*Monitoring Priority Threatened Species*

# A review of monitoring methods for the Northern Quoll *(Dasyurus hallucatus)*

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## Acknowledgement of Country

We acknowledge the Traditional Custodians of Australia and their continuing connection to land and sea, waters, environment and community. We pay our respects to the Traditional Custodians of the lands we live and work on, their culture, and their Elders past and present.

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## Disclaimer

# About

This literature review collates information on one of the 110 priority threatened species identified in the *Threatened Species Action Plan 2022-2032* and has been reviewed by invited practitioners experienced in monitoring the species.

The *Survey Guidelines for Monitoring Threatened Species* project, a collaboration of the Department of Climate Change, Energy, the Environment, and Water (DCCEEW) and the Terrestrial Ecosystem Research Network (TERN), aims to improve our knowledge of threatened species by enhancing accessibility and sharing of quality scientific threatened species data. By developing best practice field survey guidelines and recommendations, practitioners will be better equipped to conduct standardised, repeatable surveys.

By identifying the monitoring methods typically implemented by practitioners, documenting and assessing the techniques known to work, and identifying opportunities to standardise the methods, we can move towards ensuring all monitoring is species-appropriate, comparable between practitioners and populations, and repeatable over time. Further, together with consistent terminology, guidelines, instructions, and data collection, we can refine efforts and resources to measure and share information. Data collected using robust, standardised methods will improve our knowledge of threatened species and underpin threatened species recovery at scale. This project is essential to establishing monitoring protocols and data repositories to enhance the accessibility and sharing of threatened species data.

TERN has prepared the literature reviews for the Department of Climate Change, Energy, the Environment, and Water. For further information, please visit the EMSA Threatened Species Survey Guidelines website. Additional information, particularly monitoring methods and techniques not included that should be considered, can be brought to the author's attention by emailing tern@adelaide.edu.au for consideration for future updates.

# Contents



## Figures



## Tables

# 1 Background

## 1.1 Species name

The Northern Quoll (*Dasyurus hallucatus*) (Gould 1842). The Northern Quoll is significant to a number of different Traditional Owner groups across the range of the species and is known as Digul in the Guugu-Yimithirr language, Wijingadda in the Dambimangari language and Wiminji in the Martu language.

## 1.2 Conservation status

The Northern Quoll was listed as endangered under the Environment Protection and Biodiversity Conservation Act 1999 (Cth) in 2005. The Northern Quoll is one of 21 priority mammals listed in the Australian Government Threatened Species Action Plan 2022-2023 (DCCEEW 2022). The International Union for Conservation of Nature's (IUCN) Red List of threatened species lists the Northern Quoll as endangered, citing serious population decline due to habitat destruction or degradation, cane toads and introduced predators (Oakwood et al. 2016). The conservation status of the Northern Quoll is outlined in Table 1.

Table 1. National, international and state conservation status for the Northern Quoll

| Jurisdiction | Conservation status | Legislation/listing |
|---|---|---|
| IUCN | Endangered | IUCN Red List for threatened species |
| Commonwealth | Endangered | *Environment Protection and Biodiversity Conservation Act 1999* |
| Queensland | Least concern | *Nature Conservation Act 19992* (Qld) |
| Northern Territory | Critically endangered | *Territory Parks and Wildlife Conservation Act 1976* (NT) |
| Western Australia | Endangered | *Biodiversity Conservation Act 2016* (WA) |

## 1.3 Summary of data held in the Threatened Species Index

The Threatened Species Index (TSX) provides reliable and robust measures of change in the relative abundance of Australia's threatened and near-threatened species at national, state and regional levels. Understanding these changes in species populations is crucial for monitoring Australia's conservation progress and allows users to measure and report on the benefits of conservation investments and to justify and design targeted management responses. Currently, the index is restricted to birds, plants and mammals, with new groups to be added in the near future.

Table 2 summarises Northern Quoll data held in the TSX. More information on the TSX, including how to contribute threatened species monitoring data to the index, can be found at the TSX website.

Table 2. Summary of the data held in the TSX for the Northern Quoll

| TSX information | Northern Quoll data held in the TSX |
|---|---|
| Data held in the TSX? | Yes |
| Number of data sources | 9 |
| Number of unique sites | 104 |
| Average time series length (years) | 10.5 |
| Average number of sampling years | 4.2 |

## 1.4 Distribution and abundance

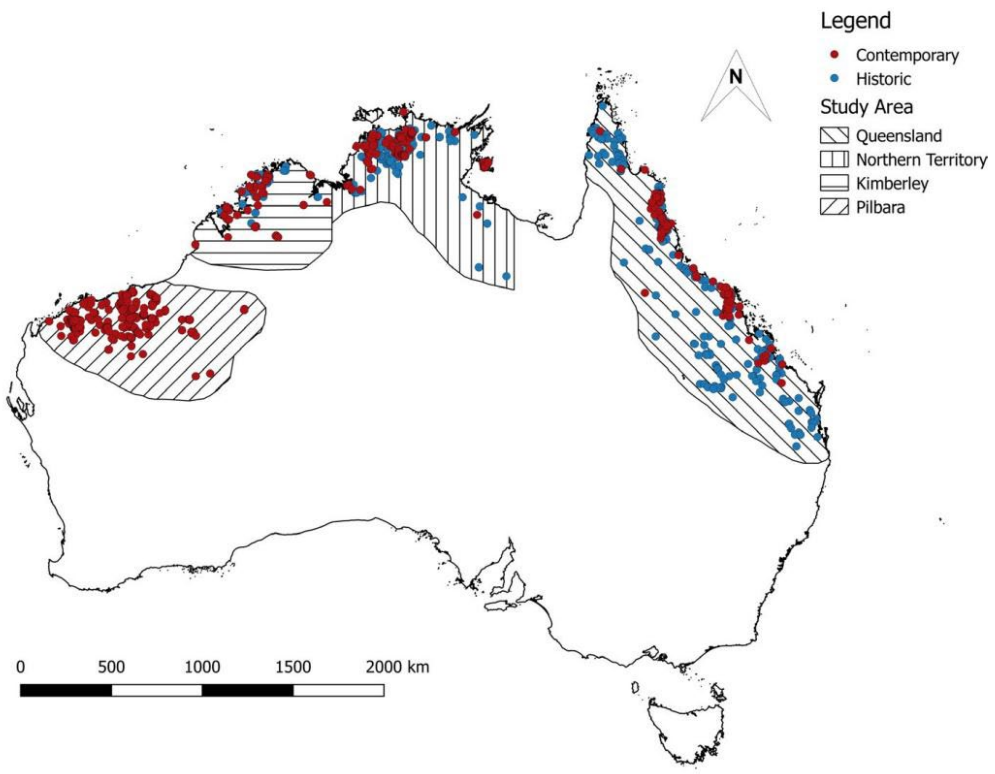
The historic range of Northern Quolls extended across the north of Australia from the Pilbara in the west to south of Brisbane in the east (see Figure 1.). Most records occur within 200 km of the coast, however, populations have been recorded further inland (Moore et al. 2019). It is likely that the historical range incorporated much of Northern Australia above the Tropic of Capricorn (900 south) (Braithwaite & Griffiths 1994; Turpin & Bamford 2015) covering an area of over 1.2 million km2 (Moore et al. 2022)

The current distribution of the species has undergone significant range reduction since European arrival in Australia (Braithwaite & Griffiths 1994). Declines have been most significant in the lowland areas and the semi-arid fringes of its range such as the south-west Kimberley (McKenzie 1981) and Purnululu National Park in south-east Kimberley (Woinarski et al. 2008). Remnant populations are associated with rocky areas (Braithwaite & Griffiths 1994).

