Bennelongia Environmental Consultants

Mulga East Subterranean Fauna Desktop

Prepared for:

Hancock Prospecting Pty Ltd

April 2019

Final Report

Short-Range Endemics I Subterranean Fauna

Waterbirds I Wetlands

Mulga East Subterranean Fauna Desktop

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EXECUTIVE SUMMARY

Introduction

JBS&G Pty Ltd (on behalf of Hancock Prospecting Pty Ltd (HPPL)) commissioned Bennelongia Environmental Consultants to write a report on subterranean fauna values at the Mulga East Iron Ore Project, which comprises tenements at Mulga East and Malay Well in the north western part of the Fortescue Valley in the Pilbara region of Western Australia. Subterranean fauna are species that inhabit interstices, voids and fissures in underground geologies. This fauna can be divided into two main groups: air-breathing troglofauna and water-breathing stygofauna.

The report refers to three areas when discussing subterranean fauna: (1) the Project area, which consists of the Mulga East and Malay Well tenements, (2) the Project vicinity where subterranean fauna sampling by HPPL's consultants or other programs occurred outside the Project area but in locations close and relevant to the Project area, and (3) the potential subterranean fauna impact area, which comprises the inferred resource outline and a larger area of potential groundwater drawdown.

The report has five main aims:

1. Identify all the required environmental approvals for the Project relating to subterranean fauna;
2. Collate data on the subterranean fauna contained within publicly available databases, including those of the Western Australian Museum (WAM), Western Australian government departments, and Atlas of Living Australia (ALA) that are relevant to the Project;
3. Review and collate results of previous surveys in the Project area and Project vicinity to determine the nature of subterranean fauna assemblages known or likely to be in the Project area and to identify any gaps in information about subterranean fauna;
4. Identify any species or communities listed under state (*Biodiversity Conservation Act 2016*) or Commonwealth (*Environment Protection and Biodiversity Conservation Act 1999*) legislation that occur in the Project area; and
5. Identify areas where Project development could be potentially constrained by broad issues associated with subterranean fauna, such as the occurrence of highly prospective or unusual subterranean habitat, or restricted species.

Methods

The report collates available information on subterranean fauna species and habitats in the Project area and Project vicinity. Analysis of survey intensity against inferred project impact areas was undertaken to determine whether the current level of survey effort was adequate for assessment and to highlight areas requiring further work. The report was compiled in accordance with three subterranean fauna guidance documents released by the Environmental Protection Authority, namely the *Environmental Factor Guideline – Subterranean Fauna*, *Technical Guidance – Subterranean Fauna Survey* and *Technical Guidance – Sampling Methods for Subterranean Fauna*.

Results

The Project lies between the Chichester and Hamersley ranges in the north-western (or lower) Fortescue Valley. This sub-region contains substantial areas of prospective habitat for stygofauna and troglofauna, which include depositional units (colluvium and alluvium), channel iron, Marra Mamba Formation and calcrete. The Wittenoom Formation, which also occurs in the region at depth, has low prospectivity for subterranean fauna.

Most survey for subterranean fauna within the Project area has occurred within the Mulga East tenement, with only three stygofauna samples known to have been collected from Malay Well. The subterranean fauna community on Malay Well is, thus, largely undocumented. Overall, the desktop review showed 103 species of subterranean fauna have been collected from the Project area. This comprises 48 and 55 species of stygofauna and troglofauna, respectively. Both the stygofauna and troglofauna communities contain relatively large numbers of species compared with previous Pilbara survey results (although richer areas are known), as well as compared with survey results worldwide.

Up to 25 species of stygofauna and 49 species of troglofauna are known only from the Project area, although this list is likely to be inflated as a result of the different names at times being applied to the same species in different surveys. Eighteen species of troglofauna are known only from within the resource outlines.

Conclusion

A high proportion of the species collected to date have known distributions restricted to the Project area (primarily at Mulga East where most work has been conducted). Comparisons of specimens collected previously in different surveys are likely to reduce the list of species recorded in the Project area. This is especially true for troglofauna.

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1. INTRODUCTION

Bennelongia Environmental Consultants was commissioned by JBS&G Pty Ltd (on behalf of Hancock Prospecting Pty Ltd (HPPL)) to conduct a baseline assessment of subterranean fauna values for the Mulga East Iron Ore Project (the Project). The Project lies in the central Pilbara of Western Australia, approximately 200 km south of Port Hedland and 185 km north west of Newman and comprises two tenements, Malay Well (E 47/2117) and Mulga East (R 47/12), collectively referred to as 'the Project area' (Figure 1). The Project has an estimated iron resource of 670 million tonnes (with a 50% Fe cut-off) and is likely to consist of numerous open-cut mine pits, an on-site processing plant, waste rock storage and a fine waste storage facility, as well as mine infrastructure that includes a rail load-out facility and rail spur.

Open-cut pits may be mined up to a maximum depth of 90 m below ground level, meaning groundwater drawdown of up to 100 m below ground level may be required to prevent mine pit flooding. These two activities – mine pit excavation and groundwater drawdown – have the potential to result in the removal of subterranean fauna habitat.

Subterranean fauna is a general term applied to species, nearly all of which are invertebrates, that live deep below the ground surface, either in the overlying unsaturated but humid layers of the regolith and bedrock or in underlying aquifers of groundwater. Although inconspicuous, subterranean fauna contribute markedly to the overall biodiversity of Australia and, additionally, play important roles in ecosystem function (Hose and Stumpp 2019; Humphreys 2006). Studies on both the Pilbara and Yilgarn cratons in Western Australia have demonstrated that these old landscapes are biodiversity hotspots for subterranean fauna. Guzik *et al.* (2010) suggested that over 4,000 species of subterranean fauna are likely to occur in the western half of Australia, with more than 80% of these species not yet discovered.

Most subterranean fauna species satisfy Harvey's (2002) criteria for short-range endemism, namely a range of less than 10,000 km^2, confinement to discontinuous habitats, slow growth and low fecundity. In fact, ranges of troglofauna are frequently only a few square kilometres in extent. Halse and Pearson 2014) and Eberhard *et al.* (2009) pointed out that a threshold of 1,000 km^2 (or a linear range of 36 km) was more appropriate than Harvey's 10,000 km^2 for recognizing stygofauna with small ranges. Given that locally-restricted species are more vulnerable to extinction, following habitat degradation, than wider-ranging species (Ponder and Colgan 2002), it follows that the very small ranges of many subterranean species make them highly susceptible to anthropogenic threats, such as habitat degradation and groundwater abstraction.

