Pilbara Northern Quoll Research Program

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Annual report 2014-2015

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Acknowledgements

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Distribution modeling and home range estimates were undertaken as a collaboration with colleagues from Edith Cowan University (Melinda Henderson, Rob Davis and Shaun Molloy). A Population Viability Analysis for Pilbara northern quoll was a collaboration with Dorian Moro and Matt Williams.

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Summary

Pilbara northern quolls have high conservation priority due to their separation from other northern populations, distinct genetics, occupy 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 2015 (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 2010, following consultation between industry, researchers, and state and federal government agencies (McGrath and van Leeuwen 2011). The Western Australian Department of Parks and Wildlife 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). The themes of the five research priorities for northern quoll in the Pilbara determined at this workshop, including the research activities that have been undertaken against each theme are listed below:

1) **Survey and monitoring:**
   a) The Threatened Fauna Portal was created as a publicly available repository for locational data relating to Pilbara threatened fauna. More than 3,000 records of northern quolls have been added since 2010.
   Status: Completed, updated regularly.
   b) Standardised monitoring procedures were developed (Dunlop *et al.*, 2014), based on protocols published by the Department of the Environment (formerly DSEWPaC (2011)) for mammal trapping. These protocols address methods for cage trapping, scat searches and remote camera detection.
   Status: Completed.
   c) Parks and Wildlife have been undertaking standardised annual surveys of northern quolls in the Pilbara for two years, collecting data on northern quoll morphology, distribution, population ecology and life history.
   Status: Data collection ongoing as part of the annual monitoring program.

   Management implications: Enhanced distributional data is publicly availability in an online repository for decision-making relating to northern quolls and other species. Future monitoring of northern quolls can be aligned with the methods of the regional program, to enable regional comparisons of population trends and change. Data collected during surveys helps to inform ecology and life history characteristics, and temporal change.

2) **Habitat requirements**
   a) Using the enhanced distributional dataset available from NatureMap, species distribution models were generated to show areas of high and low probability of northern quoll habitation in the Pilbara. These models were then combined with predicted models of future threatening processes, namely cane toad invasion and

climate change.
Status: completed, manuscripts drafted.

b) The interactions of northern quolls with large linear infrastructure were investigated during an honours project in association with Edith Cowan University. Northern quolls living near rail lines, roads and other industrial infrastructure were affixed with GPS collars, and movement data collected. Northern quolls were not observed to cross over or under any rail lines, but did cross roads where there was habitat on either side. Home ranges were estimated using two different methods of calculation.
Status: Honours thesis completed, manuscript being drafted.

Management implications: Sophisticated northern quoll population distribution maps can be used to predict the likelihood of occurrence, and inform management decisions. Areas without data collection have been identified as priorities for ground-truthing, and key populations likely to be impacted by future threatening processes have been determined. Novel GPS collars for northern quolls were tested in a field setting, and provided information on spatial use and interactions with infrastructure. To limit impacts on northern quolls, infrastructure should avoid destruction, modification or division of known habitat.

3) Population dynamics

a) The genetic importance of Pilbara northern quolls, their effective management units and dispersal capabilities are being assessed using DNA samples from animals throughout the region. More than 500 tissue samples are available to supplement initial analysis from clustered samples.
Status: Ongoing. Additional DNA samples will be analysed in 2016.

b) A current project to examine the breeding strategies of northern quolls and assess parentage of litters, relatedness of family groups and paternity characteristics is underway. This project will answer questions about patterns of dispersal of offspring, the drivers of northern quoll sexual selection and female mate choice. This work is being undertaken in a restricted island and an unrestricted mainland setting to determine differences between populations.
Status: Ongoing. DNA samples will be analysed in 2016.

c) A regional assessment of northern quoll diet is underway, using data from 500 northern quoll scats collected from throughout the Pilbara region. Preliminary results indicate that dietary items are very diverse and were identified to 42 items that were then grouped into 12 more general dietary categories. Northern quolls most frequently preyed upon insects, present in more than 85% of scats, followed by vegetative material and small mammals.
Status: Data analysis ongoing.

Management implications: Populations of highest genetic importance will be identified, which may have implication for the prioritization on management action to limit the impending arrival and colonization of the Pilbara by cane toads. Data on relatedness and genetic diversity will provide an indirect method of interpreting spatial use of Pilbara habitats. Dietary analysis provides key ecological information relating to the constraints on the species in its habitat use, and how these change temporally and spatially.

4) Key threats

a) 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. We modelled the relative impacts of feral cat predation and accidental cat bait mortality prior to the commencement of a program of broad scale feral cat control. Modelling revealed that juvenile northern quolls are the cohort most sensitive to disturbance, and small changes in mortality may have long-term population impacts. Low levels of bait-related mortality on adults are less critical to population persistence. These results are applied to potential cane toad impacts.
Status: Completed. Manuscript being prepared.

b) We present records of feral species, and other non-target native species collected via trapping, remote cameras, sightings of animals or their signs. These data are relevant to better understanding the distribution and interactions of native and introduced species.
Status: Data collection ongoing as part of the annual monitoring program.

Management implications: Modelling the changes in mortality of different cohorts of northern quolls has enabled best-practise baiting regimes to be implemented for feral cats in the Pilbara. Data on the distribution of native and introduced populations can be used to interpret the interactions between them.

5) Recolonisation of restored or artificial habitat

a) An impact mitigation strategy potentially important to northern quolls in the Pilbara is the use of artificial habitat or recolonisation of habitat following major disturbances (e.g. mining). A first step toward creating effective artificial habitat will be defining the characteristics of functional denning habitat currently used by female northern quolls. Factors such as geology, size and shape of boulders, thermal characteristics and position within the landscape (e.g. aspect) will be examined in known northern quoll populations to provide advice on the construction of trial artificial habitats.
Status: Not yet underway.

Management implications: Advice on formulation of artificial habitat or ideal characteristics of rehabilitated sites will be useful in minimising long-term impacts of disturbance on Pilbara northern quoll populations.

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 2015 (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 the iron ore industry and other development proponents. This has enabled:

a) the collation of data from external 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 2015.

1 Survey and monitoring

The review of northern quoll records undertaken by Cook (2010) examined the survey efforts in the Pilbara region from grey literature and other unpublished reports. Of these, the majority of species records involved indirect observations such as tracks, scats, bones and carcasses rather than direct animal captures (Cook, 2010b). This finding highlighted that the majority of surveys involve desktop surveys or area searches, rather than trapping. 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 spatial distribution. 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 or remains. The portal also allows for images to be uploaded, providing a useful method of verifying records by those responsible for the database. The threatened species portal allows users to submit singular records and bulk records, a feature making the process of submitting information efficient. Anyone may submit or check their records against reference information on the website, access further reading about the threatened species of the Pilbara and view all current records which have been released for viewing via NatureMap. Newly uploaded records are verified by Parks and Wildlife before becoming publicly available.

Outcomes

Since the launch of the website, the Parks and Wildlife northern quoll research program has made a substantial contribution of more than 1,100 locational records available on NatureMap (Table 1), via the Pilbara Threatened Species Portal. Some of these records were collated from a search of the published and unpublished literature (Cook, 2010b) while the majority are recent records collected from trapping and targeted searches. A number of these records are locations that have not been surveyed for northern quolls or sightings not previously recorded, expanding our knowledge of the distribution of this species in the Pilbara (Figure 1).

