Pilbara Northern Quoll Research Program

Judy Dunlop

Annual report 2016

April 2017

Department of
Parks and Wildlife

Department of Parks and Wildlife
Locked Bag 104
Bentley Delivery Centre WA 6983
Phone: (08) 9219 9000
Fax: (08) 9334 0498

www.dpaw.wa.gov.au

This document was prepared by Judy Dunlop.

Questions regarding the use of this material should be directed to:
Animal Science Program
Science and Conservation Division
Department of Parks and Wildlife
Locked Bag 104
Bentley Delivery Centre WA 6983

The recommended reference for this publication is:
Dunlop, J. 2017, *Pilbara Northern Quoll Research Program: Annual Report 2016*, Department of Parks and Wildlife, Perth.

This document is available in alternative formats on request.

Please note: urls in this document which conclude a sentence are followed by a full point. If copying the url please do not include the full point.

Contents

Figures

Tables

Acknowledgements

This project is supported by environmental offsets and public good funds provided by BHP Billiton, Rio Tinto, Atlas Iron, Fortescue Metals Group, Roy Hill, Process Minerals International and Main Roads Western Australia.

Distribution modeling and home range estimates were undertaken in collaboration with colleagues Melinda Henderson, Rob Davis and Shaun Molloy from Edith Cowan University. Analysis of northern quoll diet was a collaborative work with Tim Doherty from Deakin University

We are very grateful for the field and logistical assistance provided by Hannah Anderson, Adam Birnbaum, Neal Birch, Viki Cramer, Harriet Davie, Christine Fleay, Melissa Jensen, Brent Johnson, Jo Kuiper, Harry Moore, Frank Morris, Tali Moyle, Joe Porter, and Kelly Rayner, Nadia Rubbo, David Smith, Natasha Tay, Catherine Webb and Alicia Whittington. Work at Karlamilyi National Park was undertaken with KJ Martu Indigenous Knowledge Program and Martu Rangers.

Summary

This document reports on progress of the Pilbara northern quoll research program since the 2015 Annual Report (Dunlop *et al.*, 2016), and also addresses the third year of annual monitoring. To date, the Pilbara Northern Quoll research project has made significant 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, via searching for animals in previously unsurveyed areas, and collating additional records from 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 (Dunlop *et al.*, 2017a). Sequencing is underway for approximately 1800 tissue samples collected as part of this project in order to answer questions about patterns of dispersal, relatedness and life history. A significant volume of presence records collected via camera and cage trapping has been obtained which will assist with planned detectability analyses and assessment of the efficacy of northern quoll survey methods. A key future 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.

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 Parks and Wildlife (DPaW) 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 Western Australian Department of Parks and Wildlife 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.

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 of 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).

The Pilbara population of northern quolls has been identified as 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 the Western Australian Department of Parks and Wildlife 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 Parks and Wildlife 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.dpaw.wa.gov.au. This report serves as a progress update to the end of 2016 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 involved indirect observations such as tracks, scats, bones and carcasses rather than direct animal captures (Cook, 2010). This finding highlighted that the majority of surveys 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 remote camera detection. Parks and Wildlife 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 northern quoll is one of five threatened vertebrate species found in the Pilbara region that are listed under the Commonwealth Environment Protection and Biodiversity Conservation Act (EPBC, 1999). These species: (northern quoll, *Dasyurus hallucatus;* greater bilby, *Macrotis lagotis;* Pilbara leaf-nosed bat, *Rhinonicteris aurantia;* ghost bat *Macroderma gigas;* and Pilbara olive python *Liasis olivaceus barroni*) receive special protection under legislation due to recognition of specific threats in the Pilbara arising from increased development and growth in the resources industry. Development of resource rich areas may remove or further fragment populations of Pilbara threatened fauna, or create additional mortality pressures due to loss or modification of habitat.

Decision making for effective management of threatened species requires good information on past and present distribution and population estimates. The Threatened Fauna Portal provides a centralised repository for the collection and viewing of new and historical records for these species across Western Australia. Records may include observations of live animals, evidence such as burrows, scats, tracks, calls, hair samples, camera trap images or remains.

Outcomes

There are currently more than 5,000 presence records of northern quolls in the NatureMap database, of which 3,935 are from the Pilbara region. Since the launch of the website, the Parks and Wildlife northern quoll research program has made a substantial contribution of more than 1,500 locational records available on NatureMap (Table 1), via the Pilbara Threatened Species Portal. Records include those from trapping and targeted searches (including camera trap and scat records) undertaken by Parks and Wildlife, as well as those collated from the published and unpublished literature (Cook, 2010). Searching in previously unsurveyed areas, and accurately collating unpublished records has significantly expanded our knowledge of the distribution of this species in the Pilbara (Figure 1). This enhanced distributional dataset was used for predictive species distribution modelling (Molloy *et al.*, 2017; see Section 2.1 Species Distribution Modelling).

