Use of quarry infrastructure by the Pilbara northern quoll *Dasyurus hallucatus*

Final Report
May 2010 - June 2013
Prepared for BHP Billiton Iron Ore
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Summary

A study was undertaken to investigate the population dynamics of Pilbara northern quolls (*Dasyurus hallucatus*) and the effect of disturbance on the species. The study was completed at seven paired (disturbed and undisturbed) sites on BHPBIO tenement across the Pilbara. Techniques including trapping, radio-tracking, motion-sensing cameras and scat analysis were utilized to collect data from these sites.

Northern quolls were found to be foraging in disturbed habitats such as quarries with greater habitat complexity than surrounding regions, presumably due to higher density and/or diversity of food items. Northern quolls were found to utilise human infrastructure as well as disturbed and undisturbed granite sites. Radio tracking at Quarries 1 and 2 showed animals moving in and out of workshop areas, quarry habitat and undisturbed surrounding areas. Animals were observed to have crossed roads but no northern quolls were observed to have crossed the railway line during this study.

Radiotracking revealed that although northern quolls were using artificial ‘waterholes’ for foraging, many relied primarily on undisturbed habitat for den sites. Two males at Quarry 2 were visiting and presumably foraging in the disturbed area (as demonstrated by being trapped there), but denning exclusively in the undisturbed area. All 15 dens located at Quarry 2 were in granite outcrops in the undisturbed habitat.

Dietary analysis revealed an omnivorous diet, with invertebrates making up the majority of items consumed by northern quolls, followed by vertebrates and then plant material which represented one quarter of dietary matter analysed.

Male northern quolls were found to move large distances of up to 3 km in a 48-hour period. This movement should be taken into account when considering large-scale linear disturbances such as wide roads and railway lines that may operate as barriers to animals, particularly during breeding and dispersal seasons.

The breeding season for northern quolls at the study sites appears to be later and across a longer period of time than populations studied outside of the Pilbara. In this study, northern quolls bred across a period of at least ten weeks. Females showed pouch development as early as June and July, and pouch young were recorded in August and September. Future trapping efforts should be careful to avoid denning periods between October and February.

Male die-off following the breeding season appears to be incomplete at these Pilbara sites, with some males surviving to their second year. It is unknown whether males are able to contribute to the breeding pool in their second year. Females also showed increased survival (in comparison to other studies) with some animals surviving to their third year.

Based on this study, we recommend that future quarry developments and iron ore mining should aim to retain large boulder piles for northern quoll habitat. Creation of artificial habitat could be better informed through a dedicated radiotelemetry or GPS survey investigating home range, movement and fine-scale habitat use by northern quolls. Sites which would be suitable for such a study include Nimingarra, Cattle Gorge mine and Quarry 2. Quarry 2 would also provide ideal circumstances for further investigations into the impact of large-scale linear barriers on the movement of northern quolls.

1 Introduction

This report details work undertaken by the Department of Parks and Wildlife (Parks & Wildlife) at BHP Billiton Iron Ore (BHPBIO) Rail Quarries 1, 2, 3 and 4, Yarrie mine and nearby habitat in 2011-2013. The primary goal of the work was to ascertain interactions of northern quolls with disturbed and developed areas of the iron ore rail and mine areas, and how these compared to nearby undisturbed habitat.

1.1 Northern quoll

The northern quoll (*Dasyurus hallucatus*) is a medium-sized predatory marsupial, the smallest of Australia's four *Dasyurus* species (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 Act (EPBC,1999). This was due to an alarming decrease or complete collapse of some of the once locally abundant populations in Queensland and the Northern Territory, and a subsequent contraction of its range (Oakwood *et al.*, 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 northern quolls in their predation attempts. Although cane toads have not yet reached the Pilbara region of Western Australia, it is predicted that cane toads will invade this region between 2026–2064 (Kearney *et al.*, 2008; Elith *et al.*, 2010; Tingley *et al.*, 2013). Several other ecological factors are contributing to the decline of northern quolls and other medium sized mammal fauna, including predation by feral cats (*Felis catus*) and wild dogs (*Canis lupus*), altered fire regimes, grazing and subsequent habitat modification by introduced herbivores, habitat loss and fragmentation, as well as the interactive effects between these (Braithwaite and Griffiths, 1994).

Northern quolls inhabit a variety of areas, including rocky outcrops and ridges, rainforests, eucalypt forest and woodland, sandy lowlands, shrublands, grasslands, and desert (Oakwood, 2008; Department of Sustainability, 2011). In the Pilbara, northern quolls appear to depend primarily on complex rocky habitat, compared to northern quolls in the Northern Territory or Queensland, which rely more heavily on tree hollows and logs (Oakwood, 1997).

In Western Australia, northern quolls occur in the Kimberley and Pilbara region, however the two populations appear to be genetically disconnected and differ slightly in morphology and life history (How *et al.*, 2009). While the biology and ecology of the northern quoll has been studied in the Northern Territory (Begg, 1981; Braithwaite and Griffiths, 1994; Oakwood, 1997; Oakwood, 2000; Oakwood, 2002b) and to a lesser extent in the Kimberley (Cook, 2010; How *et al.*, 2009; Schmitt *et al.*, 1989), few studies have been undertaken on northern quolls in the Pilbara.

Pilbara northern quolls are recognised as specially protected fauna within the EPBC (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. This species is of particular relevance to iron ore mining due to its frequent occurrence in ironstone ridges and other rocky habitat throughout the Pilbara. Northern quolls are known to inhabit areas containing rocky hills, mesas, plateaux and granite boulder fields, which contain required denning habitat (Hill and Ward, 2010). The ridges and mesas of channel-iron deposits and banded iron formations 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 and rail beds.

Although they are primarily carnivorous, feeding on invertebrates and small vertebrates, northern quolls will also opportunistically eat eggs, fleshy fruit or scavenge on roadkill or waste (Oakwood, 2002a; Radford, 2012). Northern quolls are sexually dimorphic, with males tending to be larger than females (Oakwood, 2002b). This 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 6-8 young are born, grow in the pouch and are deposited in dens after eight to nine weeks (Oakwood, 2002a; Nelson and Gemmell, 2003).

The aim of this research is to improve our understanding of northern quoll ecology and demographics in Pilbara populations, in particular how these relate to industry development. This aspect of the project involved monitoring at operational and disused BHP Billiton Iron Ore (BHPBIO) mine and quarry sites over a three-year timeframe. The presence of northern quolls at BHPBIO Rail Quarries 1, 2, 3 and 4, and on BHPBIO tenure in the north-east Pilbara (Yarrie) was confirmed during previous surveys conducted by Ecologia (1999; 2005; 2008a: 2008b).

1.2 BHPBIO northern quoll studies

A trapping program for the purpose of monitoring populations at disturbed sites identified by BHPBIO commenced in Autumn 2011. Sites were trapped twice in 2011 and 2012, one final trapping session was completed by Winter 2013. This study provides information relevant to impacts identified in the Northern Quoll EPBC Act Policy Statement (Department of Sustainability, 2011). These impacts include: Loss of known or potential habitat critical to the survival of the species; Loss of known or potential foraging/dispersal habitat; Introduction of barriers restricting dispersal opportunities and genetic flow. This document reports on the results of the project, conducted from May 2011 to June 2013.
The specific objectives of these surveys were to:

- Identify northern quoll usage of operational and disused BHPBIO mine sites and granite quarry sites, and compare abundance and habitat use with nearby undisturbed areas.
- Examine population demographics such as morphology, sex ratios and breeding activity.
- Investigate potential use of VHF and GPS radio-telemetry and their application for examining northern quoll spatial use and den sites.
- Collect supplementary samples relevant to the regional program, e.g. ear tissue, scats

1.3 Previous surveys

Four granite quarry leases are located along the BHPBIO rail line, running south from Port Hedland, and were used as a source of rock during rail construction in the 1960s. Quarries 1–4 have not been active for approximately ten years, although broken rock and fines stockpiles have been accessed for rail maintenance and construction projects. Cleared areas on the quarry leases are also used for laydown areas. Rock piles in these disused quarries provide potential denning and foraging habitat for northern quolls.

Presence of northern quolls in Quarries 1 –3 were confirmed during fauna surveys in 2007 during baseline fauna surveys (Level 1) of the rail expansion project, and during a Northern Quoll targeted survey conducted in 2008–2010 (Ecologia Environment, 2008b; Ecologia Environment, 2010). Quarry 4 was also surveyed in 2008 with evidence of northern quolls observed but no northern quolls captured at this location (Ecologia Environment, 2008b). Northern quolls had also been detected at all identified Yarrie disturbed locations except for Shay Gap (Ecologia Environment, 2005a).

Table 1 details the prior captures at the study sites.

Table 1. Previous survey efforts at the study locations, and capture success of northern quolls on BHP tenure.

Date	Location	Trap nights	Captures	Individuals	Capture success (%)	Reference
June 1998	Yarrie	500	-	-	Present	(Ecologia Environment, 2005a)
Feb 2004	Cattle Gorge	700	-	-	Present	(Ecologia Environment, 2005a)
Nov 2004	Nimingarra	944	-	-	Present	(Ecologia Environment, 2005a)
Dec 2004	Sunrise Hill	680	-	-	Present	(Ecologia Environment, 2005a)
Dec 2004	Cattle Gorge haul road	420	0	0	0	(Ecologia Environment, 2005b)
May 2005	Cundaline	468	?	?	?	(Ecologia Environment, 2005a)
June 2005	Callawa	1152	?	?	?	(Ecologia Environment, 2005a)
May 2008	Quarry 1	24	4	4	16.7	(Ecologia Environment, 2008a)
July 2008	Quarry 4	10	0	0	0	(Ecologia Environment, 2008b)
Aug 2010	Quarry 1	105	11	4	10.5	(Ecologia Environment, 2010)
Aug 2010	Quarry 2	70	5	3	7.1	(Ecologia Environment, 2010)
Aug 2010	Quarry 3	85	3	2	3.5	(Ecologia Environment, 2010)
Oct 2012	Cattle Gorge	120	?	?	?	Biologic, 2013

2 Methods

2.1 Site selection

The project was undertaken at three BHPBIO mine sites and four quarries in the Pilbara (Figure 1; Table 2). Monitoring sites were determined according to northern quoll presence detected by past surveys (Ecologia Environment, 2005a; Ecologia Environment, 2008b; Ecologia Environment, 2010) and motion-sensing camera surveys by Parks & Wildlife in 2011.

Disturbed quarry and mine sites were paired with undisturbed control areas located in analogue habitat (Figure 1; Table 2). Control sites at distances greater than five kilometres apart were chosen to reduce the likelihood of northern quolls moving between sites and to retain site independence. Paired monitoring sites were established at Quarries 1, 2, 3 and 4, Shay Gap, and Cattle Gorge (ridge) during May-July 2011 and at Nimingarra in September 2011 (see Figure 1 and Table 2). Site photos and descriptions are presented in Table 2. Trapping surveys were conducted at each site twice annually in autumn (May-June) and spring (August-September) during 2011 and 2012, and once in autumn 2013. Numbers of individuals were estimated using the capture-mark-recapture method.

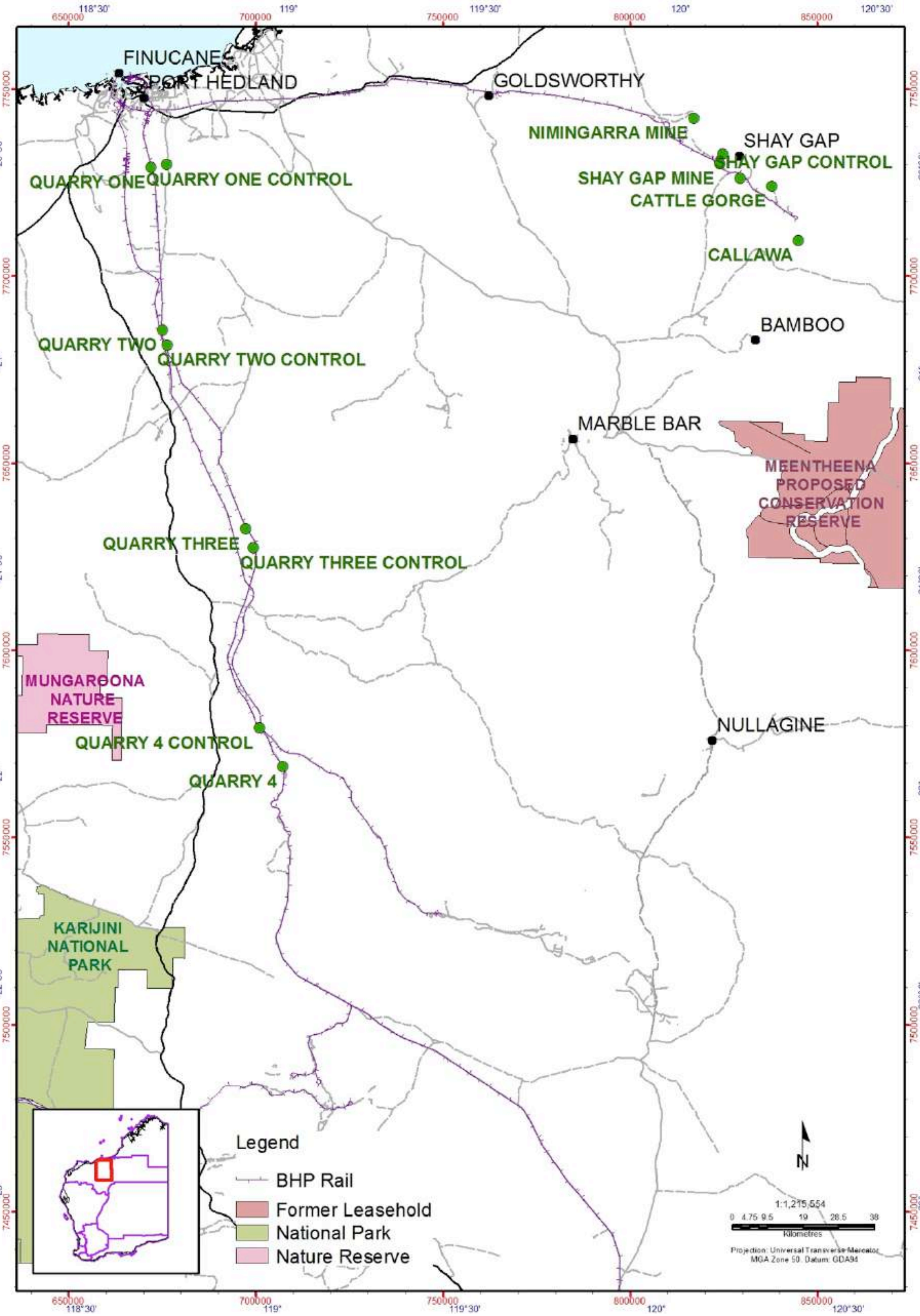

Figure 1. Regional locations of paired BHPBIO survey sites for Pilbara northern quolls. GPS locations for these sites are displayed in Table 2.

At the four quarries along the railway, the sites consisted of open-faced granite walls following removal of rock for railway construction (see site photos in Table 2). The undisturbed pairs for each of these sites were granite boulder islands in a relatively open landscape of spinifex. Cattle Gorge, Shay Gap and Nimingarra sites were located along a connected ironstone ridge in the north-east Pilbara. The disturbed areas at Nimingarra and Cattle Gorge consisted of mining pits, haul roads and associated laydown areas. Rehabilitation of landforms and vegetation was present at Nimingarra mine. The undisturbed sites (Nimingarra control and Callawa) were located along similar but undisturbed ridges and drainage gullies. All disturbed quarry and mine sites contained permanent or semi-permanent water, with seasonally varying levels.

