Threatened Species Recovery Hub

National Environmental Science Programme

Ecology and predator associations of the northern quoll in the Pilbara

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Front cover image: Northern quoll. Photo: Nicolas Rakotopare

Images throughout report: Lorna Henandez Santin, unless otherwise specified

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Photo: Nicolas Rakotopare

Executive Summary

The northern quoll (*Dasyurus hallucatus*) is an endangered carnivorous marsupial that occurs in the northern third of Australia. It has declined throughout its range, especially in open, lowland habitats. This led to the hypothesis that rocky outcrops where it persists provide a safe haven from introduced predators and provide greater microhabitat heterogeneity associated with higher prey availability. Proposed causes of decline include introduced cane toads (*Rhinella marina*, which are toxic), predation by feral cats (*Felis catus*), foxes (*Vulpes vulpes*), and the dingo (*Canis lupus*), and habitat alteration by changes in fire regimes. The National Recovery Plan highlighted knowledge gaps relevant to the conservation of the northern quoll. These include assembling data on ecology and population status, determining factors in survival, especially introduced predators, selecting areas that can be used as refuges, and identifying and securing key populations. The Pilbara region in Western Australia is a key population currently free of invasive cane toads (a major threat).

The Pilbara is a semi-arid to arid area subject to cyclones between December and March. I selected two sites: Millstream Chichester National Park (2 381 km^2) and Indee Station (1 623 km^2). These are dominated by spinifex (hummock) grasslands, with rugged rock outcrops, shrublands, riparian areas, and some soft (tussock) grasslands. They are subject to frequent seasonal fires, creating a mosaic of recently burnt and longer unburnt areas. The overall aim of this study was to assess the ecology of the northern quoll in the Pilbara to understand drivers of density and distribution of this endangered species, to enhance species-specific conservation efforts. I collected field data on six one-month trips over three years, predominantly using live-trapping, camera-trapping, sampling invertebrates, vegetation surveys, habitat structure, and den availability surveys.

In the Pilbara, the largest mammalian predators are the introduced dingo and feral cat. The largest native mammalian carnivore is the northern quoll, which is smaller than the introduced predators but larger than the other dasyurids in the guild. I explored spatial and temporal associations among introduced predators and quolls and their associations with habitat to assess the impact of introduced predators on quolls. I found evidence that dingo control programs prevent dingoes from fulfilling their role as top predators, leading to mesopredator release of feral cats. Feral cats were associated with open habitats (spinifex grasslands and recently burnt areas), and showed inverse associations to those of quolls, suggesting that quolls avoid cats in space. Quolls were positively associated with rocky habitats. I assessed spatial and temporal associations among dasyurids to understand the current role of northern quolls within their guild. I found that range contraction of northern quolls into rocky habitats prevent them from fulfilling their role as top predators across the landscape, potentially leading to mesopredator release of kalutas (*Dasykaluta rosamondae*). Kalutas were associated with spinifex grasslands and may be controlling densities of smaller dasyurids such as stripe-faced dunnarts (*Sminthopsis macroura*), which more often inhabit recently burnt areas.

Northern quolls have a synchronized annual reproductive cycle in which births are timed to enhance offspring survival by coinciding with seasonal resources. The northern quoll now occurs in patchy populations. The Pilbara is the most arid and southern portion of its range. I analysed demography and population dynamics to determine differences and similarities of this range extreme with other populations across their range. I found that the reproductive timing of northern quolls in the Pilbara differs from that of populations in more mesic and lower latitude regions where they have been studied previously. This is consistent with the hypothesis that dasyurids respond to differences in food availability, so they time reproduction to coincide with peak resources.

I assessed different aspects that contribute to defining habitat quality for northern quolls to understand if and how bottom-up processes regulate their apparent preference for rocky habitats. For this I looked at den availability, vegetation cover and diversity, and availability and diversity of potential vertebrate and invertebrate prey. Except for a few dens in riparian areas, rocky habitats were the only areas with dens available at my sites. Rocky habitats had consistently more shelter, despite better vegetation cover at the ground level provided by spinifex grasslands and shrublands. Prey availability was strongly seasonal. Spinifex grasslands had the highest records and diversity of both vertebrates and invertebrates, and rocky habitats also contained high abundance of vertebrates when corrected for sampling effort. Soft grasslands contained few potential prey.

