be;

1. development of appropriate and standardised survey and monitoring methods;
2. defining areas of critical habitat and better understanding of how disturbance affects habitat quality;
3. improved understanding of population dynamics;
4. better understanding the key threats and the interactions between these threats; and
5. determining whether the northern quoll will colonise restored / rehabilitated areas or artificial habitat.

The Department of Biodiversity, Conservation and Attractions has been undertaking northern quoll research following the above priorities, using funding from industry and other development proponents. This has enabled:

a) the collation of data from various sources;
b) collection and addition of new presence records;
c) distribution modeling;
d) deployment of a standardised annual monitoring regime for Pilbara populations;
e) research into the impacts of disturbances from industry and development;
f) movement and dietary studies; and
g) population genetics research.

Reporting of these topics is structured within the above priorities. Prior reports on the research program can be found at library.dbca.wa.gov.au. This report serves as a progress update to the end of 2017 for activities undertaken over the previous 12 months.

1 Survey and monitoring

Prior to the implementation of the region-wide standardized northern quoll trapping at twelve sites across the Pilbara, the majority of species records were indirect observations such as tracks, scats, bones and carcasses rather than direct animal captures (Cook, 2010b). This finding highlighted that most studies involve desktop surveys or area searches obtaining presence records, rather than surveys providing population estimates. Where trapping occurred, there was a lack of consistency in monitoring protocols, making it difficult to draw conclusions on temporal or spatial trends of northern quoll populations throughout the region. Standardised monitoring procedures were created (Dunlop *et al*., 2014), based on protocols from DSEWPaC (2011) for mammal trapping. These protocols cover methods for cage trapping, scat searches and camera trap detection. DBCA have been undertaking standardised annual surveys of northern quolls in the Pilbara since 2014, collecting data on northern quoll distribution, diet, population ecology and life history.

1.1 Threatened Fauna Portal

Background

The extraction and modification of habitat through increased mining activities and related infrastructure projects has been identified as a significant and specific threat to the northern quoll and four other threatened vertebrate species (greater bilby, *Macrotis lagotis*; Pilbara leaf-nosed bat, *Rhinonicteris aurantia*; ghost bat *Macroderma gigas*; and Pilbara olive python *Liasis olivaceus barroni*) found in the Pilbara; making them significant considerations in most mining project assessments (Cramer *et al.* 2015). Development of resource rich areas may fragment populations further or increase mortality, thus affording these five threatened species special legislative protections and listing under the *Commonwealth Environment Protection and Biodiversity Act (EPBC Act 1999)* and the Western Australian *Biodiversity Conservation Act 2016*.

Effective management of threatened species requires robust information and understanding of past and present distribution to inform sound decision making. While a significant and valuable dataset of distribution and occurrence for northern quoll and other threatened species has been generated through increased fauna surveys by the resource sector, it had not been made publicly available (Carwardine *et al.*, 2014). By creating the Pilbara Threatened Fauna Portal (a publicly accessible centralised repository of species records) research institutions, consultants, conservation groups and resource companies can view and contribute records to the database; records that may include observations of live animals, evidence such as burrows, scats, tracks, hair samples, camera trap images or remains. This then creates a greater certainty in the quality of occurrence records and improves understanding of habitat use to facilitate better decisions and management outcomes for the Pilbara threatened fauna.

Outcomes

The DBCA northern quoll research program has contributed more than 1600 Pilbara northern quoll records to the currently available data. These were obtained by trapping and targeted searches both in previously surveyed and unsurveyed areas, as well as records collated from published and unpublished literature (Cook, 2010). Presence records include sightings, trapped animals, tracks, scats and images from camera traps. Of the 5227 presence records of northern quolls (Figure 2) found in the NatureMap database, 4153 are from the Pilbara. The majority of these are recent records; only 315 records date back further than 2009 (Figure 1).

Searching in previously unsurveyed areas has significantly expanded our knowledge of the distribution of the species. Previous survey efforts were typically conducted around resource rich formations, resulting in an apparent preference for northern quolls to inhabit these particular geomorphologies. Past models of species distribution reflected this bias in survey effort and provided inaccurate distributional models (Molloy *et al.*, 2017). We attempted to compensate for this survey bias by searching in previously unsurveyed areas, and areas away from industrial activity. Using our expanded data set of northern quoll presence and adjusting for the bias survey efforts, using appropriate surrogate data, a high-resolution predictive species distribution model was produced which identified previously unknown marginal habitat that may be of significant conservation value to the species (Molloy *et al.,* 2017; see Section 2.1 Species Distribution Modelling). While fewer records have been added to NatureMap in the last few years, we have been targeting collection of records in poorly surveyed areas.

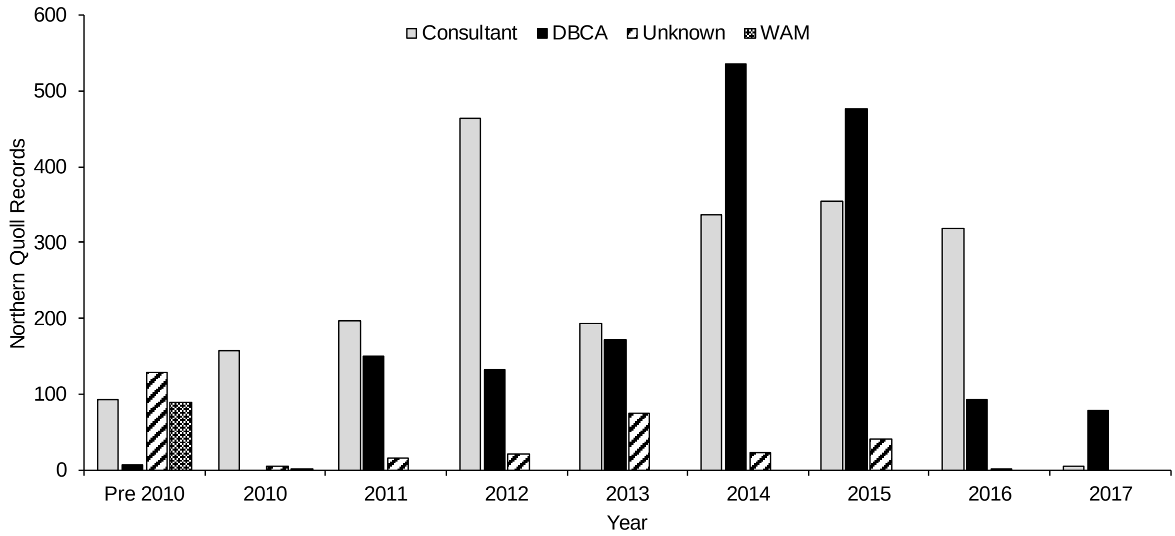

Figure 1. Contribution breakdown of different sources to the number of Pilbara northern quoll records available on Naturemap.

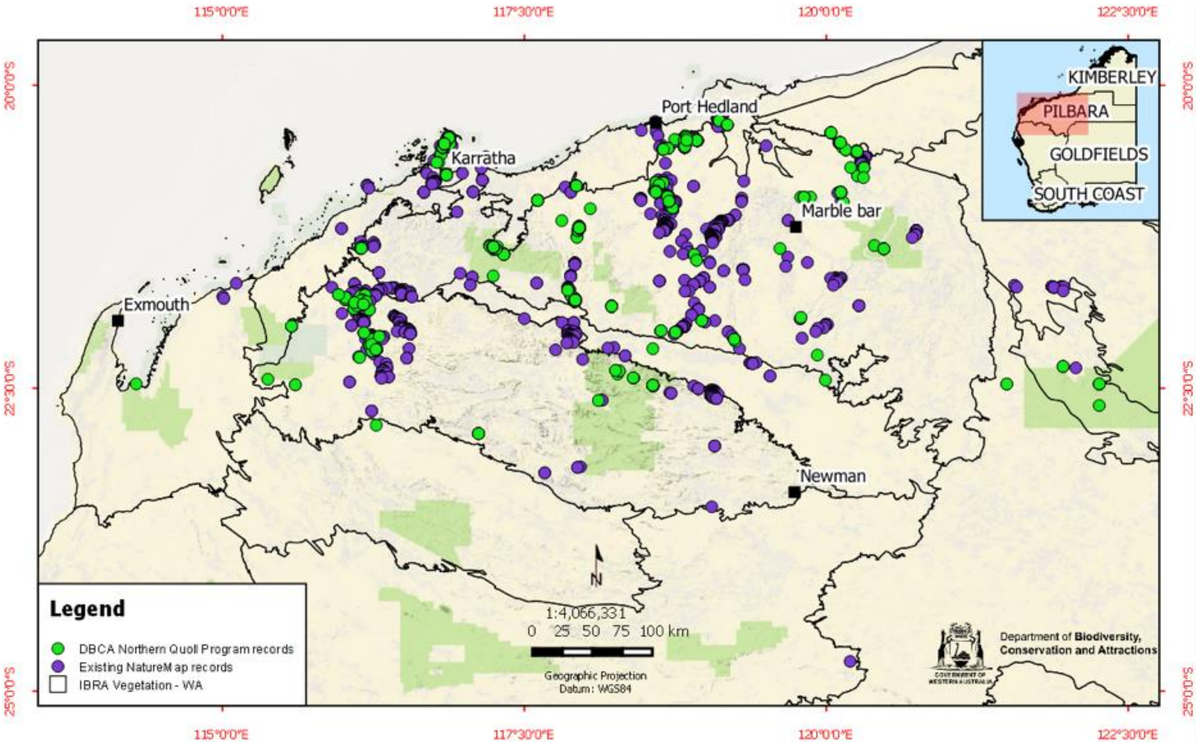

Figure 2. Northern quoll records from the Pilbara, available on NatureMap. Records collected by the Department of Biodiversity, Conservation and Attractions Pilbara northern quoll program since 2011 are shown in green, records from the Western Australian Museum, universities, biological consultants or other sources in purple.

Status

Ongoing, updated regularly

1.2 Population ecology and demographics

Background

Baseline data collection for northern quoll populations not currently co-occurring with cane toads is recognised as a priority in the national recovery plan for northern quolls (Hill and Ward, 2010). The Pilbara regional monitoring program includes trapping using standardised methods at numerous locations across the region, in order to obtain detailed information on population ecology, demographics and abundance.

Outcomes

Surveys of northern quoll populations throughout the Pilbara region have been undertaken for the last four years using cage and camera trapping techniques outlined in Dunlop *et al.* (2014). The trapping effort to date includes almost 7,500 trap nights, with capture success ranging from zero to 27 captures per 100 trap nights (Table 1). Data has been collected from 240 captured northern quoll individuals, from 571 capture instances. Capture rates vary more than one-hundred-fold between different sites; the detection probability at Cane River was 0.0017 (one capture in 600 trap nights), whereas Indee station has a detection probability of 0.27 (an average of 1 capture in 4 trap nights). The average population at each 1.2km long trapping site was 2.2 ± 0.6 individual males and 3.14 ± 0.8 females, ranging from 0 to 26 individuals per site each year. The camera trap effort has totaled more than 17,000 camera trap nights across the project duration. Northern quolls are highly detectable using both cage and camera traps, whereby required effort is approximately 30-100 camera trap nights and 75-125 cage trap nights to be 95% confident that the species is occupying an area, for high to moderate density sites. Different detection probability data via camera and cage trapping are being analysed for different habitats and aligned with the species distribution model described in Section 2.1.

