Greater Paraburdoo
Ghost Bat, *Macroderma gigas* - Contextual Study
June 2019

Prepared for
Rio Tinto Iron Ore

astron

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Abbreviations and Definitions

Abbreviation	Definition
Adit	The entrance to a mine shaft that is horizontal or near horizontal.
Astron	Astron Environmental Services
BOM	Bureau of Meteorology
cm	Centimetres
DBCA	Department of Biodiversity, Conservation and Attractions
Desktop survey area	A 30 km radius around Paraburdoo where the desktop assessment was undertaken
EPBC Act	*Environment Protection and Biodiversity Conservation Act 1999*
Field search area	The search areas determined as the project boundaries of Western Range, Paraburdoo/Eastern Range and Channar (24,732 ha)
Fecundity	The reproductive rate of an organism or population
g	Grams
GDA	Geocentric Datum of Australia
GIS	Geographical Information System
HSE	Health, safety and environment
IBRA	Interim Biogeographic Regionalisation for Australia
kHz	Kilohertz
km	Kilometres
m	Metres
Midden	A collection of scats and animal remains that indicate a frequently used feed site
mm	Millimetres
MNES	Matter of National Environmental Significance
Rio Tinto	Rio Tinto Iron Ore
Scat	Faecal matter
SM2	SM2BAT SongMeter bat detectors (Wildlife Acoustics Inc USA)
SM4	SM4BAT SongMeter bat detectors (Wildlife Acoustics Inc USA)
W	Watt
WC Act	*Wildlife Conservation Act 1950*
°C	Degrees Celsius

Executive Summary

Astron Environmental Services was commissioned by Rio Tinto Iron Ore to undertake a contextual analysis for the conservation significant Ghost Bat (*Macroderma gigas*) within the vicinity of the Greater Paraburdoo Hub. The conservation status of the Ghost Bat has recently been elevated to Vulnerable under the *Environment Protection and Biodiversity Conservation Act 1999* and Vulnerable (Schedule 3) under the *Wildlife Conservation Act 1950*. A key finding of the Level 1 targeted conservation significant fauna survey of Western Range conducted in 2018 was the recording of the Ghost Bat in the form of two confirmed diurnal roost caves and two echolocation recordings. Previous records have been scarce. To place these recent records into a regional context and gain a more detailed understanding of this species within the Greater Paraburdoo Hub, a contextual study was undertaken in late 2018.

The contextual study was completed in two parts; a desktop survey over a 30 kilometre radius of Greater Paraburdoo and a targeted field search across Western Range, Paraburdoo, Eastern Range and Channar. The field search area is approximately 24,732 hectares. The purpose of this assessment was to identify significant habitats for the Ghost Bat in the vicinity of Greater Paraburdoo and to describe this habitat within the local and regional context.

The desktop review combined data from database searches and previous surveys from within a 30 kilometre radius of Greater Paraburdoo. The review indicated nine Ghost Bat records (not including records from the current survey and targeted work at Western Range), which comprised seven echolocation recordings and two records from secondary evidence (assumed to be scat recordings).

The second part of the study was a field survey involving mapping of potential habitat and targeted survey for the Ghost Bat within the field search area. Survey effort was concentrated around Western Range, eastern Paraburdoo and Eastern Range, specifically in deeply incised, generally south facing gullies where typical roost cave habitats are known to occur. Habitats of the field search area were assessed and mapped according to their potential to support Ghost Bats, in particular the presence of roosting sites, feed cave sites and quality foraging sites.

A limited extent within the field search area (961 hectares; 4%) contains habitat considered as being high quality habitat for Ghost Bats. This is mainly restricted to the gorge/gully habitat, particularly in enclosed deeply incised and often south facing gullies. A total of 1,836 hectares (7%) of the field search area contains habitat considered as being of moderate quality habitat for Ghost Bats. This is associated with rocky habitat such as breakaways and ridgelines that are mainly north facing or large drainage features suitable as quality foraging sites. The vast majority of the field search area (21,935 hectares; 89%) contains habitat considered as being of low quality for Ghost Bats. This is associated with the majority of habitats across the Paraburdoo area that do not offer any roosting potential and with limited foraging capacity.

Eighteen caves were assessed with varying levels of importance assigned. One cave, Cave 6, was classified as a confirmed maternal roost as scats within this cave showed elevated progesterone levels supporting maternal breeding behaviour. Three caves, Cave 11, Cave 15 and Cave 18, were classified as potential maternal roosts/confirmed diurnal roosts due to their suitable characteristics and records of individuals present during the breeding season. Four caves were classified as confirmed diurnal roost sites, nine caves were classified as potential diurnal roosts and one cave was confirmed as a feed cave (nocturnal roost).

During the field surveys completed by Astron; and more recently by Biologic and Rio Tinto biologists, a total of 18 individuals have been sighted roosting in five caves. Six Ghost Bats have been observed roosting in Cave 6 on three separate occasions, five individuals at Cave 11, three individuals on two separate occasions in Cave 14, three individuals in Cave 15 and one individual in Cave 16. As such, five individuals represent the greatest number of individual separate records so far. The population of Ghost Bats within the field search area is considered to range between five and 11 individuals.

The number and distribution of Ghost Bat records from the desktop assessment and field surveys suggest that the Ghost Bat is relatively widely distributed but exists in small numbers within the Greater Paraburdoo region. This is consistent with the broader Hamersley subregion where Ghost Bats are also widely dispersed but occur in small numbers (approximately 350 individuals) with relatively few records of breeding sites.

This study has greatly improved the understanding around the presence of Ghost Bats and roosting sites within the Greater Paraburdoo area. Whilst little is still known about the seasonal movements and roost site fidelity of the local Ghost Bat population, this study provides a foundation upon which further survey work can be undertaken.

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1 Introduction

1.1 Project Background

Rio Tinto Iron Ore (Rio Tinto) is evaluating the potential development of the Greater Paraburdoo Iron Ore Hub in the Pilbara region of Western Australia, which involves the development of new deposits at Western Range and the expansion of existing operations at Paraburdoo and Eastern Range. A key finding of the recent Level 1 targeted conservation significant fauna survey of Western Range (Astron Environmental Services 2018c) was the recording of the Ghost Bat (*Macroderma gigas*). As this species represents a Matter of National Environmental Significance (MNES) species under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act), and given the infrequent recording of this species within the general Paraburdoo vicinity to date, further investigation was warranted.

The status of the Ghost Bat has recently been upgraded to Vulnerable under the EPBC Act and Vulnerable (Schedule 3) under the *Wildlife Conservation Act 1950* (WC Act)[1]. The Ghost Bat was recorded at four different locations during the survey, with two records from sightings in diurnal roosts and two from ultrasonic recordings (Astron Environmental Services 2018c). To put these records into context, a targeted field survey and desktop survey and literature review were commissioned. The survey was divided into two parts:

- Desktop survey over a 30 km radius of Paraburdoo.
- A targeted field survey including mapping of potential habitat within a 24,732 ha area including Western Range, Paraburdoo, Eastern Range and Channar (Figure 1).

This report presents the outcome of these desktop and field surveys and discusses the results in a local and regional context. Results from additional acoustic surveys following Astron's field surveys in 2018 have been incorporated into this report.

1.2 Scope and Objectives

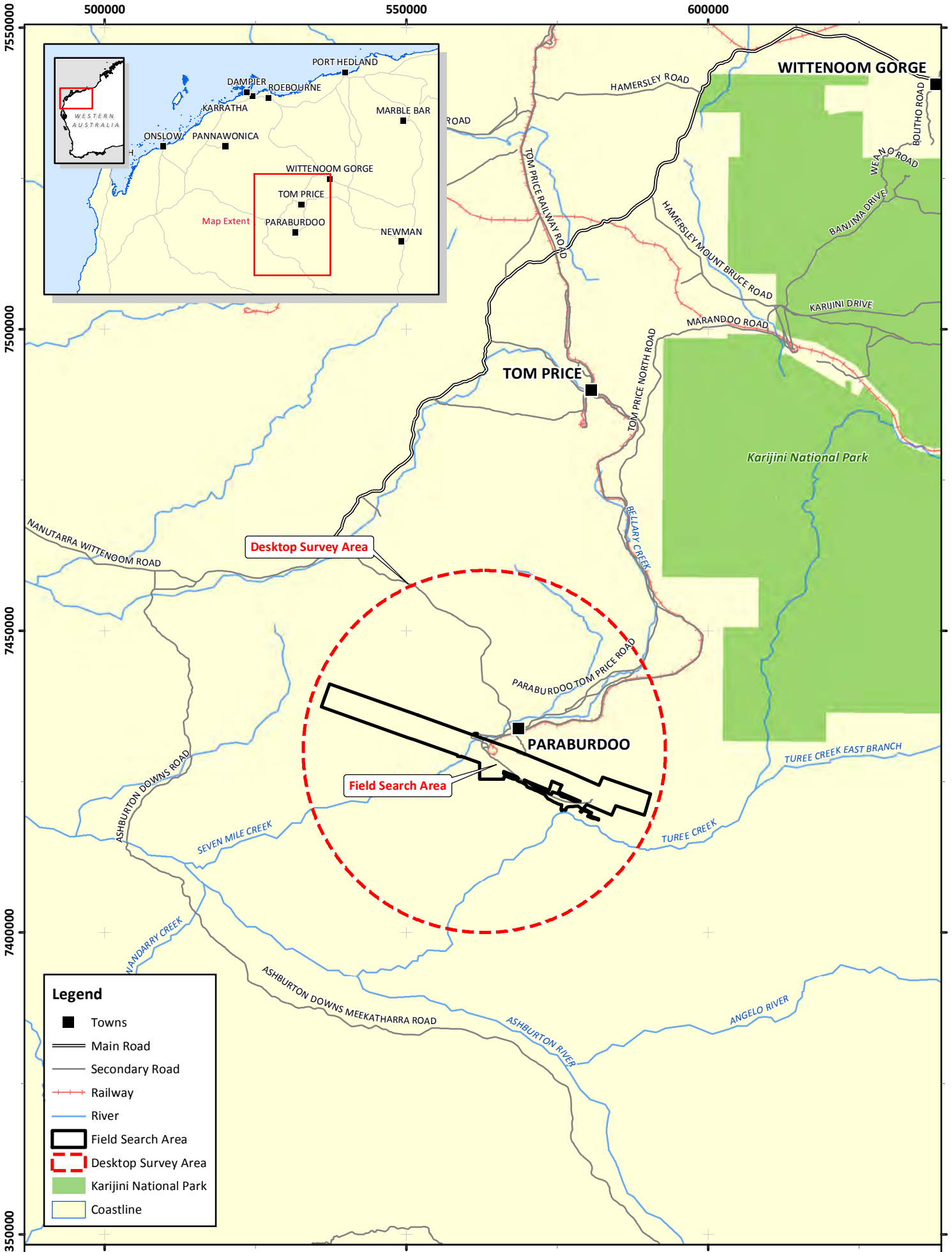
To obtain a contextual overview of the Ghost Bat within the vicinity of Paraburdoo, Astron Environmental Services (Astron) undertook a desktop review and targeted fauna survey. The desktop assessment combined data from database searches and previous surveys from within a 30 km radius of Paraburdoo, known as the desktop survey area (Figure 1).