I found that quolls ate more vegetation during the pre-mating season (June), ate more animal prey when females carry pouch young and had high energy demands (September), and a higher percentage of invertebrates during the recruitment season (April).

Discussion of key findings

I assessed aspects of the ecology of the northern quoll in the Pilbara, focusing on gaps in knowledge that have conservation implications. In the National Recovery Plan for the species, Hill and Ward (2010) suggested that rocky habitats could offer higher resource availability related to higher habitat heterogeneity or a refuge against introduced predators. I considered possible top-down and bottom-up regulation of quoll populations and region-specific demographic characteristics, to disentangle reasons why northern quolls are doing better in rocky habitats than in other habitat types. I found evidence that top-down regulation from feral cats is more important than bottom-up regulation in determining the distribution of the quoll, and that this risk is likely to have increased because the virtual absence of dingoes has likely led to mesopredator release of feral cats. However, I also found evidence that bottom-up regulation might control the density of the northern quoll, and severe droughts may alter their distribution within rocky habitats.

Survival of northern quolls is tightly linked with their life cycle and demographic characteristics. Due to sexual differences in life history strategies, the population dynamics of males and females differs greatly. The population of males fluctuates dramatically because most males die after the annual rut (mating period). In my study area, males showed increased activity levels and there was an influx of dispersing males during the pre-mating season, followed by a marked loss of body condition and then low survival after the mating season. Low post-mating survival of males associated with their life history has been reported throughout northern Australia (Begg 1981b; Braithwaite and Griffiths 1994; Schmitt et al. 1989). In some areas, the decline following the mating season can result in complete male die-off (Oakwood et al. 2001).

In my area, males were still found while females were carrying pouch young, but low post-mating survival was evident based on the low trapping rates of males during the following recruitment season. Despite this, I found equal sex ratios during the recruitment and pre-mating seasons, suggesting that more males are born and recruited into the population allowing an almost complete turnover of individuals. Conversely, female fitness depends on the survival of their offspring, and therefore they expend most energy when they are rearing young (Fisher et al. 2013). Therefore, reproductive cycles are usually timed to ensure the success for females, having the highest quality of prey when their energetic demands are greatest (Fisher and Blomberg 2011; Fisher et al. 2013). I found that females carried pouch young when the availability of prey was highest for vertebrates, compared to invertebrates.

The agreement of my results with those of studies of demography in other parts of their range (Begg 1981b; Oakwood 2000; Schmitt et al. 1989), confirms that intrinsic characteristics of life cycles are important drivers of population fluctuations. However, I found differences in population size between years that were more important than differences between sites or among seasons.

Survival rates and population sizes declined between years, regardless of seasonal variation, suggesting potential bottom-up regulation associated with rainfall. For example, September 2013 had higher population sizes than September 2014 and June 2014 had higher population sizes than June 2015. Bottom-up regulation of northern quoll population sizes, as related to temporal fluctuations in the availability of prey is supported by the comparison of invertebrate abundance by trip. In Victoria, Parrott et al. (2007) found that the body condition of another dasyurid the agile antechinus (*Antechinus agilis*) decreased in drought.

Similarly, my male northern quolls had a non-significant trend of lower body masses in April 2015 than in April 2014, suggesting a decrease in body condition as a consequence of the drought. Thus, the additive effects of decreased body condition associated with life histories and droughts may have dramatic effects in summer, lowering northern quolls' survival after the mating season. A decrease in body condition could result from a decrease in prey availability. For example, a decrease in insect abundance compared to other years was attributed to drought in the lowland savanna of New South Wales (Bell 1985). The decrease in insect abundance is evident for the months surveyed in 2015. However, the true effect of the drought might be masked by the response times of prey to resource pulses, or due to the limited time frame of my study (September 2013 to June 2015). Although January 2015 had the lowest rainfall recorded at Millstream and Indee since 2006 (< 11 mm), there was an increase in rainfall in March and April (40 - 67 mm, more than the same months in 2014 (BOM 2016), allowing prey to increase in time for my field trips. When a resource pulse occurs, food abundance increases from the bottom of the trophic chain upwards, with time lags (Yang et al. 2008; Yang et al. 2010). This is because once primary productivity increases it can support higher numbers of primary consumers, and once the numbers of primary consumers increases they can support a higher number of predators. Thus, primary consumers are the first to respond (Yang et al. 2010), especially insects, which can increase even with small environmental changes (Bergallo and Magnusson 1999; Frith and Frith 1985).

