Department of **Biodiversity, Conservation and Attractions**

GOVERNMENT OF WESTERN AUSTRALIA

The ecology of the northern quoll (*Dasyurus hallucatus*) in the Pilbara bioregion, Western Australia

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The ecology of the northern quoll (*Dasyurus hallucatus*) in the Pilbara bioregion, Western Australia

Project plans for 2016–2020

Viki Cramer and Judy Dunlop

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Department of **Biodiversity, Conservation and Attractions**

Department of Biodiversity, Conservation and Attractions
Locked Bag 104
Bentley Delivery Centre WA 6983
Phone: (08) 9219 9000
Fax: (08) 9334 0498

www.dbca.wa.gov.au

This report/document/publication was prepared by Judy Dunlop

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

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Contents

Objectives of this document

1. To outline the scope, expected outcomes and benefits of research that is, or could potentially be, undertaken under current or future funding provisions, including environmental offsets. The research projects outlined here are guided by the outcomes of a workshop to determine research priorities for the northern quoll held by the Department of Biodiversity, Conservation and Attractions (formerly Department of Parks and Wildlife in July 2013 (see Cramer et al. 2016), and a workshop to further refine these priorities held in May 2016.
2. To justify funding allocations for the research program.
3. To guide future approval conditions and potential offset decisions for research and landscape scale management actions for the northern quoll in the Pilbara bioregion of Western Australia

Background information

The northern quoll is a medium-sized predatory marsupial, the smallest of Australia's four species of *Dasyurus* (Oakwood, 2002a). Northern quolls were once widely distributed from the Pilbara, Kimberley, across the Top End to southern Queensland, but have now contracted in distribution and density to several disjunct populations within their former range (Braithwaite and Griffiths, 1994). In 2005, the northern quoll was listed as an Endangered species under the Commonwealth's *Environmental Protection and Biodiversity Conservation (EPBC) Act 1999* (Oakwood, 2008). This listing was due to an alarming decrease or the complete collapse of some of the once locally abundant populations in Queensland and the Northern Territory, and a subsequent contraction of its range (Oakwood and Foster, 2008). In particular, northern quolls have declined at a rapid rate in association with the spread of the introduced cane toad *Rhinella marina*, which poisons quolls in their predation attempts. 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 (*Canis lupus*), altered fire regimes, total grazing pressure and subsequent habitat modification by introduced herbivores, habitat loss and fragmentation, as well as the interactive effects between threatening processes (Braithwaite and Griffiths, 1994; Hill and Ward, 2010; Woinarski *et al.*, 2014).

Northern quolls inhabit a variety of areas, including rocky outcrops and ridges, rainforests, eucalypt forest and woodland, sandy lowlands, shrublands, grasslands, and desert (Department of Sustainability, 2011). In the Pilbara, northern quolls appear to depend more heavily on complex rocky habitat than do northern quolls in the Northern Territory or Queensland, where tree hollows and logs are more common (Oakwood, 1997). The ridges and mesas of channel-iron deposits and banded iron formations in the Pilbara are often the primary focus of iron-ore extraction in the Hamersley Province (Morris and Ramanaidou, 2007), while granite outcrops are often quarried for road base and rail ballast. For this reason, Pilbara northern quolls are recognised as specially protected fauna under the *EPBC*

Act 1999, due to the likelihood that the species will be impacted by the removal or alteration of habitat by mining activity and associated infrastructure development.

Although they are primarily carnivorous, feeding on invertebrates and small vertebrates, northern quolls will also opportunistically eat eggs and fleshy fruit or scavenge on roadkill or waste (Radford, 2012; Dunlop *et al.*, 2017). Northern quolls are sexually dimorphic, with males tending to be larger than females (Oakwood, 2002b). The species is the largest animal in the world to undergo suicidal reproduction (semelparity), whereby males experience immune system collapse and eventual death after an intense mating period (Oakwood *et al.*, 2001; Fisher *et al.*, 2013). This enables females to drive intense competition between males, and allow females and their young to have access to maximum food abundance during the period of pouch young development and dispersal (Fisher *et al.*, 2013). Females breed synchronously over a period of months, when six to eight young are born, grow in the pouch and are deposited in dens after eight to nine weeks (Oakwood, 2008).

