GOVERNMENT OF WESTERN AUSTRALIA

Department of **Biodiversity, Conservation and Attractions**

Pilbara Northern Quoll research program
Annual report 2017

Version: 2

Approved by: L. Gibson

Last Updated: 16 July 2019

Custodian: J Dunlop

Review date:

Version number	Date approved DD/MM/YYYY	Approved by	Brief Description
1	1 April 2019	L. Gibson	
2	15 July 2019	L. Gibson	

Pilbara Northern Quoll Research Program

2018 Annual Report

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April 2019

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April 2018

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The recommended reference for this publication is:
Dunlop, J., Birch, N., and Moore, H., 2018, *Pilbara Northern Quoll research program, Annual report 2017*, Department of Biodiversity, Conservation and Attractions, Perth.

This document is available in alternative formats on request.

Cover image: A northern quoll in a cage trap at Karijini National Park, during an annual monitoring session.
Image credit: Judy Dunlop

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Acknowledgements

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

The honours project investigating northern quoll denning refuges was undertaken by Mitch Cowan from Charles Sturt University, supported financially and in-kind by Roy Hill. Harry Moore's PhD project on the interactive effects of fire, habitat and feral predators on northern quoll populations is a collaborative project between DBCA, Roy Hill and Charles Sturt University. We are grateful to Dale Nimmo, Leonie Valentine, David Watson and Euan Ritchie for supervising these two students. Distribution modelling and home range estimates were undertaken in collaboration with colleagues Melinda Henderson, Dr Rob Davis and Dr Shaun Molloy from Edith Cowan University. Analysis of northern quoll diet was a collaborative work with Dr Tim Doherty from Deakin University. Population viability models were a collaborative work with Dr Dorian Moro, with goals to inform the Rio Tinto threatened species offset planning. Pilbara population genetics analyses and paternity testing are being undertaken by Dr Peter Spencer and Rainer Chan, as a collaboration between DBCA and Murdoch University. Trials of Felixer feral cat grooming traps are part of Dr John Read's Australia-wide trial, and are in collaboration with Roy Hill, Fortescue Metals Group and Nifty. Surveys at Karlamilyi National Park and the surrounding Martu Determination Area was undertaken with KJ Martu Indigenous Knowledge Program and Martu Rangers.

We are very grateful for the field and logistical assistance provided by Hannah Anderson, Sophie Arnall, Gareth Catt, Jacob Champney, Lachlan Crossley, Harriet Davie, Brent Johnson, Joanne King, Kirsten Marmion, Harry Moore, Mike Robinson, Coral Rowston, Zac Sims, Elizabeth Trevenen, Matthew Verdouw and Alicia Whittington.

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. We estimated capture probabilities for

northern quolls via live trapping and camera trapping in order to determine the survey effort required for 95% confidence of detection.

- Work on determining the characteristics of female northern quoll dens is ongoing, with the goal to provide guidelines for artificial habitat creation.
- Interactions between northern quolls and predators remains a focus, with current work examining the relationships between presence of quolls according to predators and habitat variables, as well as testing of the efficacy of Felixer grooming traps as another tool for controlling feral cats.

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). They are a small (240–1120g; Oakwood, 2008), omnivorous marsupial (Dunlop *et al.*, 2017) with a partly semelparous reproductive strategy, whereby nearly all males die following the mating season (Fisher *et al.*, 2013).

Northern quolls are listed as Endangered by the IUCN and Australian federal government (Oakwood *et al.*, 2016; Department of Sustainability, 2011). 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). Several other ecological factors are contributing to the decline of quolls and other medium- sized mammal species, including predation by feral cats (*Felis catus*), wild dogs/dingoes (*Canis lupus*), habitat degradation caused by altered fire regimes, grazing pressure by introduced herbivores, as well as direct habitat loss and fragmentation (Braithwaite and Griffiths, 1994; Hill and Ward, 2010; Woinarski *et al.*, 2014).

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 behaviour 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 encourage avoidance behaviour of quolls prior to the arrival of the cane toad front, allowing for long term female survival (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 populations across northern Australia (Hill and Ward, 2010). They are present in the complex 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 of habitat loss from mining and infrastructure development (McKenzie *et al.*, 2007), and living amongst industrial developments is likely to be detrimental to long term population viability (Amir Abdul Nasir *et al.*, 2018). As a consequence of these attributes, the Pilbara population is listed as Specially Protected Fauna in Western Australia under the Wildlife Conservation (Specially Protected Fauna) Notice 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), less 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 guided by 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 modelling;
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 2018.

1 Survey and monitoring

There has been a significant increase in survey effort in the Pilbara as a result of EIA associated with mining developments. Species records in the region have therefore varied in origin, from older fauna surveys, to desktop or area searches on mining tenure. Prior to 2010 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 involved 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

Effective management of threatened species requires robust information and understanding of past and present distribution to inform sound decision making. Searching in previously unsurveyed or poorly surveyed 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 (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 biased 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).

Outcomes to date

The DBCA northern quoll research program has contributed more than 1600 Pilbara northern quoll records to the previously 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, 2010b). Presence records include sightings, trapped animals, tracks, scats and images from camera traps. Of the 7234 presence records of northern quolls (Figure 2) found in the NatureMap database, 4537 are from the Pilbara. The majority of these are recent records; only 313 records date back further than 2009 (Figure 1). While fewer records have been added to NatureMap in the last few years, we have been targeting poorly surveyed areas to increase our understanding of quoll distribution.

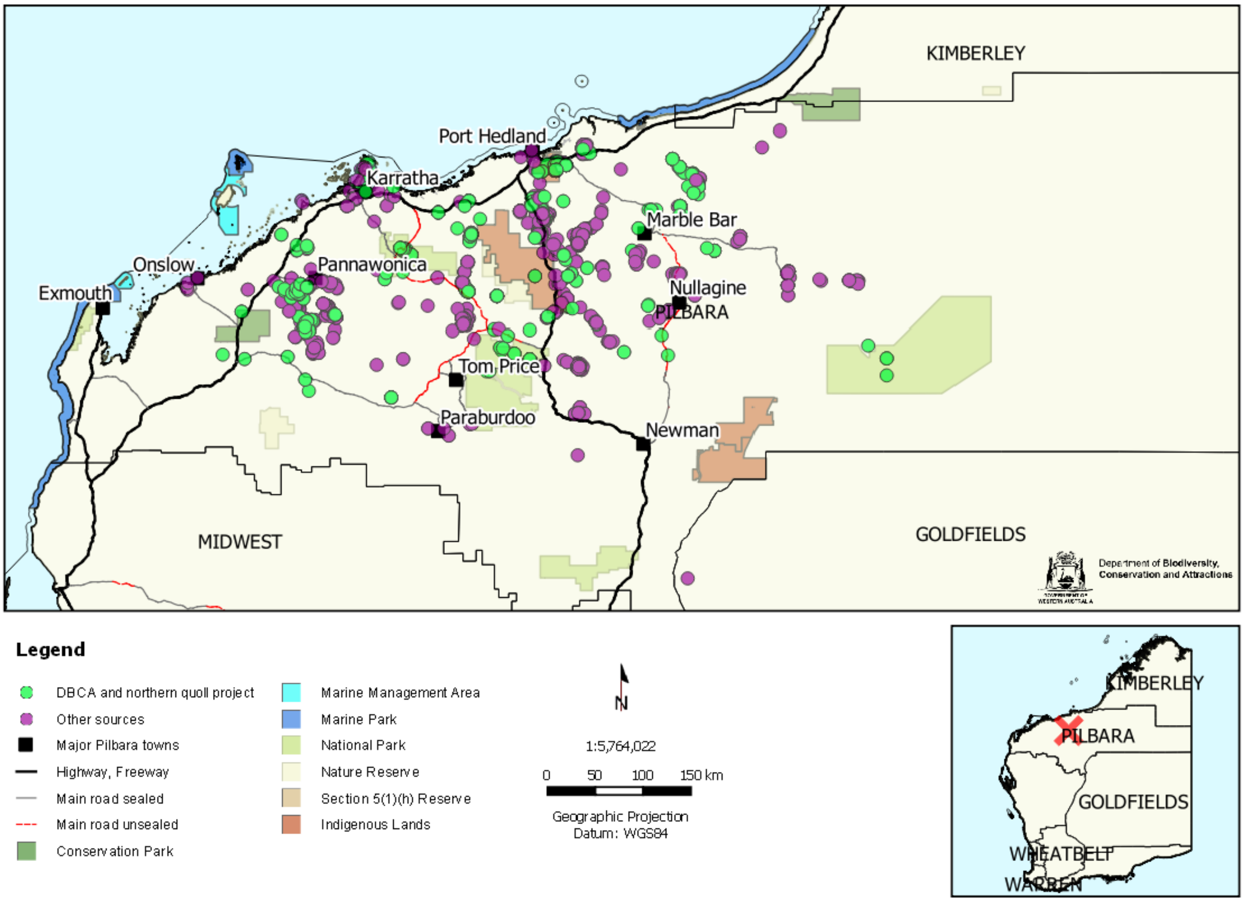

Figure 1. Northern quoll records from the Pilbara, available on NatureMap. Records collected by the Department of Biodiversity, Conservation and Attractions and the Pilbara northern quoll monitoring program since 2011 are shown in green, universities, biological consultants or other sources in purple.

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.

Existing and new data can be used to further refine and optimise the methods used to monitor northern quolls in the Pilbara to increase confidence that the data being collected can track long-term population trends. The extensive monitoring program undertaken on northern quolls on Koolan Island (in the Kimberley) potentially offers a model for comparison with both island and mainland populations in the Pilbara.

The major research effort needed now is to assess the statistical power of the existing monitoring program and its capability to detect changes in abundance of varying proportions.

Analysis can be conducted on the current monitoring data, but will be increasingly robust and useful as several years of monitoring data are accrued. These data can also be used to assess the extent of short-term fluctuations in quoll abundance resulting from seasonal conditions, and hence provide information on the capability of the monitoring program to segregate longer-term trends (signal) from short-term fluctuations (noise), especially is an episodic and highly variable environment like the Pilbara. Results from power analyses may indicate that the monitoring protocols or effort may need some refinements to achieve an acceptable level of power.

Outcomes

An additional year of monitoring data has been collected for analysis of population trends. Existing and new data can be used to further refine and optimise the methods used to monitor northern quolls in the Pilbara to increase confidence that the data being collected can track long-term population trends. The extensive monitoring program undertaken on northern quolls on Koolan Island (in the Kimberley) potentially offers a model for comparison with both island and mainland populations in the Pilbara.

Status

Long-term data collection and analysis ongoing.

