

Miralga Creek DSO Project: Northern Quoll Monitoring 2020

Biologic Environmental Survey

Report to Atlas Iron Pty Ltd

February 2022

Document Status				
Revision No.	Author	Review / Approved for Issue	Approved for Issue to	
			Name	Date
1	M. Gresser	C. Knuckey	D. Morley	20/11/2020
2	M. Gresser	C. Knuckey	D. Morley	29/11/2021
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EXECUTIVE SUMMARY

Atlas Iron Pty Ltd (Atlas) is developing the Miralga Creek Direct Shipping Ore Project approximately 100 kilometres (km) southeast of Port Hedland and 40 km northwest of Marble Bar, in the Pilbara region of Western Australia. The northern quoll (*Dasyurus hallucatus*), which is listed as Endangered under Federal and State legislation, has previously been recorded in the Project area. To help mitigate the potential impact of mining on northern quolls, Atlas developed the *Miralga Creek DSO Project Significant Species Management Plan* (SSMP), which prescribes a survey program to monitor the local population of the species for the life of the Project. The specific requirements of the monitoring program are outlined in the *Miralga Creek DSO Project Northern Quoll Monitoring Procedure* (NQMP), a key component of which is a baseline monitoring survey aimed at describing the pre-mining distribution and abundance of northern quoll in the Project area. In July 2020, Atlas commissioned Biologic Environmental Survey to undertake this baseline monitoring survey.

The baseline monitoring survey was conducted between 13th and 23rd August 2020. The survey's Study Area comprised 8,124 hectares (ha) of land encompassing the Project's development envelope. In accordance with the NQMP, eight monitoring sites were established, comprising four "impact" sites located within 1 km of the Project's indicative disturbance footprint (VMCM-01, VMCM-02, VMCM-03 and VMCM-04) and four "control" sites located more than 2 km from the Project's indicative disturbance footprint (VMCM-05, VMCM-06, VMCM-07 and VMCM-08). Each of these sites were sampled with ten motion cameras deployed over four consecutive nights.

Detections, defined as any instance in which a northern quoll was recorded on camera, were amalgamated into 'detection events' based on their timing. If fewer than ten minutes passed between detections of the same individual, the resulting images were considered to belong to the same detection event. Applying this rule, northern quolls were recorded by 152 detection events across six of the eight sites (all except VMCM-04 and VMCM-08). For those sites where northern quolls were detected, the number of detection events ranged between four detection events (VMCM-01) and 57 detection events (VMCM-02).

Images of northern quolls recorded by the cameras were analysed to identify individual northern quolls based on spot patterning, and capture-mark-recapture models were applied to estimate the size of the population present at each site. A total of 45 individuals were identified, 23 across the impact sites and 22 across the control sites. For those sites where northern quolls were detected, the number of individuals identified ranged between three individuals (VMCM-01) and 16 individuals (VMCM-02). Estimations of population size based on statistical analysis of capture/recapture data were achievable for two of the eight sites: VMCM-02 (18 individuals) and VMCM-07 (21 individuals). For the remaining six sites, the numbers of captures and recaptures were too low to allow statistical models to be applied for an estimation of population size. The number of individuals identified at each of these sites were: three individuals at VMCM-01; four individuals at VMCM-03; zero individuals at VMCM-04; four individuals at VMCM-5; five individuals at VMCM-06; and zero individuals at VMCM-08.

The baseline data collected during this survey will assist Atlas to identify whether mining activities associated with the Project are having a significant impact on northern quolls and whether specific actions are required to manage the species in accordance with the SSMP. Specifically, Atlas are committed to employing specific management actions when: (a) the species is recorded at only a single impact site during at least three consecutive monitoring events; and/or (b) the number of individuals recorded at an impact site during a monitoring event is less than 50% of the number of individuals recorded at the site during a baseline monitoring survey. It follows, then, that the trigger levels related to (b) are: fewer than 1.5 individuals for VMCM-01; fewer than 9.1 individuals for VMCM-02; and fewer than two individuals for VMCM-03. As no northern quolls were detected at VMCM-04, (b) does not apply to this site. Future monitoring conducted under the NQMP will determine the extent to which northern quolls continue to persist in the Study Area as mining progresses.

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1 INTRODUCTION

1.1 Background

Atlas Iron Pty Ltd (Atlas) is developing the Miralga Creek Direct Shipping Ore Project approximately 100 kilometres (km) southeast of Port Hedland and 40 km northwest of Marble Bar, in the Pilbara region of Western Australia (Figure 1.1). The area encompassing the Project, hereafter referred to as the Study Area, comprises five areas of land covering 8,124 hectares (ha) (Figure 1.1). Mining operations, which are due to commence in 2021, are planned for three of the six areas (Sandtrax, Miralga West and Miralga East), whereas the remaining three areas will contain supportive infrastructure such as camp facilities. A number of species of conservation significance, including northern quoll (*Dasyurus hallucatus*), have been previously recorded within the Study Area (Biologic, 2020a, 2020b).

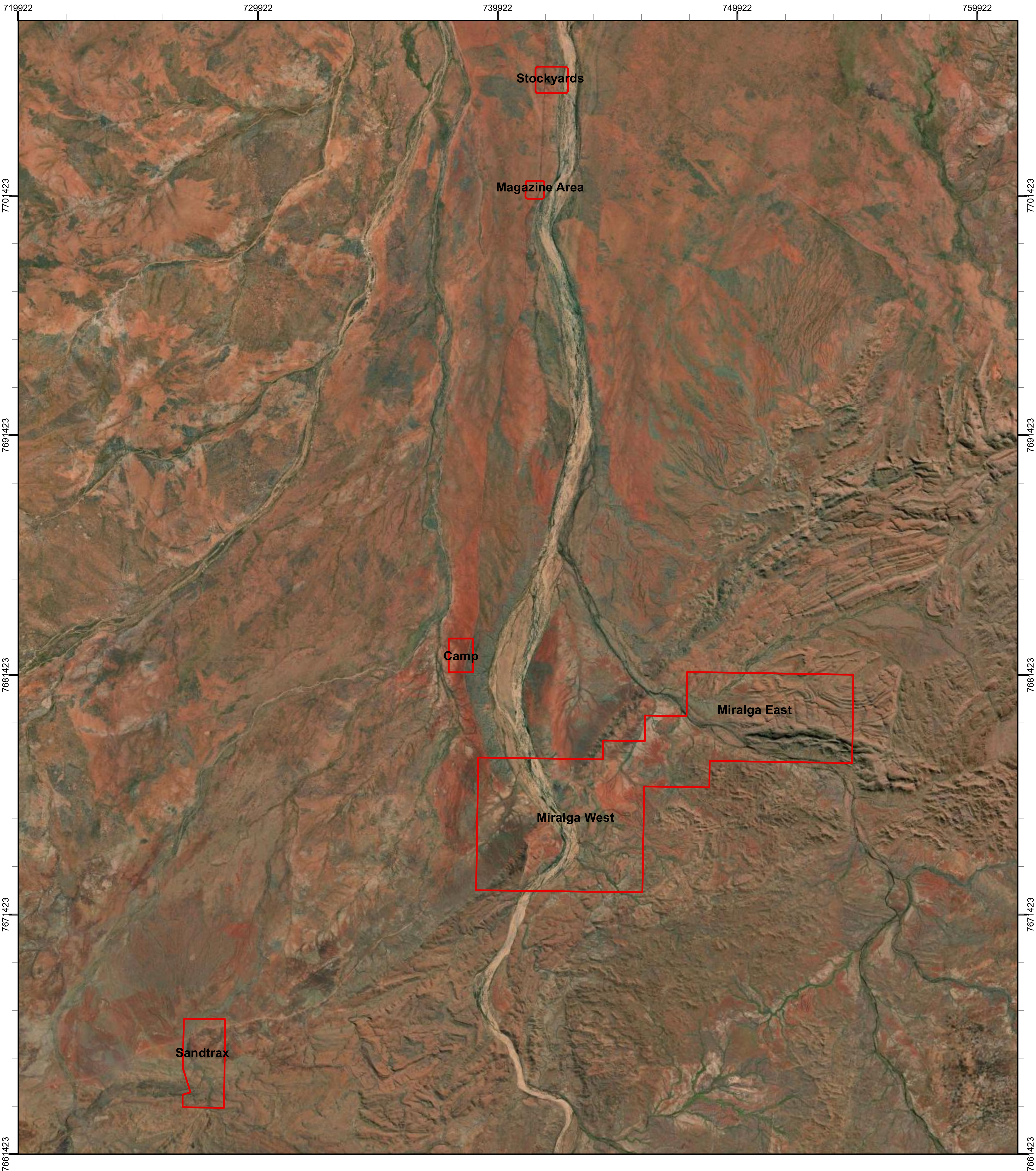
To help mitigate mining impacts to northern quolls occurring within the Study Area, Atlas developed the *Miralga Creek DSO Project Significant Species Management Plan* (SSMP; revision 1 published on 16/10/2020) (Atlas Iron, 2020). The SSMP prescribes a monitoring program to examine the northern quoll population inhabiting the Study Area for the life of the Project. The specific requirements of the monitoring program are outlined in the *Miralga Creek DSO Project Northern Quoll Monitoring Procedure* (NQMP) and include surveys conducted pre-mining, during mining and post-mining (Appendix A of Atlas Iron, 2020). These surveys are designed to gather data about the distribution and abundance of northern quoll across eight sites, including four “impact sites” located within the Study Area close to proposed mining disturbance and four “control sites” located outside the Study Area. It is anticipated that this information will help Atlas to monitor compliance with key management objectives outlined in the SSMP.

More specifically, the data will help Atlas to identify when additional management actions are required to minimise the impacts of the Project on the species. Atlas are committed to employing specific management actions when: (a) the species is recorded at only a single impact site during at least three consecutive monitoring events; and/or (b) the number of individuals recorded at an impact site during a monitoring event is less than 50% of the number of individuals recorded at the site during a baseline monitoring survey (Atlas Iron, 2020). Accordingly, a key component of the NQMP is a baseline monitoring survey aimed at describing the pre-mining distribution and abundance of northern quoll within the Study Area. In July 2020, Atlas commissioned Biologic Environmental Survey (Biologic) to undertake this baseline monitoring survey. This report documents the outcomes of this survey.

1.2 Objectives

The overarching aim of the baseline monitoring survey was to describe the pre-mining distribution and abundance of northern quoll within the Study Area. Specific objectives were to:

- establish the eight monitoring sites described in the NQMP;
- determine the abundance of northern quoll at these monitoring sites prior to the commencement of mining; and
- gather environmental data that will help to interpret changes in the distribution and abundance of northern quoll as the monitoring program progresses, with consideration of the potential impacts of mining activity as well as other variables such as habitat disturbance through natural events (e.g. fire) and natural fluctuations in the species’ distribution, abundance and activity.