While the biology and ecology of the northern quoll has been studied in the Northern Territory (Begg, 1981; Braithwaite and Griffiths, 1994; Oakwood, 2000; Oakwood, 2002b) and to a lesser extent in the Kimberley (Cook, 2010a; How *et al.*, 2009; Schmitt *et al.*, 1989; Spencer *et al.*, 2016), few studies have been undertaken on northern quolls in the Pilbara. With the availability of offset funds, research is currently underway to address knowledge gaps for Pilbara quolls (Department of Sustainability, 2011). Research was informed from a grey literature review (Cook, 2010b), and the outcomes from workshops in 2011, 2013 and 2016 (Cramer et al., 2016). The Department of Biodiversity, Conservation and Attractions (DBCA) has implemented a Pilbara-wide quoll research program (Dunlop *et al.*, 2014; Dunlop *et al.*, 2018) to provide a regional context for targeted population ecology and applied management research.

PROJECT PLANS for 2016–2020

The project plans are based on the research priorities determined at the workshop held in 2013 and described in (Cramer *et al.*, 2016), and further refined during a revisionary workshop held in May 2016.

1 Develop appropriate and standardised survey protocols

1.1 Background information and rationale

The survey objectives of this research program focus on reliably assessing whether northern quolls are present within a proposed project area, to estimate the abundance (or population size) of quolls in a particular area, and/or to provide the underpinning data for distributional and habitat modelling.

The Australian Department of the Environment (2016) (DoE) has developed survey guidelines for northern quolls, mostly relating to sampling effort and protocols that will provide an acceptable level of confidence on whether or not quolls occur in a particular area. However, surveys for quolls are undertaken for a range of reasons such that the DoE guidelines are not necessarily always the most appropriate. Furthermore, some sampling procedures have advanced considerably since the publication of the guidelines in 2016.

A desktop review by Annette Cook (Cook, 2010b) to assess fauna surveys carried out in the Pilbara found that, in many cases, the level of sampling effort was not adequate to reliably detect northern quolls. Molloy *et al.* (2017) found that a large part of survey work for the northern quoll to date has relied on revisiting the sites of known populations, rather than identifying new ones. The relatively uniform characteristics and management regimes of these sites, means that construction of species distribution models (SDMs) for the Pilbara population is potentially susceptible to a high level of sample bias.

The unusual demographic characteristics of northern quolls, whereby most males disperse widely in the breeding season and then die after the largely synchronous mating period, means that the timing of surveys for northern quolls requires special consideration. There are times of year when males may be reported in atypical habitat, other times when the population effectively halves to comprise almost exclusively pregnant females, and other times when independent young produce a flush of new individuals in an expanded population. Comparability among, and interpretation of, survey results will be compromised if sampling occurs at markedly different times in this annual cycle. Male quolls are likely to be found in a variety of habitats, including ones unsuitable for long-term occupancy, during the breeding season when they roam widely searching for females. Females appear to be far more stable in territory and are likely the far better and reliable indicators of habitat suitability.

Another recent development in sampling for northern quolls involves the ability to recognise individuals in camera trap images, from their spot patterns {Hohnen et al., 2013, #52308}.

With the appropriate lay-out of cameras and sufficient sampling duration, this advance allows for the evaluation of quolls numbers in a sampled area, and hence density estimates to be determined. Such information is a substantial advance on simply presence/absence or capture rates: for example, it can provide the basis for spatial population modelling, or can provide the evidence required in assessment of whether a particular area supports a significant quoll population.