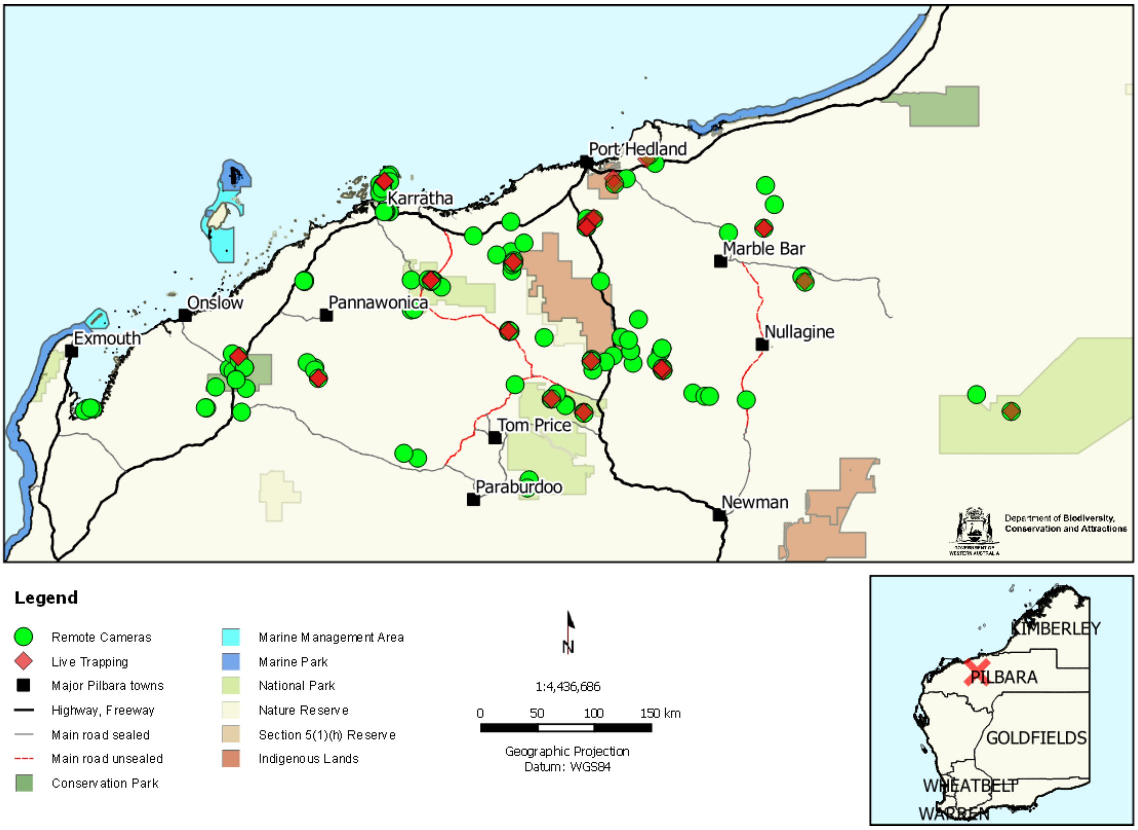

Figure 2. Spread of DBCA effort surveying northern quolls via camera and cage trapping in the Pilbara region, 2011-2018.

*Table 1. Total captures (above) and individual capture (below) statistics for northern quolls (Dasyurus hallucatus) at all sites. * indicates survey effort was conducted through remote camera deployment, and individuals are estimated numbers (below)*

Site	2014	2015	2016	2017	2018	*Total*	Trap nights	Captures/ 100 traps
Cane River Conservation Reserve	1	0	0	-	-	*1*	600	0.17
Dampier Archipelago	43	61	19	17	18	*158*	1000	15.80
De Grey Station	4	-	-	-	-	*4*	200	2.00
Hooley Station	-	0	0	*	*	*0*	400	0.00
Indee Station	65	81	30	41	124	*341*	1000	34.10
Karijini National Park	0	0	12	*	12	*24*	800	3.00
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	0	*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**	**154**	**725**	**8080**	**8.97**

Site	2014	2015	2016	2017	2018	*Total*	Trap nights	Individuals/100 traps
Cane River Conservation Reserve	1	0	0	-	-	*1*	600	0.17
Dampier Archipelago	22	17	8	11	11	*69*	1000	6.90
De Grey Station	3	-	-	-	-	*3*	200	1.50
Hooley Station	-	0	0	3*	1*	*0*	400	0.00
Indee Station	22	26	12	23	32	*115*	1000	11.50
Karijini National Park	0	0	4	4*	5	*9*	800	1.13
Karlamilyi National Park	0	-	1	-	6*	*1*	240	0.42
Mallina Station	6	14	0	8*	-	*20*	600	3.33
Meentheena Conservation Park	-	1	-	-	-	*1*	200	0.50
Millstream Chichester National Park	9	1	1	3	0	*14*	800	1.75
Mt Florance Station	6	5	3	12*	8*	*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	4	*7*	240	2.92
Yarrie Station	7	6	3	8*	6*	16	600	2.67
Grand Total	**79**	**82**	**40**	**39**	**52**	**292**	**8080**	**3.61**

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 by different techniques. 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 and minimum effort required to achieve 95% confidence in detection probabilities for two sampling methods.

To test the efficacy of cameras traps at detecting northern quolls at the landscape scape, we established 23 study landscapes across the Pilbara, each covering $0.75km^2$. Within each landscape we deployed five downward facing Reconyx PC900 remote sensing cameras for an average length of 212 days.

To test the detection probability of cage trapping, we analysed the data from annual surveys (four nights of 50 traps) at several sites using Pollock's robust design. We used (i) closed-population models to data collected within each primary survey session (i.e., between secondary sessions) to estimate the probability of capture and recapture (p and c, respectively), and (ii) open-population models to be fit to data collected between each primary survey session to estimate probability of survival (S), migrating away from the study area (γ'') and migrating *to* the study area (1-γ'). Since so few male quolls were detected across primary survey sessions, this analysis focused only on female quolls. Due to lack of differences between the datasets, the Dolphin and Indee locations were combined into a single data set. The RMark package (v. 2.2.5, Laake 2013) in R (v. 3.5.2, R Core Team 2018) was used to fit these models.

Outcomes to date

Based on camera trapping data using five baited cameras per site, averaged over 23 landscapes, our detectability model estimates suggest 95% confidence of quoll absence after 12.6 days (Figure 3).

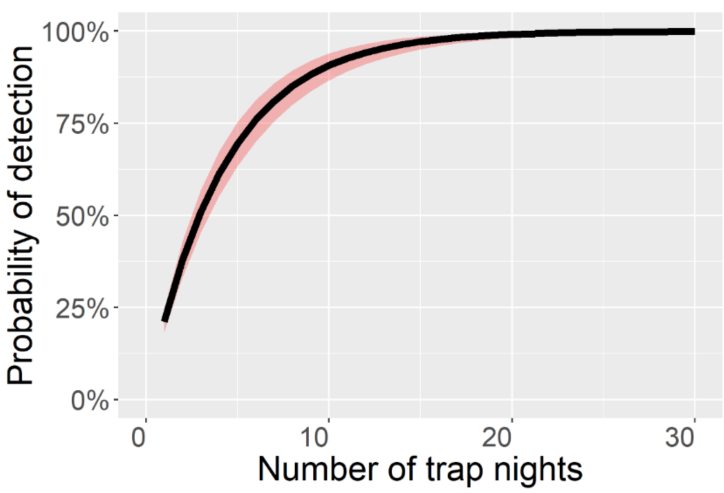

Figure 3. Probability of detecting northern quolls using five downward-facing baited camera traps. Northern quolls are highly detectable, with 95% confidence of detection after 12.6 camera-nights (5 cameras x 2.5 nights)

The estimates of capture probabilities for cage trapping via MARK analysis appeared to vary by session, indicating that environmental factors impacted the likelihood that animals would enter traps. Capture probabilities ranged from 0.28 to 0.52 for the 200-trap night methodology. SECR analysis measures capture probability in a slightly different way, and indicates the probability of detection if a trap was placed on an animal's home range centre, g0. This is not directly comparable to the MARK analysis but also indicates a high capture probability of 0.29 (95 % CI: 0.22, 0.40), with the spatial scale parameter, σ, estimated to be 77.5 m.

For population analyses using the trapping data from Dolphin Island, the best fitting modelling according to AIC model selection was when density and σ were constant for the survey period, but g0 was dependent on animal behaviour and varied at each trap location. Based on this model, the estimated average density of quolls was 0.29 per hectare (95 % CI: 0.22, 0.40), i.e., stable across the survey period.

Next steps are to provide guidelines on requirements for 95% confidence of presence/absence for traps or cameras with differing levels of effort.

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 determining 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 markings or spot patterning, camera traps can be used to estimate demographic parameters such as relative abundance (Hohnen *et al.*, 2013). 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 (Figure 4). 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 images 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 2.55m^{2}, effectively increasing battery life.

Figure 4. A comparison of vertical and horizontally oriented camera traps, with a bait pod secured to the stake with the downward-facing camera. Vertical orientation reduces the rate of 'false triggers' by reducing vegetation in the frame. Although this strategy reduces the field of view from several hundred m^2 to approximately 2.55m^2, detectability for small species such as northern quolls appears to remain comparable and permits individual identification via spot pattern.

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. 110 downward cameras have been deployed across a 7,275km^2 area within the Roebourne and Chichester subregions. Cameras are deployed for an average of 212 days each and have so far recorded over 3100 independent species detections. 1262 of these detections have been positively identified as northern quolls.

To test how downward facing cameras compared to a traditional outward facing configuration in terms of species detectability, we established 46 comparison sites, each comprising of a downward facing camera, paired with an outward facing camera. Preliminary results suggest both configurations are comparable in terms of their capacity to detect northern quolls, despite downward facing cameras having a significantly reduced field of view. Results showed downward cameras should be deployed for a minimum of 31.3 days to be 95% confident northern quolls are absent from a site. Outward cameras should be deployed for no less than 22.7 days. Further, results indicate downward-facing cameras are highly effective at capturing images suitable for individual identification, with over 80% quoll images being suitable for individual identification. Feral cats were less detectable using downward-facing cameras.

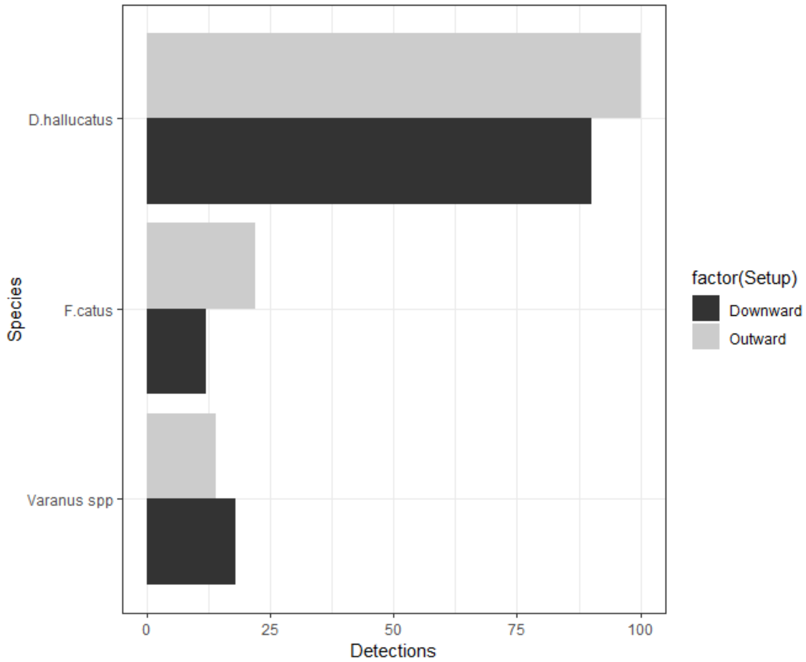

Figure 5. Detections of three species by downward-facing and outward-facing camera trap methods; northern quoll (D. hallucatus), feral cat (F. catus) and goannas (Varanus spp).