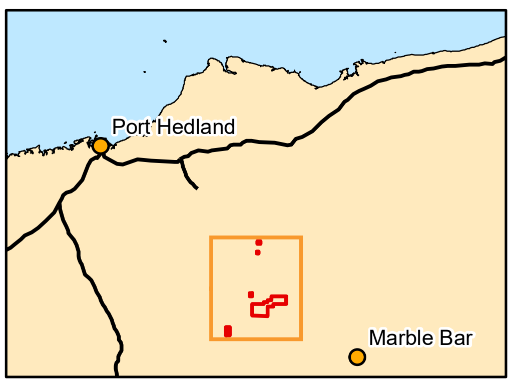


Legend

Study Area

0 4 8 Km

Coordinate System: GDA 1994 MGA Zone 50
Projection: Transverse Mercator
Datum: GDA 1994 Created 16/11/2020



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Scale: 1:150,000

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Miralga Creek Northern Quoll Monitoring 2020

Figure 1.1: Study Area location and layout

1.3 Northern Quoll (*Dasyurus hallucatus*)

The Northern Quoll is listed as Endangered under the *Environmental Protection and Biodiversity Conservation Act 1999* (EPBC Act) and *Biodiversity Conservation Act 2016* (BC Act). The species was once widely distributed across northern Australia, however it is now restricted to three isolated populations; the Pilbara, the Kimberley and Northern Territory, and Queensland, in addition to a number of islands along the north coast (DoE, 2016). Northern Quolls are opportunistic omnivores, consuming a wide range of invertebrates and small vertebrates as well as fruit, nectar, carrion and human refuse (Van Dyck & Strahan, 2008).

As a result of facultative die-off (semelparity), the abundance of the species is cyclical, and the annual reproduction is highly synchronised (Oakwood *et al.*, 2001). In the Pilbara, abundance is lowest toward the end of winter into early spring after the mating season, as a significant proportion of adult males die off and young have not yet begun to forage independently (Braithwaite & Griffiths, 1994; Hernandez-Santin *et al.*, 2019; Oakwood, 2000). Conversely, the population density is thought to be highest in the summer months, prior to the mating season and when juveniles have begun foraging independently (Oakwood, 2000). Schmitt *et al.* (1989) reported relatively small home ranges in rugged habitat in the Kimberley (*i.e.* 2.3 ha for females and 1.8 ha for males), whereas in the western Pilbara, minimum activity areas are 75 – 443 ha for females and 5 – 1,109 ha for males (King, 1989).

The Northern Quoll is both arboreal and terrestrial, inhabiting ironstone and sandstone ridges, scree slopes, granite boulders and outcrops, drainage lines, riverine habitats (Braithwaite & Griffiths, 1994; Oakwood, 2002), dissected rocky escarpments, open forest of lowland savannah and woodland (Oakwood, 2002, 2008). Rocky habitats tend to support higher densities, as they offer protection from predators and are generally more productive in terms of availability of resources (Braithwaite & Griffiths, 1994; Oakwood, 2000). Other microhabitat features important to the species include: rock cover; proximity to permanent water and time-since last fire (Woinarski *et al.*, 2008). Dens occur in a wide range of situations including rock overhangs, tree hollows, hollow logs, termite mounds, goanna burrows and human dwellings/infrastructure, where individuals usually den alone (Oakwood, 2002; Woinarski *et al.*, 2008). At present Northern Quolls are relatively common in the northern Pilbara region (generally within 150 km of the coast) but are much less common in southern and south-eastern parts of the region (Cramer *et al.*, 2016).

The species has experienced a precipitous decline in much of its former range in northern Queensland and the Northern Territory in direct association with the spread of the Cane Toad, *Bufo marinus* (Braithwaite & Griffiths, 1994; Fitzsimons *et al.*, 2010). Other threats include predation from feral predators such as foxes and cats, inappropriate fire regimes, disease, habitat degradation through grazing and weed invasion, habitat destruction through mining and agriculture (Woinarski *et al.*, 2011). The potential invasion of the Pilbara by the cane toad is regarded as the most significant future threat to the Northern Quoll in the Pilbara; however, there is little knowledge of the relative impact of the other key threats, and their interactive effects, currently and in the future (Cramer *et al.*, 2016).

2 METHODOLOGY

2.1 Approach

The survey was carried out in accordance with methods prescribed by the SSMP and NQMP, following guidelines produced by the WA Environmental Protection Authority (EPA) and the Department of Agriculture, Water and the Environment (formerly DoE):

- Technical guidance: terrestrial vertebrate fauna surveys for environmental impact assessment (EPA, 2020);
- EPBC Act referral guideline for the endangered northern quoll *Dasyurus hallucatus* (DoE, 2016).

2.2 Survey Timing

The field survey was conducted between the 13th and 23rd August 2020. This period coincides with the end of the mating season when northern quolls are most likely to be active and detectable.

The Bureau of Meteorology (BoM) weather station located at Marble Bar, approximately 45 km east-southeast of the Study Area, provides comprehensive climate data relevant to the Study Area (BoM, 2020). Maximum temperatures recorded at Marble Bar in the 12 months prior to the survey (i.e. August 2019 to July 2020) were generally warmer than average (Figure 2.1). Rainfall recorded at Marble Bar was above the long-term monthly average for three of 12 months preceding the survey, with a substantially higher than average rainfall being recorded in January 2020 (i.e. 312 mm versus a long-term average of 115 mm) (Figure 2.1). This January 2020 rainfall event brought the total rainfall for the 12 months preceding the survey (403 mm) in line with the long-term average (385 mm).

Temperatures recorded at Marble Bar during the current survey were similar to the long term average for August, with an average minimum temperature of 13.0°C (versus a long term average of 13.1°C) and an average maximum temperature of 31.2°C (versus a long term average of 30.3°C) (Table 2.1). These conditions were considered supportive of normal northern quoll activity and are unlikely to have impeded the ability of the survey to detect the species.

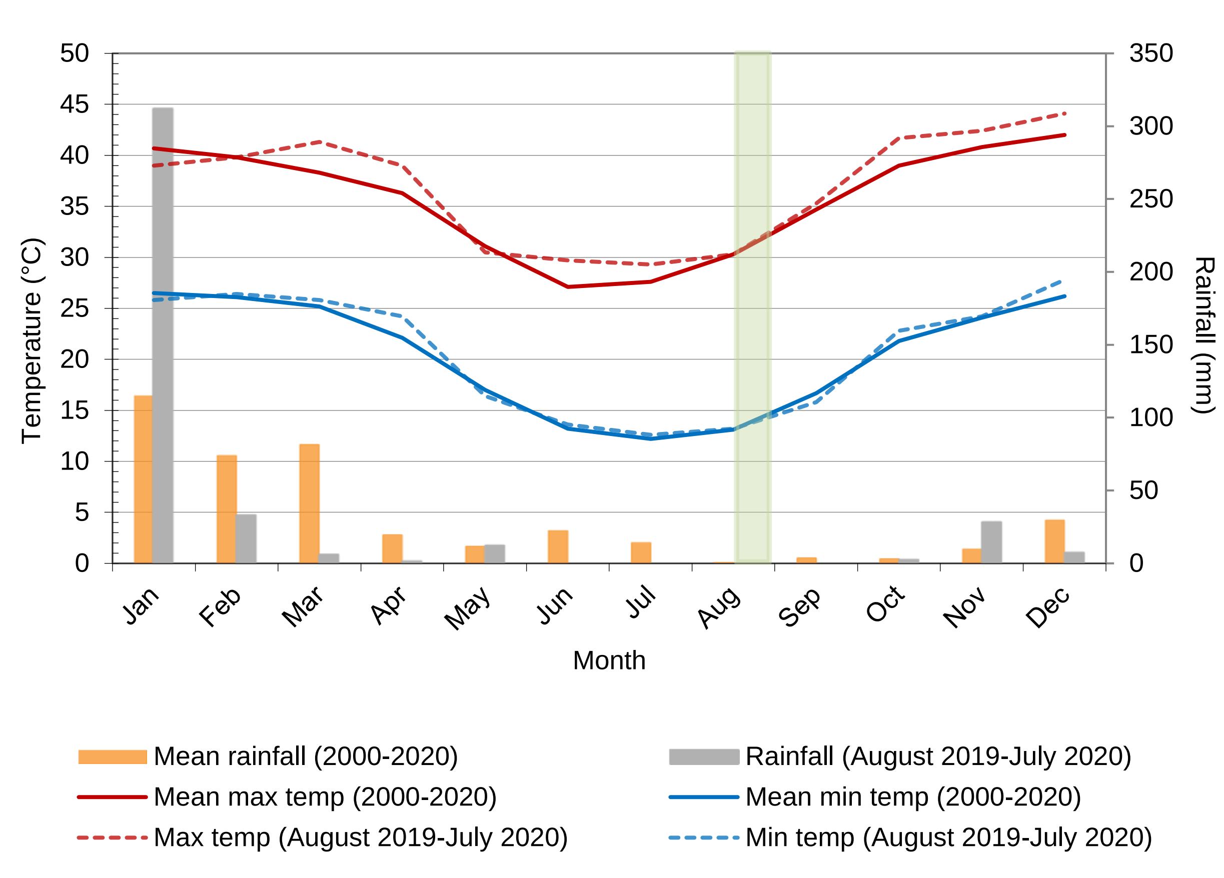


Figure 2.1: Long-term average and pre-survey climate recorded at Marble Bar
Source: BoM (2020). Shaded green box denotes current monitoring period.

Table 2.1: Daily weather data recorded at Marble Bar during the survey

Date	Temperature (°C)		Rainfall (mm)	Humidity (%)	
	Min	Max		0900	1500
13/08/2020	15.9	27.3	0	41	21
14/08/2020	13.7	28.3	0	24	13
15/08/2020	7.8	31.1	0	17	10
16/08/2020	10.5	31.4	0	29	23
17/08/2020	16.9	30.5	0	51	25
18/08/2020	11.8	28.3	0	21	14
19/08/2020	11.6	29.4	0	22	13
20/08/2020	14.4	30.8	0	18	8
21/08/2020	13.4	33.5	0	11	7
22/08/2020	12.6	35.5	0	11	5
23/08/2020	14.2	36.6	0	10	6
Average	**13.0**	**31.2**	**0**	**23.2**	**13.2**

Source: (BoM, 2020)

2.3 Survey Methods

2.3.1 Monitoring Sites

In accordance with the NQMP, eight monitoring sites were established in locations where northern quolls have previously been recorded and/or where suitable habitat (particularly habitat comprising suitable denning/breeding sites) has been documented. These sites comprised four "impact" sites located within 1 km of the Project disturbance footprint and four "control" sites located more than 2 km from the Project disturbance footprint (Table 2.2; Figure 2.2).