Individual capture rates, reflecting populations at each site, were highly variable between sites and across years. This is indicative of the variable fulfilment of habitat parameters required by northern quolls in different geographic locations, in different seasons, and with differing predation pressures. Conditions of occupancy by northern quolls are consistently met at some sites, whereas others are suitable only in favourable seasons. The variability of capture rates between sites and years also reflects the boom and bust life cycle of the northern quoll, whereby they are capable of high reproductive rates and large dispersal distances when conditions are favourable.

Captures ranged from 0 to 27 individuals at each of the 15 monitoring sites. Dolphin Island and Indee Station had the highest density northern quoll populations from the sites sampled. An average of 6.2 ± 1.3 individual northern quolls were trapped at each monitoring site each year. Capture rate per 100 trap nights, and individual captures per 100 trap night are displayed in Table 1, with lowest capture rates seen in 2016. Sex ratios were significantly skewed towards females for individuals captured (52.9% F *vs* 47.1% M, P>0.001, Z-statistic = 34.3), and also for total captures including retrapped northern quolls, indicating that males and females are similarly trappable.

Northern quolls have a nearly completely semelparous life history strategy whereby almost all males die after a frantic mating season. A small number of males have been recorded surviving beyond the mating season and to their second year in these Pilbara populations. Larger populations at Indee, Dolphin Island, Red Hill, Mt Florance and Mallina supported small numbers of second year females, and a three-year old year female was recorded on one occasion at Dolphin Island. Inter-annual survival of adult males was estimated to be 1 ± 1 % for males (n = 97 individuals), and 11 ± 4 % for females (n = 98 individuals). Few sites had adult animals surviving from year to year, at most sites the captures were entirely comprised of a new population cohort.

Two instances of wildfire have occurred at the survey sites, resulting in a reduction of quoll captures the following year. At Millstream, a fire burned the monitoring site between the 2014 and 2015 trapping. Following the fire, there was a reduction in individual animals captured from nine (2014) to one in the following years (2015 and 2016). Similarly, at Mallina, individual captures reduced from 14 (2015) to zero (2016) following a summer wildfire burning a large area around the monitoring site. A combination of low rainfall between 2006 and 2009, and extensive summer fires in 2008 to 2010 was cited as the likely reason for decline and fragmentation of a northern quoll population at Bonney Downs, west of Nullagine (Bamford *et al.*, 2012). Northern quolls were not detected at this site again until 2014, when images of a single individual were captured (Bamford and Basnett, 2014).

During the 2017 monitoring the most common non- target species trapped was the common rock rat, *Zyzomys argurus*, with 42 captures of an estimated 41 individuals. Four other species were captured during the survey effort; *Ctentous sp.* (1), *Egernia formosa* (1), *Mus musculus* (1) and *Pseudantechinus sp.* (1).

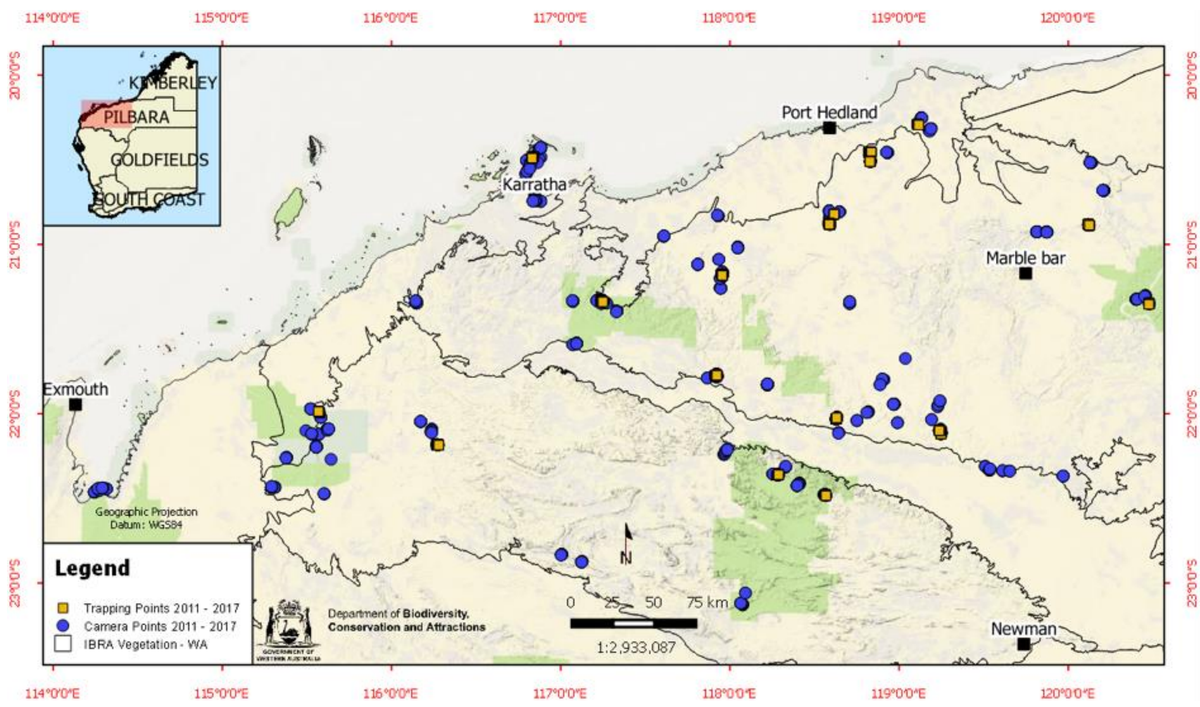

Figure 3. Spread of DBCA effort surveying northern quolls via camera and cage trapping in the Pilbara region, 2011-2017.

*Table 1. Total captures (above) and individual capture (below) statistics for northern quolls (*Dasyurus hallucatus*) at all sites.*

Site	2014	2015	2016	2017	*Total*	Trap nights	Captures/ 100 traps
Cane River Conservation Reserve	1	0	0	-	*1*	600	0.17
Dampier Archipelago	43	61	19	17	*140*	800	17.50
De Grey Station	4	-	-	-	*4*	200	2.00
Hooley Station	-	0	0	-	*0*	400	0.00
Indee Station	65	81	30	41	*217*	800	27.13
Karijini National Park	0	0	12	-	*12*	600	2.00
Karlamilyi National Park	0	-	1	-	*1*	240	0.42
Mallina Station	14	26	0	-	*40*	600	6.67
Meentheena Conservation Park	-	1	-	-	*1*	200	0.50
Millstream Chichester National Park	26	2	3	7	*38*	800	4.75
Mt Florance Station	18	10	10	-	*38*	600	6.33
Poondano	-	8	5	-	*13*	400	3.25
Red Hill Station	5	14	7	-	*26*	400	6.50
Roy Hill Rail	-	1	0	5	*6*	240	2.50
Yarrie Station	18	12	4	-	34	600	5.67
Grand Total	**194**	**216**	**91**	**70**	**571**	**7480**	**7.63**

Site	2014	2015	2016	2017	*Total*	Trap nights	Individuals/100 traps
Cane River Conservation Reserve	1	0	0	-	*1*	600	0.17
Dampier Archipelago	22	17	8	11	*58*	800	7.25
De Grey Station	3	-	-	-	*3*	200	1.50
Hooley Station	-	0	0	-	*0*	400	0.00
Indee Station	22	26	12	23	*83*	800	10.38
Karijini National Park	0	0	4	-	*4*	600	0.67
Karlamilyi National Park	0	-	1	-	*1*	240	0.42
Mallina Station	6	14	0	-	*20*	600	3.33
Meentheena Conservation Park	-	1	-	-	*1*	200	0.50
Millstream Chichester National Park	9	1	1	3	*14*	800	1.75
Mt Florance Station	6	5	3	-	*14*	600	2.33
Poondano	-	5	3	-	*8*	400	2.00
Red Hill Station	3	6	5	-	*14*	400	3.50
Roy Hill Rail	-	1	0	2	*3*	240	1.25
Yarrie Station	7	6	3	-	16	600	2.67
Grand Total	**79**	**82**	**40**	**39**	**240**	**7480**	**3.21**

Status

Data analysis ongoing

1.3 Detection probabilities and cost analysis for detection methods

Background

A key research question regarding surveys of northern quolls is that of detection probabilities in different habitats. This is particularly important to determine with respect to the effort required for detection in areas with low density populations. This work will collate the existing three years of northern quoll cage and camera trapping data to compare the efficacy, cost and minimum effort required to achieve 95% confidence in detection probabilities for two sampling methods.

Outcomes

Data and outputs generated by this investigation will be used to build a region-wide occupancy model for northern quolls that accounts for imperfect detection. Although a regional Species Distribution Model (SDM) has been developed for the Pilbara, this occupancy model will build on the SDM in two important ways. Firstly, it will account for imperfect detection, which is known to cause bias in SDMs. Secondly, and most importantly, it will provide estimates of both occupancy probability (i.e. the probability that northern quolls occur at a site) and detection probability (i.e. the probability of detecting northern quolls at sites in which it is known to occur). These two values can be used to conduct a power analysis. This will permit DBCA to provide guidance on the power of surveys designed (i.e. number of trapping sites and trapping nights) to detect changes in northern quoll abundance at a given magnitude (e.g. a 30% decline). We will compare the power and costs of live trapping and camera trapping and derive an optimal monitoring program given budgetary constraints and logistical considerations.

Status

Data analysis ongoing

1.4 Trial of downward-facing cameras

Background

Developing a standardized survey and monitoring protocol for Pilbara northern quolls was identified as a key research priority in Cramer *et al.* 2016. Live trapping using wire cages currently exists as the primary means of assessing quoll populations number as part of the Pilbara northern quoll monitoring program. The physical capture of animals allows for a collection of data such as weight, sex and reproductive stage, as well as collection of DNA. However, live trapping can be traumatic for the animal as the process requires physical handling and the animal can injure itself in the trap (Lemckert *et al*., 2006). Live trapping is also expensive and time consuming, with trapping sessions running for a minimum of four days at a time (Dunlop *et al*. 2014).

An increasingly popular alternative to live trapping in elucidating relative densities within mammal populations is the use of remote sensing cameras, commonly referred to as camera traps. When applied to species where individuals can be recognised via unique marking or spot patterning, camera traps can be used to estimate demographic parameters such as relative abundance. The aims of this project are to assess the potential of camera traps to accurately identify individual northern quolls and provide a cost-effective alternative to current live trapping efforts in monitoring population densities.

Camera traps used in this study consisted of a Reconyx PC900 Hyperfire camera unit attached to a wooden stake 1.5 metres above the ground, orientated in a downward-facing position. A vertical, overhead orientation was selected for the following reasons: 1.) Given spot patterning used to identify individual quolls is located on the animal's dorsal surface, a downward-facing orientation will most consistently capture ideal photos suitable for individual Identification. 2.) Distance between the camera and photographed animals remains constant, facilitating size comparisons between animals. 3.) Vertical orientation reduces the rate of 'false triggers' by restricting the field of view to approximately 2.55$m^{2,}$ effectively increasing battery life.

Outcomes

The expected outcome for this project is a comprehensive assessment as to the suitability of vertically orientated cameras traps as an alternative to live trapping, in estimating population numbers for northern quoll. So far, 60 of 120 downward-facing cameras have be deployed into the field for an average total of 211 days, between August 2017 and March 2018. Stage two of camera deployments will commence in August 2018. Preliminary results indicate downward-facing cameras are highly effective at capturing images suitable for individual identification, with over 80% of quolls detected also being individually identified. This project will form part of a collaborative PhD project between Charles Sturt University, the DBCA, The University of Western Australia and Deakin University.