Status: Ongoing, updated regularly

Table 1. The number of Pilbara northern quoll records available through NatureMap. Records are broken down into groups by year and source.

Source	Unknown year	Pre 1970	1970-79	1980-89	1990-99	2000-09	2010-17	Total
Department of Parks and Wildlife	47	17	11	40	15	8	1568	**1,706**
Western Australian Museum	35	17	5	19	9	4	1	**90**
Fauna Consultant Records	37	0	0	0	0	47	2055	**2,139**
Total	**90**	**36**	**15**	**43**	**31**	**86**	**3,027**	**3,935**

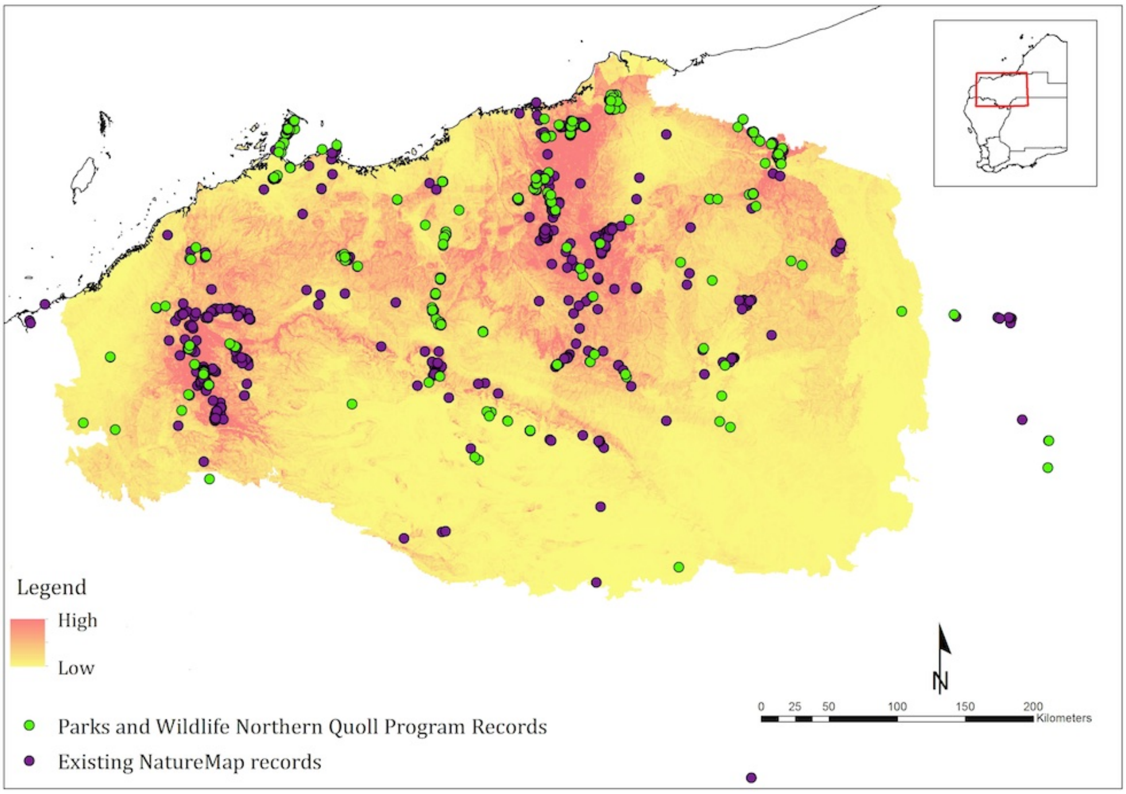

Figure 1. Northern quoll records from the Pilbara. Records collected by the Department of Parks and Wildlife Pilbara northern quoll program since 2011 are shown in green, records from the Western Australian Museum, universities, consultants or other sources in purple. The background image indicates probability of northern quoll presence and was created using a Species Distribution Model (Molloy *et al.*, 2017)***.***

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

The third trapping campaign of the Pilbara annual monitoring sites occurred in 2016 between May and October, following the trapping methods outlined in Dunlop *et al.* (2014). The program in 2016 included 2,520 trap nights at twelve sites across the Pilbara region. Opportunistic northern quoll trapping was also undertaken at Karlamilyi National Park in the Eastern Pilbara in conjunction with a survey for black-flanked rock-wallabies, where an individual northern quoll was captured for the first time in 50 years. Total and individual captures of northern quolls for each site over the three-year period are shown in Table 2.