Table 2.2: Monitoring site details

Site	Location			Distance from development envelope (m)[1]	Distance from disturbance footprint (m)[2]
	Area	Latitude	Longitude		
Impact					
VMCM-01	Sandtrax	-21.1130	119.1932	88	135
VMCM-02	Miralga West	-21.0271	119.3130	52	188
VMCM-03	Miralga West / Shaw River	-21.0013	119.3338	282	315
VMCM-04	Miralga East	-20.9735	119.4339	23	44
Control					
VMCM-05	West of Sandtrax	-21.1192	119.1396	4,610	4,635
VMCM-06	Lalla Rookh	-21.0546	119.2781	4768	4,914
VMCM-07	Miralga Creek	-20.9515	119.3669	2,918	3,045
VMCM-08	North Pole Road	-21.0303	119.3860	5,168	5,201

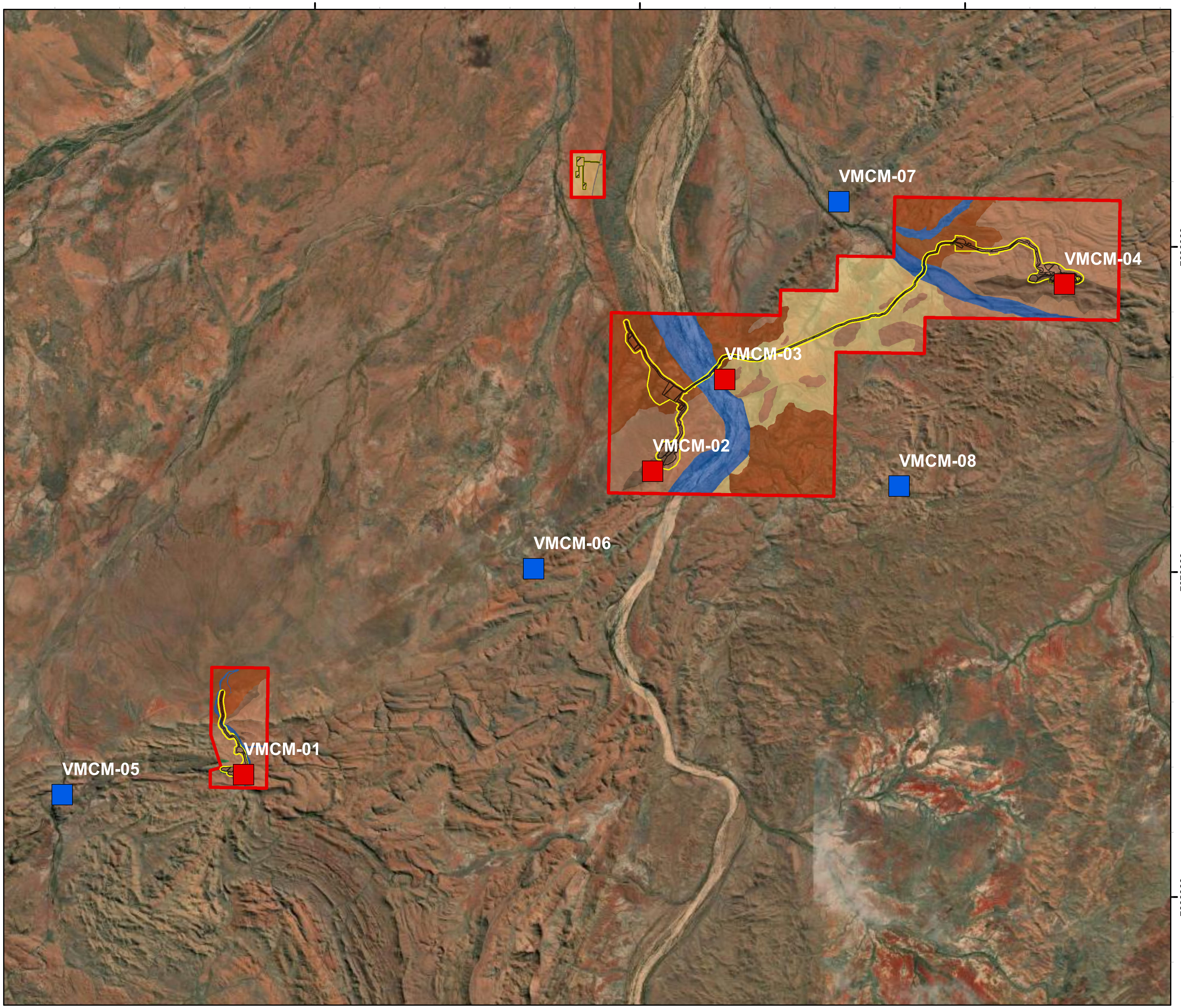
[1] Distance between Miralga Creek Project development envelope and closest motion-sensor camera
[2] Distance between Miralga Creek Project disturbance footprint and closest motion-sensor camera

2.3.2 Habitat Assessments

A habitat assessment was conducted at each monitoring site to describe the condition and complexity of habitat provided for northern quoll. Specifically, the following parameters were described:

- landform and soil features;
- vegetation structure, composition and condition;
- presence or absence of habitat structures;
- presence or absence of water; and
- types and levels of disturbance.

It is anticipated that these assessments are repeated in subsequent years, so that any habitat changes which might influence northern quoll activity can be identified and documented.



Legend

- Study Area
- Development Envelope
- Indicative Disturbance Footprint

Monitoring Sites

- Control
- Impact

Habitat Types

- Cleared/Disturbed
- Gorge/Gully
- Hillcrest/Hillslope
- Low Stony Hills
- Major Drainage Line
- Sandy Plain
- Stony Plain

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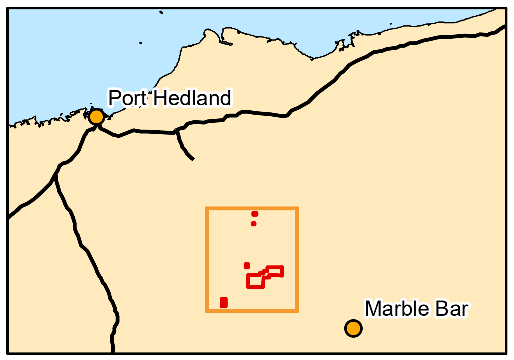
Scale: 1:110,000

0 1 2 3 4 Km

Coordinate System: GDA 1994 MGA Zone 50
Projection: Transverse Mercator
Datum: GDA 1994 Created 18/11/2021



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Miralga Creek Northern Quoll Monitoring 2020

Figure 2.2: Monitoring sites

2.3.3 Photo Point Monitoring

Two photo monitoring points were established at each site, marked *in situ* with a fence dropper (Table 2.3). A single photo was taken of the given site from each point. Point locations were chosen to ensure, as far as practical, that the entire site is captured in the photos. It is anticipated that similarly framed photos will be taken in subsequent years to provide a pictorial record of habitat changes at each monitoring site. Any documented habitat changes, which may include changes caused by natural events such as fire, or by anthropological disturbance such as mining activity, will help to explain patterns in the abundance of northern quoll recorded at the monitoring sites.

Table 2.3: Photo monitoring point locations

Site ID	Photo point ID	Latitude	Longitude
VMCM-01	VMCM-01-PPA	-21.1135	119.1930
	VMCM-01-PPB	-21.1146	119.1976
VMCM-02	VMCM-02-PPA	-21.0279	119.3124
	VMCM-02-PPB	-21.0268	119.3141
VMCM-03	VMCM-03-PPA	-20.9996	119.3318
	VMCM-03-PPB	-21.0044	119.3355
VMCM-04	VMCM-04-PPA	-20.9749	119.4386
	VMCM-04-PPB	-20.9742	119.4328
VMCM-05	VMCM-05-PPA	-21.1171	119.1381
	VMCM-05-PPB	-21.1164	119.1438
VMCM-06	VMCM-06-PPA	-21.0561	119.2777
	VMCM-06-PPB	-21.0528	119.2756
VMCM-07	VMCM-07-PPA	-20.9575	119.3648
	VMCM-07-PPB	-20.9514	119.3678
VMCM-08	VMCM-08-PPA	-21.0307	119.3846
	VMCM-08-PPB	-21.0322	119.3862

2.3.4 Motion Cameras

Ten cameras with the ability to detect northern quolls via heat and motion sensors, were deployed at each site. Each camera was fixed to a vertical star picket so it pointed directly downwards and star pickets were spaced approximately 100 m apart along an approximately 1 km long transect. The location of individual star pickets within each site was chosen to target microhabitats considered likely to be used by northern quoll, such as boulder piles and rocky tunnels and crevices which may be used for denning (but were also limited to locations containing substrate suitable for the installation of star pickets). To attract northern quoll to the field of view of each camera, a plastic tube (consisting of a 15-20-centimetre-long perforated and capped PVC pipe) containing universal bait was attached to the base of each star picket. It was anticipated that the consistent deployment of cameras in this way would assist the identification of individual northern quolls by ensuring images of the dorsal surface of individuals are captured within a standardised field of view, thereby allowing direct comparison of morphological characteristics such as size and spot patterning (Dunlop & Birch, 2019; Hohnen *et al.*, 2012). Cameras were deployed for four consecutive nights at each site, resulting in 40 camera nights for each site and 320 camera nights for the survey (Table 2.4; Appendix A).

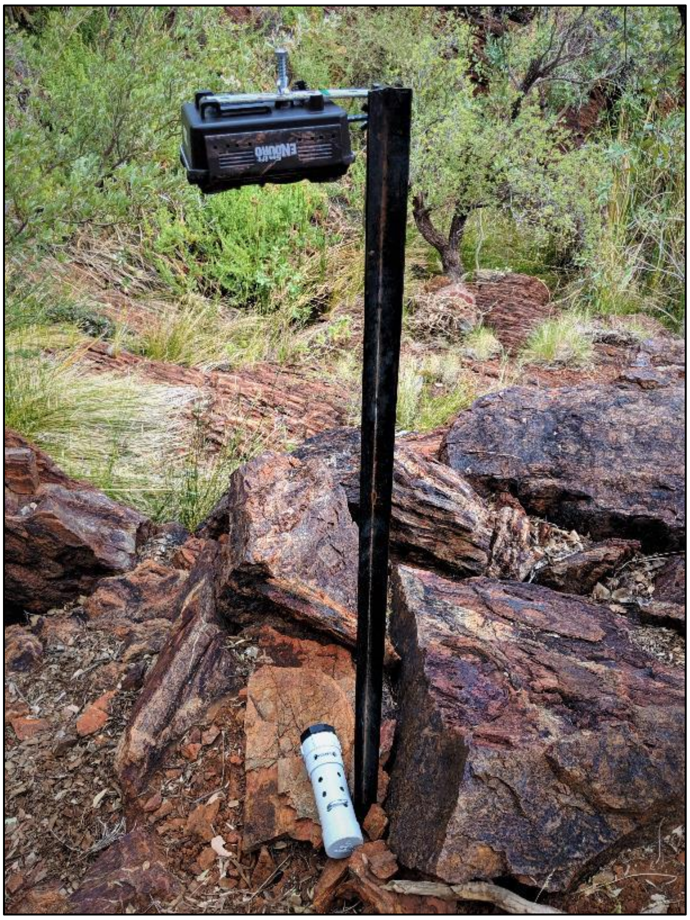

Plate 1: Example of motion camera setup

Table 2.4: Motion camera deployments

Site ID	Number of cameras	Date open	Date closed	Number of camera nights
VMCM-01	10	14/08/2020	18/08/2020	40
VMCM-02	10	16/08/2020	20/08/2020	40
VMCM-03	10	18/08/2020	22/08/2020	40
VMCM-04	10	16/08/2020	20/08/2020	40
VMCM-05	10	14/08/2020	18/08/2020	40
VMCM-06	10	19/08/2020	23/08/2020	40
VMCM-07	10	17/08/2020	21/08/2020	40
VMCM-08	10	17/08/2020	21/08/2020	40

2.3.5 Northern Quoll Identification

Photos and videos recorded on motion cameras were reviewed to identify images containing northern quolls. In the case of videos, still shots were extracted for further analysis. A manual review of all images was undertaken to identify individual northern quolls based on physical characteristics such as spot pattern, size and condition, as well as the timing of captures (Hohnen *et al.*, 2012). To verify the results of the manual review and further investigate any images of unidentified individuals, an analysis using Wild-ID software was conducted (Dartmouth University, 2011- Hanover, New Hampshire). To assist this analysis, images were cropped (to eliminate background information), rotated (so each captured individual faced in the same direction) and edited (to highlight spot patterns) to produce a set of highly comparable images. These were inputted into Wild-ID, which automatedly compared all images and produced a similarity rating of between 0 and 1 for each pair (0 indicating no similarity and 1 indicating a perfect match). Potential matches (i.e. pairs which were assigned a similarity rating of greater than 0) identified by the software were reviewed manually before the match was either accepted or rejected.