Status

Ongoing, fieldwork continuing in 2018

1.5 Survey of a remote population at Karlamilyi National Park

Background

Two previously unrecorded threatened mammal species have been discovered in recent years at Desert Queen Baths (DQB), Karlamilyi National Park. Northern quoll (known to Martu as Wiminji) and black-flanked rock-wallabies (known as Warru), both inhabit complex rocky habitats and are capable of dispersing long distances. Martu elders speak of both species being historically common in rocky areas, and important species in the landscape. In elders' living memory, black-flanked rock wallabies were more common than euros, and a popular food item. Northern quolls were commonly seen in rocky breakaways through what is now Karlamilyi National Park.

Records of individual northern quolls had previously been detected via scats and camera trap images at DQB in 2012 and 2014. These northern quoll records represented a eastwards range extension of approximately 200 km at that time; the nearest northern quoll records were from Blue Spec Mine, Bonney Downs Station and Nullagine, between 230 and 250 km west of DQB. Since 2012, northern quoll records have also been documented in the vicinity of Nifty mine, approximately 100km north of DQB. Rock wallabies were detected through presence of their scats collected in 2012, and later confirmed on camera traps between November 2014 and January 2015 (Turpin *et al.*, 2018).

KJ Martu Rangers and then Department of Parks andWildlife undertook a fauna survey at DQB in September 2016 to obtain more information about the distribution of these two threatened species. Several northern quoll scats were collected from a cave, and old rock-wallaby scats were found in nearby caves. One individual male northern quoll was captured at DQB during this survey. This was the first living quoll seen by Martu elders in more than 60 years.

In 2017, DBCA and KJ Martu Rangers expanded the search for threatened species within remote and poorly surveyed areas within and to the north of Karlamilyi. Using Martu traditional knowledge, historical and modern species records combined with GIS layers, we targeted areas of habitat likely to support black-flanked rock-wallabies or northern quoll. KJ Martu Rangers and DBCA staff accessed these areas by helicopter and conducted searches on foot. We searched for animal signs; scats, tracks, and bones in caves. Incidental sightings of other species were recorded. Predator scats were collected and sent for processing by visual microscopy to identify dietary remains of bone, hair, teeth, scales, feathers and insect parts. Northern quoll scats were collected into paper envelopes and processed at Murdoch University using DNA profiling to identify different individuals.

We targeted locations likely to capture images of passing animals when setting camera traps; on animal trails, near water and in small caves or crevices. A peanut butter scent lure was placed 2-3m in front of each camera. Camera traps were set at least 100m apart. A total of 24 cameras were set in five locations around Karlamilyi in September 2017 and will be collected in 2018.

Outcomes

Five northern quoll scats were collected from three locations approximately 50 km apart, within the Martu Determination Area. DNA was extracted from the outside of each scat using the techniques described in Carpenter and Dziminski (2017), and genotyped by Dr Peter Spencer at Murdoch University. There were at least four unique genotypes present in the samples, indicating at least four individual northern quolls were responsible for the five scats. Based on the consistent, low density records of northern quolls from 2012 to 2017 it would appear that quolls are opportunistically present in dissected rocky areas of the arid eastern Pilbara. The 24 camera traps set around Karlamilyi will be collected in 2018 and any species photographed will be identified.

Status

Ongoing, in collaboration with KJ Martu Rangers.

2 Define critical habitat, and impact of disturbances

Improving our understanding of the critical areas of northern quoll distribution, how they use different Pilbara habitats and how habitat disturbances impact northern quoll occupancy are important aspects of managing disturbance on the species. The first step of defining critical habitat for northern quolls was refining our knowledge of the likely distribution of northern quolls in the Pilbara. From this, it will be possible to better ascertain what habitat characteristics are important to northern quolls, and how they use the landscape on a finer scale. Another knowledge gap that is recognised is how large-scale threatening processes (including habitat modifiers that are natural, such as fire, or human-induced, such as habitat fragmentation from linear infrastructure) or habitat characteristics (such as poor quality habitat) may affect distribution or population densities.

2.1 Species Distribution Modelling

Background

Species Distribution Models (SDMs) combine known data about a species' presence or abundance with information about environmental variables to predict species' potential distributions across landscapes (Pliscoff and Fuentes-Castillo, 2011). Models have been used to identify critical habitats for species with greatly reduced distributions (Molloy *et al.*, 2014), provide potential translocation sites for species with known habitat requirements (Adhikari *et al.*, 2012) and predict the movement of invasive species across landscapes under different scenarios (Kearney *et al.*, 2008; Elith *et al.*, 2010). This is achieved by statistically identifying and quantifying the influence of particular environmental variables (e.g., climate and geomorphology) on the probability that a species will occupy a given area (Reside *et al.*, 2014).

Several distribution models were developed in order to facilitate the ongoing *in-situ* conservation of northern quolls in the Pilbara. Specific goals of the SDM process included:

1. Development of a predictive model of northern quoll habitat on a finer scale than is currently available based on an enhanced dataset, including new DBCA monitoring data, existing survey data, improved habitat data and dispersal estimates.

2. Evaluation of known threats to this species, such as climate change and cane toads, and incorporation of these threats into models to identify important future/core habitat.

3. Development of a data set that identifies areas of key/core habitat, or areas with a lack of data to inform conservation management and land-use planning.

The influence of sample bias on the models was recognised, that is, the potential for a greater number of northern quoll presence records in areas of targeted surveys such as along rail and road corridors. To account for this potential sample bias, a pseudo-absence bias layer was developed from presence records for other critical weight range non-volant mammals. The resulting model was then tested using an ensemble process, where five other models were constructed using a group of modelling packages and an ensemble package was created by combining these models.

Outcomes

This study demonstrated a methodology capable of addressing several of the more common problems associated with SDMs, in particular how to address bias in a high resolution SDM over a large and diverse landscape with a limited, and potentially biased presence-only data set. This source of bias was addressed by selecting an appropriate suite of predictive variables for the construction of a model, and using a bias layer based on captures of other critical weight range mammals in order to validate the outputs of the model (Figure 4).

The models confirmed high probability of occurrence for many areas already known to be northern quoll habitat, such as the western edge of the Hamersley Range, the rugged Chichester Range and in the granite outcrops of the Abydos Plain. However, the model projects beyond known presences to predict a low probability of occurrence in the Fortescue River catchment, the alluvial coastal plain (Roebourne Plain) of the Pilbara and in the southern areas of the Hamersley Range, and to predict potential northern quoll habitat in many areas where this species has not been previously identified, particularly in the central west of the region (Figure 4).

Northern quolls were found to conform strongly to ecological habitat associations of vegetation, climate and slope, within the rocky areas of the Pilbara (Figure 4). Core areas of likely northern quoll habitat were identified, as well as wider population areas with lower likelihood that may only be occupied in years with favourable seasons. Current information suggests that all Pilbara northern quoll populations are genetically linked, and high level of dispersal occurs between geographically distant populations (Spencer *et al.*, 2013; Woolley *et al.*, 2015). A population recently discovered at Karlamilyi National Park was shown to be part of the Pilbara population, despite being approximately 200 km from the next known population (Turpin and Bamford, 2014). Smaller populations of northern quolls in less preferred habitat may therefore be important in maintaining gene-flow throughout the Pilbara region.

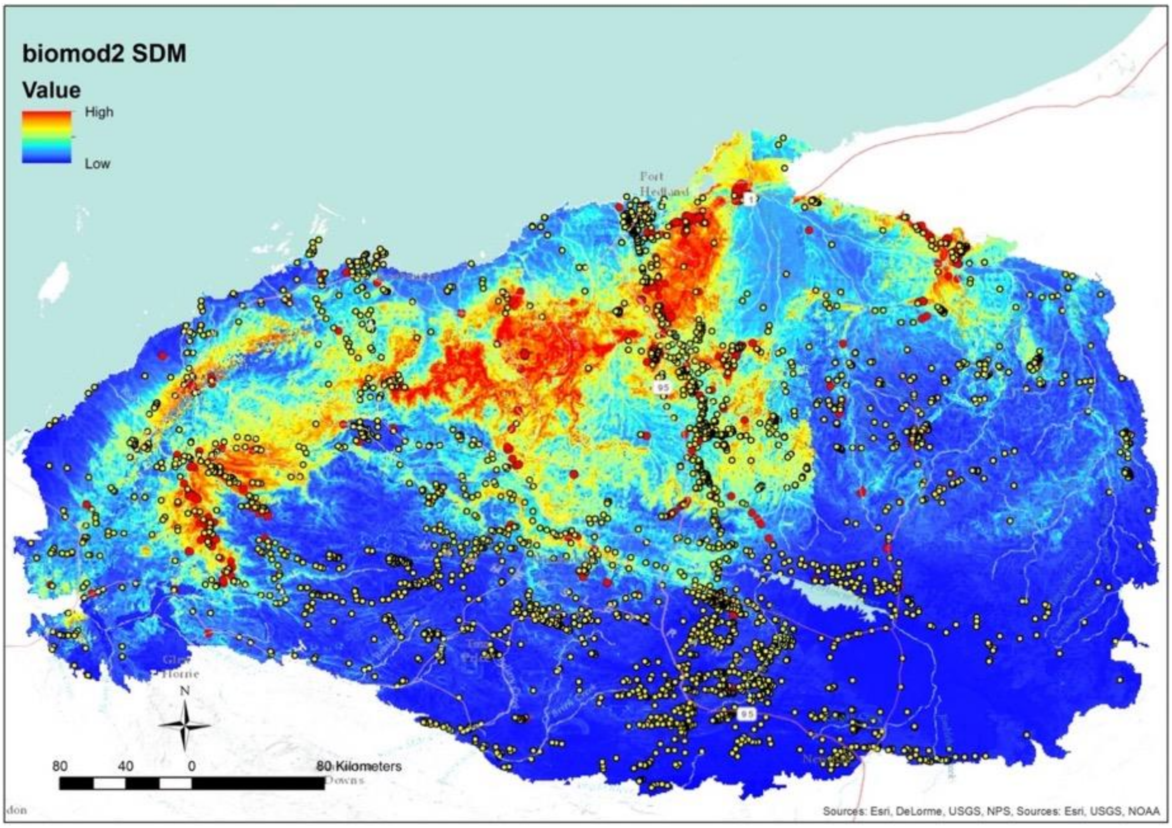

Figure 4. Heatmap of the likelihood of northern quoll presence in the Pilbara bioregion created from the final MaxEnt SDM. Likelihood of northern quoll presence ranges from red (high likelihood) to blue (low likelihood) to a 1km² resolution. Dots form the bias layer, where yellow dots indicate fauna surveys undertaken where northern quolls were not detected, and red dots indicate fauna surveys that detected northern quolls.

Status

Completed, manuscript published.

Molloy, S., W, Davis, R.A., Dunlop, J. and van Etten, E.J.B. (2017) Applying surrogate species presences to correct sample bias in species distribution models: a case study using the Pilbara population of the Northern Quoll. *Nature Conservation* 18, 25-46.

