HASTINGS
Technology Metals Limited

APPENDIX 3-2

Regional Subterranean Fauna Assessment

Bennelongia
Environmental Consultants

Yangibana Project:
Subterranean Fauna Assessment

Prepared for:

Hastings Technology Metals Limited

January 2017
Final Report

Short-Range Endemics I Subterranean Fauna

Waterbirds I Wetlands

Yangibana Rare Earths Project: Subterranean Fauna Assessment

Bennelongia Pty Ltd
5 Bishop Street
Jolimont WA 6014

P: (08) 9285 8722
F: (08) 9285 8811
E: info@bennelongia.com.au

ABN: 55 124 110 167

Report Number: 293

Report Version	Prepared by	Reviewed by	Submitted to Client	
			Method	Date
Draft	Anton Mittra	Stuart Halse	email	27-01-2017
Final	Anton Mittra	Stuart Halse	email	30-01-2017

K:\Projects\B_HAS_01\5_Report\Draft\BEC_HAS_01_Subfauna_Final_30i2016_AM

EXECUTIVE SUMMARY

Hastings Technology Metals Limited plans to develop the Yangibana Rare Earths Project (the Project) in the Gascoyne region of Western Australia. Proposed operations include excavation and dewatering of the Bald Hill, Frasers and Yangibana North/West deposits. Based on subterranean fauna findings within the Project area, Hastings determined that there was a risk that Project activities had the potential to degrade or remove prospective subterranean fauna habitat, in turn threating conservation values of subterranean species and communities. Bennelongia Environmental Consultants were therefore commissioned to assess the potential impact of mine operations on subterranean fauna in the Project area.

Building on a previous study of subterranean fauna by Ecoscape (2016), Bennelongia conducted extensive stygofauna and troglofauna field survey in the Project and surrounding area, which coincides with the Priority 1 Priority Ecological Community (PEC) '*Gifford Creek, Mangaroon, Wanna calcrete groundwater assemblage type one Lyons palaeodrainage on Gifford Creek, Lyons and Wanna Stations*'. Stygofauna sampling included 54 samples across 38 reference and 15 impact drill holes or pastoral bores. Stygofauna site type was determined by occurrence outside (reference) or inside (impact) predicted 1 m drawdown contours. Troglofauna sampling included 20 samples (comprising trap and scrape sub-samples) across 15 reference and 5 impact sites.

Stygofauna sampling yielded 830 specimens belonging to 57 species. Reference sites yielded 730 specimens, including all 57 species, while impact areas yielded 100 specimens of 6 species. The total number of stygofauna species known from the study area is at least 61, nearly half of which are undescribed and likely to be restricted to the calcrete PEC. Recorded taxa include flatworms (Turbellaria), earthworms (Oligochaeta), rotifers (Rotifera), nematode roundworms (Nematoda), ostracods (Ostracoda), copepods (Cyclopoida and Harpacticoida), amphipods (Amphipoda), isopods (Isopoda), aquatic mites (Arachnida: Acari) and beetles (Insecta: Coleoptera). On the basis that all stygofauna species known to occur in the study area have been recorded from reference areas, it is concluded that the conservation values of the stygofauna community and its constituent species are unlikely to be threatened by mining at the Project.

Troglofauna sampling yielded 16 specimens belonging to 10 species. A total of 13 troglofauna species have now been recorded from the study area, at least six of these are considered likely to be endemic to the study area. Yields of troglofauna were low in terms of both abundance and species per sample, resulting in stochastic distributions of recorded species. The Project area hosts a low-to-moderately diverse troglofaunal assemblage. Several species thought to be potentially vulnerable to mine-impacts on the basis of earlier sampling are now known to occur in reference areas, however four species are of potential conservation concern. These are the centipedes Chilenophilidae sp. and Schendylidae sp., the dipluran Parajapygidae sp. B41 and the isopod *Troglarmadillo* sp. B60. Both centipede species were recorded from two deposits and have known linear ranges of approximately 17 km. Troglofaunal centipedes have estimated median ranges of 30 km^2. Moreover, the geological unit from which both species were collected is continuous throughout reference and impact areas, probably providing suitable habitat outside proposed development areas. Both Chilenophilidae sp. and Schendylidae sp. are likely to occur in reference areas.

The dipluran Parajapygidae sp. B41 was collected from two holes at the Yangibana North deposit separated by approximately 0.25 km. The estimated median linear range of troglofaunal diplurans in the Pilbara is at least 4.5 km, which is twice the length of the Yangibana North deposit. The isopod *Troglarmadillo* sp. B60 is known from a single hole in the Frasers deposit impact area. Based on previous studies of subterranean isopod, it is likely to have a linear range of at least 1.8 km, which is approximately twice the length of the Frasers deposit. It is likely that both Parajapygidae sp. B41 and *Troglarmadillo* sp. B60 extend into reference areas due to the continuation of deposit geology. Given low yields in troglofauna samples, it is inferred that sampling intensity was insufficient to collect more

specimens of each species and demonstrate wider occurrence. Low capture rates for troglofauna species, and consequently stochastic distribution of records within the species' actual envelope of occurrence, is a common phenomenon.

Considering sampling results and the inferred distributions of the species recorded only in impact areas, the threat to the conservation values of troglofauna communities and species from operations at the Project is considered low.

CONTENTS

Executive Summary ii
1. Introduction 1
2. Framework 2
2.1. Project Description 2
2.2. Regional Setting 2
2.3. Conservation Framework 5
2.4. Subterranean Fauna 5
2.4.1. Stygofauna 6
2.4.2. Troglofauna 6
3. Impacts of mining 7
3.1. Impacts on Stygofauna 7
3.2. Impacts on Troglofauna 7
4. Previous Survey 7
4.1. Ecoscape Survey 7
4.1.1. Stygofauna 7
4.1.2. Troglofauna 8
4.2. Database and Literature Searches 8
5. Current Survey 8
5.1. Sampling effort 8
5.2. Field and Laboratory Methods 13
5.2.1. Stygofauna 13
5.2.2. Troglofauna 13
5.3. Personnel 14
6. Results 14
6.1. Stygofauna 14
6.1.1. Sampling Efficiency 17
6.1.2. Distribution of Stygofauna Species 17
6.2. Troglofauna 18
6.2.1. Sampling Efficiency 21
6.2.2. Distributions of Troglofauna Species 21
7. Potential Impacts on Subterranean Fauna 23
7.1. Stygofauna 23
7.2. Troglofauna 23
8. Conclusion 24
9. References 25
Appendix 1. Secondary impacts of mining on subterranean fauna. 28
Appendix 2. List of sampling sites for stygofauna in October 2016. 29
Appendix 4. List of sampling sites for troglofauna in October 2016. 31
Appendix 4. Higher-order stygofauna identifications that were removed from final list of species to avoid artificial inflation of richness. 32

LIST OF FIGURES

Figure 1. Location of the Yangibana Rare Earths Project area 3

Figure 2. Proposed development areas at the Yangibana Rare Earths Project, regional calcrete PECs and the WAM search area. 4
Figure 3. Locations of stygofauna sampling sites in the Project area and surrounding region in 2016. 11
Figure 4. Troglofauna sampling sites at the Project in 2016. 12
Figure 5. Collection locations for stygofauna (bottom) and troglofauna (top) currently or previously thought to be of potential conservation concern in relation to impact areas. 19

LIST OF TABLES

Table 1. Historical records of stygofauna at the Project and surrounding area. 9
Table 2. Historical records of troglofauna at the Project and surrounding area. 10
Table 3. Sampling effort for subterranean fauna at the Project in September-October 2016. 10
Table 4. Stygofauna recorded at the Yangibana Project and surrounding areas in 2016. 15
Table 5. Troglofauna recorded in the Project area in 2016. 20

1. INTRODUCTION

Hastings Technology Metals Limited plans to develop the Yangibana Rare Earths Project (the Project) in the Gascoyne region of Western Australia. The site represents a significant Australian rare earth elements project; exploration drilling programmes in the 1980s and more recently in 2014–2016 have revealed extensive deposits of ferrocarbonate and ironstone veins that could produce substantial volumes of total rare earth oxides of which neodymium, praseodymium and dysprosium are amongst the most valuable.

Accessing mineral ore at the Project will involve open-cut mining. These excavations and associated abstraction of underlying groundwater to enable dry mining will potentially degrade or remove prospective habitat of subterranean fauna species, in turn threatening the conservation values of subterranean species and communities.

Although inconspicuous, subterranean fauna contribute markedly to the overall biodiversity of Australia, and additionally play important roles in ecosystem function (Humphreys 2006). Whilst studies of subterranean fauna in the Gascoyne remain uncommon, the neighbouring Pilbara and Yilgarn regions of Western Australia are recognised as subterranean faunal biodiversity hotspots. Guzik et al. (2010) suggested that over 4,000 species of subterranean fauna are likely to occur in the western half of Australia (Guzik et al. 2010), with over 80 % of species not yet discovered. More recently, Halse (2015) suggested that the Gascoyne region is geologically similar to the Pilbara region. It is also noted that species from the Yilgarn region have also been found in the Gascoyne region (Karanovic 2004; Keable and Wilson 2002; Watts and Humphreys 2006). Therefore, given that the geologically similar Pilbara region and Yilgarn region is rich in subterranean fauna to the north and east, and the overlap in subterranean fauna species from the Yilgarn, it is expected that rich subterranean faunal assemblages also occur in the Gascoyne region despite the lack of surveys conducted to-date in the region.

Most subterranean fauna satisfy Harvey's (2002) criteria for short-range endemism (SRE), namely ranges of less than 10,000 km^2, confinement to discontinuous habitats, slow growth and low fecundity. In fact ranges are frequently only a few square kilometres in extent (Halse and Pearson 2014). Given that locally-restricted species are more vulnerable to extinction following habitat degradation than wider-ranging species (Ponder & Colgan 2002), it follows that subterranean taxa are highly susceptible to anthropogenic threats, such as habitat degradation and groundwater abstraction.

The Environmental Protection Authority (EPA) recognises the importance subterranean fauna in Western Australia, and requires consideration of these faunal communities as part of environmental impact assessment for mining and similar developments. A previous desktop assessment, Level 1 stygofauna survey and Level 2 troglofauna survey in the Project area recorded at least 15 species (Ecoscape 2016). Three of these species were recorded exclusively at locations tentatively designated as impact areas and were therefore deemed to be of potential conservation concern, although the footprints of proposed developments were not fully defined at the time of previous survey. Consequently, it was decided that extensive regional sampling was necessary to determine the distribution of subterranean fauna species and communities relative to the possible impact area. The Project area lies within the Priority 1 Priority Ecological Community (PEC), '*Gifford Creek, Mangaroon, Wanna calcrete groundwater assemblage type one Lyons palaeodrainage on Gifford Creek, Lyons and Wanna Stations*'.

The present study includes three components:

(i) Review of previous subterranean fauna survey in the Project area, including the Ecoscape (2016) study and an updated search of relevant databases and literature;

(ii) Level 2 field survey of stygofauna and troglofauna in the Project area and surrounding PEC to clarify the diversity and distribution of species relative to the impact area; and

(iii) Evaluation of risks, posed by the Project activities, to the conservation values of local and regional subterranean fauna.

2. FRAMEWORK

2.1. Project Description

The Project and relevant study area are situated approximately 290 km northeast of Carnarvon and occupy parts of the Wanna, Gifford Creek and Edmund pastoral stations in the northern Gascoyne region (Figure 1). Tenement areas cover approximately 550 km^2 including four major deposits – Yangibana West, Yangibana North, Bald Hill South and Fraser's (Figure 2), as well as several smaller deposits (Gossan, Kanes Gossan, Hook, Lion's Ear). Excavation and the dewatering associated with the major deposits proposed for development are considered to be the main potential threats to subterranean fauna.

2.2. Regional Setting

The Project occurs in the Gascoyne bioregion of Western Australia, which is characterised by low, rugged ranges and broad, flat valleys. Vegetation is dominated by open mulga woodlands and extensive sheep and cattle grazing are the major regional land uses. The Gascoyne has an arid climate with predominantly winter rainfall in the west shifting to summer-dominated rainfall further inland. Median annual rainfall is approximately 200 mm.

Three subregions are specified within the Gascoyne – Ashburton (GAS1), Carnegie (GAS2) and Augustus (GAS3). The current study area falls within both the Ashburton and Augustus subregions. The Ashburton subregion is characterised) by mountainous ranges interspersed by broad flat valleys within the Ashburton River catchment comprising the Ashburton (shales, sandstones and conglomerates) and Bangemall (sandstone, shale and carbonates) basins (Kendrick 2002). Vegetation is typified by mulga and snakewood low woodlands on earthy loams over hardpan on plains and mulga scrub and *Eremophila* shrublands on shallow loams of ranges. Kendrick (2002) and Humphreys (2001) predicted that significant subterranean fauna communities would occur in calcretes associated with the Lyons River, which falls within the study area.

The Augustus subregion is characterised by rugged low Proterozoic sedimentary and granite ranges divided by low flat valleys. Major regional drainage is supplied by the Gascoyne River System as a well as the Ashburton and Fortescue Rivers (Desmond et al. 2001).

According to geological descriptions in the previous ecological survey (Ecoscape 2016), the most common geological unit in the study area is the Pimbyana Granite (PLgpi) covering 22.5 % of the study area (12,037 ha), followed by sand and gravel with ferruginous cement; deeply dissected by present-day drainage (A3ti, 14.9 %); calcrete, developed in and adjacent to alluvial channels (Rk, 11.6 %); unconsolidated silt, sand and gravel in active drainage channels and floodplains (A1, 7.4 %); evenly-textured to weakly porphyritic medium-grained biotite-muscovite(-tourmaline) monzogranite with metasedimentary rock or porphyritic granodiorite (PLgynx, 7.1 %); and Porphyritic, medium- to coarse-grained biotite-muscovite granodiorite to syenogranite with metasedimentary and metamafic rocks (PLgpix, 6.1%).