1.1 Stygofauna

Stygofauna occupy interstices, voids and fissures in groundwater aquifers (Humphreys 1999; Humphreys 2008). Aquifers in alluvium and calcrete deposits within palaeovalleys in Western Australia often contain rich stygal communities, consisting of earthworms (Oligochaeta), beetles (Coleoptera) and Crustacea (amphipods, isopods, copepods, ostracods and syncarids). Many calcretes support communities of species that are mostly endemic to that individual calcrete body (Cooper *et al.* 2002; Guzik *et al.* 2008; Humphreys 2001; Javidkar 2014; Leijs *et al.* 2003; Watts and Humphreys 2006). The aquifers in less transmissive geologies, such as banded iron formations (BIF) and saprolite, rarely support rich stygofauna communities, although low numbers of species may occur in these geologies too (Bennelongia 2009b; Ecologia 2009; GHD 2009).

The physico-chemical tolerances of stygofauna have not been well-defined but some assumptions about tolerance of particular taxa can reasonably be made, based on the tolerances of related surface water species. Hose *et al.* (2015) suggested that stygofauna are mostly found in fresh to brackish aquifers with conductivities of less than 3,000 µS cm^{-1} (approximately 1,650 mg L^{-1} TDS), and are seldom found in hypoxic groundwater (<0.3 mg O_2 L^{-1}). Similarly, Halse *et al.* (2014) showed that few stygofauna species occur above 5,000 mg/L (or 2,700 µS cm^{-1}) in the Pilbara, although rich stygofauna communities have

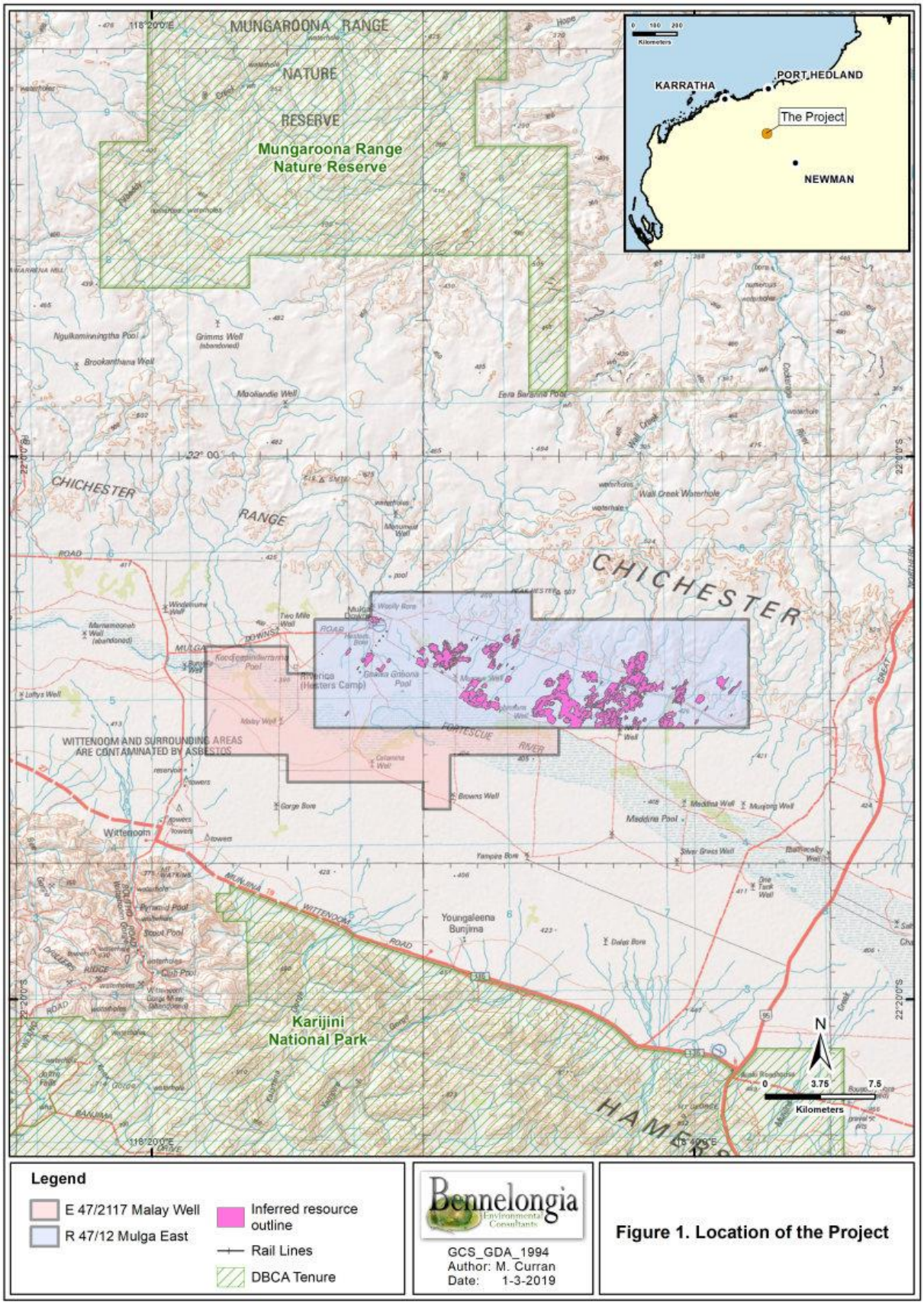

Figure 1. Location of the Project, and resource outline (modelled and inferred).

been found in conductivities of 40,000 µS cm^{-1} (28,500 mg L^{-1}) or more in the Yilgarn (Bennelongia 2016; Halse 2018b; Outback Ecology 2012).

1.2 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 throughout the Western Australian landscape, with the greatest diversity and abundance occurring in the Pilbara (Halse 2018a). 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 have focussed on areas of mining development, particularly mineralised iron formations. Consequently, while troglofauna have been found to occur widely in BIF and other iron deposits (e.g. Bennelongia 2008a, b; Biota 2006), there is little basis for assessing the extent of their occurrence in other habitats. Nonetheless, it is known that troglofauna may occur in calcrete and alluvial-detrital deposits in the Pilbara and Yilgarn (Edward and Harvey 2008; Bennelongia 2015c).

1.3 Habitat Requirements

Historically, the focus on subterranean fauna was primarily on their occurrence in large underground caves (Culver *et al.* 2006; Holthuis 1960; Schneider and Culver 2004; Skubała *et al.* 2013; Whitely 1945) but many species have more recently been found living in smaller spaces throughout vadose zones in arid areas (Guzik *et al.* 2010; Halse and Pearson 2014).

Geology influences the presence, richness and distribution of subterranean fauna by providing different types of habitat (Eberhard *et al.* 2005; Hose *et al.* 2015). Generally speaking, more transmissive geologies tend to support more substantial assemblages of subterranean fauna, both in terms of abundance and diversity. For example, Korbel and Hose (2015) found that coarser sediments in alluvial strata tend to host the greatest numbers of stygofauna, with relatively few animals in silty or clay-rich substrates.