A number of recent biological surveys have been completed within the vicinity of Paraburdoo, in particular at Western Range (Astron Environmental Services 2018c) and areas to the east at Paraburdoo, Eastern Range and Channar (Astron Environmental Services 2018b, 2018a). These assessments, and others (Section 3.1), have provided data on the Ghost Bat's presence and habitat within these areas. The field component of this survey concentrated on the project boundaries of Western Range, Greater Paraburdoo and Channar (field search area) with a strong focus at Western Range where recent Ghost Bat records have been observed.

Astron conducted the contextual study in accordance with the following:

[1]From 1 January 2019, the *Wildlife Conservation Act 1950* has been replaced by the *Biodiversity Conservation Act 2016* and its regulations. However the majority of this study was completed in 2018.

- Position Statement No. 3 (Environmental Protection Authority 2002)
- Technical Guidance - Sampling Methods for Terrestrial Vertebrate Fauna (Environmental Protection Authority 2016a)
- Technical Guidance - Terrestrial Fauna Surveys (Environmental Protection Authority 2016b)
- Survey Guidelines for Australia's Threatened Bats (Department of the Environment 2010).



Rio Tinto Iron Ore

Greater Paraburdoo Ghost Bat, *Macroderma gigas* - Contextual Study

Figure 1: Survey area location

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Author: M. Love	Date: 08-01-2019
Drawn: C. Dyde	Figure Ref: 14303-18-BIDR-1RevA_190108_Fig01_Locn

Datum: GDA 1994 - Projection: MGA Zone 50

0 5 10 15 20 25 30 Km

N

2 Environmental Context

2.1 Climate

The climate of the Pilbara region of Western Australia is classified as arid tropical with two distinct seasons: a hot, wet summer (October to April) and a mild, dry winter (May to September) (Bureau of Meteorology 2018).

Based on climatic data from the nearest Bureau of Meteorology weather station at Paraburdoo Aero (Station 007185), the mean annual rainfall since 1974 is 315 mm. The mean maximum daily temperatures range between 24.8°C and 40.6°C, and range above 30°C for much of the year (Bureau of Meteorology 2018) (Figure 2).

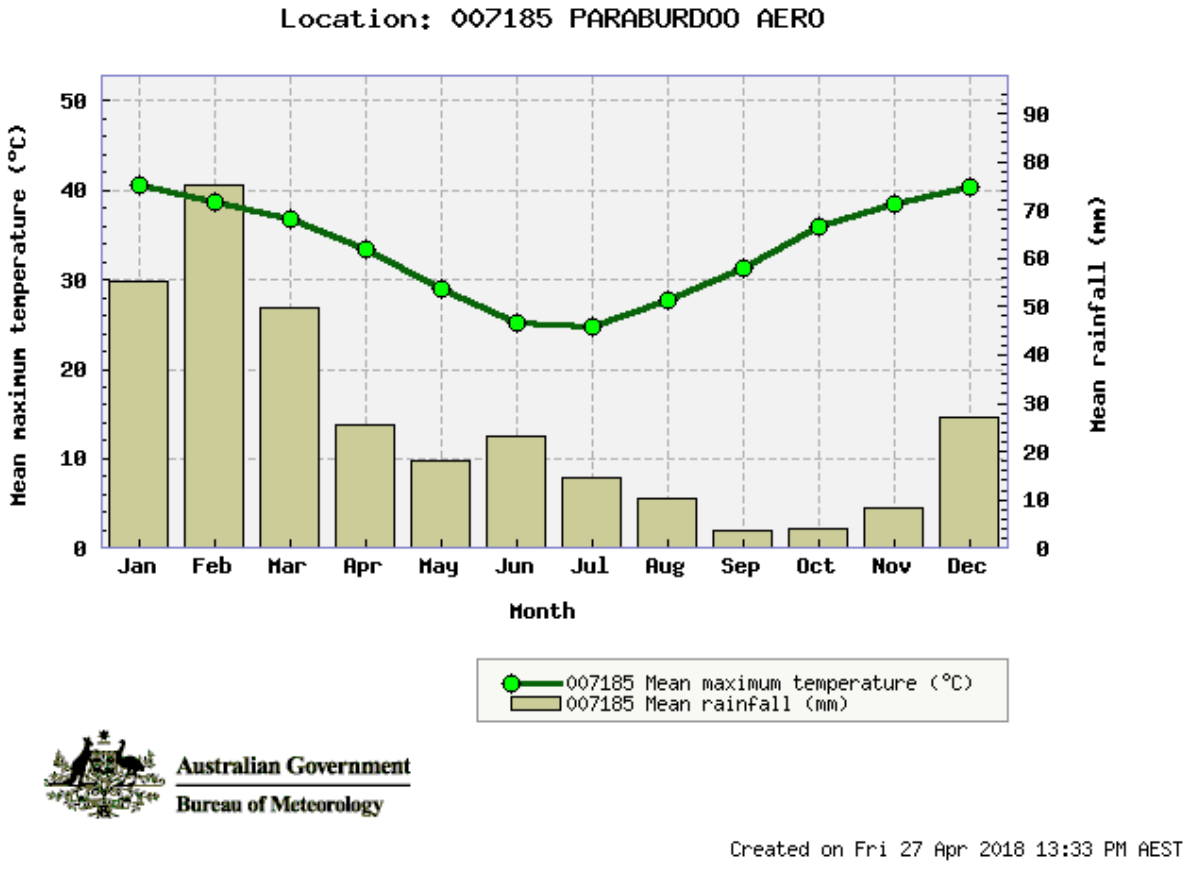

Figure 2: Climate data for Paraburdoo (Station 007185). Mean annual rainfall data has been calculated from 1974 – 2018 and mean maximum temperature has been calculated from 1966 – 2018 (Bureau of Meteorology 2018).

2.2 Geology and Soils

Twenty-four units of the surface geology mapped by Stewart et al. (2008) are found within the desktop survey area, with 14 of these found within the field search area (Table A.1 and Figure A.1; Appendix A).

2.3 Surface Water and Hydrology

No Wetlands of International Importance (i.e. Ramsar wetlands) or Nationally Important Wetlands occur within the survey area (Department of the Environment and Energy 2017a, 2017b). The

nearest Nationally Important Wetland is Mount Bruce Coolibah-Lignum flats located 95 km north-east of the survey area.

Drainage within the survey area runs off the hills mostly to the south, and eventually joins into the Minilya River south branch, to the south of the survey area. The drainage is part of the Ashburton River catchment.

2.4 Land Systems

The Interim Biogeographic Regionalisation for Australia (IBRA version 7) divides the Australian continent into 89 bioregions and 419 subregions (Department of the Environment and Energy 2017c). The IBRA regions represent a landscape-based approach to classifying the land surface, including attributes of climate, geomorphology, landform, lithology, and characteristic flora and fauna. The survey area occurs in the Pilbara and Gascoyne Bioregions, of which 5% to 10% is represented in the national reserve system (Department of the Environment and Energy 2017c).

The biodiversity of the 53 subregions recognised in Western Australia was documented as part of a national audit to provide priorities for conservation action (Department of Conservation and Land Management 2002). The survey area occurs within the Hamersley subregion of the Pilbara region and the Ashburton subregion of the Gascoyne region. These subregions are described in the audit as:

- Hamersley PIL3 – dissected bold plateaux and ranges of flat lying, moderately folded sandstone and quartzite with vegetation described as Mulga low woodland over tussock grasses occurring on fine textured soils in valley floors, with scattered snappy gum (*Eucalyptus leucophloia*) over *Triodia brizoides* on skeletal soils of the ranges (Kendrick 2001b).
- Ashburton GAS1 - mountainous range country divided by broad flat valleys of shales, sandstones and conglomerates with vegetation described as mulga or snakewood low woodlands over hardpans, with low mixed shrublands on hills and areas supporting large areas of *Triodia* (Kendrick 2001a).

Land systems of the Western Australian rangelands have been mapped and described by the Department of Agriculture and Food outlining the distributions and providing comprehensive descriptions of biophysical resources, including soil and vegetation condition. A total of 102 land systems occur in the Pilbara bioregion covering 181,723 km^2 and a total of 172 land systems occur in the Gascoyne bioregion covering 183,784 km^2.

Sixteen land systems occur across both areas, associated with the Pilbara and Gascoyne bioregions; 16 within the desktop survey area and 11 within the field search area (Table A.2; Appendix A). The most dominant land systems in the desktop survey area are the Marandoo system (71,212.6 ha) and Kooline system (65,964.1 ha) and the most dominant land systems in the field search area are the Newman system (13,931.5 ha) and Platform system (3,522.4 ha).

The layout of these land systems within the field search area is shown in Figure A.2 (Appendix A).

2.5 Ghost Bat, *Macroderma gigas*

2.5.1 Distribution and Conservation Status

The status of the Ghost Bat (*Macroderma gigas*) has been recently upgraded to Vulnerable under the Commonwealth EPBC Act and Vulnerable (Schedule 3) under the Western Australian WC Act.

This is due to the fact that the Ghost Bat has undergone a substantial decline across its distribution, including an estimated decline greater than 30% in the Pilbara population (Threatened Species Scientific Committee 2016).

Ghost Bats occur in the Pilbara (Armstrong and Anstee 2000; McKenzie and Bullen 2009), Kimberley including several islands (McKenzie and Bullen 2012), northern sections of the Northern Territory (including Groote Eylandt), and coastal and near coastal eastern Queensland from Cape York to near Rockhampton (Richards et al. 2008). Using modern, historical and subfossil data, Burbidge et al. (2009) found that the Ghost Bat occurred in 37 of Australia's 85 bioregions, and that it was extinct in 12 bioregions.

The Pilbara Ghost Bat population is estimated at 1,500 to 2,000 based on recently published estimates. This includes estimates of approximately 600 (N.L. McKenzie pers. comm. in McKenzie and Hall (2008)), approximately 1,200 based on Armstrong and Anstee (2000) and Robert Bullen's unpublished database summarising data from a range of surveys carried out in recent years by Pilbara mining companies, including Rio Tinto and other organisations (summarised in Threatened Species Scientific Committee (2016)). These recent data (estimates less than 15 years old) cover the entire Pilbara bioregion. Current population estimates in the Hamersley and Chichester subregions are approximately 350 and 1,500, respectively (Robert Bullen's unpublished database summarised in Threatened Species Scientific Committee (2016)).

Ghost Bat breeding populations are known from a small number of maternal roosts in the Pilbara; the largest of these colonies are in abandoned mines in the Chichester subregion and number up to several hundred (Armstrong and Anstee 2000). There is no known large, permanent maternal roost in the Hamersley subregion (Bat Call WA 2016). Hamersley Range populations occur in local groups of between 5 and 25 individuals (Bat Call WA 2016).

2.5.2 Relevant Biology/Ecology

The Ghost Bat is the largest microchiropteran bat in Australia, weighing up to 150 g and having a wingspan of 60 cm. It is Australia's only carnivorous bat. Its fur is light to dark grey above and paler below (Plate 1). It has long ears which are joined together, large eyes, a simple noseleaf and no tail (Richards et al. 2008). The Ghost Bat occurs in a wide range of habitats from the arid Pilbara to tropical savanna woodlands and rainforests and has a broad diet comprising small mammals, including other bats, birds, reptiles, frogs and large insects (Boles 1999; Schulz 1986; Pettigrew et al. 1986).