2.3.6 Capture Analysis

Detection events

Detections are defined as any instance in which a northern quoll was recorded on camera. Detections were amalgamated into ‘detection events’ based on their timing. If fewer than ten minutes passed between detections of the same individual, the resulting images were considered to belong to the same detection event. The detection rate of a given site is defined as the average number of detections events recorded at the site each night (i.e. the number of detection events divided by the number of camera nights).

Capture events

The occurrence of a unique northern quoll being recorded at a site during a given night is referred to as a capture event. If the same individual was detected at a site multiple times during the same night, it was considered to have been ‘captured’ only once that night. The capture rate of a given site is defined as the average number of unique individuals recorded at the site each night (i.e. the number of unique individuals divided by the number of camera nights). Capture rates can be compared between years to identify temporal patterns of change in the number of individuals being detected at each site by a systematic deployment of motion cameras. Comparing population size estimates (see Section 2.3.6) between years will provide additional information about changes in number of individuals thought to be present at each site.

The proportion of capture events which represent ‘recaptures’ – where an individual is recorded at the same site on a subsequent night of the survey – is referred to here as the ‘recapture rate’ (the number of recaptures divided by the total number of capture events multiplied by 100). Recapture rates can indicate the likelihood that more northern quolls were present than were detected, with relatively high recapture rates suggesting the survey was successful in identifying the majority of individuals which were present at the time of the survey.

2.3.7 Population Size Estimation

Capture event data were used to estimate the size of the northern quoll population inhabiting each site via closed capture-mark-recapture (CMR) models through the "RMark" package (Laake, 2013), which acts as an interface to the MARK software (White & Burnham, 1999) in the R environment (R Core Team, 2020). These models assume that the population size of each site does not change during the sampling period i.e. there is no immigration, emigration, recruitment or mortality. This is considered a reasonable assumption, given that sampling was conducted over four consecutive nights, during which time the potential for such changes is low. Due to the distance between sites and duration of the survey, this analysis also assumed that each site hosted a population that was distinct from those populations present at other sites i.e. northern quolls present at a given site will not be present at any other site.

Three 'Closed Full Likelihood' models were applied:

- *PcCc*. Capture and recapture probabilities are constant over time, but different from each other. This model allows for the possibility of trap shyness
- *Pc=Cc*. Capture and recapture probabilities are constant over time and are the same as each other. This model does not allow the possibility of trap shyness.
- *P.time=C.time*. Capture and recapture probabilities may vary over time but are always equal. This model does not allow the possibility of trap shyness.

The extent to which these models were applicable to the data available for each site depended on the number of captures and recaptures. Where it was possible to fit closed models, model-averaged estimates were calculated.

Not every detection event is going to consist of a clear image that can be incorporated into analyses of population size. When a detection event comprises unclear images, a decision must be made about whether the images are of known individuals or new individuals. As individuals are usually captured by multiple detection events, often over multiple nights, the occasional unclear image will more likely represent a known individual than a new one. Thus, incorporating unclear images as new individuals is likely to dramatically over-inflate the given population estimation. For this reason, population size estimations calculated for this survey excluded detection events comprised of unclear images.

2.4 Survey Team and Licencing

The survey was undertaken by Biologic personnel Mark Gresser (Senior Zoologist) and Aidan Williams (Zoologist), who collectively have more than six years' experience conducting fauna surveys of this nature within the Pilbara region. The fieldwork was conducted under a Regulation 27 licence (BA27000153-3) issued to C. Knuckey by the WA Department of Biodiversity, Conservation and Attractions.

3 RESULTS AND DISCUSSION

3.1 Site Description

The eight sites are broadly distributed across hills and ranges of banded iron-formation and sandstone supporting hummock grassland (Table 3.1; see Appendix C for images taken from the photo monitoring points). Five sites (VMCM-01, VMCM-03, VMCM-05, VMCM-07 and VMCM-08) are located either directly adjacent to or near seasonally inundated drainage lines (Table 3.1). Overall, the sites were in excellent condition (Table 3.1). Anthropological disturbances observed at or nearby sites included vehicle access tracks, cattle activity, historical mining and recent mining exploration activity. No disturbances are likely to have restricted northern quolls from accessing any of the monitoring sites.

Throughout the monitoring program, the impact sites will become increasingly disturbed as mining activities (i.e. clearing, construction, blasting, digging and hauling) progressively reduce the extent of habitat available nearby and introduce noise, vibration and dust. Future anthropological disturbance in the vicinity of the control sites is likely to be limited to the sporadic use of nearby access tracks by passing vehicles, as well as direct visitation of the sites during subsequent monitoring surveys.

Natural factors which might influence the distribution and abundance of northern quolls in the Study Area include fire and seasonal rainfall. Studies have reported delayed reproduction and low levels of recruitment after fire, and higher abundance in unburnt areas (Begg, 1981; Oakwood, 2000; Radford, 2012; Woinarski *et al.*, 2008). Rainfall influences the availability of prey and water resources relied upon by the species (Braithwaite & Griffiths, 1994; Oakwood, 2000). It is therefore important that fire and rainfall patterns are monitored throughout the monitoring program, to determine the extent to which they might be responsible for changes in northern quoll abundance recorded between years.

While impacts from previous fire in the local area of each site were minimal, signs of previous fire were generally common across the landscape in the form of patches of post-fire regeneration (e.g. young spinifex hummocks) (Table 3.1). Should these patches continue to regenerate in the absence of future fire events, it is likely that the overall quality of foraging and dispersal habitat present in the Study Area for the northern quolls will improve. This could lead to greater numbers of northern quolls being recorded during subsequent monitoring surveys.

The higher-than-average rainfall in the January preceding the survey (see Section 2.2) may have resulted in more water being available to northern quolls and their prey during the survey than is typically present. During the current survey, minor water pools providing a source of free water were observed in the vicinity of two impact sites (VMCM-01 and VMCM-03) and one control site (VMCM-07) (Table 3.1). It is possible that an absence of free water in subsequent years could reduce the suitability of habitat present in the Study Area for the northern quoll, leading to fewer individuals being recorded during subsequent monitoring surveys.

Table 3.1: Monitoring site descriptions

Site ID	Layout	Habitat type(s)	Composition	Habitat features	Existing disturbance
Impact sites					
VMCM-01	Camera transect crosses a drainage line from a gully to the side of rocky hill	• Low Stony Hills • Major Drainage Line	Rocky hills of sandstone and conglomerate support scattered trees (snappy gum *Eucalyptus leucophloia*) and shrubs (*Grevillea* and *Acacia*) over hummock (*Triodia*) grassland on a red-orange clay-loam substrate fully covered by stones. The seasonally active drainage line supports open woodland and tall shrublands (including river red gum *E. camaldulensis* and *Melaleuca* sp.) over tussock grasses, including the introduced buffel grass (*Cenchrus ciliaris*).	Moderately suitable denning habitat in the form of rocky crevices. Gully and drainage line are seasonally inundated and small pools were observed in both the gully and drainage line.	No anthropological disturbance observed in the immediate vicinity of the camera transect. The drainage line, when dry, is used as a vehicle access track, which provides access directly to the site. Hills to the east of the camera transect are recovering from relatively recent fire event, whereas hills west of drainage line have not been burned recently.
VMCM-02	Camera transect extends around steep upper slope of rugged ridgeline with breakaways and cliff faces	• Hillcrest/Hillslope • Low Stony Hills	Rocky hills composed of banded iron-formation, ferruginous chert, sandstone, conglomerate, siltstone and shale, support scattered trees (snappy gum *Eucalyptus leucophloia*) and shrubs (*Grevillea* and *Acacia*) over hummock (*Triodia*) grassland. Red-orange clay-loam substrate is mostly covered by stones, rocks and scattered boulders.	Highly suitable denning habitat (caves and deep rocky crevices). Occasional *Ficus*. Water-pooling will not occur. Closest significant drainage line occurs ~800 m southeast.	No anthropological disturbance observed in the immediate vicinity of the camera transect. Scattered patches on ridgetop are recovering from a recent fire event, whereas other patches have not been burned recently. The closest disturbance occurs on the ridge to the northeast where cleared vehicle access tracks and drill pads occur (~260 m from nearest camera). Site is accessed via these existing tracks, or by walking from an access track ~2.3 km northwest.
VMCM-03	Camera transect extends around low rocky hill adjacent to Shaw River.	• Low Stony Hills • Major Drainage Line	Rocky hills of sandstone and conglomerate support scattered trees (snappy gum *Eucalyptus leucophloia*) and shrubs (*Grevillea* and *Acacia*) over spinifex grassland. Red-orange clay-loam substrate is almost entirely by stones. Seasonally active drainage line supports open woodland and tall shrublands (including river red gum *E. camaldulensis*) over hummock (*Triodia*) and tussock grassland, including the introduced buffel grass (*Cenchrus ciliaris*).	Relatively few denning opportunities compared with other sites. Drainage line is seasonally inundated and small pools were observed against the bank.	Signs of anthropological disturbance are limited to drainage line where cattle activity (trampling and grazing) is high and buffel grass occurs. Site is accessed via rarely used minor vehicle track, which is reduced to tyre tracks in the vicinity of the site, approaching to within ~150 m of the camera transect.
VMCM-04	Camera transect extends along base of breakaway/cliff faces at upper slope of rugged ridgeline	• Hillcrest/Hillslope	Rocky hills composed of banded iron-formation, ferruginous chert, sandstone, siltstone and shale support scattered trees (snappy gum *Eucalyptus leucophloia*) and shrubs (*Grevillea* and *Acacia*) over hummock (*Triodia*) grassland. Red-orange clay-loam substrate is mostly covered by stones, rocks and scattered boulders.	Moderately-highly suitable denning habitat (caves and crevices). Occasional *Ficus*. Water-pooling will not occur. Closest significant drainage line occurs ~900 m south.	No anthropological disturbance observed in the immediate vicinity of the camera transect. Vehicle access tracks and drill pads have been cleared on ridgetop above (160 m from nearest camera). Site is accessed by walking from vehicle tracks on the ridgetop or from a vehicle track located approximately 1.2 km south.
Control sites					
VMCM-05	Camera transect extends around rocky hill between two gullies adjacent to medium drainage line	• Low Stony Hills	Rocky hills composed of banded iron-formation, ferruginous chert, sandstone, siltstone and shale support scattered trees (snappy gum *Eucalyptus leucophloia*) and shrubs (*Grevillea* and *Acacia*) over hummock (*Triodia*) grassland. Red-orange clay-loam substrate is almost entirely covered by stones. Nearby drainage line has formed within an area of quartz sandstone and quartzite which supports open woodland and tall shrublands (including river red gum *E. camaldulensis*) over spinifex and tussock grassland.	Low-moderately suitable denning habitat in the form of rocky crevices. Water-pooling unlikely to occur. Closest significant drainage line occurs 180 m northwest.	No anthropological disturbance observed in the immediate vicinity of the camera transect. Site is accessed via a rarely used vehicle track which passes through the drainage line ~160m from the camera transect. A disused mine pit (where mining ceased in November 2017) is located ~870 m to the southwest of the camera transect (a large hill and the drainage line lie between the camera transect and the pit.
VMCM-06	Camera transect extends along rocky ridgeline above stony plains	• Hillcrest/Hillslope	Rocky hills composed of banded iron-formation, ferruginous chert, sandstone, conglomerate, siltstone and shale, support scattered trees (snappy gum *Eucalyptus leucophloia*) and shrubs (*Grevillea* and *Acacia*) over hummock (*Triodia*) grassland. Red-orange clay-loam substrate is almost entirely covered by stones.	Moderately suitable denning habitat in the form of rocky crevices. Water-pooling will not occur. Closest significant drainage line occurs ~1.5 km southeast.	The camera transect is dissected by a vehicle track, which provides access directly to the site. Disused remnants of old mining activity at Lalla Rookh (mineshafts and associated infrastructure) are located ~400m north of the camera transect. Hills south of site are recovering from a recent fire event.
VMCM-07	Camera transect extends around rocky hills on both sides of a major drainage line	• Low Stony Hills • Medium Drainage Line	Rocky hills of sandstone and conglomerate support scattered trees (snappy gum *Eucalyptus leucophloia*) and shrubs (*Grevillea* and *Acacia*) over hummock (*Triodia*) grassland. The seasonally active drainage line supports woodland and tall shrublands (including river red gum *E. camaldulensis* and *Melaleuca* sp.) over hummock (*Triodia*) and tussock grassland, including the introduced buffel grass (*Cenchrus ciliaris*). Red-orange clay-loam substrate is mostly covered by stones.	Moderately suitable denning habitat in the form of rocky crevices. Drainage line is seasonally inundated and small pools were observed against the bank.	The drainage line is impacted by a high level of cattle activity (trampling and grazing) and buffel grass is present. Patches on surrounding hills are recovering from fire. Site is accessed via a vehicle track which passes within ~50 m of the camera transect.
VMCM-08	Camera transect extends around a rocky hill and into a wide gully which opens onto a medium drainage line	• Low Stony Hills • Medium Drainage Line	Rocky gully and hills of felsic volcanic rock support scattered trees (snappy gum *Eucalyptus leucophloia*) and shrubs (*Grevillea* and *Acacia*) over hummock (*Triodia*) grassland. Red-orange clay-loam substrate is mostly covered by stones.	Relatively few denning opportunities compared with other sites. Drainage line seasonally inundated and water-pooling may occur.	No anthropological disturbance observed in the immediate vicinity of the camera transect. Site is accessed via gravel road which passes within 120 m of camera transect.