The species' current distribution is discontinuous and comprises of populations distributed across four mainland regions, Queensland, Northern Territory, and the Kimberley and Pilbara regions of Western Australia. In addition, Northern Quolls persist naturally on at least 32 islands mostly off the Kimberley and the Northern Territory (Heiniger et al. 2020). Two translocated populations exist outside of their historical distribution on Pobassoo and Astell Islands in the Northern Territory (Rankmore et al. 2008). Many of these islands are relatively free from human disturbance and lack introduced predators and/or cane toads (Moore et al. 2022).

The most recent population estimate for the Northern Quoll was 100,000 but with rapid ongoing decline, particularly in Kakadu National Park. This decline is, in part blamed on the rapid spread of Cane Toads through northern Australia (Oakwood 2004; Watson & Woinarski 2003).

Figure 1. Distribution of the Northern Quoll in Australia.




*Source: Moore et al. (2019)*

*Notes: Red dots indicate contempory records of the speces and blue dots historic records. The shaded areas indicate the regions covered by surveys/studies.*

## 1.5 Habitat requirements

Northern Quolls occur in a range of habitats (Moore et al. 2022). They are most abundant in rugged and rocky landscapes such as rocky hills, patchy granite outcrops, boulder strewn slopes, rocky creek lines and gorges (Begg 1981b; Braithwaite & Griffiths 1994; Calaby 1973; Ibbett et al. 2018; Kitchener et al. 1981; McKenzie et al. 1975; Molloy et al. 2017; Moore et al. 2021; Oakwood 1997; Olds et al. 2016; Pollock 1999; Schmitt et al. 1989).

The climate across the Northern Quoll's range varies substantially (Moore et al. 2022) with average rainfall ranging from close to 4,500 mm in the Wet Tropics of Northern Queensland to 220 mm in the eastern extent of the Pilbara (BOM 2023). Similarly, the average maximum temperature in the warmest months ranges from 42.1˚C in the Pilbara to 25.5˚C in southern Queensland (BOM 2023).

Braithwaite and Griffiths (1994) hypothesised that the Northern Quoll's preference for rocky habitats may be due to the availability of permanent water and more food resources than surrounding habitats, however, other studies have found limited evidence to support this (Hernandez Santin 2017; Oakwood 1997). Rocky habitats also provide shelter, particularly small, enclosed spaces that can be used as dens for either short term shelter or semi-permanent shelter used to raise offspring (natal dens) (Moore et al. 2022). Northern Quolls have been recorded sheltering in dens in tree hollows (live and dead), termite mounds, logs and burrows (Oakwood 1997). In areas where trees and logs are scarce such as the Pilbara, rocky crevices in rocky outcrops and granite boulders are critical for providing short term shelter and natal dens for Northern Quolls. Rocky dens may also protect individuals from extreme external temperatures (Cooper & Withers 2010) and provide refuge from predators (Moore et al. 2022) particularly Feral Cat (*Felis catus*) and Dingo (*Canis familiaris*) that may be less likely to occur in rugged rocky habitat (Hernandez-Santin et al. 2016; Hohnen et al. 2016).

## 1.6 Biology and ecology

The sexually dimorphic and primarily nocturnal Northern Quoll has a largely solitary lifestyle except when breeding, with home ranges containing a core area around den sites, which do not overlap with other quolls of the same sex (Hernandez-Santin et al. 2021; Oakwood 2002). Home ranges reflect the availability of resources and population densities, which are significantly influenced by the abundance of competing and predatory Feral Cat and Dingo. In lowland savanna in Kakadu National Park female Northern Quolls have average home ranges of 35 ha, with male home ranges increasing to greater than 100 ha during the mating season (Oakwood 2002). Comparable home ranges were found in the Pilbara in Western Australia (Hernandez-Santin et al. 2021).

In a review of 30 Northern Quoll studies, Moore et al. (2022) reported that Northern Quolls have a broad, opportunistic diet, predominantly eating invertebrates, but also mammals, reptiles, birds, frogs, carrion and vegetation. Breeding occurs from late May to October depending on the region and the variation in rainfall (Moore et al. 2022; Oakwood 2000; Schmitt et al. 1989).

Male Northern Quolls are known to exhibit semelparity, a reproductive strategy (Gaschk et al. 2023) where they will breed for only one breeding season in their lifetime. Males of the species will have increased levels of testosterone for this period, followed by rapid condition loss and rarely live longer than one year (Oakwood et al. 2001), though some will survive for a second breeding season. Female longevity is also very low (Moore et al. 2022), with less than 40 % surviving into their second year (Braithwaite & Griffiths 1994; Hernandez-Santin et al. 2019; Oakwood 2000; Schmitt et al. 1989) and a very small percentage surviving into their third year.

The Northern Quoll's short lifespan means that population persistence is reliant on the survival of offspring. One strategy that females employ to increase juvenile survival is polyandry, where females mate with multiple males to increase the genetic diversity of their offspring (Moore et al. 2022).

The gestation period for the Northern Quoll is between 21 and 25 days and up to 17 young may be born, however the number of surviving young is determined by the number of nipples on a mother quoll (between five and nine but usually eight (Braithwaite & Griffiths 1994)). A recent study by (Chan et al. 2020) found that in 100 % of litters surveyed (n=16) the young had been sired by different males and in some, every offspring was from a different male (Moore et al. 2022).

## 1.7 Threats

A primary threat to the Northern Quoll is the sympatric (overlapping geographically), invasive and poisonous Cane Toad (*Rhinella marina*) (Burnett 1997; Woinarski et al. 2010; Woinarski et al. 2008). Northern Quoll populations have significantly declined or have entirely disappeared from their Queensland and Northern Territory range primarily due to these poisonous toads. The Pilbara population is yet to encounter cane toads but is vulnerable and naïve to the danger of the invasive species, even small losses of juveniles risks extinction in the Pilbara population (Moro et al. 2019). Primary impacts associated with the toad-induced mortality have been increased population separation and isolation, with associated increased loss of genetic diversity (von Takach et al. 2022). Efforts to use conditioned taste aversion to train Northern Quolls against eating the toads has met with some success (Jolly et al. 2018; O'Donnell et al. 2010), but also was recently shown to be unsuccessful in preventing a population going extinct (Indigo 2020).