Table 2. Paired survey locations used in this study, site descriptions, photos and their GPS coordinates

<table>
<tr><td>Site location, vegetation and geological description</td><td>Photo</td></tr>
<tr><td colspan="2">Quarry 1 (2011-2013)</td></tr>
<tr><td>Disturbed

-20.52939, 118.65090

Granite quarry with permanent water. Rocky areas consisting of flat cliffs, broken rocks, boulder piles, cracks and crevices. Surrounding vegetation sparse, including Triodia sp., Acacia sp. and Senna sp. Soils consisted of soft clay.</td><td></td></tr>
<tr><td>Undisturbed

-20.52185, 118.68990

Low, isolated granite outcrop. Minimal disturbance through grazing. Rocky areas consist of some rock piles, cracks and crevices with small ephemeral rock pools. Surrounding vegetation consisted of Triodia sp., Acacia sp. and Ficus sp. Substrate consisted of soft clay soils.</td><td></td></tr>
</table>

<table>
<tr><th colspan="2">Quarry 2 (2011-2013)</th></tr>
<tr><td>Disturbed

-20.92119, 118.68398

Granite quarry with permanent water. Rocky areas consisting of broken rocks, boulder piles, cracks and crevices. Surrounding vegetation sparse, including Triodia sp. and soft grasses, Acacia sp. and Senna sp with and over storey of scattered Terminalia sp. Substrate consisted of sandy soils.</td><td></td></tr>
<tr><td>Undisturbed

-20.95757, 118.69694

Large granite outcrop, consisting of one large boulder with cracks, crevices and ephemeral rock pools surrounded by large boulder piles. Outcrop surrounded by Triodia sp., Acacia sp. and Grevillea sp. Vegetation on the outcrop included soft grasses, Acacia sp. and Ficus sp. Substrate consisted of sandy soils.</td><td></td></tr>
</table>

<table>
<tr><th colspan="2">Quarry 3 (2011-2013)</th></tr>
<tr><td>Disturbed

-21.39923, 118.90434

Granite quarry with permanent water. Rocky areas consisting of broken rocks, boulder piles, cracks and crevices. Surrounding vegetation sparse, including Triodia sp., Acacia sp., Grevillea sp. and Senna sp. Substrate consisted of sandy soils.</td><td></td></tr>
<tr><td>Undisturbed

-21.44469, 118.92462

Large granite outcrop, connected to others in the landscape. Scattered large boulders both on and around the outcrop. Vegetation consisted of Triodia sp., Senna sp., Acacia sp. and Grevillea sp. Substrate of sandy soils.</td><td></td></tr>
</table>

Quarry 4 (2011 – discontinued)	
Disturbed **-21.97165, 119.00756** Granite quarry with permanent water. Rocky areas consisting of flat cliffs, with minimal cracks and crevices. Vegetation within the quarry was extremely sparse, surrounding vegetation included *Triodia sp.* with scattered *Acacia sp.* and *Grevillea sp.* Substrate consisted of sandy soils.	
Undisturbed **-21.87915, 118.94622** Large granite boulder with small disturbance (used for repeater tower). Minimal boulders, some cracks and crevices. Vegetation sparse, consisting of *Triodia sp*., *Acacia sp.* and *Grevillea sp*. Substrate consisting of sandy soils.	

<table>
<tr><th colspan="2">Shay Gap (2011 – discontinued)</th></tr>
<tr><td>Disturbed

-20.50048, 120.10631

Rehabilitated banded ironstone ridge. Slopes consisting of vegetated ‘moonscaping’ rehabilitation. Vegetation consisting of soft grasses, Triodia sp. and Acacia sp. Substrate consisting of rocky, hard red soils.</td><td></td></tr>
<tr><td>Undisturbed

-20.53443, 120.15976

Banded ironstone ridgeline with exposed faces and crevices at highest margins. Vegetation including Triodia sp., Acacia sp. and Ficus sp. Substrate of rocky, hard red soils.</td><td></td></tr>
</table>

<table>
<tr><td colspan="2">Cattle Gorge (2011 – discontinued) & Callawa (2011 – 2013)</td></tr>
<tr><td>Disturbed

-20.55177, 120.24064

Banded ironstone ridgeline in between roads and mining areas. Exposed rocky areas consisting of some crevices and large rocks. Vegetation consisted predominantly of Triodia sp. with some Acacia sp. and Grevillea sp. Substrate consisted of hard red soil.</td><td></td></tr>
<tr><td>Undisturbed

-20.68178, 120.31180

Banded ironstone ridgeline with exposed cliff faces and large rock piles. Vegetation predominantly Triodia sp. and Acacia sp. with Eucalyptus sp. in surrounding drainage lines. Substrate of sandy red soils in drainage lines and hard red soil elsewhere.</td><td></td></tr>
</table>

<table>
<tr><td colspan="2">Nimingarra (2011 – 2013)</td></tr>
<tr><td>Disturbed

-20.39104, 120.03845

Highly disturbed banded ironstone area intersected by roads and pits. Permanent water surrounded by some rubble piles but most exposed rock with little texture. Vegetation included Triodia sp., Acacia sp. and Ficus sp. Substrate was rocky in disturbed areas, surrounded by hard red soils.</td><td></td></tr>
<tr><td>Undisturbed

-20.47611, 120.11318

Banded ironstone ridge with exposed rock at the highest points consisting of some boulders and many crevices. Vegetation consisting of Triodia sp., Acacia sp., Eucalyptus sp. and Ficus sp. Substrate of hard red soils.</td><td></td></tr>
</table>

2.2 Site conditions

Climatic data were collated from the Port Hedland and Wittenoom weather stations in order to represent the quarry sites and Yarrie sites. The monthly averages of rainfall and temperature from 1951 to 2015 are shown in Figure 2. The project areas receive the most rainfall and highest temperatures in the months from December to March, temperatures and rainfall drop for the winter months with the lowest averages between April and October. Average rainfall and temperature during the study period (2011 to 2013) are also displayed in Figure 2. The average temperatures for the study period fell within the long-term mean, however an increased average rainfall (particularly in the northern sites) was experienced during the summer months of the study period.

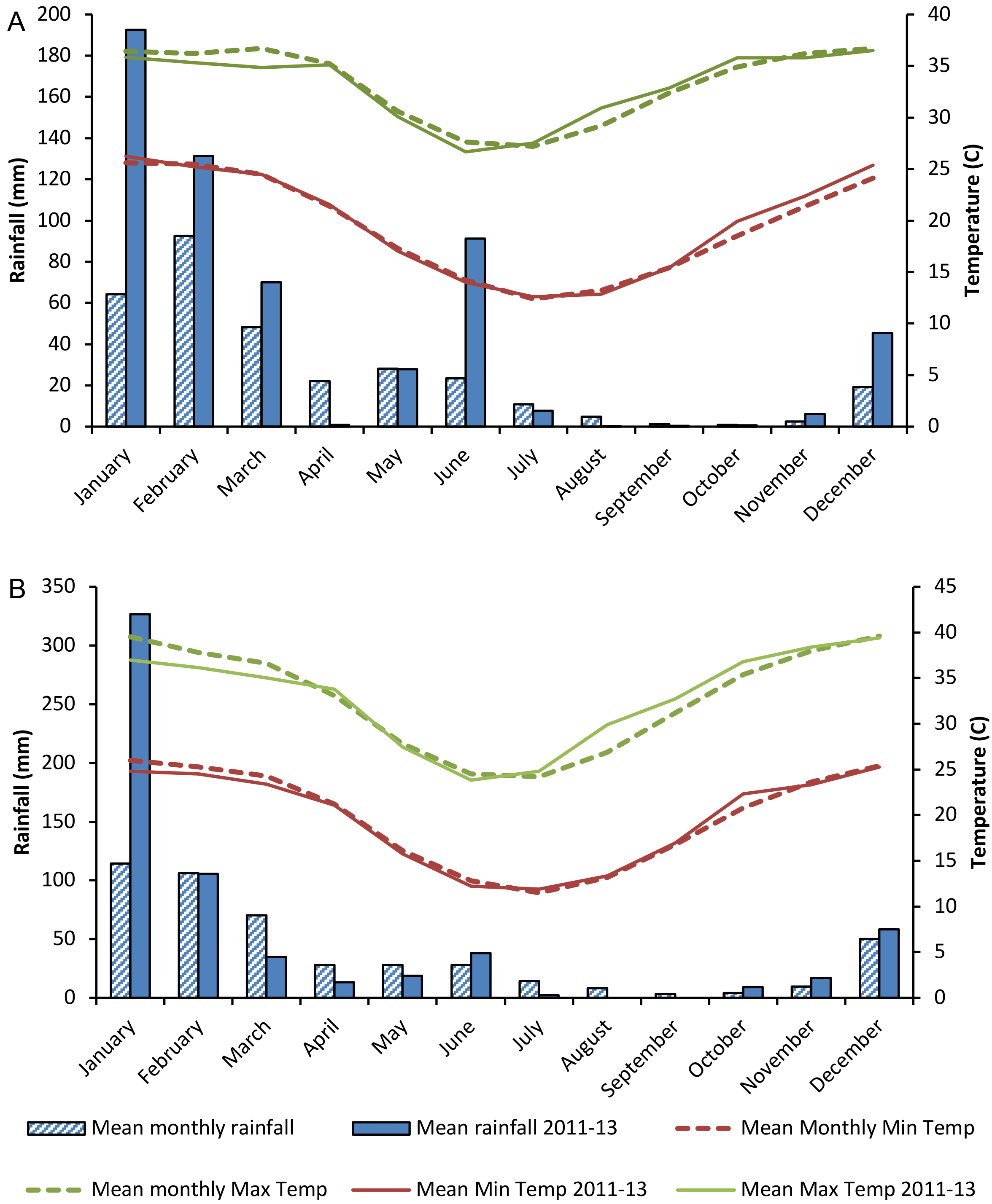

Figure 2. Climate data from Port Hedland (A) and Wittenoom (B) weather stations between 1951 and 2015 in broken colours, climate data for the same locations during the study period of 2011 to 2013 in solid colours.

2.3 Trapping

Trapping effort consisted of 30 small (17 x 17 x 46 cm) cage traps (Sheffield Wire Products, Welshpool, WA) set for four consecutive nights per session, i.e. 120 trap nights at each location, split evenly between the disturbed and control sites. Traps were baited in the late afternoon and cleared within three hours of sunrise as per Parks & Wildlife Animal Ethics guidelines (Freegard and Richter, 2009). Layout of these traps differed slightly between sites depending on terrain; at quarries, three transects of ten were used to cover all habitat types, and at mine sites, traps were placed in transects along slopes and bases of ridges. Traps were placed at 30–50 m spacing targeting shelter/refuge areas. Trapping effort and location for each site and maps of trapping transects are provided in Appendix A and B.

No northern quolls were captured at Quarry 4 during the previous trap survey in 2008 (Table 8), despite records from previous surveys (Ecologia Environment, 2008b). No records for northern quolls were collected in surveys at Shay Gap in 2010 (Onshore Environmental, 2010). After discussion with BHPBIO, it was agreed that further monitoring efforts should focus on the established sites with northern quoll presence. Surveys at Cattle Gorge were not continued due to issues with site accessibility in areas of mine activity. Instead, motion-sensing camera traps were opportunistically deployed at Cattle Gorge (control; -20.53693, 120.25583) in September 2011 and Cattle Gorge mine in June-July 2012 (-20.53257, 120.24904).

2.4 Radiotelemetry

During 2011, radiotelemetry studies were conducted to record diurnal denning locations and site characteristics. Telemetry studies were attempted at Quarries 1 and 2, and attempted at Quarry 3 using VHF collars and Yagi antennae; Sirtrack Limited, Havelock North, New Zealand. Dens were not recorded on the first day that collars were fitted as the animals shelter close to where they are released, which may not represent den sites within their usual range.

A further study was conducted in conjunction with Sonja Creese and Belinda Barnett (BHP Billiton Iron Ore) at Quarry 1 from 20 - 24 March 2012 to record habitat use and den sites (Creese, 2012). Radio collars were fitted to two adult females and one adult male. Night-time tracking was also conducted to investigate how northern quolls utilise the area and whether they cross the rail infrastructure into the adjacent spinifex plain to forage. A triangulation method was used, whereby signal direction is recorded from two or three stationary points and the animal's location calculated from the overlapping bearings. At the conclusion of each radio tracking session traps were set at den sites for one night to remove radio collars.

Home range estimates

Home range estimates were calculated using both radio tracking and trapping data. Estimates could be made for animals for which three or more locations had been collected and were calculated using 100% minimum convex polygon (MCP; Table 5). This estimation technique determines the area bounded by the outer location points and was used as it provides a more robust estimate than other techniques when the sample size (number of locations) is low (Harris *et al.*, 1990). The average home range for males was 68.21 hectares (SE 32.78), which was significantly larger (p=0.047) than that of females (0.77 hectares, SE 0.17;). To determine whether a home range has been accurately estimated, den sites were plotted against the cumulative area of the home range estimate. When the resulting curve increases by an average of less than one percent over four locations, it is accepted as having reached an asymptote and an accurate estimation of home range (Odum and Kuenzler 1955; Oakwood, 2002b). In this instance, home range estimates did not meet this criteria and should all be considered underestimates.

2.5 Motion-sensing Cameras

Motion-sensing cameras were further used to determine the presence of northern quolls when trapping surveys were deemed unsuitable. Active mining at Cattle Gorge prevented access to the area for trapping surveys; cameras were opportunistically deployed instead at the undisturbed Cattle Gorge in September 2011 (three cameras deployed over two nights 2/9/11-4/9/11) and in the disturbed, active mining area in June 2012 (eight cameras deployed over three nights 28/6/12-1/7/12).

Cameras were also used in substitution of traps at Quarry 3 Control in May 2013. This was due to repeated disturbance of Sheffield traps by Rothschild's rock-wallabies (*Petrogale rothschildi*) during 2012 trapping sessions. This disturbance significantly reduced trap effort and prevented other species such as northern quolls from entering traps.

2.6 Population Genetics

Ear tissue samples of approximately 2mm diameter were collected from ears of new individuals on their first capture. These were stored in 2 mL vials of 80% ethanol, labelled with their relevant data (individual animal identity, GPS coordinate and date). Genetic samples from the ten sites in this study plus an additional 22 sites throughout the Pilbara region were analysed by P. Spencer at Murdoch University using the laboratory methods described in Spencer *et al.* (2013). Pilbara northern quoll population genetic variation and diversity were compared to that of Kimberley, Northern Territory and Queensland populations.

2.7 Dietary analysis

Northern quoll scat searches were undertaken at the trapping sites on an opportunistic basis. Searches were undertaken with personnel spending several hours walking through likely habitat (breakaways, creek systems, mesas and ridges) examining rocky crevices and caves. Scats were collected and stored in a paper envelope with associated data (GPS location, date, species, collector). Once dry, scats are kept frozen until processed for dietary analysis via visual microscopy. Analysis was undertaken by G. Story, (Scats About, Majors Creek NSW), by examining hairs, insect carapace, scales and seeds, and approximating the volume represented by each component.

2.8 Data Analysis

Individual capture numbers were analysed using program R (© R Foundation for Statistical Computing, 2012). We used the variables Disturbance, Habitat, Site, Season and Sex for significance in a generalised linear model in order to detect statistically significant patterns in capture rates according to season, habitat and response to disturbance.

3 Results

3.1 Population demographics

Northern quolls were recorded during 37 of the 50 surveys conducted to date (including motion-sensing camera surveys). A total of 299 captures of 107 individuals were recorded during the 5351 trap nights across all sites (see Appendices). Non-target species captured during trapping included the common rock-rat *Zyzomys argurus*, house mouse *Mus musculus*, Rory's false antechinus *Pseudantechinus roryi*, Woolley's false antechinus *P. woolleyae*, Rothschild's rock-wallaby *Petrogale rothschildi* as well as one capture of the short-beaked echidna *Tachyglossus aculeatus* (see Table 9).

Sex ratio was relatively even with males making up an average of 56.25% of captures, females 43.75% (Figure 3. Overall, these ratios were not statistically significantly different ($\mathbf{X}^2_{11}$=2, p=0.1573) and did not differ between seasons ($F_{1,33}$ =0.473, P = 0.496).

There were no significant differences in number of individuals captured between spring and autumn surveys ($F_{1,33}$ = 1.113, P = 0.299, Figure 3). Mass measurements of Pilbara northern quolls during this study averaged 695.2 ± 18.08 g, (range 420 – 1100 g), n = 72 for males, and 410.9 ± 11.33 g, (range 260 – 630 g), n = 56 for females. See Table 10 for raw capture data.