Physical and chemical weathering of consolidated strata can also provide habitable spaces through the creation of underground vughs and caves. Chemical deposition of carbonate rich material in the alluvium of palaeochannels has led to the formation of calcrete aquifers that, through the re-working caused by fluctuating watertables, may offer habitat similar to classic karst formations. A considerable number of calcrete aquifers in the Yilgarn and Pilbara are listed as Priority Ecological Communities (PECs, an informal category for protection of natural habitats; see Section 3) on the basis of being known or likely to host rich subterranean communities. The calcrete aquifer occurring near the Project is not listed as a PEC.

In addition to controlling the occurrence of subterranean fauna, geological, topographical and hydrological features may influence subterranean fauna assemblages by allowing, or restricting, dispersal between populations. The relative importance of dispersal and vicariance in explaining spatial patterns of stygal community structure is likely to vary between regions according to historical and present-day geology and hydrogeology (Culver *et al.* 2009; Finston *et al.* 2007; Harms *et al.* 2018). 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). In other cases, subterranean geology and surface drainage patterns result in barricades to dispersal, causing vicariance between populations and subsequent speciation over relatively fine geographical scales. For example, adjacent mesas of only a few square kilometres in extent in the Pilbara support genetically isolated (and different) species of troglofaunal pseudoscorpions (Harvey and Leng 2008). Some troglofaunal schizomid species in the Hamersley Range also appear to have very small ranges, although the barriers to dispersal are uncertain (Harms *et al.* 2018). In general, there is a

high incidence of short-range endemism amongst the Western Australian subterranean fauna, as well as frequent cryptic (or near cryptic) speciation.

2. IMPACTS OF MINING

Two broad categories of mine-associated impact on subterranean fauna are recognised in this report:

1. *Primary Impacts* have the potential to threaten the persistence of subterranean species through direct removal of habitat; and
2. *Secondary Impacts* may adversely affect subterranean fauna through reducing population densities but do not threaten species persistence.

More information on factors causing secondary impact is given in Appendix 1, but the report has focussed on primary impacts in the potential subterranean fauna impact area when considering the possible effects of the Project on subterranean fauna.

2.1 Impacts on Stygofauna

The most common primary impacts on stygofauna are dewatering to prevent flooding of open pit mines and groundwater abstraction to supply water for ore processing. They have the potential to threaten persistence of any stygofauna species with ranges restricted to the area of groundwater drawdown. In addition, the excavation of a mine pit itself is likely to threaten the persistence of any stygofauna species restricted to the pit, although this impact can be assessed when considering dewatering drawdown because the mine pits are contained within the area of drawdown.

For the purposes of identifying the number of stygofauna species that may possibly be impacted by Project development, the potential area of impact on stygofauna is assumed (very simplistically) to extend 10 km beyond the Project area in all directions (based very broadly on observation at other Pilbara mines).

2.2 Impacts on Troglofauna

Excavation of mine pits is the most significant (and usually only) primary impact affecting troglofauna. Other mine-related works, such as the groundwater drawdown associated with dewatering, reduced infiltration associated with waste rock dumps and leakage associated with tailings dams, have minimal impact compared with pit excavation and are considered secondary impacts. Excavation may threaten the persistence of any troglofauna species known only from within the proposed pits.

Reinjection of extracted groundwater comprises a second possible primary impact (at mines where it is undertaken) because raising the water table can flood (and reduce the volume of) troglofauna habitat.

The potential troglofauna impact area associated with the Project is assumed to coincide with the inferred resource outline (i.e. it is assumed this is the area of future mine pits).

2.3 Scope of this Report

Several surveys for subterranean fauna have already been carried out within the Project area and Project vicinity to identify the presence of stygofauna and troglofauna species in this landscape. The report refers to three types of area when discussing subterranean fauna: (1) the Project area, which consists of the Mulga East and Malay Well tenements, (2) the Project vicinity where subterranean fauna sampling by HPPL's consultants or other programs occurred outside the Project area but in locations close and relevant to the Project area, and (3) the potential subterranean fauna impact area as defined in sections 2.1 and 2.2.

The aim of this report is to:

1. Identify all the required environmental approvals for the Project relating to subterranean fauna;
2. Collate data on subterranean fauna contained within publicly available databases, including those of the Western Australian Museum (WAM), Western Australian government departments, and Atlas of Living Australia (ALA) that are relevant to the Project;

3. Review and collate results of previous surveys in the Project area and Project vicinity to determine the nature of subterranean fauna assemblages known or likely to be in the Project area and to identify any gaps in information about subterranean fauna;
4. Identify any species or communities listed under state (*Biodiversity Conservation Act 2016*) or Commonwealth (*Environment Protection and Biodiversity Conservation Act 1999*) legislation that occur within the Project area; and
5. Identify areas where Project development could be potentially constrained by broad issues associated with subterranean fauna, such as the occurrence of highly prospective or unusual subterranean habitat, or restricted species.

3. FRAMEWORK

Native flora and fauna in Western Australia are protected at both state and Commonwealth levels. At the national level, a legal framework to protect and manage nationally and internationally important flora, fauna, ecological communities and heritage places is provided via the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). The EPBC Act identifies three categories requiring consideration for environmental protection:

- Threatened species;
- Threatened Ecological Communities (TECs); and
- Key threatening processes.

At the state level, protection occurs under the *Biodiversity Conservation Act 2016* (BC Act). The highest level of protection for species is given to Schedule 1 species that are considered rare, likely to become extinct, or otherwise in need of special protection. The current list of threatened species is provided by the Wildlife Conservation (Specifically Protected Fauna) Notice 2018. The Department of Biodiversity, Conservation and Attractions (DBCA) also 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.

Additionally, there is a state list of TECs that are protected under the BC Act (this is larger than the EPBC Act list). Other communities of potential conservation concern, but for which there is little information, are listed informally by DBCA as PECs.

3.1 Subterranean fauna approvals required

As a part of the planning process, it is a requirement to submit a Mining Proposal to the Department of Mines, Industry Regulation and Safety (DMIRS). The guidelines for mining proposals in Western Australia states that proponents shall determine whether short range endemic (SRE) species and/or subterranean fauna are likely to be present and whether appropriate field surveys are required (DMP 2016).

Additionally, the Department of Water and Environmental Regulation (DWER) require licencing for the extraction of groundwater. There are two components of this.

- Section 26D *Rights in Water and Irrigation* Act 1914 (*RIWI* Act) Form 1 covers commencing, constructing, enlarging, deepening or altering a well; and
- Section 5C *RIWI* Act Form 3G is to apply for a licence to take groundwater.

These forms can be submitted together and while they do not explicitly require information regarding subterranean fauna, they may result in actions being required concerning subterranean fauna.

Both DMIRS and DWER may refer projects to the Environment Protection Authority (EPA) if they feel impacts to subterranean fauna (or any other environmental factor) may be sufficient to warrant formal assessment. Alternatively, a proponent can refer a project for assessment if, after the completion of baseline and targeted surveys and project design, it is not able to reduce the significance of an impact or impacts on key environmental factors to acceptable levels.