3.2 Northern Quoll Captures

Northern quolls were recorded by 152 detection events across six of the eight sites (Table 3.2; Appendix D). No northern quolls were detected at the impact site VMCM-04, nor at the control site VMCM-08. For those sites where northern quolls were detected, the greatest number of detection events occurred at impact site VMCM-02 (57 detection events, equating to a detection rate of 1.425), whereas the fewest occurred at impact site VMCM-01 (4 detection events, equating to a detection rate of 0.1). Overall, more detection events were recorded at the impact sites (85 detection events) than the control sites (67 detection events).

A total of 45 individuals were identified, of which 23 were detected across the impact sites and 22 were detected across the control sites. For those sites where northern quolls were detected, the greatest number of individuals was identified at impact site VMCM-02 (16 individuals, equating to a capture rate of 0.4), whereas the fewest number of individuals was identified at impact site VMCM-01 (three individuals, equating to a capture rate of 0.075). No individuals were detected at more than one site and this result supports the use of closed mark-recapture models to estimate population size, which assume that individuals will not travel between monitoring sites during the monitoring period.

A total of 60% of the individuals identified were recorded by single detection events only, suggesting most of the identified northern quolls spent relatively short periods of time at each site, possibly because they were temporarily moving through the sites rather than occupying the sites as longer-term residents. Based on the proportion of individuals represented by single detection events at each site, more individuals spent longer periods of time at sites VMCM-03 and VMCM-05 (where 75% of individuals were represented by multiple detection events) than at sites VMCM-01, VMCM-02, VMCM-06 and VMCM-07 (where between 23% and 40% of identified individuals were recorded by multiple detection events) (Table 3.2).

It is surprising that no northern quolls were detected at VMCM-04. This site has not been burned recently and hosts opportunities for denning in the form of caves and rocky crevices. Furthermore, northern quolls have previously (May 2019) been recorded on motion camera within 260 m of the camera transect and scats of the species have previously been recorded within 90 m of the camera transect (Biologic, 2020a).

The fact that no northern quolls were detected at VMCM-08 may be because the site offers relatively few denning opportunities compared with other sites; however, it is not uncommon for northern quolls to be detected at sites located some distance away from suitable denning habitat and it is expected that the species would readily utilise the site while foraging and dispersing between surrounding areas of higher quality habitat (Biologic, 2021).

Table 3.2: Detection and capture data

Site	Number of detection events (detection rate)	Number of individuals identified (capture rate)	Number of capture events (recapture rate, %)	Proportion of individuals represented by single detection events (%)	Population estimate
Impact					
VMCM-01	4 (0.1)	**3** (0.075)	4 (25)	66.7	*
VMCM-02	57 (1.425)	16 (0.4)	28 (42.86)	62.5	**18.13**[2]
VMCM-03	24 (0.6)	**4** (0.1)	8 (50)	25	*
VMCM-04	0 (0)	-	-	-	*
Total (average rate)	85 (0.708)	23 (0.192[1])	40 (39.29[1])	-	NA
Control					
VMCM-05	20 (0.5)	**4** (0.1)	10 (60)	25	*
VMCM-06	20 (0.5)	**5** (0.125)	9 (44.44)	60	*
VMCM-07	27 (0.675)	13 (0.325)	18 (27.78)	76.9	**21.21**[2]
VMCM-08	0 (0)	-	-	-	*
Total (average rate)	67 (0.558)	22 (0.183[1])	37 (44.07[1])	-	NA
Total (average rate) – all sites	152 (0.475)	45 (14.1)	77 (41.56)	60	-

[1]Excludes consideration of sites where no individuals were detected.
[2]Average population estimate from three CMR models (see Appendix E for details).
* Data were insufficient for a reliable estimation of population size (see Appendix E for details about the 2021 analysis)
Red numbers provide an indication of population size, via population estimates where statistical analysis is possible, or via the number of individuals identified.

3.3 Population Size

Estimations of population size based on statistical analysis of capture/recapture data were achievable for two of the eight sites: VMCM-02, where 18.13 individuals were estimated, and VMCM-07, where 21.21 individuals were estimated (see Table 3.2). For the remaining six sites, the number of captures and recaptures were too low to allow statistical models to be applied effectively, as indicated by estimates with tiny or zero standard errors. Obtaining reliable estimations of population size at these sites would require more informative data, i.e. higher numbers of captures and recaptures. While greater sampling effort at these sites may provide more data, the size of the local population of northern quolls at these sites may still be too small, or the rate of recapture too low, to offer enough capture information for statistical models to be applied for an estimation of population size.

For VMCM-02 and VMCM-07, where 16 and 13 individuals were identified, respectively, the number of individuals identified at the sites underestimated the population size estimated for the sites, representing 88.3% and 61.3% of the estimated population size, respectively. It is therefore likely that more individuals were present within the Study Area than were detected on camera during the survey. This is supported by the fact that most capture events were of new individuals. More specifically, only 32 of the 77 capture events recorded during the survey were recaptures of previously identified individuals, equating to a recapture rate of 42%. Recapture rates at individual sites varied between 25% (VMCM-01) and 60% (VMCM-03) (see Table 3.2).

As new individuals continued to be captured up to and including the last day of the survey, it is likely that additional camera effort (i.e. a longer survey period) would have identified new individuals (Figure 3.1). It should be noted, though, that a longer sampling period may not necessarily help to detect all individuals present at a site – the fact that 60% of individuals were detected by single capture events suggests that a longer sampling period may only extend the period of time over which new individuals continue to be detected (e.g. as they move through the sites while dispersing between surrounding areas), rather than approach a finite number of individuals present. Provided that sampling effort remains consistent and comparable across subsequent monitoring surveys, the potential impact of sampling effort on estimations of abundance will be controlled.

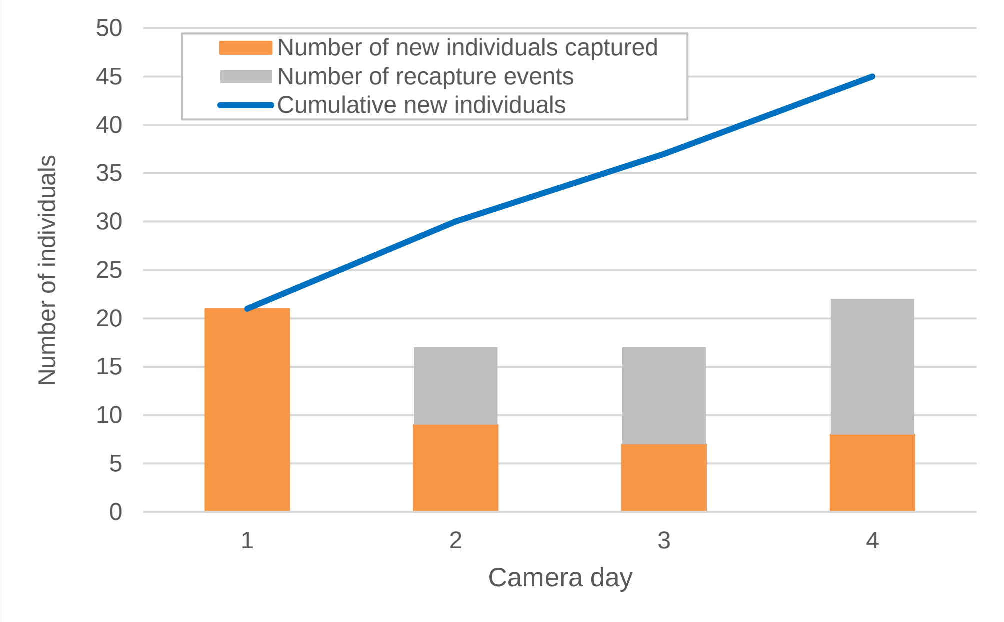

Figure 3.1: Number of individuals captured across the survey period

Although a longer sampling period may help to identify more individuals, it is still possible that the sampling effort employed during the current survey was sufficient to estimate the total number of quolls (or at least the vast majority) present at the time of the survey. This is supported by comparisons between the number of individuals identified in the Study Area during the current survey with the number of individuals identified during a May 2019 survey which involved trapping at VMCM-01 and VMCM-02 (Biologic, 2020a). Specifically, the population size estimate for VMCM-02 (18 individuals) is the same as the number of individuals identified at the site during this previous survey. Similarly, the number of individuals identified at VMCM-01 during the current survey (three individuals) is the same as the number of individuals identified at the site during the previous trapping survey. In any case, these results suggest that the number of northern quolls present in the Study Area was consistent between 2019 and 2020. It follows that the current survey was likely to have been successful in collecting reliable baseline information against which the results of subsequent monitoring surveys can be compared.