In the past three years, northern quoll populations were monitored at 15 different locations across the Pilbara region (Table 2). It was not possible to survey every site each year. We recorded a total of 518 captures of 229 individual northern quolls from 7240 trap nights. Capture rates varied 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 had a detection probability of 0.22 (1 capture in 5 trap nights).

Two instances of wildfire occurred at the survey sites, resulting in a reduction of quoll captures the following year. At Millstream, a fire burned the 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 survey 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 separate 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).

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, and in different seasons. 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 having 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 largest 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 (Figure 2), 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.

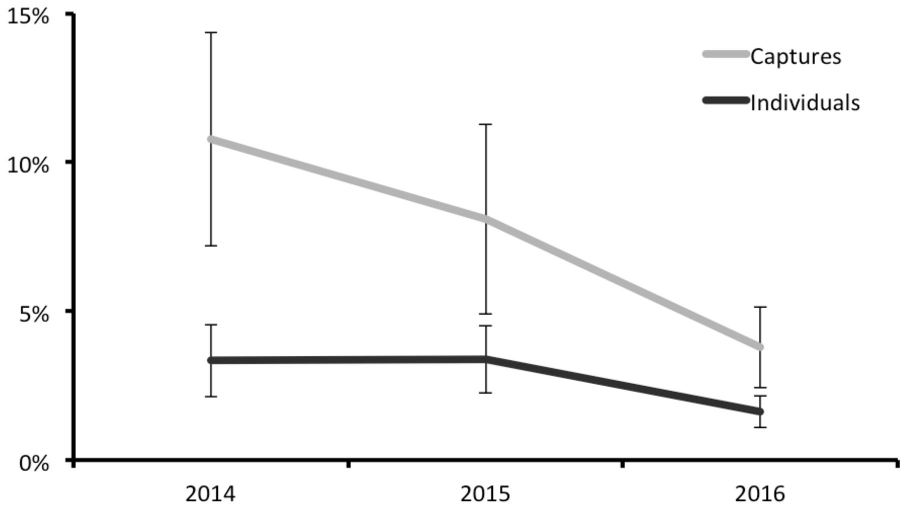

Figure 2. Capture rates and individual captures of northern quolls (*Dasyurus hallucatus*) across 12 Pilbara regional sites monitored using standard trapping methods between 2014 - 2016. *Sites monitored once (Meentheena Conservation Park and De Grey Station) or using opportunistic methods (Karlamilyi National Park) were excluded from the analyses.*

The most commonly captured species was the common rock-rat *Zyzomys argurus*, a favourite food item of the northern quoll (525 captures of an estimated 487 individuals; 7.7% capture rate). We recorded 20 captures of other species in cage traps, including *Ctenotus* sp. (3), *Egernia formosa* (2), *Tiliqua multifasciata* (1), *C. grandis* (1), *Varanus giganteus* (1), *Pseudechis australis* (1), *Pseudantechinus* sp., (2), *Petrogale rothschildi* (1), *Mus musculus* (4), *Pseudomys hermannsbergensis* (1).

For these Pilbara populations, a small number of males were recorded surviving beyond the mating season and to their second year. Larger populations at Indee, Dolphin Island, Red Hill, Mt Florance and Mallina supported small numbers of second year individuals, and a third year female was observed 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). The average population at each trapping site was 2.2 ± 0.6 individual males and 3.14 ± 0.8 females, ranging from 0 to 25 individuals per site each year. Few sites had adult animals surviving from year to year, at most sites the captures were entirely comprised of a new population cohort.

Table 2. Total captures (above) and individual capture (below) statistics for northern quolls (**Dasyurus hallucatus*****) at all sites.***

Site	2014	2015	2016	*Total*	Trap nights	Captures/ 100 traps
Cane River Conservation Reserve	1	0	0	*1*	600	0.17
Dampier Archipelago	43	61	19	*123*	600	20.50
De Grey Station	4	-	-	*4*	200	2.00
Hooley Station	-	0	0	*0*	400	0.00
Indee Station	65	81	30	*176*	600	29.33
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	*31*	600	5.17
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	*18*	200	9.00
Yarrie Station	18	12	4	*34*	600	5.67
Grand Total	**194**	**216**	**91**	***518***	**6840**	**6.50**