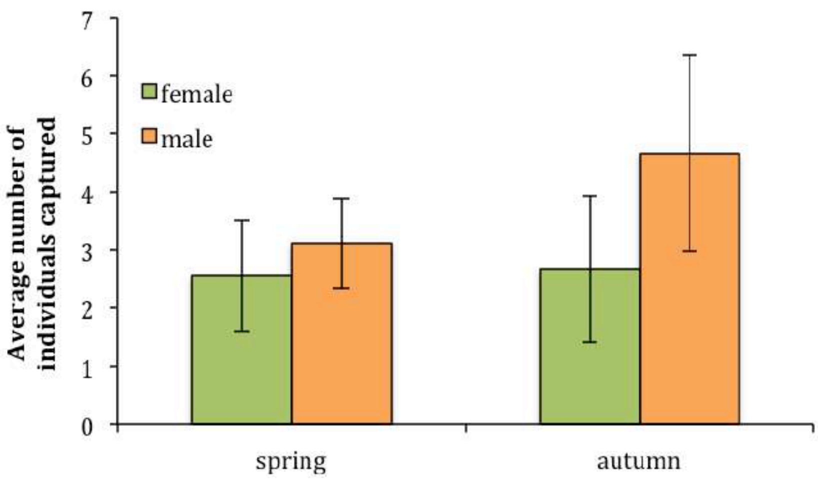

Figure 3. Average number of individual northern quolls captured per trapping session, according to sex ratio and season of trapping.

3.2 Breeding and survivorship

Evidence of breeding activity (females showing pouch development and males in poor body condition) was recorded at all sites during June through to September (see Table 3). Presence of pouch young was recorded in August 2011 and August 2012 at Quarry 1 disturbed and in September 2012 at Nimingarra mine. Females were not captured at the corresponding control sites to compare breeding status with.

Females at quarries were generally seen to persist at sites for two years, with one individual captured into her 3rd year at Quarry 2 disturbed site. No males were recaptured over the autumn period, but some new males caught appeared to have survived the spring breeding season showing new hair growth over wound areas and worn teeth (indicative of aging).

Table 3. Recorded times of breeding activity for female Pilbara northern quolls from this study (green), and the Northern Territory (orange). Northern Territory data sourced from Begg (1981; 1997).

	Apr	May	Jun	Jul	Aug	Sep
No development		■	■			
Pouch developed			■	■	■	■
Pouch young present					■	■
Teats regressed	■	■				
No development	■	■				
Pouch developed			■			
Pouch young present				■	■	
Teats regressed	■	■				■

3.3 Response to disturbance

There was a significant effect of site ($F_{3,28}$ = 17.7, P < 0.001) on number of individuals captured, indicating that sites had differing northern quoll populations. Significantly more northern quolls were captured in iron ore habitat (Callawa and Nimingarra) compared to granite outcrops (Quarries 1, 2 and 3; $F_{1,28}$ = 12.3, P = 0.002; Figure 4). Callawa had significantly higher captures to all other locations except Quarry 2 (cf Nimingarra: P < 0.001, Q1: P = 0.001, Q2: P = 0.067, Q3: P < 0.001, Tukey post-hoc comparisons), but as it had no paired disturbed site for comparison, we removed it from further analyses. This removal of Callawa still revealed significant effects of site ($F_{2,25}$ =17.12, P < 0.001). We also found there to be a significantly higher number of individuals captured in all three disturbed quarries compared to their undisturbed controls ($F_{1,25}$ = 36.45, P < 0.001) and a similar result was found for the paired Yarrie sitessee Figures 5and 6. Quarry 2 had significantly higher captures than Nimingarra (P = 0.002) and Quarry 3 (P = 0.022), but all other comparisons were non significant.

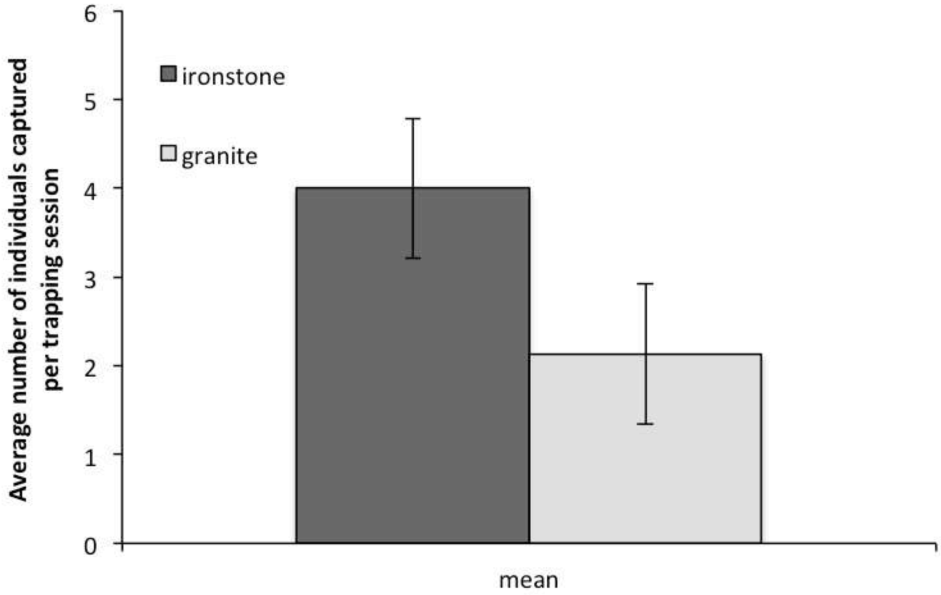

Figure 4. Comparison of average numbers of individual northern quolls captured on ironstone (Nimingarra, Callawa) and granite (Quarries) habitats.

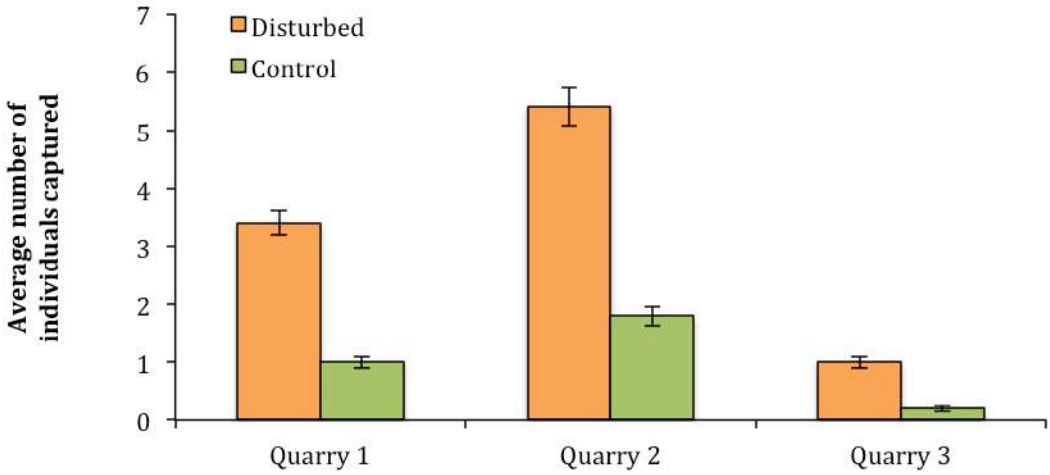

Figure 5. Average number of individual northern quolls captured per trapping session at disturbed and control sites during five trapping sessions on granite habitat in spring and autumn, 2011-2013.

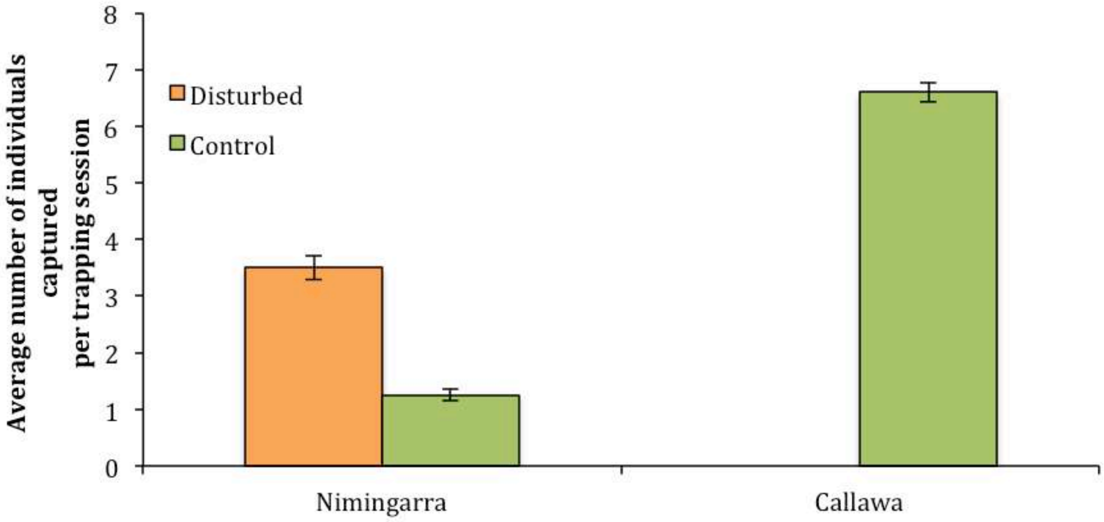

Figure 6. Average number of individual northern quolls captured at disturbed and control sites in iron ore habitat during five trapping sessions in iron ore habitat at Callawa, and four at Nimingarra in spring and autumn, 2011 -2013.

3.4 Radiotelemetry

Radio tracking was conducted using very high frequency (VHF) technology, which is labour intensive and not feasible in collaboration with trapping programs without additional staff. As VHF is really only suited to diurnal studies a move to GPS technology in 2012 was considered in order to allow for an increased capacity to gain information on the northern quolls' movements at night, and also reduce the time and labour involved in VHF tracking. GPS collars provide several advantages over VHF, including; better spatial accuracy than VHF radio tracking and allow data to be collected from more animals at the same time. GPS collars at a size and weight suitable for northern quolls (i.e. less than 30g and minimal bulk) have only recently become commercially available.

Two Telemetry solutions GPS collars were trialled in captivity on two chuditch (*Dasyurus geoffroii*). The collars were a total of 30g, requiring animals to be a minimum of 600g (ethically accepted weight of collars is 3-5 % of an animals body weight). Both chuditch were large animals (over one kilogram in weight), however the collar package was still bulky and inappropriate for use on these animals. Furthermore, the collar material caused damage to the animals skin and within one week of deployment animals had done considerable damage to major components of the collars – including the ports used to download GPS information. The outcome for this trial was that these collars were inappropriate for use on chuditch and ruled out as an option for use on the much smaller northern quoll.

Two females at Quarry 1 carried radio collars for 27 days from May to June. Northern quolls were radio tracked to their dens daily for ten of 27 days. At Quarry 2, two adult males and two adult females were fitted with radio collars between 25 - 28

July 2011, during the autumn survey. Individuals were radio tracked to their dens daily, from the 9-16 August. In addition, one male and one female were fitted with collars between 20 – 24 March 2012. One female at Quarry 1 control and one female at Quarry 3 were also fitted with collars but these were subsequently removed from individuals as no other individuals were captured that could be collared due to size constraints.

Quarry 1, 2011

Over the ten nights of tracking in May 2011 at Quarry 1, the two collared females denned in three distinct areas Figure 7. Two areas were inaccessible within broken boulder piles against the blasted quarry wall, and one was located beneath a rock sheet with minimal disturbance at the top of the granite outcrop (Table 4). Multiple dens were recorded beneath the minimally disturbed rock sheet, as is possible in the inaccessible broken boulder areas (Appendix C). The same dens, or dens amongst the same rock pile within very close proximity, were used by both individuals on alternating days, which may not be unusual between maternal relations. Man-made dens included a concrete sleeper pile and a rock pile within a work yard.

Table 4. Locations and origins of den sites used by northern quolls radio tracked at Quarries 1 and 2. Den origins were classified as Natural: a den in its original form, Disturbance: dens created by human disturbance, and Man-made: a den within human infrastructure.

Animal ID	Den number	Latitude	Longitude	Date located	Origin of den
QUARRY 1 (Quarry)					
1	1	-20.52041	118.6494	21.03.2012	Disturbance
1	2	-20.52061	118.6492	23.03.2012	Natural
2	1	-20.52022	118.6499	21.03.2012	Disturbance
2	2	-20.52398	118.6464	23.03.2012	Man-made
3	1	-20.52029	118.6499	21.03.2012	Disturbance
3	2	-20.52362	118.6466	23.03.2012	Man-made
4	1	-20.52060	118.6492	17.05.2011	Disturbance
4	2	-20.52054	118.6492	18.05.2011	Natural
5	1	-20.52054	118.6492	17.05.2011	Natural
5	2	-20.52060	118.6492	01.06.2011	Disturbance
QUARRY 2 (Quarry)					
1	1	-20.9143	118.6928	09.08.2011	Natural
1	2	-20.9134	118.6959	10.08.2011	Natural
1	3	-20.9133	118.6864	11.08.2011	Natural
1	4	-20.9108	118.6867	12.08.2011	Natural
1	5	-20.9188	118.6849	14.08.2011	Natural
1	6	-20.9108	118.6896	15.08.2011	Natural
1	7	-20.9214	118.6983	16.08.2011	Natural
10	1	-20.9124	118.6926	09.08.2011	Natural
10	2	-20.9143	118.6928	10.08.2011	Natural
10	3	-20.9134	118.6923	11.08.2011	Natural
10	4	-20.9133	118.6864	12.08.2011	Natural
10	5	-20.9134	118.6865	13.08.2011	Natural
10	6	-20.9107	118.6863	14.08.2011	Natural
10	7	-20.9107	118.6863	15.08.2011	Natural
10	8	-20.9221	118.6982	16.08.2011	Natural
7	Collar dropped	-20.9103	118.6861	10.08.2011	-
9	Collar dropped	-20.92	118.6852	09.08.2011	-

Figure 7. Refuge sites (located via radio tracking) and capture points (from cage trapping) at Quarry 1 in 2011 and 2012.

Quarry 1, 2012

Additional radio tracking was undertaken in collaboration with Sonja Creese, (BHPBIO) in March 2012. The three northern quolls radio tracked at Quarry 1 carried radio collars for four days. They were trapped on the forth night and collars were removed the following morning. Because of bad weather, radio collared animals were only radio tracked to dens on days two and four. Two separate dens were recorded for each individual. The male was recorded denning in the quarry and in a windrow of small boulders adjacent to Mooka workshop, approximately 400 m from the quarry. A female was tracked to a stockpile of concrete sleepers, also adjacent to the Mooka workshop area (Figure 7; Table 4). All other dens were recorded in the quarry and were very close to those recorded in May 2011 within boulder piles against the blasted quarry wall and beneath a rock sheet at the top of quarry (Figure 7). Because of the unstable substrate within the quarry and the sheer wall the exact location of the quarry dens could not be accessed.

No accurate locations could be calculated from the night tracking data. However, based on observation of signals at the time of recording none of the three collared individuals crossed the rail infrastructure during the time of the survey (Figure 8). Signals indicated that two of the northern quolls moved towards or into the workshop/construction area west of the quarry, which is confirmed by the den sites located there.