Mining, particularly in the Pilbara threatens Northern Quoll populations by fragmenting rocky habitats favoured by the species (Cowan et al. 2024; Cowan et al. 2022). Drill and blast mining used in the Pilbara often targets the rocky habitats as they are typically rich mineral deposits. The overlap of Northern Quoll habitat and potential mining activity is significant, with 79 % of the Pilbara bioregion currently under mining tenement (Moore et al. 2023). In addition to destroying denning habitat, the artificial light and noise produced by mining processes interferes with foraging and mating (Cowan et al. 2024). Numbers and movement of predator species such as Dingoes and Feral Cats also increases in mining areas facilitated by roads and waste dumps.

Predation from Dingoes (Cowan et al. 2020; Jolly et al. 2018; Oakwood 2000) and Feral Cats (Cowan et al. 2020; Oakwood 2000; Palmer et al. 2021) are additional threats to Northern Quolls. The predatory impact of these species interacts with the habitat changes caused by fire, itself exacerbated by the invasion of alien grasses (Rossiter et al. 2003), with for example cats shown to preferentially and more successfully hunt burnt areas (McGregor et al. 2015; McGregor et al. 2016). However, the responses of Northern Quoll populations to fire are more complex and require more research (Begg et al. 1981; Cramer et al. 2016; Moore et al. 2022; Oakwood 2000; Woinarski et al. 2010).

Predation by the Red Fox (*Vulpes vulpes*) is likely to be an additional threat in the lower latitudes of the Northern Quoll distribution where its occurrence overlaps with the Northern Quoll (Cramer et al. 2016).

# 2 Existing monitoring

## 2.1 Overview of monitoring methods

Direct indicators of the presence of Northern Quolls include images on remote cameras (Hohnen et al. 2013) and quolls being directly observed (e.g. road mortality) or trapped (Begg 1981b; Oakwood 2000, 2002). Indirect evidence of their presence includes scats (Oakwood 2002; Turpin & Bamford 2015) tracks and habitat surveys.

- Camera trapping – a standard monitoring tool that can effectively monitor Northern Quolls in both an active (baited) and passive mode. With appropriate bait placement to maximise quoll spot pattern capture, individual quolls can also be identified (Hohnen et al. 2013).
- Cage trapping – a standard monitoring method used to survey Northern Quolls as the species is readily trapped. Using meat baits can reduce off-targets and enhance quoll captures. Trap spacing is required to suit home ranges in varying habitats, and the smaller home ranges of female Northern Quolls.
- Radio-tracking/GPS collaring – the radio-collaring of a significant number and proportion of a population can provide much more sensitive temporal and spatial survival and movement data, including identification of primary threats and issues. It has been a primary monitoring tool for Northern Quoll survival and movement parameters.

## 1.2 Monitoring resources

Key resources with information to guide monitoring the Northern Quoll include:

- 'Survey techniques and impact mitigation for an endangered marsupial predator, the Northern Quoll, *Dasyurus hallucatus*' is currently *in review* for publication (Dunlop et al.).
  - It provides guidelines for surveying the Northern Quoll in the Pilbara, Western Australia including protocols for less invasive monitoring techniques of habitat assessment, sign surveys and camera trap monitoring and more invasive live trapping
- 'A brief history of the northern quoll (*Dasyurus hallucatus*) a systematic review' (Moore et al. 2022) reviews 143 studies relevant to the conservation and ecology of the Northern Quoll.
  - Summarised research relevant to taxonomy, genetics, distribution, habitat associations, diet, reproduction, movement, threats, management and Indigenous knowledge.
  - Includes a non-exhaustive list of ten future research direction options that may provide information critical to managing and conserving the species.
- The 'Terrestrial Vertebrate Fauna Survey Assessment Guidelines for Queensland, Version 4.0' (Eyre et al. 2022) outlines the minimum requirements, standards and appropriate practice for the survey of terrestrial vertebrate fauna in Queensland as required by the Department of Environment and Science (DES)
  - Provides guidelines for a number of generic and targeted surveys methods for Queensland fauna.
  - Does not provide species specific species recommendations but provides guidelines for design and procedure of a chosen method.
  - Provides guidance from the planning stages through to surveying

  - Recommendations for list mammals such as quolls being optimal for detection using infrared flash camera traps, spotlighting search and hair tubes, live trapping was only recommended if not undertaking camera trapping.
- 'Technical guidance – Terrestrial vertebrate fauna surveys for environmental impact surveys' (EPA 2020) provides guidelines to ensure that terrestrial vertebrate fauna data of an appropriate standard are obtained and used for environmental impact assessments (EIA) in Western Australia.
  - Includes advice on: desk top studies, survey preparation, conducting habitat assessments, survey techniques, survey design, specimen processing, data analysis and reporting.
- 'EPBC Act referral guideline for the endangered northern quoll *Dasyurus hallucatus*' (Commonwealth of Australia 2016)
  - Provides guidelines for conducting reconnaissance surveys, including mapping suitable habitat and calculating area
  - Recommends remote activated cameras and scat searches for detection surveys and targeted surveys using live trapping or camera traps for population capture-recapture estimates when habitat critical to survival of the Northern Quoll is proposed to be cleared or indirectly impacted
  - Provides survey recommendations including timing, survey design and effort, detectability
- Cramer et al. (2016) details research and monitoring "priorities for the Northern Quoll (Dasyurus hallucatus) in the Pilbara region of Western Australia", priorities determined from a workshop to define research priorities including:
  - To develop appropriate and standardised survey and monitoring methods.
- The 'Survey guidelines for Australia's threatened mammals' (DSEWPC 2011)has recommendations for the Northern Quoll on pages 185-188
  - Provides guidelines for survey methods to detect the presence of threatened mammal species at a site (does not offer survey effort to assess abundance)
  - Monitoring methods are based on previous survey techniques and include direct capture using cages (preferred) and large Elliott traps conducted between May and August. Recommends that traps should be concentrated in rocky 'denning' habitat.
  - Recommends baiting traps with oats, sardines and peanut butter and lists chicken wings and diced bacon as optional. Also suggests spraying the area around the trap with a purified solution of red meat and water to attract Northern Quolls.
  - Recommends a different trapping effort for different jurisdictions (seven consecutive nights in Western Australia and a minimum of three nights in the Northern Territory and Queensland).
  - Recommended monitoring techniques that are complementary to live capture include: daytime searches for signs such as latrines, scats and tracks and remote camera traps in suitable habitats.
- 'A guide for the use of remote cameras for wildlife survey in northern Australia' (Gillespie et al. 2015) provides information on the general uses and application of remote cameras for wildlife research projects in northern Australia.