Status: Completed, updated regularly

Table 1. The number of Pilbara northern quoll records available online 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	2010-16	Total
Department of Parks and Wildlife	0	0	1	0	5	1	1,136	1143
Western Australian Museum	28	20	7	20	10	4	9	**98**
Consultancies	37	0	0	0	5	79	1508	**1,629**
Universities	0	0	0	0	0	0	249	**249**
Other/Unknown	35	16	7	23	11	2	124	**219**
Total	**90**	**36**	**15**	**43**	**31**	**86**	**3,027**	**3,338**

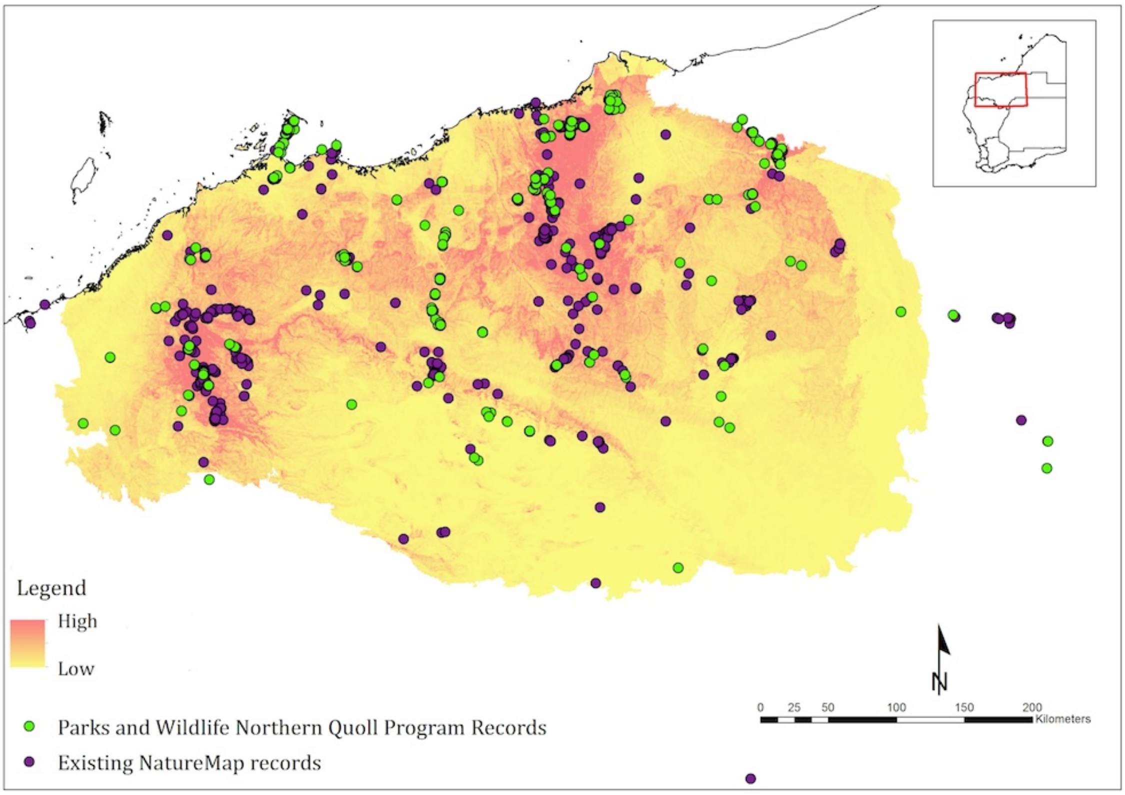


Figure 1. Northern quoll records from the Pilbara. *Records collected by the Department of Parks and Wildlife Pilbara northern quoll program since 2011 are shown in green, records from the Western Australian Museum, universities, consultants or other sources in purple. The background image indicates probability of northern quoll presence and was created using a Species Distribution Model* (Molloy *et al.*, 2015).

1.2 Population ecology and demographics

Background

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

Outcomes

The second trapping campaign of the Pilbara annual monitoring sites occurred in 2015 between May and October, following the trapping methods outlined in Dunlop *et al.* (2014). The program in 2015 included two additional sites, Hooley Station (22.0233, 118. 2454) and Mesa 228 (22.1054, 119.2456), which were supported through additional funding provided by Roy Hill. Additional opportunistic trapping was also undertaken at Meentheena Conservation Park in the north-eastern Pilbara. A total of 3,000 trap nights was achieved in

2015, across the Pilbara. Captures for the two most commonly encountered mammal species, northern quolls and common rock rats (*Zyzomys argurus*) are shown in Table 2.

In total, 127 individual northern quolls were captured, ranging from 0 to 27 individuals at each surveyed site. Dolphin Island and Indee Station had the largest northern quoll populations from the sites sampled. On average, 7.1 ± 2.3 individual northern quolls were trapped per monitoring site. The total northern quoll capture rate was 8.2% (247 captures, including re-trapped individuals), similar to the 2014 capture rate of 9.9% (198 captures from 2,000 trap nights). Sex ratios were significantly skewed towards females (59.3% F : 40.7%M, $P>0.001$, Z-statistic = 413.2) for individuals captured and for total captures including retrapped northern quolls, indicating that males and females are similarly trappable.

Table 2. Capture statistics for individuals of the two mammals most commonly captured at annual monitoring sites; northern quolls (Dasyurus hallucatus) and common rock rats (Zyzomys argurus)*. Dolphin Island Nature Reserve and Indee Station were surveyed twice in 2015 for reproductive studies; the second visit is shown in parentheses.*

Site	***D. hallucatus***			***Z. argurus***		
	2014	**2015**	***total***	**2014**	**2015**	***total***
Cane River Conservation Park	1	0	*1*	0	0	*0*
Dolphin Island Nature Reserve	23	18 (18)	*59*	9	76	*85*
De Grey Station (discontinued)	3	-	*3*	17	-	*17*
Hooley station	-	0	*0*	-	1	*1*
Indee Station	23	27 (17)	*67*	2	4	*6*
Karijini National Park				28	13	*41*
Mallina Station	7	13	*20*	19	23	*42*
Meentheena Conservation Park	-	1	*1*	-	2	*2*
Millstream Chichester National Park	9	1	*10*	7	20	*27*
Mt Florance Station	6	6	*12*	2	2	*4*
Poondano	-	5	*5*	-	-	-
Red Hill Station	3	11	*14*	0	7	*7*
Roy Hill Rail	-	4	*4*	-	17	*17*
Yarrie Station	8	6	*14*	10	8	*18*
Grand Total	**83**	**127**	***210***	**94**	**166**	***260***

The most commonly captured species was the common rock-rat *Z. argurus*, a favourite food item of northern quolls (166 captures; 5.5% capture rate). Other species captured in traps included *Ctenotus* sp. (2), *Egernia formosa* (1)*, Tiliqua multifasciata* (1)*, Ctenotus grandis* (1)*, Varanus giganteus* (1)*, Pseudechis australis* (1) *Mus musculus* (4)*, Pseudomys hermannsbergensis* (1).

Data on morphometrics (Figure 2), populations (Table 3) and breeding (Figure 3) have been collated during monitoring throughout the Pilbara. These data are available for comparison with northern quoll populations elsewhere in Australia. We used body mass records for almost 170 individual northern quolls from the Pilbara to assess whether this population is on average larger than northern quolls from other regions. A summary of the variance in mass data from northern quoll populations throughout northern Australia is shown in Figure 2. Male northern quolls from the Pilbara appear to be larger than populations in the Kimberley and on many islands, but not as variable in size as those from Kakadu. Female northern quolls appear to be of a fairly consistent size throughout their geographical range.

Northern quolls are one of a small number of terrestrial vertebrates that are semelparous; that is, all males die shortly after the mating season (Oakwood *et al.*, 2001). This life-history strategy is also present in the genera *Antechinus, Parantechinus* and *Phascogale* (Dickman and Braithwaite, 1992), whereby females drive a short and intense mating season involving high energy investment and sexual competition for males (Fisher *et al.*, 2013). This results in poor body condition, elevated stress hormones and an ultimate lethal immune system collapse at 10-12 months of age (Oakwood *et al.*, 2001). This strategy is thought to have an evolutionary advantage, where females can take advantage of sperm competition in order to have fitter offspring (Fisher *et al.*, 2013) and resources for the mother and her developing offspring are maximized due to a lack of males present in the population (Braithwaite and Lee, 1979).

Northern quolls do not appear to undergo complete male die-off in all years (i.e they are facultatively semelparous). Although complete die-off has been recorded (Oakwood, 2000; Dickman and Braithwaite, 1992), a small number of males survive the breeding season in some years (Dickman and Braithwaite, 1992; Fisher *et al.*, 2013). Begg (1981) recorded a 28 month old male, Dickman and Braithwaite (1992) observed two previously unrecorded adult males in the population following the breeding season, and Schmitt *et al.* (1989) recorded a post-mating survival of 11.5% for a Kimberley population.

For these Pilbara populations, a small number of males were recorded surviving beyond the mating season and to their second year. Although a third annual trapping session is required to derive population trends and survivorship analyses for all sites within the regional survey, preliminary data has been presented for two sites in Table 3. Capture probabilities, apparent survivorship and population number were estimated using a Cormack-Jolly-Seber capture-mark-recapture analysis. Apparent survival of males in the post-breeding season was estimated to be 13 ± 9 % for males, and 15 ± 10 % for females (Table 3). Capture probabilities for both sexes indicate that males are more likely to be captured in the breeding season, and females are more likely to be capture post-breeding. Higher capture probabilities may be correlated to heightened foraging efforts during these seasons.