1.2 Scope of research and potential methods

Some limited additional research is required to ensure that appropriate survey standards are developed or refined, more consistently used, and provide optimally for impact assessment, distributional modelling and other objectives. There are three main issues that merit additional research:

1. The extent to which the existing DoE guidelines can be enhanced using technological advances (e.g. in camera trapping), to ensure that they provide the most cost-effective and robust protocols for use at a regional level. Analysis of existing data sets should provide the answers for much of this question, but some additional comparative testing of survey methods may be required.
2. Targeted consideration of detectability (e.g. by sampling over a longer time period and reporting when quolls are first detected at sites), and hence more robust estimation of appropriate sampling effort (and protocols) to reliably demonstrate presence or absence. Again, some of this information may be available from analysis of existing data, but some limited additional targeted research that specifically addresses this question would be highly beneficial.
3. Further refinement of sampling procedures that can provide estimates of density and local population size. Although some relevant existing data may be available from previous studies, additional specific research is likely required to substantially advance our knowledge of quoll population sizes.

1.3 Potential outputs

1. Guidelines on the minimum survey effort and the protocols required to reliably detect northern quolls using alternative sampling methods, including clear guidance on animal ethics and the timely clearing of traps. Guidance should also be provided on the time(s) of year most appropriate to conduct surveys, the collection of detailed site descriptions and on the method or combination of methods considered to be ‘best practice’ for northern quoll surveys for environmental impact assessment in the Pilbara.
2. Specific information on the survey effort needed to infer that non-detection represents a true absence of northern quolls, for specified levels of confidence (e.g. 80%, 90%, 95%).

3. Development of appropriately robust sampling regimes to allow estimation of local population size and density.

2 Assess and refine monitoring programs

2.1 Background information and rationale

Monitoring objectives relate to assessments of trends in abundance (or occupancy) over time, sometimes in relation to a particular management imposition or other factor. In many cases, it may be ideal to have consistent sampling methods for both survey and monitoring, but this may not always be optimal or necessary. Some of the issues described above for sampling/survey also apply for monitoring (e.g. sampling season, sampling effort, consistent sampling protocols). However, to date there has only been a single quoll monitoring program in the Pilbara, so inconsistency in approach is not currently a concern.

Furthermore, while there is a Commonwealth guideline (DoE 2016) addressing survey protocols for northern quolls, there is no equivalent national standard for monitoring of northern quolls.

Dunlop et al. (2014) developed and implemented a monitoring protocol for ten sites with known populations of northern quolls in the Pilbara, with monitoring expected to occur over a 10-year period. The aim of this monitoring program is to obtain detailed information on population ecology, demographics and trends in abundance across these Pilbara sites. Such data on northern quolls in areas not occupied by cane toads is considered a priority in the national recovery plan, and will greatly improve the utility of population viability analyses (PVA) of northern quolls in the regions {Hill and Ward, 2010; Cadenhead *et al.*, 2015; Moro et al., 2019, #10908}. A shorter-term (ca. 5-year) monitoring program in a more restricted area (Yarraloola and Red Hill stations) in the west Pilbara has also recently been established by Rio Tinto and DBCA as part of Rio Tinto's Yandicoogina Threatened Species Offset Plan (Morris *et al.*, 2015b; Morris *et al.*, 2015a; Palmer *et al.*, 2017). This monitoring program is primarily designed to assess the response of northern quoll to improved feral cat management. This monitoring program includes experimental (i.e. cat-baited) and control (i.e. without such management intervention), and is based on (but differs somewhat from) the existing more extensive DBCA regional monitoring program.

The longer-term benefit of such conservation monitoring programs includes:

(i) the ability to contextualise longer-term population trends from shorter-term fluctuations due to rainfall variability or other factors;

(ii) assessment of the responses of quolls to targeted management interventions (e.g. broad-scale control of introduced predators); and

(iii) the identification of life history – vital attribute trigger points that activate management intervention when changes in a critical 'state variable' (e.g. juvenile survival rates, total population size) are detected (Lindenmayer *et al.*, 2013).