2.2 Occupancy Modelling

Background

Another priority identified in Cramer *et al.* (2016) was to improve understanding of northern quolls habitat requirements. This included an improved definition of critical habitat for northern quolls in the Pilbara, as we well as increased understanding of the role of fire in influencing habitat quality and connectivity. Much of our current knowledge related to these questions is derived from course-scale species distribution models, which do not account for the role smaller outcrops and the matrix of savanna and grassland within which they are embedded play on quoll occupancy. In addressing these knowledge gaps, we use a 'whole-of-landscape' experimental design to assess the landscape-scale habitat preference of northern quolls (following Kelly *et al*. 2012; Nimmo *et al*. 2013). A total of 24 circular landscapes, each 1km in diameter, have been chosen according to the stratifying variables: 1) extent of rocky habitat, 2) configuration of rocky habitat, and 3) landscape fire history, ranging from zero to twenty-nine years since last burnt. All landscapes will comprise potentially suitable rocky habitat and will be chosen to represent a spectrum of fire histories based on satellite imagery collected over the last 30 years. A total of eight sites will be nested within each of the 1km dimeter landscapes. Sites will be surveyed using remote sensing cameras (Reconyx PC900). Cameras will remain in operation for at least five months, encompassing the northern quoll breeding period when the detection rate should be at its highest. Sites will be positioned on rocky habitat and on the intervening spinifex dominated habitat (i.e. the matrix) to monitor differences in how quolls use these areas.

Outcomes

Twelve of 24 landscapes were established in the Pilbara region in August 2017 (***Figure 5***). 120 Remote sensing cameras were deployed between the 10 - 20 August 2017 and collected from the 13- 20 March 2018 giving an approximate total of 26, 000 trap nights. Whilst data processing from this initial sampling block is not yet complete, over 560 independent quoll detections have so far been recorded across 10 of the 12 study landscapes. Once data processing for this sampling block has been completed, analysis will commence and will provide preliminary modelling results prior to the initiation of sampling block two. This project forms part of a collaborative PhD project between Charles Sturt University, DBCA, The University of Western Australia and Deakin University.

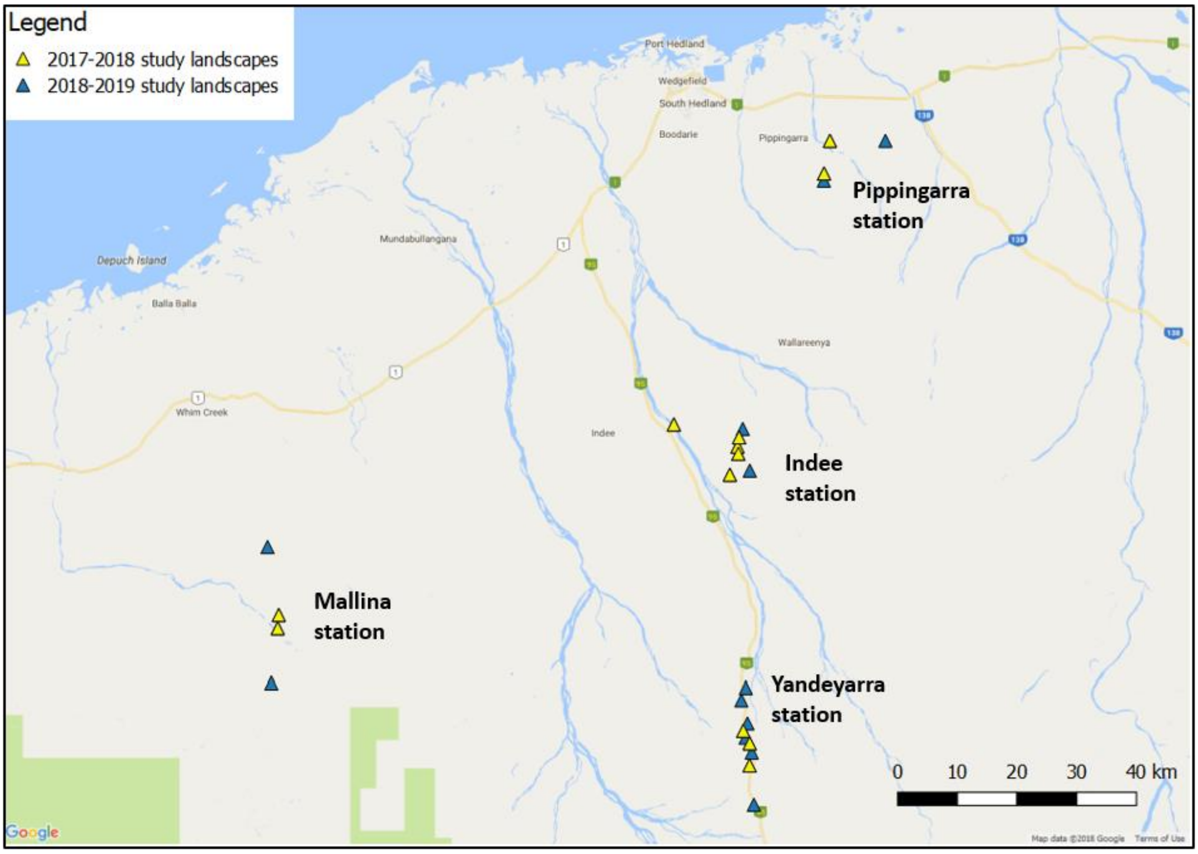

Figure 5. Locations of the 24 study landscapes for both 2017-2018 and 2018-2019 sampling periods. Landscapes are spread across four pastoral stations, including Mallina station, Indee station, Pippingarra station and Yandeyarra station. Each study landscape contains 8 sites.

Status

Ongoing. PhD student Harry Moore started 2017; fieldwork continuing 2018

2.3 Habitat use

Background

Better definitions of habitat attributes favoured by northern quolls is required to advance both species distribution models, as well as the development of predictive site-based habitat modelling (Cramer *et al.* 2016). Fine scale data detailing how northern quolls use habitat may be gained from the association of habitat features with the presence of quolls as determined by tracking using Global Positioning System (GPS) receivers (Gaillard *et al*. 2010). GPS technology has become an important tool in wildlife research and offers a number of major advantages over traditional techniques such as VHF radio tracking. These include their capacity to collect much larger volumes of locational data, with greater accuracy and at a lower cost than VHF transmitters. With the availability of this data comes the potential to conduct much finer scale analysis of animal behaviour than what has previously been achievable. However, there are no published studies to date investigating the use of GPS telemetry systems to study northern quolls (but see unpublished works by Henderson 2015; Hernandez-Satin 2016). This absence within the literature is likely an artefact of weight restrictions imposed on the application of GPS devices on small to medium-sized animals (total collar weight must be <5% total animal weight) as well as cost limitations. However, recent advances in technology (availability of affordable light weight devices) have recently made GPS telemetry a viable technique with which to study northern quolls.

This study aims to expand on our limited understanding of quoll habitat use through GPS telemetry. To achieve this, we will collar animals across several study landscapes, each characterized by varying degrees of habitat extent, fragmentation and configuration. Collars will be programmed to attempt satellite fixes at high frequencies to maximize data resolution whilst also providing information as to the temporal extent animals spend within varying components of the landscape.

Outcomes

Expected outcomes for this project include an enhanced understanding of northern quoll fine scale habitat use, previously unattainable using traditional techniques. Further, we hope to assess the potential impacts of increasingly frequent and large fires on quoll movement/foraging by locational data from recently burnt and long unburnt sites. Finally, this project will contribute to the small pre-existing database of northern quoll GPS records, increasing total sample size and potentially facilitating a more powerful suite of statistical analyses. This project will form part of a collaborative PhD project between Charles Sturt University, DBCA, The University of Western Australia and Deakin University.

Status

Ongoing, PhD student Harry Moore started 2017; fieldwork continuing 2018

3 Population dynamics and ecology

Genetic and dietary studies offer insights into how northern quolls utilise their environment, their dispersal patterns and breeding strategies. In addition to the life history data gained from the annual surveys, genetics and dietary analyses are being used to better understand northern quoll population dynamics and ecology. These techniques both use samples collected from a variety of sources over a long period of time to create a large, regional dataset.

3.1 Using population genetics to infer large and small-scale spatial patterns of northern quolls

Background

Recent examinations of northern quoll population genetics have identified the existence of four genetic lineages: Queensland; Northern Territory (including the Gulf of Carpentaria Islands); the Kimberley; and the Pilbara region (Woolley *et al.*, 2015). It is notable that Pilbara and Kimberley populations are genetically distinct with no evidence of gene flow between populations, despite the recent discovery of northern quolls on the edge of the Little Sandy Desert (Turpin and Bamford, 2014; Westerman and Woolley, 2015). The high conservation value of island populations has been highlighted, as they represent repositories of genetically diverse populations that are potentially secure from cane toad invasion (Woinarski *et al.*, 2007; Spencer *et al.*, 2010; How *et al.*, 2009).

This study used genetic information to investigate the population and spatial structure of northern quolls in the Pilbara. The aims of the study are to:

a) determine the diversity and “genetic importance” of the Pilbara population; particularly in comparison with populations elsewhere in Australia;
b) determine if there are patterns of population structure including phylogeography and regional management units; and
c) investigate if there are relationships between genetic relatedness and spatial distribution.

An initial analysis of nuclear markers from 32 sampling locations was undertaken in 2013. DNA profiles were examined at 11 nuclear genes (microsatellite) from 253 individuals from three focal sites from the Pilbara region. Measures of genetic diversity were compared between different populations of northern quolls across its range.

Samples used in the preliminary work were biased toward a few sites, where DNA samples from a large number of individuals came from a small number of sites. Additional samples collected between 2012 and 2017, as well as tissue samples lodged at the WA Museum were selectively added to the above analysis to reduce the spatial clustering of samples that was present in the original dataset and provide insights into lower density populations. These additional samples will assist in filling spatial gaps in the current dataset. The sole individual northern quoll captured in Karlamilyi National Park (see Section 1.4) represents the most isolated Pilbara northern quoll population, and the most likely to show relatedness with Kimberley populations. We have expanded the northern quoll tissue databank from 253 samples to approximately 1800 samples to allow for a comprehensive population analysis of the northern quolls in Western Australia.

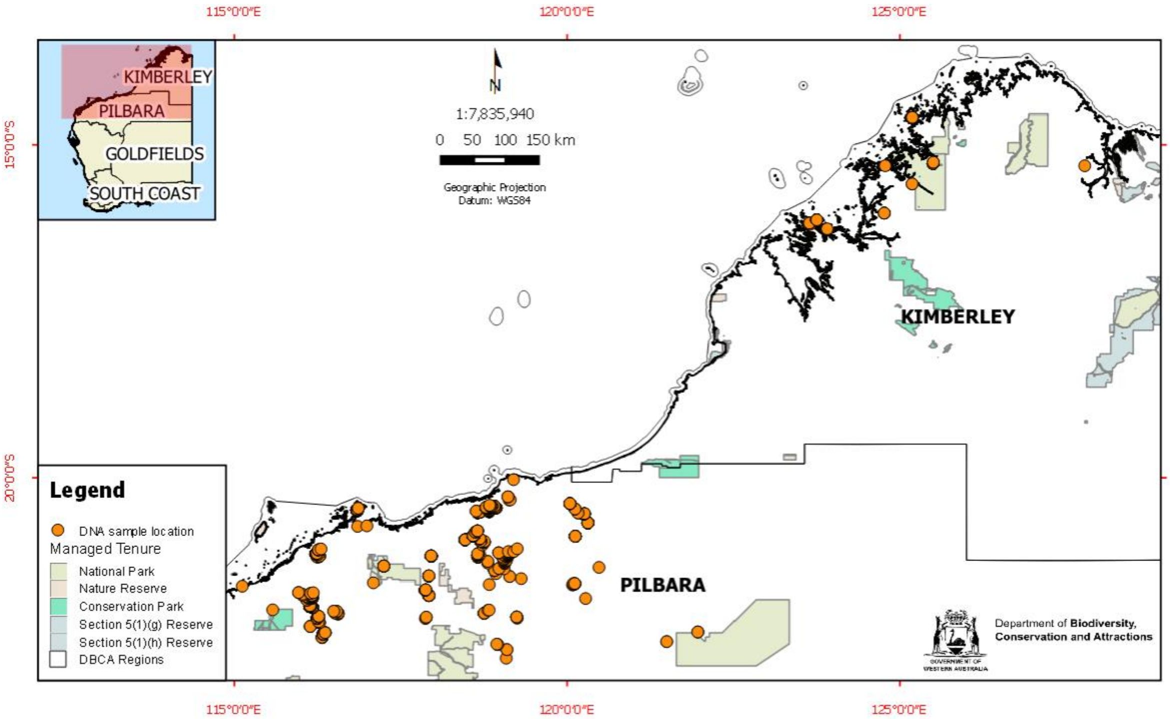

Figure 6. Spatial spread of northern quoll tissue sample locations in the Kimberley and Pilbara regions. A total of approximately 1800 Western Australian northern quoll tissue samples are available.