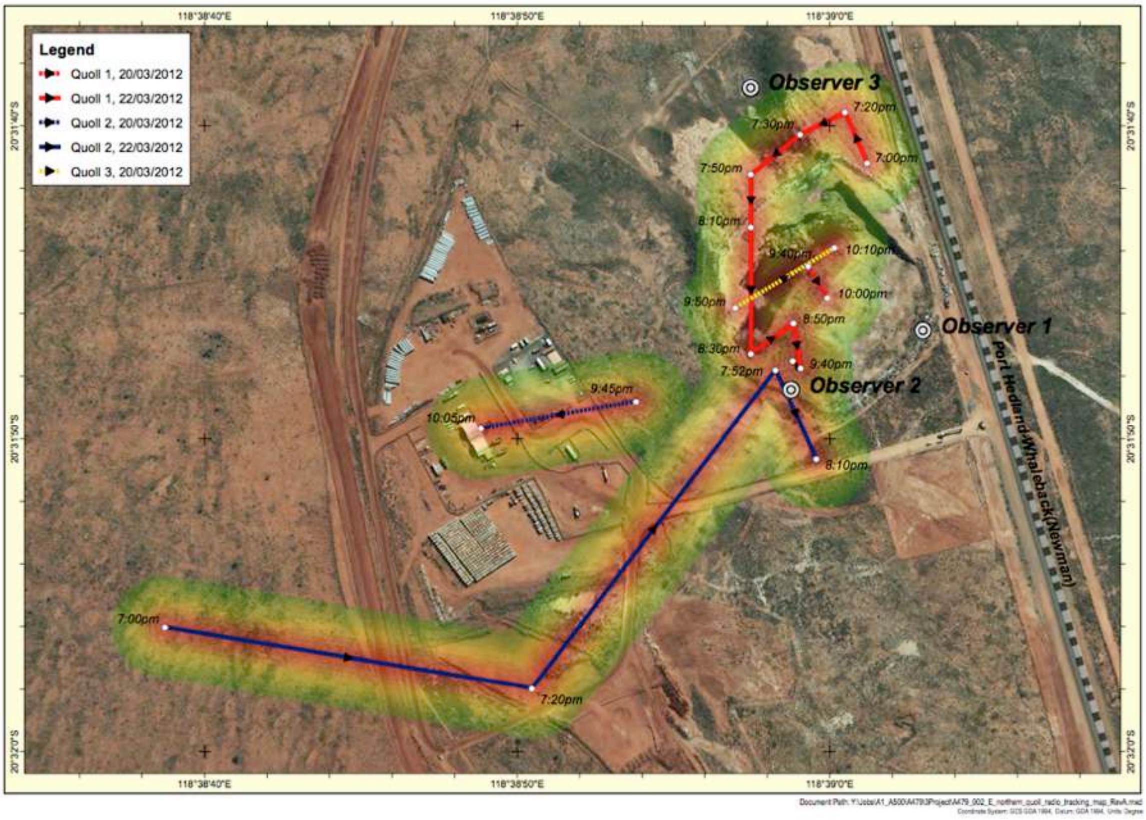

Figure 8. Night radio tracking of three northern quolls at Quarry 1, over four days in March 2012.

Quarry 2, 2011
Of the four northern quolls collared at Quarry 2, the two females shed their collars before any dens could be recorded. One collar was retrieved from under a small boulder pile at the top of the quarry close to the quarry wall. The second could not be retrieved due to its location deep within a boulder pile on a granite outcrop located 1 km north of the quarry.

The two remaining males were tracked to their dens daily between 9 – 16 August. Seven den locations were recorded for one male and six for the other. One location was used by both individuals. All dens were located in granite outcrops in undisturbed granite outcrops (Figure 9; Table 4), up to 1.5 km from the quarry site with up to 1.5 km distance between consecutive dens. No dens were recorded within the quarry itself.

Table 5. Average distance moved by quolls between consecutive daily locations and minimum convex polygon (MCP) home range estimates for animals radio collared at Quarries 1 and 2

Site	Year	Animal ID	Sex	Average distance moved (m)	Number of consecutive points	MCP Home range estimate (ha)	Number of points
Quarry 1	2011	699695	Female	96.14	9	0.4948	9
Quarry 1	2011	699090	Female	113	5	0.5187	12
Quarry 1	2012	723636	Male	110.33	4	2.88	8
Quarry 1	2012	699090	Female	88	2	0.85	4
Quarry 2	2011	698747	Male	535.1	15	105.77	16
Quarry 2	2011	698700	Male	346.3	17	95.99	17
Quarry 2	2011	698887	Female	83.1	8	1.24	9

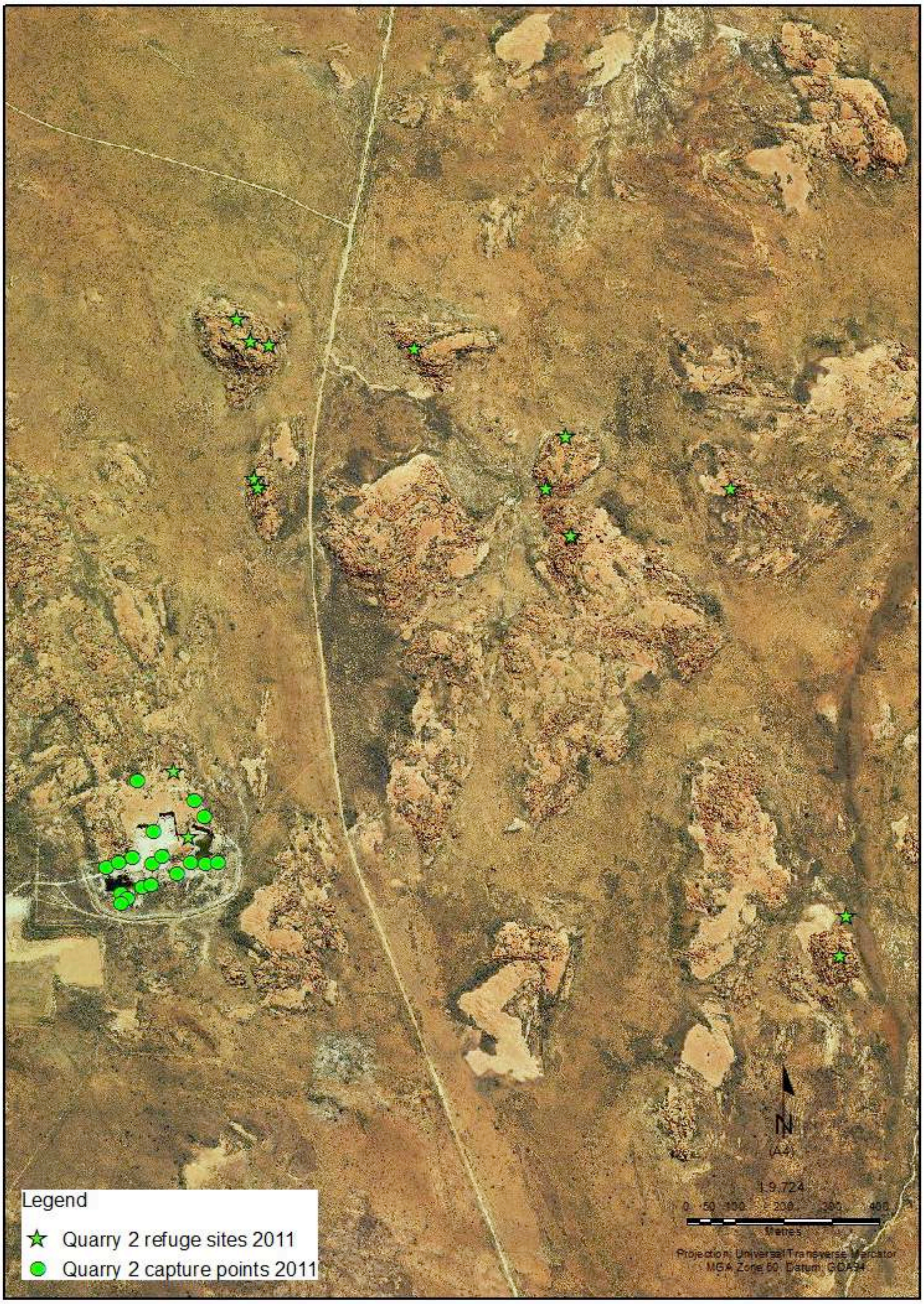

Figure 9. Refuge sites (located via radio tracking) and capture points (from cage trapping) at Quarry 2 in 2011.

3.5 Motion-sensing cameras

Northern quolls and common rock rats (*Z. argurus*) were detected at Cattle Gorge on all four motion-sensing cameras set in September 2011 and on four of eight cameras set in June 2012 (Table 6). Three individual northern quolls were identified. Other species recorded to be present by remote camera survey included common rock rats (on 75% of cameras), Rothschild's rock-wallabies (*P. rothschildi*: on 50% of cameras), *Pseudantechinus* sp. (likely *P. roryi* or *P. woolleyae*; 25% of cameras) and a *Macropus* sp. (likely *M. robustus* or *M. rufus*; on 25% of cameras) was recorded. Non-target species records are presented in Appendix A (Table 9).

During the autumn 2013 survey at Quarry 3 Control, 29 motion-sensor cameras were deployed in substitution for Sheffield traps. No northern quolls were detected using these cameras. Rothschild's rock-wallabies (*P. rothschildi*) were captured on all of the 29 cameras, common rock rats (*Z. argurus*) were captured on 21/29 cameras and unidentified *Pseudantechinus* species were captured on 15/29 cameras.

Table 6. Motion-sensor camera locations and detection records of northern quolls at Cattle Gorge.

Code	**Latitude**	**Longitude**	**Northern quolls detected**	**Date of detection**
CGG01	-20.54669	120.25448	*	03/09/2011
CGG02	-20.54544	120.25550	*	03/09/2011
CGG03	-20.54472	120.25690	*	04/09/2011
CGG04	-20.54409	120.25622	*	04/09/2011
CGM5	-20.54078	120.24890	*	28/06/2012
CGM6	-20.54105	120.24967	*	30/06/2012
CGM7	-20.54131	120.25022		
CGM8	-20.54188	120.25065	*	30/06/2012
CGM9	-20.54086	120.24763		
CGM10	-20.54089	120.24695		
CGM11	-20.54241	120.24765		
CGM12	-20.54449	120.24557	*	01/7/2012

3.6 Population Genetics

DNA profiles were examined at 11 nuclear genes (microsatellite) from 253 individuals. These samples came from 32 sites, including the ten sites in this study listed in Table 7. DNA samples taken from each site, contributing to the regional analysis of northern quoll population genetics.. All northern quoll samples from the Pilbara clustered in a 'Pilbara' population (10). From the entire sample, 99.7 percent of individuals clustered with their source population. The Pilbara appears to form a single, genetically homogenous population cluster.

In general, there were only small differences in the diversity amongst sampled sites from the Pilbara. Genetic diversity, as measured by heterozygosity did not vary to any degree, with most sampling sites displaying about 70% heterozygosity. The fixation index (*F*) suggests that northern quolls at any one of the sampling sites showed random mating (i.e. F~0, and +1 highly inbreed). The exception was the reduced diversity found on Dolphin Island, which is expected for insular island samples.

Table 7. DNA samples taken from each site, contributing to the regional analysis of northern quoll population genetics.

Sampling location	Latitude	Longitude	Number of DNA samples
Quarry 1	-20.5283	118.6497	6
Control 1	-20.5209	118.6891	4
Quarry 2	-20.9201	118.6859	17
Control 2	-20.9574	118.6961	5
Quarry 3	-21.3969	118.905	1
Nimingarra Mine	-20.394	120.0365	8
Nimingarra control	-20.4739	120.1156	2
Shay Gap	-20.5333	120.1594	2
Cattle Gorge	-20.5497	120.2408	2
Callawa	-20.6814	120.3074	19
Total			***66***

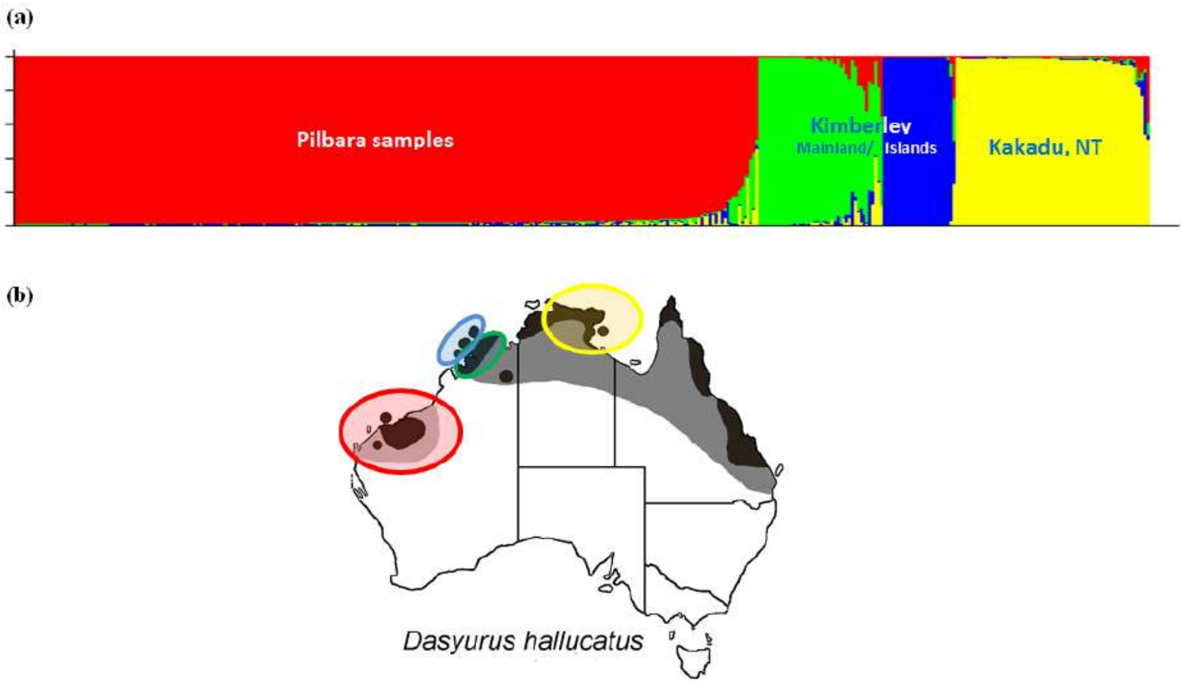

Figure 10. Bayesian population structure analysis of the northern quolls, Dasyurus hallucatus, to populations, based on 11 nuclear microsatellite loci (a) assuming a population number of K = 4. Individuals are along the x-axis. The y-axis denotes the

cumulative posterior probability of an individual's placement in particular population(s). The analysis uncovered (b) four distinct populations (the population sample from Pilbara are in red; the Kimberley mainland in green and adjacent islands in blue and yellow indicating the samples from Kakadu.

3.7 Dietary analysis

A total of 96 scats were collected and analysed for content. Contents were grouped into 11 categories (rodent, marsupial, bat, bird, reptile, amphibian, arthropod, mollusc, vegetation, carrion and grooming hairs) and measured for both percentage frequency and average percentage of occurrence. Results for all 11 categories are displayed in Figure 11.

Of the 96 samples, 65.6% contained more than one food type. Animal matter was identified in 91.7% of scats as compared to plant material, which occurred in 36.45% of scats. These results indicate a generalist predator with an omnivorous diet, consistent with previous studies (Oakwood, 1997).

Invertebrate matter appeared to be one of the most important dietary components being present in 82.3% of scats and on average making up 38.5% of material occurring in scat samples. Plant material also contributed to a large proportion of scat matter, making up 25.4%. Of this amount, just over half (54.3%) was seeds from fig tree fruits (*Ficus sp.*). Other remains in scats identified to species level included *Zyzomys argurus* (present in 15.6% of scats), *Pseudomys hermannsburgensis, Ningaui timealeyi, Dasykaluta rosamondae, Macropus robustus* (presumably as carrion), *Rhinonicteris sp.* and *Eucalyptus sp*.