  - Provides guidelines for planning and implementation of wildlife surveys using remote cameras including information on camera types settings and other equipment.
  - For medium sized mammals such as quolls recommends setting the sensor so it is approximately 50 cm above the ground.
  - Baits have been successful at detecting small and medium sized native mammas such as quolls

- The 'National recovery plan for the Northern Quoll' (Hill & Ward 2010), lists monitoring actions including:
  - Monitoring offshore islands supporting quoll populations to detect the presence of cane toads, cats and any other potential invasive predators.
  - Determining which factors affect survival and recovery of Northern Quolls in areas with cane toads.
  - Identifying potential refuge habitats in Western Australia and the Northern Territory where quolls might be most likely to persist in the long-term alongside cane toads.
  - Collecting baseline data on population densities and monitor trends of quolls at a series of key sites not currently occupied by cane toads.
  - Investigating factors causing declines in Northern Quoll populations not yet affected by cane toads.
  - Determining the status of Northern Quolls on islands with suitable habitat and assessing the potential for future translocations to these islands.
  - Increasing knowledge and monitoring for disease in Northern Quoll populations
  - Assessing the impacts of feral predators on populations of Northern Quolls

## 2.2 Survey methods

Northern Quolls are easily captured and monitored using cage traps and remote cameras. Effective live capture methods allow for capture-mark recapture studies and remote tracking using collars or microchips under the skin (Gaschk et al. 2023; Nasir et al. 2018). These methods preclude the use of techniques such as hair traps, tracks and scats, that may, however, be used to indicate presence (Turpin & Bamford 2015). The primary survey technique to assess Northern Quoll diet is the microscopic analysis of their scats (Dunlop et al. 2017; Oakwood 2008; Pollock 2014; Thomas et al. 2021). Additional insights, especially for dietary components that leave minimal, if any, macroscopic fragments, may be obtained from DNA analysis of scats, as per Bannister et al. (2021).

An increase in fauna surveys associated with environmental impact statements, particularly in the Pilbara have generated valuable datasets for the Northern Quoll, however, much of this data is not publicly available (Carwardine et al. 2014). Better data sharing would improve knowledge of species ranges, critical habitats and could be used to develop more effective targeted survey designs.

### 1.2.1 Live trapping

The Northern Quoll is relatively easily captured in traps, and therefore, live trapping is a commonly used method for surveying the species to assess distribution abundance and dispersal (DSEWPC 2011). Live trapping also allows for the collection of data related to animal condition, morphology, sex, breeding and genetics, as well as for the attachment of tracking devices. When planning and conducting surveys, considerations should be made to minimise the impact on the wellbeing of individual animals and normal ecological function. Queensland guidelines for surveying terrestrial vertebrate fauna reflect this by recommending that if possible camera traps are used instead of cage traps (Eyre et al. 2022).

When conducting trapping surveys for Northern Quoll, small cage traps (typically between 14-20 cm wide and high and 45-60 cm long) are preferred; a small gauge mesh (~ 10 $mm^2$) is advised to prevent animals injuring themselves by repeatedly pressing their noses through larger gaps. Aluminium box (Elliott) traps are not recommended for targeted trapping of Northern Quolls in the Pilbara (DCCEEW 2023). The small size of Elliott traps may cause undue stress to quolls because though they may be able to enter an Elliot trap their movement is severely restricted. Elliot traps will also heat up very quickly once exposed to sunlight, causing heat stress. Detectability may also be reduced using Elliot traps if larger animals are able to remove bait without disturbing the trap trigger.

Trapping should be concentrated in rocky denning habitat with some focus on non-rocky foraging and dispersal habitats (DSEWPC 2011). Safe placement of traps should be considered, particularly in rocky, uneven terrain. One study reported Elliott traps rolling down vertical mineshafts as quolls were attempting to extract bait (Schulz & Menkhorst 1984).

In Western Australia where linear rock habitats dominate Northern Quoll habitat, trapping transects are recommended (Commonwealth of Australia 2016; Cowan et al. 2020). In the Northern Territory and Queensland where the species disperses into adjoining habitats trapping grids are more common (Gaschk et al. 2023; Heiniger et al. 2020; Oakwood 2000, 2002). Western Australian guidelines recommend that traps should be set for seven consecutive nights (EPA 2020) unless two or more individuals are caught twice, in which case the traps should be closed after four nights of trapping (Commonwealth of Australia 2016). In the Northern Territory and Queensland, traps should be set for a minimum of three and four nights respectively with the aim of sampling as many sites as possible over the four nights (Eyre et al. 2022; NT EPA 2013).

Traps are typically baited with a smelly, meaty substance. Recent studies have found canned dog food to be effective (Gaschk et al. 2023; Heiniger et al. 2020; Nasir et al. 2018) however in some regions such as the Pilbara pure meat baits are not advisable for their attractiveness to ant during the day and night, which can quickly overcome traps and any animal inside (DCCEEW 2023). A standard peanut butter and oat mix with additional meat such as chicken, sardines or bacon are also an effective bait (Begg 1981a; Begg 1981b; Cowan et al. 2020; DSEWPC 2011; Schmitt et al. 1989). The standard data collected from captured animals include: sex, breeding status, body mass, estimated age (based on incisor wear and reproductive condition), head width, head length, body length, right and left forelimb length, maximum tail width and tail length (Gaschk et al. 2023; Nasir et al. 2018).

It is recommended that trapping programs are timed to avoid disturbance when females have large or denned young (Commonwealth of Australia 2016) – breeding time varies across the populations; recommended survey time will reflect this. Live capture is also used to capture Northern Quolls for subsequent radio-collaring and then monitoring using very high frequency (VHF) or GPS telemetry (Cowan et al. 2020; King 1989; O'Donnell et al. 2010; Oakwood 2000, 2002). Table 3 summarises live capture survey methods typically used for monitoring.