Outcomes

Pilbara mainland populations of northern quolls were found to be relatively similar to each other across all measures of genetic variability and share high levels of ancestral genetic background with each other. Thus, all mainland sites were found to function as a single mainland genetic unit. Genetic diversity for each population was estimated over all loci within each population by the observed average number of alleles per locus, NA. Individuals from the mainland retained higher levels of genetic diversity, (NA = 10.00 ± 0.92 SE) than their island counterparts (NA = 3.60 ± 0.43 SE). Mainland Pilbara northern quolls retain high levels genetic diversity, similar to that for the Kimberley populations, and show no evidence of recent or long-term population bottleneck. This result indicates that despite habitat fragmentation and population decline, the Pilbara population has not yet suffered a loss in genetic diversity. As is frequently the case for island populations, the Dolphin Island population has lower levels of genetic diversity than the mainland. The reduction in genetic diversity for the Dolphin Island population is similar to that identified for Koolan Island compared to the Kimberley mainland (Spencer *et al.*, 2016), and for other island vs mainland comparisons (Cardoso *et al.*, 2014; Eldridge *et al.*, 1999).

Seasonal monitoring in the Pilbara region has identified that northern quolls are not widespread throughout the landscape, but reliant on patches of complex rocky habitat of ranges and rocky outcrops. Despite the discontinuous and rugged nature of quoll habitat throughout the Pilbara region, it's consistent genetic diversity and high levels of mixing imply overlapping home ranges and the capacity to move large distances. There was a clear genetic differentiation of Dolphin Island from other mainland sites, but all four mainland sites examined showed a high degree of overlap (Figure 7). For conservation management purposes, the Pilbara populations should be treated as two units; the entire mainland population and the Dolphin Island population.

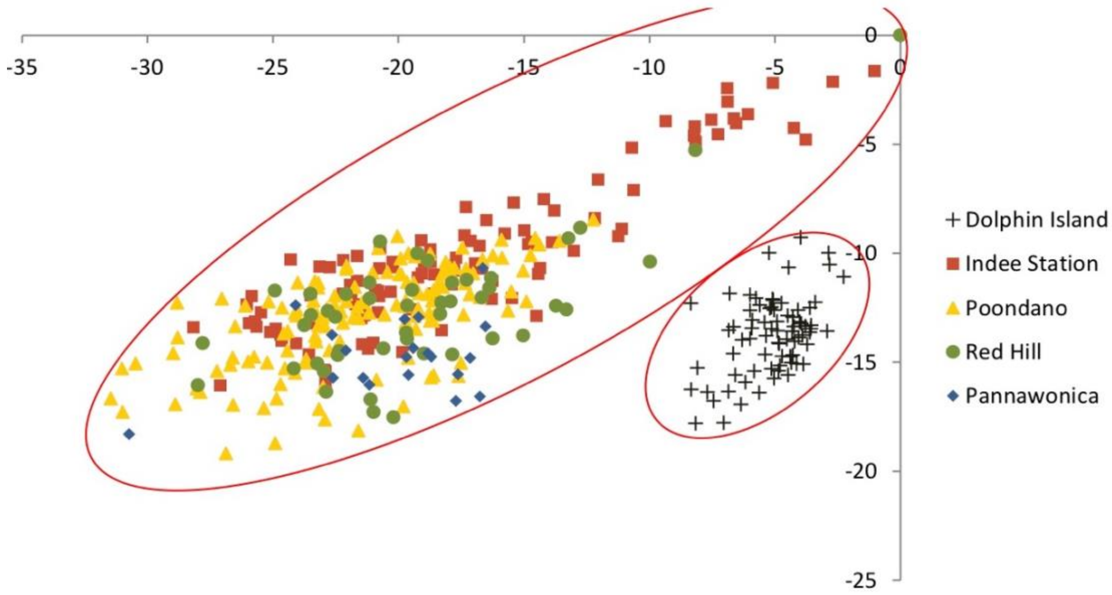

Figure 7. Population assignment of adult northern quoll individuals sampled from five sites in the Pilbara. Individuals from each population are designated with a different symbol and placed according to how genetically similar or dissimilar they are to other individuals.

Status

Ongoing. Genetic sequencing complete, analysis occurring in 2018

3.2 Understanding northern quoll mating, sexual selection and dispersal of young

Background

Promiscuous mating in marsupials appears to be a common strategy, with possible benefits including genetic "bet-hedging" and reducing the relatedness of individuals occupying an area. Female northern quolls occupy fairly small, exclusive territories and produce a single litter of 6-8 young per year, whereas males have large, overlapping home ranges (Oakwood, 2002; Glen and Dickman, 2006). Multiple paternity within litters has been found in other marsupials with similar life histories, including the agile antechinus (*Antechinus agilia,* Kraaijeveld-Smit *et al.*, 2002), brown antechinus (*Antechinus stuartii*, Holleley *et al.*, 2006), and honey possum (*Tarsipes rostratus,* Wooller *et al.*, 2000). A similar study of paternity testing undertaken on spotted-tail quolls (Glen *et al.*, 2009), discovered that litters were sired by more than one male, and males sired offspring in more than one litter.

We aimed to:

a) determine the paternity of pouch young of known mothers in two wild populations of northern quoll;
b) determine whether mating systems differ between a mainland and island site;
c) explore the relationship between paternity and characteristics of males – e.g. body mass, scrotal size.
d) use this information in order to infer the system of mate choice, and if there is strong sexual selection by female northern quolls.

Tissue from northern quoll pouch young and mothers was collected from two sites where northern quolls are at high densities; Indee Station near Port Hedland, and Dolphin Island in the Dampier Archipelago (Table 2). Tissue from pouch young was obtained using fine sharp scissors to take a tiny (0.5mm) portion of skin from the tip of the tail (Animal Ethics approval 2014/19). These were compared with DNA samples collected from adults in the same population, and also compared to three other independent populations that were 50-200 km apart. Paternity of litters of 100 pouch young was tested using microsatellite markers.

Outcomes

Northern quolls showed a higher degree of female promiscuity and multiple paternity within a litter that has been described for any other marsupial. All 16 litters of northern quoll pouch young were fathered by more than one male, with up to eight males fathering eight young. It has been hypothesised that females drive this fiercely competitive mating strategy to ensure fitness of offspring (Fisher *et al.*, 2013), resulting in a nearly complete die-off of males following the mating season.

For the Dolphin Island population, male reproductive success (number of pouch young fathered) appeared to be linked to smaller body size. Identified fathers on Dolphin Island weighed significantly less than males which were not identified as fathers (t = 2.92; df = 51; p = <.01). Female northern quolls on Dolphin Island consistently have six nipples, whereas females on the mainland have eight. Both of these reproductive characteristics appear to favour conservative numbers of smaller offspring, rather than riskier investments in large offspring, in an unpredictable island environment. These selective pressures are lessened on the mainland, where animals have more capacity to disperse.

Table 2. List of pouch young mothers and body measurements for (A) Dolphin Island and (B) Indee Station, as well as the number of pouch young, number of pouch young without a successfully identified father, and number of identified mates for each mother (Chan, 2017).

(A) Dolphin Island

Mother ID	Weight (g)	no. PY	No. PY without identified father	no. of fathers
16-747	365	6	4	1 (>3*)
16-754	335	6	0	4
16-761	320	6	0	2
16-768	360	5	0	3
16-774	285	6	1	4
16-781	415	6	0	6
16-788	350	6	0	4
16-795	390	5	1	4
16-801	350	3*	0	3

*There were 6 pouch young in this litter, but only 3 were successfully sampled.

(B) Indee Station

Mother ID	Weight (g)	no. PY	No. PY without identified father	no. of fathers
16-805	345	5	4	1(>2*)
16-811	400	8	0	8
16-820	455	7	0	4
16-828	390	5	0	3
16-834	440	8	0	4
16-843	360	6	0	5
16-850	360	6	0	5

Status

Honours thesis completed, thesis completed
Chan, R. (2017) Investigating mate choice, sexual selection and multiple paternity based on parentage testing in island and mainland populations of the northern quoll (*Dasyurus hallucatus*). **Honours thesis, Murdoch University, Perth.**

3.3 Dietary composition, and regional variation

Background

The diet of a species is key knowledge for understanding its ecology and habitat requirements, particularly when considering the management and conservation of threatened species. Changes in diet over time or throughout a species' geographical range may indicate environmental change or competition from sympatric species (Dickman, 1986). Dietary studies of predators may also be used to identify the presence or changes in abundance of species in an area (Bilney *et al.*, 2010; McDonald *et al.*, 2014).

Despite its small size, the northern quoll is the largest marsupial carnivore extant in the Pilbara region. Little is known of its role as a key predator in this area; studies examining the diet of the northern quoll have been in mid-eastern Queensland (Pollock, 1999), Kakadu National Park (Oakwood, 1997) and the Kimberley (Radford, 2012). These studies indicate that invertebrates and small vertebrates made up most food items for northern quolls in northern savanna and rainforest habitats.

To better understand the ecology of this small carnivore, we undertook a dietary analysis of nearly 500 scats collected across ~100,000 km^2 in the Pilbara. We calculated dietary composition and niche breadth and modeled these against biogeophysical factors (latitude, longitude, rainfall, elevation, and distance to coast) for 10 study landscapes. We also conducted pairwise comparisons of diet groups to evaluate regional dietary differences.

Outcomes

Four hundred and ninety-eight northern quoll scats from 325 locations throughout the Pilbara region (Figure 8) were analysed for dietary components, identified as precisely as possible. The majority (80%) of scats were collected in the coolest months of the year in the Pilbara (June – September). For comparisons of regional dietary composition, we created site clusters from the areas with the majority of scats collected. These comprised of 19 or more scats that were within a 30 km central radius of each other and situated in similar physiogeographical setting.

Food items were identified by G. Story (Scats About, Majors Creek NSW) from the undigested parts of plants and animals remaining in the scats. These primarily included hair, teeth, claws, scales, feathers or bones of vertebrates and exoskeletal remains of arthropods (Brunner and Triggs, 2002; Watts and Aslin, 1981). Shells of molluscs, cocoons from metamorphs, seeds, flowers and other vegetative material were also present.