Reproductive data was summarized for 171 captures of female northern quolls in the Pilbara, and compared to other reproductive studies (Figure 3). Female breeding condition in Pilbara northern Quoll was categorized as undeveloped (pouch shallow, pale, nipples not developed), developed (pouch deep, pink, nipples developed), and with pouch young present or lactating (indicating that young were denned). Oakwood, (2000) recorded female northern quolls to have a highly synchronous reproduction, where reproductive events (e.g. mating, deposition of young in dens) occur within a two-week period. At a population level female northern quolls have also been recorded to give birth within a four-week period in other regions of Australia, usually in July (Begg, 1981; Braithwaite and Griffiths, 1994; Oakwood, 2000).

Northern quolls in the Pilbara have an extended breeding season compared to observations elsewhere in Australia. Female northern quolls have been observed with new pouch young from August to October, within the same year (Figure 3). It is possible that the extended breeding period and therefore less intense mating season indicates a reduction in competition between males, and may be responsible for the incomplete male die-off observed in the Pilbara.

Status: Data collection ongoing as part of the annual monitoring program.

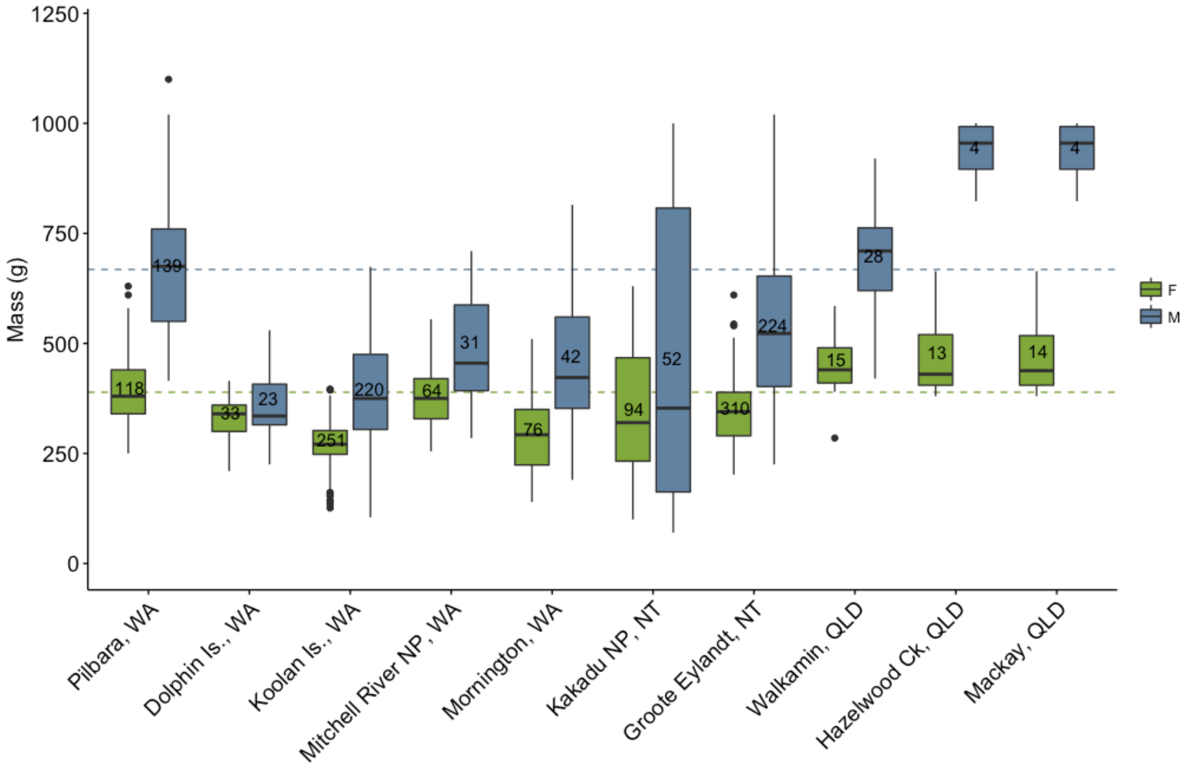


Figure 2. Body mass of male and female northern quolls from different locations within Australia. *Boxes show the first and third quartiles of data, with the band in the centre showing the median, whiskers extend to the highest value that is within 1.5 inter-quartile range and dots show outliers. Numbers denote sample size; dashed lines indicate the average female (green) and male (blue) body mass for Pilbara quolls. Data from sites outside of the Pilbara were sourced from an ACEAS-TERN workshop* (Fisher, 2015).

Table 3. Apparent survivorship, capture probability and population estimates for male and female northern quolls at two sites in the Pilbara, calculated using a Cormac-Jolly-Seber capture mark recapture analysis*. Breeding and post-breeding were determined to be Sep - Oct and Apr – May, respectively.*

	Breeding		**Post-breeding**	
	Male	**Female**	**Male**	**Female**
Capture probability (p)	0.51	0.35	0.47	0.56
SE	*0.08*	*0.07*	*0.06*	*0.07*
Apparent survivorship (s)	0.31	0.59	0.13	0.15
SE	*0.09*	*0.15*	*0.09*	*0.10*
Millstream Chichester National Park				
Population estimate (N-hat)	4.10	2.00	1.10	3.20
SE	*0.35*	*0.24*	*0.34*	*0.65*
Indee Station				
Population estimate (N-hat)	3.60	14.4	7.80	15.7
SE	*0.92*	*2.27*	*1.08*	*1.68*

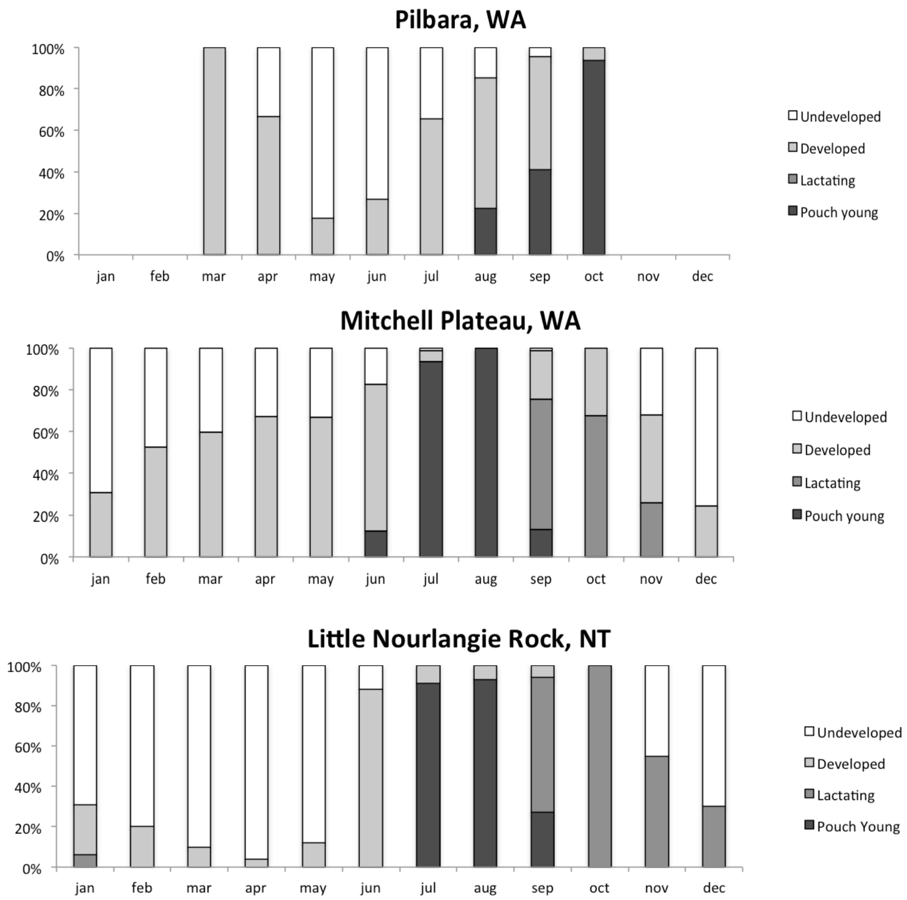


Figure 3. Comparison of breeding seasons for northern quolls across northern Australia. *Data from Mitchell Plateau and Little Nourlangie Rock from Braithwaite and Griffiths (1994) and Begg (1981), respectively.*

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. A first step of defining critical habitat for northern quolls is defining the distribution of northern quolls in the Pilbara with better accuracy than has previously been available. From this, it will be possible to better ascertain how large-scale disturbances (including habitat modifiers that are natural, such as fire, or human-induced, such as habitat fragmentation from linear infrastructure) or habitat characteristics (such as less preferred habitat) may affect distribution or population densities.

2.1 Species Distribution Modelling

Background

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

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

1. Development of a predictive model of northern quoll habitat on a finer scale than is currently available based on an enhanced dataset, including new 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 4).