3.5 Limitations and Constraints

The EPA Guidance Statement No. 56 outlines a number of factors that can affect the adequacy of fauna surveys (EPA, 2016). These were assessed in relation to the current survey and no significant limitations or constraints were identified (Table 3.3).

Table 3.3: Survey limitations and constraints

Potential limitation or constraint	Applicability to this survey	Limitation to survey
Scope	The survey was undertaken using standardised and well-established techniques which are considered suitable for an ongoing monitoring program (DoE, 2016; Dunlop & Birch, 2019).	No
Survey effort and completeness	Eight monitoring sites were established and sampled over four consecutive nights as planned. The data collected allowed an analysis of the size of the local northern quoll population present at each monitoring site prior to mining, thereby providing sufficient baseline data for the purposes of an ongoing monitoring program.	No
Competency and experience of survey team	Field personnel consisted of qualified zoologists with extensive experience in conducting biological surveys in the Pilbara, including previous northern quoll monitoring surveys.	No
Efficacy of methods	Raw data used in population size estimate analyses excluded six detection events represented by unclear images from which individuals could not be identified. Four of these comprised images of a tail only (one at VMCM-03 and three at VMCM-07), while the other two comprised blurry images in which spot patterns could not be discerned (one at VMCM-06 and the other at VMCM-02). Whether these detection events are from new or otherwise identified individuals is not known. As 60% of individuals identified during the survey were represented by single detection events, it is fair to assume these detection events could represent new individuals. It is anticipated that subsequent monitoring surveys will consider unclear images in the same way, thereby enabling consistent and reliable comparisons of survey results between years. Subsequent monitoring surveys should also monitor the proportion of detection events which comprise unclear images – should they remain low, then the overall impact on the efficacy of the monitoring survey is considered negligible. (Biologic, in prep)No northern quolls were detected at one control site (VMCM-08), limiting its effectiveness as a control site. Future surveys could consider replacing this site with a new site located in suitable habitat elsewhere.	Partial
Timing of survey, weather, seasonality	The timing of this survey was chosen with consideration given to breeding behaviour i.e. the survey was conducted at the end of the mating season when northern quolls are most likely to be active and detectable. It is anticipated that subsequent monitoring surveys are conducted at the same time of year. Weather conditions experienced during the survey were considered supportive of normal northern quoll activity and are unlikely to have impeded the ability of the survey to detect the species.	No
Disturbances	The monitoring program is designed to track the occurrence of disturbances within the Study Area. Signs of historical and recent disturbances observed in the Study Area were described.	No
Availability of data and information	All contextual resources required to complete the assessment were available (previous capture data, environmental information, climate data).	No

4 CONCLUSION

This survey was successful in establishing eight sites suitable for an ongoing monitoring program designed to document changes in the distribution and abundance of northern quolls at the Miralga Creek Project as mining progresses. Replicable sampling methods were successfully applied to obtain baseline data describing the pre-mining size of the local northern quoll population present at these sites. Overall, a total of 45 individuals were identified across six of the eight monitoring sites and population size estimates based on statistical analysis were possible for two sites. These data will assist Atlas to identify whether mining activities associated with the Miralga Creek Project are having a significant impact on northern quolls and whether specific actions are required to manage the species in accordance with the SSMP. Specifically, Atlas are committed to employing specific management actions when: (a) the species is recorded at only a single impact site during at least three consecutive monitoring events; and/or (b) the number of individuals recorded at an impact site during a monitoring event is less than 50% of the number of individuals recorded at the site during a baseline monitoring survey. It follows, then, that the trigger levels related to (b) are: fewer than 1.5 individuals for VMCM-01; fewer than 9.1 individuals for VMCM-02; and fewer than two individuals VMCM-03. As no northern quolls were detected at VMCM-04, (b) does not apply to this site. Future monitoring conducted under the NQMP will determine the extent to which northern quolls continue to persist in the Study Area as mining progresses. The next monitoring survey is due to take place in August 2021.

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6 APPENDICES

Appendix A – Motion camera locations

Site ID	Camera ID	Latitude	Longitude	Site	Camera ID	Latitude	Longitude
VMCM-01	SY-178	-21.1130	119.1932	VMCM-05	SY-320	-21.1192	119.1396
	ACN-722	-21.1132	119.1930		ACN-133	-21.1198	119.1399
	SY-333	-21.1141	119.1929		SY-183	-21.1203	119.1403
	ACN-149	-21.1124	119.1941		ACN-719	-21.1189	119.1400
	SY-329	-21.1129	119.1940		ACN-822	-21.1187	119.1404
	ACN-148	-21.1135	119.1941		SY-328	-21.1181	119.1410
	SY-325	-21.1138	119.1948		ACN-751	-21.1179	119.1418
	SY-179	-21.1142	119.1957		SY-184	-21.1174	119.1423
	ACN-708	-21.1142	119.1969		ACN-727	-21.1165	119.1422
	SY-331	-21.1143	119.1980		SY-189	-21.1165	119.1416
VMCM-02	ACN-793	-21.0268	119.3128	VMCM-06	SY-331	-21.0547	119.2780
	ACN-698	-21.0271	119.3126		SY-322	-21.0546	119.2786
	SP-01	-21.0277	119.3123		ACN-822	-21.0541	119.2790
	ACN-724	-21.0285	119.3119		SY-184	-21.0535	119.2793
	ACN-720	-21.0291	119.3117		SY-189	-21.0531	119.2792
	ACN-007	-21.0267	119.3134		SY-179	-21.0553	119.2777
	ACN-128	-21.0270	119.3139		ACN-751	-21.0556	119.2771
	ACN-151	-21.0264	119.3145		SY-329	-21.0562	119.2765
	ACN-721	-21.0250	119.3142		ACN-149	-21.0569	119.2758
	ACN-185	-21.0257	119.3137		SY-279	-21.0572	119.2759
VMCM-03	SY-333	-20.9994	119.3354	VMCM-07	BSH-17	-20.9514	119.3665
	SY-178	-21.0002	119.3346		ACN-745	-20.9513	119.3672
	ACN-148	-21.0003	119.3336		ACN-131	-20.9514	119.3678
	SY-183	-21.0010	119.3328		ACN-645	-20.9511	119.3683
	ACN-719	-21.0018	119.3324		SY-315	-20.9504	119.3691
	SY-320	-21.0026	119.3329		ACN-004	-20.9501	119.3700
	ACN-708	-21.0022	119.3341		BSH-16	-20.9555	119.3647
	SY-328	-21.0018	119.3350		ACN-123	-20.9565	119.3645
	ACN-133	-21.0014	119.3361		AC-16	-20.9575	119.3648
	SY-325	-21.0009	119.3367		SY-332	-20.9572	119.3658
VMCM-04	ACN-726	-20.9740	119.4378	VMCM-08	ACN-730	-21.0302	119.3859
	ACN-132	-20.9740	119.4386		ACN-723	-21.0297	119.3867
	SY-148	-20.9742	119.4391		ACN-130	-21.0295	119.3876
	ACN-792	-20.9744	119.4397		BSH-13	-21.0298	119.3888
	ACN-206	-20.9749	119.4399		ACN-142	-21.0303	119.3883
	ACN-196	-20.9737	119.4368		ACN-124	-21.0308	119.3875
	ACN-020	-20.9735	119.4357		SY-327	-21.0312	119.3875
	SP-02	-20.9734	119.4345		AC-05	-21.0317	119.3879
	ACN-272	-20.9739	119.4336		BSH-06	-21.0320	119.3885
	ACN-127	-20.9738	119.4327		AC-13	-21.0321	119.3890

Appendix B – Monitoring site habitat assessments

Site ID	VMCM-01	VMCM-02	VMCM-03	VMCM-04	VMCM-05	VMCM-06	VMCM-07	VMCM-08
Latitude	-21.1129789	-21.02708211	-21.00130293	-20.97348206	-21.1192208	-21.0546496	-20.95149529	-21.0302562
Longitude	119.1932169	119.3130052	119.3338491	119.4339247	119.1395876	119.2781428	119.3668906	119.3859519
Assessment date	14/08/2020	15/08/2020	18/08/2020	15/08/2020	14/08/2020	19/08/2020	17/08/2020	17/08/2020
Habitat type(s)	Low Stony Hills, Major Drainage Line	Hillcrest/Hillslope, Low Stony Hills	Low Stony Hills, Major Drainage Line	Hillcrest/ Hillslope	Low Stony Hills	Hillcrest/ Hillslope	Low Stony Hills, Medium Drainage Line	Low Stony Hills, Medium Drainage Line
Aspect	East	Southeast	West	South	East	East	West	West
Slope	Steep	Steep	Low	Very Steep	Steep	Steep	Moderate	Steep
Soil type	Clay loam	Clay loam	Clay loam	Clay loam	Clay loam	Clay loam	Sandy clay loam	Clay loam
Soil availability	None discernible	Many small patches	Scarce	Few small patches	Scarce	Scarce	Scarce	Scarce
Burrowing suitability	Low	Nil	Low	Low	Low	Nil	Low	Low
Outcropping extent	Major outcropping	Extensive outcropping	Moderate outcropping	Extensive outcropping	Major outcropping	Moderate outcropping	Major outcropping	Moderate outcropping
Rock presence	Gravel (1-4cm)	Large Rocks (21-60cm)	Small Rocks (11-20cm)	Boulders (>61cm)	Pebbles (5-10cm)	Gravel (1-4cm)	Pebbles (5-10cm)	Pebbles (5-10cm)
Rocky cracks/crevices availability	Moderate	High	Low	Very high	High	Moderate	Moderate	Moderate
Vegetation types	Scattered eucalypts, spinifex hummock grassland	Scattered eucalypts, spinifex hummock grassland	Spinifex hummock grassland, scattered *Acacia*	Scattered eucalypts, spinifex hummock grassland	Scattered eucalypts, spinifex hummock grassland	Scattered eucalypts, spinifex hummock grassland, tussock grassland	Scattered eucalypts, spinifex hummock grassland, tussock grassland	Scattered eucalypts, spinifex hummock grassland
Leaf litter availability	Few small patches	Scarce	Scarce	Few small patches	Few small patches	Few small patches	Scarce	Scarce
Woody debris availability	Few small patches	Scarce	Scarce	Scarce	Scarce	Few small patches	Scarce	Scarce
Hollows <10cm	Scarce	None	Scarce	Scarce	Scarce	Scarce	Scarce	Scarce
Hollows >10cm	Scarce	None	Scarce	None	Scarce	None	Scarce	Scarce
Water presence	Prone to pooling	None	None	None	None	None	None	None
Fire age	Old (6+ yrs)	Recent (0- 2 yrs)	Old (6+ yrs)	Old (6+ yrs)	Old (6+ yrs)	Moderate (3- 5 yrs)	Old (6+ yrs)	Old (6+ yrs)
Habitat condition	1	0.8	0.8	1	1	0.8	1	1
Disturbances	Road/access track	Relatively recent fire affecting patches	Cattle grazing, weed invasion	Mining exploration	Road/access track, disused mine pit approx. 1km distant	Cattle grazing, mining exploration, road/access track, relatively recent fire affecting patches	Cattle grazing, road/access track	Road/access track
Notes	Small pools were present in drainage line. Several small water pools present in gully. Hills to southwest of site recovering from fire. Hills west of drainage line unburnt. Access track runs along drainage line.	Caves and crevices are abundant. Patches burned in recent years and other patches unaffected by recent fire. Hills across drainage line from camera line comprises lower quality habitat (less extensive breakaway and more extensive impacts from recent fire).	Relatively few denning opportunities compared with other sites. High cattle activity along drainage line. Small pools along riverbank. Disturbance is restricted to drainage line and hills are in excellent condition.	-	-	Hills south of site relatively recently burnt compared with surrounding areas	Immediate vicinity of camera line is in excellent condition. Patches of surrounding hills recovering from fire (young spinifex hummocks). Drainage line is impacted by cattle activity and access track. Small water pools present in drainage line.	Relatively few denning opportunities compared with other sites.