Although the difference in quoll population sizes between years was greater than differences between sites, the latter can help us to understand other bottom-up factors that may be important for the quolls' distribution. Dickman et al. (2010) noted that cycles of pulses and droughts can generate fluctuations in population dynamics. In fact, species may shift their space use during severe droughts and retract to refuges until the next pulse, which might result in local extinctions of some species (Dickman et al. 2011). Based on population densities, I found evidence that Indee may act as a refuge, with densities comparable to those on offshore islands of the Northern Territory that are free or nearly free of predators and have intact understorey shelter as a result of infrequent burning, such as (Groote Eylandt, Robbie Wilson personal communication). Conversely, densities at Millstream were low but comparable to those in rocky areas of the Kimberley. While the trapping area at Indee was a rock outcrop, that at Millstream was part of a mountain range with continuous rocky habitat. This characteristic of Millstream could allow spatial contraction of quolls to unknown refuges where the population could survive until the arrival of rainfall. Population density suggests that Indee is particularly high quality habitat, but other factors must be considered before we make assumptions about differences in habitat quality between rocky sites. This is because inference based on demographic characteristics alone can be confounded by source-sink dynamics (Andreasen et al. 2012).

I assessed the possibility of bottom-up regulation based on the availability of prey, cover and dens. I found differences among habitat types in terms of the diversity and numbers of records of prey. Although rocky habitats had the highest abundance of vertebrates (corrected for sampling effort), this habitat type ranked fifth in abundance of invertebrates. Regardless of the their high levels of prey availability, my results suggest that some rocky areas fail to completely supply the energetic needs of northern quolls throughout the year, and that quolls may need to seek food supplements in surrounding habitats such as spinifex grasslands. The survival of some males beyond their first year (oldest recorded at 25 months old) and of a female beyond her second year (31 months old) in a high density population at Indee suggest that this refuge is either especially productive, which is not the case, or that quolls supplement their diet from neighbouring areas.

I found the greatest temporary cover in rocky habitats, but other areas such as riparian and spinifex grasslands also had good cover. However, rocky habitats had significantly more potential dens available than the other habitats, with low availability in riparian, spinifex, and shrub habitats. The supply of dens can limit the density (Bakker and Hastings 2002; Cruz et al. 2012) and survival (Crook and Chamberlain 2010; Hwang et al. 2007) of denning species such as the northern quoll. Thus, the availability of temporary and permanent cover shows that bottom-up regulation is important within rocky habitats.

There was evidence of top-down regulation at two different levels in my study area. The mammalian carnivore guild was composed of species within a very wide range of body masses, from ningauis to dingoes. The quoll was the largest dasyurid species. The relatively large size of quolls along with low co-occurrence values with the smaller dasyurids suggests that smaller dasyurids pose no threat or competition to northern quolls. In fact, smaller dasyurids are sometimes eaten by quolls; I recorded kalutas in quoll scats. Range contractions of the top-predator dasyurids (quolls and mulgaras) may have resulted in the mesopredator release of kalutas, which may be suppressing numbers and distribution of stripe-faced dunnarts. A similar top-down relationship between dasyurids has also been shown in the Simpson Desert, where Dickman (2006) found evidence of mesopredator release of the lesser hairy-footed dunnart (*Sminthopsis youngsoni*) following the experimental removal of brush-tailed mulgara (*Dasycercus blythi*) in field-based closed-exclosures.