In order to conduct subterranean fauna surveys, a Regulation 17 licence to take fauna for scientific purposes needs to be obtained from DBCA. These forms must be obtained by the company conducting the survey rather than by project proponent and the reporting onus is on the individual supervising fieldwork.

4. METHODS

This desktop assessment was conducted in accordance with *Environmental Factor Guideline – Subterranean fauna* (EPA 2016a), *Technical Guidance – Subterranean fauna survey* (EPA 2016c), and *Technical Guidance – Sampling methods for subterranean fauna* (EPA 2016b).

The geology and hydrogeology of the Project area were reviewed for their prospectivity for subterranean fauna.

Records of subterranean fauna in the Project area were collated using the results of three dedicated subterranean fauna surveys commissioned by HPPL, namely:

- Murray Hill troglofauna survey in 2009-2010 (ecologia 2011) – troglofauna targeted in two rounds of sampling;
- Subterranean fauna survey at the Mulga Downs Project in 2012-2013 (Phoenix 2013) – stygofauna and troglofauna targeted in three rounds of sampling; and
- Mulga Downs Project troglofauna assessment in 2014 (Bennelongia 2014) – stygofauna and troglofauna targeted in a single round of sampling.

The above three surveys included some sampling in the Project vicinity, although predominantly the Project area was surveyed, and thus provided some information about the wider distribution of species recorded within the Project area. Higher-order identifications were not included in the final count of species recorded during surveys unless they belonged to taxonomic units that were not otherwise recorded. Searches were made in available databases and reports for the wider occurrence (in either the Project vicinity or the wider Pilbara) of species found in the Project area to determine whether or not species may be restricted to the Project area.

Databases of the Department of the Environment and Energy via an EPBC Act protected matters search, and DBCA via searches of the Threatened Flora, Fauna and Ecological Communities database and NatureMap were reviewed to identify the occurrence of any listed subterranean fauna species or TECs and PECs in the Project area or Project vicinity. In addition, the database of the WAM was reviewed for the occurrence of any subterranean fauna species in the Project area and vicinity collected from non-HPPL sampling. Note, however, that the focus of the report is to provide information about the subterranean community/ies within the Project area and information from the Project vicinity is used (in addition with information from other parts of the Pilbara) only to show that species within the Project area have a wider distribution.

Fine-scale assessment of potential impacts to stygofauna and troglofauna arising from the Project is not currently possible because mine plans are yet to be developed. However, an indicative level of impact was inferred based on the potential subterranean fauna impact area. Subterranean species recorded within the Project area are treated as possibly impacted by the Project unless they have also been recorded outside the potential subterranean fauna impact area. For stygofauna, this means more than 10 km outside the Project area, based on an assumption that significant groundwater drawdown will extend approximately 10 km from the Project area. For troglofauna, this means outside the inferred resource outlines.

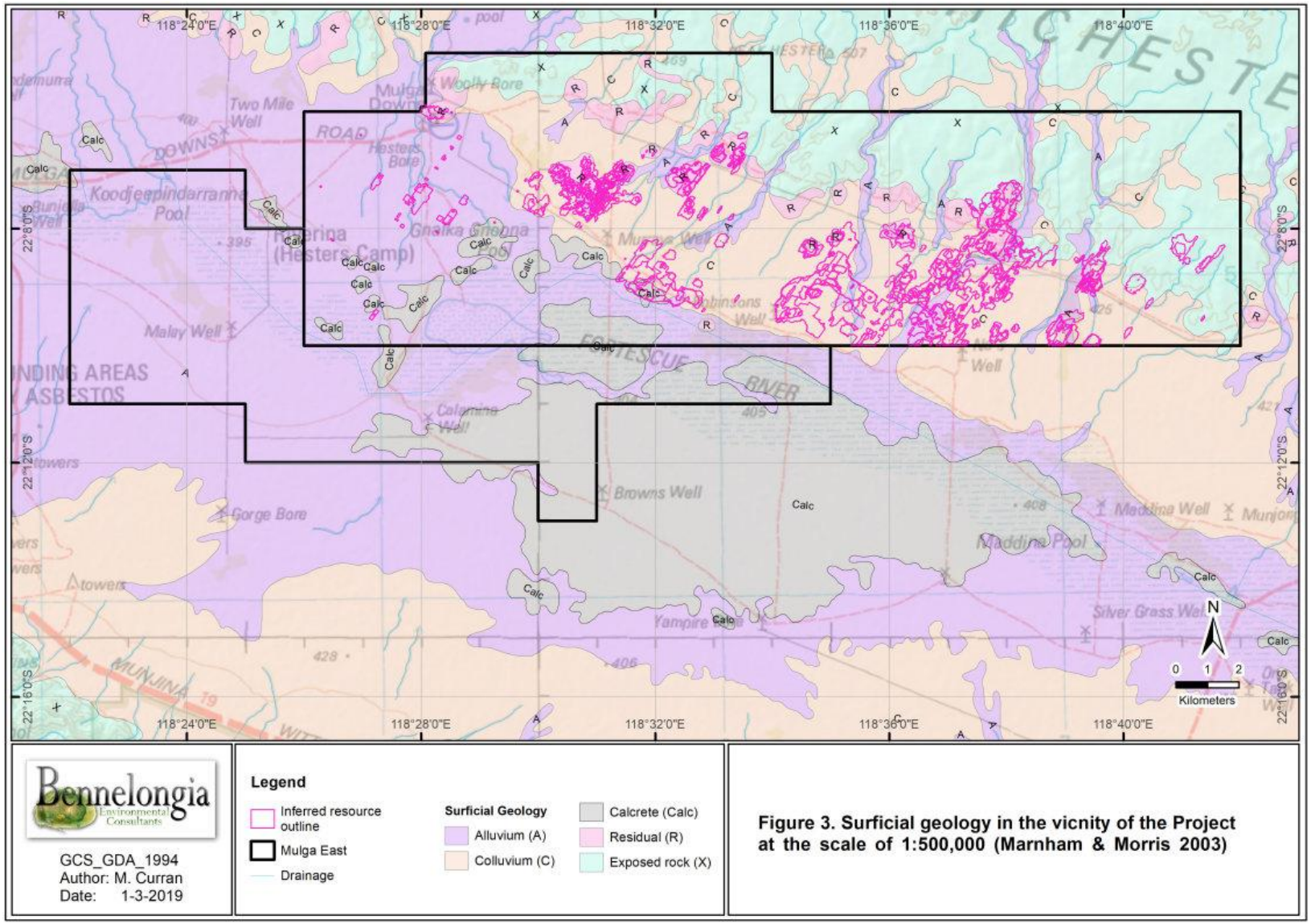

Figure 2. Surficial geology in the vicinity of the Project at the scale of 1:500,000 (Marnham and Morris 2003).