Several calcrete aquifers in the study area comprise the PEC '*Gifford Creek, Mangaroon, Wanna calcrete groundwater assemblage type on Lyons palaeodrainage on Gifford Creek, Lyons and Wanna Stations*' (Figure 2) and are known or highly likely to harbour significant and unique assemblages of subterranean fauna.

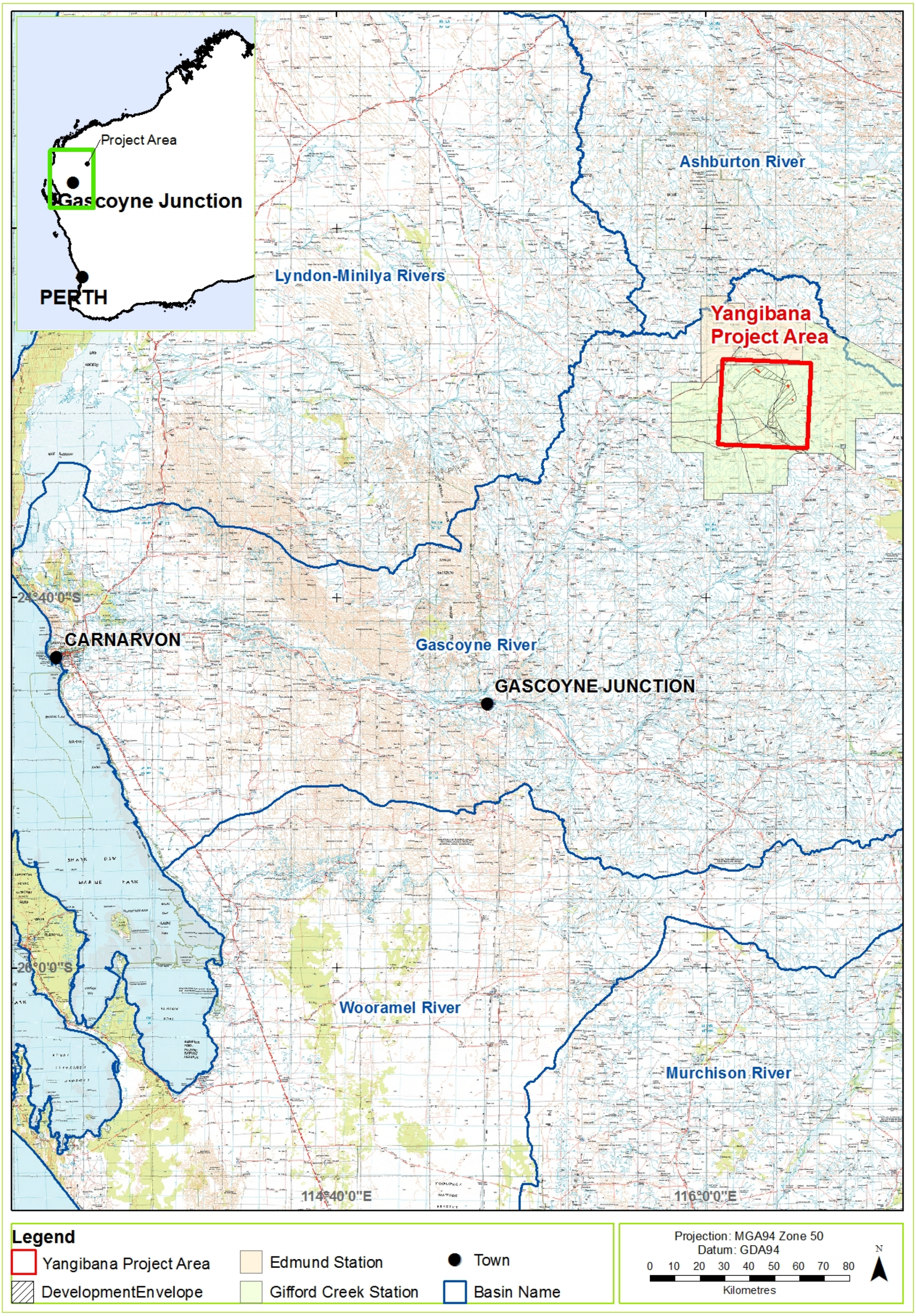

Figure 1. Location of the Yangibana Rare Earths Project area.

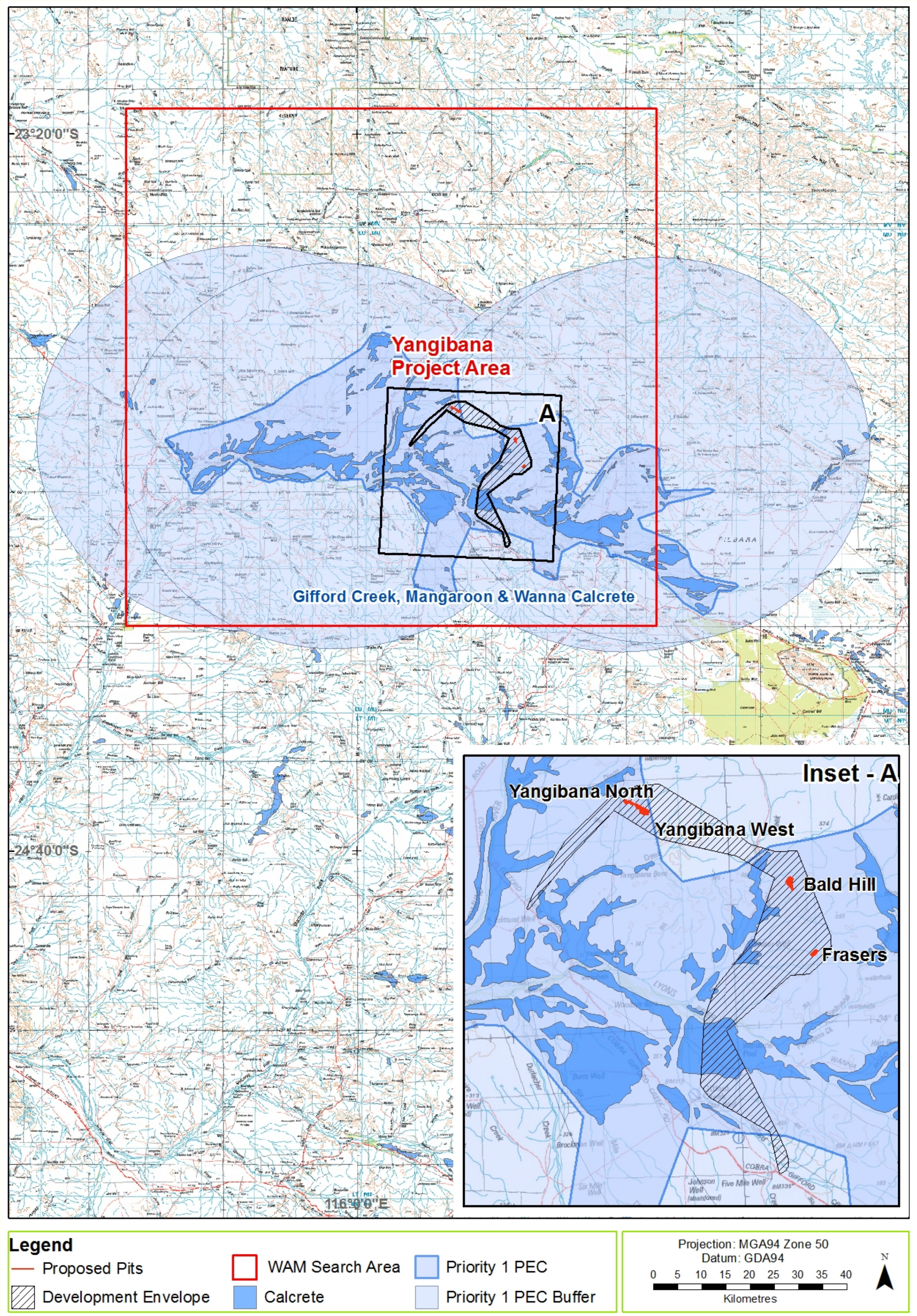

Figure 2. Proposed development areas at the Yangibana Rare Earths Project, regional calcrete PECs and the WAM search area.

2.3. Conservation Framework

Consideration of impacts on subterranean fauna is a requirement of environmental impact assessment in Western Australia under the Environmental Protection (EP) Act (1986). The Environmental Protection Authority's (EPA) approach to protection is laid out in EPA (2016a). Subterranean fauna are also afforded protection by state and federal legislation for the protection of native flora, fauna and ecosystems. At the federal level, the Environmental Protection and Biodiversity Conservation (EPBC) Act (1999) provides a legal framework for the protection of threatened species and threatened or endangered ecological communities (TECs).

At the state level, the Wildlife Conservation (WC) Act (1950) states that, "all fauna is wholly protected throughout the whole of the State at all times", excepting circumstances where alternative declarations are made by the Minister for Environment. In addition, special protection is provided to those species listed as endangered, threatened or otherwise in need of special protection under the Wildlife Conservation (Specially Protected Fauna) Notice 2015. This state list of threatened species contains several subterranean fauna species, including crustaceans, arachnids and myriapods. Additionally, the Department of Parks and Wildlife (DPaW) maintains a list of priority fauna species that are of conservation importance, but for various reasons do not meet the criteria for listing as threatened.

Currently, the state has no provision for formal listing of TECs but the Minister annually endorses a List of TECs for protection. In addition, the Department of Parks and Wildlife (DPaW) has a list of Priority Ecological Communities (PECs) for protection. Several subterranean ecological communities in Western Australia are listed as TECs, including the stygofaunal community in the Ethel Gorge aquifer in the Pilbara, the Cape Range remipede community, Camerons Cave in Cape Range and a number of subterranean root mat communities in the south-west (the latter are also listed under the EPBC Act). Additionally, more than 80 subterranean communities in calcretes, predominantly recognised for their stygofauna element, are listed in Western Australia as PECs.

2.4. Subterranean Fauna

With the exception of two known species of cave-dwelling fish, Western Australian subterranean fauna are invertebrates and are divided into aquatic stygofauna and air-breathing troglofauna. Both groups typically lack eyes and are poorly pigmented due to lack of light. Other characteristic morphological and physiological adaptations such as vermiform bodies, elongate sensory structures, loss of wings, increased lifespan, a shift towards K-selection breeding strategy and decreased metabolism reflect low inputs of carbon and nutrients in subterranean habitats and the requirement to navigate enclosed spaces (Gibert & Deharveng 2002).

Geology influences the presence, richness and distribution of subterranean fauna by providing different types of habitat (Eberhard et al. 2005; Hose et al. 2015). Highly transmissive geologies support greater assemblages of subterranean fauna, both in terms of abundance and diversity, than consolidated ones. Alluvial deposits may host subterranean fauna in interstitial spaces between constituent sand and gravel, and coarser sediments tend to host greater assemblages than silty or clay-rich substrates (Korbel and Hose 2011). Physical and chemical weathering of consolidated strata can also provide prospective niches such as fissures, vugs and caves.

Fluctuating groundwater levels and resulting precipitation of carbonates along the internal palaeochannel river system of Western Australia has resulted in the formation of many calcrete aquifers. Although classical karst formations are absent from the Western Australian landscape, calcretes display karstic characteristics and provide excellent habitat for stygofauna, as well as for troglofauna above the water table (Humphreys 2001).

Geological, topographical and hydrological features influence subterranean faunal assemblages by allowing, or restricting, dispersal between populations. The relative importance of dispersal and vicariance (i.e. geographical range is disconnected resulting in physical or biotic barriers) in explaining spatial patterns of stygofauna community structure is likely to vary between regions according to historical and present-day hydrogeology (Finston et al. 2007; Culver et al. 2009). For instance, vertical shifts in the water table may act to unite previously isolated aquifers, thus allowing gene flow between populations (Finston et al. 2007). By the same token, subterranean geology and surface features such as drainage patterns and tributary boundaries may barricade dispersal, causing vicariance between populations and subsequent speciation over relatively fine geographical scales. For instance, populations of some troglofaunal pseudoscorpions in the Pilbara are known to be genetically isolated between adjacent mesas (i.e. ranges of a few square kilometres), as a result of being restricted to specific geological structures (Harvey et al. 2008).

2.4.1. Stygofauna

Hydraulic conductivity is an important factor dictating the movement of oxygen and carbon into and throughout ecosystems. Therefore, transmissive aquifers with large pore spaces allowing movement of oxygen and carbon tend to accommodate the most abundant and diverse stygofauna communities (Hose et al. 2015). In the Pilbara and Yilgarn, surveys of calcrete aquifers have revealed rich and endemic stygofaunal assemblages.

Earthworms (Oligochaeta), beetles (Coleoptera) and crustaceans (amphipods, isopods, copepods, ostracods and syncarids) comprise typical stygal communities in calcretes and many species are restricted to single aquifers (Humphreys 2001; Cooper et al. 2002; Guzik et al. 2008; Watts and Humphreys 2006; Leys et al. 2008; Javidkar 2014). The listing of a large number of Yilgarn calcretes as PECs reflects their physical, biological and genetic isolation and high prevalence of locally endemic species. Less transmissive geologies, such as banded iron formations (BIF) and saprolite rarely support rich stygofaunal communities, although low numbers of species may occur in these geologies too (Bennelongia 2009; Ecologia 2009; GHD 2009).