On the larger side of the mass spectrum of the predator community, low numbers of dingoes appear to have resulted in mesopredator release of feral cats, which may have excluded quolls from freely accessing open plains, restricting them mainly to rocky habitats. Recent evidence suggests no competition of resources in the diet of dingoes, cats, and quolls, which take large, medium, and small prey, respectively, with almost no overlap (Russell Palmer, personal communication). Spatial and temporal differences in resource partitioning among predators show avoidance of risk of predation at two different levels.

Temporal partitioning often results from short-term avoidance, occurring in areas associated with low predation risk (Broekhuis et al. 2013). In contrast, in areas with high risk smaller predators will often shift their resource use spatially, avoiding top predators in the long-term (Broekhuis et al. 2013). The degree of spatial and temporal partitioning can also be related to prey availability (Edwards et al. 2015) and it may depend on the degree of intraguild diet overlap, where the smaller predator shifts to lowest quality of resources (Cupples et al. 2011). In my study area, quolls responded to feral cats through spatial avoidance, which can be generally considered long-term. This suggests that quolls perceive cats as a significant risk, although in some instances quolls are willing to venture into spinifex grasslands to forage. Thus, the larger size of cats, their widespread distribution in open habitats, and the temporal avoidance of cats by quolls together suggest that cats regulate the northern quoll's distribution.

Overall, I found evidence that top-down regulation affects northern quoll's distribution across the landscape in the Pilbara, while bottom-up regulation may alter northern quolls' density there. However, severe droughts may alter both density and distribution of northern quolls by lowering survival (density) and forcing individuals to move\ to pockets of higher productivity (distribution) within rocky habitats.

Management implications and future research

My results suggest that rocky habitats currently represent the highest habitat quality for northern quolls. This is in agreement with a recent GIS-based species distribution model, where Molloy et al. (2015) found that rocky habitats had highest probability of occurrence of northern quolls. Therefore, management plans should include ways to preserve rocky habitats and the features that provide natural connectivity between them. For example, 'rocky riparian' habitats are mostly linear features that can connect rock outcrops. Such connectivity is important to maintain genetic diversity and to re-establish quoll populations following periods of severe drought.

In the National Recovery Plan for the species, Hill and Ward (2010) hypothesised that rocky habitats serve as a refuge by providing higher prey availability associated with higher habitat heterogeneity or by providing protection against introduced predators and extreme weather events such as fires. In my thesis I was able to disentangle parts of this hypothesis. I found that bottom-up regulation can control density of quolls within rocky habitats and that top-down regulation (i.e. feral cats) restrict their distribution, with the exception of severe loss of resources following drought periods. Droughts can be more important than top-down regulation only when they are so severe that northern quolls are forced to retreat into resource refuges within their predator-refuges until conditions become favourable again, with the possibility of local extinction. Creek-lines in my study area are in close proximity to rocky habitats (Appendix A) and water is often associated with higher productivity. Therefore, overexploitation and disruption of naturally available water should be avoided, especially in creeks with low levels of water, because this has the potential to diminish resource availability that may be crucial during droughts.

Although feral cats pose a predation risk to northern quolls, I found evidence that northern quolls can still exploit resources from adjacent habitats where cats might be present, such as spinifex grasslands. I found higher activity of cats associated with spinifex grasslands and recently burnt areas. Long-unburnt spinifex grasslands are likely to be associated with relatively low predation risk, because they ranked highest in vegetation cover with intermediate temporarily available shelters, while recently burnt areas had the lowest rank in shelters. This suggests that, although northern quolls cope with fire in rocky habitats (Cook 2010), they might be at higher risk of predation when foraging in adjacent recently burnt habitats. In a fire-prone area like the Pilbara, conservation actions should include fire management that allows patchiness of burnt and unburnt areas surrounding rocky habitats. That is, fire management should prevent high intensity fires that may deplete all vegetation cover surrounding the entirety of rocky habitats, especially in isolated or relatively isolated rock outcrops. Such action would also ensure availability of relatively intact patches with higher prey availability, removing the potential of bottom-up control on northern quoll density that could potentially occur with limiting diet supplementation.