Table 2. Detectability model for testing confidence of absence for three Pilbara species, using downward- and outward-facing camera traps.

Species	Method	Number of nights needed to be confident of absence		
		80%	90%	95%
D. hallucatus	Outward	22.78	17.51	12.23
	Downward	31.37	24.11	16.85
F. catus	Outward	133.62	102.7	71.78
	Downward	237.88	182.84	127.8
Varanus spp	Outward	120.24	92.42	64.6
	Downward	116.81	89.787	62.75

Status

Ongoing, data analysis occurring in 2019. This project forms part of a collaborative PhD project between Charles Sturt University, DBCA, The University of Western Australia and Deakin University, supported financially and in-kind by Roy Hill.

1.5 Survey of a remote population at Karlamilyi National Park

Background

Two previously unrecorded endangered mammal species were rediscovered in 2012 at Desert Queen Baths (DQB), Karlamilyi National Park. Northern quoll (known to Martu as Wiminji) and black-flanked rock-wallabies (*Petrogale lateralis,* 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 (pre-1960s), black-flanked rock wallabies were more common than euros, and a popular food item. Northern quolls were commonly seen in rocky breakaways through Karlamilyi National Park and the greater Martu Determination Area (MDA).

We have now collected records of northern quolls from a variety of areas within Karlamilyi and the MDA almost every year since 2012. Records have been collected using several methods; via camera trap images, scat collection and DNA fingerprinting, or by cage trapping. These northern quoll records represented a modern 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 Desert Queen Baths. 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 and Wildlife undertook a fauna trapping survey at Desert Queen Baths in September 2016 to attempt to capture animals that had been seen on camera traps. 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 2017-18, DBCA and KJ Martu Rangers expanded the search to broader 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 and set camera traps in targeted areas. A total of 24 cameras were set in five locations around Karlamilyi in September 2017 and were collected nine months later in June 2018.

During camera setting and collection activities, we searched for animal signs; scats, tracks, and bones in caves. Northern quoll scats were collected from five locations into paper envelopes and processed at Murdoch University using DNA profiling to identify different individuals. 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.

Northern quolls have a frenetic life cycle whereby all the one-year-old males expend so much energy in the breeding season and have such extreme hormonal spikes that their immune system collapses, and they die in October after they have bred. Young emerge from their mothers' dens in January to February, so photos of small animals in January confirms breeding is occurring there.

Outcomes

Five northern quoll scats were collected from three locations approximately 50 km apart, within the Martu Determination Area. There were at least four unique genotypes present in the samples, indicating at least four individual northern quolls were responsible for the five scats.

Northern quolls were photographed at three of the five camera trapping locations. We used the quolls' individual spot patterns to estimate that there were at least six quolls detected, of both sexes. Smaller, young quolls were seen to emerge in summer, confirming breeding is occurring.

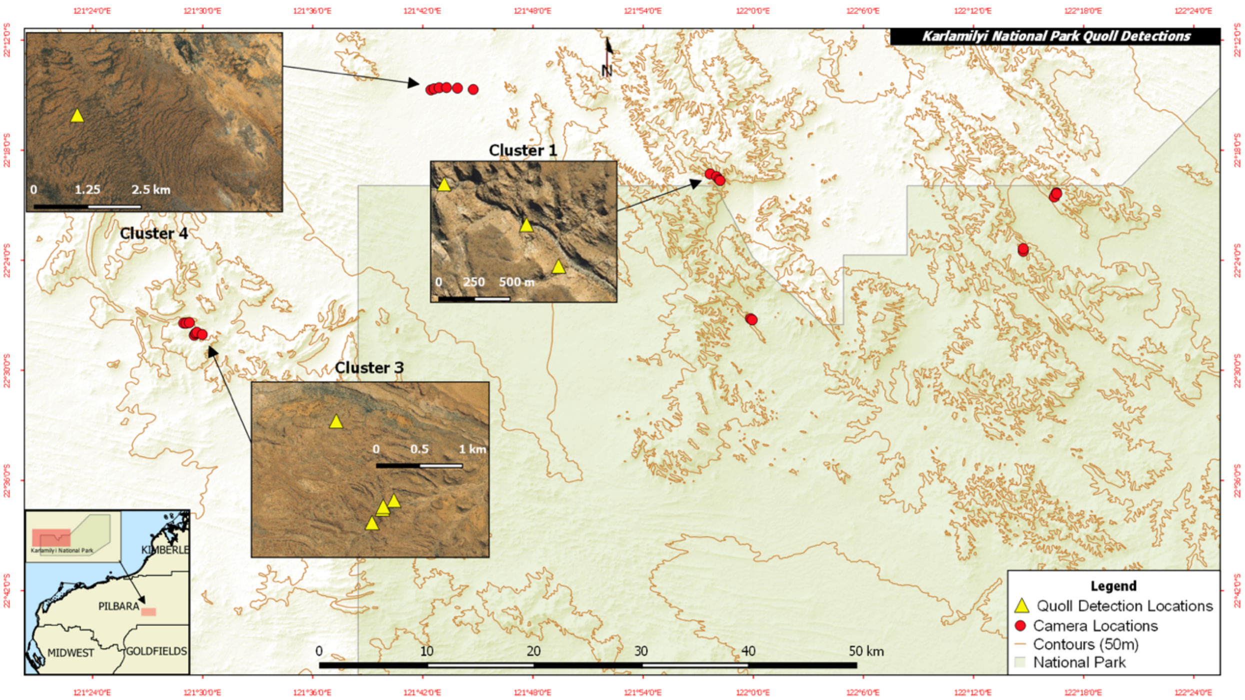

Figure 6. Locations of camera traps set from Sept 2017 to June 2018 (red dots) in order to detect northern quolls (yellow dots). Three of the six camera groups detected northern quolls. Karlamilyi National Park is shaded green within the Martu Determination Area.

Based on the consistent, low density records of northern quolls from 2012 to 2018 it would appear that quolls are opportunistically present in dissected rocky areas of the arid eastern Pilbara. Quolls have now been detected in this area in six of the last seven years, with the searches getting broader each time. This indicates that the marginal desert habitat is supporting a low-density population of quolls that are successfully breeding and surviving.

Status

Ongoing, in collaboration with KJ Martu Rangers.

Publications

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, 40(2), 234-242.

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

Dunlop, J.A. (2019). Quolls spotted in the desert. Landscope, 33(1), 20-23

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.

The EPBC Act referral guideline (Department of the Environment, 2016) defines critical habitat as habitat that is within the modelled distribution of the northern quoll that 'provides shelter for breeding, refuge from fire/predation and potential poisoning from cane toads'. Northern quolls may occur in (and be reported from) a wide range of habitats, but some of these habitats may be of marginal suitability or 'sink' habitats (e.g. some areas occupied temporarily by dispersing males during the breeding season). Habitats that are preferred by females for denning are likely to be the most critical for the long-term survival of any particular subpopulation. Factors that define such den sites are not yet well established. Our understanding of fine-scale habitat use has been limited as a result of inconsistent and inadequate site descriptions in presence/absence records (Molloy *et al.*, 2017).

Factors determining habitat suitability may not be constant, for example a rockpile may be generally suitable habitat, but not if its vegetation has recently been impacted by wildfire, or if that rockpile also happens to support several feral cats. Hence, it is necessary to record, in a uniform manner that can be compared across sites, both the permanent features of habitat (e.g. topographic relief, geology, den entrance characteristics) and the dynamic features of that habitat (proximity of vegetation, signs of feral predators, grazing by introduced herbivores).

Furthermore, currently there is little information on quoll subpopulation structure and responses to landscape-scale connectivity. An isolated rockpile may have the requisite geological and topographic features to render it suitable habitat for quolls, but if it is small or distant from other suitable habitat, it may be unable to retain a viable subpopulation, and hence should not be considered critical habitat.

Completed projects

We developed several distribution models in order to facilitate the ongoing *in-situ* conservation of northern quolls in the Pilbara (Molloy *et al.*, 2017). 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.

Northern quolls were found to conform strongly to ecological habitat associations of vegetation, climate and slope, within the rocky areas of the Pilbara (Figure 7). 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 genetic information suggests that all Pilbara northern quoll populations are genetically linked, and high level of dispersal occurs between geographically distant populations within the Pilbara (Spencer *et al.*, 2013; Woolley *et al.*, 2015).

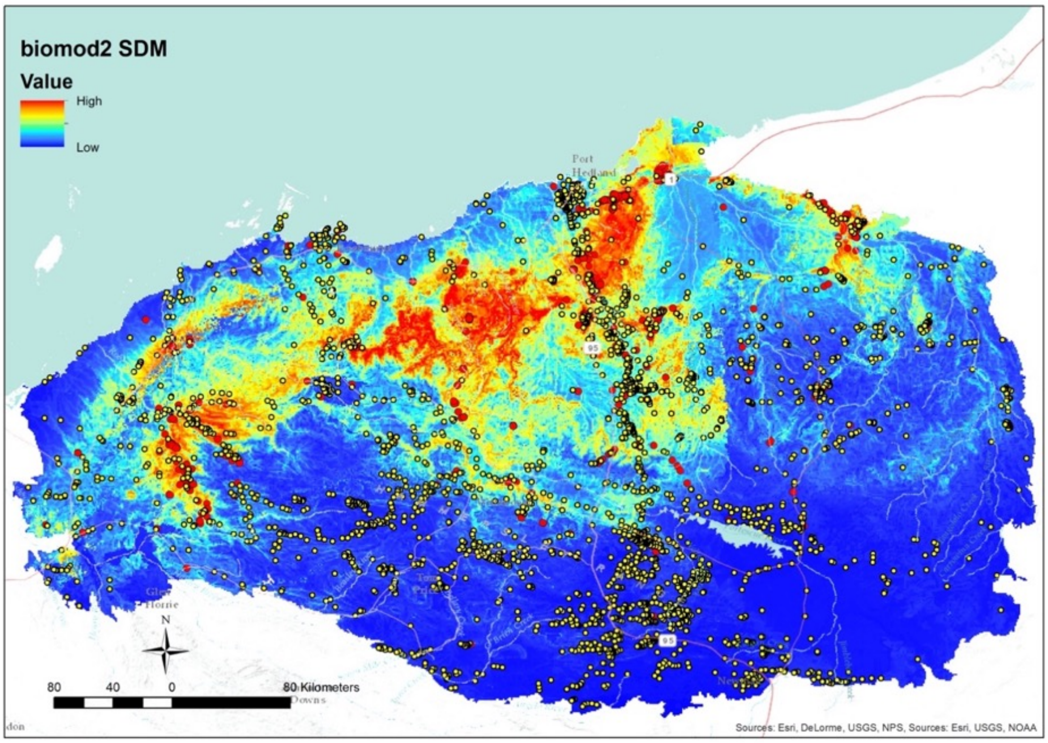

Figure 7. Heatmap of the likelihood of northern quoll presence in the Pilbara bioregion created from the final MaxEnt SDM. Likelihood of northern quoll presence ranges from red (high likelihood) to blue (low likelihood) to a 1km² resolution. Dots form the bias layer, where yellow dots indicate fauna surveys undertaken where northern quolls were not detected, and red dots indicate fauna surveys that detected northern quolls.