In the Pilbara, pregnancy in Ghost Bats has been recorded from August until September and births from October until December (Armstrong and Anstee 2000). Hoyle et al. (2001) studied the southernmost known colony in Queensland and found that female bats gave birth to a single young in late spring and females bred at age two to three years. At Mount Etna, Toop (1985) found that pregnant females congregated in the warmest caves and gave birth over a month commencing in mid-October. As caves became warmer as summer progressed, some mothers shifted the young to other caves. Juvenile bats commenced flying at seven weeks with all young capable of flight by the end of January. Ghost Bats disperse widely when not breeding, but concentrate in relatively few maternal roost sites when breeding. Few of these sites are known (Worthington Wilmer 2012; Richards et al. 2008), and most are not protected or managed.

Bat Call WA (2017) describes the roosting requirements of Ghost Bats as follows: "an 'apartment block' of roosting opportunities, at least one deep cave with characteristics of a maternal roost, multiple caves/shelters and overhangs in close proximity offering nocturnal feeding and refuge opportunities, a productive set of gullies and gorges locally, and a productive foraging area within a

5 km to 10 km radius, usually including a good quality riparian line and appropriate protection from human interference".

Roost sites include caves, rock crevices and disused mine adits. In the Hamersley Range in the Pilbara, preferred roosting habitat appears to be caves beneath bluffs of low rounded hills composed of Marra Mamba geology, and larger hills of Brockman Iron Formation; in the eastern Pilbara caves beneath bluffs composed of Gorge Creek Group geology and granite rockpiles are preferred (Armstrong and Anstee 2000). Ghost Bats use three types of roost regularly, these being nocturnal roosts or feeding sites, diurnal roosts that may be permanent or semi-permanent sites and maternal roosts that are diurnal roosts with the range of characteristics allowing regular or permanent occupancy:

- Nocturnal roosts or feeding sites are only used at night, either habitually or for transitory visits. They are typically shallow caves and shelters that are well lit during the day. They are often high in the strata and may be well or poorly insulated from the elements. They usually contain guano scatters and/or midden(s) of various sizes containing guano and food scraps.
- Diurnal roosts are generally deep, complex caves or disused mines that contain domed ceilings, fissures or passages which create a stable microclimate. They typically have one or more large chambers at or beyond the twilight area with additional fissures or chambers at the rear in the fully dark regions. They have a minimum roof height in the chambers of 2 m to 3 m providing protection from attack by terrestrial predators. They are often at mid-levels or lower in the strata and are well insulated overhead providing a stable temperature environment (McKenzie and Bullen 2009; Armstrong and Anstee 2000; Hall et al. 1997; Leitner and Nelson 1967). They typically contain multiple scat piles and middens of guano and food remains that include feathers and skeletal materials.
- Maternal roosts are diurnal roosts that provide additional features listed above that are able to support a reproducing population. These features usually include an interior chamber that is rising toward the rear thereby trapping warmer and more humid air at the top allowing suitable conditions to form during the period when reproductive females and pups are present (Armstrong and Anstee 2000; Churchill 1991; Churchill and Helman 1990; Pettigrew et al. 1986).
- Ghost Bats hunt their prey in two primary ways. They hunt birds and bats at cave entrances and elsewhere "air-to-air" by swooping from above or from a perch (Bat Call WA 2016). They also hunt ground level prey in their target food size range by dropping onto the prey from a perch, either a tree branch or rock outcrop (Bat Call WA 2016). Their diet includes small mammals such as other bats, birds, reptiles, frogs and large insects. The proportion of food items in the diet varies with availability and reported foraging areas vary from a few kilometres to over 10 km from the roost cave (Bat Call WA 2016).

2.5.3 Threats

Threats to the Ghost Bat have been outlined by Woinarski et al. (2014) and are summarised in Table 1.

Table 1: Summary of threats to the Ghost Bat (Woinarski, Burbidge, and Harrison 2014).

Threat factor	Consequence rating	Extent over which threat may operate	Evidence base
Disturbance of (human visitation at) maternal roost sites	Severe	Moderate	Ghost Bats easily disturbed and may abandon sites where disturbance occurs (K. Armstrong pers. comm., cited in. Woinarski et al. (2014)).
Habitat loss: destruction of, or disturbance to, roost sites (and nearby areas) due to mining	Moderate-severe	Moderate	Mt Etna and surrounding area contains maternal roost sites; some maternal roost sites destroyed; Mt Etna now protected in a national park and visited by tourists; declines reported at Mt Etna following mining (Worthington Wilmer 2012); Mount Consider cave west of Cairns destroyed; other sites still vulnerable; most Pilbara roosts are vulnerable to iron ore mining and the deterioration and disturbance of old underground gold and copper mines.
Collision with fences, especially those with barbed wire	Moderate	Moderate	Ghost Bats have low fecundity and survival (Hoyle, Pople, and Toop 2001), often fly at about fence height and substantial numbers are known to be killed when colliding with fencing wire (McKenzie and Bullen 2009; Armstrong and Anstee 2000).
Collapse or reworking of old mine adits	Minor-moderate	Minor-moderate	Many of the known maternal roosts are in old mine workings that are collapsing, flooding or subject to disturbance (Armstrong 2001; Hall et al. 1997) e.g. the Pine Creek colony roosts in an adit that is in danger of collapse (Richards et al. 2008).
Contamination by mining residue at roost sites	Moderate	Moderate	Several roosting sites in old mines have high levels of pollutants.
Disease	Unknown	Unknown	A possible herpes type virus appears to be affecting the Mt Etna population, but pathology yet to be confirmed (J. Augusteyn pers. comm., cited in Woinarski et al. (2014)).

3 Methodology

3.1 Desktop Assessment

Database searches were conducted to identify previous Ghost Bat records within a 30 km radius of Paraburdoo termed the desktop survey area (Table 2). The 30 km radius search area was used as it encompasses all of the recent survey work completed within the Greater Paraburdoo Hub including the search areas from Western Range through to Channar.

Table 2: Database searches and regional literature.

Source		Information	Administrating agency
Databases	*NatureMap* (Department of Biodiversity, Conservation, and Attractions 2018a)	List of species recorded, including threatened fauna	Department of Biodiversity, Conservation, and Attractions (DBCA)
	Threatened Species Database (Department of Biodiversity, Conservation, and Attractions 2018b)	List and details of the Ghost Bat (*Macroderma gigas*) recorded in vicinity of survey area	
	Rio Tinto Fauna Data Database	List and details of the Ghost Bat (*Macroderma gigas*) recorded in vicinity of survey area	Rio Tinto
Regional literature	Stewart, Sweet et al. (2008)	Surface geology of Australia	N/A
	Beard (1975)	Vegetation associations of the Pilbara region	N/A
	Van Vreeswyk, Payne et al. (2004)	Land Systems (geology, soils, and topography) and vegetation associations of the Pilbara region	N/A
	Previous survey reports and GIS data	List of fauna, particularly conservation significant species, previously recorded within or adjacent to study area	Various consultant reports

Relevant fauna surveys that have previously been commissioned by Rio Tinto within the vicinity of the contextual survey area and reviewed as part of this assessment are detailed in Table 3.

Table 3: Summary of literature review results from surveys conducted within the vicinity of the survey area.

Author (year)	Survey area and size (ha)	Survey level	Survey timing	Survey effort	Ghost Bat recorded
Astron (2018b)	Greater Paraburdoo 11,203 ha	Level 2 (two-phase)	August 2017 April 2018	Nine trapping sites, motion sensitive cameras, avifauna census, nocturnal searches and ultrasonic recordings targeting bat species.	*Yes
Astron (2018a)	Channar 7,305 ha	Targeted/ Level 1	April 2018	Targeted Northern Quoll trapping, avifauna census, motion sensitive cameras, nocturnal searches and ultrasonic recordings targeting bat species.	None recorded
Astron (2014)	Eastern Ranges 2,190 ha	Targeted/ Level 1	May 2014	Targeted searches of suitable habitat, motion sensor cameras and SM2 ultrasonic recorders were used to detect the presence of conservation significant fauna species.	Yes
Astron (2013)	Western Range 488 ha	Level 1	August 2013	Targeted searches of suitable habitat specifically for the presence of suitable bat roost caves and Northern Quoll dens.	Yes
Biota (2011)	Western Ranges 6,077 ha	Level 2 (two-phase)	October 2009 May 2010	Habitat assessments, 17 trapping sites, avifauna censuses at each trapping site, foot traverses, targeted searches for both vertebrates and invertebrates, and the use of Anabat SD1 ultrasonic recorders and harp traps.	Yes
Biota (2010)	Eastern Ranges 1,792 ha	Targeted/ Level 1	October 2010	Targeted searches of suitable habitat and Anabat SD1 ultrasonic recorders used to detect the presence of conservation significant fauna species.	Yes
Ecological (2016)	Doggers Gorge 272 ha	Level 1	August 2015	Level 1 survey to support a Native Vegetation Clearing Permit application.	None recorded
Ecologia (2011)	Paraburdoo 5,655 ha	Level 1	July 2011	Avifauna census, habitat assessments and Anabat II acoustic bat call recorders.	None recorded
GHD (2009)	Turee Syncline 3,075 ha	Level 2 (two-phase)	June 2008 October 2008	Eleven trapping sites, avifauna census, nocturnal searches and ultrasonic recordings targeting bat species.	None recorded
Mattiske (1998)	Paraburdoo 3,691 ha	Level 1	April 1998	Habitat assessments of 11 sites and opportunistic searches.	None recorded

* An unconfirmed call was made directly adjacent to the eastern boundary of the survey area.

3.2 Field Survey

3.2.1 Timing and Personnel

Four separate field surveys were undertaken within the field search area and involved a targeted conservation significant fauna assessment (Table 4). Field work was undertaken by Matthew Love and John Trainer who both have over 10 years of experience conducting vertebrate fauna surveys, specifically within the Pilbara region of Western Australia. Survey effort was concentrated to the west of Paraburdoo, specifically within the Western Range area, as these locations have revealed the most recent Ghost Bat records and data to date.

Table 4: Summary of field survey timing and location surveyed for Ghost Bat. X = survey conducted.

Survey	Personnel	Survey dates	Western Range	Paraburdoo/ Eastern Range	Channar*
1	Matthew Love and John Trainer	25 – 27 July 2018	X		
2		02 – 05 August 2018	X		
3		07 – 12 October 2018	X	X	
4	Matthew Love	04 December 2018	X		

*Channar constraints discussed in Section 3.3.

Further targeted Ghost Bat surveys, in the form of a VHF tracking program, scat collection for genetic and hormonal analysis and acoustic surveys were also conducted by Biologic Environmental Survey zoologists and Rio Tinto biologists from mid-December 2018 to mid-March 2019. The data and results from these surveys have been incorporated into this report.