Although the physiochemical tolerances of stygofauna have not been well-defined, assumptions about tolerance of specific taxa can be made based on related surface water surrogates. Stygofauna occur in aquifers of varying salinities, but are mostly found in fresh to saline waters with conductivities of less than 35,000 µS cm^{-1} (approximately 25,000 mg L^{-1} TDS) in Western Australia. They are seldom found in hypoxic groundwater (<0.3 mg O_2 L^{-1}) (Hose et al. 2015). Whilst stygofauna sometimes occur in hyporheic zones and groundwater springs, this report focusses on the presence of stygofauna in groundwater aquifers.

2.4.2. Troglofauna

While the earliest troglofauna surveys in Western Australia focussed on cave habitats, subsequent records from pisolitic mesas in the Robe River Valley in the Pilbara (Biota 2006) demonstrated the occurrence of troglofauna in non-karstic formations. Troglofauna have since been recorded through much of Western Australia, with the greatest diversity and abundance seeming to be in the Pilbara. Troglofauna are represented by a wide variety of invertebrate groups, including isopods, palpigrads, spiders, schizomids, pseudoscorpions, harvestmen, millipedes, centipedes, pauropods, symphylans, bristletails, silverfish, cockroaches, bugs, beetles and fungus-gnats.

Regional patterns of troglofauna occurrence and community composition in various habitats are not well understood because the majority of surveys been focussed on areas of mining development, particularly mineralised iron formations. Consequently, although troglofauna have been found to occur widely in mineralised iron formations (e.g. Biota 2006; Bennelongia 2008a, b), there is little basis for assessing the extent of their occurrence in other habitats. Nonetheless, it is known that troglofauna occur in calcrete and alluvial-detrital deposits in the Pilbara (Edward and Harvey 2008).

Troglofauna surveys in the Yilgarn have been limited, and in most cases have recorded modest abundances and diversities of troglofauna in calcretes above the water table. Bennelongia (2015) notably recorded 45 species of troglofauna from the Yeelirrie calcrete, while Outback Ecology (2012) recorded 20 species at Lake Way. These relatively rich assemblages illustrate the suitability of calcrete as a subterranean fauna habitat. Surveys in BIF in the Yilgarn at Koolyanobbing, Mt Jackson, Mt Dimmer and Yendilberin Hills have yielded depauperate to moderately rich troglofauna communities (Bennelongia 2008a; Bennelongia 2008b; Bennelongia 2009a).

3. IMPACTS OF MINING

The effects of developing mining infrastructure and subsequent mining operations on subterranean fauna communities can be broadly divided into two categories:

1. Primary impacts – possible extinction, or threat to the persistence of local populations, of subterranean fauna through the direct removal of habitat; and
2. Secondary impacts – reduction of population densities of subterranean fauna through a range of environmental factors, for example pollutants and increased turbidity (Appendix 1).

3.1. Impacts on Stygofauna

Open cut and underground mining sometimes requires a dewatering program to enable access to mineral ore and to prevent the mine being flooded. This abstracted groundwater is typically also used in ore processing. The consequent drawdown of the aquifer poses a primary threat to stygofauna communities that occur within the dewatering footprint. In particular, species restricted to the impact footprint face possible extinction. Besides dewatering, the excavation of the pit itself cause complete loss of stygofauna habitat within the pit area, while construction of other infrastructure such as tunnels, drainage and tailing dams may degrade or remove networks of suitable habitat within the mine area, or could disrupt connectivity between populations on either side of the disturbance.

3.2. Impacts on Troglofauna

The direct habitat loss from mine pit excavation is the main mine-related threat to troglofauna in the Project area. The extent of habitat loss will depend on the area and depth of mine pits and other excavations, as well as the occurrence and connectivity of suitable habitat outside the impact zone. Animals utilising small isolated pockets of habitat are more vulnerable to significant primary impacts than those inhabiting more extensive geologies.

4. PREVIOUS SURVEY

4.1. Ecoscape Survey

Ecoscape conducted a desktop assessment identifying physical and biological aspects of the Project area followed by a two-season field survey of subterranean fauna in 2015. Survey comprised two sampling rounds: post wet season in May 2015; and during the dry season in September 2015. Sampling methods were consistent with those recommended in EAG 12 (EPA 2013) and with those used by Bennelongia in the present study (Section 5).

4.1.1. Stygofauna

Thirteen and 18 boreholes were sampled during wet and dry season components of the Level 1 stygofauna survey, respectively (Ecoscape 2016). Eight holes were sampled in both seasons. Sampled boreholes occurred in Rk, C1f, PLgpi and PLgpix geological units with most samples taken from PLgpi geology. Broadly, these units comprise calcrete (Rk), unconsolidated ferruginous rubble and scree (C1f) and granites (Plgpi and PLgpix). Stygofauna samples were taken largely from inside proposed pit areas and therefore correspond to the likely impact area.

Stygofauna were collected from eight boreholes across four deposits (Lion's Ear, Yangibana North, Hook and Kane's Gossan) and one regional reference site (Andy's Bore). Deposit sites occurred largely in PLgpi geology (granite), while Andy's Bore occurred in Rk geology (calcrete).

Stygofauna recorded by Ecoscape are given in Table 1, alongside records from current database and literature searches. Ecoscape collected 236 stygofauna specimens from four families representing 10 species. Copepods, ostracods, amphipods, oligochaetes and nematodes were all recorded. Three recorded taxa were deemed to be of conservation significance in the context of the Project: the copepod Ameiridae gen. nov. sp. B04; the candonid ostracod *Areacandona* sp. BOS550; and the amphipod Paramelitidae sp. B49. In particular, Paramelitidae sp. B49 was recorded from a single bore in the Lions Ear deposit and is therefore only known from impact areas. All three species are known only from records within the Project area during the 2015 survey and are considered likely to be restricted to the Gifford Creek calcrete PEC. They are considered potential SREs for which, at the time of survey, there was insufficient data to infer wider ranges.

4.1.2. Troglofauna

Ecoscape conducted troglofauna sampling at 34 drill holes, 11 of which were sampled during both wet and dry season sampling. Overall, 43 traps were deployed in the Project area, with 18 and 25 traps deployed during wet and dry season survey, respectively. Additionally, troglofauna scraping was undertaken at 32 drill holes.

Troglofauna were collected from five drill holes across three deposits (Frasers, Kanes Gossan and Bald Hill) in PLgpi geology. Records of troglofauna by Ecoscape are reported in Table 2. Eleven troglofauna specimens from five orders representing five separate species were recorded from five drill holes in the Yangibana study area by Ecoscape in 2015, including the isopod *Troglarmadillo* sp. B60, the dipluran Projapygidae sp. B19, the thysanuran *Trinemura* sp. B29, the centipede Geophilidae sp. and the symphylan *Scutigerella* sp. B09. All recorded species of troglofauna were deemed to be of potential or unknown conservation concern due to their likely-restricted distributions.

4.2. Database and Literature Searches

Previous records of subterranean fauna in the vicinity of the Project were collated by searching available databases (Bennelongia, Western Australian Museum) and relevant literature for records of subterranean fauna within an area of 10,000 km^2 defined by 23°28'S, 115°57'E and 24°24'S, 116°55'E (Figure 2). Distributions were estimated for species-level taxa. Where a taxon had not been identified to species-level a suitable congeneric or confamiliar surrogate species was used to approximate likely distribution. To avoid artificial inflation of species lists, higher level identifications were excluded from the list of taxa present unless no other species had been recorded in that taxonomic unit. Records of stygofauna and troglofauna in the Project area are shown in Table 1 and Table 2, respectively.

5. CURRENT SURVEY

5.1. Sampling effort

Totals of 20 troglofauna samples and 54 stygofauna samples were collected across 53 sites in the Project area and its surrounds from 5–10 October 2016. Sampling sites for stygofauna and troglofauna are shown in Figures 3 and Figure 4, respectively. Stygofauna samples included 15 impact and 39 reference samples, delineated according to their occurrence inside (impact) or outside (reference) predicted 1 m drawdown contours determined by modelling (GRM 2017; Figure 3).

Table 1. Historical records of stygofauna at the Project and surrounding area.
10,000 km^2 WAM search area defined by 23°28'S, 115°57'E and 24°24'S, 116°55'E. Grey shading indicates taxa recorded in studies other than the Ecoscape (2016) survey.

Higher classification	Lowest identification	Locations	Comments on Distribution
ANNELIDA **Oligochaeta** Enchytraeidae	*Enchytraeus* sp. 1 (PSS) Pilbara**	Hook, Yangibana North	Potential SRE[1,5]
Phreodrilidae	*Phreodrilus peniculus*	Hook	Also recorded in the Pilbara[4]
	Phreodrilidae with dissimilar ventral chaetae	Yangibana North, Lion's Ear	Widely-distributed[5]
NEMATODA	Nematoda sp.	Gossan, Lion's Ear, Yangibana North	Not assessed in EIA
CRUSTACEA **Copepoda** Ameiridae	Ameiridae gen. nov. sp. B04	Andy's Bore	Only record of this genus; potential SRE; potentially conservation-significant[1]
Cyclopidae	*Diacyclops cockingi*	Lion's Ear, Yangibana North, Hook	Pilbara-wide[2]
	Diacyclops humphreysi humphreysi	Kane's Gossan	Pilbara-wide[2]
	Orbuscyclops westaustraliensis	Andy's Bore	Pilbara-wide[2]
Ostracoda Candonidae	*Areacandona* sp. BOS550	Andy's Bore	Presently known only from this record; potential SRE; potentially conservation-significant[1]
Amphipoda Paramelitidae	Parametlitidae sp. B49	Lion's Ear	Only record of species; potential SRE; potentially conservation-significant[1]
ISOPODA			
Tainisopidae	*Pygolabis gascoyne*	1 record from Stonetank Well (Gifford Creek PEC)	Likely restricted to Gifford Creek PEC[3]

[1]Ecoscape (2016); [2]Karanovic (2006); [3]Keable and Wilson 2002; [4]ABRS 2009; [5]Bennelongia unpublished data and expertise.
** *Enchytraeus* sp. 1 (PSS) Pilbara represents the same taxa as *Enchytaeus* spp. in Table 4.

Table 2. Historical records of troglofauna at the Project and surrounding area.
10,000 km^2 WAM search area defined by 23°28'S, 115°57'E and 24°24'S, 116°55'E. All records of troglofauna in the Project area were recorded by Ecoscape (2016).

Higher classification	Lowest identification	Locations	Comments on Distribution
CRUSTACEA			
Isopoda			
Armadillidae	*Troglarmadillo* sp. B60	Frasers	Only record of this genus in vicinity; likely SRE; potentially conservation-significant
HEXAPODA **Diplura** Projapygidae	Projapygidae sp. B19	Kane's Gossan	Only known from this record; potential SRE; potentially conservation-significant[1]
Insecta			
Nicoletiidae	*Trinemura* sp. B29	Bald Hill, Fraser's, Kane's Gossan	Only known from study area; potential SRE; potentially conservation-significant[1]
MYRIAPODA			
Chilopoda			
Geophilidae	Geophilidae sp.	Kane's Gossan	Damaged specimen; conservation status unknown
Diplopda Scutigerellidae	*Scutigerella* sp. B09	Bald Hill	Only known from this record; potentially conservation-significant[1]

[1]Ecoscape (2016)

The appropriateness of the 1 m drawdown contour as a separator of reference and impact sites is discussed further in Section 7.1. The regional stygofauna reference site Judy's Bore was opportunistically sampled a second time at a later date, resulting in two samples for that site, thus enabling 54 samples to be collected from 53 sites.

Troglofauna samples comprised 5 impact and 15 reference samples (Figure 4), with each sample consisting of trap and scrape sub-samples (see Halse and Pearson 2014). Traps were emptied after approximately two months. A summary of sampling effort is given in Table 3 and complete lists of sites sampled for stygofauna and troglofauna are given in Appendix 2 and Appendix 3, respectively.

Table 3. Sampling effort for subterranean fauna at the Project in September-October 2016.

Sampling type	Site Type	No. Of Sites	Net	Filtered Outflow	Scrape	Trap*	Total no. of Samples
Stygofauna	Reference	38	19	20	-	-	39
	Impact	15	15	-	-	-	15
Troglofauna	Reference	15	-	-	15	15	15
	Impact	5	-	-	5	5	5

*In every fourth hole two traps were set.