Table 3. Methods overview of key studies using live capture surveys

| Study purpose | Study design | Survey effort | Location | Reference |
|---|---|---|---|---|
| Monitoring the movements of Northern Quolls | ▪ Cage traps used to catch 13 Northern Quolls (6 female and 7 male)<br>▪ Conducted during breeding season (July-August) 2019<br>▪ Trapping conducted at three sites: a rocky outcrop with variation in topography, a eucalyptus woodland with dense undergrowth and mixed habitat near urban living<br>▪ Tomahawk original series cage traps (14 × 14 × 45 cm); were set up in grids, and baited with canned dog food<br>▪ Quolls were also microchipped between the shoulder blades (with a Trovan nano-transponder) and marked with an ear tag<br>▪ Measurements taken included sex, breeding status, body mass, estimated age (based on incisor wear and reproductive condition), head width, head length, body length, right and left forelimb length, maximum tail width and tail length. | ▪ Conducted during breeding season (July-August) 2019<br>▪ Trapping conducted at three sites<br>▪ Cage traps set up in grids, four rows (100 m apart) of 10 traps (60 m apart) | Groote Eylandt, Northern Territory | Gaschk et al. (2023) |
| Comparison of camera trap and live trap survey methods in terms of cost and statistical power in tracking occupancy for the Northern Quoll | ▪ Large baseline survey undertaken to identify suitable locations to establish Pilbara Northern Quoll monitoring (PNQM).<br>▪ Sites that produced one or more quoll detections were selected for inclusion in the PNQM.<br>▪ Live trapping and camera trapping were undertaken<br>▪ Live trapping sites were separated from one another by at least 50 km and sampled annually<br>▪ Two transects of 25 traps, each trap separated by 50 m<br>▪ Each transect separated by 200 m.<br>▪ Baited with a mixture of peanut butter, oats and sardines | ▪ All live trap surveys conducted between May and October<br>▪ Large baseline survey undertaken across 100 monitoring sites<br>▪ 12 sites selected for inclusion in the PNQM.<br>▪ Traps were open for four consecutive nights<br>▪ total area covered by live traps at each site was 25 ha | Pilbara region, Western Australia | (Moore et al. 2023) |
| Monitoring the growth, reproduction and survival of Northern Quolls | ▪ Five permanent 540 x 300 m trapping grids, with 200 m between the grids<br>▪ Each grid contained 40 cage traps (45 x 12 x 12 cm; Medalist) at 60-m | ▪ 5 permanent trapping grids<br>▪ Each grid with 40 cage traps | Groote Eylandt, Northern Territory | Heiniger et al. (2020) |

| Study purpose | Study design | Survey effort | Location | Reference |
|---|---|---|---|---|
| | intervals along four transect lines spaced 100 m apart<br>▪ Three separate trapping periods per year over four year project<br>▪ Traps were baited at dusk with tinned dog food<br>▪ 391 (197 females and 194 males) unique Northern Quolls were captured across the 4-year study period (23 April 2012 – 13 October 2015)" | ▪ Surveys undertaken during pre-breeding (May to June), breeding (July to August) and post-breeding (September to October) during a 4 year study period.<br>▪ Each trapping grid was opened for a minimum of four consecutive nights with a continual cycle over the five grids, until a recapture rate greater than 80% was achieved. | | |
| Monitoring the survival and causes of mortality of Northern Quolls during aerial Eradicat® cat baiting | ▪ Small Sheffield cage traps (170 x 170 x 460 mm)<br>▪ Baited with a mixture of peanut butter, oats and sardines.<br>▪ Traps were set at ~25-m spacing, placed in sheltered, shady locations, and covered with a hessian bag to protect trapped animals from the heat.<br>▪ Trap lines ran along the foot slopes or on top of rocky breakaways and mesas, as well as in and around gorges<br>▪ 21 Northern Quolls were trapped in the baited area and 20 in the nearby reference area | ▪ Trapping occurred from May- June 2015<br>▪ Linear transects of varying numbers (between 10 and 50, depending on the environment)<br>▪ Maximum of four consecutive nights at any single location | Yarraloola and Red Hill, Pilbara region, Western Australia | Cowan et al. (2020) |
| Assessing impact of exposure to Mn from mining activity | ▪ Trapping occurred at sites proximate to mining sites where Mn is extracted and sites distant from the mine by 15-20 km.<br>▪ Tomahawk original series cage traps (20x20x60 cm; Tomahawk) at 60 m intervals, baited them with canned dog food<br>▪ Quolls were also tagged by inserting a PIT tag between its shoulder blades (Trovan nano-transponder).<br>▪ Measurements taken included sex, breeding status, body mass, estimated age (based on incisor wear and reproductive condition), head width, head length, body length, right and left forelimb length, maximum tail width and tail length. | ▪ Surveys occurred between May- September 2014 during three separate dry season periods, pre-breeding, during breeding and post breeding<br>▪ Trapping at 7 mining sites and 4 sites 15- 20 km from mining sites<br>▪ Trapping occurred over three consecutive nights at each site<br>▪ 30 cage traps per site | Groote Eylandt, Northern Territory | (Nasir et al. 2018) |
| Monitoring the growth, reproduction and survival of translocated Northern Quolls | ▪ Sampling undertaken using trapping grids (initially an array of 7 x 10 traps, spaced 20 m apart, in later trips an array of 5 x 5 traps, spaced 20 m apart) or trapping transects (a line of 10 traps spaced 20 m apart),<br>▪ All traps used were cage traps (65 cm x 15 cm x 15 cm),<br>▪ Traps were baited with a mixture of peanut butter, honey and oats. | ▪ Traps occurred over a three or five night period. | Astell and Pobassoo Islands, Northern Territory | Rankmore et al. (2008) |
| Monitoring the social and spatial organisation of Northern Quolls including mating activities | ▪ During 1992-93, traps were set in 6 rows each of 10 traps.<br>▪ Trap lines were 100 m apart, and traps were spaced at 50 m intervals.<br>▪ During the 1994-95 period, 48 traps (all wire cage) were set in 8 rows each of 6 traps, all 100 m apart.<br>▪ Occasional additional trapping at occupied dens (located by radio-tracking) | ▪ Trapping grid covering 22.5 ha for November 1992-December 1993, 35 ha from January 1994 to February 1995.<br>▪ During 1992-93, 60 traps (50 wire cage, 10 Elliott)<br>▪ Traps were set for 2 consecutive nights/ fortnight. | Kapalga Research Station, Kakadu National Park, Northern Territory | Oakwood (2000, 2002) |