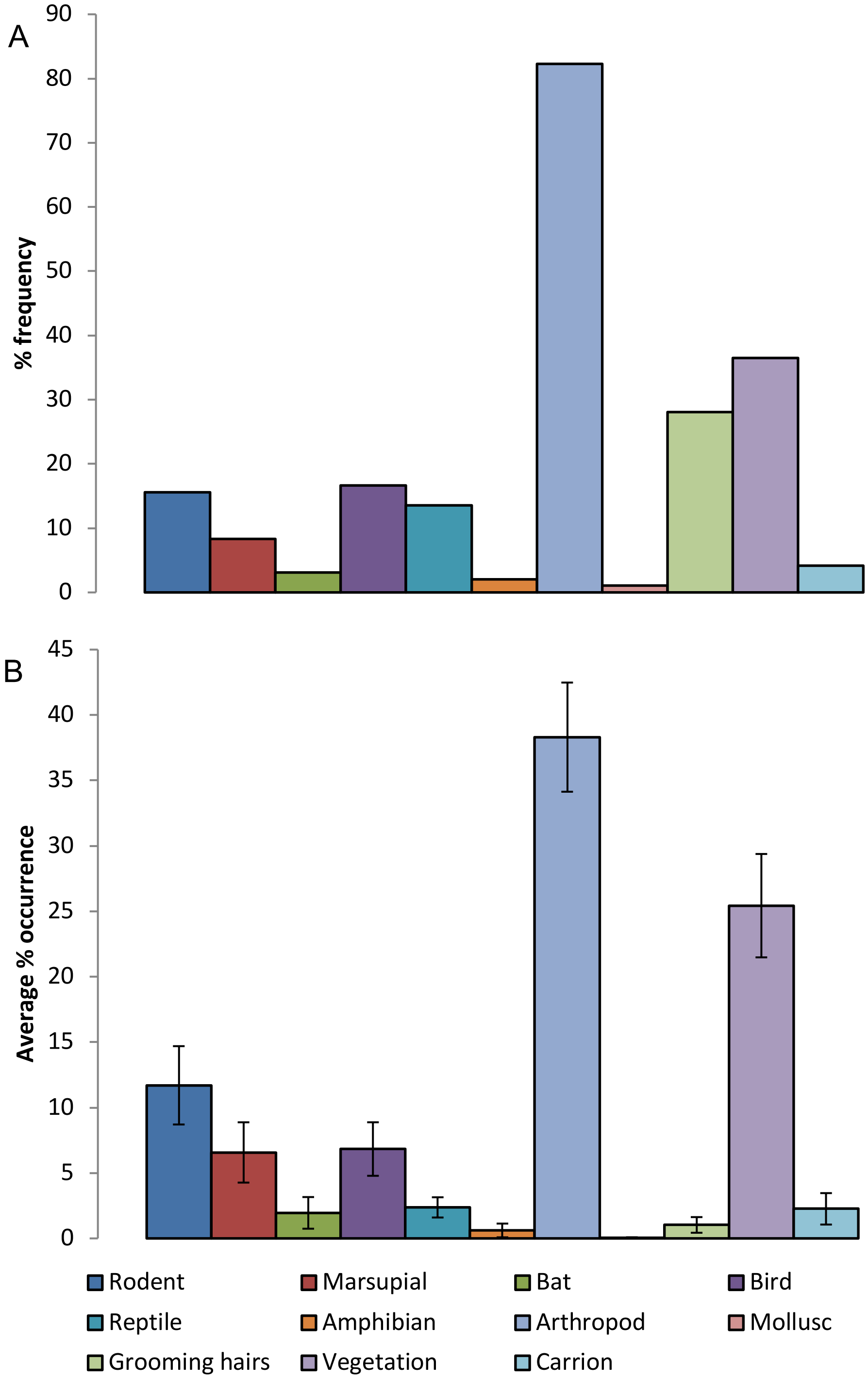

Figure 11. Percentage frequency (A) and average percentage occurrence (B) of 11 food types identified in 96 northern quoll scats

4 Discussion

4.1 Population demographics

Northern quolls were abundant at the majority of these sites, with 299 captures of 107 individuals in 5351 trap nights over three years. New individuals entered the population each year, as well as some individuals being re-trapped between sessions. This information indicates that there are established, breeding populations at these sites. Significantly more northern quolls were captured at the Quarry 2 site than the other quarries. This is probably due to its larger size, habitat complexity and close proximity of other suitable boulder habitat (Table 2). It is important to note that Quarry 4 was not used in this study due to an apparent absence of northern quolls. It is likely that the sheer rock face and absence of loose boulders at this disturbed site does not provide suitable habitat for northern quoll denning or foraging (Table 2).

Capture numbers were statistically equivalent between seasons. Population demographics of northern quolls differ slightly according to season; in autumn the population consists of adults and recently dispersed new individuals, while spring captures are made up of resident females and transient males in search of females. No significant sex bias was detected during trapping of these sites, indicating that trapping occurred before any male die-off had taken place.

Adult body mass measures from these Pilbara sites were similar to those recorded for Kimberley and Northern Territory populations (Figure 12. Average adult body mass for male and female northern quolls in their different areas of distribution. Error bars indicate minimum and maximum values recorded for the populations. Kimberley data sourced from Cook (2010), Northern Territory data sourced from Oakwood (1997).). Kimberley northern quolls were studied by Cook (2010), who reported the mean weight of 537 g (330-718 g; n = 15) for males and 370 g (range 290-458 g; n = 13) for females. Oakwood (1997) reported Northern Territory populations of northern quolls were similar in size to those in the Pilbara, with a mean weight of males being 761 g (ranged 540-1120 g; n = 26) and 448 g for females (range 350-690 g; n = 11).

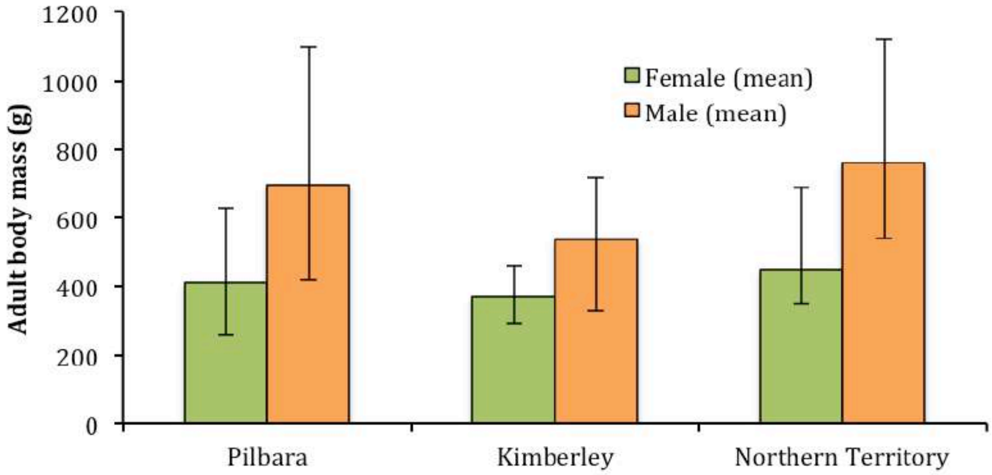

Figure 12. Average adult body mass for male and female northern quolls in their different areas of distribution. Error bars indicate minimum and maximum values recorded for the populations. Kimberley data sourced from Cook (2010)*, Northern Territory data sourced from* Oakwood (1997).

4.2 Response to disturbance

Northern quolls were found to utilise human infrastructure as well as disturbed and undisturbed granite sites. Radio tracking at Quarries 1 and 2 showed animals moving in and out of workshop areas, quarry habitat and undisturbed surrounding areas. Animals were observed to have crossed roads but no northern quolls were observed to have crossed the railway line during this study.

There were significantly higher capture rates in disturbed areas than in undisturbed control areas. The most likely explanation for this is the presence of permanent water that has collected in excavated quarry areas as a result of the disturbance. These pools, inadvertently created during excavation and not present at control sites, paired with complex rock piles made up of large (>2 m) and medium (>0.5 m) boulders have a diversity of microhabitats. This diversity supports higher productivity and thus greater prey density and/or diversity compared to adjacent undisturbed habitat (Burnett, 1997). These areas create suitable habitat for foraging prey species such as reptiles, small birds and rodents, and food resources such as native fig trees.

It appears that northern quolls are using these artificial ‘waterholes’ for foraging, but still relying on intact habitat for den sites. Two males at Quarry 2 were visiting and presumably foraging in the disturbed area (as demonstrated by being trapped there), but denning exclusively in the undisturbed area. All 15 dens located at Quarry 2 were in granite outcrops in the undisturbed habitat (Appendix C; Figure 9). Further quarry developments undertaken in northern quoll habitat should aim to replicate the habitat created at Quarry 2, with large rock retained and boulder piles of various sizes formed (Table 2). It is important to note that the bare rock faces at Quarry 4, where few boulders have been retained (Table 2), did not appear to support any northern quolls.

4.3 Site and habitat usage

Northern quoll populations at each location were dependent on the substrate as well as the site. Significantly more individuals were captured on iron ore ridgelines than granite quarries when the Callawa site was included in analysis. When Callawa was removed, this effect was not significant. There was also a significant site effect, demonstrating that northern quoll populations are highly dependent on suitable habitat at that location. The quarry and quarry control sites were not all equal in the northern quoll populations supported, with the Quarry 1 and 2 disturbed sites supporting the highest numbers of northern quolls in granite habitat.
These site effects are probably a product of connectivity of large amounts of suitable habitat on the 80km long rocky ridgeline incorporating Callawa and Nimingarra, where a more dense population of animals are present throughout. This is in comparison to isolated granite outcrops separated by less favourable sandy habitat at the quarry sites. Occurrence of northern quolls has been shown to be directly related to topographic complexity or ruggedness (Woinarski *et al.*, 2007) where diverse and dispersed rocky areas are thought to support denser populations of northern quolls (Hill and Ward, 2010). Rocky habitats such as iron ore ridges tend not to be used for livestock production and may be less impacted by fire. Northern quoll densities may be enhanced in complex rocky terrain where cats are less able to forage effectively (Hill and Ward, 2010).

4.4 Breeding and survivorship

Previous breeding data for northern quolls collected from populations across northern Australia have shown synchronised breeding. At any given locality, females are expected to give birth over a discrete three to four week period in May/June (Nelson and Gemmell, 2003; Oakwood, 1997). However, northern quolls in the Pilbara appear to breed later in the year and over a more extended period (Table 3). The Pilbara populations examined in this study breed across a period of at least ten weeks, between June and September. Animals showed signs of mating (bites and scarring on females, and males in poor body condition) throughout this time. Females showed pouch development as early as June and July, and pouch young were recorded in August and September.

Male northern quolls from the Kimberley to Queensland experience a severe post-mating die-off and at some sites a total die-off of males has been recorded (Dickman and Braithwaite, 1992; Oakwood, 1997). Consequently, males generally do not live to be older than one year. In the Northern Territory, this die-off occurs in Sep-Oct, when few to no males are captured. It appears that male die-off is incomplete in these Pilbara populations. Despite no males being recaptured over the autumn period, some males captured the following season were classified as second year animals having survived the breeding season based on new hair growth and worn teeth. Females at quarries were generally seen to persist at sites for two years, with one individual captured into her third year at the Quarry 2 disturbed site.

4.5 Home range and movement

Northern quolls were observed to den in a variety of locations, with consecutive dens up to 1.7km apart. Fifteen dens were recorded for two males in undisturbed boulder piles around Quarry 2. Tracking undertaken at Quarry 1 revealed animals using human infrastructure as dens, including a rock windrow adjacent to a workshop and a stock-pile of concrete sleepers (Figure 9; Table 4). All other dens were recorded in the quarry and were very close to those recorded in May 2011. These dens were within boulder piles against the blasted quarry wall and beneath a rock sheet at the top of quarry, demonstrating the opportunistic nature of this species. Northern quolls are known to exploit infrastructure for both shelter and sources of prey, such as invertebrates and small reptiles that quickly colonise artificial habitat and structures.

Northern quolls were observed to move long distances, detected with a combination of trapping and radio tracking information (Table 4). One male was recorded to have moved three kilometres in 48 hours. Northern quolls are capable of traversing large distances and probably utilise large areas of the landscape within their home range. Home range data from other studies indicate that female home ranges are approximately 30 ha, while male home ranges are at least 100ha, and likely to be larger in the breeding season (Oakwood, 2002b). These estimates are considerably larger than those from this study. As previously stated, home range sizes from Quarries 1 and 2 are underestimates but other factors that contribute to differences in home range size are population density, prey availability and habitat availability (Oakwood, 2002a). In the instance of Quarry 1, it would be expected that home range size would be small as the area of available habitat was also small and isolated. At Quarry 2, where there is connectivity with other granite outcrops beyond the disturbed area it would be expected that home range estimates would be larger.

4.6 Population genetics

The genetic profiles were consistent with our earlier studies that indicate the Pilbara population is a single genetic cluster, suggesting that dispersal of individuals occurs between localities across the region. Population structure analysis shows that they clearly group well within a ‘Pilbara’ cluster, differentiated from the Kimberley Islands, Kimberley mainland, and Northern Territory.

The DNA profiles identified that the northern quolls from the Pilbara showed a similar level of genetic variation to that previously described, which was lower than that found on the Kimberley mainland. The genetic profiles identified a single Pilbara genetic cluster and dispersal of individuals occurs between localities within but not between regions. While genetic diversity is lower than that found on the mainland populations in the Kimberley, northern quolls retain moderate genetic diversity, and show no evidence of recent or long-term population bottlenecks.

The general detected trend suggests a sex biased dispersal with females showing a stronger philopatric behavior than males, which appear to disperse. However, this is based on a relatively small sample, from a single sampling site (Panawonnica), and clearly need to be explored with a larger dataset at more regional scale(s). The dispersal distance, as defined by a ‘neighbour-size’ appears to vary, but can be up to 15 kilometers.

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Appendices

Appendix A

Trapping sites and raw capture data

Table 8. Site locations (WGS84) and sampling effort for surveys conducted between May 2011 and June 2013

Site	Latitude	Longitude	Dates	Trap nights	Individual northern quolls captured	Sex Ratio (M:F)	Total northern quoll captures	Capture rate (%)
Quarry 1	-20.52939	118.65090	15/5/11-19/5/11	160	4	1:1	11	6.9
			13/8/11-16/8/11	120	4	2:1	9	7.5
			7/5/12-11/5/12	65	4	1:1	9	13.8
			14/8/12-17/8/12	120	5	2:3	10	8.3
			11/6/13-14/6/13	120	0	-	0	0
Quarry 1 – radio collar removal	-20.52939	118.65090	10/6/11	4	4	1:1	4	100
Quarry 1 radio tracking	-20.52939	118.65090	20/3/12,24/3/12	20	7	3:4	9	45
Quarry 1 control	-20.52185	118.68990	15/5/11-19/5/11	120	2	1:1	7	5.8
			13/8/11-16/8/11	120	2	1:1	4	3.3
			7/5/12-11/5/12	55	1	1:0	1	1.8
			14/8/12-17/8/12	96	0	-	0	0
			12/6/12-14/6/12	72	0	-	0	0
Quarry 2	-20.92119	118.68398	1/6/11-4/6/11	120	6	2:1	17	14.1
			25/7/11-28/7/11	120	6	1:1	14	11.6
			27/5/12-30/5/12	120	6	1:1	15	12.5
			10/8/12-13/8/12	120	6	2:1	13	10.8
			28/5/13-31/5/13	105	1	0:1	2	1.9
Quarry 2 Dens – collar removal	-20.92119	118.68398	17/8/11	20	8	3:1	8	40
Quarry 2 control	-20.95757	118.69694	1/6/11-4/6/11	120	2	1:1	4	3.3
			25/7/11-28/7/11	120	4	3:1	7	5.8
			27/5/12-30/5/12	120	1	1:0	1	0.8
			10/8/12-13/8/12	120	1	1:0	1	0.8

Site	Latitude	Longitude	Dates	Trap nights	Individual northern quolls captured	Sex Ratio (M:F)	Total northern quoll captures	Capture rate (%)
			28/5/13-31/5/13	120	1	1:0	4	3.3
Quarry 3	-21.39923	118.90434	6/6/11-9/6/11	120	2	1:1	7	5.8
			9/8/11-12/8/11	120	2	1:1	7	5.8
			22/5/12-25/5/12	120	0	-	0	0
			6/8/12-9/8/12	120	0	-	0	0
			25/5/13-27/5/13	74	1	1:0	2	2.7
Quarry 3 control	-21.44469	118.92462	6/6/11-9/6/11	120	1	1:0	1	0.8
			9/8/11-12/8/11	120	0	-	0	0
			22/5/12-25/5/12	120	0	-	0	0
			6/8/12-9/8/12	120	0	-	0	0
			25/5/13-27/5/13	87	0	-	0	0
Quarry 4	-21.97165	119.00756	20/7/11-23/7/11	120	0	-	0	0
Quarry 4 control	-21.87915	118.94622	20/7/11-23/7/11	120	0	-	0	0
Shay Gap	-20.50048	120.10631	26/6/11-29/6/11	120	0	-	0	0
Shay Gap control	-20.53443	120.15976	26/6/11-29/6/11	120	2	2:0	4	3.3
Cattle Gorge (ridge)	-20.55177	120.24064	30/6/11-3/7/11	120	2	2:0	2	1.6
Cattle Gorge (gorge) – motion-sensor camera survey	-20.54669	120.25448	2/9/11-4/9/11	12				
Cattle Gorge Mine – motion-sensor camera survey	-20.54078	120.24890	28/6/12-1/7/12	24				
Callawa (CG control)	-20.68178	120.31180	30/6/11-3/7/11	120	11	6:5	17	14.1
			3/9/11-6/9/11	120	6	1:5	14	11.6
			28/6/12-1/7/12	120	14	9:4	34	28.3
			29/8/12-1/9/12	120	6	1:1	8	6.6
			20/6/13-23/6/13	120	7	3:4	14	11.6
Nimingarra mine	-20.39104	120.03845	7/9/11-8/9/11	60	1	0:1	1	1.6
			23/6/12-26/6/12	120	4	3:1	6	4.9
			2/9/12-5/9/12	120	6	2:1	13	10.8
			16/6/13-19/6/13	120	3	3:0	8	6.6
Nimingarra control	-20.47611	120.11318	7/9/11-8/9/11	60	0	-	0	0
			23/6/12-26/6/12	120	4	1:2	6	4.9
			2/9/12-5/9/12	120	1	1:0	3	2.5