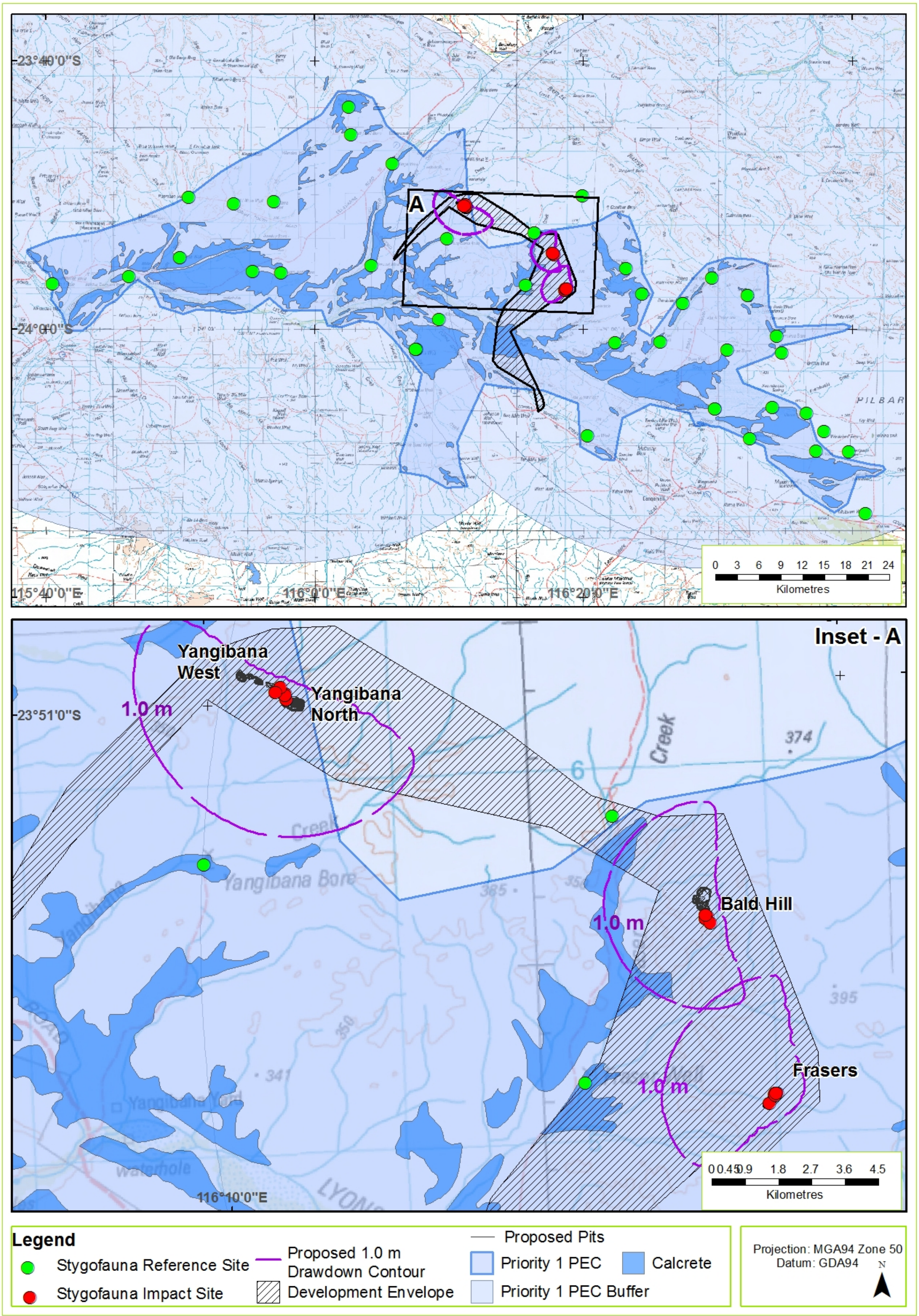

Figure 3. Locations of stygofauna sampling sites in the Project area and surrounding region in 2016.
1 m drawdown contours were determined by hydrological modelling by GRM (2017).

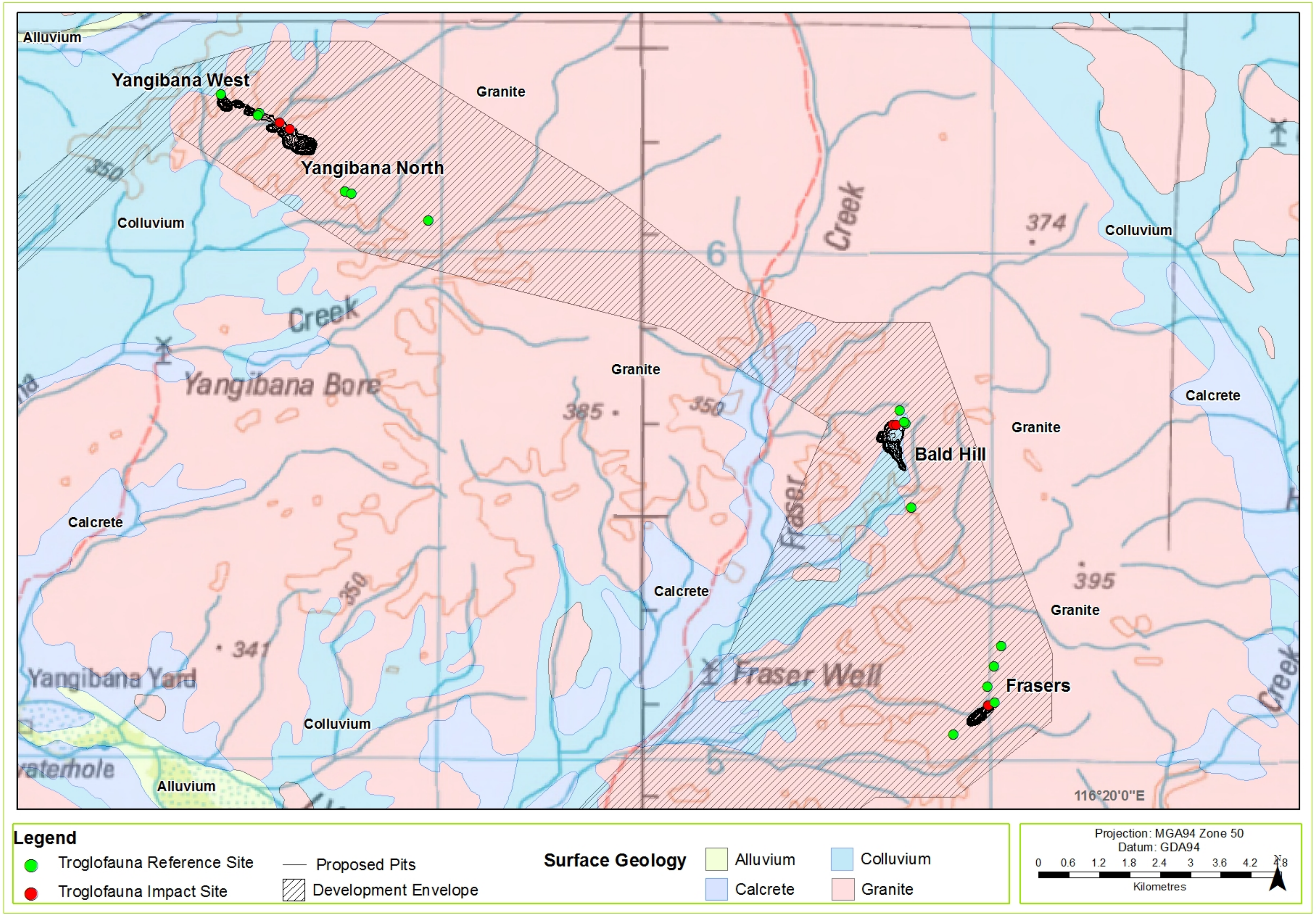

Figure 4. Troglofauna sampling sites at the Project in 2016.

5.2. Field and Laboratory Methods

5.2.1. Stygofauna

Sampling for stygofauna adhered to methods prescribed in the EPA's (EPA 2016b) sampling advice, whereby stygofauna were sampled at each bore using weighted plankton nets. Six hauls were taken at each site, three using a 50 µm mesh net and three with a 150 µm mesh net. The net was lowered to the bottom of the hole and jerked up and down briefly to agitate benthos (increasing the likelihood of collecting benthic species) and then slowly retrieved. This method was not possible at some regional sites, which rather than drill holes comprised windmill-driven pastoral bores. At these sites, pump outflow was filtered for approximately 20 minutes through a 150 µm mesh net. Contents of the net were transferred to a 125 ml polycarbonate vial after each haul, flushed with bore water to reduce fine sediment content, preserved in 100% ethanol and refrigerated at a constant 4 °C. Nets were washed between holes to minimise site-to-site contamination. One regional reference site, Judy's Bore, was sampled opportunistically a second time by sampling pump outflow overnight.

In situ water quality parameters – temperature, electrical conductance (EC) and pH – were measured at each site using a WP 81 field meter. Standing water level and total depth of hole were also measured using a Solinst water level meter.

In the laboratory, samples were elutriated to separate out heavy sediment particles and sieved into size fractions using 250, 90 and 53 µm screens. All samples were sorted under a dissecting microscope and specimens identified to species where possible using available keys and species descriptions. When necessary for identification, animals were dissected and examined under a compound microscope. If stygofauna did not represent a described species, they were identified to species/morphospecies using characters from species keys.

5.2.2. Troglofauna

In a departure from EPA (2016b) advice but recognising best practice (Halse and Pearson 2014), each troglofauna sample from a drill hole consisted of the results of two separate collecting techniques, trapping and scraping:

1. *Trapping*. Custom made cylindrical PVC traps (270 x 70 mm, entrance holes side and top) were used for trapping. Traps were baited with moist leaf litter (sterilised by microwaving) and lowered on nylon cord to the most suitable habitat within the hole (this ranged from areas where there was a root constriction, to areas where vuginess was detected during scraping or to areas within a few metres of the water table). In every fourth hole a second trap was set mid-way down the bore. Holes were sealed while traps were set to minimise the ingress of surface invertebrates. Traps were retrieved 12 weeks later. All traps were set between the 5–6 October 2016 and retrieved on the 6 December 2016.

2. *Scraping*. Scrapes were collected immediately prior to setting traps. A troglofauna net (weighted ring net, 150 µm screen, various apertures according to diameter of the hole) was lowered to the bottom of the hole, or to the watertable, and scraped back to the surface along the walls of the hole. Each scrape comprised four sequences of lowering and retrieving the net. After each scrape, the contents of the net were transferred to a 125 ml vial and preserved in 100% ethanol. Scrapes were taken on the same dates as traps were set.

After return to the laboratory, troglofauna were extracted from the leaf litter bait used in traps using Tullgren® funnels under incandescent lamps. The light and heat drives the troglofauna and other invertebrates out of the litter into the base of the funnel containing 100% ethanol, which acts as a preservative. After about 72 hours, the ethanol and its contents were removed and sorted under a dissecting microscope. Litter from each funnel was also examined under a microscope for any remaining live or dead animals. Preserved scrapes were elutriated in the laboratory to separate animals from heavier sediment and screened into size fractions (250 and 90 μm) to remove debris and improve searching efficiency. Samples were then sorted under a dissecting microscope.

All fauna picked from scrapes or extracted from bait were examined for troglomorphic characteristics (lack of eyes and pigmentation, well developed sensory organs, slender appendages, vermiform body). Surface and soil-dwelling animals were identified only to Order level. Troglofauna were, as far as possible, identified to species/morphospecies level, unless damaged, juvenile or the wrong sex for identification. Identifications were based on morphology and made under dissecting and/or compound microscopes, with specimens dissected as necessary to aid their identification.

5.3. Personnel

Field survey was undertaken by Michael Curran and Anton Mittra. Species identifications were undertaken by Jane McRae and Stuart Halse. Maps were produced by Mike Scanlon. Reporting was done by Anton Mittra.

6. RESULTS

6.1. Stygofauna

A total of 830 specimens belonging to 57 species of stygofauna were recorded from the Project and surrounding region during surveys conducted in 2016 (Table 4). Reference sites yielded 730 specimens, including all 57 species, while impact areas yielded 100 specimens of six species. Combining results from current and previous studies (Table 1), at least 61 stygofauna species are known from the broader Gifford Creek PEC study area.

Major groups present include flatworms (Turbellaria), earthworms (Oligochaeta), rotifers (Rotifera), nematode roundworms (Nematoda), ostracods (Ostracoda), copepods (Cyclopoida and Harpacticoida), amphipods (Amphipoda), isopods (Isopoda), aquatic mites (Arachnida: Acari) and beetles (Insecta: Coleoptera). Seven of the 11 stygofauna species recorded in the previous Ecoscape (2016) survey were also recorded in the current survey (Ameiridae gen. nov. sp. B04, *Diacyclops cocking*, *Diacyclops humphreysi humphreysi*, *Diacyclops cockingi*, Paramelitidae sp. B49, *Enchytraeus* spp., Phreodrilidae \`with dissimilar ventral chaetae\` and Nematoda sp.), while four species (*Orbucyclops westraliensis*, *Areacandona* sp. BOS550, *Enchytraeus* sp. 1 (PSS) Pilbara and *Phreodrilus peniculus*) were not recollected. Higher-order identifications were removed from the final species list to avoid artificial inflation of richness; these taxa are shown in Appendix 4.

Results clearly demonstrate that the PEC containing the Project hosts a diverse stygofaunal assemblage. Furthermore, at least 30 species recorded in the Ecoscape (2016) and current survey (~48% of known species) are undescribed and probably restricted to the Gifford Creek Calcrete PEC. When compared with other extensively surveyed calcrete aquifers in Western Australia, with 62 species the Gifford Creek Calcrete PEC appears to be one of the most diverse in terms of known species richness. Other rich PECs include the Yeelirrie PEC where 70 species are known (Bennelongia 2015) and Lake Way PECs (Lake Violet, Uramurdah, Hinckler Well) where more than 58 species occur in calcretes associated with Lake Way (Outback Ecology 2012; MWH 2015).

Harpacticoid copepods are the most diverse taxonomic group in the area, with 13 species recorded. Twelve of these species are undescribed. Other notably diverse groups are ostracods (11 species), cyclopoid copepods (9) and amphipods (8).

Table 4. Stygofauna recorded at the Yangibana Project and surrounding areas in 2016.
Values are absolute abundance. Higher order identifications not included in final list of species are given in Appendix 4.