5. RESULTS

5.1 Habitat Prospectivity

The Project is situated on the north flank of the western end of the Fortescue Valley and is located between the Chichester and Hamersley ranges (Figure 2). Previous work conducted along the Chichester Range has demonstrated that suitable subterranean habitat exists in the area for both troglofauna and stygofauna (Bennelongia 2009a, 2011, 2012, 2015a, 2018). Similar habitat occurs along the northern length of the Fortescue Valley for approximately 200 km and, therefore, suitable habitat for troglofauna and stygofauna is likely to occur within Project area and broader Project vicinity (van Vreeswyk *et al.* 2004). However, there is a hydrological divide in the Fortescue Valley at the Goodiadarrie Hills (Aquaterra 2004), meaning that saline water from below the Fortescue Marsh does not extend downstream to the Project. As a result, the species composition of the stygofaunal community in the vicinity of the Project may be distinct from those east of the divide (Bennelongia 2015b).

In addition to lying in the lower Fortescue Valley, the Project area also extends a short distance north into the Chichester Range. The valley is overlain by depositional units, with large areas of colluvium interspersed with alluvium in creek lines that have washed down from the exposed rock of the Chichester Range (Figure 2). Below the depositional units, there is mainly Wittenoom Formation and Marra Mamba Iron Formation. Calcrete deposits have very high hydraulic conductivity just below the watertable. The mineralised Marra Mamba Iron Formation often contains abundant water and can be highly transmissive. Some channel iron deposits are also likely to be present in the Project area, and vicinity, with moderate to high yielding aquifers.

Colluvium, alluvium, calcrete, channel iron and Marra Mamba are all potentially prospective for stygofauna and troglofauna, depending on situation in the profile (Halse and Pearson 2014; Humphreys 1999; Mokany *et al.* 2017). However, in general, areas with a very shallow water table, i.e. less than 5 m, are unlikely to be prospective for troglofauna as minimal habitat is available, especially when considering that natural fluctuations in the water table may intermittently reduce the amount of habitat available. Similarly, areas with a deep water table, i.e. >30 m, are unlikely to support rich or diverse stygofauna communities owing to limited surface inputs of nutrients and energy (Halse *et al.* 2014).

The water table in the Project area is mostly 4 to 6 m below ground level but increases to approximately 30 m below ground level where ground is elevated.

5.2 Previous Survey Results

Survey effort for both stygofauna and troglofauna in the HPPL-funded surveys is presented in Table 1. The distribution of samples from these surveys and a very small amount of ad-hoc sampling represented by WAM records (only in the Project vicinity) is shown in Figure 3 and Figure 4.

Sampling effort troglofauna can be complex. Current best practice for troglofauna sampling involves two sampling methods: scraping and trapping. The relative effort expended on these methods differed between each survey and, to facilitate comparisons of the amount of sampling effort in each survey, sampling effort was standardised in the following way. When scraping occurred at a drill hole, it was treated as collecting half a sample unit and, similarly, setting traps was treated as a half sample. Ideally, a full 'sample unit' equates to one hole being scraped (regardless of how many scrapes are collected) and trapped (regardless of how many traps) during one visit but it may also comprise two scrape half-samples or two trap half-samples.

Sampling results are summarised in Table 2 and Table 3.

Species names have been updated where necessary (and possible) to maintain consistency of identifications across surveys and to achieve the most accurate species lists possible. However, despite attempts to align taxonomy, some species may be listed under multiple names, due to nomenclature differing between practitioners. It is also noted that abundance values for each species were not reported in Phoenix (2013) and therefore the number of specimens reported is likely to be an underestimate.

ecologia (2011) surveyed 87 bores with two traps in each bore, giving a total of 194 traps (as 10 bores were trapped in both rounds). Sixty-eight of the bores were also scraped, with two bores scraped for troglofauna in both rounds. Samples yielded 39 troglofauna specimens belonging to three higher-order taxa, equating to 0.47 troglofaunal specimens and 0.04 troglofaunal species per sample unit.

Table 1. Sample effort for subterranean fauna within the Project.

Target fauna and method	2009-2010 Ecologia	2012-2013 Phoenix	2014 Bennelongia	Total
Stygofauna				
Net	-	103	37	**139**
Karaman-Chappuis	-	2	-	**2**
Stygofauna sample effort	**-**	**105**	**37**	**141**
Troglofauna				
Scrape	68	121	119	**308**
Single Trap	-	241	77	**197**
Double Trap	97	-	24	**121**
Banana Trap	-	4	-	**4**
Troglofauna sample effort*	**82.5**	**122.5**	**110**	**315**

*A single troglofauna sample unit comprises a hole being scraped and trapped during one visit.

Phoenix (2013) sampled 65 bores using traditional subterranean fauna sampling methods (103 stygofauna nets, 121 troglofauna scrapes, 241 troglofauna traps and 4 banana traps) as well as two hyporheic samples (sampled using the Karaman-Chappuis technique). A sample incorrectly reported in Phoenix (2013) as a troglofauna scrape has been re-assigned as a stygofauna net sample. In total, Phoenix samples yielded 1,126 stygofauna specimens of 28 species and at least 108 troglofaunal specimens (precise abundance values were not reported for troglofauna) of 27 species. These yields equate to 10.7 and at least 0.88 specimens per sample unit for stygofauna and troglofauna, respectively.

Bennelongia sampled 155 bores via 37 stygofauna nets, 119 troglofauna scrapes, 77 single troglofauna traps and 24 double troglofauna traps and recorded 34 troglofauna species and 28 stygofauna species. Samples yielded 22.8 and 1.33 specimens per sample unit for troglofauna and stygofauna, respectively.

Searches of grey and published literature and available databases did not find any other subterranean fauna surveys, other than the three HPPL-funded surveys, within the Project area. No troglofauna samples or specimens are known from the Malay Well tenement.

5.2.1 Distribution of survey effort within the Project

Survey intensity for subterranean fauna is greater in areas where knowledge of resource quality and availability is highest. For example, the area known as Murray Hill has had the most intensive subterranean fauna survey. Figure 3 shows the locations of stygofauna sampling to date in the Project area and the Project vicinity, including a small amount of ad-hoc sampling in the WAM database not associated with Project assessment. Figure 4 shows troglofauna survey effort.

The sites sampled for troglofauna in 2009-2010 (ecologia (2011) are coloured differently in Figure 4 because sampling in 2009-2010 appears to have had relatively low efficiency. Troglofauna yield in 2009-2010 was 0.47 specimens per sample and only three species were recorded, whereas later surveys collected at least 0.88 specimens per sample and 27 species in 2012-2013, and 1.33 specimens per sample and 28 species in 2014. Furthermore, at the three sites sampled by all three consultants using similar effort, no troglofauna were collected in the 2009-2010 survey compared with between one and seven species of troglofauna in 2012-2013 and 2014.