Site	2014	2015	2016	*Total*	Trap nights	Individuals/ 100 traps
Cane River Conservation Reserve	1	0	0	*1*	600	0.17
Dampier Archipelago	22	17	8	*64*	600	10.67
De Grey Station	3	-	-	*3*	200	1.50
Hooley Station	-	0	0	*0*	400	0.00
Indee Station	22	26	12	*68*	600	11.33
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	*11*	600	1.83
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	*4*	200	2.00
Yarrie Station	7	6	3	*16*	600	2.67
Grand Total	**79**	**107**	**40**	***229***	**7240**	**2.49**

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 to northern quolls occurs 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 Parks and Wildlife 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 Survey of a remote population at Karlamilyi National Park

Background

Two previously unrecorded endangered mammal species have been discovered in recent years at Desert Queen Baths, Karlamilyi National Park. These species, the northern quoll (known to Martu as Wiminji) and black-flanked rock-wallabies (known as Warru), both inhabit complex rocky habitat and are capable of dispersing long distances. Rock wallabies were detected via scats collected in 2012, and later confirmed on remote cameras between November 2014 and January 2015. Records of individual northern quolls had previously been detected via scats and camera trap images at Desert Queen Baths in 2012 and 2014.

KJ Martu Rangers and Parks & Wildlife undertook a fauna survey at Desert Queen Baths in September 2016 to obtain more information about the distribution of these two threatened species. We used a combination of scat searches and trapping in the Broadhurst Range, centred around Desert Queen Baths.

Outcomes

Northern quoll scats were found in the cave next to Pool 2, and one individual male quoll was captured on the fourth morning of trap checking. The animal was measured, microchipped and a DNA sample was taken for further research into the individuals relatedness to the greater Pilbara and Kimberley populations. One old rock-wallaby scat was found in a cave next to Pool 2 within Desert Queen Baths, and one in a cave approximately 20 km to the south-east, but no animals were captured.

Martu elders talked about 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.

As northern quolls have now been positively identified on three occasions at this location (2012, 2014 and 2016), recommendations for future work on this remote population include searching other likely habitat (steep, complex, rocky habitat, preferably nearby to permanent or semi-permanent water) in the wider Throssell Ranges. This opportunity for a collaborative exchange between Parks and Wildlife and KJ Martu Rangers facilitates good relationships between the two organisations, will encourage further records through opportunistic scat searches when Rangers are on country. Further detail is available in Dunlop *et al.* (2017b)

Status: Completed, further remote surveys may occur in 2017 depending on funding availability.

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

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 Parks and Wildlife 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 3).

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 3).

Northern quolls were found to conform strongly to ecological habitat associations of vegetation, climate and slope, within the rocky areas of the Pilbara (Figure 3). 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.