The Pilbara is a region of important economic value due to mining activities, and most of the mining impacts occur in rocky habitats (Cramer et al. 2016). This can be crucial for northern quolls. Considering that introduced predators restrict quoll distribution to rocky habitats, removal of rocky habitats due to anthropogenic impacts can push northern quolls in the Pilbara beyond the threshold of population resilience. Since the Pilbara is considered one of the remaining strongholds of northern quolls (How et al. 2009), anthropogenic impacts in the Pilbara may be relevant at the species conservation level. It seems imperative to restrict exploitation of resources in key areas so that disruption of northern quolls and their habitat is not widespread across the landscape until we know the thresholds of northern quolls to anthropogenic impacts. This is especially true since current efforts of the creation of artificial habitats have not been successful, suggesting that we do not know enough about quality variation within rocky habitat types to re-create adequate habitat for this species. An important area of future research will be to understand differences in habitat quality among rocky habitats, including those that have been subject to mining. This research should include the analysis of microhabitat characteristics of dens, and how quoll density might be associated with particular characteristics of dens. It would also be useful to determine the importance of native predators of quolls in this system. This would help us to understand quoll's perceptions of den acceptability and quality.

My study is one more addition to the substantial evidence that introduced predators are an important problem for native prey-sized species across the world (Doherty et al. 2016b). In Australia, there have been two waves of extinction and severe range decline in mammals since European settlement, the first in the 19th and early 20th centuries in non-tropical Australia and the second now in tropical Australia (Fisher et al. 2014). Although many factors might be in play, the direct role of foxes and feral cats in killing their preferred prey-sized mammal species becomes increasingly undeniable, especially in open habitats such as arid and recently burnt grasslands. The Pilbara has both foxes and cats, however foxes occur at lower densities and their distribution is more restricted. Feral cats are responsible for 26% of vertebrate extinctions in the world (Doherty et al. 2016a; Doherty et al. 2016b). Therefore, the management of introduced predators is in the interest of conservation plans for many species, including northern quolls.

There are two ways to manage introduced predators, considering that total exclusion is near impossible at the continental scale. One is through lethal control, the other is through restoration of ecological processes. Lethal control in Australia is complicated because of intrinsic differences among introduced predators and the likelihood of consuming wildly used poison-baits. Dingoes are successfully controlled using baits, while cats are more selective, less likely to eat carrion, and therefore less likely to consume baits (Claridge et al. 2010). Current widespread control efforts are selective against dingoes and have led to mesopredator release of cats (Glen et al. 2011; Moseby et al. 2012). This was also evident in my study area. However, it is important to note new delivery mechanisms and bait preparations are being tested, with promising results. For example, the use of Eradicat®, a bait prepared with kangaroo meat, chicken fat, flavour enhancers, and poison (Algar et al. 2013; Doherty and Algar 2015). Eradicat® currently being tested in the Pilbara (Morris et al. 2015; Morris et al. 2016). Regardless, existing broad methods of predator control may worsen the effect of cats.

Restoration of ecological processes can be through better fire management or through the restoration of trophic interactions. Cats prefer recently burnt areas, but not all fires attract them equally. In the Kimberley region of Western Australia, cats showed special preference for areas that have been subject to high intensity fires in productive habitats (McGregor et al. 2014). Therefore, one way to lower the success of cats is to prevent high intensity fires. Before European settlement, Aboriginal people used to manage fires with a timing that avoided high intensity fires and promoted mammal presence and diversity through a matrix of fire scars of different age (Bird et al. 2008; Burbidge et al. 1988). After the abandonment of traditional lands, fire practices were left to their natural occurrence which is 'infrequent but very extensive' (Burbidge et al. 1988). As a result, current fire practices promote presence and high success of feral cats. Therefore, reverting fire management practices to promote less intense fires would allow the landscape patchiness that favours native wildlife while reducing success of cats. Restoration of trophic interactions can be achieved through the restoration of dingo populations, which might help to control invasive predators without the adverse effects of mesopredator release. Control practices can remove dominant dingoes, disrupting the social system and pack cohesion (Doherty and Ritchie 2016). Removal of individual dingoes invariably leads to vacant territory that can then be filled by immigrants that are often replaced by the new generation, increasing survival of young and resulting in higher population sizes than before control practices took place (Doherty and Ritchie 2016). The removal of adult dingoes can also disrupt social systems because young may be unable to learn social etiquette of the species. An extreme case of social disruption in younger generations occurs with orphan male elephants which have even been labelled as 'delinquents' (Slotow and Van Dyk 2001). Parts of the Pilbara may be particularly suitable to explore the role of dingoes as top-predators in areas with stable social systems (Thomson, P.C., 1992b), because dingoes are not necessarily baited in non-pastoral regions such as mining areas.