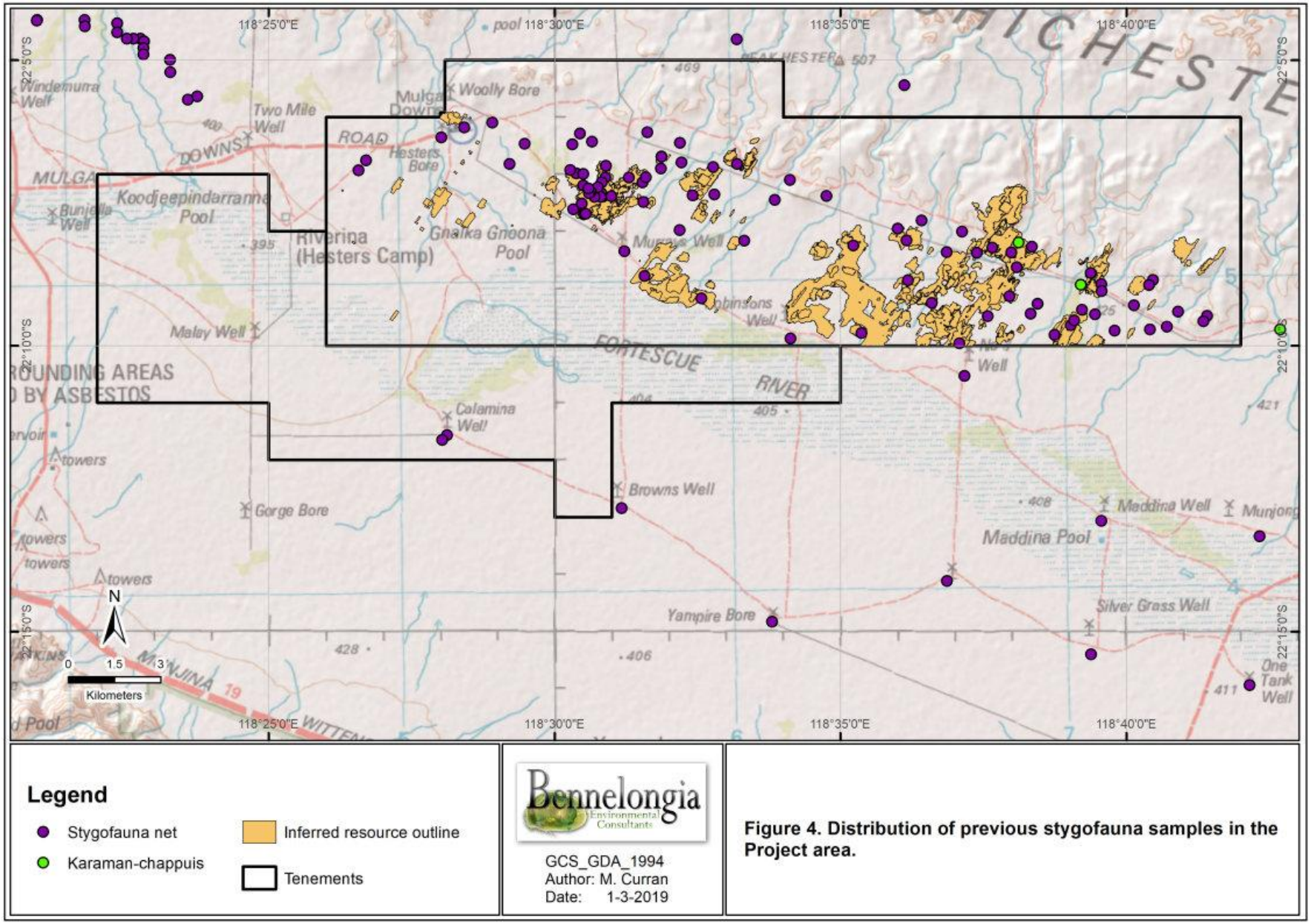

Figure 3. Distribution of previous stygofauna samples in the Project area.