Given that the current monitoring program has had only a short history, it is important to be prepared to adapt the program as results accrue, and the power of the program to detect changes in critical state variables can be rigorously assessed (Lindenmayer *et al.*, 2013).

2.2 Scope of research and potential methods

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 analyses such as power analyses may indicate that the monitoring protocols or effort may need some refinements to achieve an acceptable level of power.

2.3 Potential outputs

1. Increased knowledge of abundance and demographics of northern quoll in the Pilbara to further refine PVA.
2. Increasingly robust assessments of the responses of northern quolls to threats and their management, and hence informed cost-benefit analyses of a range of management options.
3. Increased understanding of the differences between island and mainland populations in terms of population dynamics and threat management.

3 Improve our understanding of fine-scale habitat use to identify areas of critical habitats

3.1 Background information and rationale

The EPBC Act referral guideline (DoE 2016: 16) 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.

3.2 Scope of research and potential methods

Radio-tracking and other autecological studies are required to better understand detailed habitat use (and reasons for such use), with particular focus on defining those factors that are most significantly associated with female den sites. Data on habitat features must be collected in a consistent manner across studies undertaken by different groups or organisations. Where possible, such studies should be extended over time, or a range of management scenarios, to assess the extent to which such habitat use is constant or inconstant (i.e. variably affected by dynamic factors). The timing of studies needs to consider questions related to home range use and dispersal during both mating and non-mating seasons by both sexes.

Collecting habitat attribute data from sites where northern quolls have not been captured is equally as important to model development. Reliance on descriptions of land systems and/or land units that were developed for pastoral rangeland purposes is not adequate as a descriptor of northern quoll habitat. The development of a standardised method of recording both permanent and dynamic features of habitat at fine-scales is required.

The most sophisticated understanding of what constitutes critical habitat for northern quolls would be gained by developing spatially-explicit models of population viability (Heinrichs *et al.*, 2010). It may also be useful to study quoll meta-population structure and landscape connectivity.

3.3 Potential outputs

1. Scientific paper on home range characteristics and fine-scale habitat use by different demographic groups of northern quolls across a variety of habitat types in the Pilbara.
2. Improved SDM for the northern quoll in the Pilbara.
3. Statistical models used as a basis for identifying and rehabilitating northern quoll habitat at very fine, site-specific scales.

4. Development of spatially-explicit models of population viability

4 Population dynamics and structure

4.1 Background information and rationale

It is useful for management to know the population structure of northern quolls in the Pilbara because:

(i) sub-population structuring can determine whether management needs to consider separate conservation approaches and outcomes across different components of the species range;

(ii) it helps assess overall population viability, and the consequences to that viability of some potential population losses (or gains); and

(iii) it helps consider translocation options and need should they be required.

Analysis of the genetic diversity and population structure of the Pilbara population of the northern quoll is ongoing. The Pilbara population is homogenous and genetically distinct from the Kimberley and Northern Territory populations. It is also the least diverse, with around 77% heterozygosity (10.3 alleles) compared with 84% heterozygosity (11.1 alleles) in the Kimberley mainland population (How *et al.*, 2009; Spencer *et al.*, 2013; Spencer *et al.*, 2016). Current data shows no evidence of genetic bottlenecks and a stable effective population size at landscape level (both now and historically; based on both coalescence and Bayesian analysis). The mating system of northern quolls appears to be random. Additional samples collected between 2012 and 2015 have been selectively added to the above analysis to reduce the clustering of samples that was present in the original dataset, and provide additional insights into lower density populations.

4.2 Scope of research and potential methods

Genotyping of an additional 547 tissue samples will continue to build on the analyses reported in (Spencer *et al.*, 2013).

4.3 Potential outputs

1. Scientific paper on the population genetics and effective dispersal of northern quolls in the Pilbara.
2. Scientific paper on the paternity and relatedness of northern quoll litter-mates to gain information about female mate choice and dispersal of young.