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

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

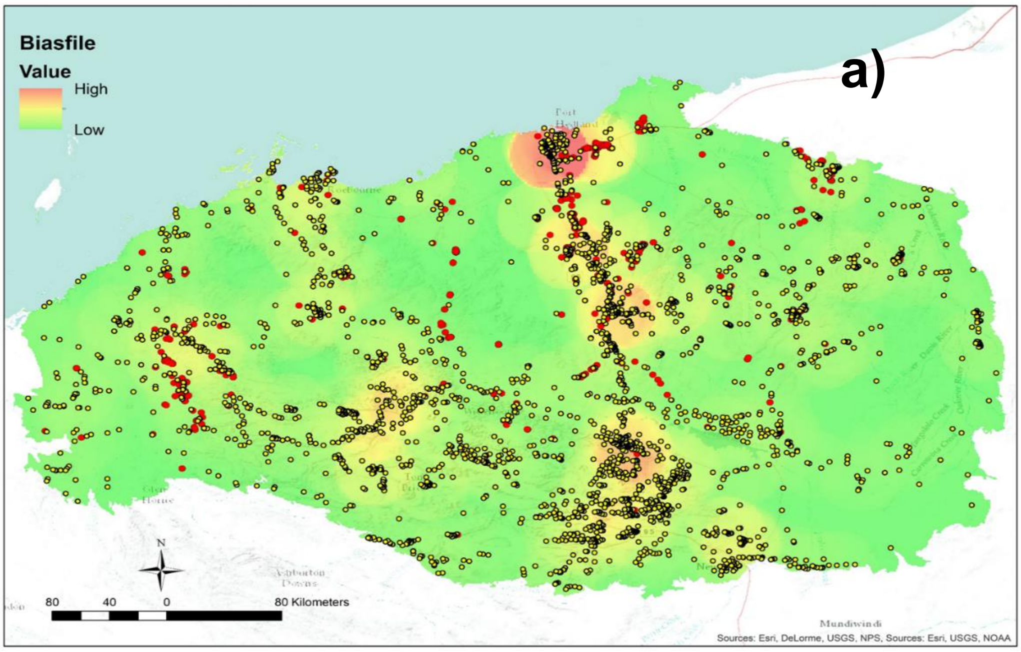
Status: completed, manuscripts submitted/in preparation:

Molloy, S., Davis, R.A., Dunlop, J., van Etten, E.J.B., Predictive distribution modeling can inform the management of endangered species; a case study with the Northern Quoll. Submitted.

Molloy, S., Dunlop, J., Davis, R.A., van Etten, E.J.B., Spatial Modelling for the Northern Quoll in the Pilbara: Assessing Threats to a Unique and Isolated Population of an Endangered and Iconic Species.

Table 4. Final suite of variables with percentage contribution and permutation importance as determined through step-wise MaxEnt analyses. *All contribution and importance values reflect positive relationships to northern quoll presence.*

Variable	Percentage Contribution	Permutation Importance
Landsystem Mapping (VegAg)	35	14
Digital Elevation Model (DEM)	17	35
Annual Mean Temperature (BIO1)	17	8
Slope	11	11
Precipitation of Warmest Quarter (BIO18)	9	15
Euclidean Distance to Water Courses	4	6
Precipitation of Coldest Quarter (BIO19)	4	4
Soil Mapping (Soils)	3	5
Mean Temperature of Driest Quarter (BIO9)	2	2



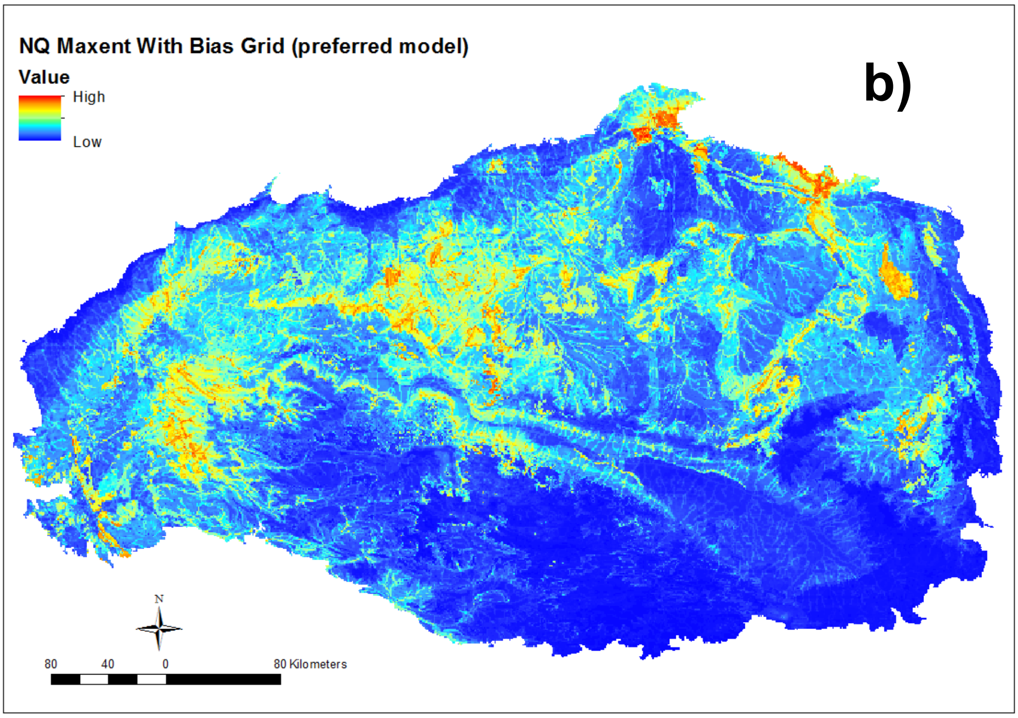


Figure 4. a) Bias grid GIS file created from known fauna trapping surveys, used to generate pseudo-absence data, where red dots are northern quoll presences, and yellow dots are other non-volant critical weight range species records, and;
b) the final MaxEnt SDM, constructed with the bias grid and minimum variable set listed in Table 4. *Likelihood of northern quoll presence ranges from red (high likelihood) to blue (low likelihood) to a 1km² resolution.*

2.2 Interactions between northern quolls and infrastructure

Background

Mining and infrastructure impacts on northern quoll populations are not limited to direct factors such as habitat loss, but also the effects of associated development and human activity. Large linear infrastructure (such as rail lines and roads) has the potential to disrupt wildlife via habitat fragmentation and vehicle collision (Taylor and Goldingay, 2010). Landscape barriers may modify behavior due to animal avoidance and create subpopulations by restricting gene flow (Holderegger and Di Giulio, 2010). Crossing structures such as bridges and underpasses are often created to assist with animal movements, but the efficacy of such impact mitigation strategies can be variable (Lesbarrères and Fahrig, 2012; Soanes *et al.*, 2013)

The aims of this study were to expand the limited knowledge of northern quoll spatial ecology, investigate the interactions of northern quolls with linear infrastructure habitat barriers, and determine whether manufactured underpasses were effective in facilitating movement between areas of habitat separated by rail lines. This study was undertaken as an Honours project by Melinda Henderson (Edith Cowan University) in collaboration with Roy Hill at an area 143km northwest of Newman (Henderson, 2015).

Ten northern quolls were fitted with custom-made combination GPS/VHF collars, each with the capacity to collect 50 GPS locations. Nocturnal GPS fixes were supplemented with VHF tracking to diurnal den sites and trap locations to create home range estimates using minimum convex polygons (MCP) and kernel density estimation (KDE). These two techniques can produce different estimations of home range as MCPs estimate home range area by determining the smallest area (or polygon) that encompasses all of the recorded animal locations, while KDE measures home range by predicting the likelihood of an animal using an area (this also allows core areas of activity to be identified). The maximum distances moved by animals overnight was calcultaed, and determined the relationships between landscape features and northern quoll home range areas.

Outcomes

Tracking collars were retrieved from seven northern quolls; three females and four males. On average, each collar made 42 attempts to record a location and of these attempts 29% were successful. A total of 130 locations were collected, ranging between 10 and 32 locations per individual. The average MCP home range estimates were 13.4 ± 2.7 ha for females and 58.0 ± 5.65 ha for males. The much larger KDE estimates were 45 ± 35 ha and 143 ± 151 ha for females and males respectively (Table 5). Based on accumulation plots, these estimates are under representations of home range area (factors limiting the number of locations collected were the battery capacity of the GPS unit on the collar and the habitat type used by the northern quolls).