Site	Latitude	Longitude	Dates	Trap nights	Individual northern quolls captured	Sex Ratio (M:F)	Total northern quoll captures	Capture rate (%)
			16/6/13-19/6/13	120	1	0:1	2	1.6

Non-target records

Table 9. Non-target mammal species recorded. T: trapped, C: motion-sensor camera image, S: sighted

	Date	Z. argurus	M. musculus	Pseudantechinus sp.	P. rothschildi	Macropus sp.	Tachyglossus aculeatus
Quarry 1	May-11						
	Aug-11		T				
	May-12	T					
	Aug-12						
	Jun-13	T					
Quarry 1 control	May-11						
	Aug-11						
	May-12						
	Aug-12	T					
	Jun-13						
Quarry 2	Jun-11	C		C			
	Jul-11	T					
	May-12				S		
	Aug-12	T					
	May-13	T					T
Quarry 2 control	June 2011						
	July 2011	T					
	May 2012	T					
	Aug 2012	T					
	May 2013	T					
Quarry 3	June 2011				C		
	Aug 2011	T					
	May 2012	T	T				
	Aug 2012	T			T		
	May 2013	T		T			
Quarry 3 control	June 2011	T		T	C		
	Aug 2011	T		T	T		
	May 2012	T		T	T		
	Aug 2012				T		
	May 2013 – Motion-sensor cameras	C		C	C		
Quarry 4	July 2011	T					
Quarry 4 control	July 2011			C			
Shay Gap	June 2011	T					
Shay Gap control	June 2011	T					
Cattle Gorge Ridge	June/July 2011	T; C					
Callawa (CG control)	June/July 2011	T					
	Sept 2011	T					
	June/July 2012	T					
	August/Sept 2012	T					
	June 2013	T					

Nimingarra mine	Sept 2011	T					
	Jun 2012						
	Sept 2012	T					
	June 2013	T					
Nimingarra control	Sept 2011	T					
	Jun 2012			T			
	Sept 2012	T					
	June 2013	T					
Cattle Gorge (gorge) – motion-sensor camera survey	Sept 2011	C					
Cattle Gorge Mine – motion-sensor camera survey	June/July 2012	C		C	C	C	

Table 10. Raw trapping data from all northern quoll captures during all surveys 2011 – 2013.

Site	Latitude	Longitude	Date	Pit#	Sex	Weight (g)	Pouch status (F)	Testes width mm (M)
Quarry 1	-20.52859	118.6491	15.05.2011	699377	M	980		
Quarry 1	-20.5286	118.65043	15.05.2011	699695	F	500	No pouch development	
Quarry 1	-20.52846	118.64904	15.05.2011	699090	F	505	No pouch development	
Quarry 1	-20.5286	118.65043	16.05.2011	699090	F	530		
Quarry 1	-20.52853	118.64897	16.05.2011	699377	M	960		
Quarry 1	-20.52846	118.64904	16.05.2011	699695	F	520		
Quarry 1	-20.5291	118.64977	18.05.2011	699421	M	810		
Quarry 1	-20.5286	118.65043	18.05.2011	699377	M	950		
Quarry 1	-20.52897	118.65068	18.05.2011	699695	F	500		
Quarry 1	-20.5286	118.65043	19.05.2011	699695	F	480		
Quarry 1			19.05.2011	699377	M	930		
Quarry 1	-20.5286	118.65043	10.06.2011	699090	F	535		
Quarry 1	-20.5286	118.65043	10.06.2011	699695	F	530		
Quarry 1			10.06.2011	702768	M	830		
Quarry 1			10.06.2011	698804	M	680		
Quarry 1	-20.52859	118.6491	13.08.2011	699695	F	415	8 pouch young, 1cm	
Quarry 1	-20.52846	118.64904	13.08.2011	699090	F	450	8 pouch young, 1cm	
Quarry 1	-20.52853	118.64897	14.08.2011	699090	F	420		
Quarry 1	-20.52974	118.64934	14.08.2011	698804	M	450		
Quarry 1	-20.5286	118.65043	14.08.2011	699695	F	415		
Quarry 1	-20.52897	118.65068	15.08.2011	699090	F	460		
Quarry 1	-20.52859	118.6491	15.08.2011	699695	F	415		
Quarry 1	-20.52853	118.64897	16.08.2011	699695	F	400		
Quarry 1	-20.52859	118.6491	16.08.2011	700545	M	680		
Quarry 1	-20.5286	118.65043	08.05.2012	699090	F	545	Pouch developed	
Quarry 1	-20.52834	118.64948	08.05.2012	723636	M	880		27
Quarry 1	-20.52772	118.64958	08.05.2012	699582	F	470	No pouch development	
Quarry 1	-20.52853	118.64897	09.05.2012	699150	M	790		
Quarry 1	-20.52772	118.64958	10.05.2012	699582	F	470		
Quarry 1	-20.52846	118.64904	10.05.2012	699150	M	780		
Quarry 1	-20.52859	118.6491	11.05.2012	723636	M	865		30
Quarry 1	-20.52846	118.64904	11.05.2012	699582	F	430		
Quarry 1	-20.52832	118.64904	11.05.2012	699150	M	755		

Site	Latitude	Longitude	Date	Pit#	Sex	Weight (g)	Pouch status (F)	Testes width mm (M)
Quarry 1	-20.52942	118.64883	14.08.2012	723636	M	720		
Quarry 1	-20.52846	118.64904	14.08.2012		F	0		
Quarry 1	-20.52859	118.6491	14.08.2012	699582	F	510	8 Pouch young	
Quarry 1	-20.5286	118.65043	14.08.2012	699090	F	445	8 Pouch young, CR 8mm	
Quarry 1	-20.52974	118.64934	15.08.2012	723636	M	735		
Quarry 1	-20.5291	118.64977	15.08.2012	699090	F	465		
Quarry 1	-20.52939	118.6509	16.08.2012	723636	M	735		
Quarry 1	-20.52832	118.64904	16.08.2012	699582	F	495		
Quarry 1	-20.5286	118.65043	17.08.2012	723636	M	740		
Quarry 1	-20.52832	118.64904	17.08.2012		M			
Quarry 1 control	-20.52094	118.68912	15.05.2011	708827	M	960		
Quarry 1 control	-20.52096	118.68934	16.05.2011	708827	M	950		
Quarry 1 control	-20.51906	118.68859	16.05.2011	699087	F	400	Pouch developed	
Quarry 1 control	-20.52106	118.68987	18.05.2011	708827	M			
Quarry 1 control	-20.52025	118.68967	18.05.2011	699087	F	382.5		
Quarry 1 control	-20.52118	118.68984	19.05.2011	699087	F	390		
Quarry 1 control	-20.52025	118.68967	19.05.2011	708827	M	890		25.7
Quarry 1 control	-20.52104	118.69028	13.08.2011	699087	F	395	Pouch developed	
Quarry 1 control	-20.52123	118.69047	13.08.2011	708827	M	875		25
Quarry 1 control	-20.52118	118.68984	14.08.2011	708827	M	810		
Quarry 1 control	-20.52096	118.68934	14.08.2011	699087	F	410		
Quarry 1 control	-20.52094	118.68912	09.05.2012	700261	M	810		
Quarry 2	-20.9206	118.68355	01.06.2011	698887	F	430	Pouch developed	
Quarry 2	-20.92127	118.68386	01.06.2011	698700	M	880		
Quarry 2	-20.92041	118.68407	02.06.2011	698887	F	430		
Quarry 2	-20.92013	118.68419	02.06.2011	699429	F	370		
Quarry 2	-20.92053	118.68447	02.06.2011	698747	M	795		
Quarry 2	-20.92119	118.68398	02.06.2011	698700	M	840		
Quarry 2	-20.9206	118.68355	03.06.2011	699429	F	330		
Quarry 2	-20.92037	118.68468	03.06.2011	699887	F	420		
Quarry 2	-20.92005	118.68585	03.06.2011	699274	M	730		
Quarry 2	-20.92095	118.68427	03.06.2011	698700	M	840		
Quarry 2	-20.9207	118.68496	03.06.2011	698747	M	770		
Quarry 2	-20.9205	118.68554	03.06.2011	700343	M	810		
Quarry 2	-20.92086	118.68497	04.06.2011	700343	M	780		

Site	Latitude	Longitude	Date	Pit#	Sex	Weight (g)	Pouch status (F)	Testes width mm (M)
Quarry 2	-20.9205	118.68523	04.06.2011	698747	M	790		
Quarry 2	-20.92041	118.68407	04.06.2011	698700	M	850		
Quarry 2	-20.91992	118.68449	04.06.2011	698887	F	420		
Quarry 2	-20.91945	118.68319	04.06.2011	699429	F	340		
Quarry 2	-20.92041	118.68407	25.07.2001	698887	F	430	Pouch developed	
Quarry 2	-20.91963	118.68551	25.07.2011	698747	M	850		
Quarry 2	-20.91932	118.68529	25.07.2011	698700	M	1030		
Quarry 2	-20.9206	118.68355	26.07.2011	698700	M	1030		
Quarry 2	-20.91932	118.68529	26.07.2011	699334	F	440	Pouch developed	
Quarry 2	-20.92119	118.68398	26.07.2011	698747	M	820		
Quarry 2	-20.92091	118.68446	26.07.2011	698887	F	435		
Quarry 2	-20.92005	118.68585	26.07.2011	699561	F	385	Pouch developed	
Quarry 2	-20.9206	118.68355	27.07.2011	698747	M	880		
Quarry 2	-20.9205	118.68381	27.07.2011	698887	F	420		
Quarry 2	-20.92037	118.68468	27.07.2011	698700	M	1080		
Quarry 2	-20.91906	118.68379	28.07.2011	699274	M	745		
Quarry 2	-20.91896	118.68417	28.07.2011	698887	F	430		
Quarry 2	-20.92107	118.68386	28.07.2011	698747	M	840		
Quarry 2	-20.9205	118.68523	28.07.2011	698700	M	1070		
Quarry 2	-20.92119	118.68398	17.08.2011	703287	M	560		
Quarry 2	-20.92095	118.68427	17.08.2011	699561	F	370		
Quarry 2	-20.92127	118.68386	17.08.2011	699682	M	760		
Quarry 2	-20.92107	118.68386	17.08.2011			580		
Quarry 2	-20.92091	118.68446	17.08.2011	698887	F		Pouch developed	
Quarry 2	-20.9205	118.68554	17.08.2011	698747	M	685		
Quarry 2	-20.9207	118.68496	17.08.2011	699274	M	610		
Quarry 2	-20.9206	118.68355	10.08.2012	699659	M	850		
Quarry 2	-20.92013	118.68419	10.08.2012	699561	F	450		
Quarry 2	-20.91906	118.68379	11.08.2012	699659	M	840		
Quarry 2	-20.9205	118.68554	11.08.2012			0		
Quarry 2	-20.92047	118.68578	11.08.2012	699460	F	365		
Quarry 2	-20.9207	118.68496	12.08.2012	699659	M	845		
Quarry 2	-20.91945	118.68319	12.08.2012	699580	M	650		
Quarry 2	-20.9205	118.68381	12.08.2012	699686	M	875		
Quarry 2	-20.92013	118.68419	12.08.2012	699403	M	560		

Site	Latitude	Longitude	Date	Pit#	Sex	Weight (g)	Pouch status (F)	Testes width mm (M)
Quarry 2	-20.9207	118.68496	13.08.2012	699403	M	570		
Quarry 2	-20.91965	118.68461	13.08.2012	699580	M	630		
Quarry 2	-20.92037	118.68468	13.08.2012	196505	M	715		
Quarry 2	-20.92053	118.68447	13.08.2012	699659	M	830		
Quarry 2	-20.91945	118.68319	13.08.2012	699686	M	880		
Quarry 2	-20.91932	118.68529	27.05.2012	699919	M	765		26
Quarry 2	-20.91963	118.68551	27.05.2012	699561	F	510	No pouch development	
Quarry 2	-20.92107	118.68386	27.05.2012	702839	M	760		27.9
Quarry 2	-20.92005	118.68585	27.05.2012	700058	F	380	No pouch development	
Quarry 2	-20.92005	118.68585	28.05.2012	699460	F	325	No pouch development	
Quarry 2	-20.91963	118.68551	28.05.2012	700058	F	395		
Quarry 2	-20.91932	118.68529	28.05.2012	699919	M	765		
Quarry 2	-20.92041	118.68407	28.05.2012	699561	F	515		
Quarry 2	-20.91945	118.68319	28.05.2012	702839	M	780		
Quarry 2	-20.91906	118.68379	28.05.2012	703123	M	800		
Quarry 2	-20.92005	118.68585	29.05.2011	699460	F	340		
Quarry 2	-20.91932	118.68529	29.05.2012	699919	M	750		
Quarry 2	-20.9206	118.68355	29.05.2012	703123	M	770		27
Quarry 2	-20.92041	118.68407	30.05.2012	703123	M	780		
Quarry 2	-20.91982	118.68472	30.05.2012	702839	M	775		28
Quarry 2	-20.92091	118.68446	28.05.13	699561	F	470	No pouch development	
Quarry 2	-20.92086	118.68497	29.05.13	699561	F	470		
Quarry 2	-20.92047	118.68578	17.08.2011	698700	M	1010		
Quarry 2 control	-20.95752	118.69603	01.06.2011	699265	M	650		26.6
Quarry 2 control	-20.95818	118.69662	02.06.2011	698969	F	380	No pouch development	
Quarry 2 control	-20.95752	118.69603	03.06.2011	698969	F	365		
Quarry 2 control			04.06.2011	698969	F	350		
Quarry 2 control	-20.95774	118.69631	26.07.2011	698969	F	365	Pouch developed	
Quarry 2 control	-20.95743	118.69592	26.07.2011	698717	M	1100		
Quarry 2 control	-20.95743	118.69592	27.07.2011	699999	M	875		
Quarry 2 control	-20.95729	118.69656	27.07.2011	699922	M	900		
Quarry 2 control	-20.95748	118.69667	28.07.2011	699999	M	830		
Quarry 2 control	-20.9569	118.69591	28.07.2011	698969	F	535		
Quarry 2 control	-20.95781	118.69644	28.07.2011	699922	M	875		
Quarry 2 control	-20.95706	118.69635	11.08.2012	196505	M	705		22.2