2.1 Occupancy Modelling

Background

A priority identified in Cramer *et al.* (2016) was to gain an improved understanding of northern quoll habitat requirements. This included an improved definition of critical habitat for northern quolls in the Pilbara, as well as an 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 23 circular landscapes, each 1km in diameter, were chosen according to three 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 (Figure 8). All landscapes are comprised of 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 are nested within each of the landscapes. Sites were 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 are 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

Since the beginning of this project in August 2017, motion detecting cameras have now been deployed at all 23 landscapes (184 sites), with over 48,000 traps nights achieved to date. 1822 independent quoll detections have so far been recorded (15th Jan 2019), across 70% (16/23) of landscapes, and across four pastoral stations including Indee, Mallina, Pippingarra and Yandeyarra. An extensive catalogue of fine scale habitat data has also been collected using a combination of field surveys and remote sensing techniques. Preliminary modelling using these data has commenced, with initial results suggesting factors such as den availability, as well as the presence of ficus trees (known food source) may be useful predictors for quoll occurrence. Further work will investigate the interactive effects of fire, feral predators and habitat substrate to provide fine-scale information on the critical habitat for northern quolls.

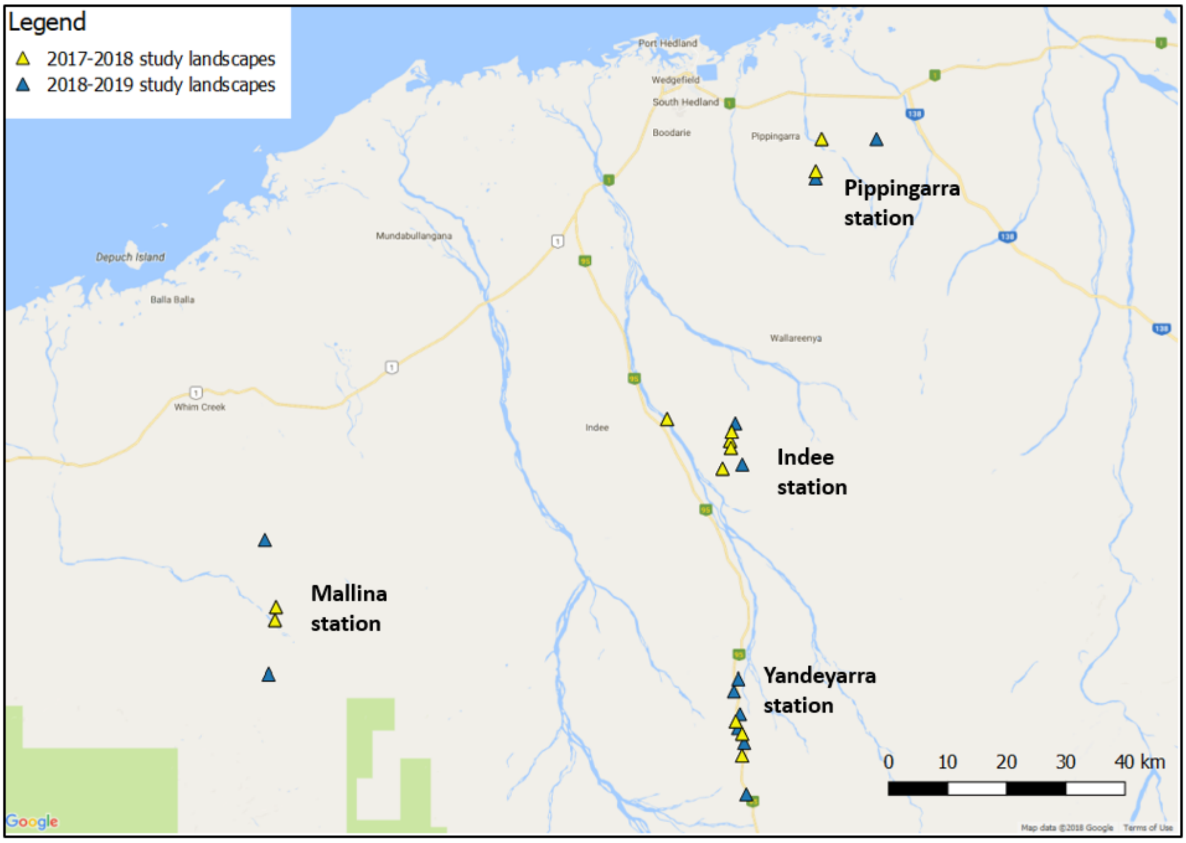

Figure 8. Locations of the 24 study landscapes for both 2017-2018 and 2018-2019 sampling periods. Landscapes are spread across four pastoral stations, including Mallina station, Indee station, Pippingarra station and Yandeyarra station. Each study landscape contains 8 sites.

Status

Ongoing. PhD student Harry Moore started 2017; fieldwork continuing 2019. This project forms part of a collaborative PhD project between Charles Sturt University, DBCA, The University of Western Australia and Deakin University, supported financially and in-kind by Roy Hill.

2.2 Fine-scale 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.

A previous study (Henderson, 2015) provided the first home range estimates from GPS data, analysed using two estimation methods. Estimates of male and female home range from this study and the literature are provided in Table 3. We also recorded maximum distance moved during nocturnal foraging, which was higher than previous estimates. Males moved more than 5 km in a 24 hr period, and females more than 2.8 km. Weight and technological limitations prevented more than 50 fixes being collected per animal in the 2015 study (total collar weight must be <5% of total animal weight). Recent advances in technology (availability of affordable light weight devices) have recently made GPS telemetry an increasingly 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

In 2018, we attached and collected GPS collars to 12 northern quolls across 3 separate sites on Indee station. Collars were set to a high fix rate – attempting fix every 1-5 minutes and only attempting between 5pm and 7am - and left attached to animals for an average of 9 days. Collars collected an average of 566 locational data points each, totalling in almost 7000 locational data points. This data will be used to track the fine scale movement of northern quolls, as to elucidate which features of the landscape are most important while foraging.

Table 3. Home range and movement data published for northern quolls. Estimates vary greatly, due to differing habitat types, as well as techniques of data collection and analysis and habitat. KDE: Kernel Density Estimation, MCP: Minimum Convex Polygon

Reference	Method of estimation	Data collection	Location	Male home range (ha)	Female home range (ha)	Max distance travelled
Henderson (2015)	KDE Estimates MCP	GPS locations (night only)	Pilbara, WA	143 (± 151) 58.0 (± 5.6)	45 (± 35) 13.4 (± 2.74)	5.01 km (Male, 1 day) 2.85 km (Female, 1 day)
Johnson and Oates (2013)	MCP 95%	VHF, daytime dens	Pilbara, WA	1002.6 (± 476.6)	8.2 (± 4.2)	10 km (4 days)
Cook (2010a)	MCP	VHF, daytime dens	Kimberley, WA	64.2 (± 36.6)	6.8 (± 1.56)	-
Oakwood (2002)	MCP	VHF, daytime dens, grid trapping	Kakadu NP, NT	99 (± 17)	35 (± 8)	1.85 km (male, 1 day) 1.21 km (female, 1 day
Braithwaite and Griffiths (1994)	Index of Movement	Grid trapping	Kakadu NP, NT	246.6 (±17.2) 1985-1987, 108.5 (±21.4) 1989-1992.	187.3 (± 68.1) 1985 – 1987, 44 (± 13.1) 1989-1992	-
Schmitt *et al.* (1989)	?	Grid trapping	Kimberley, WA	1.8 (± 1.6)	2.3 (± 1.2)	2.5 km (1 day)
King (1989)	?	VHF, daytime dens	Pilbara, WA	382	220	3.5 km (7 days)
Begg (1981)	Mean distance between captures	Trapping	Kakadu NP, NT	94 (± 95)	131 (± 125)	939 m (male) 1.16 km (female)

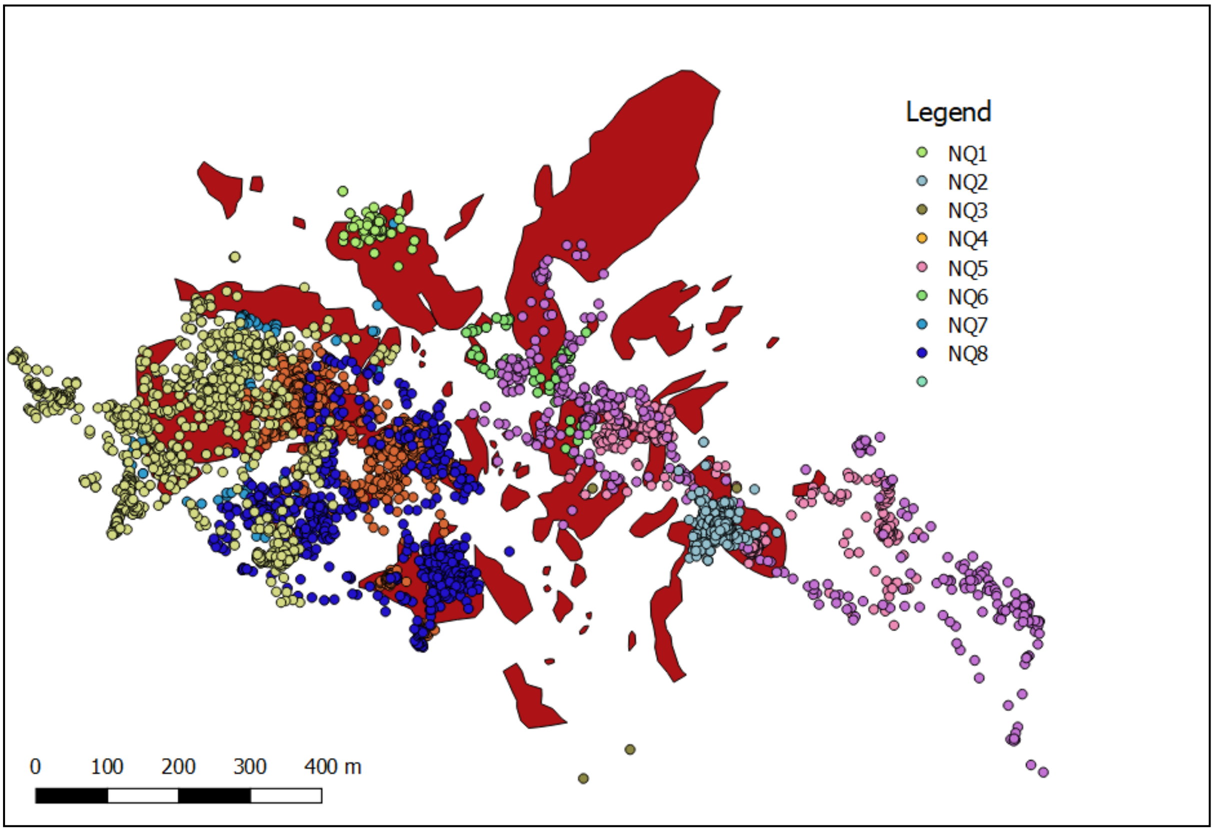

Figure 9. GPS data collected from eight northern quolls tracked on Indee station, in the Pilbara. Red areas denote rocky habitat.