Table 5. Home range (HR) estimates, methods of estimation and overnight distances moved for male and female northern quolls determined for this study (Henderson, 2015) and from the published literature.

Reference	Method	Data collection	Location	Male HR (ha)	Female HR (ha)	Max distance travelled (km/night)
Henderson (2015)	MCP	Trap locations, VHF and GPS	Pilbara	58.0 (± 5.6)	13.4 (± 2.7)	5.0 (male) 2.8 (female)
Henderson (2015)	KDE	Trap locations, VHF and GPS	Pilbara	143.0 (± 151.0)	45.0 (± 35.0)	
Johnson and Oates (2013)	MCP	VHF	Pilbara	1,097.0 (± 477.0)	9.7 (± 4.3)	-
Cook (2010a)	MCP	VHF, trap locations	Kimberley	74.8 (± 36.6)	11.6 (± 2.3)	4.2 (male) 0.6 (female)
Oakwood (2002)	MCP	VHF, grid trapping	Kakadu	84.1 (± 16.0)	34.8 (± 6.4)	1.8 (male) 1.2 (female)
Schmitt *et al.* (1989)	MCP	Grid trapping	Kimberley	1.8 (± 1.6)	2.3 (± 1.2)	2.5
King (1989)	MCP	VHF	Pilbara	382.4 (± 189.0)	219.6 (± 113.0)	-
Begg (1981)	n/a	Trapping	Kakadu	-	-	0.9 (male) 1.2 (female)

Using customized technology and nocturnal foraging area, this study provided new northern quoll movement and home range estimates in the presence of large linear infrastructure. Home range areas for both estimates were strongly associated with rocky linear landscape features, while the KDE estimates showed multiple core areas of foraging habitat that were also strongly associated with landscape features.

During nocturnal foraging, large distances were traversed by northern quolls. Maximum overnight distances recorded for male and female northern quolls were 5.0 km and 2.8 km respectively. These distances are comparable to those recorded in other studies (Table 5), but probably represent greater accuracy due to the distances being calculated using multiple points recorded by GPS throughout the night rather than just two consecutive daily locations. Northern quoll night time foraging areas have only been represented in previous home range studies by trap locations (King, 1989; Oakwood, 2002; Oakwood, 2002; Johnson and Oates, 2013). The inclusion of unbiased nighttime locations in this study rather than locations determined by baited traps makes these estimates of home range the best representation of foraging area available for northern quolls.

Collared northern quolls were not observed to cross over or under (via underpasses) rail lines in this study. Paired remote cameras set on underpass entrances failed to record northern quolls passing through these structures despite animals being recorded at the entrances. Species that were recorded using underpasses included euros (*Macropus robustus*), feral cats (*F. catus*) and canids (*Canis* sp.). In the Pilbara northern quolls have previously been recorded to use large rail underpasses (two to three metres in diameter) that are suitable for cattle (Creese, 2012).

Both this study and previous work conducted elsewhere in the Pilbara found that home range areas and animal movement are strongly influenced by landscape features (Astron Environmental Services, 2014; Dunlop *et al.*, 2015). In this instance, there was a strong relationship between rocky landscape features, geology and northern quoll habitat preference. It was demonstrated that northern quolls will continue to cross roads that intersect preferred habitat, however no evidence of crossing rail lines was recorded in this study, suggesting that this type of infrastructure may act as a barrier to movement. Northern quolls did not interact with infrastructure that was away from their preferred habitat features. Infrastructure that avoids the destruction or fragmentation of complex rocky habitat utilised by northern quolls for foraging and denning will have the least impact on this species.

Status: Completed, Manuscript for publication being prepared

Honours thesis available;

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

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, in resource limitations, 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 movement 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 region of Western Australia. 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.

Outcomes

Samples used in the preliminary work were biased toward a few sites, where DNA samples from large numbers of individuals came from a small number of sites. Additional samples collected between 2012 and 2015 (approx. 500: Table 6) have been selectively added to the above analysis to reduce the clustering of samples that was present in the original dataset, and provide insights into lower density populations.

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.

Status: Ongoing. Additional DNA samples will be analysed in 2016

Table 6. Northern quoll tissue samples collected 2011–2015 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	-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 Mine	-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 mine	-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**
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 *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 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 7). Both of these sites are part of the annual monitoring program so there had been two years of 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).

Table 7. 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
PY sampled	65	35	100
Average number of PY ± Standard Error	5.00 ± 0.47	7.00 ± 0.63	

Status: Ongoing, DNA samples will be analysed in 2016

3.3 Composition and regional variation in the diet of Pilbara northern quolls

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).

The few 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.

This project examines how northern quoll diet varies throughout the Pilbara bioregion, and identifies any key dietary components required for persistence. The project also tests the influence of environmental factors and location on the relative importance of dietary categories.

Outcomes

Five-hundred northern quoll scats from 325 locations throughout the Pilbara region (Figure 5) were collected for analysis. 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.

Dietary items were very diverse (Table 8) and were identified to 42 items that were then grouped into 12 more general dietary categories (Figure 6). Pilbara northern quolls most frequently preyed upon insects, present in more than 85% of scats. Other invertebrates consumed by northern quolls included crustaceans (probably ghost crabs; *Ocypodinae*), molluscs, arachnids and myriapods. Reptiles and small mammals were the most frequently consumed vertebrate prey, occurring in 20% and 17% of scats, respectively. Food items larger than one kilogram and therefore unlikely to have been predated upon by a northern quoll were categorised as carrion. Northern quolls frequently consumed the seeds, fruit, flowers and other parts of several plant species. Vegetative material featured in 29% of scats. Much of this material was from native fig (*Ficus* spp.), which occurred in 10% of the scats sampled.

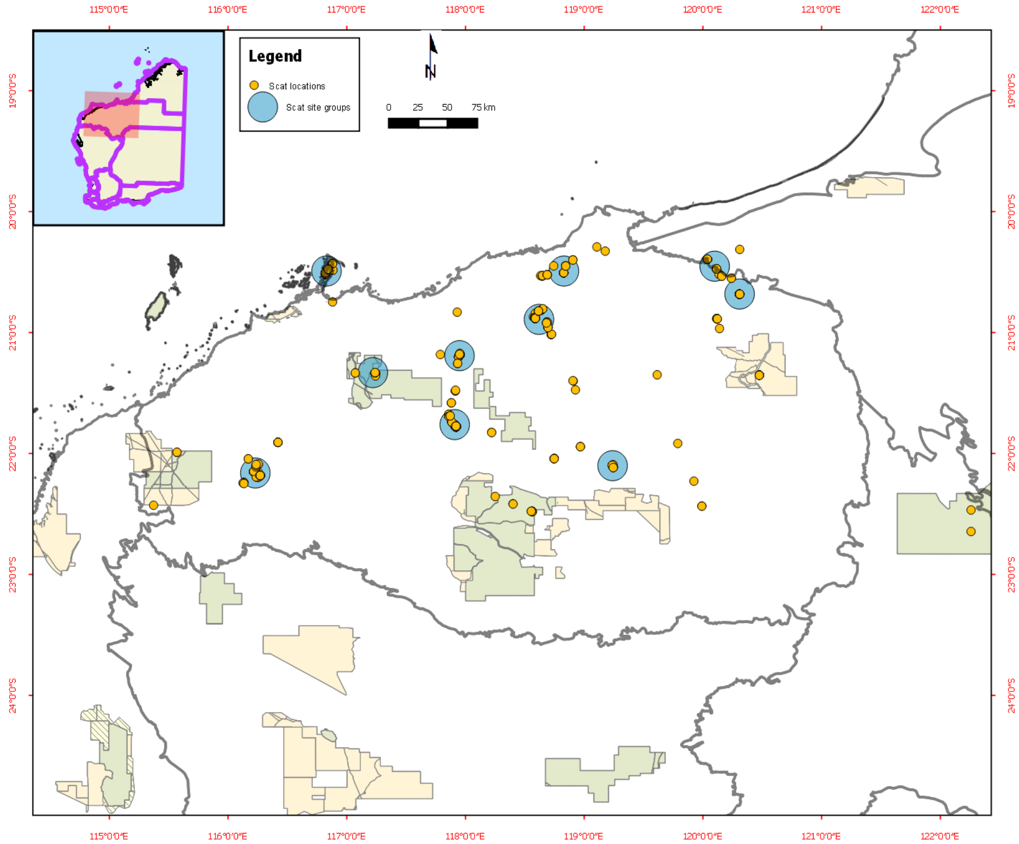


Figure 5. Map depicting northern quoll scats collected throughout the Pilbara, and the ten site groupings with 19 or more scats within a 30km radius. *The raster layer depicts Parks and Wildlife managed conservation reserves and unallocated crown land managed for conservation, with the grey line delimiting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