Higher Taxonomy	Lowest Identification	Abundance			Comments on Distribution
		Reference	Impact	Total	
Platyhelminthes **Turbellaria** Microturbellaria	Microturbellaria sp.	3		3	Not assessed in EIA.
Nematoda	Nematoda sp.	38	4	42	Not assessed in EIA.
Rotifera Eurotatoria **Bdelloidea**	Bdelloidea sp. 2:2	22		22	Not assessed in EIA.
	Bdelloidea sp. 3:3	5		5	Not assessed in EIA.
Monogononta Flosculariacea Flosculariidae	Flosculariidae sp.	2		2	Not assessed in EIA.
Ploima Lecanidae	*Lecane bulla*	2		2	Not assessed in EIA.
Annelida **Aphanoneura** Aeolosomatidae	*Aeolosoma* sp.	7		7	Not identified to species level. Genus is widespread across WA. Recorded outside 1 m drawdown.
Clitellata Enchytraeida Enchytraeidae	*Enchytraeus* spp.	1	10	11	Common taxa for which taxonomy is unresolved. Species tend to be restricted to single catchments but some are more widespread (Brown et al. 2015).
Haplotaxida Naididae	*Pristina longiseta*	74		74	Cosmopolitan (ABRS 2009).
Phreodrilidae	Phreodrilidae `with dissimilar ventral chaetae`	21	6	27	Widespread morphospecies that represents a species-complex.
	Phreodrilidae `with similar ventral chaetae`	10		10	Widespread morphospecies that represents a species-complex..
Tubificidae	Tubificidae sp.	5		5	Not identified to species-level, but confamiliar species are mostly widespread.
Arthropoda Chelicerata **Arachnida** Trombidiformes Piersigiidae	nr. *Stygolimnochares* sp. B02	1		1	New species, may be endemic to the PEC.
Crustacea **Ostracoda**	Ostracoda sp. BOS663	2		2	New species, may be endemic to the PEC.
Popocopida Candonidae	*Areacandona* sp. BOS675	8		8	New species, may be endemic to the PEC.
	Candonopsis tenuis	6		6	Widespread outside study area (ABRS 2009).
	Deminutiocandona murrayi	3		3	Also known from Pilbara (Karanovic 2007).
	Deminutiocandona sp. BOS673	6		6	New species, may be endemic to the PEC.
Cyprididae	*Cypricercus* sp. MB	35		35	Also occurs in Mulga Downs calypans (Bennelongia unpublished data)
	Riocypris sp.	2		2	Incomplete specimen; resembles *R. hinzeae* that occurs across the Yilgarn but species identification uncertain.
	Sarscypridopsis nr *aculeata*	23		23	Closely resembles *S. aculeatea*, a

Higher Taxonomy	Lowest Identification	Abundance			Comments on Distribution
					cosmopolitan species (ABRS 2009).
	Strandesia sp. 466	6		6	Also occurs in Pilbara (Pinder et al. 2010) and Carnarvon Basin (Halse et al. 2000).
Limnocytheridae	*Limnocythere dorsosicula*	20			Also occurs in Pilbara (Pinder et al. 2010) and Carnarvon Basin (Halse et al. 2000).
Maxillopoda Cyclopoida Cyclopidae	*Australoeucyclops karaytugi*	2		2	Australia-wide distribution (ABRS 2009).
	Diacyclops cockingi	41		41	Widespread throughout Pilbara and Yilgarn (Karanovic 2006).
	Diacyclops humphreysi humphreysi	47	62	109	Widespread throughout Pilbara and Yilgarn (Karanovic 2006).
	Fierscyclops (Fierscyclops) fiersi	5		5	Widespread throughout Pilbara and Yilgarn (Karanovic 2004).
	Mesocyclops brooksi	2		2	Australia-wide distribution (ABRS 2009).
	Mesocyclops notius	3		3	Australia-wide distribution (ABRS 2009).
	Microcyclops varicans	55	7	62	Australia-wide distribution (ABRS 2009).
	nr *Eucyclops* (ngen?) sp. B01	8		8	New species, may be endemic to the PEC.
Harpacticoida Ameiridae	Ameiridae gen. nov. sp. B04	11		11	New species, may be endemic to the PEC.
	Nitokra lacustris pacifica	6		6	
Canthocamptidae	*Australocamptus* sp. B16	5		5	New species, may be endemic to the PEC.
	Australocamptus sp. B17	4		4	New species, may be endemic to the PEC.
Ectinosomatidae	*Pseudectinosoma* sp. B02	8		8	New species, may be endemic to the PEC.
Miraciidae	*Schizopera* sp. B25	2		2	New species, may be endemic to the PEC.
	Schizopera sp. B26	2		2	New species, may be endemic to the PEC.
	Schizopera sp. B27	2		2	New species, may be endemic to the PEC.
	Schizopera sp. B28	3		3	New species, may be endemic to the PEC.
	Schizopera sp. B29	2		2	New species, may be endemic to the PEC.
	Schizopera sp. B30	2		2	New species, may be endemic to the PEC.
Parastenocarididae	*Parastenocaris* sp. B37	22		22	New species, may be endemic to the PEC.
	Parastenocaris sp. B38	4		4	New species, may be endemic to the PEC.
Malacostraca Amphipoda Bogidiellidae	*Bogidiella* sp. B06	1		1	New species, may be endemic to the PEC.
Melitidae	*Nedsia* sp. B06 (*hurlburti* group)	12		12	New species, may be endemic to the PEC.
Paramelitidae	Paramelitidae sp. B49	17	10	27	Previously of conservation concern, now known from reference areas with a range of approximately 1,000 km^2.
	Paramelitidae sp. B51	30		30	New species, may be endemic to the PEC.
	Paramelitidae sp. B52	2		2	New species, may be endemic to the PEC.

Higher Taxonomy	Lowest Identification	Abundance			Comments on Distribution
	Paramelitidae sp. B53	1		1	New species, may be endemic to the PEC.
	Paramelitidae sp. B54	1		1	New species, may be endemic to the PEC.
	Paramelitidae sp. B55	17		17	New species, may be endemic to the PEC.
Isopoda Tainisopidae	*Pygolabis* sp. B11	5		5	New species, differs from nearby *P. gascoyne* in male genital morphology. May be endemic to the PEC.
Syncarida Parabathynellidae	nr. *Atopobathynella* sp. B21	5		5	New species, may be endemic to the PEC.
	nr. *Atopobathynella* sp. B22	3		3	New species, may be endemic to the PEC.
Hexapoda **Insecta** Coleoptera Dytiscidae	*Paroster* sp. B02	4		4	New species, may be endemic to the PEC.
	Paroster sp. B03	1		1	New species, may be endemic to the PEC.
Total abundance*		**730**	**100**	**830**	
Total no. of species		**57**	**6**	**57#**	

*Total abundance was calculated to include higher-order identifications that were not included in final count of species.
#Does not include results from previous surveys and literature, which augment number of known species to 62.

6.1.1. Sampling Efficiency

Comparison of sample yields (abundance and species) between reference and impact areas using Chi-squared tests revealed that reference areas produced both significantly more species and specimens per sample than impact areas (1.46 vs. 0.40 species per sample; $\chi^2 = 6.58$, $p = 0.01$ and 18.72 vs. 6.67 specimens per sample; $\chi^2 = 11.10$, $p < 0.01$). Given that the reference area largely coincided with areas of calcrete and that impact samples were taken from granite and granitoid units, this result is not surprising. Calcrete is highly prospective stygofauna habitat compared with granite units and the perched aquifers on granite.

6.1.2. Distribution of Stygofauna Species

Records of the six stygofauna species in impact areas included 11 specimens of two species at Bald Hill, 84 specimens of five species at Yangibana North and two specimens of one species at Yangibana West. Five of the species (*Diacyclops humphreysi humphreysi*, *Microcyclops varicans*, Phreodrilidae `with dissimilar ventral chaetae`, *Enchytraeus* sp. (ex sp. 1 PSS Pilbara) and Nematoda sp.) are common species that are regarded as widespread outside the study area. The remaining species, Paramelitidae sp. B49, is probably restricted to the PEC. However, it was recorded in moderate abundance throughout the study area, including reference areas, and has a known range of approximately 1,000km ^{2}.

Ecoscape (2016) highlighted three species of stygofauna as being of potential conservation concern: the harpacticoid Ameiridae gen. nov. sp. B04; the ostracod Areacandona sp. BOS550; and the amphipod Paramelitidae sp. B49. Based on drawdown modelling (GRM 2017), collection locations for all three of these species are now considered to occur in reference areas as they occur outside the 1 m drawdown contour (Figure 5). Two of these species were also collected in the current survey at reference locations: Ameiridae gen. nov. sp. B04 was recorded from four additional regional reference sites (Figure 5) and Paramelitidae sp. B49 was recorded from four additional reference sites (Figure 5).

The presence of all stygofauna species in reference areas provides evidence that groundwater drawdown associated with mine dewatering at the Bald Hill, Frasers and Yangibana West/North deposits is unlikely to threaten the persistence of stygofauna species.

6.2. Troglofauna

A total of 16 specimens representing 10 species of troglofauna were recorded across 10 drill holes in the study area in 2016 (Table 5). Five troglofaunal specimens belonging to four species were collected in traps, nine animals of six species were collected in stygofauna samples and one specimen was collected in a scrape sample. One specimen of the millipede family Lophoproctidae was damaged and could not be identified further (i.e. Lophoproctidae sp.). However, it probably belongs to the recorded species *Lophoturus madecaccus* and is therefore not regarded as a separate species. Additional terrestrial (surface-dwelling) invertebrates were also collected in many holes but are not considered further here because they are not troglofauna and are likely to be widespread. All troglofaunal species were collected in very low abundances as either one or two individuals (Table 5).

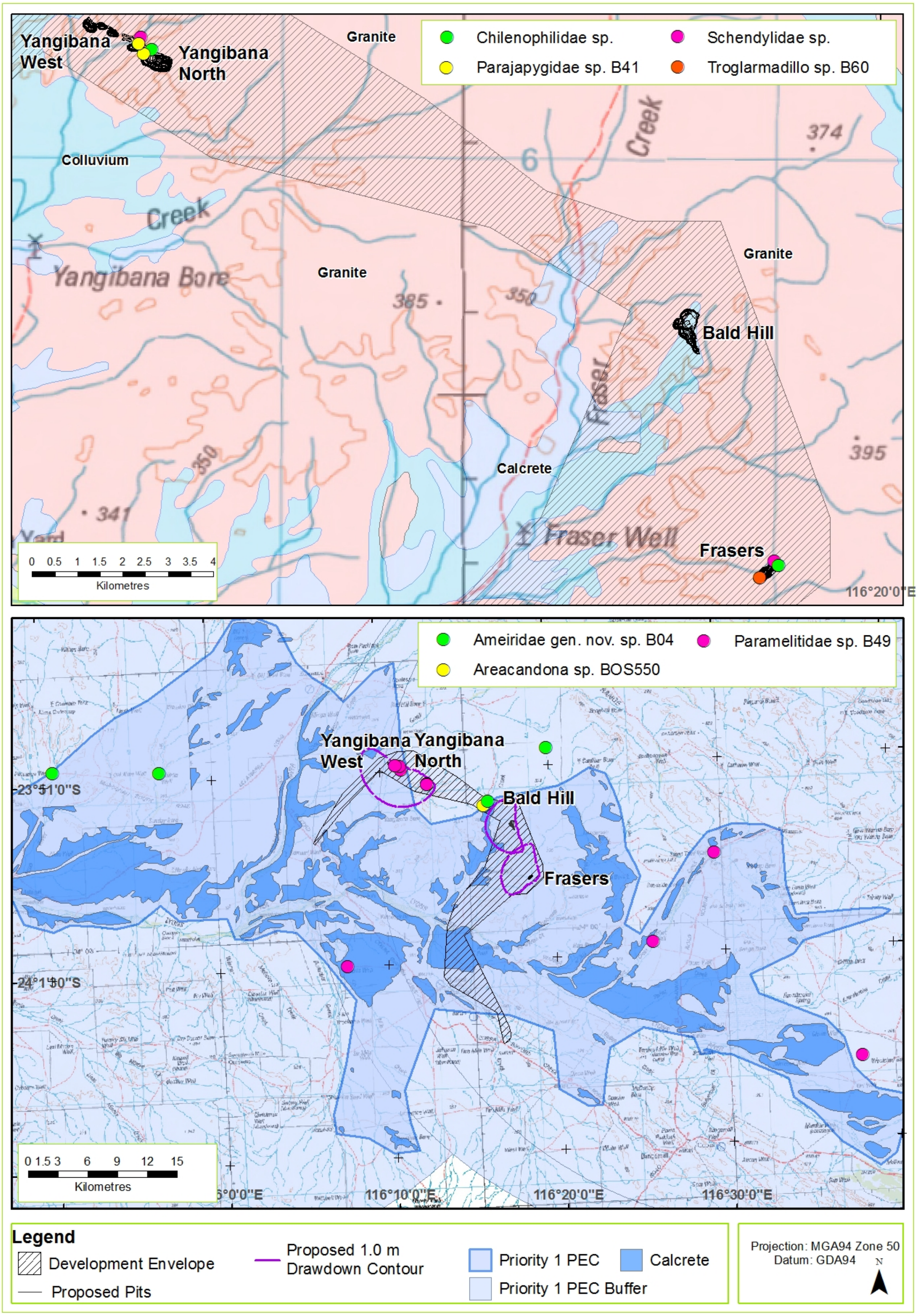

Figure 5. Collection locations for stygofauna (bottom) and troglofauna (top) currently or previously thought to be of potential conservation concern in relation to impact areas.

Table 5. Troglofauna recorded in the Project area in 2016.
Values are the number of specimens. Species shaded in grey are only known from impact areas.