Appendix C – Photo monitoring point photos

Point ID (photo date)	Photo
VMCM-01-PPA (18/08/2020)	
VMCM-01-PPB (18/08/2020)	
VMCM-02-PPA (20/08/2020)	
VMCM-02-PPB (20/08/2020)	

Point ID (photo date)	Photo
VMCM-03-PPA (18/08/2020)	
VMCM-03-PPB (18/08/2020)	
VMCM-04-PPA (20/08/2020)	
VMCM-04-PPB (20/08/2020)	

Point ID (photo date)	Photo
VMCM-05-PPA (18/08/2020)	
VMCM-05-PPB (18/08/2020)	
VMCM-06-PPA (19/08/2020)	
VMCM-06-PPB (19/08/2020)	

Point ID (photo date)	Photo
VMCM-07-PPA (17/08/2020)	
VMCM-07-PPB (17/08/2020)	
VMCM-08-PPA (21/08/2020)	
VMCM-08-PPB (21/08/2020)	

Appendix D – Northern quoll detections

Site ID	Latitude	Longitude	Camera ID	Date (actual)	Time	Date (night of)	Northern quoll individual reference #
VMCM-01	-21.1129789	119.1932169	ACN-149	17/08/2020	1948	17/08/2020	3
	-21.1129789	119.1932169	SY-325	15/08/2020	2150	15/08/2020	1
	-21.1129789	119.1932169	SY-333	14/08/2020	2338	14/08/2020	2
	-21.1129789	119.1932169	SY-333	17/08/2020	1917	17/08/2020	2
VMCM-02	-21.02708211	119.3130052	ACN-007	17/08/2020	0211	16/08/2020	4
	-21.02708211	119.3130052	ACN-007	17/08/2020	1827	17/08/2020	4
	-21.02708211	119.3130052	ACN-007	18/08/2020	1921	18/08/2020	5
	-21.02708211	119.3130052	ACN-007	19/08/2020	0018	18/08/2020	6
	-21.02708211	119.3130052	ACN-007	19/08/2020	1918	19/08/2020	11
	-21.02708211	119.3130052	ACN-007	19/08/2020	2330	19/08/2020	12
	-21.02708211	119.3130052	ACN-128	16/08/2020	1911	16/08/2020	7
	-21.02708211	119.3130052	ACN-128	17/08/2020	0009	16/08/2020	7
	-21.02708211	119.3130052	ACN-128	18/08/2020	2213	18/08/2020	12
	-21.02708211	119.3130052	ACN-151	16/08/2020	1901	16/08/2020	6
	-21.02708211	119.3130052	ACN-151	16/08/2020	2105	16/08/2020	7
	-21.02708211	119.3130052	ACN-151	17/08/2020	0028	16/08/2020	7
	-21.02708211	119.3130052	ACN-151	17/08/2020	0045	16/08/2020	8
	-21.02708211	119.3130052	ACN-151	18/08/2020	2001	18/08/2020	7
	-21.02708211	119.3130052	ACN-151	18/08/2020	2219	18/08/2020	12
	-21.02708211	119.3130052	ACN-151	19/08/2020	0110	18/08/2020	7
	-21.02708211	119.3130052	ACN-151	19/08/2020	1846	19/08/2020	7
	-21.02708211	119.3130052	ACN-185	16/08/2020	2323	16/08/2020	8
	-21.02708211	119.3130052	ACN-185	17/08/2020	1842	17/08/2020	9
	-21.02708211	119.3130052	ACN-698	16/08/2020	1836	16/08/2020	10
	-21.02708211	119.3130052	ACN-698	16/08/2020	1854	16/08/2020	4, 12[1]
	-21.02708211	119.3130052	ACN-698	16/08/2020	1921	16/08/2020	4
	-21.02708211	119.3130052	ACN-698	16/08/2020	2008	16/08/2020	4
	-21.02708211	119.3130052	ACN-698	16/08/2020	2030	16/08/2020	13
	-21.02708211	119.3130052	ACN-698	16/08/2020	2205	16/08/2020	13
	-21.02708211	119.3130052	ACN-698	17/08/2020	0039	16/08/2020	13
	-21.02708211	119.3130052	ACN-698	17/08/2020	0244	16/08/2020	13
	-21.02708211	119.3130052	ACN-698	17/08/2020	0313	16/08/2020	14
	-21.02708211	119.3130052	ACN-698	17/08/2020	1814	17/08/2020	10
	-21.02708211	119.3130052	ACN-698	17/08/2020	1939	17/08/2020	13
	-21.02708211	119.3130052	ACN-698	17/08/2020	2058	17/08/2020	13
	-21.02708211	119.3130052	ACN-698	18/08/2020	0334	17/08/2020	13
	-21.02708211	119.3130052	ACN-698	18/08/2020	0551	17/08/2020	7
	-21.02708211	119.3130052	ACN-698	18/08/2020	1819	18/08/2020	13
	-21.02708211	119.3130052	ACN-698	18/08/2020	2025	18/08/2020	7
	-21.02708211	119.3130052	ACN-698	18/08/2020	2246	18/08/2020	15
	-21.02708211	119.3130052	ACN-698	18/08/2020	2310	18/08/2020	5
	-21.02708211	119.3130052	ACN-698	18/08/2020	2353	18/08/2020	16
	-21.02708211	119.3130052	ACN-698	19/08/2020	0033	18/08/2020	7
	-21.02708211	119.3130052	ACN-698	19/08/2020	1804	19/08/2020	4
	-21.02708211	119.3130052	ACN-698	19/08/2020	1947	19/08/2020	10
	-21.02708211	119.3130052	ACN-698	19/08/2020	2320	19/08/2020	4
	-21.02708211	119.3130052	ACN-720	17/08/2020	2005	17/08/2020	9

Site ID	Latitude	Longitude	Camera ID	Date (actual)	Time	Date (night of)	Northern quoll individual reference #
	-21.02708211	119.3130052	ACN-721	16/08/2020	2107	16/08/2020	13
	-21.02708211	119.3130052	ACN-721	16/08/2020	2323	16/08/2020	13
	-21.02708211	119.3130052	ACN-721	17/08/2020	1845	17/08/2020	9
	-21.02708211	119.3130052	ACN-721	18/08/2020	0450	17/08/2020	7
	-21.02708211	119.3130052	ACN-724	18/08/2020	2021	18/08/2020	17
	-21.02708211	119.3130052	ACN-724	19/08/2020	1819	19/08/2020	10
	-21.02708211	119.3130052	ACN-724	19/08/2020	2159	19/08/2020	18
	-21.02708211	119.3130052	ACN-793	16/08/2020	2036	16/08/2020	10
	-21.02708211	119.3130052	ACN-793	17/08/2020	0049	16/08/2020	4
	-21.02708211	119.3130052	ACN-793	17/08/2020	0459	16/08/2020	4
	-21.02708211	119.3130052	ACN-793	17/08/2020	1931	17/08/2020	NA[2]
	-21.02708211	119.3130052	ACN-793	18/08/2020	1905	18/08/2020	19
	-21.02708211	119.3130052	SP-01	18/08/2020	2042	18/08/2020	13
VMCM-03	-21.00130293	119.3338491	ACN-148	18/08/2020	2015	18/08/2020	20
	-21.00130293	119.3338491	ACN-148	19/08/2020	0049	18/08/2020	20
	-21.00130293	119.3338491	ACN-148	19/08/2020	0432	18/08/2020	21
	-21.00130293	119.3338491	ACN-148	19/08/2020	2334	19/08/2020	22
	-21.00130293	119.3338491	ACN-148	20/08/2020	0309	19/08/2020	22
	-21.00130293	119.3338491	ACN-148	20/08/2020	0402	19/08/2020	22
	-21.00130293	119.3338491	ACN-148	20/08/2020	1915	20/08/2020	22
	-21.00130293	119.3338491	ACN-148	20/08/2020	2022	20/08/2020	22
	-21.00130293	119.3338491	ACN-148	20/08/2020	2330	20/08/2020	22
	-21.00130293	119.3338491	ACN-148	21/08/2020	0340	20/08/2020	22
	-21.00130293	119.3338491	ACN-148	21/08/2020	2231	21/08/2020	22
	-21.00130293	119.3338491	ACN-148	22/08/2020	0230	21/08/2020	22
	-21.00130293	119.3338491	ACN-719	22/08/2020	0310	21/08/2020	22
	-21.00130293	119.3338491	SY-138	19/08/2020	1818	19/08/2020	NA[3]
	-21.00130293	119.3338491	SY-138	22/08/2020	0244	21/08/2020	22
	-21.00130293	119.3338491	SY-178	18/08/2020	1927	18/08/2020	20
	-21.00130293	119.3338491	SY-178	19/08/2020	0059	18/08/2020	20
	-21.00130293	119.3338491	SY-320	20/08/2020	0352	19/08/2020	23
	-21.00130293	119.3338491	SY-320	21/08/2020	1857	21/08/2020	22
	-21.00130293	119.3338491	SY-320	22/08/2020	0450	21/08/2020	21
	-21.00130293	119.3338491	SY-325	18/08/2020	1844	18/08/2020	20
	-21.00130293	119.3338491	SY-325	22/08/2020	0210	21/08/2020	20
	-21.00130293	119.3338491	SY-333	19/08/2020	0103	18/08/2020	20
	-21.00130293	119.3338491	SY-333	20/08/2020	0541	19/08/2020	23
VMCM-05	-21.1192208	119.1395876	ACN-751	15/08/2020	0237	14/08/2020	24
	-21.1192208	119.1395876	SY-138	14/08/2020	2051	14/08/2020	25
	-21.1192208	119.1395876	SY-138	16/08/2020	1826	16/08/2020	25
	-21.1192208	119.1395876	SY-184	16/08/2020	2015	16/08/2020	24
	-21.1192208	119.1395876	SY-184	18/08/2020	0152	17/08/2020	24
	-21.1192208	119.1395876	ACN-822	14/08/2020	1816	14/08/2020	26
	-21.1192208	119.1395876	ACN-822	14/08/2020	2013	14/08/2020	26
	-21.1192208	119.1395876	ACN-822	14/08/2020	2051	14/08/2020	26
	-21.1192208	119.1395876	ACN-822	14/08/2020	2141	14/08/2020	26
	-21.1192208	119.1395876	ACN-822	15/08/2020	0026	14/08/2020	26