3.2.2 Weather

Daily weather observations recorded from Paraburdoo Aero (Bureau of Meteorology station 007185) were used to describe local rainfall and temperatures preceding the survey (Figure 3). The annual rainfall recorded preceding the survey was slightly below (20 mm) the long-term mean of 315.1 mm recorded at Paraburdoo (Bureau of Meteorology 2018). Rainfall in the 12 weeks preceding the first field survey was slightly higher than the long term mean (75 mm versus 57 mm) owing to a large rainfall event in early June 2018 (Bureau of Meteorology 2018). The maximum daily temperatures during the field survey period ranged between 24.3°C and 39.6°C (Bureau of Meteorology 2018).

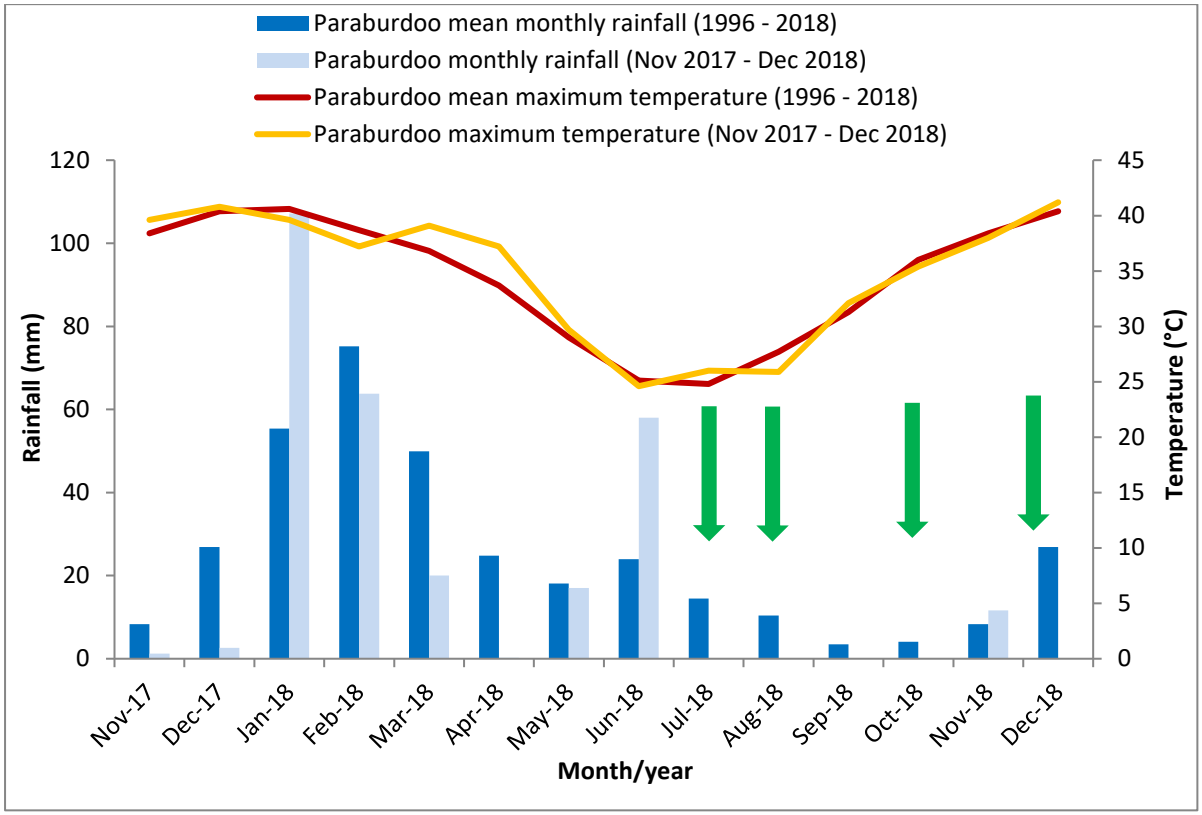

Figure 3: Paraburdoo Aero (station 007185) mean monthly rainfall (1996 – 2018), monthly rainfall (November 2017 – December 2018), long-term mean monthly maximum temperatures (1996 – 2018) and mean monthly maximum temperatures (November 2017 – December 2018). The green arrow indicates the field survey timing for Astron field surveys.

3.2.3 Acoustic Bat Survey

A total of 17 locations within the field survey area had either a SM2BAT SongMeter (Wildlife Acoustics Inc. USA) or SM4BAT bat detector set up, with a total of 693 nights of overnight bat acoustic recordings (Table 5 and Figure 4; Appendix B). The units were situated at the entrance of caves or overhangs or semi-permanent water sources where Ghost Bats were considered likely to forage (Plate 2). The units were left at these locations over varying periods of time ranging from one overnight recording (BAT4) to up to 127 overnight recordings (BAT8). BAT1, BAT6 and BAT7 were set up by Rio Tinto biologists independent to the Astron field visits listed in Table 4; data were provided to Astron for inclusion in this report. BAT5 and BAT8 to BAT15 were collected by Rio Tinto biologists outside of the Astron field visits listed in Table 4. Bat detectors were also set up and collected by Rio Tinto biologists in Cave 2 (BAT1), Cave 11 (BAT2), Cave 13, Cave 17 and Cave 18 in 2019.

The recordings were made using ultrasonic SM2 and SM4 units. The audio settings used followed the manufacturer's recommendations contained in the user manuals and included the full frequency range that Ghost Bats use during social and ultrasonic communication. Analysis of recordings was undertaken by Robert Bullen (Appendix D) (Bat Call WA 2019a).

Table 5: Summary of bat detector locations.

Astron ID	Cave number	Sample start date	Sample end date	Total night recordings	Details
BAT1	Cave 2	16/07/2018 08/02/2019	27/07/2018 13/03/2019	44	Potential diurnal roost
BAT2	Cave 11	03/08/2018 07/02/2019	05/08/2018 13/03/2019	36	Potential maternity roost/confirmed diurnal roost
BAT3	Cave 12	04/08/2018 07/02/2019	05/08/2018 13/03/2019	36	Potential diurnal roost
BAT4	-	04/08/2018	05/08/2018	1	Permanent pool (Pool 5)
BAT5	Cave 6	26/07/2018 10/12/2018	10/09/2018 13/03/2019	127	Confirmed maternity roost
BAT6	Cave 1	16/07/2018	27/07/2018	11	Confirmed diurnal roost
BAT7	-	16/07/2018	27/07/2018	11	Gorge
BAT8	Cave 14	08/10/2018	14/03/2019	120	Confirmed diurnal roost
BAT9	Cave 15	11/10/2018	14/03/2019	115	Potential maternity roost/confirmed diurnal roost
BAT11	Cave 1	04/12/2018	10/12/2018	6	Confirmed diurnal roost
BAT12	Cave 3	04/12/2018	10/12/2018	6	Potential diurnal roost
BAT13	Cave 4	04/12/2018	10/12/2018	6	Confirmed diurnal roost
BAT14	Cave 5	04/12/2018	10/12/2018	6	Feed cave
BAT15	Cave 16	04/12/2018	29/01/2019	45	Confirmed diurnal roost
-	Cave 13	07/02/2019	13/03/2019	34	Potential diurnal roost
-	Cave 17	10/01/2019	22/02/2019	43	Potential diurnal roost
-	Cave 18	07/02/2019	13/03/2019	35	Potential maternity roost/confirmed diurnal roost

3.2.3.1 Long-term Monitored Sites

The sites with greater than 50 continuous overnight recordings were classified as long-term monitoring locations. These locations were high quality habitat for the Ghost Bat such as a potential maternity or diurnal roost cave and were deemed worthy of thorough investigation.

Three locations (BAT5, BAT8 and BAT9) were utilised as long-term monitoring sites as these were caves with excellent roost properties: Cave 6 (BAT5), Cave 14 (BAT8) and Cave 15 (BAT9) (Table 5). A full-spectrum ultrasonic bat detector (SM4BAT FS model Wildlife Acoustics, USA) was deployed at the cave entrances and fitted with a microphone (SMM-U1). The settings used on the SM4 detector, in particular the minimum trigger frequency setting of 9 kHz allow the recording of any present Ghost Bats as they exit the cave. The SM4 detector was powered by a 12 volt battery that was charged during the day using a 50 W solar panel. Analysis of recordings was undertaken by Robert Bullen (Appendix D) (Bat Call WA 2019a).

3.2.4 Habitat Assessment

Habitats of the field search area were assessed and mapped on their ability to support Ghost Bats, in particular the presence of roosting sites, feeding sites and quality foraging sites. In this report, unless otherwise stated, the term 'roost sites' is the collective term for both maternal and diurnal roosts, and nocturnal roosts are colloquially termed 'feed caves'. Significant rocky habitats such as gorges, cliffs and breakaways were identified from aerial photographs or visual inspection during the field survey. If accessible, these habitat features were traversed by foot during the day and any caves or overhangs were inspected for signs of Ghost Bats and assessed on their suitability as roost caves or feeding sites.

Any cave or overhang that contained Ghost Bat scats and/or feeding remnants (typically feathers and small animal bones) and that were not classified as diurnal and/or maternal roosts, were classified as nocturnal roosts/feeding sites and their location was recorded. The overall concentration of nocturnal roosts/feeding sites is used to indicate the key locations where Ghost Bats forage (given their methods of hunting discussed in Section 2.5.2) and their distribution through the contextual survey area. The focus of the survey was to find and assess the presence of diurnal roosts and maternal roosts. Diurnal roosts were identified by the presence of Ghost Bats (visual observation, presence of scats or low call numbers from acoustic recordings) within or at a complex cave. Maternal roosts were identified by the presence of multiple Ghost Bats (visual observation or high call numbers from acoustic recordings) within or at a complex cave, and very large scat piles that are indicative of generational use (Plate 3). For this assessment, a complex cave is defined as one which contains domed chambers, internal passages or fissures, and is deep enough to provide a different microclimate (stable temperature and elevated humidity) to the ambient.

Cave assessment datasheets were completed at each roost site to document the caves' physical characteristics and their potential to support Ghost Bats. The following details were recorded:

- location – coordinates measured using a handheld GPS (GDA94)
- location on slope – the position of the cave on the slope relative to the top of the slope
- local foraging habitat – broad vegetation description, approximate distance to any nearby water
- entrance description – including aspect and approximate dimensions
- internal description (if visible) – cave depth and height; presence of features such as rear passages, domed chambers
- evidence of bats
- photographs of the cave entrance.

Habitats were rated and mapped as high, moderate or low quality based on the significance each habitat has within the Ghost Bat's ecological requirements. The Ghost Bat habitats were classified according to the criteria detailed in Table 6.

Table 6: Suitability/significance of habitat criteria for Ghost Bats.

High quality habitat *Potential/confirmed roosting habitat*	**Moderate quality habitat** *Potential/confirmed feeding sites and quality foraging habitat*	**Low quality habitat** *Widespread foraging habitat*
Rocky habitats containing, or classified as likely to contain, maternal roosts and/or diurnal roosts.	Habitats containing or likely to contain shallow feeding sites/nocturnal roosts; areas of permanent water sources and drainage lines suitable for foraging and are likely to be used on a regular basis.	Widespread habitat providing foraging potential only.