Site	Latitude	Longitude	Date	Pit#	Sex	Weight (g)	Pouch status (F)	Testes width mm (M)
Quarry 2 control	-20.95743	118.69592	28.05.13	615256	M	820		25
Quarry 2 control	-20.95774	118.69631	29.05.13	615256	M			
Quarry 2 control	-20.95781	118.69644	30.05.13	615256	M	800		
Quarry 2 control	-20.95752	118.69603	31.05.13	615256	M	785		
Quarry 3	-21.3993	118.90417	06.06.2011	698967	F	630		
Quarry 3	-21.39743	118.90557	06.06.2011	713775	M	720		
Quarry 3	-21.39809	118.90557	07.06.2011	713775	M	720		
Quarry 3	-21.39814	118.90641	08.06.2011	713775	M	690		
Quarry 3	-21.39723	118.90574	08.06.2011	698967	F	670		
Quarry 3	-21.399	118.90516	09.06.2011	713775	M			
Quarry 3	-21.39704	118.90512	09.06.2011	698967	F	625		
Quarry 3	-21.399	118.90516	09.08.2011	698967	F	580		
Quarry 3	-21.39704	118.90512	09.08.2011	724400	M			
Quarry 3	-21.3993	118.90417	10.08.2011	698967	F	605		
Quarry 3	-21.39743	118.90557	10.08.2011	724400	M	695		
Quarry 3	-21.39743	118.90557	11.08.2011	724400	M	740		
Quarry 3	-21.39958	118.90404	12.08.2011	698967	F	550		
Quarry 3	-21.39743	118.90557	12.08.2011	724400	M	715		
Quarry 3	-21.39723	118.90574	25.05.13	604730	M	735		25
Quarry 3	-21.39743	118.90557	26.05.13	604730	M	715		
Quarry 3 control	-21.44528	118.92626	09.06.2011	699583	M	700		
Shay Gap control	-20.53337	120.15968	26.06.2011	699577	M	565		28
Shay Gap control	-20.53297	120.15957	28.06.2011	709569	M	490		
Shay Gap control	-20.53269	120.15897	29.06.2011	709569	M	465		
Shay Gap control	-20.53245	120.15912	29.06.2011	699577	M	585		
Callawa	-20.68119	120.30686	30.06.2011	700164	F	370	Pouch developed	
Callawa	-20.68156	120.30812	30.06.2011	698831	F	370	Pouch developed	
Callawa	-20.68119	120.31091	30.06.2011	698963	M	560		
Callawa	-20.68103	120.30661	1.07.2011	699363	M	510		28
Callawa	-20.68148	120.3086	1.07.2011	700164	F	370		
Callawa	-20.68119	120.31022	1.07.2011		M			
Callawa	-20.68163	120.30839	3.07.2011	699033	F	365		
Callawa	-20.68147	120.3077	3.07.2011	699257	M	515		
Callawa	-20.68112	120.30666	3.07.2011	699316	F	400		
Callawa	-20.68144	120.30688	3.07.2011	699363	M	500		

Site	Latitude	Longitude	Date	Pit#	Sex	Weight (g)	Pouch status (F)	Testes width mm (M)
Callawa	-20.68183	120.3092	3.07.2011	703534	M	420		
Callawa	-20.68178	120.3118	3.07.2011	698668	M	700		25
Callawa	-20.68144	120.30688	2.07.2011	698831	F	385		
Callawa	-20.68112	120.30666	2.07.2011	699363	M	525		
Callawa	-20.68082	120.3085	2.07.2011	699257	M	515		27
Callawa	-20.68103	120.30853	2.07.2011	699033	F	350	No pouch development	
Callawa	-20.68123	120.31005	2.07.2011	699316	F	398	No pouch development	
Callawa	-20.68112	120.30666	03.09.2011	698831	F	285	Pouch developed	
Callawa	-20.6811	120.31072	04.09.2011	699033	F	330	Pouch developed	
Callawa	-20.68163	120.31156	04.09.2011	698759	F	270	Pouch developed	
Callawa	-20.68178	120.3118	04.09.2011	699316	F	320	Pouch developed	
Callawa	-20.68147	120.3077	04.09.2011	698831	F	330		
Callawa	-20.68148	120.3086	05.09.2011	699033	F	380		
Callawa	-20.68119	120.30686	05.09.2011	698831	F	295		
Callawa	-20.68112	120.30666	05.09.2011	699316	F	330		
Callawa	-20.6815	120.31155	05.09.2011	698759	F	245		
Callawa	-20.6815	120.31155	06.09.2011	698831	F	395		
Callawa	-20.6811	120.31072	06.09.2011	699316	F	345		
Callawa	-20.68119	120.31091	06.09.2011	699437	F	395	Pouch developed	
Callawa	-20.68071	120.30811	06.09.2011	699033	F	380		
Callawa	-20.68178	120.3118	06.09.2011	699105	M	535		22.5
Callawa	-20.68119	120.31091	28.06.2012	699033	F	525	Pouch developed	
Callawa	-20.68183	120.3092	28.06.2012	304373	F	370	No pouch development	
Callawa	-20.68189	120.30881	28.06.2012			445		
Callawa	-20.68144	120.30688	28.06.2012	699316	F	400		
Callawa	-20.68112	120.30666	28.06.2012	700341	M			27
Callawa	-20.68103	120.30661	28.06.2012	698968	F	270	No pouch development	
Callawa	-20.6812	120.31118	29.06.2012	699033	F	520		
Callawa	-20.68119	120.31022	29.06.2012	304373	F	375		
Callawa	-20.68071	120.30811	29.06.2012	699316	F	435		
Callawa	-20.68156	120.30812	29.06.2012	699541	M	420		28
Callawa	-20.68137	120.30737	29.06.2012	707091	M	700		26.5
Callawa	-20.68144	120.30688	29.06.2012		M	665		28
Callawa	-20.68103	120.30661	29.06.2012	698968	F	260		
Callawa	-20.68112	120.30666	29.06.2012	10102	M	675		

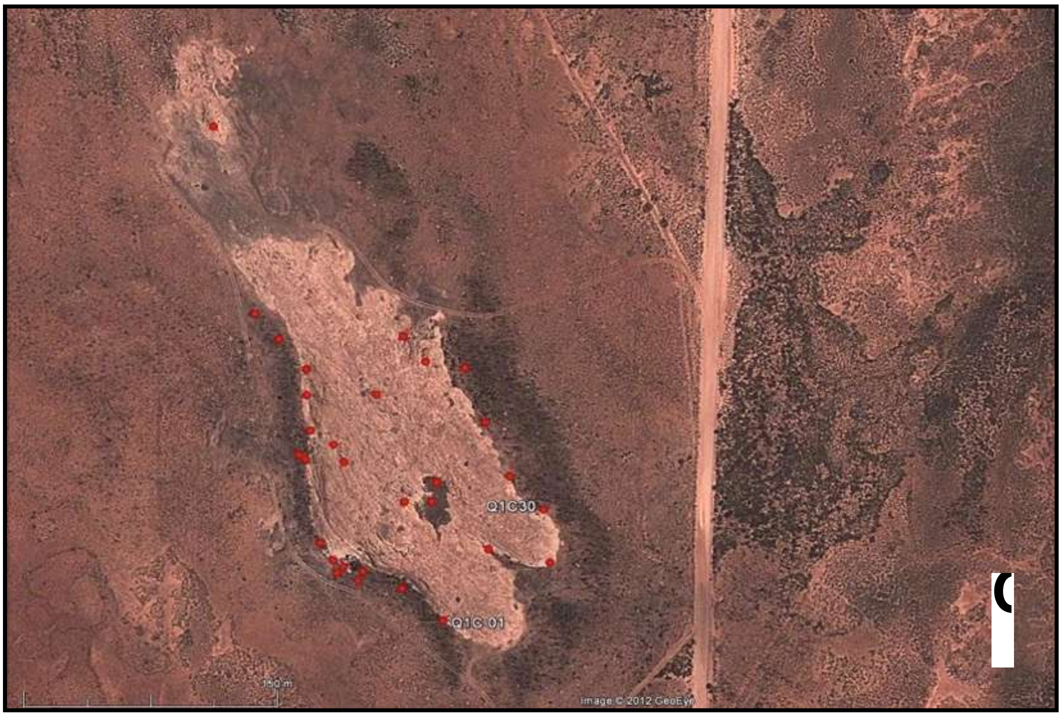
Site	Latitude	Longitude	Date	Pit#	Sex	Weight (g)	Pouch status (F)	Testes width mm (M)
Callawa	-20.68119	120.30686	29.06.2012	700341	M	680		
Callawa	-20.6812	120.31118	30.06.2012	304373	F	370		
Callawa	-20.68119	120.31091	30.06.2012	699033	F	510		
Callawa	-20.68119	120.31022	30.06.2012	699316	F	405		
Callawa	-20.68163	120.30839	30.06.2012	699518	M	760		25.5
Callawa	-20.68103	120.30661	30.06.2012			0		
Callawa	-20.68112	120.30666	30.06.2012		M	665		
Callawa	-20.68144	120.30688	30.06.2012	700341	M	640		
Callawa	-20.68156	120.30812	30.06.2012	699541	M	350		
Callawa	-20.68071	120.30811	30.06.2012	10102	M	720		
Callawa	-20.68129	120.30856	30.06.2012	700137	M	495		27
Callawa	-20.68103	120.30661	01.07.2012	698593	M	505		24
Callawa	-20.68112	120.30666	01.07.2012	700341	M	645		
Callawa	-20.68144	120.30688	01.07.2012	10102	M	680		
Callawa	-20.68137	120.30737	01.07.2012	699518	M	740		
Callawa	-20.68163	120.30839	01.07.2012	699541	M	400		
Callawa	-20.68172	120.30859	01.07.2012	699316	F	0		
Callawa	-20.68082	120.3085	01.07.2012	702661	M	480		26.5
Callawa	-20.68071	120.30811	01.07.2012	700137	M	490		
Callawa	-20.68119	120.31091	01.07.2012	304373	F	365		
Callawa	-20.68119	120.31022	01.07.2012	699033	F	495		
Callawa	-20.68103	120.30853	29.08.2012	703385	M	685		24
Callawa	-20.68143	120.31125	30.08.2012	304373	F	380	Pouch developed	
Callawa	-20.68112	120.30666	30.08.2012	723837	M?	580		
Callawa	-20.68163	120.31156	31.08.2012	304373	F	345		
Callawa	-20.68137	120.30737	01.09.2012	699033	F	480	Pouch developed	
Callawa	-20.68147	120.3077	01.09.2012	723835	F	310	Pouch developed	
Callawa	-20.68178	120.3118	01.09.2012	304373	F	375		
Callawa	-20.68163	120.31156	01.09.2012	699518	M	605		
Callawa	-20.68071	120.30811	20.06.13	639271	F	260	No pouch development	
Callawa	-20.68144	120.30688	21.06.13	723809	F	265		
Callawa	-20.68119	120.30686	21.06.13	539189	M	535		27
Callawa	-20.6811	120.31072	21.06.13	623134	F	310	No pouch development	
Callawa	-20.68172	120.30859	21.06.13	699620	M	580		28
Callawa	-20.68071	120.30811	22.06.13	639271	F	260		

Site	Latitude	Longitude	Date	Pit#	Sex	Weight (g)	Pouch status (F)	Testes width mm (M)
Callawa	-20.68144	120.30688	22.06.13	506166	M	480		25
Callawa	-20.68119	120.30686	22.06.13	539189	M	550		
Callawa	-20.68103	120.30661	22.06.13	723809	F	260	No pouch development	
Callawa	-20.68117	120.31046	23.06.13	623134	F	305		
Callawa	-20.68103	120.30661	23.06.13	539189	M	545		
Callawa	-20.68119	120.30686	23.06.13	506166	M	480		
Callawa	-20.68148	120.3086	23.06.13	699195	F	515		
Callawa	-20.68071	120.30811	23.06.13	723809	F	260		
Nimingarra control	-20.47322	120.11618	24.06.2012	276955	F	365	Pouch developed	
Nimingarra control	-20.47111	120.11741	25.06.2012			0		
Nimingarra control	-20.47203	120.11618	25.06.2012	276955	F	380		
Nimingarra control	-20.47292	120.1153	25.06.2012	700422	M	575		25
Nimingarra control	-20.47322	120.11618	26.06.2012	698905	F	325	No pouch development	
Nimingarra control	-20.47292	120.1153	26.06.2012	700422	M	555		
Nimingarra control	-20.4728	120.11475	03.09.2012	700422	M	500		21.9
Nimingarra control	-20.47301	120.11506	04.09.2012	700422	M	480		
Nimingarra control	-20.47292	120.1153	05.09.2012	700422	M	450		
Nimingarra control	-20.47364	120.11394	18.06.13		F	460	Pouch developed	
Nimingarra control	-20.47393	120.11365	19.06.13		N	450		
Nimingarra mine	-20.39156	120.0384	08.09.2011	699192	F	360	8 pouch young, 1.5cm	
Nimingarra mine	-20.3935	120.03979	23.06.2012	699192	F	440	Pouch developed	
Nimingarra mine	-20.39309	120.03859	24.06.2012	699192	F	400		
Nimingarra mine	-20.39266	120.03803	25.06.2012	699984	M	615		26
Nimingarra mine	-20.39101	120.039	26.06.2012	699192	F	410		
Nimingarra mine	-20.39309	120.03859	26.06.2012	300024	M	820		27
Nimingarra mine	-20.39347	120.03852	26.06.2012	196283	M	775		
Nimingarra mine	-20.39104	120.03845	02.09.2012	699868	F	420	Pouch young	
Nimingarra mine	-20.39261	120.03883	02.09.2012	699984	M	550		
Nimingarra mine	-20.39184	120.03887	03.09.2012	300024	M	695		21.5
Nimingarra mine	-20.39116	120.03963	03.09.2012	699868	F	390	8 Pouch young. CR 14mm	
Nimingarra mine	-20.3935	120.03979	03.09.2012	698639	F	345	Pouch developed	
Nimingarra mine	-20.39376	120.03594	03.09.2012	703348	M	545		24
Nimingarra mine	-20.39181	120.03847	04.09.2012	300024	M	645		
Nimingarra mine	-20.39101	120.039	04.09.2012	699868	F	370		
Nimingarra mine	-20.39246	120.03951	04.09.2012	703348	M	580		

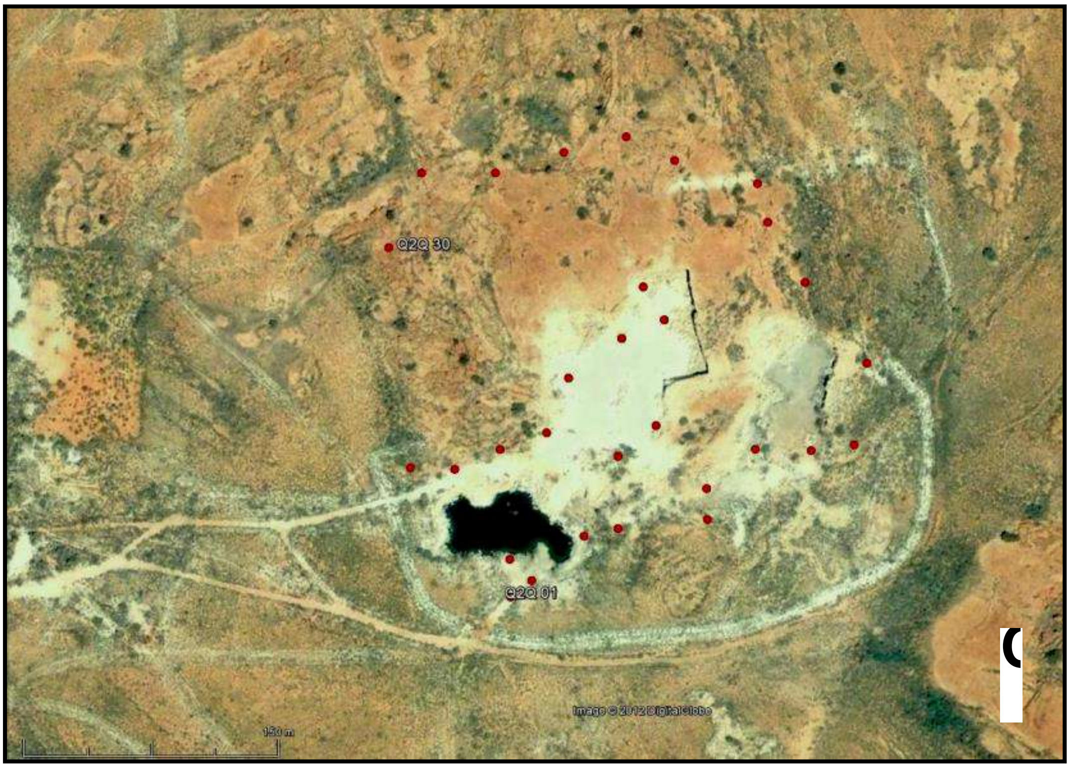
Site	Latitude	Longitude	Date	Pit#	Sex	Weight (g)	Pouch status (F)	Testes width mm (M)
Nimingarra mine	-20.3935	120.03979	04.09.2012	699984	M	510		
Nimingarra mine	-20.39324	120.03795	05.09.2012	300024		650		
Nimingarra mine	-20.39396	120.03653	05.09.2012	699951	M	860		22
Nimingarra mine	-20.39246	120.03951	05.09.2012	699984	M	480		
Nimingarra mine	-20.39104	120.03845	16.06.13	611267	M	510		21
Nimingarra mine	-20.39184	120.03887	17.06.13	611267	M	540		
Nimingarra mine	-20.39272	120.03746	17.06.13	703163	M			22.5
Nimingarra mine	-20.39104	120.03845	18.06.13	703163	M	475		
Nimingarra mine	-20.39181	120.03847	18.06.13	594873	M	595		24.6
Nimingarra mine	-20.39184	120.03887	18.06.13	611267	M	500		
Nimingarra mine	-20.39266	120.03803	19.06.13	703163	M	465		
Nimingarra mine	-20.39184	120.03887	19.06.13	594873	M	620		