| Study purpose | Study design | Survey effort | Location | Reference |
|---|---|---|---|---|
| | ▪ Traps were baited with a mixture of peanut butter, rolled oats and vegetable oil.<br>▪ Individuals were marked with ear-tags (Hauptner). | | | |
| Examining the life history and possible causes of the decline of Northern Quolls | ▪ Study 1 a single grid of 12 rows at 50-m spacing and 30 trap sites on each row at 25-m spacing.<br>▪ : 1 :5 mixture of wire-cage and Elliott metal traps<br>▪ Study 2: each of the 16 grids was arranged as 4 rows at 50-m spacing with 20 trap sites at 20-m spacing.<br>▪ They were trapped with 1 : 4 trap-type ratio (wire: Elliott) | ▪ Data used from two studies, the first occurred on three consecutive nights every month between November 1985 and November 1987. 30 trap sites<br>▪ Second study occurred for two nights every two months, from July 1989 to March 1992, 20 trap sites | Kapalga Research Station, Kakadu National Park, Northern Territory | Braithwaite and Griffiths (1994) |
| Monitoring the survival and causes of mortality of Northern Quolls during aerial 1080 dingo baiting | ▪ Elliott traps (15 x 16 x 46 cm or 9 x l0 x 33 cm)<br>▪ Baited with peanut paste and rolled oats.<br>▪ Trapping undertaken in two hilly areas separated by a flat area approximately 2 km wide." | ▪ Detail not available | Western Pilbara region, Western Australia | King (1989) |
| Monitoring the ecology and physiology of Northern Quolls (and numerous other species) | ▪ Square grids consisting of 100 traps located at 15-m intervals<br>▪ One small Elliott trap (10 x 9 x 32 cm) was placed at each site. Ten cage traps cm) were distributed evenly throughout the trap sites on all grids, as were 10 large Elliott traps (15 by 15 by 45 cm).<br>▪ Traps were baited with a mixture of peanut paste, rolled oats, raisins and bacon bits. | ▪ Grids of 100 traps<br>▪ Trapping was carried out over five nights on each grid; additional trap nights were conducted for specific purposes." | Mitchell Plateau, Western Australia | Bradley et al. (1987); Schmitt et al. (1989) |
| Monitoring the ecology of Northern Quolls (and other species) | ▪ Aluminium box-type traps (Elliott) measuring 33 x 10 x 10 cm<br>▪ Baited with a mix of oats, peanut butter, mixed fruit and sardines.<br>▪ 100 traps were set in each habitat in two fixed lines of 50 traps,<br>▪ Spaced about 10 m apart and the lines were 20-40 m apart, depending on the terrain.<br>▪ | ▪ 100 traps per survey<br>▪ Traps set every month for three consecutive nights from February 1977 to June 1979;<br>▪ A total of 300 trap-nights per habitat per month. The study totalled 34,800 trap-nights. | Little Nourlangie Rock, Arnhem Land, Northern Territory | Begg (1981a); Begg (1981b) |

### 1.2.2 Camera trapping

Infrared motion activated cameras are commonly used to assess Northern Quoll occupancy and their relationship with associated habitat features, pest animals and survival during baiting operations (Hernandez-Santin et al. 2016; Hohnen et al. 2013; Moore et al. 2023; Nelson & Gemmell 2003; Palmer et al. 2021; Turpin & Bamford 2015). Camera trapping has been shown to more cost effective, and less stressful for the animal than live trapping, and in some circumstances it is a more successful method for detecting medium to large sized mammals (De Bondi et al. 2010). Queensland state guidelines recommend where live capture is not necessary (for instance, surveys that do not require condition measurements), that camera trapping is undertaken in favour of live trapping (Eyre et al. 2022).

Camera trap surveys may be set up as active or passive monitoring. An active set up utilises a lure such as sardines (Hernandez-Santin et al. 2016), a putrefied meat solution (Wayne et al. 2008), such as peanut butter, oats and tuna (Hohnen et al. 2013), or tuna oil to actively attract and photograph any Northern Quolls in the area. Passive monitoring captures any quoll (or other animal) that pass by an unbaited camera trap. Northern Quoll latrines are effective sites for passive camera trap set up (Meek et al. 2012). Individuals may be identified by spot pattern, allowing for abundance, distribution and ecology to be assessed using the camera trapping monitoring technique. Using a lure placed ~0.4 m off the ground as bait smeared on a vertical surface improves spot pattern identification (Hohnen et al. 2013).

Survey standards for monitoring the Northern Quoll in the Pilbara (Dunlop et al.) have been drafted and are currently *in review* (at the time of this document's publication). The standards include a summary of the methodology for using camera traps to monitor Northern Quoll and were developed as part of the recent Pilbara Bioregion EPBC Act Policy Statement. Several other guidelines for using camera traps for monitoring wildlife in Australia also exist (Gillespie et al. 2015; Meek et al. 2012). In these documents Northern Quolls fall within the category of medium sized mammals and thus, it is recommended that sensors be set approximately 50 cm above the ground.

Moore et al. (2020) found that cameras oriented vertically (downward) at 1.5 m with a scent lure beneath them facilitated individual identification via unique dorsal patterns without compromising detectability. Although camera orientation had no effect on the probability of detection, vertically oriented cameras generally captured images facilitated easier identification of individuals via dorsal patterns than in images from horizontally orientated cameras. Table 4 summarises camera trap survey methods typically used for monitoring.

Table 4. Methods overview of key studies using camera trap survey methods

| Study purpose | Study design | Survey effort | Location | Reference |
|---|---|---|---|---|
| Comparison of camera trap and live trap survey methods in terms of cost and statistical power in tracking occupancy for the Northern Quoll | ▪ Large baseline survey undertaken to identify suitable locations to establish Pilbara Northern Quoll monitoring (PNQM).<br>▪ Sites that produced one or more quoll were selected for inclusion in the PNQM.<br>▪ Live trapping and camera trapping were undertaken<br>▪ Sites sampled using camera traps between 2017 and 2018<br>▪ Cameras used: Reconyx PC900 Hyperfire.<br>▪ Sites were separated from each other by at least 1 km.<br>▪ Cameras were attached to a wooden stake 1.5 m above the ground, oriented downward<br>▪ At least 200 m between each camera | ▪ Large baseline survey undertaken across 100 monitoring sites<br>▪ 12 sites selected for inclusion in the PNQM<br>▪ Each camera trapping site consisted of five cameras spread across 75 ha<br>▪ Cameras deployed for a period of up to eight months.<br>▪ Only ten nights of repeat sampling used for study as this is realistic of effort applied by land mangers conducting presence absence surveys. | Pilbara region, Western Australia | (Moore et al. 2023; Moore et al. 2020) |
| Monitoring the survival and causes of mortality of Northern Quolls (and feral cats) during aerial Eradicat® cat baiting | ▪ Camera traps set were ≥ 3 km apart<br>▪ Each camera (Reconyx HyperFire™ PC900, Reconyx) was mounted 30 cm above the ground on a 45 cm heavy duty plastic tent peg and positioned to face south<br>▪ Cameras were programmed to take five pictures up to two frames per second upon a trigger, using an infra-red flash.<br>▪ A lure pole, optimised for attracting feral cats were set 3 m in front of each camera trap<br>▪ The olfactory lure consisted of 15–20 ml of 'Catastrophic' scent lure in an oil suspension, attached to a stake approximately 30 cm from the ground. Also attached to this stake, was a 1.5 m long | ▪ Camera traps were set for a minimum of 25 nights prior to the July baiting operation each year and then re-set three weeks afterwards for a further 25 nights. | Pilbara region, Western Australia | Palmer et al. (2021) |