535000 540000 545000 550000 555000 560000

7440000 7435000 7430000 7425000

BAT 1 BAT 2
BAT 4
BAT 9
BAT 3
BAT 5 BAT 6
BAT 15
BAT 14
BAT 13
BAT 12 BAT 7
BAT 8

4.1
4.2

BAT 4
BAT 9
BAT 3

BAT 5
BAT 6 BAT 11
BAT 15
BAT 14
BAT 7 BAT 13
BAT 12

Bat Sites
Rio Tinto Supplied Tracklogs
Greater Paraburdoo GPS Tracklogs
Western Range FV1/2 GPS Tracklogs
Field Search Area

Rio Tinto Iron Ore

Greater Paraburdoo Ghost Bat, *Macroderma gigas* - Contextual Study

Figure 4.1: Survey effort

Coordinate System: GDA 1994 MGA Zone 50

0 1 2 3 4 5 Kilometres

N

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Author: M. Love | Drawn: C. Dyde | Date: 13-06-2019 | Figure Ref: 14303-18-BIDR-1RevA_190613_Fig04_SurvEff

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7435000 7430000 7425000 7420000

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4.1

4.2

Towns

Greater Paraburdoo GPS Tracklogs

Western Range FV1/2 GPS Tracklogs

Field Search Area

Rio Tinto Iron Ore

Greater Paraburdoo Ghost Bat, *Macroderma gigas* - Contextual Study

Figure 4.2: Survey effort

Coordinate System: GDA 1994 MGA Zone 50

0 1 2 3 4 5 Kilometres

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Author: M. Love | Drawn: C. Dyde | Date: 13-06-2019 | Figure Ref: 14303-18-BIDR-1RevA_190613_Fig04_SurvEff

3.3 Survey Limitations

The targeted survey was assessed against the potential limitations suggested in Guidance Statement 56 for fauna surveys (Environmental Protection Authority 2016b). Table 7 lists the key limitations of the targeted survey.

Description of internal dimensions and cave properties was limited to what could be safely observed in each individual cave. Due to the complex nature of the rocky environment within roost caves, not all of the aspects of the caves could be safely surveyed. For example, there is the potential that small cracks and crevices could lead to other chambers which house Ghost Bats, which have been missed purely due to a lack of accessibility into these areas. This is also relevant to ledges and other features at height within a cave that cannot be safely accessed.

Although the Greater Paraburdoo area has been extensively surveyed for fauna, not all of the field search area has been directly assessed for Ghost Bat presence/suitability. This is particularly evident within Channar where access into high quality habitat was hindered by site access restrictions and no targeted Ghost Bat habitat searches were able to be undertaken. The Ghost Bat habitat mapping for this portion of the field search area was inferred from existing fauna habitat mapping.

Table 7: Statement of limitations for the targeted Ghost Bat survey.

Potential limitation	Statement regarding potential limitations
(i) Competency/experience	The zoologists responsible for conducting the survey have extensive experience in conducting vertebrate fauna surveys, including targeted bat surveys in the Pilbara.
(ii) Scope What faunal groups were sampled and were some sampling methods not able to be employed because of constraints such as weather conditions.	The survey scope was able to be completed with a total of 182 nights of SM2/SM4 echolocation recording and cave assessments undertaken in significant habitats. Internal cave inspections were undertaken at significant roost locations to better understand these sites. Harp trapping or thermal imaging was not required as part of the scope of this survey.
(iii) Proportion of fauna identified, recorded and/or collected	This was a targeted Ghost Bat survey and focused mainly on this species and did not record any other species or assemblages. It is not possible to determine Ghost Bat abundance/population number from echolocation records; Ghost Bat activity levels provide a relative measure of the population within the contextual survey area.
(iv) Sources of information Previously available information (whether historic or recent) as distinct from new data.	Adequate information was available from database searches and previous studies in the Paraburdoo area and desktop survey area and region.
(v) Proportion of task achieved Further work which might be needed?	The field survey and the desktop assessment were undertaken and considered complete. Any further data required such as population estimates and numbers using each maternal roost are outside of the scope of this assessment and would require a more detailed work program.

Potential limitation	Statement regarding potential limitations
(vi) Timing/weather/season/ cycle	The surveys were conducted in July, August, October and December 2018, primarily to avoid interruption during the breeding season. Human visitation to roost caves particularly during the breeding season is seen a serious risk to this species' breeding habits. Often individuals are 'flushed' from caves and may not return to that roost cave. However the timing of the surveys also allowed an inference to be made as to whether the caves were used for breeding, particularly during the October survey when Ghost Bats congregate in a centralised maternity cave for breeding purposes. The entrance into potential maternal and or confirmed diurnal roost caves were limited as much as possible. Weather is not seen to affect the survey outcomes as the Ghost Bat roosts during the day and is generally independent of the cave microclimate. Roost caves have high humidity and high temperature levels which are maintained due to the properties of the cave and the insulating layer of rocky material that buffers caves thereby reducing any humidity and temperature fluctuations. Also, bat species generally emerge from their roosts each night independent of season.
(vii) Disturbances e.g. fire, flood, accidental human intervention which affected results of survey	No disturbance affected the survey outcomes for the field surveys.
(viii) Intensity In retrospect, was the intensity adequate?	The intensity of the surveys was considered adequate to ground-truth the desktop assessment and to assess potential areas of significance.
(xi) Completeness Was the relevant area fully surveyed?	Due to the large survey area and the fact that assessments had to be completed on foot, not all breakaways/gorges could be assessed. The points of interest identified during the desktop assessment were suitably covered with all other areas mapped via aerial photographs.
(x) Resources Degree of expertise available in animal identification to taxon level.	All personnel involved in identification have extensive experience in conducting bat monitoring surveys in the Pilbara. All bat call identifications were conducted by Robert Bullen (Bat Call WA) who is considered an expert in this field.
(xi) Remoteness and/or access problems	The majority of significant habitats were able to be accessed by vehicle or on foot. There were two areas classified as high quality habitat that were not able to be assessed due to lack of access.
(xii) Availability of contextual information e.g. biogeographic information on the region.	Database searches and previous fauna surveys in the desktop survey area provided by Rio Tinto provided contextual information.

4 Results

4.1 Desktop Assessment

The database searches and literature review indicate that only nine Ghost Bat records (not including records from the current survey and Astron (2018c)) exist within 30 km of the Paraburdoo area (Table 8; Figure 5). The majority of these records were generated through echolocation recordings (seven records); however, two records were generated from secondary evidence, which were assumed to be scat recordings. Echolocation recordings provide information on the presence of this species at the location only and do not provide data on relative abundance or habitat context (i.e. foraging individual versus roost site) unless stated.

Thirteen caves were previously recorded within the Western Range portion of the field search area during a previous fauna assessment (Astron Environmental Services 2013). These caves have high potential to support the Ghost Bat and the conservation significant Pilbara Leaf-nosed Bat (*Rhinonicteris aurantius*) with one recording as a Ghost Bat feeding site (Astron Environmental Services 2013).

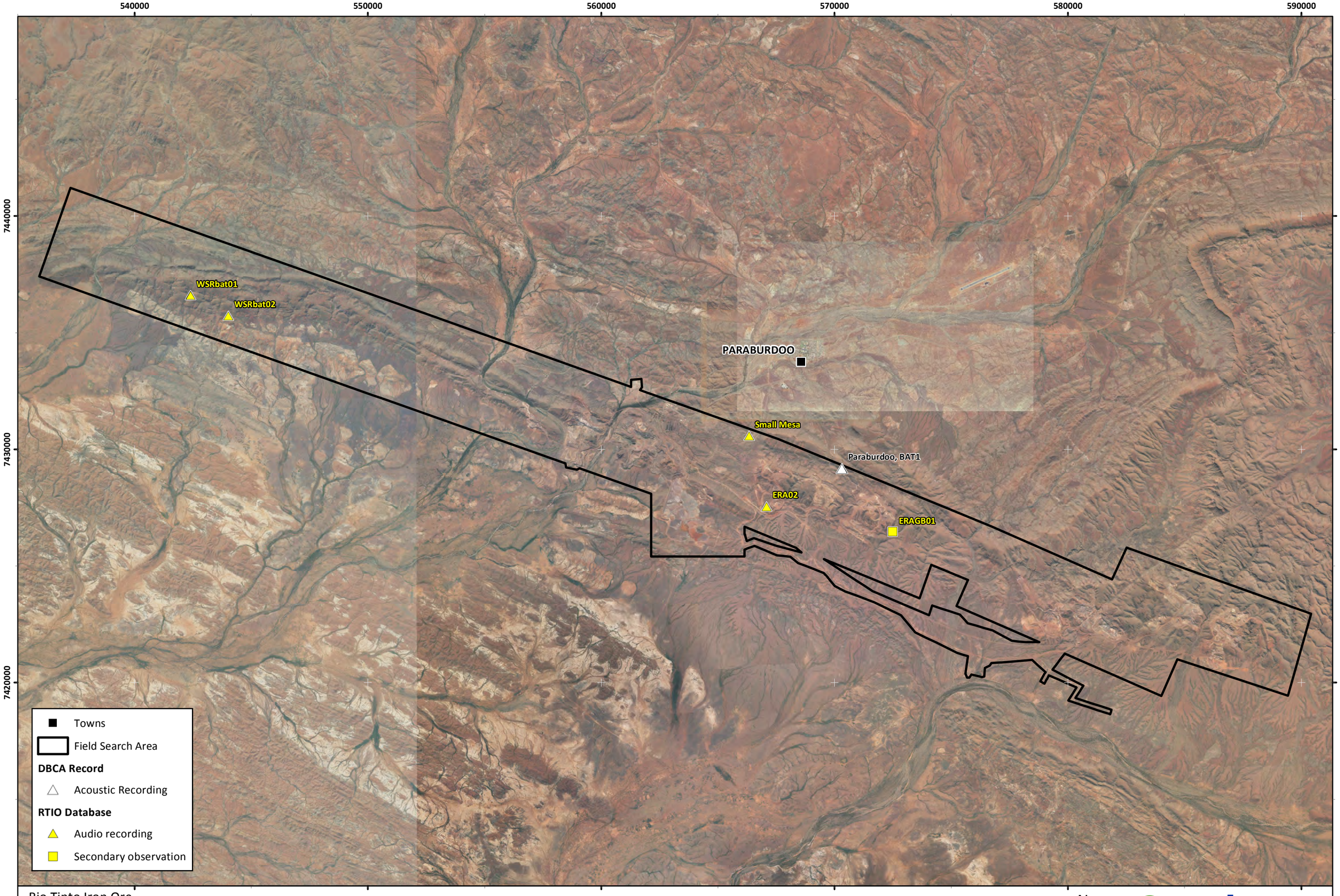
At Eastern Range a small number of Ghost Bat calls were also recorded from a cave entrance during a previous fauna assessment on a small mesa in the north-west corner of the Paraburdoo/Eastern Range portion of the field search area (Bat Call WA 2014). Also, 15 cave assessments were undertaken from outside the cave entrance, of which five caves had evidence of bat species using the caves, such as guano and bat odour, although no signs of evidence that could be attributed to the Ghost Bat (Astron Environmental Services 2014).

The Ghost Bat was recorded at four different locations during the Level 1 targeted survey at Western Range; two records from sightings in diurnal roosts (Cave 1, Cave 4) and two from ultrasonic recordings (Astron Environmental Services 2018c). Cave 1 (confirmed diurnal roost) had one individual recorded and Cave 4 (confirmed diurnal roost) had three individuals recorded (Astron Environmental Services 2018c). Both of these caves were found within the same gully nearing the eastern boundary of Western Range.