Appendix B: Aerial images of trap sites

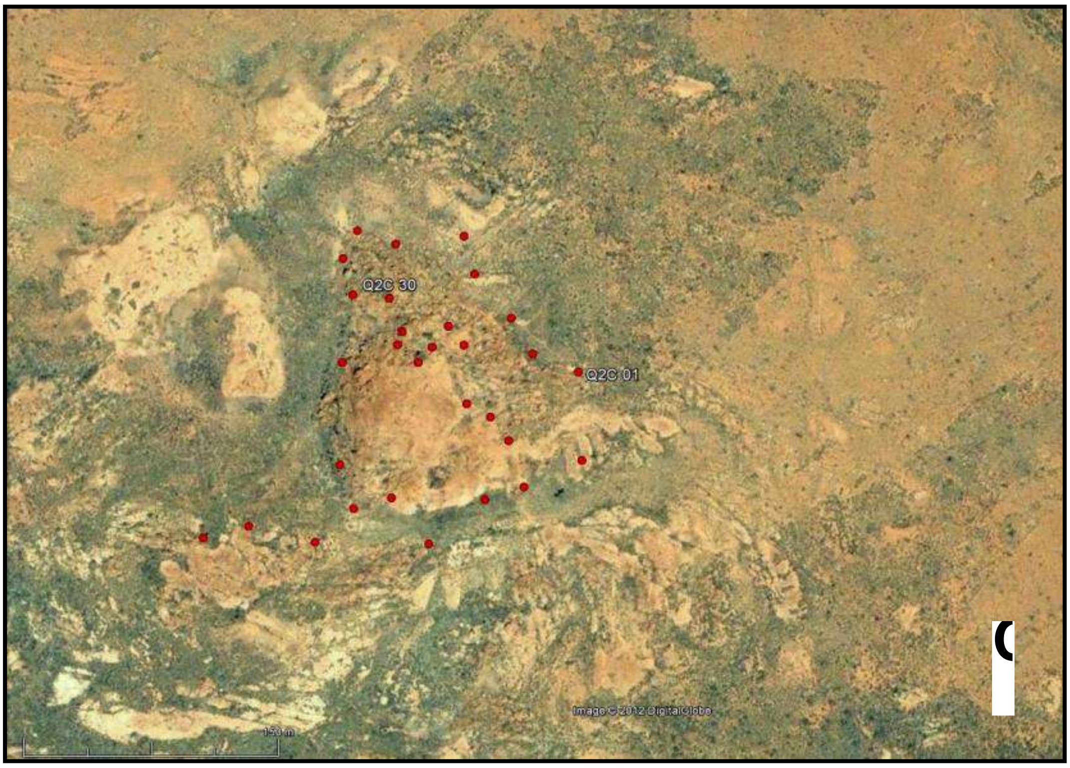
Quarry 1 – Disturbed (-20.52939, 118.65090)



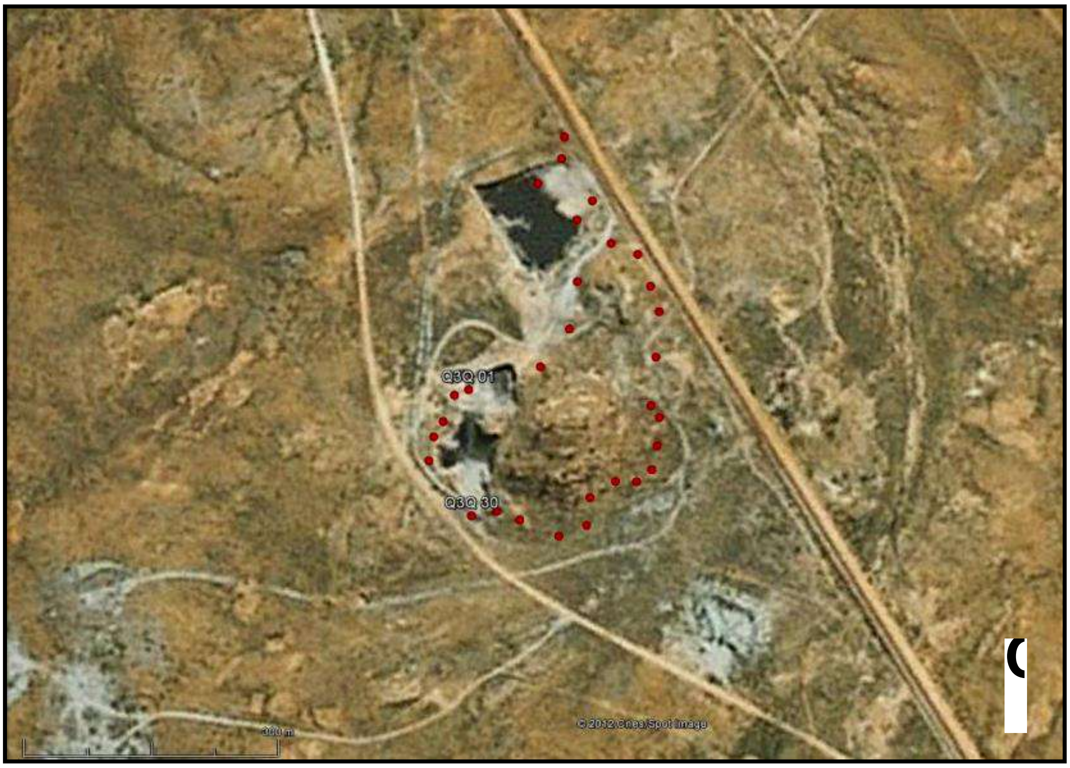
Quarry 1 – Control (-20.52185, 118.68990)



Quarry 2 – Disturbed (-20.92119, 118.68398)



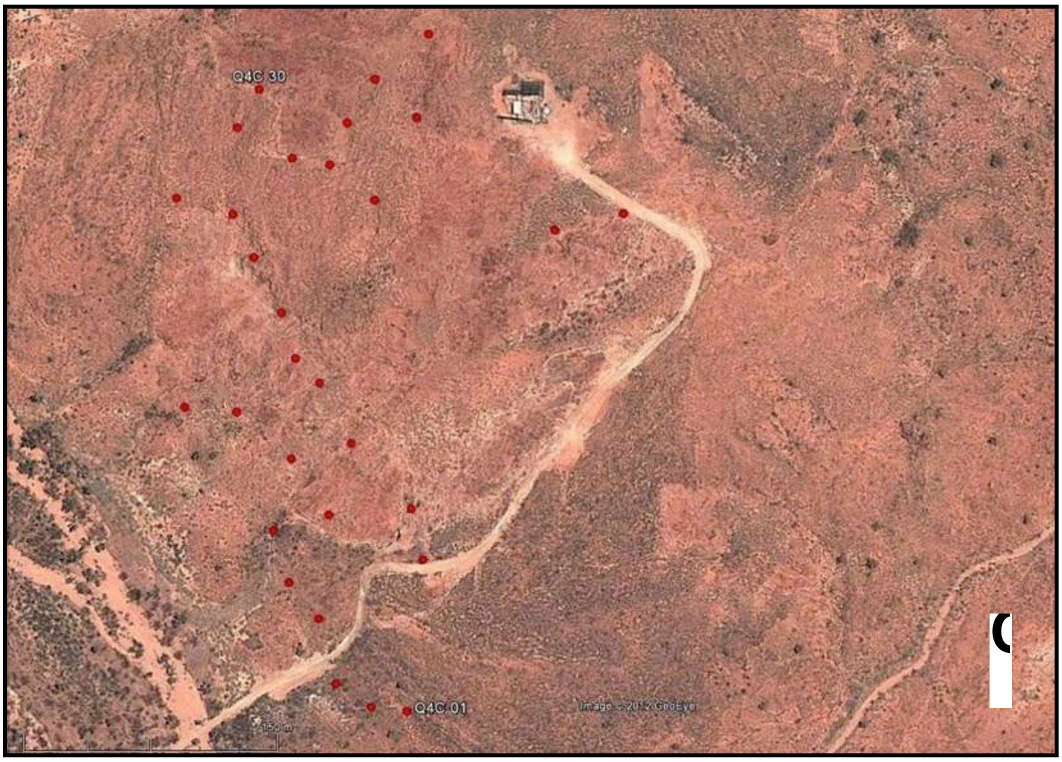
Quarry 2 – Control (-20.95757, 118.69694)



Quarry 3 – Disturbed (-21.39923, 118.90434)

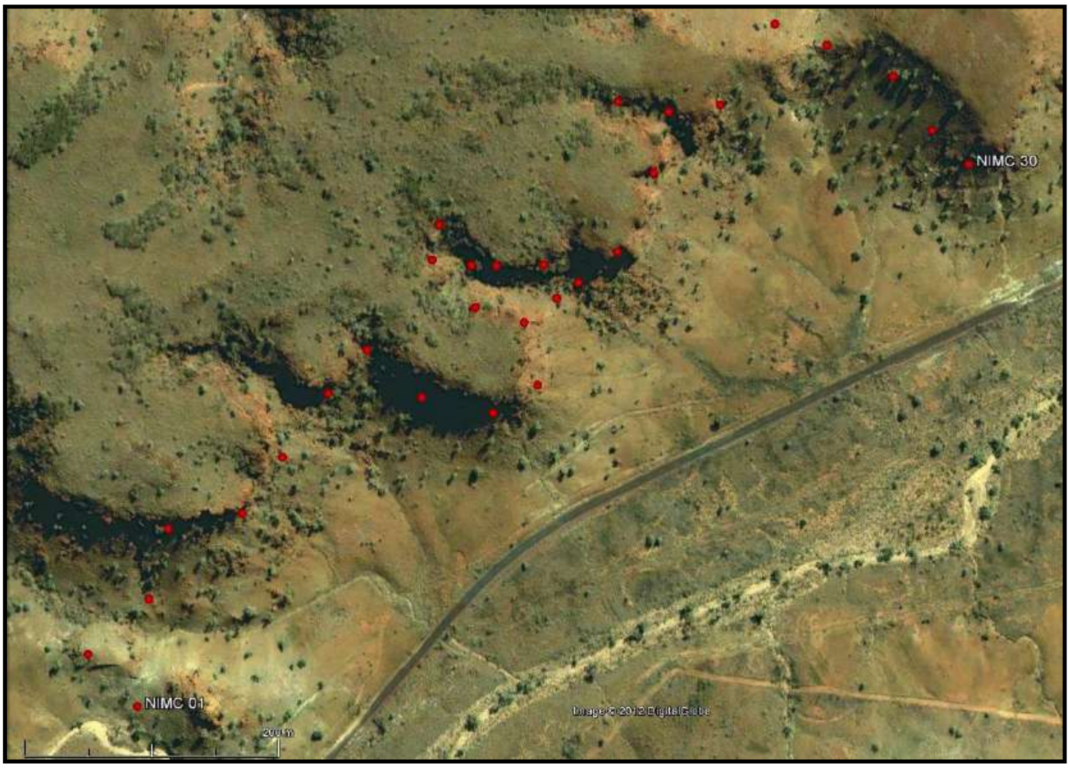
Quarry 3 – Control (-21.44469, 118.92462)

Quarry 4 – Disturbed (-21.97165, 119.00756)



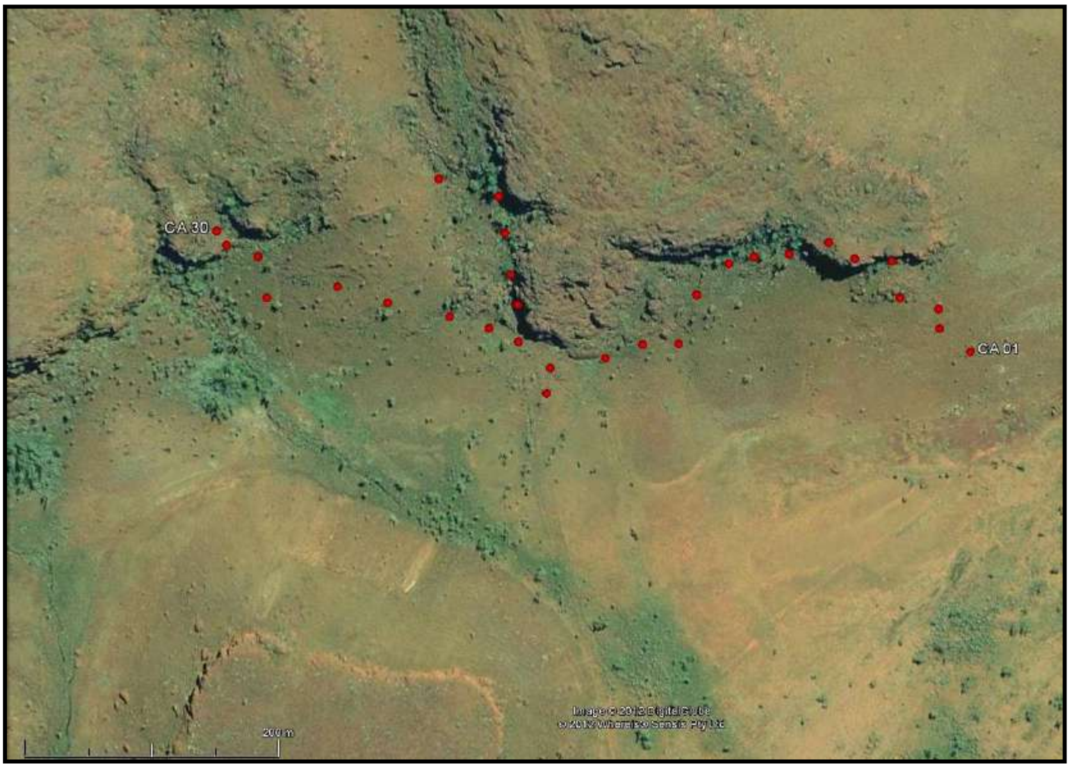
Quarry 4 – Control (-21.87915, 118.94622)

Nimingarra – Disturbed (- 20.39396, 120.03653)



Nimingarra – Control (-20.47220, 120.11822)

Cattle Gorge – Disturbed (-20.55177, 120.24064)



Callawa (-20.68178, 120.31180)

Appendix C: Photographs of den sites

Refuge one from quarry two used by male one on 9/8/2011 and male two on 10/8/2011

Refuge two from quarry two used by male one on 10/8/2011

Refuge three from quarry two used by male one on 11/8/2011

Refuge four from quarry two used by male one on 12/8/2011 and 13/8/2011

Refuge five from quarry two used by male one on 14/8/2011

Refuge six from quarry two used by male one on 15/8/2011

Refuge seven from quarry two used by male two on 9/8/2011

Refuge seven from quarry two used by male two on 11/8/2011

Refuge nine from quarry two used by male two on 12/8/2011

Refuge ten from quarry two used by male two on 13/8/2011 and 14/8/2011

Refuge eleven from quarry two used by male two on 15/8/2011

Refuge twelve from quarry two used by male two on 16/8/2011

Wall of quarry one containing two refuge sites for two female quolls. Animals were radio-tracked three times to this location in May 2011

Rock slab at quarry one used as a refuge site for two female quolls. Animals were radio-tracked to this location eight times in May 2011