5 Assessing the impacts of introduced predators

5.1 Background information and rationale

Predation by feral cats is predicted to have severe effects on the northern quoll, but the current levels of predation, how this varies among sex and life stage of the northern quoll, and whether predation risk differs across habitat types, is not known (Woinarski et al. 2014). Preliminary data from a field trial investigating the mortality risk to northern quolls through ingestion of toxic baits during an intensive cat-baiting program found that about 20–25% of collared quolls (at control and impact sites) were taken by feral cats over a period of ca. 4–5 months of radio-tracking (M. Cowan unpub. data), with another 20% killed by other introduced predators (dogs or foxes). A PVA of the northern quoll population at this site suggested that >5% increase in juvenile mortality due to cat predation would potentially lead to a dramatic decline (up to 50%) in the population within 20-years {Moro et al., 2019, #10908}. Feral cats may also compete with quolls for food items and den sites, and are likely to contribute to mortality of dispersing sub-adults.

Foxes are present along coastal and riverine areas within the Pilbara, and in these areas the risk from fox predation may also be severe. Dingoes and wild dogs have been found to be a major source of mortality for northern quolls in some areas of the Northern Territory (Oakwood, 2000; Webb *et al.*, 2015). This risk may be greater in areas where human resource subsidies support higher numbers of dingoes and/or wild dogs. Potentially counter-balancing this risk, dingoes/wild dogs may regulate the numbers and/or activity of smaller carnivores such as cats and foxes, and therefore reduce total predation pressure on northern quolls within an area.

5.2 Scope of research and potential methods

Permanent remote-camera stations can be used to examine the spatial and temporal relationship between northern quolls, cats, foxes and dingoes/dogs in different habitat types at the sites used for long-term monitoring. Data from cameras permanently installed at these sites will provide data on changes in predator activity over time and throughout the geographic range of northern quolls in the Pilbara. These predator densities can be compared against the data collected from trapping at the monitoring sites, giving insights into the impact of feral predators on quoll populations.

At sites that are baited for feral cats, the interactions between northern quolls and cats can be assessed by using fine-scale camera arrays that allow estimates of the density of both quoll and cat populations, including the reinvasion of cats after baiting. An extension of this project would be to use GPS collars on both northern quolls and cats to investigate differences in the patterns of fine-scale habitat use by quolls in areas that are baited/not baited for cats, and to assess the interactions between cats and quolls. This approach could also be applied in areas along the coast baited for foxes.

5.3 Potential outputs

1. Scientific paper on the interactions between northern quolls and introduced predators at long-term monitoring sites across the Pilbara.
2. Data on fine-scale habitat use of quolls in the presence/absence of feral cats, which can be incorporated into future SDM.

6 Understanding the spread and impacts of cane toads

6.1 Background information and rationale

The cane toad has caused an immediate collapse or extinction of northern quoll populations in the areas it has invaded (Burnett, 1997). There has been some uncertainty about the likelihood of invasion to, and potential impact of, cane toads in the Pilbara. Earlier modelling work that only considered climate parameters, as well as more recent work that incorporates future climate change, suggest that cane toads will not invade the Pilbara (Sutherst et al. 1996; Pavey and Bastin 2014). Other recent work that considers the fundamental niche of the cane toad and incorporates the location of artificial watering points predicts that they will colonise the Pilbara from the Kimberley via the coastal edge of the Great Sandy Desert (Kearney *et al.*, 2008; Florance *et al.*, 2011; Tingley *et al.*, 2013; Southwell *et al.*, 2017). The most recent modelling by Molloy *et al.* (2017) predicts that cane toads will invade the Pilbara, but that future climate change will lead to a divergence in the ranges of northern quolls and cane toads, with quolls moving to the east and cane toads to the west. This suggests that delaying the invasion of cane toads into the Pilbara will potentially limit the interaction between northern quolls and cane toads in the medium term. Confounding the models are plans for substantial irrigated agriculture development in the Pilbara (e.g. Pilbara Hinterland Agricultural Development Initiative (PHADI), Transforming Agriculture in the Pilbara (TAP)) (Department of Primary Industries and Regional Development, 2017) which will increase the likely abundance and distribution of suitable habitat for cane toads across the region.