Status

Ongoing. PhD student Harry Moore started 2017; fieldwork continuing 2019. This project forms part of a collaborative PhD project between Charles Sturt University, DBCA, The University of Western Australia and Deakin University, supported financially and in-kind by Roy Hill.

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 have been 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.

To better understand the ecology and niche requirements of the northern quoll, we undertook a dietary analysis of nearly 500 scats collected across ~100,000 km^2 in the Pilbara (Dunlop *et al.*, 2017). 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.

Quolls were found to be 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.

This study confirmed 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 (*Macropus 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.

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.

Additional samples collected between 2012 and 2018, as well as tissue samples lodged at the WA Museum have been selectively added to assist in filling spatial gaps in the current dataset. 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 10)

Outcomes

Results to date indicate that the Pilbara mainland populations of northern quolls are 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 overall 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 sparse 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. This is supported by movement studies that have shown male quolls to be capable of movements of 5 km in a 24-hour period (Henderson, 2015). 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 11). For conservation management purposes, the Pilbara populations should be treated as two units; the entire mainland population and the Dolphin Island population. The sole individual northern quoll captured in Karlamilyi National Park (see Section 1.4) represents the most isolated record but still aligned genetically with Pilbara populations.

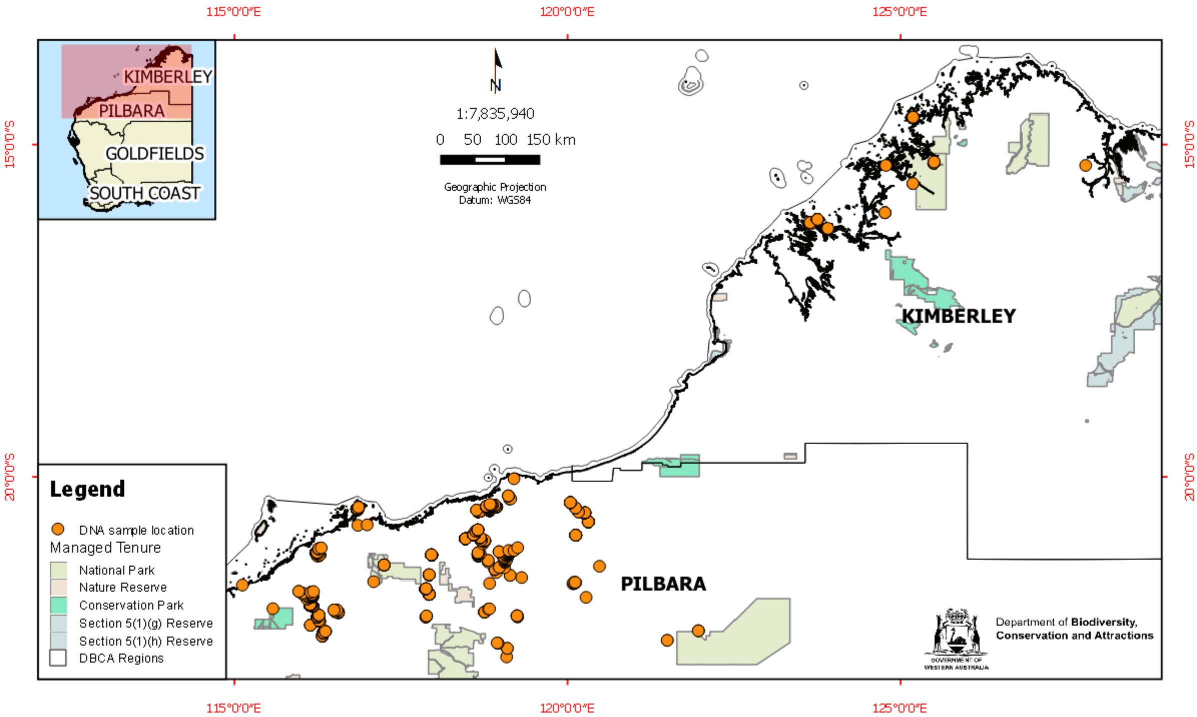

Figure 10. Spatial spread of northern quoll tissue sample locations in the Kimberley and Pilbara regions. A total of approximately 1800 Western Australian northern quoll tissue samples are available.

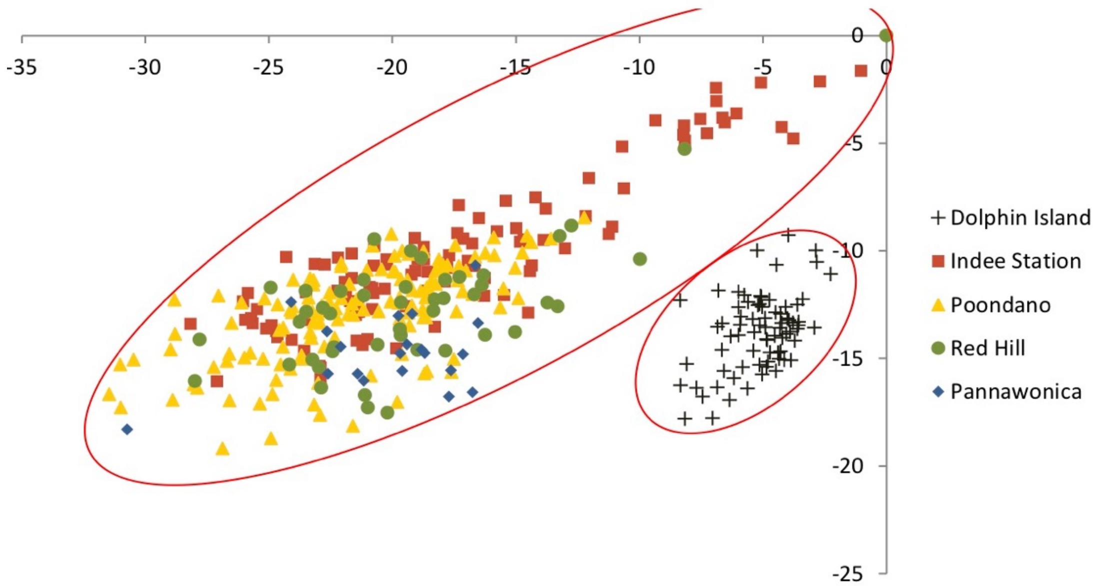

Figure 11. Population assignment of adult northern quoll individuals sampled from five sites in the Pilbara. Individuals from each population are designated with a different symbol and placed according to how genetically similar or dissimilar they are to other individuals.

Status

Ongoing, in collaboration with Murdoch University. Genetic sequencing complete, manuscript in draft.

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 body size of males; and
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. 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.

Males were differently selected for by females on the mainland compared to the island. 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 4. 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, manuscript in draft.

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.**

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 quolls elsewhere in Australia (Woinarski *et al.*, 2014). Feral cats have been implicated in at least 27 mammal extinctions across Australia and currently threaten more than 100 species. A broad-scale 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), and other tools such as the Felixer grooming trap are being trialled. 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 Population viability models for differing threat scenarios

Background

Population Viability Analyses (PVA) are useful in determining likely outcomes for populations based on known life history parameters, threatening processes and environmental variables. They are particularly useful for species that occur as fragmented populations and whose densities are naturally low (Frankham, 1995). In these models, simulations may be used to identify conservation actions that have a higher likelihood of reducing a species' extinction risk.

We used a PVA to model population viability for northern quolls, and a set of alternative scenarios to simulate the trajectories of a northern quoll population under increased levels of mortality (for example, due to increased feral cat predation or cane toad incursions), or alternatively, improved survivorship (for example, due to reduced feral cat predation). We also investigated whether we could improve quoll abundance, survivorship or persistence in a population under existing ecological pressures by population supplementation. Empirical life history data (demographic structure, mortality, survival and reproductive rates) from field studies across the Pilbara region – and supplemented with data from elsewhere in their range – were combined to develop a base demographic population model.

Outcomes

Under current conditions, individual Pilbara populations of northern quoll are projected to persist for over 20 years. However, these populations are sensitive to extinction events. Population growth rate and local extinction risk were most sensitive to changes in juvenile mortality as low as 5% per annum. Increased mortality of the juvenile age cohort above current levels resulted in a projected decline in population size of 22–54%, with a moderate-to-high chance (20–96%) of local extinction within 20 years. Supplementing the population produced a moderate increase in quoll persistence over this time period.

Populations of northern quolls in the Pilbara, and potentially elsewhere in their range, are highly sensitive to even small perturbations in juvenile mortality rates. The continued persistence of quoll populations in fragmented landscapes is likely to be supported by high rates of dispersal in good seasons, but is identified to be vulnerable if threatening processes reduce this.

Increased juvenile mortality above current levels – for example through the spread of cane toads or increased predation by feral cats – may have serious implications for the persistence of the current network of northern quoll populations and other mammals that exhibit population fragmentation in arid environments. In the Pilbara, young disperse from dens in the first three months of the year. Management actions should therefore work towards reducing threatening processes that impact survival of young; for example, maintaining natural corridors for dispersing animals, or reducing predation impacts. We recommend actions that may negatively impact young (e.g. incidental poisoning from feral cat baiting, burning) be done outside of the first three months of the year. The outcomes from this modelling are also useful in predicting the population impacts of invading cane toads.

Status

Completed, manuscript published.

Publications

Moro, D., Dunlop, J. and Williams, M.R. (2019). Northern quoll persistence is most sensitive to survivorship of juveniles. Wildlife Research, 46(2), 165.