I was unable to test associations between dingoes and quolls in the Pilbara. However, quolls might benefit from the presence of a top-predator that restricts abundance of cats. Although dingoes can have a severe negative impact on quoll survival (e.g. in Kakadu (Jonathan Webb, personal communication), we do not know if this is the case in the more arid and very sparsely populated Pilbara, where the natural social system of dingoes may be better preserved away from towns and pastoral lands. The benefit of dingoes suppressing cats might outweigh the direct impact of dingoes to quolls in the Pilbara (Cramer et al. 2016). Further research is needed to test this hypothesis before being implemented at the landscape scale.

Northern quoll live trapping and processing

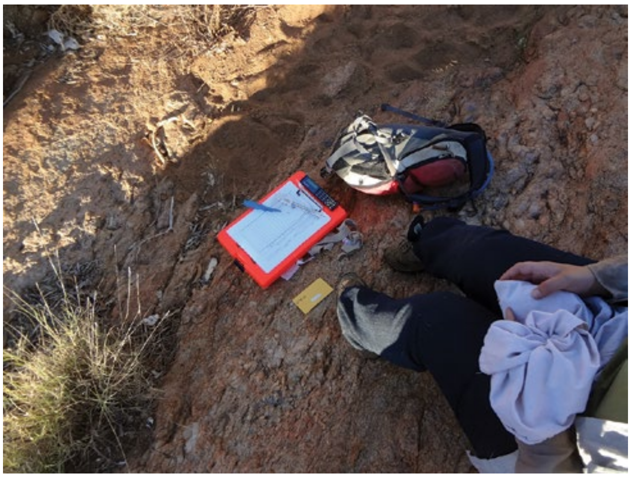
Monitoring is undertaken by live trapping using wire cage traps and a tempting bait. Once we have captured a northern quoll, we carefully place it in a hessian bag, before finding a comfortable spot to process it. For all captured quolls, this involves checking for or implanting a microchip under the skin to identify individuals, taking a small amount of tissue for genetic analysis, and taking their measurements (body weight, head length, age, sex). For females, we examine their reproductive condition and pouch state. We determine the age of both sexes by tooth wear, as their very sharp teeth dull down noticeably with age.

We select a few of the larger individuals for fitting with a GPS backpack. We only use the larger quolls for this, as the GPS has to weigh less than 5% of their body weight. Our work done, we then release the animals until we retrap them a week later to recover the GPS.

1. Find it

2. Put it in a bag

3. Sit down "comfortably"



4. Process it

5. Sex it (for females: define pouch state)


Pouch not visible


Nipples and pouch start preparing


Pouch starts to fold


Pouch folds


Pouch folds deeper


Babies are born and carried pouch


Babies are left in den

6. Define age using tooth wear

Very pointy: 1st year (recently weaned)

Pointy: 1st year quoll

Not pointy: 2nd year quoll

7. Fit a few lucky ones with a GPS backpack

The GPS has to weigh less than 5% of their body weight, so it is only used on big quolls