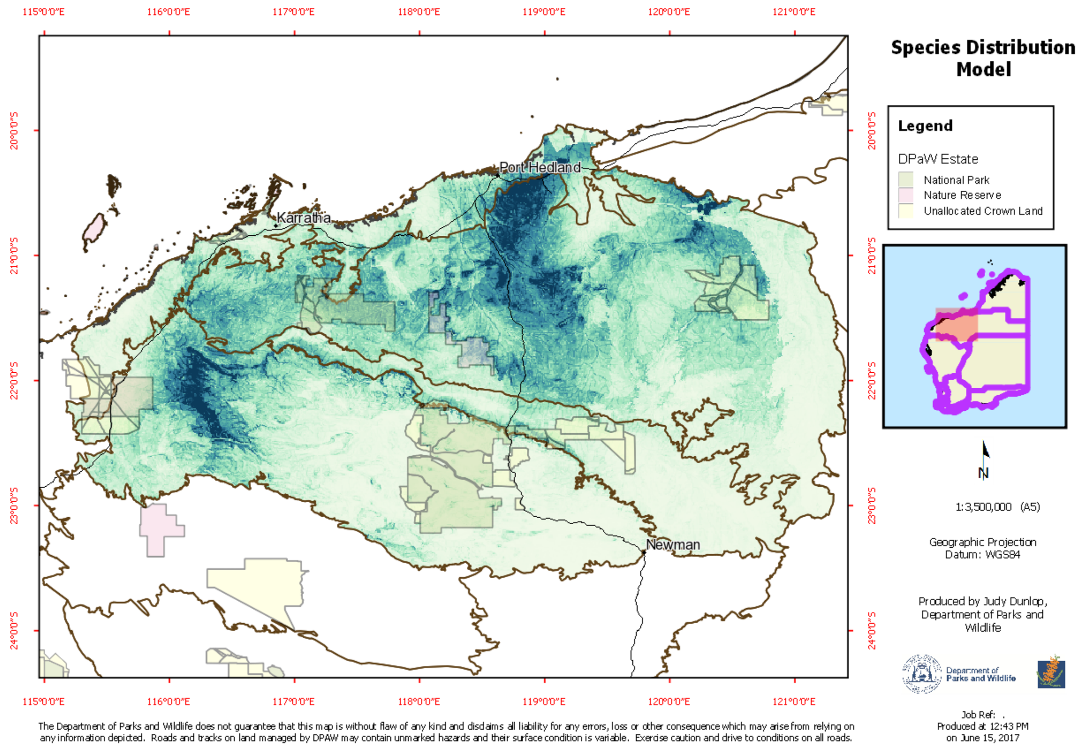

Figure 3. Heatmap of the likelihood of northern quoll presence in the Pilbara bioregion created from the final MaxEnt SDM. Likelihood of northern quoll presence ranges from dark (high likelihood) to light (low likelihood) to a 1km^2 resolution.

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

Cramer *et al.* (2016) note the requirement to “improve our understanding of habitat use, particularly in terms of defining habitat suitability at finer scales than is currently available”. Although SDMs are useful on a regional scale to identify areas of likely northern quoll presence, they are generally coarse-scale, drawing upon broad-scale GIS layers at a maximum resolution of $1km^2$. Much less certain is finer scale habitat use by northern quolls, particularly the role of smaller outcrops and the matrix of savanna and grassland within which they are embedded. This project will fill these gaps by providing landscape-scale occurrence data for northern quolls in areas that are a mix of smaller rocky outcrops, savannah and spinifex grassland. We will deploy camera traps in 24 study landscapes, each 4km in diameter, chosen according to the presence of suitable, rocky habitat, and a mix of fire ages surrounding the rocky outcrop habitat, from areas that have burnt frequently to areas that are infrequency burnt.

Outcomes

The expected outcomes of this project include occupancy models of the northern quoll, and for predators (feral cats, foxes and dingoes) in different fine-scale habitats within the Pilbara bioregion. This project will be part of a collaborative PhD project between Charles Sturt University, the Department of Parks and Wildlife and Deakin University.

Status: PhD student started March 2017; fieldwork occurring in 2017

3 Population dynamics and ecology

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. Genetic and dietary studies offer insights into how northern quolls utilise their environment, their dispersal patterns and breeding strategies.

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 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. This study aims 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 analyses 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 Australian northern quolls.