Of further note is a single record (two possible calls) from a Ghost Bat that was recorded during the Greater Paraburdoo fauna assessment (Astron Environmental Services 2018b); although this record is considered unconfirmed and hence not included in the desktop assessment.

Table 8: Summary of Ghost Bat records from within the desktop search area.

Report title	Company	Year of report	Field search area location	Ghost Bat records
Western Range Two-Phase Fauna Survey (Biota Environmental Sciences 2011)	Biota	2011	Western Range	2 echolocation records
Eastern Ranges Targeted Fauna Survey (Biota Environmental Sciences 2010)	Biota	2010	Paraburdoo/Eastern Range	1 echolocation record 1 scat record
Western Ranges Level 1 Vegetation, Flora and Fauna Survey (Astron Environmental Services 2013)	Astron	2013	Western Range	1 scat record
Eastern Range Level 1 and Targeted Fauna Survey (Astron Environmental Services 2014)	Astron	2014	Paraburdoo/Eastern Range	1 echolocation record
Eastern Range Survey, Pilbara WA, March to June 2014. Echolocation Survey of Bat Activity (Bat Call WA 2014)	Bat Call WA	2014	Paraburdoo/Eastern Range	1 echolocation record
Western Range EPA Level 1 Targeted Conservation Significant Fauna Assessment (Astron Environmental Services 2018c)	Astron	2018	Western Range	2 diurnal roosts 2 acoustic records
Threatened Species Database (Department of Biodiversity, Conservation, and Attractions 2018b)	DBCA	N/A	Paraburdoo/Eastern Range	2 echolocation records



Rio Tinto Iron Ore

Greater Paraburdoo Ghost Bat, *Macroderma gigas* - Contextual Study

Figure 5: Database search results

Coordinate System: GDA 1994 MGA Zone 50

0 2 4 6 8 10 Kilometres

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Author: M. Love | Drawn: C. Dyde | Date: 09-01-2019 | Figure Ref: 14303-18-BIDR-1RevA_190108_Fig05_Database

4.2 Field Survey

4.2.1 Habitat Assessments

Habitats were classified as high, moderate or low corresponding to the resources they provide to the Ghost Bat's ecological requirements (Table 9). Data collected from the cave assessments undertaken during the survey are detailed in Appendix C and the habitat mapping presented in Figure 6.

High quality habitats correspond to the locations where diurnal roosts or maternal roosts were identified or areas where aerial photography showed the topography corresponded to significant gorges or landforms likely to contain suitable caves for roost sites. High quality habitat was mainly restricted to the gorge/gully habitat, particularly in enclosed deeply incised gullies often south facing (Plate 4). The south facing gorges at Western Range in particular generally contained caves that had the potential for diurnal or maternal roosting. The north facing caves are more than likely exposed too often to high temperatures from the sun resulting in the caves in these areas not being suitable, as the temperature and humidity would be too extreme. A total of 961 ha (4%) of the field search area contained habitat considered as being high quality habitat for Ghost Bats.

Moderate quality habitats correspond to rocky breakaways and cliffs where feeding sites were recorded or considered likely to occur and sites where semi-permanent water sources occur. These areas were mapped based on the type of geology identified in the field visit or from the topography identified from aerial photographs. The areas mapped as moderate quality habitat lack the significant gorges and gullies likely to contain suitable caves for roost sites (Plate 5). Generally these areas were north facing breakaways and riparian areas. Permanent/semi-permanent water sources were classified as moderate quality habitat due to the fact they are likely to be important foraging sites used on a regular basis. A total of 1,836 ha (7%) of the field survey area contained habitat considered as being moderate quality habitat for Ghost Bats.

Low quality habitats correspond to areas of rocky hills, low hills, stony/clay plain and drainage lines where caves were not recorded or considered unlikely to occur (Plate 6). Ghost Bats forage over a variety of habitat types, as such all natural habitats within the field search area provide foraging habitat for this species. Besides foraging these areas do not provide another biological function such as roosting or breeding sites. The vast majority of the field search area (21,935 ha; 89%) contained habitat considered as being low quality habitat for Ghost Bats.

Table 9: Summary of habitat quality in the field search area.

Habitat quality	Area in the field search area (ha)	Proportion in the field search area (%)
High quality habitat	961	4
Moderate quality habitat	1,836	7
Low quality habitat	21,935	89

Plate 1: Ghost Bat (photo credit Gina Barnet).

Plate 2: Typical SM4 unit set up.

Plate 3: Ghost Bat, *Macroderma gigas*, midden pile.

Plate 4: High Quality habitat in a south facing gully at Western Range.

Plate 5: Moderate Quality habitat in a north facing breakaway at Eastern Range.

Plate 6: Low Quality habitat in a low hill with nearby active mining pit at Eastern Range.

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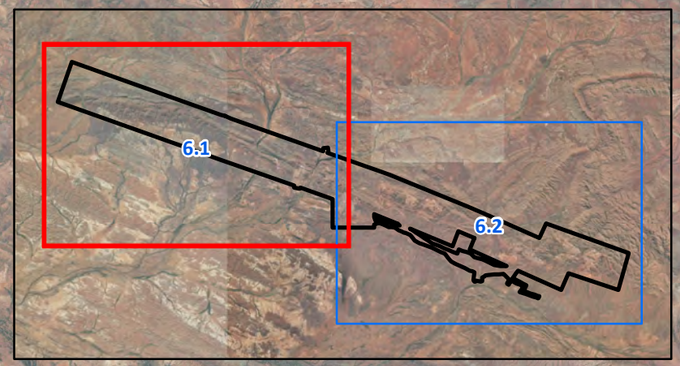

Field Search Area

Habitat Quality

High Quality Habitat

Moderate Quality Habitat

Low Quality Habitat

Rio Tinto Iron Ore

Greater Paraburdoo Ghost Bat, *Macroderma gigas* - Contextual Study

Figure 6.1: Ghost Bat habitat mapping

Coordinate System: GDA 1994 MGA Zone 50

0 1 2 3 4 5 Kilometres

N

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Author: M. Love | Drawn: C. Dyde | Date: 08-01-2019 | Figure Ref: 14303-18-BIDR-1RevA_190108_Fig06_Habitat

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Field Search Area

Habitat Quality

High Quality Habitat

Moderate Quality Habitat

Low Quality Habitat

Rio Tinto Iron Ore

Greater Paraburdoo Ghost Bat, *Macroderma gigas* - Contextual Study

Figure 6.2: Ghost Bat habitat mapping

Coordinate System: GDA 1994 MGA Zone 50

0 1 2 3 4 5 Kilometres

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Author: M. Love | Drawn: C. Dyde | Date: 08-01-2019 | Figure Ref: 14303-18-BIDR-1RevA_190108_Fig06_Habitat

4.2.2 Echolocation Recordings

Ghost Bat ultrasonic calls were detected at 16 sites: BAT1 (Cave 2); BAT2 (Cave 11); BAT3 (Cave 12); BAT5 (Cave 6); BAT6 and BAT11 (Cave 1); BAT7; BAT8 (Cave 14); BAT9 (Cave 15); BAT12 (Cave 3); BAT13 (Cave 4); BAT14 (Cave 5), BAT15 (Cave 16), Cave 13, Cave 17 and Cave 18 (Bat Call WA 2019a, 2019b; Appendix D). The majority of the recordings were made from cave entrances; one recording was made of a foraging individual in a gorge/gully (BAT7) (Bat Call WA 2019a, 2019b). These records are consistent with the Ghost Bat being present year round on the Western Range ridges and with the known presence of low numbers of Ghost Bat in the Paraburdoo area of the central Pilbara (Bat Call WA 2019a).

Three caves, Cave 6, Cave 11 and Cave 15, showed the consistent presence of Ghost Bats and the monthly variation and timing of call detections suggest diurnal roosting within these caves (Bat Call WA 2019b). Ghost Bats utilised these three caves on 30% or more of all detector nights and typically over 50% (Bat Call WA 2019b). Diurnal roosting was suggested in each month of the survey at the three caves, except in December 2018 at Cave 6 and January 2019 at Cave 15 (Bat Call WA 2019b).

Caves 1 – 4, Caves 12 – 14 and Caves 16 – 17 were visited during the majority of, but not all, months (Bat Call WA 2019b). The number of nights with visits detected in any month varied widely but was typically under 50% (Bat Call WA 2019b). The highest visit rate was Cave 2, 73% of nights in February (Bat Call WA 2019b). Roosting was rare in these caves with only single nights recorded at Caves 2 and 14 in February 2019 and Cave 13 in March 2019 (Bat Call WA 2019b).

4.2.3 Roost Caves

Eighteen caves (inclusive of Caves 1 to 4; Astron (2018c)) were assessed with varying levels of importance assigned (Table 9 and Figure 7, Appendix C). To classify the caves adequately, each cave was rated at the highest level possible, but this rating does not exclude that cave from other roosting type behaviour. For example, if a cave was recorded as containing feeding evidence, but the properties of the cave were conducive to diurnal roosting, then the cave was rated as a potential diurnal roost, but still acts as a feed cave. If that cave is revisited and individuals are recorded then the cave becomes a confirmed diurnal roost.

One cave, Cave 6, was deemed a confirmed maternal roost and three caves (Cave 11, Cave 15 and Cave 18 (discovered in 2019)) were classified as potential maternal roosts given the apparent extensive interior properties of the cave and/or the recording of individuals present within them during the breeding season (Bat Call WA 2019a, 2019b; Appendix D).

Four caves (Cave 1, Cave 4, Cave 14 and Cave 16) were classified as confirmed diurnal roost sites, nine caves classified as potential diurnal roosts and one cave was confirmed as a feed cave (nocturnal roost).

Table 10: Summary of roost caves recorded in the field search area.

Site ID	Category	Details
Cave 1	**Confirmed diurnal roost**	Ghost Bat present (x1). Ghost Bat scats present. Ghost Bat calls recorded.
Cave 2	Potential diurnal roost	Cave properties conducive to diurnal roosting. Ghost Bat scats present. Ghost Bat calls recorded and roosting indicated.
Cave 3	Potential diurnal roost	Cave properties conducive to diurnal roosting. Ghost Bat calls recorded.
Cave 4	**Confirmed diurnal roost**	Ghost Bat present (x3). Ghost Bat scats present. Ghost Bat calls recorded.
Cave 5	Ghost Bat feed cave	Ghost Bat scats present.
Cave 6	**Confirmed maternal roost**	Ghost Bats recorded roosting on two occasions (four individuals and one individual from separate recording events). Large midden piles present. Ghost Bat calls recorded and roosting indicated.
Cave 7	Potential diurnal roost	Cave properties conducive to diurnal roosting.
Cave 8	Potential diurnal roost	Cave properties conducive to diurnal roosting.
Cave 9	Potential diurnal roost	Cave properties conducive to diurnal roosting.
Cave 10	Potential diurnal roost	Cave properties conducive to diurnal roosting.
Cave 11	**Potential maternal roost**	Ghost Bats present (x5). Large midden pile present. Ghost Bat calls recorded and roosting indicated.
Cave 12	Potential diurnal roost (feed cave)	Ghost Bat scats present. Cave properties conducive to diurnal roosting, located near pools Ghost Bat calls recorded.
Cave 13	Potential diurnal roost (feed cave)	Ghost Bat scats present. Cave properties conducive to diurnal roosting. Ghost Bat calls recorded and roosting indicated.
Cave 14	**Confirmed diurnal roost**	Ghost Bats present (two individuals and one individual on separate occasions). Ghost Bat calls recorded and roosting indicated.
Cave 15	**Potential maternal roost**	Ghost Bat present (x3). Large midden pile present. Ghost Bat calls recorded and roosting indicated.
Cave 16	**Confirmed diurnal roost**	Ghost Bat present (x1). Large midden piles present. Ghost Bat calls recorded.
Cave 17	Potential diurnal roost	Cave properties conducive to diurnal roosting. Ghost Bat calls recorded.
Cave 18	**Potential maternal roost**	Very large midden pile present. Ghost Bat calls recorded.