Site ID	Latitude	Longitude	Camera ID	Date (actual)	Time	Date (night of)	Northern quoll individual reference #
	-21.1192208	119.1395876	ACN-822	15/08/2020	0111	14/08/2020	24
	-21.1192208	119.1395876	ACN-822	15/08/2020	0214	14/08/2020	24
	-21.1192208	119.1395876	ACN-822	15/08/2020	1818	15/08/2020	26
	-21.1192208	119.1395876	ACN-822	15/08/2020	1841	15/08/2020	26
	-21.1192208	119.1395876	ACN-822	15/08/2020	1930	15/08/2020	26
	-21.1192208	119.1395876	ACN-822	15/08/2020	2332	15/08/2020	27
	-21.1192208	119.1395876	ACN-822	16/08/2020	1810	16/08/2020	26
	-21.1192208	119.1395876	ACN-719	14/08/2020	2126	14/08/2020	25
	-21.1192208	119.1395876	SY-328	15/08/2020	0227	14/08/2020	24
	-21.1192208	119.1395876	SY-328	17/08/2020	2109	17/08/2020	25
VMCM-06	-21.0546496	119.2781428	ACN-822	22/08/2020	0230	21/08/2020	28
	-21.0546496	119.2781428	SY-179	19/08/2020	2026	19/08/2020	29
	-21.0546496	119.2781428	SY-179	20/08/2020	2241	20/08/2020	30
	-21.0546496	119.2781428	SY-179	21/08/2020	1841	21/08/2020	29
	-21.0546496	119.2781428	SY-179	22/08/2020	1837	22/08/2020	29
	-21.0546496	119.2781428	SY-179	22/08/2020	2030	22/08/2020	28
	-21.0546496	119.2781428	SY-184	19/08/2020	2112	19/08/2020	NA[2]
	-21.0546496	119.2781428	SY-189	19/08/2020	2027	19/08/2020	31
	-21.0546496	119.2781428	SY-189	19/08/2020	2118	19/08/2020	31
	-21.0546496	119.2781428	SY-189	21/08/2020	0512	20/08/2020	32
	-21.0546496	119.2781428	SY-189	22/08/2020	0233	21/08/2020	29
	-21.0546496	119.2781428	SY-189	22/08/2020	0245	21/08/2020	28
	-21.0546496	119.2781428	SY-322	19/08/2020	1917	19/08/2020	29
	-21.0546496	119.2781428	SY-322	22/08/2020	0218	21/08/2020	28
	-21.0546496	119.2781428	SY-322	22/08/2020	0444	21/08/2020	29
	-21.0546496	119.2781428	SY-329	20/08/2020	2029	20/08/2020	29
	-21.0546496	119.2781428	SY-329	20/08/2020	2314	20/08/2020	30
	-21.0546496	119.2781428	SY-331	21/08/2020	0306	20/08/2020	29
	-21.0546496	119.2781428	SY-331	21/08/2020	0541	20/08/2020	29
	-21.0546496	119.2781428	SY-331	21/08/2020	1824	21/08/2020	29
VMCM-07	-20.95149529	119.3668906	AC-16	17/08/2020	2028	17/08/2020	33
	-20.95149529	119.3668906	AC-16	17/08/2020	2053	17/08/2020	33
	-20.95149529	119.3668906	AC-16	18/08/2020	0313	17/08/2020	34
	-20.95149529	119.3668906	AC-16	18/08/2020	0353	17/08/2020	34
	-20.95149529	119.3668906	AC-16	18/08/2020	1915	18/08/2020	34
	-20.95149529	119.3668906	AC-16	19/08/2020	0346	18/08/2020	33
	-20.95149529	119.3668906	AC-16	19/08/2020	1922	19/08/2020	NA[3]
	-20.95149529	119.3668906	AC-16	20/08/2020	2108	20/08/2020	35
	-20.95149529	119.3668906	AC-16	21/08/2020	0222	20/08/2020	34
	-20.95149529	119.3668906	ACN-745	17/08/2020	2314	17/08/2020	36
	-20.95149529	119.3668906	ACN-745	18/08/2020	2041	18/08/2020	NA[3]
	-20.95149529	119.3668906	ACN-745	19/08/2020	2208	19/08/2020	NA[3]
	-20.95149529	119.3668906	BSH-16	18/08/2020	0418	17/08/2020	37
	-20.95149529	119.3668906	BSH-16	18/08/2020	2346	18/08/2020	38
	-20.95149529	119.3668906	BSH-16	19/08/2020	0001	18/08/2020	38
	-20.95149529	119.3668906	BSH-16	20/08/2020	2116	20/08/2020	39
	-20.95149529	119.3668906	BSH-16	21/08/2020	0146	20/08/2020	40

Site ID	Latitude	Longitude	Camera ID	Date (actual)	Time	Date (night of)	Northern quoll individual reference #
	-20.95149529	119.3668906	SY-315	19/08/2020	1909	19/08/2020	41
	-20.95149529	119.3668906	SY-315	21/08/2020	0118	20/08/2020	42
	-20.95149529	119.3668906	SY-315	21/08/2020	0242	20/08/2020	43
	-20.95149529	119.3668906	SY-315	21/08/2020	0425	20/08/2020	43
	-20.95149529	119.3668906	SY-332	17/08/2020	2328	17/08/2020	44
	-20.95149529	119.3668906	SY-332	18/08/2020	1944	18/08/2020	33
	-20.95149529	119.3668906	SY-332	18/08/2020	2120	18/08/2020	45
	-20.95149529	119.3668906	SY-332	19/08/2020	0034	18/08/2020	45
	-20.95149529	119.3668906	SY-332	19/08/2020	1816	19/08/2020	45
	-20.95149529	119.3668906	SY-332	20/08/2020	1813	20/08/2020	45

[1] Two individuals in the same video, counted as two separate detection events
[2] Could not be identified (blurry image)
[3] Could not be identified (tail only)

Appendix E – Population size estimation analysis results

This analysis assumes the monitoring sites are sufficiently distant to represent areas with distinct quoll populations. It also assumes that individuals can be uniquely identified by motion camera. Abundance has been estimated with closed capture-mark-recapture (CMR) models. These models assume a closed population, one with no changes in abundance for the duration of the study. This means there are no gains due to immigration or recruitment, nor losses due to emigration or mortality; a reasonable assumption with only four nights of sampling.

Three 'Closed Full Likelihood' models were applied: (i) "PcCc" – capture and recapture probabilities are constant over time, but different from each other (since recapture is different to capture, the possibility of trap-shyness is allowed); (ii) "Pc=Cc" – capture and recapture are the same and constant (no possibility of trap-shyness); and (iii) "P.time=C.time" – capture and recapture probabilities may vary over time, but are always equal (no possibility of trap-shyness).

Summaries of these models are presented below, along with a model-averaged estimated of total abundance (where possible). In the model summaries: '# parameters' is the number of parameters estimated; 'AICc' is a measure of model fit, whereby smaller values indicate better fit; 'Delta AICc' is the difference in AICc between a given model and that of the model above in the same table; 'weight' is the weight given to the model in obtaining the population size estimate by averaging across models; and 'Deviance' is a measure of difference between the model and that of a saturated ('perfect') model and is a measure of model fit, although this measure is influenced by the number of parameters.

Only two sites (VMCM-02 & VMCM-07) had sufficient data to obtain reliable estimates of abundance.

<u>VMCM-01</u>

The best fitting model is Pc=Cc. The N abundance estimate from this model is 3 and 95% CI (3,3); it is clear there is insufficient information in the data to be able to estimate N properly.

Number of observed individuals: 3

Model	No. parameters	AICc	Delta AICc	Weight	Deviance
Pc=Cc	2	18.385	0.000	0.821	10.044
PcCc	3	22.052	3.667	0.131	13.044
P.time=C.time	5	24.055	5.669	0.048	1.046

<u>VMCM-02</u>

Model averaged abundance 18.13068 95% CI= 16.18016 - 41.19927

Number of observed individuals: 16

Model	No. parameters	AICc	Delta AICc	Weight	Deviance
Pc=Cc	2	29.017	0.000	0.695	21.853
PcCc	3	31.219	2.203	0.231	21.852
P.time=C.time	5	33.497	4.481	0.074	19.496

VMCM-03

The best fitting model is Pc=Cc. The N abundance estimate from this model is 4 and 95% CI (4,4); it is clear there is insufficient information in the data to be able to estimate N properly.

Number of observed individuals: 4

Model	No. parameters	AICc	Delta AICc	Weight	Deviance
Pc=Cc	2	20.748	0.000	0.725	13.863
PcCc	3	22.742	1.995	0.267	12.781
P.time=C.time	5	29.732	8.984	0.008	11.770

VMCM-04

Number of observed individuals: 0

N estimate from Closed CMR: NA

VMCM-05

The best fitting model is Pc=Cc. The N abundance estimate from this model is 4 and 95% CI (4,4); it is clear there is insufficient information in the data to be able to estimate N properly.

Number of observed individuals: 4

Model	No. parameters	AICc	Delta AICc	Weight	Deviance
Pc=Cc	2	19.737	0.000	0.734	12.852
PcCc	3	21.806	2.069	0.261	11.844
P.time=C.time	5	29.732	9.995	0.005	11.770

VMCM-06

The best fitting model is Pc=Cc. The N abundance estimate from this model is 5 and 95% CI (5,5); it is clear there is insufficient information in the data to be able to estimate N properly.

Number of observed individuals: 5

Model	No. parameters	AICc	Delta AICc	Weight	Deviance
Pc=Cc	2	22.656	0.000	0.730	14.204
PcCc	3	24.711	2.054	0.261	13.464
P.time=C.time	5	31.631	8.975	0.008	13.599

VMCM-07

Model averaged abundance 21.20669 95% CI = 13.14396 - 480.8473

Number of observed individuals: 13

Model	No. parameters	AICc	Delta AICc	Weight	Deviance
Pc=Cc	2	21.922	0.000	0.636	18.779
PcCc	3	23.960	2.037	0.230	18.561
P.time=C.time	5	25.029	3.107	0.134	14.827

VMCM-08

Number of observed individuals: 0

N estimate from Closed CMR: NA