Training northern quolls to avoid cane toads through conditioned-taste aversion (CTA) prior to their reintroduction to an area has shown promise in trials undertaken in the Northern Territory, as long as fire is managed and predation by dingoes/dogs is controlled (Webb *et al.*, 2015). The aerial delivery of toad 'sausages' ahead of the cane toad invasion front is being trialled on wild populations of northern quolls in the Kimberley (Webb *et al.*, 2015). Despite some difficulties with the longevity of sausages under field conditions, 50% of northern quolls consumed baits in the Kimberley trial, and there is evidence to show an inter-generational response to cane toads from the training (Cremona *et al.*, 2017a).

Based on extirpations and marked declines of quolls in other parts of Australia following cane toad invasion, there is some need to consider 'what if?' responses for quolls by managers to toad arrival in the Pilbara. One component of such a response may be to evaluate (including costs-benefits and risks) options for island translocations and securing of isolated quoll populations.

6.2 Scope of research and potential methods

A simple precautionary research project would be to evaluate the options for translocations of quolls to Pilbara (or other) islands, as a potential emergency response to toad invasion. Such assessment should consider risks to biodiversity values already present on islands, island size and habitat suitability, likelihood of toad arrival, and population viability analysis for a range of emigrant quoll numbers and demographic compositions taking into account genetic considerations.

Improving the field longevity of the toad sausages, and testing their delivery and uptake under field conditions in the Pilbara, would ensure that a CTA program is ready to deliver operationally in the year before cane toads invade the Pilbara. Modelling suggests that the invasion point will be around the mouth of the De Grey River (Tingley *et al.*, 2013). Given the level of research activity around cane toads and northern quolls currently underway, any additional provision of research funds should be used to expand upon these programs to support Pilbara-specific work.

Another potential area of research (and management) relates to the likelihood of management actions in the coastal strip between the Kimberley and Pilbara to effectively reduce accessibility to water sources, sufficient to prevent movement of toads and prevent their arrival in the Pilbara (Southwell *et al.*, 2017). The practicality of such actions, and likelihood of success, needs to be contextualised relative to the likelihood of toad arrival in the Pilbara through transport ('hitch-hiking') and through episodes of major flooding associated with cyclones and other high rainfall events. The feasibility of this waterless barrier solution (Tingley *et al.*, 2013) also needs to be assessed in light of the irrigated agricultural development plans for the La Grange and Pardoo area.

6.3 Potential outputs

1. Assessment of options for island translocations as an emergency response to toad invasion.
2. Technical report on the uptake and potential longer-term aversion of toad sausages by northern quolls and non-target species in the Pilbara.
3. Protocols for operational delivery of toad sausages in the Pilbara.
4. Development of surveillance and rapid response protocols for initial incursions of toads in the Pilbara.
5. Detailed assessment of the practicality of water-source management as a mechanism to prevent toad arrival in the Pilbara, relative to likelihood of toad arrival through transport or during major flood events.

7 Interactions with infrastructure and built environments

7.1 Background information and rationale

Sealed roads, heavy haulage carriage routes, rail corridors, and other infrastructure easements such as high-tension power transmission lines and overland conveyers, are increasingly being built throughout the range of the northern quoll in the Pilbara. These linear infrastructure fixtures increase the risk of mortality and create a potential barrier to movement. New lightweight GPS collars suitable for northern quolls provide an opportunity to better understand the impact of infrastructure on movement. A recent study that followed the movement of ten northern quolls in an area north of Newman found that quolls would cross roads that intersected high quality habitat, they did not cross over nor under (via underpasses) railway lines (Henderson, 2015). Other quolls fitted with GPS collars have been recorded crossing railway lines (G. Thompson unpubl. data).