Quolls were highly omnivorous, consuming at least 23 species of vertebrates (mammals, birds, reptiles, frogs), as well as arthropods, molluscs, fruit, and carrion. Diet varied widely across the region, with up to a 3-fold difference in dietary niche breadth between study landscapes. We found few clear environmental drivers for the diet of northern quoll. The most frequently consumed food type was insects, but their occurrence in diets decreased as that of rodents and vegetation increased, indicating potential dietary preferences.

Dietary items were very diverse (Table 3) and were identified to 42 items that were then grouped into 12 more general dietary categories. Insects, vegetation, small mammals, and reptiles appeared to be the most important food groups. This result is similar to previous studies from tropical northern Australia (Oakwood, 1997; Pollock, 1999; Radford, 2012). The occasional occurrence of food items, such as bats and molluscs, illustrates the range of food items consumed.

This study confirms that Pilbara northern quolls are broadly carnivorous, with invertebrates making up most of their diet. However, vegetative material was present in almost 30% of scats and made up 19% of the volume of northern quoll scats. Food items consumed by the Pilbara northern quoll were incredibly diverse, indicating that they are highly opportunistic in their diet. In addition to an array of insects, arachnids and myriapods, northern quolls were observed to eat a range of plant materials, prey on small vertebrates including microbats and eat crustaceans when available. They also utilised what was presumed to be carrion of larger mammals such as the brushtail possum (*Trichosurus vulpecula*), red kangaroo (*M. rufus*), euro (*M. robustus*), feral cat (*F. catus),* wild dog/dingo (*Canis* spp.)*,* and cattle (*Bos taurus*). The wide variety of food items recoded at small percentages in most scats appears to indicate that Pilbara northern quolls are feeding opportunistically on available food items, rather than relying on a cornerstone dietary species.

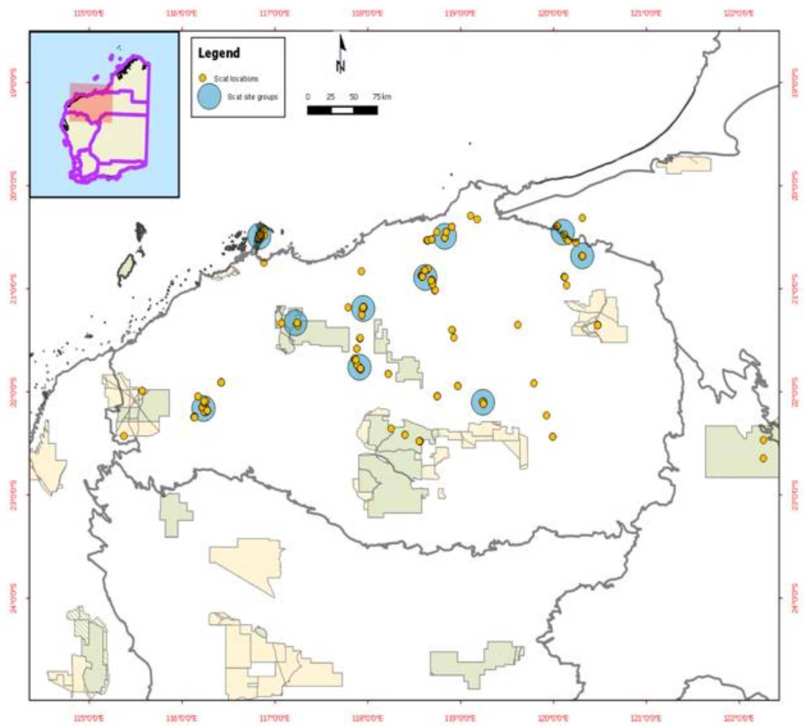

Figure 8. Map depicting northern quoll scats collected throughout the Pilbara, and the ten site groupings with 19 or more scats within a 30km radius. The raster layer depicts DBCA managed conservation reserves and unallocated crown land managed for conservation, with the grey line delimiting the Pilbara bioregion.

Status

Completed, manuscript published.

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

Table 3. Dietary items consumed by Pilbara northern quolls, derived from scat analysis by microscopy. Results are displayed as frequency of occurrence from 500 scats, and composition of each dietary item by volume.

Food type	Count	*%FO*	*%VO*
VERTEBRATES	**217**	**43.4**	**24.7**
Small Mammals	**84**	**16.8**	**11.5**
Bats (total)	***7***	***1.4***	***0.8***
Unidentified microbat	4	0.8	0.4
Rhinonicteris aurantia	2	0.4	0.3
Nyctophylus sp.	1	0.2	0.1
Rodents (total)	***66***	***13.2***	***8.9***
Zyzomys argurus	46	9.2	6.6
Pseudomys hermannsbergensis	15	3.0	2.1
Pseudomys delicatulus	3	0.6	0.1
Unidentified rodent	2	0.4	0.1
Marsupials (total)	***14***	***2.8***	***1.8***
Unidentified dasyurids	5	1.0	0.3
Ningaui timeleyai	4	0.8	0.6
Dasykaluta rosamondae	2	0.4	0.3
Sminthopsis youngsoni	1	0.2	0.2
Sminthopsis macroura	1	0.2	0.2
Pseudantechinus sp.	1	0.2	0.2
Large and medium-sized mammals (carrion)	**17**	**3.4**	**1.7**
Macropus rufus	5	1.0	0.6
Macropus robustus	5	1.0	0.6
Bos taurus	3	0.6	0.2
Trichosurus vulpecula	1	0.2	0.1
Felis catus	1	0.2	0.2
Canis sp.	1	0.2	0.1
Bone	1	0.2	0.0
D. hallucatus **(primarily grooming)**	**96**	**19.2**	**2.1**
Birds (total)	**59**	**11.8**	**5.3**
Reptiles (total)	**99**	**19.8**	**6.0**
Scincidae	65	13.0	3.4
Agamidae	9	1.8	0.8
Varanidae	3	0.6	0.4
Gekkonidae	6	1.2	0.3
Serpentia	18	3.6	1.0
Frogs (total)	**7**	**1.4**	**0.3**
INVERTEBRATES	**451**	**90.2**	**54.3**
Molluscs	**17**	**3.4**	**0.6**
Arthropods (total)	**445**	**89**	**50.5**
Crustacea	***33***	***6.6***	***3.2***
Insecta	***436***	***87.2***	***43.1***
Coleoptera	238	47.6	12.4
Orthoptera	195	39.0	13.4
Hymenoptera/Isoptera	260	52.0	6.6
Lepidoptera	20	4.0	1.3
Larvae/caterpillar	89	17.8	9.0
Other insect	18	3.6	1.5
Arachnida	***27***	***5.4***	***0.7***
Araneae	25	5.0	0.5
Scorpione	2	0.4	0.2
Myriapoda	***62***	***12.4***	***5.4***
Chilopoda	54	10.8	4.8
Diplopoda	9	1.8	0.6
VASCULAR PLANTS	**146**	**29.2**	**18.8**
Seeds (total)	**111**	**22.2**	**15.5**
Ficus sp.	80	16.1	11.2
Vegetation	**27**	**5.4**	**2.1**
Fruit	**8**	**1.6**	**1.0**
Flower	**1**	**0.2**	**0.2**

4 Key threats to the northern quoll, and the interactions between these

Introduced fauna, including feral cats, red foxes and cane toads are considered primary causes of the decline and local extinction of northern quoll elsewhere in Australia (Woinarski *et al.*, 2014). A broad-scale baiting feral cat-baiting program is being experimentally trialled in the Pilbara in an attempt to ameliorate this threat (Morris *et al.*, 2015a; Morris *et al.*, 2015b). Although we have some evidence of the impact of feral cats on northern quolls, it is not well known how the threatening processes of feral cats, red foxes and dingoes interact, and the resulting consequences they have on northern quoll populations or distribution.

4.1 Introduced predators

Background

Cramer *et al.* (2016) identify predation by feral cats, foxes and dingoes, altered fire regimes and over-grazing by introduced herbivores as three primary threats facing northern quolls in the Pilbara. Recent work by Hernandez-Santin *et al.* (2016) suggests that northern quolls avoid flat, open habitats frequented by feral cats. Northern quolls existing in the presence of predators may adjust their behaviour both spatially and temporally to avoid predators. Where “islands” of preferred habitat are further apart, the probability of predation may be too high and prevent northern quoll populations from persisting. Large, hot fires that remove protective habitat may further exacerbate predation risk.

We aim to examine the relationship between introduced predators, fire, and northern quoll occurrence. Landscapes will be chosen according to their fire history, to enable a model of the impact of fire history on northern quoll occupancy to be developed. Fire history will be quantified for the landscape surrounding rocky outcrops by measuring the frequency and average interval of fires over the past few decades (based on fine scale fire history maps). We hypothesise that frequent fires have diminished the use of savannah and grassland habitat by northern quolls, and interrupted their movement ecology, leading to range contractions in the northern quoll. As we will be simultaneously monitoring other predators, including feral cats, foxes and dingoes, we will be able to examine both the influence of fire history on these species that pose a threat to northern quolls, and the spatial and temporal relationships between these predators and northern quolls.

Outcomes

As part of the occupancy modelling project, 12 of 24 landscapes were established in the Pilbara region in August 2017 (Figure 1). Historical satellite imagery was used to map fire history within each of the study landscapes dating back to 1988. One hundred and twenty remote sensing cameras were deployed between the 10 - 20 August 2017 and collected from the 13 - 20 March 2018 giving an approximate total of 26,000 trap nights. Whilst data processing from this initial sampling block yet to be completed, preliminary data indicates both introduced predators and quolls are present across most of the landscapes. Northern quolls have been detected across over 80% of landscapes, whilst feral cats and wild dogs have been detected at 90% and 60% of landscapes respectively. Assessing the interactions between other predators, fire and northern quolls will allow us to examine the interactions between two high level threats (predation and fire) on northern quolls. The key outcome of this project will be the development of causal statistical models that will enable exploration of the most effective management interventions, such as introduced predator control or different approaches to fire management. This project will be part of a collaborative PhD project between Charles Sturt University, DBCA, and Deakin University.