Higher Taxonomy	Lowest Identification	Abundance			Comments on Distribution
		Impact	Reference	Total	
Arthropoda **Chelicerata** Arachnida Palpigradi	Palpigradi sp. B21		1	1	New species represented by a singleton from a reference site; possibly endemic. Median range[1] for troglofaunal palpigrades in Pilbara is 345 km^2, although group poorly studied[2]
Crustacea Malacostraca **Eumalacostraca** Isopoda Platyarthridae	*Trichorhina* sp. B29		1	1	New species represented by singleton from a reference site. Likely to be an SRE[1, 3]
Myriapoda Chilopoda Geophilida Chilenophilidae	Chilenophilidae sp.	2		2	Neither taxa identified to species level. Known linear ranges 30 km, Median range[1] for troglofaunal centipedes in Pilbara is 30 km^2
Schendylidae	Schendylidae sp.	2		2	
Diplopoda Polyxenida Lophoproctidae	Lophoproctidae sp.*	1		1	Likely to be *Lophoturus madecassus*
	Lophoturus madecassus		2	2	Widely distributed troglophile frequently recorded across the Pilbara[4] and Yilgarn[5]
Symphyla Cephalostigmata Scutigerellidae	*Scutigerella* sp.	1		1	May be *Scutigerella* sp. B09 previously recorded in the Bald Hill reference area[7]. Median range[1] for troglofaunal Symphyla of 8.3 km^2
Hexapoda Entognatha Diplura Parajapygidae	Parajapygidae sp. B41	2		2	Known linear range of 0.25 km; possibly endemic. Median range[1] for troglofaunal diplurans 16 km^2
Insecta Diptera Sciaridae	Sciaridae sp. B01		1	1	Widespread morphospecies frequently recorded across northwestern Australia[6]
Hemiptera Meenoplidae	*Phaconeura* sp.		2	1	Family widely recorded throughout WA[7], median range[1] of 19,725 km^2 although family under review and species ranges likely smaller than estimated[8].
Thysanura Nicoletiidae	*Trinemura* sp.		1	1	May be *Trinemura* sp. B29 recorded previously in study area[7]. Median range for troglofaunal silverfish 11 km^2
Total abundance		**8**	**8**	**16**	
Total no. of species		**5**	**6**	**10**	

[1]Halse and Pearson 2014; [2]Barranco and Harvey 2008; [3]Javidkar 2014; [4]Bennelongia 2012; [5]Bennelongia 2008c; [6]Bennelongia 2014; [7]Ecoscape 2016; Bennelongia unpublished data.

After appropriately aligning historical (Ecoscape 2016) and current results, at least 13 species of troglofauna are known from the study area, including a palpigrade, two isopods, three centipedes, a millipede, a symphylan, two diplurans, a sciarid fly, a meenoplid bug and a silverfish. At least six of these species are considered likely to be restricted to the study area, although assessments of endemism are limited by unresolved taxonomy in many groups. Two taxa recorded in the current survey are considered likely to be the same species recorded previously by Ecoscape (2016) and so are not regarded as additional species. These are *Scutigerella* sp., which is probably *Scutigerella* sp. B09; and *Trinemura* sp., which is likely to be *Trinemura* sp. B29. Overall, the Project appears to harbour a troglofauna community of low-to-moderate diversity. Additional sampling would probably increase the known ranges of the recorded species but would probably also add to the species list.

6.2.1. Sampling Efficiency

Of the 20 troglofauna samples collected, only four yielded troglofaunal (three by trapping and one by scraping). Six net haul samples for stygofauna also yielded troglofauna. The collection of troglofauna in stygofauna samples is not unusual and reflect the capture of animals that have fallen into water or the collection of animals from the sidewalls of the drill holes in the same way as scrape sampling.

Targeted troglofauna samples (combined traps and scrapes in each hole) in reference areas yielded an average of 0.4 specimens and 0.33 species per sample, while those in impact areas did not yield any troglofauna. Stygofauna net samples taken from holes inside deposit boundaries (including reference and impact samples across Bald Hill, Frasers and Yangibana North; Figure 3) yielded, on average, 0.67 specimens and 0.4 species per sample.

6.2.2. Distributions of Troglofauna Species

Holes in four deposit areas yielded troglofauna – Frasers, Gossan, Yangibana North and Yangibana West. The underlying geology of these deposits is largely granite and granitoid rock (PLgpi), with some unconsolidated ferruginous rubble and scree (C1f) present at Frasers (Ecoscape 2016). Troglofauna were also collected from the Bald Hill and Kanes Gossan deposits by Ecoscape (2016) but were not recorded there in the current survey. Bald Hill geology comprises granites (PLgpi and PLgpix) and unconsolidated units (C1f), while geology at Kanes Gossan largely comprises granite (PLgpi) (Ecoscape 2016). Additionally, the troglofaunal hemipteran *Phaconeura* sp. was collected from calcrete in a stygofauna sample in the regional reference site No. 1 Bore. The presence of troglofauna at Gossan and Kanes Gossan, which are not currently proposed for development, provides evidence that prospective troglofauna habitat occurs outside proposed development areas. Three specimens belonging to three species (Palpigradi sp. B21, Sciaridae sp. B01 and *Trichorhina* sp. B29) were collected in the current survey at Gossan, while four specimens of three species (Geophilidae sp., Projapygidae sp. B19 and *Trinemura* sp. B29) were collected by Ecoscape (2016) at Kanes Gossan.

Six of the 10 troglofauna species collected in the current survey were recorded at single sites, with the centipedes Chilenophilidae sp. and Schendylidae sp., the millipede *Lophoturus madecassus*/Lophoproctidae sp. and the dipluran Parajapygidae sp. B41 each being collected at two sites. Both centipedes have known linear ranges of approximately 17 km, while collection sites for Parajapygidae sp. B41 were separated by just 0.25 km (Figure 5). Lophoturus madecassus is very widespread in the Pilbara and Yilgarn (Bennelongia 2008c, 2012).

Six species were recorded in reference areas and are therefore not of conservation concern (Table 4). An additional higher-order identification, Lophoproctidae sp., was only recorded at a single impact site, but as this animal is considered likely to belong to the widespread species *Lophoturus madecassus*, it is currently not of conservation significance. The symphylan *Scutigerella* sp. was recorded as a singleton at the impact site YGWB001, but as it probably belongs to *Scutigerella* sp. B09 that was recorded previously at a reference site (Ecoscape 2016), it is not currently considered to be of conservation concern.

Based on proposed operation boundaries at the time of survey in 2015, Ecoscape (2106) suggested that five species of troglofauna recorded at the Project area were of potential or unknown conservation concern. Pit boundaries have since been altered, meaning that four of these speies (Projapygidae sp. B19, *Trinemura* sp. B29, Geophilidae sp. and *Scutigerella* sp. B09) were actually recorded at sites that will not be impacted by mine excavations (i.e. reference areas). However, the troglofaunal isopod *Troglarmadillo* sp. B60 remains known from only a single hole within the impact area at the Frasers deposit. Discounting *Scutigerella* sp. and Lophoproctidae sp. (discussed above), three troglofauna species recorded in the current survey are also known only from impact areas (Figure 3) and are of potential conservation concern. Therefore, a total of four troglofauna species are of potential concern in the current context of operations at the Project. They are discussed in further detail below.

Centipedes

The two centipede species, recorded as the family-level identifications Chilenophilidae sp. and Schendylidae sp., were each collected from two impact sites and have known linear ranges of approximately 17 km (Figure 5). Including these taxa, three centipede species have been recorded from the Project area, with Geophilidae sp. having been recorded by Ecoscape (2016) at reference site KGRC011.

Taxonomy of troglofaunal centipedes is incomplete, making estimates of ranges difficult. In a study of troglofauna in the Pilbara, Halse and Pearson (2014) estimated a median range for troglofaunal centipede species of 30 km^2. This is a far greater area than the proposed mine operations area and suggests that it is reasonably likely that both Chilenophilidae sp. and Schendylidae sp. also occur in reference areas. Furthermore, the two species were recorded from both Yangibana North and Frasers pits and areas not proposed for excavation or development occur between these collection locations (Figure 5). The intermediate areas consist mainly of the same PLgpi geological units as the collection locations. This suggests both species are likely to occur in reference areas interspersed between proposed pits, if not further afield as well.

Parajapygidae sp. B41

Subterranean diplurans, and indeed all members of the hexapod order Dilpura, are poorly studied in Western Australia and only a small proportion of species are described. Koch (2009) suggested that diplurans were diverse in arid and semi-arid regions of WA.

Parajapygidae sp. B41 is one of two dipluran species that have been recorded from the Project area and each represents a separate family. Projapygidae sp. B19 was recorded from a hole at the Kanes Gossan deposit that is now considered to be a reference location (Ecoscape 2016). Parajapygidae sp. B41 was recorded from two holes separated by approximately 0.25 km in the Yangibana North impact area (Figure 5). Troglofaunal species of Diplura in the Pilbara have estimated median ranges of 16 km^2 (Halse and Pearson 2014), suggesting that Parajapygidae sp. B41 is moderately likely to occur outside the proposed operations area. The notion that it occurs in reference areas is further supported by the continuation of deposit geology (PLgpi) outside impact areas (Figure 5).

Troglarmadillo sp. B60

Two males and one female belonging to the troglofaunal isopod species *Troglarmadillo* sp. B60 were collected from a single hole in the impact area at the Frasers deposit by Ecoscape (2016). The species was not recollected in the current survey. Based on previous biogeographic studies of subterranean isopods in the Yilgarn, it is highly likely that *Troglarmadillo* sp. B60 is restricted to the calcrete PEC. In a study of 12 calcretes along three palaeodrainages in the Yilgarn, Javidkar (2014) identified 28 discrete lineages of troglofaunal isopods, each of which probably represents a new species. Only three lineages were recorded from more than one calcrete, invariably from neighbouring calcretes within a single palaeodrainage, while the remaining species were restricted to individual calcretes. This exemplifies the restricted distributions common amongst troglofaunal isopods in Western Australia (see also Cooper *et al*. 2008 for a study of stygofaunal isopods).

Although *Troglarmadillo* sp. B60 is likely to be restricted to the PEC, the continuation of the deposit geology (PLgpi) outside impact areas where *Troglarmadillo* sp. B60 was collected suggests it also occurs in reference areas (Figure 5).

7. POTENTIAL IMPACTS ON SUBTERRANEAN FAUNA

In general, there are two types of mine-related impacts:

1. *Primary Impacts* have the potential to threaten the persistence of subterranean fauna through direct removal of habitat; and

2. *Secondary Impacts* reduce population densities rather than threatening the persistence of species.

This assessment focusses on whether mine development is likely to threaten persistence of species and, therefore, considers only primary impacts. More information on the factors causing secondary impacts (and only reducing population sizes) is given in Appendix 1. The potential effects of primary impacts are considered below.

7.1. Stygofauna

The primary mine-related factors contributing to the loss of stygofauna habitat are:

(1) *Groundwater drawdown*. Drawdown of aquifers from dewatering of mine pits or the abstraction of groundwater for ore processing is likely to threaten the persistence of any stygofauna species restricted to the area of drawdown.

(2) *Pit excavation*. Removal of stygofauna habitat when excavating mine pits is likely to threaten the persistence of any stygofauna species restricted to the mine pit. This impact can be included in the assessment of groundwater drawdown, because the mine pits are contained within the area of drawdown.

All stygofauna species known from the Project area have been recorded in areas outside the 1 m drawdown contour modelled by GRM (2017) (Figure 3). The 1 m drawdown contour is regarded as representing the extent of potential impact of stygofauna because the likely depth and volume of saturated calcrete in the vicinity of proposed development areas means that substantial stygofauna habitat would remain intact outside the 1 m drawdown contour. It should be recognised, however, that much of the proposed dewatering, as well as the minepits themselves, will occur in consolidated granite and granitoid units (PLgpi) that are mostly unconducive to stygofauna. Thus, sampling in impact areas yielded significantly fewer animals and species per sample than in reference areas (that for the most part coincided within calcrete aquifers).

Given that all stygofauna species recorded in impact areas were also collected in reference areas, it is considered unlikely that dewatering, excavation and other mine-related activities at the Project will have any substantial impacts on the conservation values of stygofauna communities or the persistence of any individual species.

7.2. Troglofauna

The primary mine-related factor contributing to the loss of troglofauna habitat is mine pit excavation. In the case of proposed mining operations at the Project, pit excavations are the only proposed operations that will result in significant loss of troglofauna habitat.

As discussed in Section 6, four troglofauna species are known only from inside proposed pit boundaries. It is considered probable that all four species have ranges extending outside the mine pits. For the centipedes Chilenophilidae sp. and Schendylidae sp., the evidence of wider occurrence is very strong because both species were recorded from two pits approximately 17 km apart, with the intervening reference areas having similar geology to the collecting sites. It is very unlikely the species do not occur in at least some of the intervening reference areas and, therefore, proposed mining is considered unlikely to threaten these species.

The dipluran Parajapygidae sp. B41 was collected from two holes (YGRC069 and YGRC067) in the Yangibana North deposit and has a known linear range of approximately 0.25 km. Granite and granitoid (PLgpi) geologies similar to those at collection locations occur extensively in the adjacent reference areas and it is considered likely the species extends into these. The median linear range of Pilbara troglofaunal diplurans is estimated to be at least 4.5 km (recalculated from Halse and Pearson 2014), which is approximately twice the length of the Yangibana North deposit.

Troglarmadillo sp. B60 was recorded as three individuals from a single hole in the Frasers deposit. Granite and granitoid (PLgpi) geologies similar to those at collection location occur extensively in the adjacent reference areas and it is considered likely the species extends into these. The median linear range of Pilbara troglofaunal isopods is estimated to be at least 1.8 km (recalculated from Halse and Pearson 2014), which is approximately twice the length of the Frasers deposit.