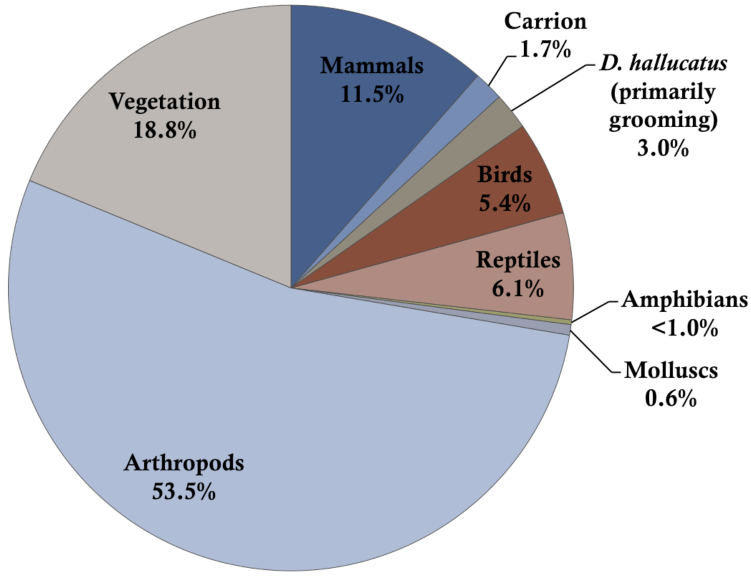


Figure 6. Composition of food items contained in 500 Pilbara northern quoll scats. *Dietary items were categorized by volume for 12 food groupings.*

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 being prepared

Table 8. 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.*

Dietary item	Frequency (%)	Volume (%)
VERTEBRATES	**42.0**	**23.2**
MAMMALS	**16.8**	**11.5**
Chiroptera	**1.4**	**0.8**
unidentified Microbat	0.8	0.4
Rhinonicteris aurantia	0.4	0.3
Nyctophylus sp	0.2	0.1
Rodents	**13.2**	**8.9**
Zyzomys argurus	9.2	6.6
Pseudomys hermannsbergensis	3.0	2.1
Pseudomys delicatulus	0.6	0.1
other Rodent	0.4	0.1
Marsupials	**2.8**	**1.8**
Dasyurid	1.0	0.3
Ningaui timeleyai	0.8	0.6
Dasykaluta rosamondae	0.4	0.3
Sminthopsis youngsoni	0.2	0.2
Sminthopsis macroura	0.2	0.2
Pseudantechinus sp	0.2	0.2
CARRION	**3.4**	**1.7**
Macropus rufus	1.0	0.6
Macropus robustus	1.0	0.6
Bos taurus	0.6	0.2
Trichosurus sp	0.2	0.1
Felis catus	0.2	0.2
Canis sp	0.2	0.1
Bone	0.2	0.0
D. hallucatus	**19.2**	**2.1**
BIRDS	**12.0**	**5.4**
REPTILES	**20.2**	**6.1**
Skink	13.4	3.5
Dragon	1.8	0.8
Varanid	0.6	0.4
Gecko	1.2	0.3
Snake	3.6	1.0
AMPHIBIANS	**1.4**	**0.3**
INVERTEBRATES	**90.6**	**54.2**
MOLLUSCS	**3.4**	**0.6**
ARTHROPODS	**90.4**	**53.6**
Crustaceans	**6.6**	**3.2**
Insects	**87.8**	**44.3**
Beetle/bug	48.0	12.4

Dietary item	Frequency (%)	Volume (%)
Grasshopper/cricket	39.0	13.4
Ant/termite	52.2	6.6
Cocoon	4.0	1.3
Grub/caterpillar	17.8	9.0
Other insect	3.6	1.5
Arachnids	**5.4**	**0.7**
Spider	5.0	0.5
Scorpian	0.4	0.2
Myriapods	**12.4**	**5.4**
Centipede	10.8	4.8
Millipede	1.8	0.6
VEGETATION	**29.4**	**18.8**
Seed	22.4	15.5
Vegetation	5.4	2.1
Fruit	1.6	1.0
Flower	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. However, the impact of mortality (via predation, or accidental bait uptake) on different cohorts of the northern quoll population was required in order to undertake the most efficient control program. Modelling these threats lends itself to extrapolating the potential future impacts of the arrival of the cane toad. Species records for introduced and other native species of interest are also reported on in this section.

4.1 Long-term impacts on quoll populations by feral cat predation, baiting and cane toad invasion

Background

The potential risk to northern quoll populations in the Pilbara via enhanced mortality from predation or non-target poison bait consumption was assessed using Population Viability Analyses (PVA), to determine any impact of cat baiting on population persistence.

A series of simulated PVA models were constructed to understand the significance of a change to a northern quoll population over a 20-year period under increased bait-related mortalities, or increased initial northern quoll population sizes. The answers to these questions can help to inform managers on what:

a) the presumed effects of current feral cat baiting programs are likely to be on population persistence of northern quoll over a 20-year period; and

b) the degree of change over time with an increased initial population size of northern quolls.

Specific aims were to investigate:

1. the persistence of a northern quoll over a 20-year period under current (baseline, in the absence of feral cat baiting) conditions in terms of: population growth rate (deterministic and stochastic), probability of population extinction; mean population size and population persistence.
2. the variation in northern quoll persistence with a change in:
    a. initial population size numbers;
    b. bait-related mortality to adult or juvenile northern quolls;
    c. carrying capacity; or
    d. an increase of the adult or juvenile northern quoll population over time as a result of the effect of a reduction in feral cat predation.

The population viability model used empirical data derived from northern quoll monitoring programs across the Pilbara and from demographic studies elsewhere in Australia. A set of alternative scenarios were also modelled to examine potential changes to a northern quoll population under increased bait-related mortalities, or increased survivorship, over a duration of 20-years.

Outcomes

Improving adult or juvenile survivorship above current levels (including reducing feral cat predation) increased population size and reduced the risk of local extinction. Population growth rate was most sensitive to perturbations in adult and juvenile mortality, with increases of more than 10% or 5%, respectively, above current estimated (baseline) levels leading to dramatic declines in northern quoll numbers. Importantly, increasing juvenile mortality by 5% caused a predicted 22-54% decline in population size, with a moderate to high chance (20-96%) of local extinction within 20 years.

Changes in the mortality rates of juvenile northern quolls were found to have the most impact on population estimates. From a management perspective, an increase in feral cat-predation, and the real possibility of increased mortality following the inevitable arrival of cane toads in the Pilbara have potentially serious implications for the juvenile cohort, and the persistence of local populations of northern quoll.

Status: Completed, manuscript being prepared

4.2 Threatened and introduced species records

Background

The collection of incidental records for non-target species provides valuable information regarding the species' distribution and critical habitats (Carwardine et al 2014; Cramer et al 2016). This data is valuable for informing the management of northern quolls when considering their interaction with predators, prey species and animals capable of major habitat modification. We aim to contribute to this dataset by recording locations of non-target species encountered during the activities of the northern quoll program.

Outcomes

In the course of completing northern quoll surveys and annual monitoring during 2015, records were collected for introduced species and other native species of significance. Although the records for non-target species were opportunistic, a similar survey effort was involved for each surveyed site. Detection methods of non-target species included direct sightings, capture in a trap or via remote camera and observations of tracks and scats.

Introduced species were detected at 12 different sites during the course of the 2015 northern quoll program. A total of 50 observations were made, these consisted of the following five species - feral cats (*F. catus*), wild dogs/dingoes (*Canis* sp.), one-humped camels (*Camelus dromedarius*), donkeys (*Equus africanus*) and cattle (*Bos taurus*). Locations of the eight introduced species that have been recorded since the commencement of the northern quoll program are displayed in Figure 7.

Observations of other native species of significance were made on 23 occasions and recorded at 11 sites across the Pilbara in 2015. The six species detected were Rothschild's rock wallaby (*Petrogale rothschildi*), Rory's or Woolley's Pseudantechinus (*Pseudantechinus sp.*), the short-beaked echidna (*Tachyglossus aculeatus*), black-headed python (*Aspidites melanocephalus*) and the Pilbara olive python (*L. olivaceus barroni)*, currently listed as Vulnerable under the EPBC Act. Since 2011, contributions have been made to records for seven species of significance across 18 sites in the Pilbara (Figure 8).

Status: Data collection ongoing as part of the annual monitoring program.