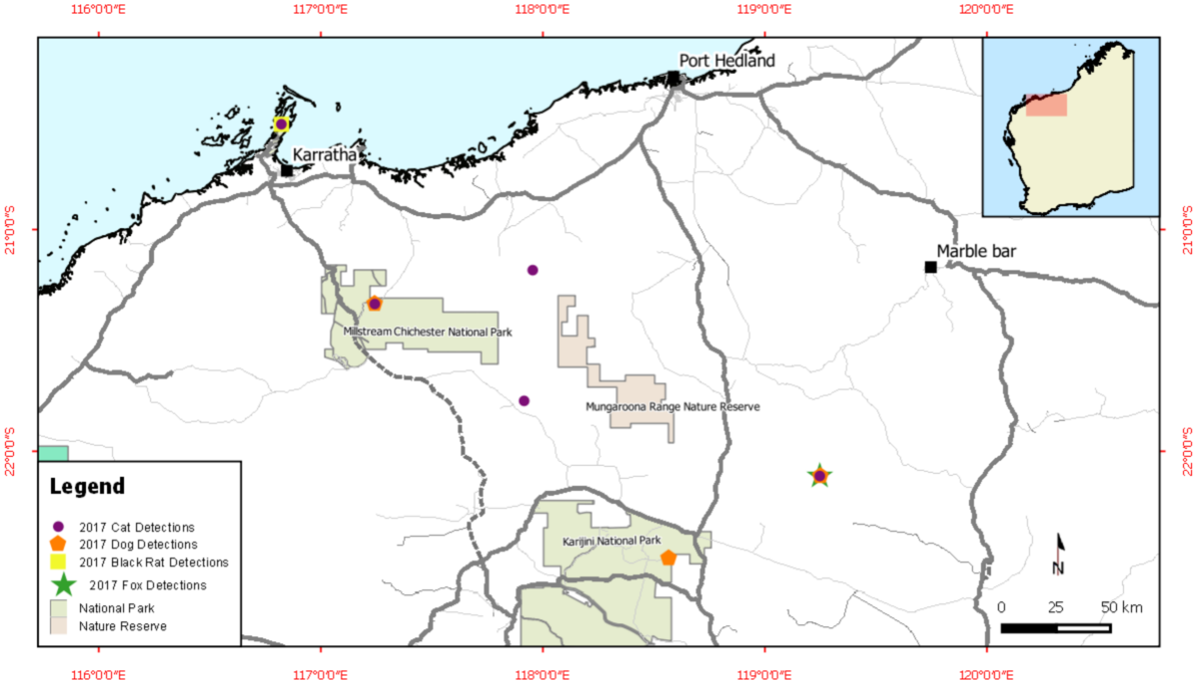

Figure 9. Feral cat, wild dog, red fox detections from the Pilbara in 2017

Status

Ongoing

5 Recolonisation of restored or artificial habitat

Background

An aspect of quoll research identified to be important in years 5-8 of the research program is to determine the ability of northern quolls to recolonise disturbed areas or colonise artificial habitat (Cramer *et al.*, 2016). Whilst some information exists on the northern quoll's ability to utilise disturbed habitat and artificial infrastructure (Creese, 2012; Johnson and Oates, 2013; Dunlop *et al.*, 2015; Henderson, 2015), we have not yet examined recolonisation of highly disturbed areas after rehabilitation or the potential use of artificially created habitat. Although it is appealing to offset habitat loss with restored or artificial alternative habitat options, we are limited in our ability to re-create habitat that is equivalent in structure, composition and function, particularly on highly disturbed sites (Maron *et al.*, 2012).

A key component of northern quoll habitat in the Pilbara is the complex, rocky denning habitat relied on for refuge. These rocky landforms provide a diversity of environments, denning opportunities, protection from weather and diurnal predators and immediate refuge from fire (Braithwaite and Griffiths, 1994; Oakwood, 2000; Cook, 2010a). In summer, females use rocky dens to deposit dependent offspring when they are too large to be carried (Begg, 1981). For small mammals such as northern quolls, dens also provide resting places, buffer extreme temperatures, and provide protection from predators (Hwang *et al.*, 2007). Complex habitats may also support more dense and diverse prey populations (Pavey *et al.*, 2017).

In the Pilbara, some of the complex rocky habitats that form northern quoll habitat is also targeted by the mining industry. The ridges and mesas of channel-iron deposits and banded iron formation ranges are the primary focus of iron-ore extraction (Ramanaidou and Morris, 2010) while exposed granite outcrops are quarried for road and rail beds. For this reason, a focus of mitigating impacts on this endangered species is to protect critical denning habitat, or recreate habitat to maintain population numbers and connectivity (Cramer *et al.*, 2016).

Although habitat likely to be occupied by quolls is somewhat known, denning requirements for this species have not been characterized on a fine scale. It is likely that suitable denning habitat comprises lower than ambient temperatures, higher humidity and a higher prey density than the surrounding area. Females have significantly smaller home ranges than males (Oakwood, 2002), suggesting that they are more tied to core denning habitat and probably occupy prime denning sites.

Understanding the characteristics of natural denning habitat (thermal properties, physical size and aspect, prey availability) enable us to generate requirements for artificial habitat creation. We aim to investigate the key elements of northern quoll habitat that need to be restored/created so that habitat complexity and productivity is maximised.

Specifically, we aim to;

- Determine the thermal and physical properties of natural dens used by females and compare these to natural (and non-denning) sites which were available but not selected by denning females, presumably because they do not possess required characteristics
- Compare the thermal and physical properties of occupied dens to artificial dens.
- Compare prey availability at occupied dens to non-denning sites and artificial sites.
- Compare visitation rates of predators (feral cats, dingoes) at denning sites, non-denning sites and artificial sites

- Examine how female quolls use natural denning habitat and close surroundings
- Summarise information and data gathered to create guidelines for artificial den and habitat construction.

Status

Research project in formative stages for an honours project beginning mid-2018

Reports, papers and presentations

Chan, R. (2017) *Investigating mate choice, sexual selection and multiple paternity based on parentage testing in island and mainland populations of the northern quoll (*Dasyurus hallucatus*)*. Honours thesis, Murdoch University, Perth.

Dunlop, J.A. (2017). Quolls on Country. *Landscope*, 32, 20-26.

Dunlop, J. (2018) Plenary- Threatened species in the arid zone. Presented at *University of Western Australia Environmental Postgraduate* Conference*,* Perth.

Dunlop, J., Morris, K. and van Leeuwen, S. (2017) Northern quoll in the Pilbara: diet, space use and population dynamics of a marsupial carnivore. Presented at *International Mammal Congress* Conference*,* Perth.

Dunlop, J.A. and Johnson, B. (2016). Northern Quoll trapping surveys at Wall Creek and Mesa 228. *Report prepared for Roy Hill Pty Ltd*, Department of Parks and Wildlife, Kensington 1-42.

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

Dunlop JA, Whittington A and Catt G. (2017). Targeted survey of northern quolls and black-flanked rock-wallabies in Karlamilyi National Park. Department of Parks and Wildlife, Kensington.

Molloy, S., W, Davis, R.A., Dunlop, J. and van Etten, E.J.B. (2017) Applying surrogate species presences to correct sample bias in species distribution models: a case study using the Pilbara population of the Northern Quoll. *Nature Conservation* 18, 25-46.

Moro, D., Dunlop, J. and Williams, M.R. (2018). Northern quoll persistence is most sensitive to juvenile survivorship. (Accepted) *Wildlife Research*

References

Adhikari, D., Barik, S.K. and Upadhaya, K. (2012). Habitat distribution modelling for reintroduction of *Ilex khasiana* Purk., a critically endangered tree species of northeastern India. Ecological Engineering, **40**, 37-43.

Bamford, M. and Basnett, G. (2014). BC Iron Nullagine Iron Ore Expansion Project - M46/522 and M46/523 Northern Quoll (*Dasyurus hallucatus*) April 2014 Survey. Report prepared for BC Iron, Nullagine: Bamford Consulting Ecologists, Kingsley.

Bamford, M.J., Turpin, J. and Bancroft, W. (2012). BC Iron Nullagine Iron Ore Project Northern Quoll (*Dasyurus hallucatus*) Monitoring Programme. Stage 3: Bamford Consulting Ecologists, Kingsley.

Begg, R.J. (1981). The small mammals of Little Nourlangie Rock, NT III. Ecology of *Dasyurus hallucatus*, the northern quoll (Marsupialia: Dasyuridae). Wildlife Research, **8**, 73-85.

Bilney, R.J., Cooke, R. and White, J.G. (2010). Underestimated and severe: small mammal decline from the forests of south-eastern Australia since European settlement, as revealed by a top-order predator. Biological Conservation, **143**, 52-59.

Braithwaite, R.W. and Griffiths, A.D. (1994). Demographic variation and range contraction in the northern quoll, *Dasyurus hallucatus* (Marsupialia: Dasyuridae). Wildlife Research, **21**, 203-217.

Brunner, H. and Triggs, B. (2002). Hair ID: an interactive tool for identifying Australian mammalian hair. CSIRO Publishing, Collingwood.

Burnett, S. (1997). Colonizing cane toads cause population declines in native predators: reliable anecdotal information and management implications. Pacific Conservation Biology, **3**, 65-72.

Burnett, S. and Zwar, A. (2009). Quolls (*Dasyurus maculatus* and *D. hallucatus*) in the southern Mary River catchment, south-east Queensland. Wildlife Preservation Society of Queensland, Sippy Downs.

Cardoso, M.J., Mooney, N., Eldridge, M.D.B., Firestone, K.B. and Sherwin, W.B. (2014). Genetic monitoring reveals significant population structure in eastern quolls: implications for the conservation of a threatened carnivorous marsupial. Australian Mammalogy, **36**, 169-177.

Carpenter, F.M. and Dziminski, M.A. (2017). Breaking down scats: degradation of DNA from greater bilby (Macrotis lagotis) faecal pellets. Australian Mammalogy, **39**, 197.

Carwardine, J., Nicol, S., Van Leeuwen, S., Walters, B., Firn, J., Reeson, A., Martin, T.G. and Chades, I. (2014). Priority threat management for Pilbara species of conservation significance. CSIRO Ecosystems Sciences, Brisbane.

Chan, R. (2017) *Investigating mate choice, sexual selection and multiple paternity based on parentage testing in island and mainland populations of the northern quoll (*Dasyurus hallucatus*)*. Honours thesis, Murdoch University, Perth.

Cook, A. (2010a) *Habitat use and home-range of the northern quoll,* Dasyurus hallucatus*: effects of fire*. Masters thesis, University of Western Australia, Perth, Western Australia.

Cook, A. (2010b). Northern quoll Pilbara Distribution - A desktop review. Department of Environment and Conservation Science Division, Perth.

Cramer, V., Dunlop, J., Davis, R.A., Ellis, R., Barnett, B., Cook, A., Morris, K. and van Leeuwen, S. (2016). Research priorities for the northern quoll (*Dasyurus hallucatus*) in the Pilbara region of Western Australia. Australian Mammalogy, **http://dx.doi.org/10.1071/AM15005**, 1-14.

Creese, S. (2012) *The use of rail culverts to facilitate the movement of fauna*. Masters thesis, University of Queensland, Brisbane.

Cremona, T., Crowther, M.S. and Webb, J.K. (2014). Variation of prey responses to cues from a mesopredator and an apex predator. Austral Ecology, **39**, 749-754.

Cremona, T., Spencer, P., Shine, R. and Webb, J.K. (2017a). Avoiding the last supper: parentage analysis indicates multi-generational survival of re-introduced 'toad-smart' lineage. Conservation Genetics, 73.

Cremona, T., Crowther, M.S. and Webb, J.K. (2017b). High mortality and small population size prevents population recovery of a reintroduced mesopredator. Animal Conservation, 658.

Dickman, C.R. (1986). Niche compression: two tests of an hypothesis using narrowly sympatric predator species. Australian Journal of Ecology, **11**, 121-134.

Dunlop, J. (2017). Pilbara Northern Quoll Research Program. Annual Report 2016: Deparment of Parks and Wildlife, Perth.

Dunlop, J.A., Cook, A. and Morris, K. (2014). Pilbara northern quoll project - Surveying and monitoring *Dasyurus hallucatus* in the Pilbara, Western Australia. Department of Parks and Wildlife, Kensington.

Dunlop, J.A., Cook, A., Rayner, K. and Lees, J. (2015). Use of quarry infrastructure by the Pilbara northern quoll *Dasyurus hallucatus*. Report prepared for BHP Billiton Iron Ore: Department of Parks and Wildlife, Kensington.

Dunlop, J.A., Rayner, K. and Doherty, T.S. (2017). Dietary flexibility in small carnivores: a case study on the endangered northern quoll, Dasyurus hallucatus. Journal of Mammalogy, **98**, 858-866.