In the continuous suitable habitat around the deposits, it is likely the both Parajapygidae sp. B41 and *Troglarmadillo* sp. B60 have larger ranges than many of the other species in their respective groups and it is considered unlikely that proposed mining would threaten either of these species.

8. CONCLUSION

This report summarised the results of previous and current field surveys of subterranean fauna at the Yangibana Project and surrounding area, including the Priority 1 PEC, '*Gifford Creek, Mangaroon, Wanna calcrete groundwater assemblage type on Lyons palaeodrainage on Gifford Creek, Lyons and Wanna Stations'*. It subsequently evaluated the risks posed by proposed mining operations, including excavations and dewatering, to the conservation values of subterranean fauna communities and species.

Combining results of previous and current studies, at least 61 species of stygofauna have been recorded in the study area, making it one of the most speciose assemblages of stygofauna known from Western Australia. Recorded taxa include flatworms (Turbellaria), earthworms (Oligochaeta), rotifers (Rotifera), nematode roundworms (Nematoda), ostracods (Ostracoda), copepods (Cyclopoida and Harpacticoida), amphipods (Amphipoda), isopods (Isopoda), aquatic mites (Arachnida: Acari) and beetles (Insecta: Coleoptera). Notably diverse groups include harpacticoid copepods (13 species), ostracods (11 species), cyclopoid copepods (9) and amphipods (8). Just under half of the species recorded are undescribed and are likely to be restricted (endemic) to the study area, particularly the calcrete aquifer PEC. The suitability of calcrete geologies as stygofauna habitat was demonstrated by significantly higher yield rates in terms of both abundance and species in calcrete samples than in those taken from granite geologies.

All stygofauna species that have been recorded in the study area, including those previously thought to be of conservation concern, are known from reference areas outside predicted 1 m drawdown contours associated with proposed developments. This provides evidence that the conservation values of stygal species and communities will not be threatened by mine-related activities at the Project.

Combining historic and current studies, a total of 13 species of troglofauna have been recorded from the study area in subterranean spaces above the water table. At least six of these are considered likely to be endemic to the study area, although range assessments are hampered by unresolved taxonomy in many troglofauna groups, and the proportion of restricted species may indeed be higher. Targeted troglofauna sampling was largely confined to deposit areas in granite and granitoid geologies and yield rates were low in terms of both abundance and species per sample. It would appear that the

Project area hosts a low-to-moderately diverse troglofauna assemblage, although additional sampling would probably augment the number of known species.

Many troglofauna species previously considered to be of potential conservation concern were, in the light of updated pit boundaries, actually collected from reference locations. Considering all records of troglofauna at the Project, four species are known only from within the proposed mine pits – the centipedes Chilenophilidae sp. and Schendylidae sp., the dipluran Parajapygidae sp. B41 and the isopod *Troglarmadillo* sp. B60. Both centipede species were recorded from two deposits and have linear ranges of approximately 17 km. Troglofaunal centipedes have estimated median ranges of 30 km^2. Furthermore, the geological unit from which both centipede species were collected is continuous throughout reference and impact areas, and probably provides suitable habitat away from proposed development sites. It is considered likely that both Chilenophilidae sp. and Schendylidae sp. occur in reference areas and their conservation values are not threatened.

The dipluran Parajapygidae sp. B41 was collected from two holes in the Yangibana North deposit, while *Troglarmadillo* sp. B60 was recorded as three individuals from a single hole in the Frasers deposit. Granite and granitoid (PLgpi) geologies similar to those at the collection locations occur extensively in reference areas around both deposits and it is considered likely that both species extend into these. Thus, while the evidence of their wider range is based only on surrogate information (habitat connectivity and the ranges of related species) it is considered unlikely that proposed mining would threaten the conservation values of either of these species.

9. REFERENCES

ABRS (2009) Australian Faunal Directory. Australian Biological Resources Study, Canberra. http://www.environment.gov.au/biodiversity/abrs/online-resources/fauna/afd/index.html

Barranco, P., and Harvey, M.S. (2008) The first indigenous palpigrade from Australia: a new species of *Eukoenenia* (Palpigradi: Eukoeneniidae). *Invertebrate Systematics* **22**, 227-233. [5]Bennelongia 2008 South Flank

Bennelongia (2008a) Troglofauna survey of the Orebody 18 Mine Modification. Report 2008/27. Bennelongia Pty Ltd, Jolimont, 21 pp.

Bennelongia (2008b) Troglofauna Survey: Area C Mine – E and F Deposits. Report 2008/39. Bennelongia Pty Ltd, Jolimont, 35 pp.

Bennelongia (2008c) Troglofauna Survey at Koolyanobbing. Report 2008/49. Bennelongia Pty Ltd, Jolimont, 24 pp.

Bennelongia (2009) Yilgarn Iron Ore Project: Carina deposit, subterranean fauna assessment. Report 2009/69, Bennelongia Pty Ltd, Jolimont, 30 pp.

Bennelongia (2014) Subterranean fauna survey at Orebody 24. Report 2014/209. Bennelongia Pty Ltd, Jolimont, 51 pp.

Bennelongia (2015) Yeelirrie Subterranean Fauna Assessment. Report 2015/236. Bennelongia Pty Ltd, 38 pp.

Biota (2006) BHP Biliton Iron Ore Regional Subterranean Fauna Study Project No. 312, Biota Environmental Sciences, Leederville, 32 pp. Cooper et al. 2002

Culver, D.C., T. Pipan and K. Schneider (2009) Vicariance, dispersal and scale in the aquatic subterranean fauna of karst regions. *Freshwater Biology* **54**, 918-929.

ecologia Environment (2009) Tropicana Gold Project - Stygofauna Survey Report. ecologia Environment, West Perth, 40 pp. Ecoscape (2016)

Eberhard, S.M., Halse, S.A. and Humphreys, W.F. (2005) Stygofauna in the Pilbara region, north-west Western Australia: a review. *Journal of the Royal Society of Western Australia*, **88**, 167-176.

Edward, K.L. and Harvey, M.S. (2008) Short-range endemism in hypogean environments: the pseudoscorpion genera *Tyrannochthonius* and *Lagynochthonius* (Pseudoscorpiones: Chthoniidae) in the semiarid zone of Western Australia. *Invertebrate Systematics* **22,** 259–293.

EPA (2016a) Environmental factor guideline: subterranean fauna. Environmental Protection Authority, Perth, 5 pp.

EPA (2016b) Technical guidance: subterranean fauna survey. Environmental Protection Authority, Perth, 20 pp.

Desmond, A., Kendrick, P., & Chant, A. 2001, "Gascoyne 3 (*GAS3 - Augustus subregion*)," in *A Biodiversity Audit of Western Australia's 53 Biogeographical Subregions in 2002*, N. McKenzie, J. May, & S. McKenna eds., Department of Conservation and Land Management, pp. 240-251.

Finston, T.L., Johnson, M.S., Humphreys, W.F., Eberhard, S.M., and Halse, S.A. (2007) Cryptic speciation in two widespread subterranean amphipod genera reflects historical drainage patterns in an ancient landscape. *Molecular Ecology* **16**, 355-365.

GHD (2009) Report for Jack Hills expansion project regional stygofauna phase 1 survey. GHD, Perth,Gibert & Deharveng 2002

GRM (2017) Unpublished report to Ecoscape by Groundwater Resource Management, January 2017.

Guzik, M.T., Abrams, K.M., Cooper, S.J.B., Humphreys, W.F., Cho, J.-L., Austin, A.D., (2008). Phylogeography of the ancient *Parabathynellidae* (Crustacea: Bathynellacea) from the Yilgarn region of Western Australia. *Invertebrate Systematics* 22, 205-216.

Guzik, M.T., Austin, A.D., Cooper, S.J.B., Harvey, M.S., Humphreys, W.F., Bradford, T., Eberhard, S.M., King, R.A., Leys, R., Muirhead, K.A., and Tomlinson, M. (2010) Is the Australian subterranean fauna uniquely diverse? *Invertebrate Systematics* **24**, 407-418.

Halse, S. (2015) Subterranean biodiversity in the Pilbara provides difficulties for environmental assessment. In 'New generation, next generation. Society of Australian Systematic Biologists national conference, 6-9 December 2015.' (Society of Australian Systematic Biologists: Fremantle).

Halse, S., and Pearson, G. (2014) Troglofauna in the vadose zone: comparison of scraping and trapping results and sampling adequacy. *Subterranean Biology* **13**, 17-34.

Halse, S.A., Shiel, R.J., Storey, A.W., Edward, D.H.D., Lansbury, I., Cale, D.J., and Harvey, M.S. (2000) Aquatic invertebrates and waterbirds of wetlands and rivers of the southern Carnarvon Basin, Western Australia. *Records of the Western Australian Museum Supplement* **61**, 217-267.

Harvey, M.S. (2002) Short-range endemism among the Australian fauna: some examples from non-marine environments. *Invertebrate Systematics* **16,** 555-570.

Harvey, M.S., Berry, O., Edward, K.L., and Humphreys, G. (2008) Molecular and morphological systematics of hypogean schizomids (Schizomida:Hubbardiidae) in semiarid Australia. *Invertebrate Systematics* **22**, 167–194.

Hose, G.C., J. Sreekanth, O. Barron and C. Pollino (2015) Stygofauna in Australian Groundwater Systems: Extent of knowledge. CSIRO, Australia.

Humphreys, W.F. (2001) Groundwater calcrete aquifers in the Australian arid zone: the context to an unfolding plethora of stygal biodiversity. *Records of the Western Australian Museum Supplement* **64**, 63-83.

Humphreys, W.F. (2006) Aquifers: the ultimate groundwater dependent ecosystem. *Australian Journal of Botany* **54**, 115-132. Humphreys, W.F. (2008) Rising from Down Under: developments in subterranean biodiversity in Australia from a groundwater fauna perspective. *Invertebrate Systematics* **22**, 85–101.

Javidkar, S. (2014) Molecular systematics and biogeographic histroy of oniscidean isopod troglofauna in groundwater calcretes of central Western Australia. Ph D Thesis, The University of Adelaide, Adelaide, South Australia.

Karanovic, I. (2007) Candoninae (Ostracoda) from the Pilbara region in Western Australia. *Crustaceana Monographs* **7**, 1-432.

Karanovic, T. (2004) Subterranean copepods (Crustacea: Copepoda) from arid Western Australia. *Crustaceana Supplement* **3**, 1-366.

Karanovic, T. (2006) Subterranean copepods (Crustacea, Copepoda) from the Pilbara region in Western Australia. *Records of the Western Australian Museum Supplement* **70,** 1-239.

Kendrick, P. 2002, "Gascoyne 1 (GAS1 - Ashburton subregion)," in *A Biodiversity Audit of Western Australia's 53 Biogeographic Subregions in 2002*, Department of Conservation and Land Management, Perth, pp. 224-232.

Koch, M. (2009) Biodiversity of the two-pronged bristletails (Diplura) in Western Australia as revealed from recent mining projects. 10 pp. Korbel, K., and Hose, G. (2011). A tiered framework for assessing groundwater ecosystem health. *Hydrobiologia* **661**, 329-349.

Leys, R., Watts, C.H.S., Cooper, S.J.B., and Humphreys, W.F. (2003) Evolution of subterranean diving beetles (Coleoptera: Dytiscidae Hydroporini, Bidessini) in the arid zone of Australia. *Evolution* **57**, 2819-2834.

MWH (2015) Wiluna Uranium Project: Millipede targeted subterranean fauna assessment. MWH, Jolimont, 53 pp + appendices.

Outback Ecology (2012) Lake Way borefield subterranean fauna assessment. Outback Ecology, Jolimont, Western Australia. 64 pp.

Ponder, W.F., and Colgan, D.J. (2002) What makes a narrow-range taxon? Insights from Australian freshwater snails. . *Invertebrate Systematics* **16**, 571-582.

Watts, C.H.S., and Humphreys, W.F. (2006) Twenty-six new Dytiscidae (Coleoptera) of the genera Limbodessus Guignot and Nirripirti Watts & Humphreys, from underground waters in Australia. *Transactions of the Royal Society of Australia* **130**, 123-185.

Wilson, G.D.F., and Keable, S.J. (2002) New Genera of Phreatoicidea (Crustacea: Isopoda) from Western Australia. *Records of the Australian Museum* **54**, 41-70.

Appendix 1. Secondary impacts of mining on subterranean fauna.

Mining activities that may result in secondary impacts to subterranean fauna include:

1. *De-watering below troglofauna habitat*. The impact of a lowered water table on subterranean humidity and, therefore, the quality of troglofauna habitat is poorly studied but it may represent risk to troglofauna species in some cases. The extent to which humidity of the vadose zone is affected by depth to the watertable is unclear. Given that pockets of residual water probably remain trapped throughout de-watered areas and keep the overlying substrate saturated with water vapour, de-watering may have minimal impact on the humidity in the unsaturated zone. In addition, troglofauna may be able to avoid undesirable effects of a habitat drying out by moving deeper into the substrate if suitable habitat exists at depth. Overall, de-watering outside the proposed mine pits is not considered to be a significant risk to troglofauna.
2. *Percussion from blasting*. Impacts on both stygofauna and troglofauna may occur through the physical effect of explosions. Blasting may also have indirect detrimental effects through altering underground structure (usually rock fragmentation and collapse of voids) and transient increases in groundwater turbidity. The effects of blasting are often referred to in grey literature but are poorly quantified and have not been related to ecological impacts. Any effects of blasting are likely to dissipate rapidly with distance from the pit and are not considered to be a significant risk to either stygofauna or troglofauna outside the proposed mine pits.
3. *Overburden stockpiles and waste dumps*. These artificial landforms may cause localised reduction in rainfall recharge and associated inflow of dissolved organic matter and nutrients because water runs off stockpiles rather than infiltrating through them and into the underlying ground. The effects of reduced carbon and nutrient input are likely to be expressed over many years and are likely to be greater for troglofauna than stygofauna (because lateral movement of groundwater should bring in carbon and nutrients). The extent of impacts on troglofauna will largely depend on the importance of chemoautotrophy in driving the subterranean system compared with infiltration-transported surface energy and nutrients. Stockpiles are unlikely to cause species extinctions, although population densities of species may decrease under them.
4. *Aquifer recharge with poor quality water*. It has been observed that the quality of recharge water declines during, and after, mining operations as a result of rock break up and soil disturbance (i.e. Gajowiec 1993; McAuley and Kozar 2006). Impacts can be minimised through management of surface water and installing drainage channels, sumps and pump in the pit to prevent of recharge though the pit floor.
5. *Contamination of groundwater by hydrocarbons*. Any contamination is likely to be localised and may be minimised by engineering and management practices to ensure the containment of hydrocarbon products.