After one week we trap again to recover the GPS

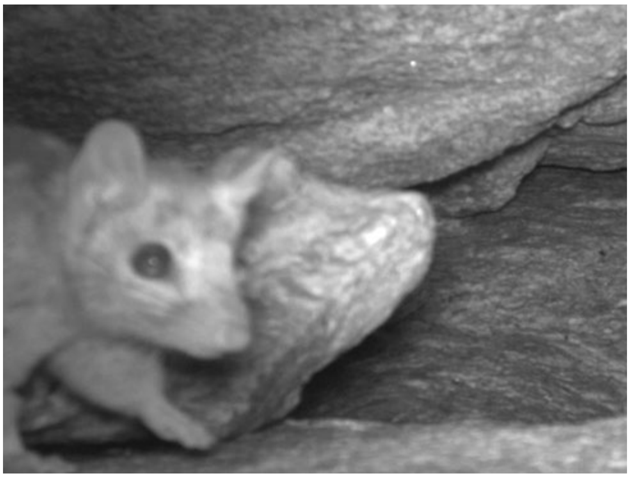
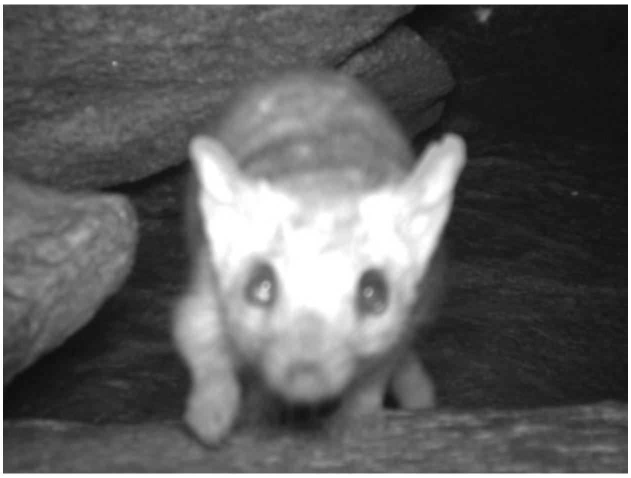
8. Let it go

Northern Quoll - fast facts

- The northern quoll (*Dasyurus hallucatus*) is a carnivorous marsupial, cousin to the Tasmanian devil and the extinct thylacine. It has an omnivorous diet, with opportunistic habits. It relies heavily on insects, but also consumes small mammals, reptiles, and even birds. And, when they are available, it will eat fruits.
- It has a short life span. Most males die soon after the first reproductive season, but second year females are common. Some female quolls can survive to three years old.
- It is the smallest of the quoll species found in mainland Australia, but the largest native mammalian predator in most of its range, including the Pilbara.
- It was once distributed in the third northern part of Australia, from Brisbane to the Pilbara, but is now restricted to a few populations, mainly in rocky areas. It has disappeared from most of its former range in savannas and grasslands.
- It has been nationally and internationally listed as endangered.
- Its main threat is the cane toad with its killer toxins. These secretions are so poisonous that they can kill a quoll, even if the quoll spits it out. Fortunately, there are not yet any cane toads in the Pilbara, making it a special place to find out about other threats.

Camera Trapping: northern quoll




Introduced predators observed

Cat

Dingo

Fox

Other native species observed

Kaluta

Mulgara

Kangaroo and Wallabies

Goannas

Birds

Rock rat

Echidna

Goldfields crevice skink

Dunnart

Hopping mouse

Cangrass dragon

Centralian blue tongue

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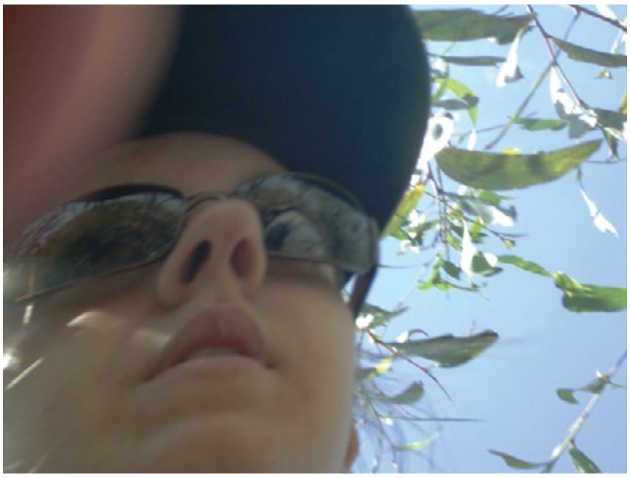
Renata

Cat

Cristina

Sharna

Penny



Nancy

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