4.2 Interactions between introduced predators

Background

Cramer *et al.* (2016) identify predation by feral cats, foxes and dogs, 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 hypothesize 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 dogs, 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. 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.

Outcomes

Since the beginning of this project in August 2017, motion detecting cameras have now been deployed at all 23 landscapes (184 sites), with over 48,000 traps nights achieved to date. Detections of quolls, feral cats and dogs are shown in Figure 12. 1822 independent quoll detections have so far been recorded (15th Jan 2019), across 69.6% (16/23) of landscapes, and across four pastoral stations including Indee, Mallina, Pippingarra and Yandeyarra. We have also recorded 76 independent dog detections across 73.9% of landscapes (17/23), and 289 independent feral cat detections across 95.6% of landscapes (22/23). At the site scale, feral cats were present at 50.7% of sites where quolls were detected. Dogs were present at 17.8% of sites quolls were detected.

Historical satellite imagery was used to map fire history within each of the study landscapes dating back to 1988. 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.

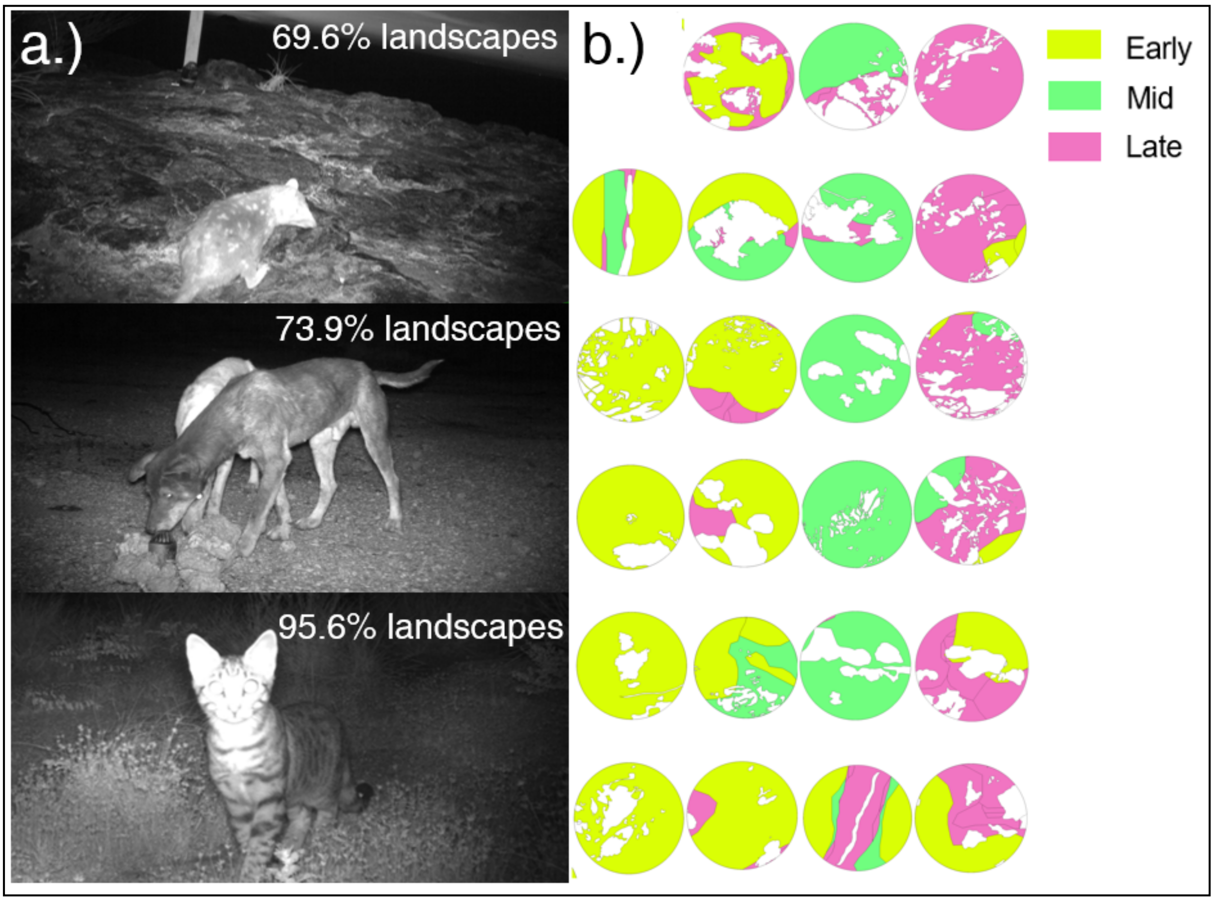

Figure 12. a.) Percentage occurrence of northern quolls, wild dogs/dingoes and feral cats captured on camera traps deployed across 23 landscapes as part of our project to determine intraguild interactions between northern quolls (top image), dogs (middle image) and feral cats (bottom image) b.) Fire successional age map across the 23 landscapes. Yellow represents early successional, green represents mid successional and pink represents late successional.

Status

Ongoing. PhD student Harry Moore started 2017; fieldwork continuing 2019. This project forms part of a collaborative PhD project between Charles Sturt University, DBCA, The University of Western Australia and Deakin University, supported financially and in-kind by Roy Hill.

4.3 Efficacy of Felixer grooming traps

Background

Predation by feral cats is a primary threat to more than 100 species of native Australian animals, including mammals, reptiles and ground-dwelling bird species. Control of feral cats is difficult due to their predisposition to hunting live prey rather than accepting baits, their cryptic and nocturnal behaviour, and their ability to persist in almost every habitat across the continent.

Ecological Horizons Pty Ltd are developing an automated Feral Cat Grooming Trap (the "Felixer") as a potential new tool for feral cat management. The unit detects the presence of a feral cat and sprays a lethal dose of 1080 toxic gel onto the fur of the feral cat from up to four metres away. The feral cat instinctively grooms itself to remove the gel and in doing so ingests a lethal dose of the poison. The Felixer is capable of discharging 20 times (utilising 20 separate, measured dose cartridges) before the internal magazine needs to be reloaded with new cartridges. The unit takes a photograph every time the detection beams are crossed, allowing managers to assess the efficacy of the trap in differentiating feral cats from non-target species and also allowing Felixers to be used as stand alone, solar powered camera traps. This new technology is being trialled Australia-wide, with more than 50 units deployed in different environments, initially with non-toxic cartridges. Northern quolls were identified as a potentially problematic non-target issue for using Felixers to control feral cats in Western Australia due to their cat-like shape, and vulnerability to doses of 1080. In collaboration with Roy Hill and FMG, DBCA have been trialling three Felixer units in the Pilbara to determine their safety and efficacy.

If found to be efficient and effective, this automated unit provides a promising method for targeted feral cat control at specific localities. Situations such as: high-value threatened species populations in limited areas (such as night parrot populations), locations that have a predator "sink" (such as on the outside of predator exclosures), or in locations where cats travel through limited areas (such as peninsulas or islands) The units have low maintenance requirements, which is particularly helpful in remote regions. Data on the efficacy of these units will be important to the ongoing development of affordable and effective feral cat control in Australia.

Our key goals for the Pilbara trials can translate into a several step process:

1. Are the Felixers sufficiently target specific (i.e. not recognising other species, particularly threatened species such as northern quolls, as targets)?
2. Are they effective at reducing cat numbers at a local scale?
3. Does this translate into a positive effect on threatened species (e.g. northern quolls or bilbies)?

Outcomes

Proper testing of this new technology is essential for validating the Felixer as an effective and low-risk feral cat management tool and eventually securing APVMA approvals for non-research deployments. False targeting of native non-target species would be a critical error for conservation measures and require optimisation of detection algorithms or potentially redesign.

We used three Felixers in photo-only mode, paired with Reconyx cameras, for six months in high-density quoll habitat in order to address the first goal. In that time there were almost 200 independent instances of northern quolls crossing in front of the Felixers, of which zero were identified as targets. There were also 19 other species (birds, mammals, reptiles) that were not targeted (Figure 13). The only species that were targeted were feral cats and one individual domestic dog, about the size of a Jack Russell. We did not have very many instances of feral cats, surprisingly it appears that only two individuals crossed the cameras on six occasions (Figure 14).

In order to answer the next questions, the Felixers will be trialled somewhere with cats and quolls, where the live 1080 trial can take place once approvals are secured. The criteria for a toxic trial site are for it to be: not publicly accessible, away from towns and communities, away from other non-target issues (e.g. domestic dogs) and ideally with long-term data for cats and northern quolls. We will deploy the units for a further non-toxic trial period and later with 1080 toxin, subject to approvals. All units can be trialled together at this site for the trial duration (~6 months) in order to determine the effectiveness at reducing cat populations, and to determine if there is a subsequent response from threatened species.

Figure 13. Photos from the WA Pilbara trial of Felixers operating in photo-only mode in the presence of northern quolls. Clockwise from top left: A feral cat correctly identified by the Felixer

as a target, a northern quoll correctly identified by the Felixer as a non-target, northern quolls regularly spent time investigating the units.

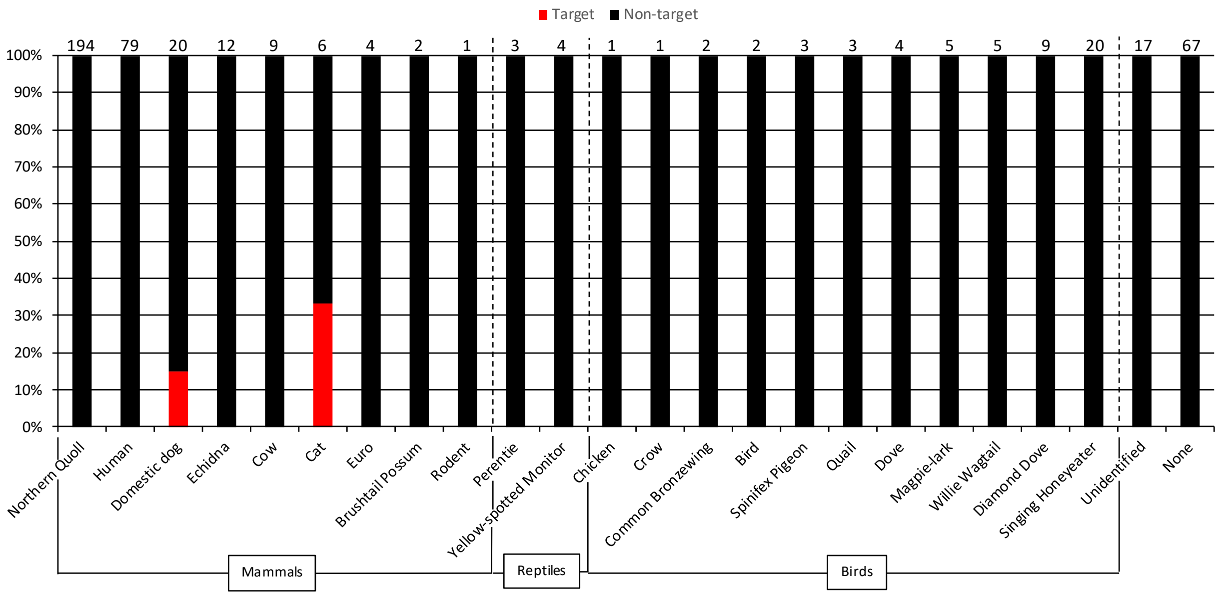

Figure 14. Summary of targeting results showing whether an animal was designated by Felixer units as a target (Red) or non-target (Black). Results shown the proportion of total detections of a species were determined to be targets, values on the top of the bars are total detections for each species.