All of the 13 caves that were previously recorded within the Western Range portion of the field search area by Astron (2013), were revisited during the current field survey. None of the previously recorded caves had any evidence of Ghost Bat usage nor offered any diurnal or maternal roosting potential. Of the 15 cave assessments that were undertaken at Eastern Range by Astron (2014), seven caves were revisited during the current field survey. None of these revisited caves recorded any Ghost Bat usage or offered any diurnal and/or maternal roosting potential. A further four caves were also visually seen from afar and were detailed as being north facing high in the landscape; as such they were not considered conducive to diurnal and maternal roosting for conservation significant bats due to their orientation and position.

4.2.3.1 Nocturnal Feeding Roosts

During the field survey, one cave (Cave 5) was considered a nocturnal feed cave only. This cave comprised of a large exposed overhang with feeding debris and scats recorded within. Nocturnal feeding roosts are typically open overhangs along breakaway habitat or in small caves. Scats and feed debris are usually concentrated on the ground under the domed sections of caves/overhangs, indicating a favoured foraging area and feeding location. Sites frequently used often have a large build-up of scats (midden) indicating prolonged use. Other caves also have scats and/or large midden piles and are therefore confirmed feed caves, but they were classified as confirmed diurnal roosts or potential maternal roosts due to their properties and the presence of Ghost Bats.

4.2.3.2 Maternal/Diurnal Roost Caves

Eight caves recorded during the field searches, including the assessments of Cave 1 to 4 from Astron (2018c), were considered important roost sites (Table 11). Of the eight caves, one cave (Cave 6) was deemed a confirmed maternal roost cave, three caves (Cave 11, Cave 15, Cave 18) were considered a potential maternal roost cave, and four were considered confirmed diurnal roost caves.

The cave properties of Cave 6, Cave 11, Cave 15 and Cave 18 were conducive to roosting with high humidity and elevated temperatures. There were also large midden piles at a number of locations within each cave indicating frequent use. Cave 6 in particular contained one main large dome up to 15 m in height with a very a large midden pile in the centre of this. The high dome perhaps offers a predator avoidance protection mechanism not seen in lower caves which may be of considerable importance when rearing young. Following the field survey, scat collection and subsequent hormone analysis of these scats within Cave 6 revealed elevated levels of progesterone within seven (35%) of the 20 samples taken, indicating the presence of pregnant females at some stage in the past (Biologic Environmental Survey 2019; Appendix E). In addition, consistent presence and call times pairs were recorded within Cave 6, with Ghost Bats using this cave on 30% or more of the detector nights and typically over 50% (Bat Call WA 2019b). Diurnal roosting within Cave 6 was suggested in each of the months of detection aside from December 2018 (Bat Call WA 2019b) .

Like Cave 6, Cave 11 and Cave 15, showed consistent presence and call times pairs were recorded on a number of days suggesting diurnal roosting (Bat Call WA 2019b). Along with the large midden piles and frequented use, typically over 50% of the detector nights, this indicates the elevated importance of these caves and their use as potential maternal and confirmed diurnal roosts within the survey area. Within Cave 15 only the front dome was explored internally and perhaps this cave offers other roosting properties given the frequent roosting call times recorded within every month of the survey (30% to 56% of detector nights), except January 2019 (Bat Call WA 2019b), as well as the presence of a very large midden and elevated temperatures and humidity levels. A fourth cave (Cave 18) was also considered a confirmed diurnal roost due to its size and internal configuration, the presence of a very large midden pile and regular detection of calls, although no roosting bats have been observed during the two months of surveys (Bat Call WA 2019b).

Four confirmed diurnal caves were recorded in the field search area: Cave 1, Cave 4, Cave 14 and Cave 16. All caves contained roosting individuals during internal inspection. Of the confirmed diurnal caves, Cave 14 and Cave 16 all contain very good and prospective internal cave properties of high humidity and elevated temperatures, with some caves recording adjoining side caverns and therefore further enclosed roosting potential. Cave 1 and specifically Cave 4 are reduced in their roosting potential given the internal cave properties are relatively simple in comparison, also Cave 4 contains a large open and exposed entry with the individuals perhaps only transiting when found.

Table 11: Significant Ghost Bat roost locations

Ghost Bat cave type/evidence	Site ID	Location	Entrance description/ orientation (H x W)	Internal description (H x W)	Photo
Confirmed diurnal roost Ghost Bat calls (BAT6 and BAT11) Ghost Bat (x1) observed	Cave 1	Western Range 36W deposit	**Entrance:** narrow and pinched (1 m wide x 0.6 m high) **Orientation:** south-west	**Internal:** 1 dome with 2 side pockets (12 m deep x 4 m wide x 3 m high) **Conditions:** One Ghost Bat present, scats, raised humidity and elevated temperature	
Confirmed diurnal roost Ghost Bat calls (BAT13) Ghost Bats (x3) observed	Cave 4	Western Range 36W deposit	**Entrance:** overhang that is open/wide (5 m wide x 2 m high) **Orientation:** west	**Internal:** large cavernous dome with solution pipes (10 m deep x 4 m wide x 5 m high) **Conditions:** Three Ghost Bats present, scats, raised humidity and elevated temperature	

Ghost Bat cave type/evidence	Site ID	Location	Entrance description/ orientation (H x W)	Internal description (H x W)	Photo
Confirmed maternal roost Ghost Bat calls (BAT5) Ghost Bat calls indicate roosting Ghost Bats observed roosting on multiple occasions (four individuals and one individual) Hormone analysis of scats indicating presence of pregnant females Two large midden piles	Cave 6	Western Range 36W deposit	**Entrance:** open/wide (6 m wide x 1 m high) **Orientation:** south-west	**Internal:** two domed caverns, left dome has soultion pipes 5 m to 7 m in height, right dome is large cavern (15 m deep x 10 m wide x 15 m high) **Conditions:** Mulitple Ghost Bats present, midden piles, high humidity and high elevated temperatures	
Potential maternal roost/confirmed diurnal roost Ghost Bat calls (BAT2) Ghost Bats (x5) observed Ghost Bat calls indicate roosting Large midden pile	Cave 11	Western Range 66W deposit	**Entrance:** narrow (4 m wide x 0.5 m high) **Orientation:** south	**Internal:** pinched section that opens into a highe dome on a side chamber (20 m deep x 8 m wide x 4 m high)	

Ghost Bat cave type/evidence	Site ID	Location	Entrance description/ orientation (H x W)	Internal description (H x W)	Photo
Confirmed diurnal roost Ghost Bat calls (BAT8) Ghost Bat calls indicate roosting Ghost Bats observed roosting on multiple occasion (two individuals and one individual)	Cave 14	Paraburdoo 27W deposit	**Entrance:** open/wide, large cathedral (12 m wide x 6 m high) **Orientation:** south	**Internal:** one large rear domed cavern, left dome with multiple cracks and crevices and mini roosting spots, main dome is 5 m to 8 m in height, 25 m deep x 12 m wide	
Potential maternal roost/confirmed diurnal roost Ghost Bat calls (BAT9) Ghost Bat calls indicate roosting Ghost Bats observed roosting on one occasion (three individuals) Large midden pile	Cave 15	Western Range 55W deposit	**Entrance:** narrow (0.5 m wide x 0.4 m high) **Orientation:** east	**Internal:** three domed caverns (potential), front dome 1.5 m high x 2 m wide x 2 m high, rear caverns dome dimensions unknown **Conditions:** Mulitple Ghost Bats present, midden piles, high humidity and high elevated temperatures	

Ghost Bat cave type/evidence	Site ID	Location	Entrance description/ orientation (H x W)	Internal description (H x W)	Photo
Confirmed diurnal roost Ghost Bat calls (BAT15) Ghost Bats observed roosting on one occasion (one individual)	Cave 16	Western Range 36W deposit	**Entrance:** wide (3.0 m wide x 2.5 m high) **Orientation:** east-south-east	**Internal:** one long tunnel (~15 m to 20 m) leading to one high rear domed cavern	
Potential maternal roost/confirmed diurnal roost Ghost Bat calls Very large midden pile	Cave 18	Western Range 36W deposit	**Entrance:** wide (3.0 m wide x 3.0 m high **Orientation:** south	**Internal:** one large chamber (8 m wide x ~12 m deep), one rear chamber (6 m x 4 m); cave has three domes 3 m high	

540000

545000

550000

7440000

7435000

Cave 8
Cave 7
Cave 9
Cave 10
Cave 2
Cave 11

Cave 6
Cave 1
Cave 16
Cave 17
Cave 5
Cave 4
Cave 3

Cave 8
Cave 7
Cave 10
Cave 9
Cave 2
Cave 11

Cave 13
Cave 15
Cave 12
Cave 18 (Bat Call WA 2019b)

Cave 6
Cave 1
Cave 16
Cave 17
Cave 5
Cave 4
Cave 3

Cave 14

Field Search Area

Ghost Bat Roost Locations

- Confirmed maternal roost
- Potential maternal roost
- Confirmed diurnal roost
- Potential diurnal roost
- Confirmed feed cave

Rio Tinto Iron Ore

Greater Paraburdoo Ghost Bat, *Macroderma gigas* - Contextual Study

Figure 7: Ghost Bat roost locations

Coordinate System: GDA 1994 MGA Zone 50

0 1 2 3 Kilometres

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4.2.4 Ghost Bat Individuals

Eighteen individuals have been visually recorded roosting within caves during the Astron field surveys and more recent surveys conducted by Biologic (cited in Bat Call WA (2019b)) (Table 12). A total of six individual Ghost Bats on three separate occasions; four individuals and one individual by Astron and one individual by Biologic (cited in Bat Call WA (2019b)) were observed within Cave 6. Three individuals on one occasion were observed within Cave 15 (Table 10). This is consistent with acoustic surveys that indicated the presence of up to four individuals roosting at Cave 6 and two to three individuals at Cave 15 (Bat Call WA 2019b). A total of three individuals have also been observed on two separate visits to Cave 14 (two individuals by Astron and one individual by Biologic (cited in Bat Call WA (2019b)) and one individual at Cave 16 (Table 12). Five individuals were also recently observed at Cave 11 by Biologic (cited in Bat Call WA (2019b)) and acoustic surveys have indicated the presence of between two and seven individuals at this cave (Bat Call WA 2019b). No roosting bats were observed, nor have acoustic surveys indicated the presence of roosting bats within the potential maternal/confirmed diurnal roost Cave 18.