Northern Quoll in the Pilbara are also know to readily colonise man-made structure such as accommodation villages, workshops, material storage facilities (e.g. railway sleepers laydown areas) and basic raw material stockpiles, especially hard rock quarries producing rail ballast, aggregate and rock armour.

7.2 Scope of research and potential methods

Further understanding of the interactions of northern quolls with infrastructure and built environments will be gained through programs that track the movement of quolls with GPS collars. An important consideration is to differentiate the movements of males and females. Males are known to roam widely during the breeding season in search of mates. The impact of infrastructure on the home ranges of females, particularly during breeding and lactation is likely of greater significance to population viability.

Camera traps and spot recognition can be used on culverts to assess how many quolls use underpasses and how frequently. Data from camera traps can also be used to assess whether underpasses are being used as ‘prey traps’ for predators. Camera traps and spot recognition will also be useful to assess rates of colonisation and accompany in built environments.

7.3 Potential outputs

1. Data on the movement of quolls around large linear infrastructure and their use of culverts/underpasses and associated built infrastructure.

Recommendations on design criteria for the construction of artificial habitat.

8 Other Research Opportunities

The research questions outlined below are outside the scope of research expected to be undertaken with the timeframe of the current document, but exist as additional and/or longer-term research opportunities that would benefit northern quoll conservation.

8.1 Improve understanding of how fire and grazing affect habitat quality and connectivity

The alteration of fire regimes towards large, hot summer fires has been pervasive throughout the Pilbara. Between 1993 and 2006, over 72% of the region was burnt, with more than 28% of the area burnt two or more times (McKenzie *et al.*, 2009). In northern Australia, Woinarski *et al.* (2004) found that northern quolls may be able to tolerate a moderately high frequency of fire, as long as these fires were low-intensity, early-season burns, and the impacts of fire on vegetation structure and composition were not exacerbated by grazing from introduced herbivores. Also in northern Australia, Griffiths and Brook (2015) modelled the demography of northern quolls exposed to different fire regimes over a six-year period and concluded that a fire frequency of once every two years caused the total population size to decline substantially, regardless of fire extent. Reducing the frequency of fire reduced the threat posed to population persistence.

Northern quolls are strongly associated with rugged rocky landforms in the Pilbara, where the changes in fire regime may have less influence on habitat structure and quality.

Movement of northern quolls through lower quality habitat for dispersal and repopulation is an important consideration for a species in which both sexes tend towards semelparity, and is therefore predisposed to local extinction (Oakwood, 1997). Therefore, the impact of frequent and intense fires and/or overgrazing, and the subsequent change in vegetation structure and cover, may be greatest on male quolls during the breeding season, when they range widely in search of mates (up to 15 km), and when young disperse.

Detailed analysis of how fire regimes have changed in the Pilbara is lacking. DBCA has recently analysed satellite imagery extending back 20-years to determine trends in a range of fire metrics (e.g. time since last fire, fire frequency, fire extent) across the Pilbara conservation estate and other selected target areas. Within these areas it is now possible to compare current fire regimes (and their trends) with regimes considered most suitable for quolls based on information from northern Australia.

However, it would be useful to develop more regional-specific information on the relationship of quoll abundance (and survivorship) to fire regimes in the Pilbara. This can most usefully be undertaken with:

(i) longitudinal studies that monitor quoll populations over time, with some of those populations exposed (deliberately or otherwise) to a range of fire regimes;

(ii) local autecological studies that track use by individual quolls of vegetation patches within their home range that have variable fire histories; and/or

(iii) correlative studies that relate survey results across many sites with the fire histories of those sites.

With such locally relevant information on responses to fire regimes by quolls, the currently described fire patterns can be compared with regimes that are most appropriate for quolls; and hence the need for changes in fire regime to provide greater benefit for quolls can be assessed.