Status

Ongoing, further trials occurring 2019. This project is a collaborative effort between DBCA, Ecological Horizons, Roy Hill and Fortescue Metals Group.

5 Recolonisation of restored or artificial habitat

Background

An aspect of research identified to be important was to determine the ability of northern quolls to recolonise disturbed areas or colonise artificial habitat (Cramer *et al*., 2016). The mesas and ranges that make up the preferred habitat of Pilbara northern quolls are increasingly subject to destruction by mining development due to their deposits of iron-ore, as well as granite outcrops which are used in the construction of roads as well as railway beddings (Amir Abdul Nasir *et al*., 2018; Ramanaidou & Morris, 2010). In cases where known quoll habitat is disturbed due to mining development, the creation of artificial habitat has been proposed to mitigate direct impacts on resident quoll populations and to restore habitat (Atlas Iron, 2012). Recreating den sites—rock crevices located at mesas or rocky landforms in which female quolls raise their litters—is a particular challenge. These rocky landforms provide complex habitat, denning opportunities, protection from weather and predators as well as refuge from fire and extreme temperatures (Braithwaite and Griffiths, 1994; Oakwood, 2000; Cook, 2010a). In summer, females use dens to secure dependent offspring when they are too large to be carried (Begg, 1981). Complex habitats may also support more dense and diverse prey populations (Pavey *et al.*, 2017).

Currently, some information exists on the northern quoll's ability to colonise and use artificial infrastructure (Creese, 2012; Johnson and Oates, 2013; Dunlop *et al.*, 2015; Henderson, 2015). However, to create artificial dens, rehabilitators must hold a genuine understanding of key characteristics associated with suitable natural denning sites (Maron *et al*., 2012). This information is currently limited within the literature. Breeding dens will likely be structured such that internal temperature and humidity are lower than the external ambient temperature, particularly given that: 1) the Pilbara experiences extreme temperatures during summer when average maxima exceed 40 °C and temperatures regularly exceed 45 °C, and 2) quolls are prone to dehydration and hyperthermia at high temperatures (Cooper & Withers, 2010). Dens are also likely to have specific physical characteristics—such as an opening that is large enough for a quoll to enter but small enough to exclude potential predators (Hernandez-Santin *et al.,* 2016; O'Connell & Keppel, 2016)—as well as specific food resources in close proximity (Cook, 2010).

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. While there have been attempts to recreate northern quoll habitat, there remains very little information on how these dens compare to natural quoll dens. Understanding the characteristics of natural denning habitat (thermal properties, physical size, prey availability, predator abundance) will enable us to elucidate necessary conditions to be replicated as part of future artificial habitat creation.

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.

Female northern quolls were trapped at Indee Station near Port Hedland and tracked back to rocky dens using a combination of VHF tracking, fluorescent pigment tracking and line-and-spool tracking. Unoccupied natural dens were identified within 50 metres of occupied dens using no sign of quoll occupation (scat search, camera trap). Artificial sites were chosen using current artificial habitat constructions at Indee Station, Mount Dove and a Roy Hill bridge rock armoury. Remote camera traps were deployed at each den site to survey predator and prey activity. iButton temperature data loggers were deployed inside and outside dens to measure temperature differences between internal and external environments. Vegetation transects were undertaken to measure ground cover and active searches for native fig (*Ficus* spp.) were also undertaken. Physical features of dens (entrance size, aspect, depth) were also noted. Characteristics of each den type will be compared to measure the success of artificial habitat at emulating natural denning habitat as well as differences between occupied and unoccupied natural dens.

Outcomes

We observed differences in the physical characteristics of artificial and natural den types. Occupied dens show a greater percentage of embedded rock than that of unoccupied dens, while artificial dens show little to no embedded rock at any site (

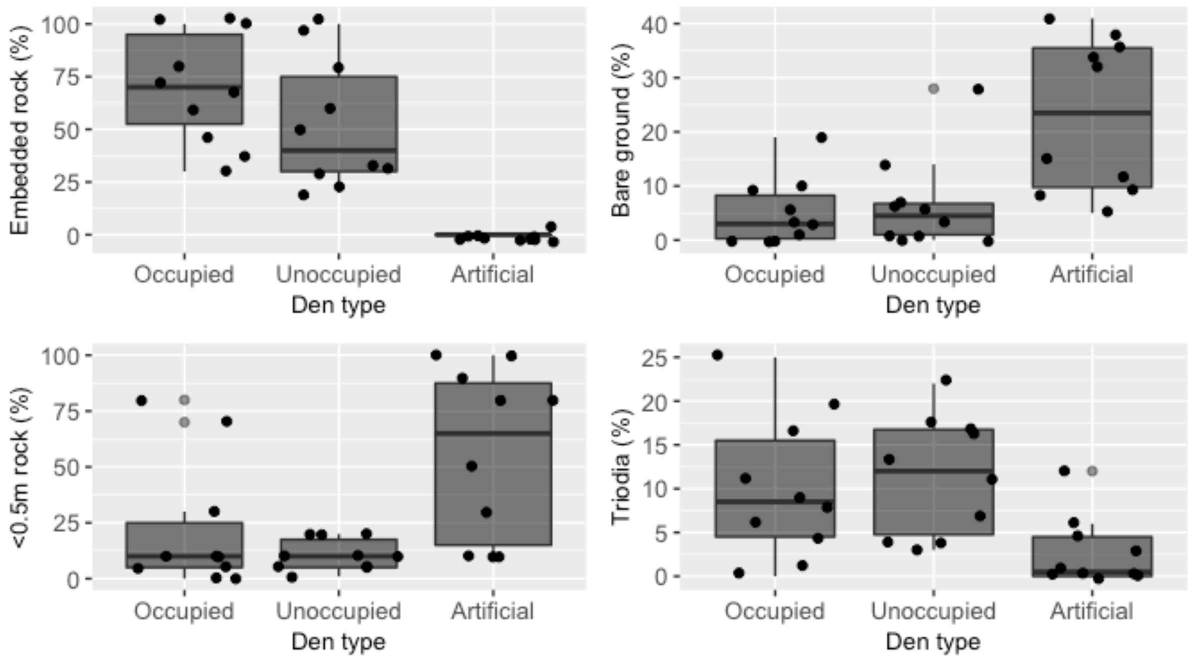

Figure 15). This is likely due to artificial dens existing in highly disturbed areas with previous development, structures or construction occurring away from natural rocky areas. This is reinforced by bare ground percentage where artificial dens show a higher percentage of bare

ground at their sites (

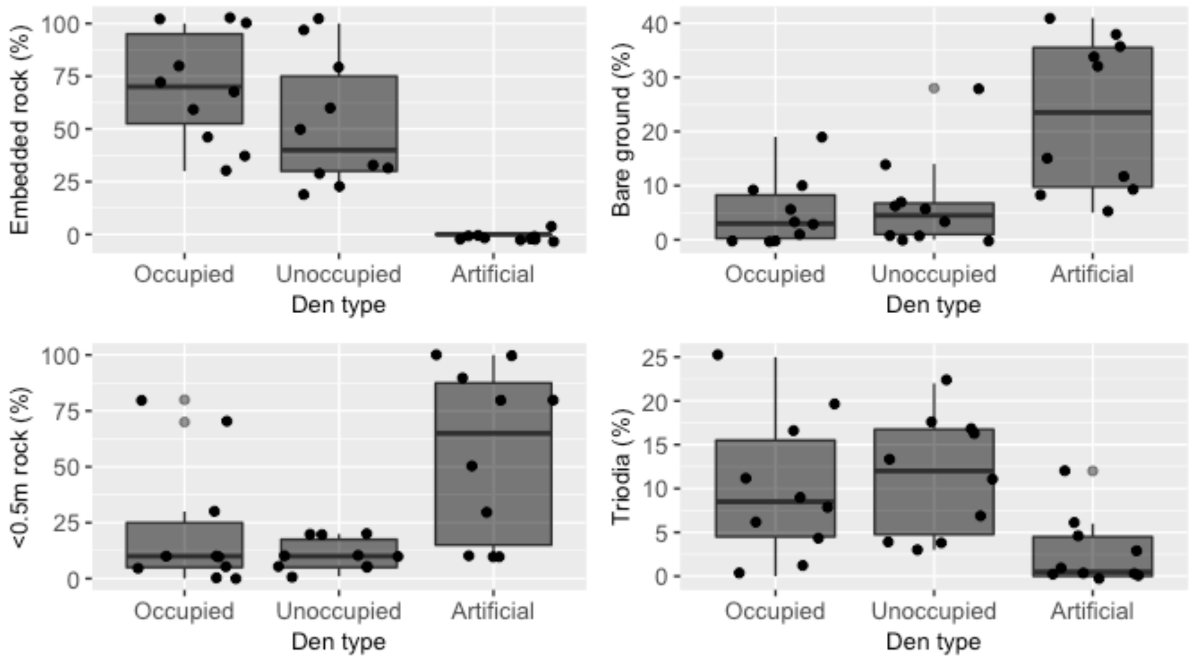

Figure 15). This trend continues for percentage of rock less than 0.5 metres in size, with artificial dens showing a higher percentage of small rocks across sites when compared with occupied and unoccupied dens (