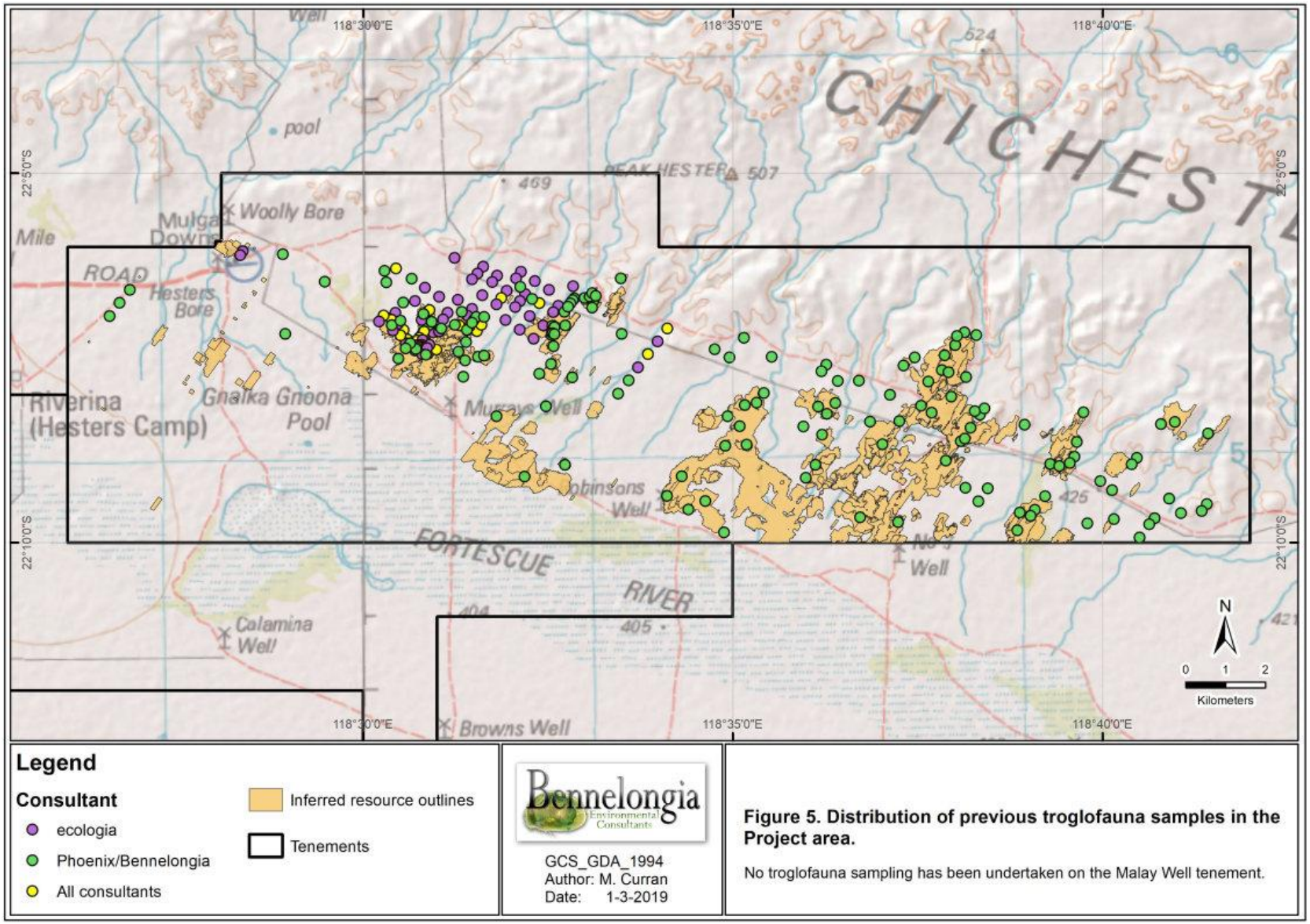

Figure 4. Distribution of previous troglofauna samples in the Project area.

Table 2. Species list of stygofauna found within the Project area.
Note, grey denotes higher order identifications that could belong to other listed species. These higher order identifications are not currently viewed as representing unique species. Blue represents species complexes that may contain multiple species. Pink shows species only known from the Project area.

Higher Order Identification	Lowest identification	No. of Specimens	Only Known From Project	Notes on Distribution
Nematoda	Nematoda spp.	119	-	Not assessed in EIA per EPA (2016c)
Rotifera	Bdelloidea sp. 2:2	5	-	Not assessed in EIA per EPA (2016c)
Annelida				
Aphanoneura	Aeolosomatidae sp.	51	-	Higher order identification. Likely to represent a single species.
Clitellata				
Oligochaeta				
Enchytraeida	*Enchytraeus* sp. AP PSS1 s.l.	53	-	Species complex and may be restricted to the Project area
	Enchytraeus sp. AP PSS2 s.l.	222	-	Species complex and may be restricted to the Project area
Haplotaxida				
Naididae	*Pristina longiseta*	1	No	Recorded throughout WA
Phreodrilidae	Phreodrilidae sp. AP DVC s.l.	9	-	Species complex and may be restricted to the Project area
	Phreodrilus peniculus	1	No	Recorded throughout the Pilbara and Gascoyne
Tubificidae	Tubificidae sp.	4	-	Species complex and may be restricted to the Project area
Arthropoda				
Acari				
Mideopsidae	*Guineaxonopsis* sp. B03 (S01 group)	2	Yes	Known only from the Project area, linear range 20 km
Crustacea				
Amphipoda				
Paramelitidae	Paramelitidae `MH1`	66	No	Known from both sides of Fortescue River at Mulga East and Pyramid Pool
	Paramelitidae sp. B47	155	Yes	Known only from the Project area, linear range 17.5 km
	Paramelitidae sp. B48	29	Yes	Known only from the Project area, linear range 17.5 km
Syncarida				
Bathynellaceae				
Bathynellidae	Bathynellidae sp./*Pilbaranella* sp.	6	-	Higher order identification
	Pilbaranella `MH1`	3	Yes	Known only from the Project area, linear range 15.8 km, collected in stygofauna nets and a surface Karaman-Chappuis sample
	Pilbaranella `MH2`	3	Yes	Singleton, known only from the Project area
	Pilbaranella sp. B18	1	Yes	Singleton, known only from the Project area
Parabathynellidae	*Atopobathynella* sp. B09	10	Yes	Known only from the Project area, linear range 3 km, collected in a stygofauna net and a surface Karaman-Chappuis sample, also called Parabathynellidae `MH1
	Billibathynella sp. B10	1	Yes	Singleton, known only from the Project area
	Billibathynella sp. B11	14	Yes	Known only from the Project area, linear range 10.3 km
	nr *Billibathynella* `MH2`	5	Yes	Known only from the Project area, linear range 18 km, collected in stygofauna nets and a surface Karaman-Chappuis sample, also called Parabathynellidae `MH2`
	Parabathynellidae `MH3`	2	Yes	Singleton, known only from the Project area
Maxillopoda				

Higher Order Identification	Lowest identification	No. of Specimens	Only Known From Project	Notes on Distribution
Copepoda				
Cyclopoida				
Cyclopidae	*Australocyclops similis* s.l.	64	-	Species complex and may be restricted to the Project area
	Diacyclops humphreysi humphreysi	959	No	Recorded throughout the Pilbara
	Diacyclops scanloni	5	No	Recorded throughout the Pilbara
	Dussartcyclops sp. B11	31	Yes	Known only from the Project area, linear range 15.7 km
	Mesocyclops brooksi s.l.	35	-	Species complex and may be restricted to the Project
	Mesocyclops notius	107	No	Recorded throughout the Pilbara
	Mesocyclops sp.	22	-	Higher order identification.
	Microcyclops varicans	23	No	Recorded throughout WA
	Orbuscyclops westaustraliensis	1	No	Recorded throughout the Pilbara
	Pescecyclops pilbaricus	38	No	Recorded throughout the Pilbara
	Pilbaracyclops sp. B03 (nr *frustratio*)	3	No	Recorded throughout the Pilbara
Harpacticoida				
Ameiridae	*Abnitocrella eberhardi*	5	No	Recorded along the Fortescue River at Mulga Downs and Mt Florance, linear range 106 km
	Megastygonitocrella sp. B04	126	No	Recorded along the Fortescue valley west of Goodiadarrie Hills at Mulga East and Mt Florance Station
Canthocamptidae	Canthocamptidae sp. B03	26	Yes	Known only from the Project area, six locations within a linear range of 2.8 km
	Canthocamptus australicus	15	No	Recorded throughout WA
	Elaphoidella sp. B02	6	Yes	Singleton, known only from the Project area
Parastenocarididae	*Dussartstenocaris* sp. B01	50	Yes	Singleton, known only from the Project area, collected in a surface Karaman-Chappuis sample
	Dussartstenocaris sp.	1	-	Higher order identification.
	Parastenocaris sp. B18	2	Yes	Known only from the Project area, linear range 5.8 km
	Parastenocaris sp. B29	101	Yes	Known only from the Project area, linear range 9.5 km
Ostracoda	Ostracoda sp. unident.	1	-	Higher order identification.
Candonidae	*Areacandona arteria*	2	No	Recorded at Mulga Downs and Telfer
	Areacandona mulgae	3	No	Records throughout the Pilbara
	Areacandona brookanthana	6	No	Recorded throughout the Pilbara
	Areacandona cf. *clementia*	1	-	Species complex and may be restricted to the Project
	Candonopsis tenuis	14	No	Recorded throughout WA
	Deminutiocandona cf. *quasimica*	2	-	Species complex and may be restricted to the Project
	Humphreyscandona waldockae	25	No	Recorded throughout the Pilbara
	Meridiescandona `BOS297`	2	No	Known from both sides of Fortescue River at Mulga East and Pyramid Pool
Cypretta	*Cypretta seurati*	5	No	Found throughout central WA
	Strandesia sp. 466	1	No	Recorded throughout the Pilbara
	Cyprididae sp./Cypridopsinae sp.	2	-	Higher order identification.