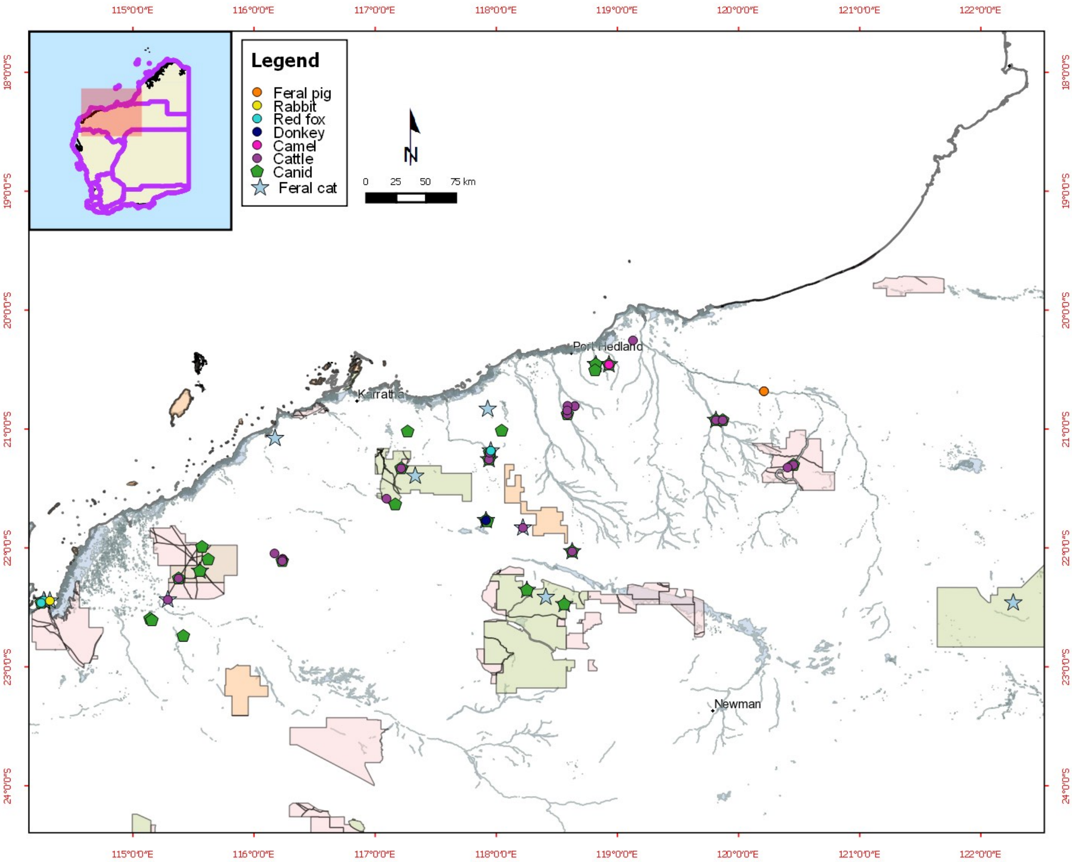


Figure 7. Locations across the Pilbara of introduced animal species records collected by the northern quoll research program since 2011. *Specific records are listed below in Appendix 1.*

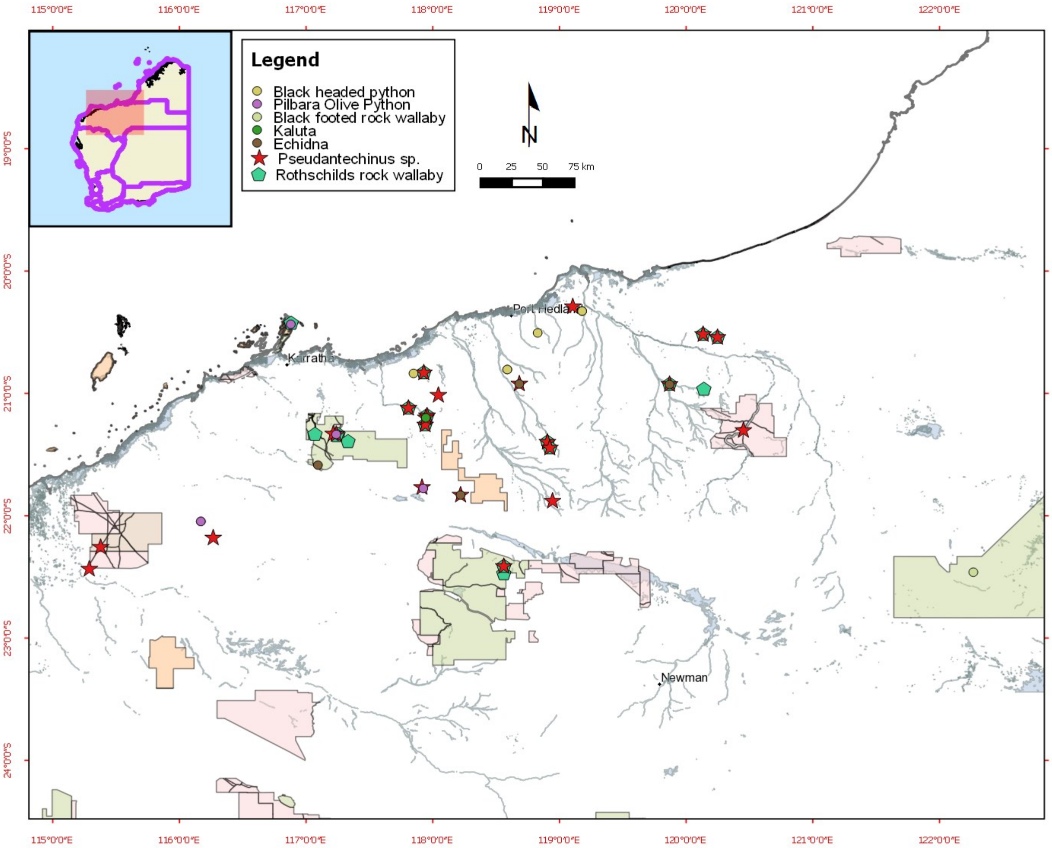


Figure 8. Map depicting records of threatened and other species of interest collected by the northern quoll program since 2011. *Specific records are listed below in Appendix 2.*

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 2014-2015

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Appendices

Appendix 1. Introduced species records collected by the northern quoll program since 2011. *Detection methods are annotated as follows: A – animal sighting, S – scat, R – remote camera, T – track. CP = Conservation Park, NP = National Park.*

Location	Species	Latitude	Longitude	Year	Detection method
Cane River CP	Canid	22.0962	115.6210	2012	S,R
Cane River CP	Canid	21.9910	115.5708	2012	S,R
Cane River CP	Canid	22.5950	115.1417	2012	A
Cane River CP	Canid	22.6083	115.1417	2012	A
Cane River CP	Canid	22.7400	115.1417	2012	A
Cane River CP	Canid	22.193	115.5540	2015	T
Cane River CP	Canid	22.2562	115.3778	2015	T
Cane River CP	Cat	22.4349	115.2884	2014	R
Cane River CP	Cat	22.1930	115.5540	2014, 2015	R,T
Cane River CP	Cattle	22.4349	115.2884	2014	A,T
Cane River CP	Cattle	22.2562	115.3778	2015	T
De Grey Station	Cattle	20.2534	119.1291	2014	T
Eginbah Station	Canid	20.9243	119.8139	2015	T
Eginbah Station	Cat	20.9243	119.8139	2015	R
Eginbah Station	Cattle	20.9243	119.8139	2015	T
Giralia Station	Canid	22.4606	114.2423	2012	R
Giralia Station	Cat	22.4502	114.2699	2012	R
Giralia Station	Cat	22.4417	114.2647	2012	R
Giralia Station	Cat	22.4433	114.3145	2012	R
Giralia Station	Rabbit	22.4433	114.3145	2012	R
Giralia Station	Red fox	22.4502	114.2699	2012	R
Giralia Station	Red fox	22.4417	114.2647	2012	R
Giralia Station	Red fox	22.4606	114.2423	2012	R
Hooley Station	Canid	22.0292	118.6269	2014	S,R,T
Hooley Station	Cat	21.8296	118.2201	2014	R
Hooley Station	Cat	22.0292	118.6269	2014	T
Hooley Station	Cattle	21.8296	118.2201	2014	R
Hooley Station	Cattle	22.0292	118.6269	2014	T
Indee Station	Canid	20.8760	118.5880	2015	T
Indee Station	Cattle	20.8065	118.6476	2014	T
Indee Station	Cattle	20.8065	118.6476	2014	T
Indee Station	Cattle	20.8037	118.5888	2015	T
Indee Station	Cattle	20.8760	118.5880	2015	S,T
Indee Station	Cattle	20.8426	118.5863	2015	T
Karijini NP	Canid	22.4738	118.5614	2011	R
Karijini NP	Canid	22.3544	118.2532	2015	R
Karijini NP	Cat	22.4738	118.5614	2015	T
Karijini NP	Cat	22.4131	118.4097	2015	R
Karijini NP	Cat	22.3544	118.2532	2015	R
Karlamilyi NP	Cat	22.4605	122.2687	2015	R
Mallina Station	Canid	21.0200	117.2683	2012	S
Mallina Station	Canid	21.0133	118.0448	2014	T
Mallina Station	Canid	21.2555	117.9405	2015	T
Mallina Station	Canid	21.1981	117.9459	2015	T
Mallina Station	Cat	21.1814	117.9552	2014	T
Mallina Station	Cat	20.8305	117.9298	2014	S
Mallina Station	Cat	21.2555	117.9405	2015	R,T
Mallina Station	Cattle	21.1814	117.9552	2014, 2015	T
Mallina Station	Cattle	21.2555	117.9405	2015	T
Mallina Station	Cattle	21.1981	117.9459	2015	T