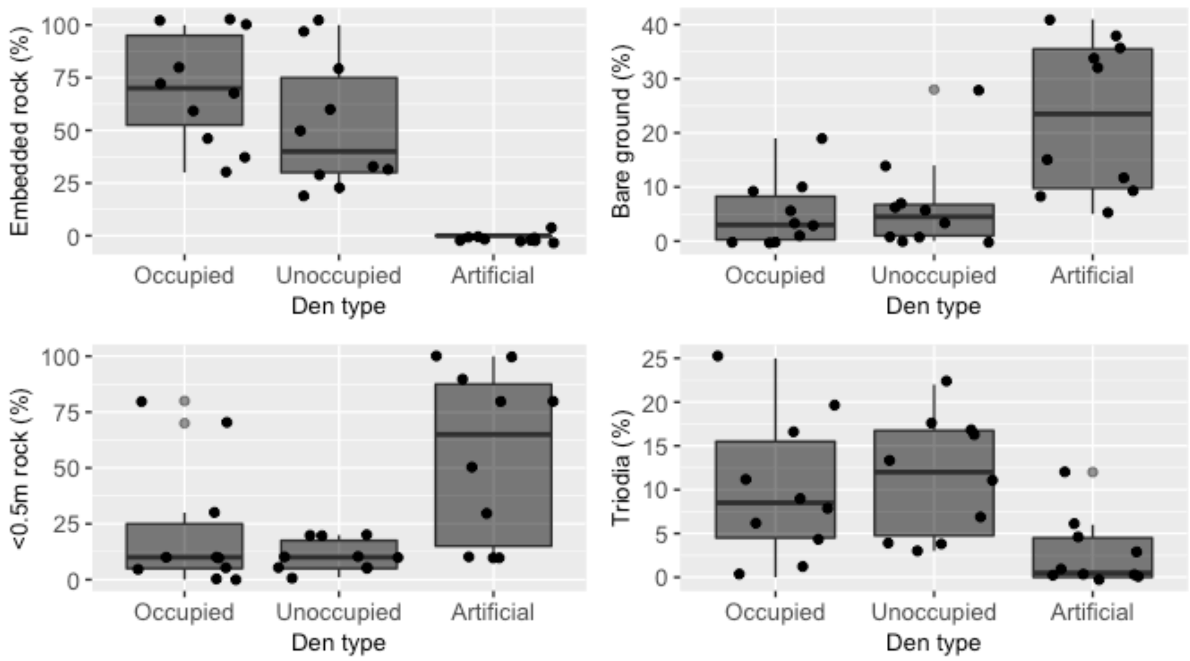

Figure 15). Triodia *percentage is very similar for both occupied dens and unoccupied crevices, however, occupied dens have the highest range between the ten sites prompting the fact that*

Triodia *percentage may not be a limiting factor (*

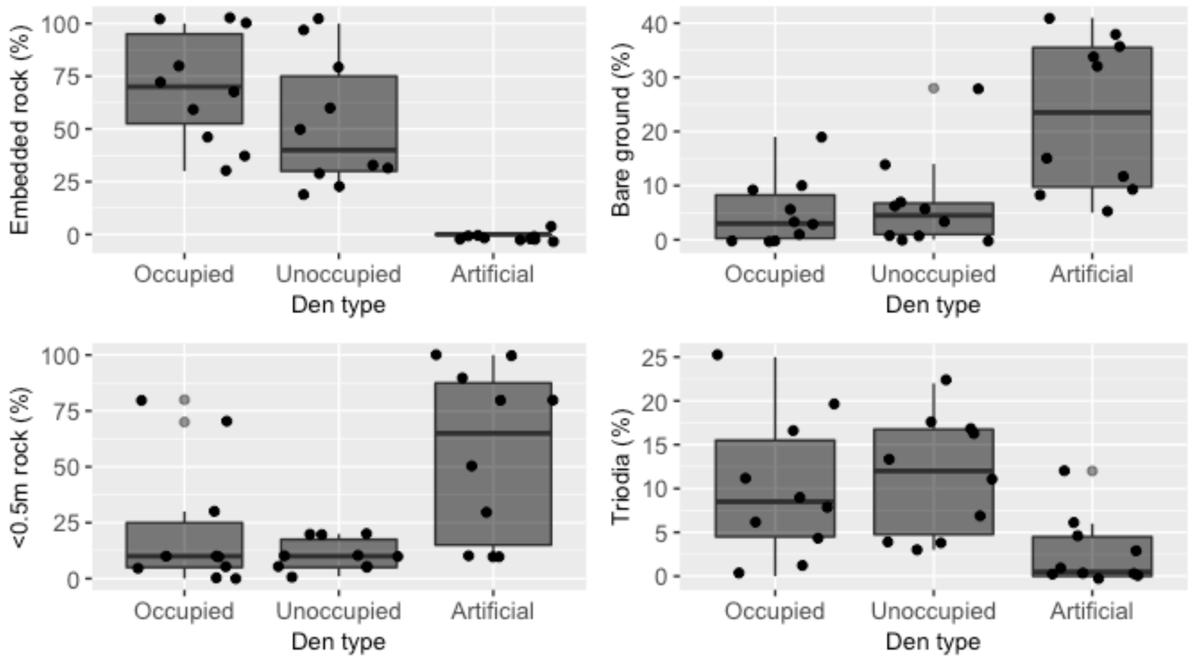

Figure 15). In relation, artificial dens have the lowest range of *Triodia* percentage, which may reflect occupied dens and unoccupied crevices existing in natural areas, while artificial den sites are currently undergoing vegetation rehabilitation after previous development or disturbance. Analyses of den temperature as well as predator and prey abundance are ongoing with no outcomes yet available.

The majority of den entrance heights for occupied dens, unoccupied dens and artificial dens exist under 600 mm (Figure 16). However, occupied dens show the largest range in entrance height as well as displaying the smallest range in den entrance width when compared with unoccupied crevices (Figure 16). Artificial dens show the lowest values across all sites when looking at entrance height and width, most likely due to the type of resources used in their creation (i.e. rock, concrete, gravel). Majority of occupied den sites are deeper than unoccupied crevices and artificial dens when compared, most likely for quoll security, as well as light and temperature factors (Figure 16). Unoccupied dens mostly contain one entrance, this seems to be unappealing to northern quolls with more variation occurring for occupied dens having between one and six entrances (Figure 16). This may be for many reasons including escape options and airflow.

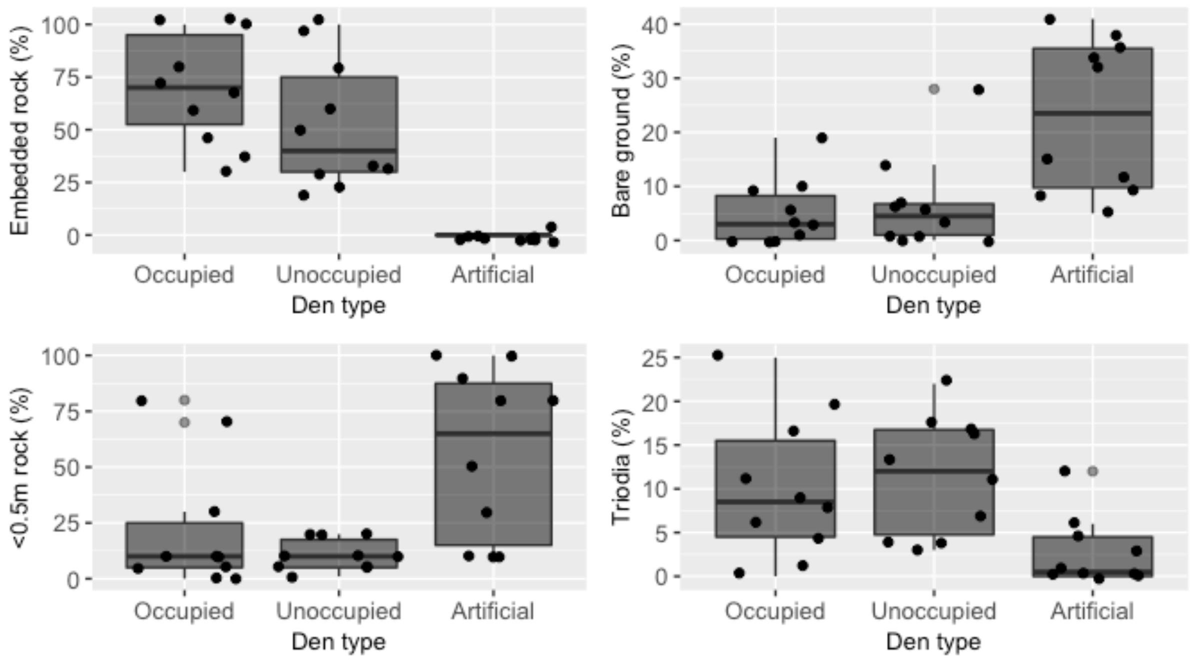

Figure 15. Occupied, unoccupied and artificial dens plotted against ground cover percentages; embedded rock, bare ground, >0.5m rock and Triodia (spinifex).

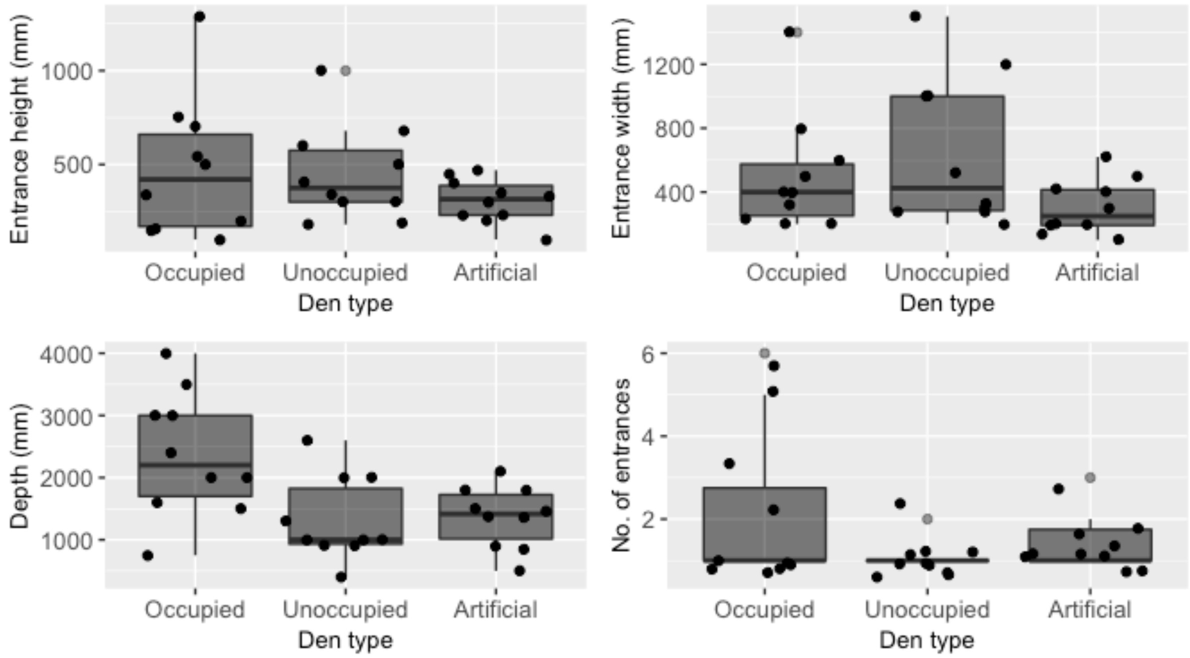

Figure 16. Occupied, unoccupied and artificial dens plotted against den characteristics; entrance height, entrance width, depth and number of entrances.

Status

Data analysis ongoing. Honours student Mitchell Cowan began in 2018, completing mid 2019. This project is a collaboration between DBCA and Charles Sturt University, supported financially and in-kind by Roy Hill.

Reports, papers and presentations

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