As tracking data, therefore individual marking, is not available at the time of this report, the population of Ghost Bats within the field search area is considered to range between five and 11 individuals. This is consistent with the results of further acoustic surveys that suggest up to 10 individuals are using the ridge lines within the Western Range area (Bat Call WA 2019b).

Table 12: Ghost Bat individuals recorded during the current survey.

Site	Date	Number of individuals
Cave 6	26/07/2018	4
	05/08/2018	1
	February 2019	1*
Cave 11	May 2019	5*
Cave 14	08/10/2018	2
	February 2019	1*
Cave 15	11/10/2018	3
Cave 16	04/12/2018	1

*Observed by Biologic (cited in Bat Call WA (2019b))

4.3 Environmental Context and Ghost Bat Records

The habitat mapping and Ghost Bat records from both the desktop assessment and the field survey were compared against the geological (Stewart et al. 2008) and land systems (van Vreeswyk et al. 2004) mapping to obtain a regional perspective on the habitat within the survey area. This was based on the assumption that Ghost Bat habitat and geology/land systems are closely correlated within the survey area. As the Ghost Bat requires caves for its important ecological requirements (feeding, roosting and breeding), the surface geology and land systems that contain critical habitat were identified.

The high quality Ghost Bat habitat was associated with a wider diversity of 10 geological units; however, the majority of significant Ghost Bat habitat was associated with the Hamersley Group (54.7%), Brockman Iron Formation (36.8%) and Marra Mamba Iron Formation (5.6%) units.

The Newman land system contained the most significant Ghost Bat habitat and coincided with the majority of the high quality habitat (97%), and all 18 roost caves for the field search area, including the significant diurnal roosts and maternal roosts (both potential and confirmed) are all found in this

land system. The land system is described by Van Vreeswyk et al. (2004) as extensive high plateaux, mountains and strike ridges with vertical escarpments and steep scree slopes and more gently inclined lower slopes; moderately spaced dendritic and rectangular tributary drainage patterns of narrow valleys and gorges with narrow drainage floors and channels. The system contains iron ore deposits which are currently being mined and deposits which are likely to be mined in the future (van Vreeswyk et al. 2004). Approximately 14,580 km² of this land system occurs in the Pilbara and is widespread between Pannawonica and Newman (van Vreeswyk et al. 2004).

5 Discussion and Conclusions

Widespread survey effort for conservation significant bats has been undertaken in recent years across the Greater Paraburdoo area (Western Range, Eastern Range, Paraburdoo and Channar), resulting in only a limited number of Ghost Bat records (Astron Environmental Services 2014; Biota Environmental Sciences 2011, 2010; Bat Call WA 2014). These records are from infrequent ultrasonic calls or secondary evidence such as scats or feeding debris. Given the presence of suitable foraging habitat, potential shelter and standing water, it is surprising that the Ghost Bat has not been more commonly recorded in the Greater Paraburdoo area. The bats utilising Paraburdoo Range may have moved west down the range, away from current active mining at Eastern Ranges, Paraburdoo and Channar. The finding of four caves at Western Range during a targeted fauna survey by Astron (2018c), comprising two records from sightings in diurnal roosts and two records from ultrasonic recordings, highlighted that a more comprehensive understanding of this species within the area was required.

The database searches and literature review of the desktop survey indicated that only nine Ghost Bat records, not including records from the current survey and Astron (2018c), existed within 30 km of the Paraburdoo area. The majority of these records were obtained through echolocation recordings and therefore the ability to estimate population size is limited. The search effort to date has been biased to geology prospective for future mining activity and further work outside of mining tenements in suitable habitat may potentially result in more records.

The key ecological requirements of the Ghost Bat (multiple roosting opportunities in close proximity, a productive set of gullies and gorges locally, and a productive foraging area) were used to assess the habitats within the field search area for their suitability and ability to support Ghost Bats. High quality habitat corresponded to the locations where diurnal roosts or maternal roosts were identified or areas where aerial photography showed the topography corresponded to significant gorges or landforms likely to contain suitable caves for roost sites. High quality habitat was mainly restricted to the gorge/gully habitat, particularly in enclosed deeply incised gullies, often south facing and hence not overly exposed to the northern sun. The assumption being north orientated caves are over exposed, particularly in the summer months, the caves' internal temperatures would be too high and variable and the humidity would be too low in comparison to the more well insulated south facing caves. Only a small fraction of the habitat within the field search area was classified as high quality (961 ha; 4%).

Moderate quality habitats corresponded to rocky breakaways and cliffs where feeding sites were recorded or considered likely to occur and where semi-permanent water sources occurred. Low quality habitats corresponded to the remaining habitats (areas of rocky hills, low hills, stony/clay plain and drainage lines), where caves were not recorded or considered unlikely to occur.

Ghost Bats were recorded within the field search area, specifically through echolocation recordings, secondary evidence of scats and midden piles within caves and a total of 18 individuals observed roosting within five important roost caves. These records are significant given the low number of records made from previous fauna assessments to date and the minimal amount of high quality habitat that exists across the field search area. The bias in survey effort in and around active mining activities, for example the Eastern Range/Paraburdoo and Channar areas, perhaps in part explains this. However, the Ghost Bat is notoriously difficult to detect, particularly through echolocation recordings as the species often does not call when entering and exiting caves like other species of bats. Therefore, many hours of echolocation recordings have failed to record this species when potentially it may have been present. Also Ghost Bats are seasonally unpredictable in their habits and may move from one cave to another depending upon their ecological requirements at the time.

As tracking data, therefore individual marking, was not available at the time of this report, the population of Ghost Bats within the field search area is considered to range between five and 11 individuals, based on sightings of individuals during surveys. The results are consistent with other Hamersley Range ridge lines where Ghost Bats occur in small numbers and utilise a number of caves for varying times throughout the year and occasionally come together in larger groups for short periods (Bat Call WA 2019a). The findings of the surveys are also consistent with the results of further acoustic surveys conducted from late 2018 to 2019 that suggest up to 10 individuals are using the ridge lines within the Western Range area, probably on a seasonal basis with low numbers present year round (Bat Call WA 2019b).

Eighteen caves (inclusive of Caves 1 to 4; Astron (2018c)) were assessed for their suitability as Ghost Bat roost sites. One cave, Cave 14, was found within the Eastern Range/Paraburdoo tenement, with the remaining 17 caves all found within the Western Range tenement. Of the 18 caves recorded, one cave (Cave 6) was deemed a confirmed maternal roost, three caves (Caves 11, 15 and 18) were classified as potential maternal roosts/confirmed diurnal roosts and four caves (Caves 1, 4, 14 and 16) were considered confirmed diurnal roosts. Cave 6, Cave 11, Cave 15 and Cave 18 provided numerous Ghost Bat recordings inclusive of call times conducive to roosting (except Cave 18), with excellent internal roosting properties and an ongoing presence of the species, as indicated by large midden piles. These caves represent the first confirmed (Cave 6) and potential maternal sites (Caves 11, 15 and 18) recorded within the Greater Paraburdoo hub.

Ghost Bats have been observed roosting in Cave 6 on three separate occasions (four individuals, one individual and one individual) and acoustic surveys suggested the presence of bats in over 50% of detector nights, as well as evidence of diurnal roosting in all months of the survey except December 2018 (Bat Call WA 2019b). This, along with the size and properties of the cave, large midden piles observed, and hormone analysis of scats confirming the presence of pregnant females, strongly indicates that this cave is a confirmed maternal roost. The grouping of roost sites (including Caves 16, 17 and 18) near the confirmed maternal roost (Cave 6), together with the presence of middens and scat piles, is consistent with this area providing an “apartment block” of roosting opportunities in close proximity to a local productive set of gullies and gorges and a productive foraging area (Bat Call WA (2017).

One cave (Cave 5) was deemed to be a nocturnal roost cave only. This shallow, open and exposed cave did not exhibit the elevated temperatures and humidity necessary for daytime and maternal roosting. Although Ghost Bats forage over all habitat types, they return to nocturnal feeding roosts to eat their prey and hence, foraging evidence is generally only found within rocky habitats at nocturnal feeding roosts. Nocturnal feeding roosts were noted within the desktop review stage through documented scat recordings at Western Range (Astron Environmental Services 2013) and Eastern Range (Biota Environmental Sciences 2010). Generally open shallow overhangs have the potential to provide feeding sites for the Ghost Bat, which are an extremely common feature within the Pilbara landscape.

Armstrong and Anstee (2000) stated that roost sites in the Hamersley Ranges are associated with the Marra Mamba Iron and Brockman Iron formations. In the field search area, the roost sites were associated with Brockman Iron and Hamersley Group formations and the majority of high quality Ghost Bat habitat was mapped within the Hamersley Group (54.7%), Brockman Iron Formation (36.8%) and Marra Mamba Iron Formation (5.6%). The geological formation mapping was not as strongly correlated with potential Ghost Bat habitat as the land systems mapping, where 97% of the high quality habitat and all 18 roost sites occurred within the Newman land system. This land system is well represented locally and is widespread throughout the Pilbara bioregion.

The key threat to the Ghost Bat is the habitat loss and degradation due to mining activities (McKenzie and Hall 2008). The species' slow reproductive rate, and the lack of suitable habitat which restricts its movement, renders it vulnerable to threats and localised extinctions (Queensland Department of Environment and Heritage Protection 2015). The Pilbara population is genetically distinct at both a regional and local scale (Armstrong, Chavand, and Worthington-Wilmer In prep). The genetic isolation of each subpopulation suggests areas are unlikely to be recolonised if a local extinction occurs (Queensland Department of Environment and Heritage Protection 2015). In the Pilbara, most known breeding sites of the Ghost Bat are confined to underground gold/copper mines that are now collapsing or being open cut, and to caves in banded ironstone strata that may be mined out over the next 30 to 50 years. On current trends, most Pilbara roost sites may be destroyed over the next 30 years (Woinarski, Burbidge, and Harrison 2014). Numbers are likely to decline by over 30% in Western Australia in the future with local extinction in areas such as the central and eastern Hamersley Range, with the extent of occupancy likely to decline by over 10,000 km² (Bullen pers. comm., Threatened Species Scientific Committee 2016). However, barbed wire fences are being replaced, or planned to be replaced, in crucial areas and breeding sites are being identified for protection (Department of Parks and Wildlife 2015), which may reduce the current rate of decline.

Relatively little is known about this species' roost site fidelity, seasonal movements or local population estimates in the Pilbara, and while this study has greatly improved knowledge around the presence of Ghost Bats and roosting sites within the Greater Paraburdoo area, little is still known about the seasonal movements and roost site fidelity of the local Ghost Bat population. Adopting a precautionary approach, greater protection should be afforded to the confirmed maternal roost cave (Cave 6) and the potential maternal roosts/confirmed diurnal roosts (Cave 11, Cave 15 and Cave 18). In addition, exclusion zones around nearby Caves 2, 12, 16 and 17 (potential or confirmed diurnal roosts) (Bat Call WA 2019b) and the gully south of Cave 6, will protect the key ecological requirements for Ghost Bats roosting within the Western Range area.

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Appendix A: Existing Environmental Context

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