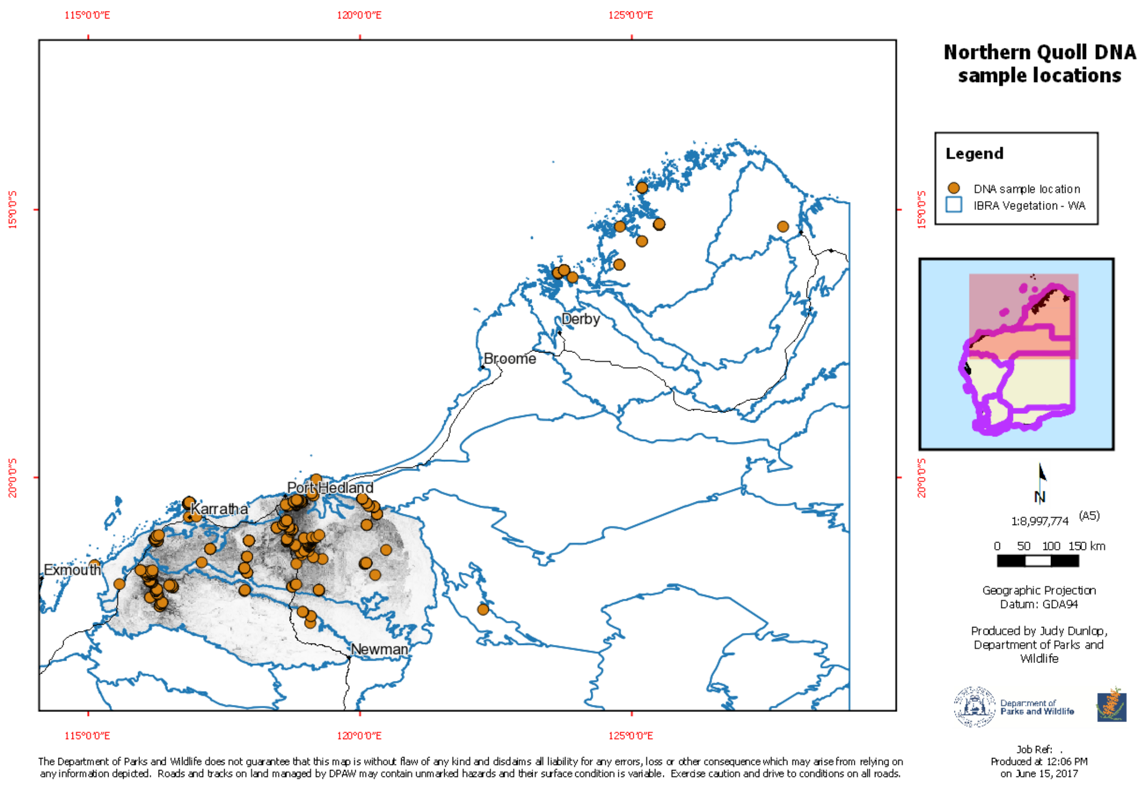

Figure 4. Spatial spread of northern quoll tissue sample locations in the Kimberley and Pilbara regions. A total of approximately 1800 Western Australian northern quoll tissue samples are available.

Outcomes

Initial results align with How *et al.* (2009), indicating that measures of genetic diversity of northern quolls from the Pilbara were lower than that recorded on the Kimberley mainland. The genetic profiles demonstrate that the Pilbara population is a single genetic cluster throughout, suggesting high levels of annual male dispersal occurring between localities across the region. Mainland Pilbara northern quolls retain moderate genetic diversity, and show no evidence of recent or long-term population bottleneck. This result contradicts current opinions that the Pilbara population has undergone significant, recent population decline.

Samples used in the preliminary work were biased toward a few sites, where DNA samples from a large numbers of individuals came from a small number of sites. Additional samples collected between 2012 and 2016 (Table 3) have been 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. A further 343 tissue samples have been collected from tissue vouchers at the WA Museum. 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 to approximately 1800 for a comprehensive population analysis of the northern quolls in Western Australia (Figure 4).

Status: Ongoing. Genetic sequencing occurring in 2017

Table 3. Northern quoll tissue samples collected 2011–2016 for analysis of Pilbara population genetics. *Locations are presented west to east across the Pilbara. Latitude and longitudes are approximate localities for the sample groups. CP = Conservation Park, NP = National Park, NR = Nature Reserve.*

Location	**Latitude**	**Longitude**	**Samples already genotyped**	**Additional samples collected**	**Total**
Cane River CP	-22.0	115.6		1	**1**
Robe River Valley	-21.7	115.9	10	0	**10**
Yarraloola Station	-21.8	116.1		45	**45**
Red Hill Station	-22.1	116.2	42	114	**156**
Pannawonica	-22.0	116.5		13	**13**
Dolphin Island NR	-20.5	116.8	7	38	**45**
Karratha Townsite	-20.7	116.8		1	**1**
Mt Anketell	-20.7	117.0		1	**1**
Millstream Chichester NP	-21.3	117.2		15	**15**
Coolawanyah Station	-21.7	117.9		20	**20**
Hamersley Station	-22.1	117.9	1	4	**4**
Mt Florance Station	-21.8	117.9		11	**11**
Mallina Station	-21.2	118.0		19	**19**
Mt Dove	-20.9	118.5	2	3	**5**
Indee Station	-20.9	118.6		69	**69**
BHP Rail Sites			33	8	**41**
Wodgina	-21.2	118.6		19	**19**
Roy Hill rail corridor				15	**15**
Hooley Station	-22.0	118.7		1	**1**
Tom Price	-22.0	118.7	1	5	**6**
Poondano	-20.4	118.8	63	84	147
Port Hedland	-21.3	118.8		2	**2**
Koodaideri	-22.5	118.9		5	**5**
Woodstock	-21.6	119.0	2		**2**
Turner River	-21.2	119.0	23		**23**
Abydos Station	-21.1	119.1	42	14	**56**
De Grey Station	-20.3	119.1		4	**4**
Mt Webber	-21.5	119.3		1	**1**
McPhee Creek	-21.6	120.1	11	1	**12**
Yarrie Station	-20.5	120.1	33	33	**66**
Nullagine	-21.8	120.3	1		**1**
Meentheena CP	-21.4	120.5		1	**1**
Karlamilyi	-22.5	122.3		1	**1**
Total number of Pilbara tissue samples			**271**	**547**	**817**

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 (Holleley *et al.*, 2006Holleley *et al.*, 2006, #94906;) *et al.*, 2006, #94906;), 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 aim 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.