In the Pilbara, as with many other grazing regions of Australia, early pastoralists often overestimated the productivity and resilience of native vegetation to sheep and cattle grazing, which has led to severe degradation of vegetation, particularly along river frontages (Hennig, 2004). Loss of vegetative cover also exposes animals to greater risk of predation (Legge *et al.*, 2008; Doherty *et al.*, 2015). There is little available information on the responses of quolls to disturbance by grazing, partly because quolls mostly occur in relatively rugged areas with limited pastoral use. Responses of quolls to disturbance or habitat degradation due to total grazing pressure can be assessed through localised livestock removal experiments (such as those described by Legge *et al.*, 2008).

8.2 Interactions between threats

At present, wildfire, the subsequent loss of vegetation cover and increased predation of northern quolls is likely to be the most significant of the interactions between threats. The direct effects of wildfire have been found to be less significant in the subsequent decline of small- to medium-sized mammals, particularly for denning species such as the northern quoll, than the indirect consequences of reduced resource availability and the increased risk of predation due to lack of cover (Oakwood, 2000; McKenzie *et al.*, 2007; Letnic *et al.*, 2005). Introduced predators may actively make expeditions to hunt in areas that have been recently burnt by intense fires (McGregor *et al.*, 2016).

Increased risk of predation around infrastructure may also occur when resource subsidies (e.g. food from poorly managed waste sites) allows expansion of predator populations (Newsome *et al.*, 2015). Some evidence also exists that culverts and underpasses under roads and railway lines may become 'prey traps' for predators.

In the future, the cumulative impacts of cane toad poisoning, fire and predation by cats and canids are likely to lead to the extirpation of small and disjunct populations of northern quoll in the Pilbara. At a reintroduction site at East Alligator in the Northern Territory, late dry season fires meant little cover was available for young quolls when they began foraging, with dog and dingo predation a major source of mortality (Cremona *et al.*, 2017b).

Better understanding of how the current fire regimes in the Pilbara affect the structural complexity and cover of vegetation is needed. Preliminary data from the Yarraloola study suggest that northern quolls are most likely to be killed by cats or canids along drainage lines away from rocky habitat. These habitats are also more likely to be affected by fire, and so provide an obvious starting point for investigation of the interactions between fire intensity/severity and predation of northern quolls.

8.3 Recolonisation of restored and/or artificial habitat

Anecdotal evidence suggests that northern quolls will den in waste rock dumps, but whether artificial or restored habitat provides for long-term population viability (maternal dens and juvenile survival) is unknown. There is a future opportunity in the Pilbara to conduct 'natural' experiments on the recolonisation of 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.

Greater understanding of den-site selection of northern quolls in undisturbed habitat is required to guide the restoration of disturbed habitat or the placement and construction of artificial habit. Future research should attempt to understand the microhabitat attributes associated with dens, the availability of resources surrounding den sites, differences in den use between seasons, and differences in den use between males and females.

8.4 Physiological studies

Many of the ecological studies outlined above could be augmented with studies that examine how northern quolls respond physiologically to environmental change/stress. Some examples of potential research opportunities include:

- Studies to determine energy requirements and expenditure could be undertaken in conjunction with studies on fine-scale use of habitat. This will also help to determine the carrying capacity of the landscape and how robust a population may be to change based on available resources and resource requirements.
- Investigating the role of phenotypic plasticity in enhancing the tolerance of northern quolls to variations in environmental stimuli. Low levels of heterozygosity exist in a population with a very broad distribution across a number of ecotones, so functional and morphological plasticity must play a role in survivability of these populations. How robust is the population to change and how will the phenotype have the potential to influence the genotype over time?
- Investigating how varying predation pressure influences the physiological stress of quoll populations, through analysing cortisol concentrations from hair samples and correlating against data on the density of feral cats. Hair samples should be used (rather than faeces or blood) as it better reflects long-term environmental stressors.
- Investigating the seroprevalence of *Toxoplasma gondii* in cats and northern quolls. Do infection rates decline through time with the removal of feral cats? Blood samples, as per Fancourt *et al.* (2014) to be taken as part of animal processing during trapping sessions.

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