| Study purpose | Study design | Survey effort | Location | Reference |
|---|---|---|---|---|
| | metal curtain rod with three white turkey feathers taped obliquely at its midpoint and a 30 cm length of silver tinsel secured to the top of the rod | | | |
| Studying the effect of camera orientation on the detectability of the Northern Quoll and other species | ▪ Two reconyx PC900 Hyperfire covert cameras deployed at each site, one positioned vertically on a wooden stake 1.5 m above the ground. The second was attached to a second wooden stake, oriented horizontally, 50 cm above the ground, 2.5 m north from camera one.<br>▪ PVC canister with 159 g of pilchards were attached to the bottom of the stake supporting camera one, within the centre focus of both cameras<br>▪ Cameras set to high sensitivity, five images were taken at one-second intervals per trigger. | ▪ 46 camera sites<br>▪ 23 study landscapes<br>▪ Two sites separated by at least 300 m assigned to each landscape<br>▪ Each landscape ~0.79 km2<br>▪ Sites were sampled for 200 days each, between August and March | Indee Station, Mallina Station, Pippingarra Station and Yandeyarra Indigenous Reserve,<br>Pilbara region, Western Australia | (Moore et al. 2021; Moore et al. 2020) |
| Monitoring to assess how interactions among predators might affect the decline of the Northern Quoll | ▪ Camera-traps (Reconyx Rapidfire™ models HC500 and PC900)<br>▪ All transects set on roads in different habitat types<br>▪ Each transect contained 10 cameras, separated by 250 m baited with a punctured can of sardines in vegetable oil. Transects remained the same throughout the study.<br>▪ During the first two trips, cameras were set about 300 mm from the ground. During the last three trips cameras were set on the ground to record smaller nontarget species, while still allowing detection of target species<br>▪ The cameras were set to take five pictures (one picture per second) each time the motion sensor was triggered. | ▪ Two 'pilot' studies (13-Mar 2013 to 27-Mar-2013 and 19-Sep-2013 to 5-Oct-2013), and five main trips corresponding to specific parts of the quoll life cycle, including population recruitment (April and May), the start of the mating season (June and July), and the reproductive season (September and October)<br>▪ Five sites monitored per site visit<br>▪ After removing camera failures, this gave a total of 2415 trap nights | Pilbara region, Western Australia | Hernandez-Santin et al. (2016) |
| Monitoring the distribution of Northern Quolls | ▪ One motion-sensitive camera (Bushnell Trophy Cam) was placed at eight sites<br>▪ Sites selected due to presence of extensive dissected rocky habitat close to permanent or seasonal waterholes and the perceived potential for Northern Quoll denning. Cameras were placed in two caves adjacent to permanent waterholes; scats thought to be from the Northern Quoll were found in one of the caves<br>▪ All motion-sensitive cameras were set to record one photograph per trigger event, with a 1-s delay<br>▪ Baited with universal bait (a mixture of rolled oats, peanut butter and sardines)" | ▪ Monitoring occurred began on Aug 3 2012, three cameras were collected after four days, and four were collected 41 days later totalling the 176 survey nights) | Broadhurst and Throssell Ranges<br>in the Little Sandy Desert Bioregion, Western Australia | Turpin and Bamford (2015) |
| Identifying Northern Quoll individuals | ▪ PC800 HyperFire camera traps (Reconyx, Holmen, Wisconsin) | ▪ Cameras set for 10 days | Artesian Range and Mornington | Hohnen et al. (2013) |

| Study purpose | Study design | Survey effort | Location | Reference |
|---|---|---|---|---|
| | ▪ Cameras were set to capture 3 or 20 images per burst, taken one second apart with no minimum time delay between triggers.<br>▪ Night mode was set as balanced and the images taken at night were monochromatic, made under an infrared flash."<br>▪ Bait consisting of peanut butter, oats and tuna<br>▪ Lure placement at ~0.4 m height was varied to improve photographs of quoll spot patterns. | | Australian Wildlife Conservancy sanctuaries, Kimberley region, Western Australia | |

### 1.2.3 Radio-tracking

Radio-tracking of Northern Quolls is the primary survey technique to assess individual quoll movements and dispersal, densities, survival and causes of mortality, including after management actions such as poison baiting and quoll translocation (Cowan et al. 2020; Heiniger et al. 2020; King 1989; Oakwood 2000, 2002). Both radio collar (Cowan et al. 2020; King 1989; O'Donnell et al. 2010; Oakwood 2002) and backpack (Heiniger et al. 2020) attachments have been used successful for monitoring Northern Quoll. The Backpack design allows for slightly larger GPS tracking units to be used, however it is necessary to modify the units to reduce their weight (Heiniger et al. 2020). Tracking devices should weight no more than 5 % of the body weight of the tracked individual (Kenward 1987).

Smaller, very high frequency (VHF) radio collar trackers were found to have interrupted transmission during the day when quolls were sheltering within rock piles and mesas (Cowan et al 2020), making it difficult to determine accurate locations. To overcome this radio trackers were programmed to emit radio signals later in the day and into the evening when Northern Quolls are more active and in the open. Alternately GPS enabled radio transmitters may overcome this issue (Heiniger et al. 2020), however they are larger, heavier and more expensive. Table 5 summarises radio tracking methods typically used for monitoring the Northern Quoll.

Table 5. Methods overview of key studies using radio-tracking surveys

| Study purpose | Study design | Survey effort | Location | Reference |
|---|---|---|---|---|
| Understand the spatial needs for the Northern Quoll | ▪ Monitored sites that had previous monitoring for Northern Quoll<br>▪ Quolls were trapped using wire cage traps (45 cm 17 cm 17 cm, Sheffield Wire Co., Welshpool, WA)<br>▪ Baited with a mixture of peanut butter, oats, and sardines<br>▪ Traps spaced 25 - 50 m apart<br>▪ All trapped quolls were processed and released on site<br>▪ Fitted with a unique injectable transponder (12-mm FDX-B; Allflex, Queensland, Australia), and GPS-units were fitted to individuals that were large enough to carry the units<br>▪ Morphological measurements included sex, mass, tail circumference at the base, scrotal width and length, reproductive status of females, ectoparasite numbers per individuals, injuries, overall appearance, tooth wear was used to determine age class. | ▪ Four sites monitored<br>▪ Transmitters were attached and quolls were monitored from September-October at two sites and from June-July at three sites<br>▪ 6-50 traps per site<br>▪ Traps set for 1–5 nights | Pilbara region, Western Australia | (Hernandez-Santin et al. 2019; Hernandez-Santin et al. 2021) |