To answer these questions, tissue from northern quoll pouch young and mothers was collected from two sites where northern quolls are abundant; Indee Station near Port Hedland, and Dolphin Island in the Dampier Archipelago (Table 4). Both of these sites are part of the annual monitoring program so there is background genetic data from prior data collection and tissue sampling of adults. 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). Analysis of paternity and relatedness of pouch young to adults, forms a collaborative honours project being completed in 2017, under Dr Peter Spencer at Murdoch University.

Table 4. Summary of DNA samples taken from northern quoll mothers and pouch young (PY) for paternity testing. Trapping included 200 trap nights at each location.

	Dolphin Island Nature Reserve	Indee Station	Total
Females captured	13	5	18
Pouch young sampled	65	35	100
Average number of PY ± Standard Error	5.00 ± 0.47	7.00 ± 0.63	

Status: Ongoing, forming an honours project in 2017

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 the majority of 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 a large number of scats collected across ~100,000 km2. 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 5) 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 (Jun–Sep). 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 3-fold differences 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. The broad and variable diet of northern quoll indicates opportunism similar to that of other small carnivores. Given this broad dietary niche, conservation managers will need a priori knowledge of local prey abundance if they are to accurately predict the composition of northern quoll diets.

Dietary items were very diverse (Table 5) 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 the majority 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 an 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.

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.

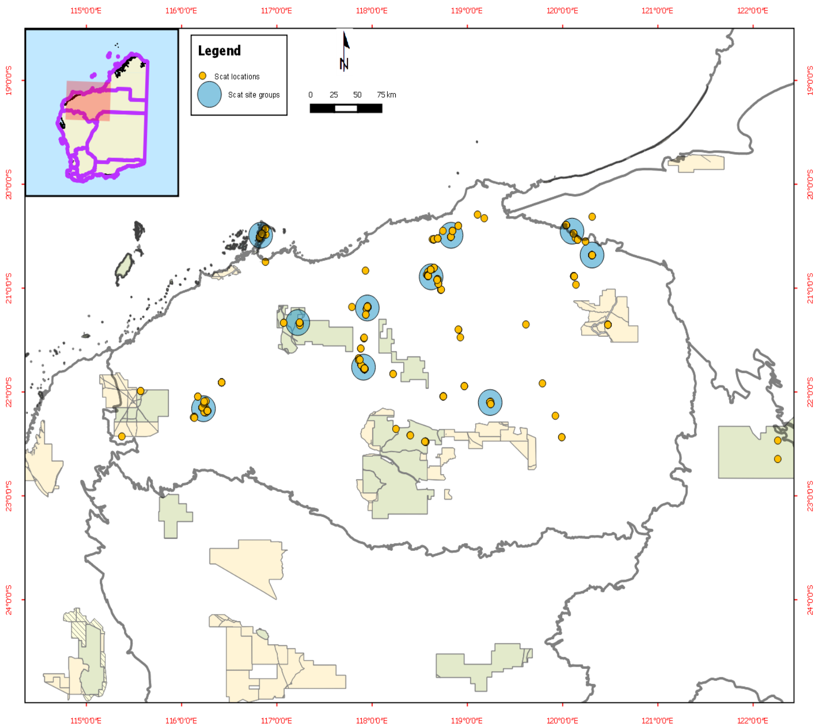

Figure 5. Map depicting northern quoll scats collected throughout the Pilbara, and the ten site groupings with 19 or more scats within a 30km radius. *The raster layer depicts Parks and Wildlife managed conservation reserves and unallocated crown land managed for conservation, with the grey line delimiting the Pilbara bioregion.*

Table 5. 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 to be 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

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 feral predator control or different approaches to fire management. This project will be part of a collaborative PhD project between Charles Sturt University, the Department of Parks and Wildlife and Deakin University.

Status: Ongoing, forming part of a PhD project from March 2017

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).

The potential exists in the Pilbara to conduct 'natural' experiments on the recolonisation of northern quolls after mining ceases, including how to best design waste rock dumps so that habitat complexity and productivity is maximised by, for example, experimenting with the size and positioning of boulders, and their spatial arrangement in relation to surrounding landscape features. First steps toward creating effective artificial habitat will be defining the characteristics of functional denning habitat currently known to be used by female northern quolls. Factors such as geology, size and shape of boulders, thermal characteristics and position within the landscape could be examined in known northern quoll populations to provide advice on the construction of trial artificial habitats. Although resources are not currently allocated to this aspect of the program, it is a priority area that will be investigated, should the opportunity become available.