Appendix 2. List of sampling sites for stygofauna in October 2016.

Site Identification	Orebody	Latitude	Longitude	Type	Date	Sample Method#	Groundwater Depth (m)	Depth of Hole (m)	Temperature (°C)	EC (µS cm^{-1})	pH
BHRC082	Bald Hill	-23.90855939	116.2965337	Reference	5/10/2016	Net	23.09	49	30	1759	7.44
BHRC158	Bald Hill	-23.90733035	116.295256	Reference	5/10/2016	Net	23.6	57	27.6	398	7.1
BHRC160	Bald Hill	-23.90688341	116.2957598	Impact	5/10/2016	Net	25.25	54	33.8	498	7.04
BHRC164	Bald Hill	-23.90643161	116.2951837	Impact	5/10/2016	Net	25.76	48	30.3	755	6.75
Minga Well	Edmund Station	-23.7954585	116.095883	Reference	9/10/2016	Net	4.21	5	22.2	17	7.25
No. 1 Bore	Edmund Station	-23.72481296	116.0421623	Reference	9/10/2016	Net	4.42	6.4	22.6	17	7.6
Old Shed Bore	Edmund Station	-23.75947274	116.0446259	Reference	9/10/2016	Net	7.94	12	23.8	16.1	7.27
FRRC074	Frasers	-23.950612	116.3116682	Impact	5/10/2016	Net	34.62	41.6	26.7	215	7.07
FRRC075	Frasers	-23.95045228	116.3114999	Impact	6/10/2016	Net	34.07	42	27.5	75.1	7.15
FRRC080	Frasers	-23.95099592	116.311481	Impact	5/10/2016	Net	35.9	43.4	28.2	276	7.1
FRRC082	Frasers	-23.95083989	116.3113088	Impact	5/10/2016	Net	34.08	50.58	30.5	310	6.88
FRRC098	Frasers	-23.95284862	116.3097478	Reference	5/10/2016	Net	32.13	41.5	34	316	6.9
FRRC100	Frasers	-23.95060093	116.3120397	Impact	6/10/2016	Net	35.73	44	26.9	2082	7.09
Buffer Well	Gifford Creek Station	-23.92865971	115.9229582	Reference	9/10/2016	Pump	-	-	26.5	61.7	6.81
Burts Bore	Gifford Creek Station	-24.02557693	116.1254482	Reference	10/10/2016	Pump	-	-	22.9	5480	7.55
Burts Well	Gifford Creek Station	-24.02554393	116.1256126	Reference	10/10/2016	Net	5	18.5	22.3	7650	7.7
Dixons Well	Gifford Creek Station	-24.13324093	116.3384921	Reference	8/10/2016	Pump	-	-	25.3	566	7.46
Edmund Well	Gifford Creek Station	-23.92192443	116.0700261	Reference	9/10/2016	Net	12.39	13	27.7	3540	7.37
Elliot Well	Gifford Creek Station	-24.01607222	116.4285924	Reference	8/10/2016	Pump	-	-	27.6	42.2	6.7
Foxys Bore	Gifford Creek Station	-23.83506353	116.3316856	Reference	7/10/2016	Pump	-	-	29.8	2156	7.09
Fraser Well	Gifford Creek Station	-23.94588443	116.2614996	Reference	10/10/2016	Net	10.79	34.5	23	2780	7.37
Hart Bore	Gifford Creek Station	-24.01769607	116.372702	Reference	8/10/2016	Pump	-	-	27.1	46.7	7.08
Hawkes Nest Bore	Gifford Creek Station	-23.93104944	115.958275	Reference	9/10/2016	Pump	-	-	28.7	2870	6.96
Henderson Bore	Gifford Creek Station	-23.92530284	116.38635	Reference	7/10/2016	Pump	-	-	26.6	6170	7.67
Judys Bore*	Gifford Creek Station	-24.09971308	116.4956005	Reference	8/10/2016	Pump	-	-	29.1	78.2	7.32
Minga Bore	Gifford Creek Station	-23.88136783	116.2719768	Reference	7/10/2016	Net	-	-	25.6	3050	7.44
Pimbyana Bore	Gifford Creek Station	-23.95731252	116.4059847	Reference	7/10/2016	Pump	-	-	28.1	2510	7.43
Range Bore	Gifford Creek Station	-24.0267352	116.5110249	Reference	8/10/2016	Pump	-	-	27	2279	7.37
Roadside Bore	Gifford Creek Station	-23.96855254	116.4559119	Reference	7/10/2016	Pump	-	-	26.5	3580	7.81
Stone Tank Bore	Gifford Creek Station	-23.93721025	116.4927801	Reference	7/10/2016	Net	6.67	16	30.1	3070	6.77
Swamp Bore	Gifford Creek Station	-23.95867834	116.5363186	Reference	7/10/2016	Pump	-	-	30.7	198.1	7.03
Terminus Bore	Gifford Creek Station	-24.00952379	116.5729493	Reference	7/10/2016	Pump	-	-	30	167.8	6.92
Woodsys Bore	Gifford Creek Station	-23.98868246	116.1535755	Reference	9/10/2016	Pump	-	-	26.6	2990	7.52
Yangibana Bore	Gifford Creek Station	-23.88842296	116.1637604	Reference	9/10/2016	Net	10.67	17	26.7	33.7	7.05
Alma Well	Mangaroon Station	-23.91219602	115.8323321	Reference	9/10/2016	Net	13.39	14	28.3	8340	7.23
No. 1 Bore	Mangaroon Station	-23.94401164	115.6746289	Reference	9/10/2016	Pump	-	-	26.8	6810	7.27
River Bore	Mangaroon Station	-23.93505681	115.7693148	Reference	9/10/2016	Pump	-	-	25.3	2960	7.43
Middle Well	Maroonah Station	-23.84224323	115.9490486	Reference	9/10/2016	Net	5.34	7	26.6	3590	6.96
Old Alma Well	Maroonah Station	-23.84515529	115.8999084	Reference	9/10/2016	Net	4.71	6.71	28.7	1576	7.25
Pooranoo Well	Maroonah Station	-23.83719788	115.8437093	Reference	9/10/2016	Net	8.51	9.51	28	3090	7.06
5-01	Mt Augustus Station	-24.1272314	116.6311185	Reference	8/10/2016	Net	10.57	14	28.3	82.8	7.43

Site Identification	Orebody	Latitude	Longitude	Type	Date	Sample Method#	Groundwater Depth (m)	Depth of Hole (m)	Temperature (°C)	EC (µS cm^{-1})	pH
Borpheus	Mt Augustus Station	-24.03039338	116.5788653	Reference	7/10/2016	Net	5.5	11	30.7	148.7	7.19
Centipede Bore	Mt Augustus Station	-24.15306219	116.6621479	Reference	8/10/2016	Pump	-	-	28.6	3460	7.61
Clarke Well	Mt Augustus Station	-24.1045411	116.6094617	Reference	8/10/2016	Pump	-	-	27.1	81.6	7.04
Jamieson Well	Mt Augustus Station	-24.13615377	116.5390278	Reference	8/10/2016	Net	3.2	3.7	26.9	71.1	7.26
McEwen Well	Mt Augustus Station	-24.2296283	116.6829457	Reference	7/10/2016	Net	4.5	6	27.6	122.9	7.96
Ryans Bore	Mt Augustus Station	-24.09793257	116.56708	Reference	8/10/2016	Net	-	-	27.5	57.4	7.21
Uni Well	Mt Augustus Station	-24.15175889	116.6212478	Reference	8/10/2016	Net	7.15	7.65	29.7	2299	7.45
YGRC066	Yangibana North	-23.84800524	116.1874499	Impact	6/10/2016	Net	16.6	18.6	31.2	198	6.9
YGRC067	Yangibana North	-23.8483922	116.1871824	Impact	6/10/2016	Net	15.65	28.15	32.2	207.5	6.17
YGRC069	Yangibana North	-23.84635465	116.186164	Impact	6/10/2016	Net	10.72	15	33.9	237	7.24
YGRC073	Yangibana North	-23.84753068	116.1848114	Impact	6/10/2016	Net	7.2	34.2	31.8	147.7	6.63
YGWB001	Yangibana North	-23.84938753	116.1875297	Impact	6/10/2016	Net	17	39	29.8	1402	8.5

#Pump refers to samples taken by filtering bore pump outflow.

*Sampled opportunistically on 6/12/2016.

Appendix 4. List of sampling sites for troglofauna in October 2016.

Site Identification	Orebody	Date	Type	Depth to Groundwater (m)	Depth of Hole (m)	Method	Latitude	Longitude	Trap Depth
BHRC023	Bald Hill	5/10/2016	Reference	-	20	Trap	-23.89786363	116.2961102	30
BHRC135	Bald Hill	5/10/2016	Reference	-	18	Trap*	-23.90012646	116.2971687	10, 18
BHRC230	Bald Hill	5/10/2016	Impact	-	35	Trap	-23.90038013	116.2954222	34
BHRC231	Bald Hill	5/10/2016	Impact	-	42	Trap*	-23.90039619	116.2949274	10, ?
BHRC232	Bald Hill	5/10/2016	Reference	-	24	Trap	-23.89992565	116.2968648	23
BHRC250	Bald Hill	5/10/2016	Reference	20	-	Trap	-23.91511744	116.2981457	19
FRRC031	Frasers	6/10/2016	Reference	-	13	Trap	-23.95549445	116.3056256	12
FRRC035	Frasers	6/10/2016	Reference	-	16	Trap	-23.94695988	116.311774	15
FRRC040	Frasers	6/10/2016	Reference	-	28	Trap	-23.94338799	116.3128346	27
FRRC047	Frasers	6/10/2016	Reference	-	15.5	Trap	-23.93973599	116.3141609	15
FRRC103	Frasers	6/10/2016	Impact	35	-	Trap*	-23.95039214	116.311805	8, 31
FRRC106	Frasers	6/10/2016	Reference	20	-	Trap	-23.94985596	116.3130854	19
GSRC002	Gossan	6/10/2016	Reference	28	-	Trap	-23.85885087	116.1974777	
GSRC004	Gossan	6/10/2016	Reference	6	-	Trap	-23.85922669	116.198536	5
LERC012	Lions Ear	6/10/2016	Reference	14	-	Trap*	-23.86405747	116.2122947	6, 13
YGRC065	Yangibana North	6/10/2016	Impact	-	10	Trap	-23.84778043	116.1876379	9
YGRC070	Yangibana North	6/10/2016	Impact	12	-	Trap*	-23.8465875	116.1857894	6, 11
YWRC013	Yangibana West	6/10/2016	Reference	11	-	Trap	-23.84497866	116.1821565	10
YWRC014	Yangibana West	6/10/2016	Reference	6	-	Trap	-23.84536576	116.1819184	6
YWRC042	Yangibana West	6/10/2016	Reference	14	-	Trap	-23.84159174	116.1753829	13

*Two traps deployed.

Appendix 4. Higher-order stygofauna identifications that were removed from final list of species to avoid artificial inflation of richness.

Higher Taxonomy	LowestID	Reference	Impact	Likely Species
Platyhelminthes				
Turbellaria	Turbellaria sp.	1		Possibly Microturbellaria sp.
Annelida				
Clitellata				
Enchytraeida				
Enchytraeidae	Enchytraeidae sp.	1		Probably part of the *Enchytraeus* species complex.
Arthropoda				
Crustacea				
Ostracoda				
	Ostracoda sp. unident.	9		One of many ostracod species recorded.
Popocopida				
Candonidae	Candonopsis sp.	53		Possibly *Candonopsis tenuis*.
Cyprididae	Cyprinopsinae sp.	15		Possibly *Sarscypridopsis* nr. *aculeate*.
	Sarscypridopsis sp.	1		Possibly Sarscypridopsis nr. Aculeate.
Limnocytheridae	Limnocythere sp.	1		Possibly *Limnocythere dorsosicula*.
Maxillopoda				
Cyclopoida	Cyclopoida sp.	1		One of eight cyclopoid species recorded.
Cyclopidae	Diacyclops sp.	1		One of two *Diacyclops* species recorded.
	Mesocyclops sp.	1		One of two *Mesocyclops* species recorded.
Harpacticoida				
Ameiridae	Ameiridae sp.	6		One of two ameirid species recorded.
Malacostraca				
Amphipoda				
Melitidae	Nedsia sp.	3		Probably *Nedsia* sp. B06 (*hurlburti* group)
Paramelitidae	Paramelitidae sp.		1	One of six paramelitid species recorded.