| Study purpose | Study design | Survey effort | Location | Reference |
|---|---|---|---|---|
| Monitoring the survival and causes of mortality of Northern Quolls during aerial Eradicat® cat baiting | ▪ 21 Northern Quolls captured in the baited area and 20 in the nearby reference area<br>▪ Adult quolls weighing between 300 and 790 g were fitted with VHF collar radio-transmitters equipped with a mortality mode,<br>▪ Radio-collar weight was no more than 3–5% of the bodyweight (Sirtrack, Havelock North, New Zealand).<br>▪ The mortality sensor was set for activation if the collar remained stationary for at least 12 h; after this time, the pulse rate doubled. | ▪ Radio-collars initially tasked with operating only during daylight hours (~0600to 1800) to prolong battery life to 6 months. | Pilbara region, Western Australia | Cowan et al. (2020) |
| Monitoring the growth, reproduction and survival of Northern Quolls | ▪ 391 (197 females and 194 males) unique Northern Quolls were captured across the study period"<br>▪ Modified i-gotU GT-120 GPS tracking units used for tracking movements<br>▪ Tracking units attached to quolls with backpack-style harnesses.<br>▪ Tracking units were modified to reduce weight<br>▪ Modified units were adhered to fleece with heat-shrink tubing before attachment to the quoll (ensuring the device was situated between the shoulder blades).<br>▪ For larger quolls, a two-stage VHF transmitter (Sirtrack) with a whip aerial attached to the base of the GPS to increase unit retrieval.<br>▪ The units weighed between 19.2 and 26.7 g and were matched to individual quolls to ensure that they weighed no more than 5% of their bodyweight.<br>▪ Female quolls were tracked only during pre-breeding and breeding to minimise stress during lactation (post-breeding). | ▪ Study conducted from 23 April 2012 – 13 October 2015 (4 year study period)<br>▪ Each unit was set to record every 5 min between 1800 hours to 0600 hours | Groote Eylandt, Northern Territory | Heiniger et al. (2020) |
| Monitoring the survival and causes of mortality of toad-smart and toad-naïve Northern Quolls | ▪ Transmitters fitted to 31 toad-smart and 31 toad-naïve quolls<br>▪ Prior to release, each quoll was fitted with a radio collar containing a mortality sensor (Sirtrack) and applied a topical anti-parasite agent (Frontline).<br>▪ Collars weighed <5% of quoll body mass and were designed to fall off the animals within a month. | ▪ Further detail not available | Darwin region, Northern Territory | O'Donnell et al. (2010) |
| Monitoring the social and spatial organisation of Northern Quolls | ▪ Radio-collars with whip aerials (Sirtrack) were fitted to 14 female and 20 male quolls<br>▪ The collars were made of a soft PVC, secured by a nylon nut and bolt.<br>▪ The transmitters were encased in heat-shrink tubing, pulsed at 40 pulses/min and battery life was 3.8 and 6.3 months for 10:18 and 10:25 cells, respectively.<br>▪ The 13-21 g packages were matched to individuals to ensure that they weighed no more than 3-4% of their body weight. | ▪ Radio collars fitted for period of 1-266 days | Kapalga Research Station, Kakadu National Park, Northern Territory | Oakwood (2002) |
| Monitoring the survival and causes of mortality of Northern Quolls during aerial 1080 dingo baiting | ▪ Quolls were fitted with 27 MHz crystal-controlled pulsed transmitters attached to brass collars and were released at the point of capture.<br>▪ Tracking was done during the hours of 1000 to 1600 on foot or from a 4-wheel-drive vehicle, using CB receivers and directional loop antennae | ▪ 13 quolls tracked for 20-33 days during September-October 1987 | Western Pilbara region, Western Australia | King (1989) |

# 3 Key agencies and organisations involved in the species research and recovery

Key agencies, organisations or individuals identified as having been previous, or currently actively involved in monitoring the Northern Quoll include:

- Australian Wildlife Conservancy
- James Cook University
- Quoll Seekers Network
- Terrain NRM
- Western Yalanji Traditional Owners
- Harry Moore – WA Department of Biodiversity and Conservation and Attractions
- Russell Palmer - WA Department of Biodiversity and Conservation and Attractions
- Judy Dunlop – School of Agriculture and Environment – University of Western Australia
- Meri Oakwood – Australian National University and Southern Cross University

# 4 Key survey guideline recommendations gathered from the literature

This literature review of monitoring methods for the Northern Quoll has identified some key points to be considered when developing species-specific survey guidelines. These points include:

- Cage trapping, camera trapping and radio-tracking are well established, highly functional and applicable methods used for monitoring the Northern Quoll.
- Camera trapping can be a cost effective and ethical option for detecting Northern Quoll. The Queensland government has guidelines in place recommending that surveys of terrestrial vertebrate fauna, where possible be conducted via camera traps rather than live capture surveys (Eyre et al. 2022).
- Guidelines for surveying the Northern Quoll in the Pilbara, Western Australia including protocols for less invasive monitoring techniques of habitat assessment, sign surveys and camera trap monitoring and more invasive live trapping (Dunlop et al.) are currently in review for publication (at the time of this publication).
- Optimal bait lure set up allows for clear spot pattern identification on Northern Quolls (Hohnen et al. 2013), allowing for individual identification via camera trap surveys and capture-recapture abundance studies.
- Vertical (downward facing) orientation of cameras at a height of 1.5 m allows for clear images of spot patterns and individual identification without compromising detectability for Northern Quolls when using camera traps (Moore et al. 2020).
- Standardisation of methodology may include spacing of cage and camera traps, noting that this is primarily driven by Northern Quoll home ranges, which can vary depending on habitat and predator abundance. Hence a 250 m spacing for cage traps may be appropriate for the Pilbara populations (Hernandez-Santin et al. 2016), whereas 20 m was used for highly abundant populations on Astell and Pobassoo Islands (Rankmore et al. 2008).
- State guidelines currently recommend different lengths of times for trapping effort (number of consecutive nights traps are opened) targeting terrestrial fauna. Western Australian guidelines recommend traps to be open seven nights (EPA 2020), guidelines for the Pilbara suggest fourthe Northern Territory recommends three nights (Dunlop et al.), the Northern Territory recommends three nights (NT EPA 2013) and Queensland four nights (Eyre et al. 2022), this is reflected in the inconsistency between studies (see Table 3). Approving a standard that finds a compromise between cost and animal welfare concerns, and conducting robust capture-mark-recapture population assessments should be considered.
- Similarly, there is no standard for the duration of camera trapping efforts, and duration may vary depending on the complexity of the monitoring being undertaken, the season and time of year that monitoring is occurring and battery life duration (Gillespie et al. 2015; Meek et al. 2012). Detectability is a key consideration in survey design. In surveys where the primary goal is to determine presence or absence a shorter duration may be sufficient. However, if the goal of the study is to estimate the number of individuals presence then a longer survey period is recommended. The presence of predators such as cane toads in a region should also be factored in to survey duration as they may also affect detection rates.
- Radio-tracking is an established monitoring method to help assess specific Northern Quoll demographics, home range and den site attributes, and the timing of and causes of mortality. It is much more sensitive than both cage trapping and camera traps and can be critical to identify causes of quoll mortality and achieve reintroduction success (Moseby et al. 2021;

Moseby et al. 2015). An area for possible standardisation is the percentage of a translocated Northern Quoll population that should be monitored by radio-collaring to best assess survival, home ranges, dispersal and causes of mortality, noting though that this is predominantly driven by cost and available funds, and the human resources available to effectively monitor the collared quolls.

- TERN has developed a suite of standardised ecological field monitoring protocols, known as the Ecological Field Monitoring System Australia (EMSA) modules. The EMSA modules for camera trapping and vertebrate fauna  may be relevant to surveying the Northern Quoll.

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