Status: Scoping of research project continuing in consultation with development proponents and regulators.

Reports, papers and presentations

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*, 38(2) 135-148

Dunlop, J.A. (2017). Quolls on Country. *Landscope*, 32(3), 20-26.

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.

Molloy, S.W., Davis, R.A., Dunlop, J. and van Etten, E.J.B. (2016) Spatial modelling the northern quoll (*Dasyurus hallucatus*) in the Pilbara: Informing conservation management of an isolated population of an endangered and iconic species. Presented at *Species on the Move International Conference* Conference*,* Hobart, Tasmania.

References

Adhikari D, Barik SK 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 MJ, 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 RJ (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 RJ, Cooke R and White JG (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 RW and Griffiths AD (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.

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

Cramer V, Dunlop J, Davis RA, 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 MS and Webb JK (2014). Variation of prey responses to cues from a mesopredator and an apex predator. *Austral Ecology*, **39**, 749-754.

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

Dunlop JA, 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 JA, 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 JA, Rayner K and Morris KD. (2016). Pilbara northern quoll research program - Annual Report. Annual Report 2014-2015: Department of Parks and Wildlife, Kensington.

Dunlop JA, Rayner K and Doherty TS (2017a). 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. (2017b). Targeted survey of northern quolls and black-flanked rock-wallabies in Karlamilyi National Park. Department of Parks and Wildlife, Kensington.

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.

Glen AS, Cardoso MJ, Dickman CR and Firestone KB (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 AS and Dickman CR (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 AW and Fisher DO (2016). Introduced predators and habitat structure influence range contraction of an endangered native predator, the northern quoll. *Biological Conservation*, **203**, 160-167.

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

Holleley CE, Dickman CR, Crowther MS and Oldroyd BP (2006). Size breeds success: multiple paternity, multivariate selection and male semelparity in a small marsupial, Antechinus stuartii. *Molecular Ecology*, **15**, 3439-3448.

How RA, Spencer PBS and Schmitt LH (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.

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.

Kearney M, Phillips BL, Tracy CR, Christian KA, Betts G and Porter WP (2008). Modelling species distributions without using species distributions: the cane toad in Australia under current and future climates. *Ecography*, **31**, 423-434.

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 RJ, Moilanen A, Matthews JW, Christie K, Gardner TA, Keith DA, Lindenmayer D and McAlpine CA (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 NL, Burbidge AA, Baynes A, Brereton RN, Dickman CR, Gordon G, Gibson LA, Menkhorst PW, Robinson AC and Williams MR (2007). Analysis of factors implicated in the recent decline of Australia's mammal fauna. *Journal of Biogeography*, **34**, 597-611.

Molloy SW, Davis RA, Dunlop JA and van Etten EJB (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 SW, Davis RA and Van Etten EJB (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 KD, Cowan M, Angus GJ, Anderson H, Garretson S, Algar D, Moro D and Williams MR. (2015a). The northern quoll cat bait uptake and survivorship study, Yarraloola Land Management Area, Pilbara Region, WA. Department of Parks and Wildlife, Perth.

Morris KD, Cowan M, Angus GJ, Anderson H, Garretson S, Palmer, Russell, Williams, Matthew R and Pearson DJ. (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.

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

Reside AE, Welbergen JA, Phillips BL, Wardell Johnson GW, Keppel G, Ferrier S, Williams SE and VanDerWal J (2014). Characteristics of climate change refugia for Australian biodiversity. *Austral Ecology*, **39**, 887-897.

Schmitt LH, Bradley AJ, Kemper CM, Kitchener DJ, Humphreys WF and How RA (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 PBS, How RA, Hillyer M, Cook A, Morris KD, 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 PBS, How RA and Schmitt LH. (2010). The Northern Quoll population on Koolan Island: Molecular and demographic analysis. Report prepared for Mount Gibson Iron Limited: Murdoch University, Perth.

Start AN, Burbidge AA, McKenzie NL 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 BL, Letnic M, Brown GP, Shine R and Baird SJE (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.

Watts CHS and Aslin HJ. (1981). The rodents of Australia. Angus & Robertson, Sydney.

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

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

Woinarski JCZ, 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 RD, Richardson KC, Garavanta CAM, Saffer VM and Bryant KA (2000). Opportunistic breeding in the polyandrous honey possum, *Tarsipes rostratus*. *Australian Journal of Zoology*, **48**, 669-680.

Woolley PA, 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.