Location	Species	Latitude	Longitude	Year	Detection method
Mallina Station	Red fox	21.1814	117.9552	2014	S
Mardie Station	Cat	21.0767	116.1733	2014	S
Meentheena CP	Canid	21.3012	120.4535	2015	T
Meentheena CP	Cattle	21.3012	120.4535	2015	T
Meentheena CP	Cattle	21.3228	120.4056	2015	R,T
Millstream Chichester NP	Canid	21.6333	117.1667	2012	S
Millstream Chichester NP	Canid	21.3299	117.2148	2015	T
Millstream Chichester NP	Cat	21.3937	117.3312	2014	R
Millstream Chichester NP	Cattle	21.5849	117.0939	2015	T
Millstream Chichester NP	Cattle	21.3299	117.2148	2015	T
Mt Florance Station	Canid	21.7675	117.9156	2015	T
Mt Florance Station	Canid	21.7760	117.9253	2015	R,T
Mt Florance Station	Cat	21.7675	117.9156	2015	R
Mt Florance Station	Donkey	21.7675	117.9156	2015	S,T
Muccan Station	Canid	20.9249	119.8702	2015	T
Muccan Station	Cattle	20.9249	119.8702	2015	T
Poondano	Camel	20.4551	118.8223	2015	S
Poondano	Camel	20.4332	118.8581	2015	T
Poondano	Camel	20.4573	118.9307	2015	T
Poondano	Canid	20.4551	118.8223	2015	S,T
Poondano	Canid	20.5057	118.8162	2015	T
Poondano	Canid	20.4573	118.9307	2015	T
Poondano	Cat	20.4551	118.8223	2015	T
Poondano	Cat	20.4573	118.9307	2015	T
Red Hill Station	Canid	22.1095	116.2333	2014, 2015	T
Red Hill Station	Cattle	22.0906	116.2368	2014	T
Red Hill Station	Cattle	22.0455	116.1693	2014	R
Red Hill Station	Cattle	22.0973	116.2330	2014	T
Red Hill Station	Cattle	22.1095	116.2333	2014	T
Yarrie Station	Cattle	20.6811	120.2107	2014	R
Yarrie Station	Feral pig	20.6811	120.2107	2014	R

Appendix 2. Records of threatened and other species of interest collected by the northern quoll program since 2011. *Detection methods are annotated as follows: C- capture, A – animal sighting, S – scat, R – remote camera, T – track. CP = Conservation Park, NP = National Park, NR = Nature Reserve.*

Location	Species	Latitude	Longitude	Year	Method
BHP Rail	Echidna	20.9212	118.6839	2013	C
BHP Rail	*Pseudantechinus* sp.	20.9212	118.6839	2011	R
BHP Rail	*Pseudantechinus* sp.	21.3972	118.9057	2011, 2013	C,R
BHP Rail	*Pseudantechinus* sp.	21.4447	118.9246	2011	C,R
BHP Rail	*Pseudantechinus* sp.	21.8791	118.9462	2011	R
BHP Rail	Rothschild’s rock-wallaby	21.3972	118.9057	2011, 2012	C,R
BHP Rail	Rothschild’s rock-wallaby	21.4447	118.9246	2011, 2012	C,A,R
Cane River CP	*Pseudantechinus* sp.	22.4349	115.2884	2014	R
Cane River CP	*Pseudantechinus* sp.	22.2562	115.3778	2015	R
Cattle Gorge	*Pseudantechinus* sp.	20.5408	120.2489	2011	R
Cattle Gorge	Rothschild’s rock-wallaby	20.5408	120.2489	2011	R
De Grey Station	Black-headed python	20.3258	119.1796	2012	R
De Grey Station	Echidna	20.3258	119.1796	2012	R
De Grey Station	*Pseudantechinus* sp.	20.2895	119.1059	2014	C
Dolphin Island NR	Rothschild’s rock-wallaby	20.4260	116.8828	2014, 2015	R
Hooley Station	Echidna	21.8296	118.2201	2014	R
Hooley Station	*Pseudantechinus* sp.	21.8296	118.2201	2014	R
Indee Station	Black-headed python	20.8037	118.5888	2015	R
Indee Station	Echidna	20.8037	118.5888	2015	R
Karijini NP	*Pseudantechinus* sp.	22.4131	118.5614	2015	R
Karijini NP	Rothschild’s rock-wallaby	22.4738	118.5614	2015	R
Karijini NP	Rothschild’s rock-wallaby	22.4131	118.5614	2015	R
Karlamilyi NP	Black-footed rock-wallaby	22.4605	122.2687	2014	R
Mallina Station	Kaluta	21.1981	117.9459	2015	R
Mallina Station	*Pseudantechinus* sp.	21.1814	117.9552	2014	C
Mallina Station	*Pseudantechinus* sp.	21.1198	117.8085	2012	R
Mallina Station	*Pseudantechinus* sp.	21.0133	118.0448	2014	R
Mallina Station	*Pseudantechinus* sp.	20.8305	117.9298	2014	R
Mallina Station	*Pseudantechinus* sp.	21.2555	117.9405	2015	R
Mallina Station	*Pseudantechinus* sp.	21.1981	117.9459	2015	R
Mallina Station	Rothschild’s rock-wallaby	21.1814	117.9552	2015	A,R
Mallina Station	Rothschild’s rock-wallaby	21.1198	117.8085	2012	R
Mallina Station	Rothschild’s rock-wallaby	20.8305	117.9298	2014	R
Mallina Station	Rothschild’s rock-wallaby	21.2555	117.9405	2015	R
Meentheena CP	*Pseudantechinus* sp.	21.3012	120.4535	2015	R
Millstream Chichester NP	Echidna	21.5849	117.0939	2015	R
Millstream Chichester NP	*Pseudantechinus* sp.	21.3336	117.2387	2011	R
Millstream Chichester NP	*Pseudantechinus* sp.	21.3299	117.2148	2015	R
Millstream Chichester NP	Rothschild’s rock-wallaby	21.3336	117.2387	2011	R
Millstream Chichester NP	Rothschild’s rock-wallaby	21.3345	117.0708	2011	R
Millstream Chichester NP	Rothschild’s rock-wallaby	21.3347	117.2526	2014	R
Millstream Chichester NP	Rothschild’s rock-wallaby	21.3937	117.3312	2014	R
Millstream Chichester NP	Rothschild’s rock-wallaby	21.3444	117.2415	2011, 2014	R
Mt Florance Station	Pilbara Olive Python	21.776	117.9253	2014	C
Mt Florance Station	*Pseudantechinus* sp.	21.7675	117.9156	2015	R

Location	Species	Latitude	Longitude	Year	Method
Muccan Station	Echidna	20.9249	119.8702	2015	R
Muccan Station	*Pseudantechinus* sp.	20.9249	119.8702	2015	R
Muccan Station	Rothschild's rock-wallaby	20.9249	119.8702	2015	R
Poondano	Black headed python	20.5042	118.8287	2015	C
Red Hill Station	Echidna	22.0455	116.1693	2014	R
Red Hill Station	*Pseudantechinus* sp.	22.1798	116.2671	2014	C
Whim Creek	Black-headed python	20.8355	117.8485	2015	C
Yarrie Station	*Pseudantechinus* sp.	20.5166	120.1351	2014	R
Yarrie Station	Rothschild's rock-wallaby	20.9656	120.1409	2014	S
Yarrie Station	Rothschild's rock-wallaby	20.5166	120.1351	2014	R