Eldridge, M.D.B., King, J.M., Loupis, A.K., Spencer, P., Taylor, A.C., Pope, L.C. and Hall, G.P. (1999). Unprecedented Low Levels of Genetic Variation and Inbreeding Depression in an Island Population of the Black-Footed Rock-Wallaby. Conservation Biology, **13**, 531-541.

Elith, J., Kearney, M. and Phillips, S. (2010). The art of modelling range-shifting species. Methods in ecology and Evolution, **1**, 330-342.

EPBC (1999). Environment Protection and Biodiversity Conservation Act 1999. 1-431.

Fisher, D.O., Dickman, C.R., Jones, M.E. and Blomberg, S.P. (2013). Sperm competition drives the evolution of suicidal reproduction in mammals. Proceedings of the National Academy of Sciences, **110**, 17910-17914.

Glen, A.S., Cardoso, M.J., Dickman, C.R. and Firestone, K.B. (2009). Who's your daddy? Paternity testing reveals promiscuity and multiple paternity in the carnivorous marsupial *Dasyurus maculatus* (Marsupialia: Dasyuridae). Biological Journal of the Linnean Society, **96**, 1-7.

Glen, A.S. and Dickman, C.R. (2006). Home range, denning behaviour and microhabitat use of the carnivorous marsupial *Dasyurus maculatus* in eastern Australia. Journal of Zoology, **268**, 347-354.

Henderson, M. (2015) *The Effects of Mining Infrastructure on Northern Quoll Movement and Habitat*. Honours thesis, Edith Cowan University, Joondalup.

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

Hill, B.M. and Ward, S.J. (2010). National Recovery Plan for the Northern Quoll *Dasyurus hallucatus*. Department of Natural Resources, Environment, The Arts and Sport, Darwin.

Holleley, C.E., Dickman, C.R., Crowther, M.S. and Oldroyd, B.P. (2006). Size breeds success: multiple paternity, multivariate selection and male semelparity in a small marsupial, Antechinus stuartii. Molecular Ecology, **15**, 3439-3448.

How, R.A., Spencer, P.B.S. and Schmitt, L.H. (2009). Island populations have high conservation value for northern Australia's top marsupial predator ahead of a threatening process. Journal of Zoology, **278**, 206-217.

Hwang, Y.T., Lariviere, S. and Messier, F. (2007). Local-and landscape-level den selection of striped skunks on the Canadian prairies. Canadian Journal of Zoology, **85**, 33-39.

Indigo, N., Smith, J., Webb, J.K. and Phillips, B. (2018). Not such silly sausages: Evidence suggests northern quolls exhibit aversion to toads after training with toad sausages. Austral Ecology,

Johnson, B. and Oates, J. (2013). Poondano Iron Ore Project - Northern quoll radio-tracking study. Report prepared for Polaris Metals Pty Ltd: Astron Environmental Services, Perth.

Jolly, C.J., Kelly, E., Gillespie, G.R., Phillips, B. and Webb, J.K. (2017). Out of the frying pan: Reintroduction of toad-smart northern quolls to southern Kakadu National Park. Austral Ecology, 229.

Kearney, M., Phillips, B.L., Tracy, C.R., Christian, K.A., Betts, G. and Porter, W.P. (2008). Modelling species distributions without using species distributions: the cane toad in Australia under current and future climates. Ecography, **31**, 423-434.

Kelly, E. and Phillips, B.L. (2017). Get smart: native mammal develops toad-smart behavior in response to a toxic invader. Behavioral Ecology,

Kraaijeveld-Smit, F., Ward, S. and Temple-Smith, P. (2002). Multiple paternity in a field population of a small carnivorous marsupial, the agile antechinus, *Antechinus agilis*. Behavioral Ecology and Sociobiology, **52**, 84-91.

Maron, M., Hobbs, R.J., Moilanen, A., Matthews, J.W., Christie, K., Gardner, T.A., Keith, D.A., Lindenmayer, D. and McAlpine, C.A. (2012). Faustian bargains? Restoration realities in the context of biodiversity offset policies. Biological Conservation, **155**, 141-148.

McDonald, K., Burnett, S. and Robinson, W. (2014). Utility of owl pellets for monitoring threatened mammal communities: an Australian case study. Wildlife Research, **40**, 685-697.

McGrath, T. and van Leeuwen, S. (2011). Project plan - the ecology of the northern quoll Dasyurus hallucatus in the Pilbara bioregion, Western Australia 2010 - 2015. Department of the Environment, Water, Heritage and the Arts, Canberra.

McKenzie, N.L., Burbidge, A.A., Baynes, A., Brereton, R.N., Dickman, C.R., Gordon, G., Gibson, L.A., Menkhorst, P.W., Robinson, A.C. and Williams, M.R. (2007). Analysis of factors implicated in the recent decline of Australia's mammal fauna. Journal of Biogeography, **34**, 597-611.

Molloy, S.W., Davis, R.A., Dunlop, J.A. and van Etten, E.J.B. (2017). Applying surrogate species presences to correct sample bias in species distribution models: a case study using the Pilbara population of the Northern Quoll. Nature Conservation, **18**, 25-46.

Molloy, S.W., Davis, R.A. and Van Etten, E.J.B. (2014). Species distribution modelling using bioclimatic variables to determine the impacts of a changing climate on the western ringtail possum (*Pseudocheirus occidentalis*; Pseudocheiridae). Environmental Conservation, **41**, 176-186.

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

Morris, K.D., Cowan, M., Angus, G.J., Anderson, H., Garretson, S., Palmer, Russell, Williams, Matthew R and Pearson, D.J. (2015b). 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.

Oakwood, M. (2000). Reproduction and demography of the northern quoll, *Dasyurus hallucatus*, in the lowland savanna of northern Australia. Australian Journal of Zoology, **48**, 519-539.

Oakwood, M. (2002). Spatial and social organization of a carnivorous marsupial *Dasyurus hallucatus* (Marsupialia: Dasyuridae). Journal of Zoology, **257**, 237-248.

Oakwood, M. (1997) *The ecology of the northern quoll,* Dasyurus hallucatus*.* PhD thesis, Australian National University, Canberra, ACT.

Oakwood, M. (2008). Northern quoll, *Dasyurus hallucatus*. In 'The Mammals of Australia'*,* (Eds S. Van Dyck and R. Strahan), pp. 57-59. (New Holland: Sydney.)

Pavey, C.R., Addison, J., Brandle, R., Dickman, C.R., McDonald, P.J., Moseby, K.E. and Young, L.I. (2017). The role of refuges in the persistence of Australian dryland mammals. Biological Reviews of the Cambridge Philosophical Society, **92**, 647-664.

Pliscoff, P. and Fuentes-Castillo, T. (2011). Modeling of the species distribution and ecosystems in time and space: an review of new available tools and approaches. Revista De Geografia Norte Grande, 61-79.

Pollock, A.B. (1999). Notes on status, distribution and diet of northern quoll *Dasyurus hallucatus* in the Mackay-Bowen area, mideastern Queensland. Australian Zoologist, **31**, 388-395.

Radford, I.J. (2012). Threatened mammals become more predatory after small-scale prescribed fires in a high-rainfall rocky savanna. Austral Ecology, **37**, 926-935.

Ramanaidou, E.R. and Morris, R.C. (2010). A synopsis of the channel iron deposits of the Hamersley Province, Western Australia. Applied Earth Science: Transactions of the Institutions of Mining and Metallurgy: Section B, **119**, 56-59.

Reside, A.E., Welbergen, J.A., Phillips, B.L., Wardell Johnson, G.W., Keppel, G., Ferrier, S., Williams, S.E. and VanDerWal, J. (2014). Characteristics of climate change refugia for Australian biodiversity. Austral Ecology, **39**, 887-897.

Schmitt, L.H., Bradley, A.J., Kemper, C.M., Kitchener, D.J., Humphreys, W.F. and How, R.A. (1989). Ecology and physiology of the northern quoll, *Dasyurus hallucatus* (Marsupialia, Dasyuridae), at Mitchell Plateau, Kimberley, Western Australia. Journal of Zoology, London, **217**, 539-558.

Spencer, P.B.S., How, R.A., Hillyer, M., Cook, A., Morris, K.D., Stevenson, C. and Umbrello, L. (2013). Genetic Analysis of Northern Quolls from the Pilbara Region of Western Australia. Report to the Department of Parks and Wildlife: Murdoch University, Perth.

Spencer, P.B.S., How, R.A. and Schmitt, L.H. (2010). The Northern Quoll population on Koolan Island: Molecular and demographic analysis. Report prepared for Mount Gibson Iron Limited: Murdoch University, Perth.

Spencer, P.B.S., Sandover, S., Nihill, K., Wale, C.H., How, R.A. and Schmitt, L.H. (2016). Living in isolation: ecological, demographic and genetic patterns in northern Australia's top marsupial predator on Koolan Island. Australian Mammalogy, **http://dx.doi.org/10.1071/AM16004**,

Start, A.N., Burbidge, A.A., McKenzie, N.L. and Palmer, C. (2007). The status of mammals in the North Kimberley, Western Australia. Australian Mammalogy, **29**, 1-16.

The IUCN Red List of Threatened Species (2016) *Version 2015-4* www.iucnredlist.org. Accessed 27 April 2016.

Tingley, R., Phillips, B.L., Letnic, M., Brown, G.P., Shine, R. and Baird, S.J.E. (2013). Identifying optimal barriers to halt the invasion of cane toads *Rhinella marina* in arid Australia. Journal of Applied Ecology, **50**, 129-137.

Turpin, J. and Bamford, M. (2014). A new population of the northern quoll (*Dasyurus hallucatus*) on the edge of the Little Sandy Desert, Western Australia. Australian Mammalogy, **37**, 86-91.

Turpin, J.M., White, N.E., Dunlop, J.A. and Bamford, M.J. (2018). New populations of the black-flanked rock-wallaby (Petrogale lateralis) from the Little Sandy Desert and Murchison, Western Australia. Australian Mammalogy,

Watts, C.H.S. and Aslin, H.J. (1981). The rodents of Australia. Angus & Robertson, Sydney.

Westerman, M. and Woolley, P.A. (2015). Comment on a research note reporting new populations of the northern quoll in Western Australia. Australian Mammalogy, **38**, 124-126.

Woinarski, J.C.Z., Burbidge, A. and Harrison, P. (2014). Northern Quoll. In 'Action Plan for Australian Mammals 2012'*,* pp. 76-81. (CSIRO Publishing: Collingwood.)

Woinarski, J.C.Z., Rankmore, B., Fisher, A., Brennan, K. and Milne, D. (2007). The natural occurrence of northern quolls *Dasyurus hallucatus* on islands of the Northern Territory: assessment of refuges from the threat posed by cane toads *Bufo marinus*. Report to Natural Heritage Trust, 1-40.

Wooller, R.D., Richardson, K.C., Garavanta, C.A.M., Saffer, V.M. and Bryant, K.A. (2000). Opportunistic breeding in the polyandrous honey possum, *Tarsipes rostratus*. Australian Journal of Zoology, **48**, 669-680.

Woolley, P.A., Krajewski, C. and Westerman, M. (2015). Phylogenetic relationships within *Dasyurus* (Dasyuromorphia: Dasyuridae): quoll systematics based on molecular evidence and male characteristics. Journal of Mammalogy, **96**, 37-46.