Table 3. Species list of troglofauna found within the Project area.

Note, grey denotes higher order identifications that could be members of species already listed; pink denotes species currently only known from resource outlines.

Higher Order Identification	Lowest Identification	No. of Specimens	In-pit Only*	Notes on Distribution
Arthropoda				
Chelicerata				
Arachnida				
Araneae				
Gnaphosidae	Gnaphosidae sp. B03	1	Yes	Singleton, only known from Project area
Symphytognathidae	*Anapistula* `MH1`	4	No	Only known from Project area, linear range 14.7 km
Trochanteriidae	Trochanteriidae sp. B01	1	No	Singleton, only known from Project area
Palpigradi	Palpigradi `MH1`	1	Yes	Singleton, only known from Project area
	Palpigradi `MH2`	1	No	Singleton, only known from Project area
	Palpigradi sp.	1	-	Higher order identification
	Palpigradi sp. B18	6	Yes	Only known from Project area, linear range 4 km (reference area lies between the two locations). Possibly congeneric with MH1 or MH2
Pseudoscorpiones				
Chthoniidae	*Tyrannochthonius* `MH1`	4	No	Only known from Project area, linear range 9.9 km. Possibly congeneric with B35 or B36
	Tyrannochthonius sp. B35	1	Yes	Singleton, only known from Project area
	Tyrannochthonius sp. B36	1	Yes	Singleton, only known from Project area
Hyidae	*Indohya* ?`PSE002`	3	No	Singleton, only known from Project area but its affinity with the terrestrial species `PSE002` suggests it is not a troglofaunal species. Previously called *Indohya* `MH1`
	Indohya sp.	1	-	Higher order identification
Olpiidae	*Linnaeolpium* sp. B03	1	Yes	Singleton, only known from Project area
Schizomida				
Hubbardiidae	*Draculoides* `SCH084-DNA`	1	Yes	Singleton, only known from Project area, previously called *Draculoides* `MH1`
	Draculoides `SCH085-DNA`	1	Yes	Singleton, only known from Project area, previously called *Draculoides* `MH2`
	Draculoides sp. B53	3	No	Singleton, only known from Project area
	Draculoides sp. B54	1	No	Singleton, only known from Project area
	Draculoides sp.		-	Higher order identification
Crustacea				
Isopoda				
Philosciidae	nr *Andricophiloscia* sp. B18	1	No	Singleton, only known from Project area
Armadillidae	*Buddelundia* sp. B57	2	No	Only known from Project, linear range 1.8 km
	Troglarmadillo `MH1`	1	Yes	Singleton, only known from Project area. Possibly congeneric with B54 or B55
	Troglarmadillo sp. B54	1	Yes	Singleton, only known from Project area
	Troglarmadillo sp. B55	3	No	Only known from Project area, linear range 6.7 km
	Troglarmadillo sp.	1	-	Higher order identification
Hexapoda				
Entognatha				
Diplura	Diplura sp.	1	-	Higher order identification

Higher Order Identification	Lowest Identification	No. of Specimens	In-pit Only*	Notes on Distribution
Campodeidae	Campodeidae sp. B10	1	Yes	Singleton, only known from Project area
Japygidae	Japygidae sp.	6	-	Higher order identification
	Japygidae `MH1`	2	No	Only known from Project area, linear range 13.6 km
	Japygidae `MH2`	2	No	Only known from Project area, linear range 11 km
Parajapygidae	Parajapygidae sp.	1	-	Higher order identification
	Parajapygidae `MH1`	2	No	Only known from Project area, linear range 1.8 km. Possibly congeneric with B29 or B30
	Parajapygidae sp. B29	1	No	Singleton, only known from Project area
	Parajapygidae sp. B30	1	Yes	Singleton, only known from Project area
Projapygidae	Projapygidae `MH1`	3	No	Only known from Project area, linear range 16.8 km. Possibly congeneric with B18
	Projapygidae sp. B18	1	Yes	Singleton, only known from Project area
Insecta				
Blattodea				
Nocticolidae	*Nocticola* `MH1`	38	No	Only known from Project area, linear range 15.7 km. Previously called Nocticola sp. B34 (Bennelongia 2014)
	Nocticola sp.	18	-	Higher order identification
Coleoptera				
Carabidae	*Gracilanillus* `BCO176`	1	No	Singleton, only known from Project area, previously called Bembidiinae sp. B22
	Magnanillus `BCO175` (nr *quartermainei*)	10	No	Only known from Project area, linear range 18.6 km, previously called *Anillini* `MH1` and Bembiinae sp. B21
Curculionidae	Curculionidae Genus 1 sp. B12	10	No	Only known from Project area, linear range 8.1 km
	Curculionidae Genus 2 sp. B18	6	No	Only known from Project area, linear range 8.1 km
Ptiliidae	*Ptinella* sp. B01	2	No	Recorded throughout the central Pilbara
	Coleoptera sp. B07	2	Yes	Singleton, only known from Project area
Diptera				
Sciaridae	Sciaridae sp. B01	2	No	Recorded throughout central WA
Hemiptera				
Meenoplidae	Meenoplidae sp.	6	-	Higher order identification
	Meenoplidae sp. Solomon 1	1	No	Known from Mulga East and Solomon mine. Previously called Meenoplidae `USF`
	Phaconeura sp.	2	-	Higher order identification
	Phaconeura sp. B04	39	No	Troglophile recorded across WA. Previously called Meenoplidae `widespread`
Zygentoma				
Nicoletiidae	Nicoletiinae sp.	2	-	Higher order identification
	Atelurinae `MH1`	5	No	Only known from Project, linear range 12 km. Previously called Atelurinae sp. B20 (Bennelongia 2014)
	Trinemura sp.	4	-	Higher order identification
	Trinemura `MH1`	6	No	Only known from Project area, linear range 15.5 km
	Trinemura `MH2`	7	No	Only known from Project area, linear range 8.5 km
	Trinemura sp. B27	1	Yes	Singleton, only known from Project area
	Trinemura sp. B28	9	No	Only known from Project area, linear range 7.3 km

Higher Order Identification	Lowest Identification	No. of Specimens	In-pit Only*	Notes on Distribution
Myriapoda				
Chilopoda				
Scolopendrida				
Cryptopidae	*Cryptops* `MH1`	1	Yes	Singleton, only known from Project area
	Cryptops `MH2`	3	No	Recorded inside and immediately outside the Project area
	Cryptops sp. B41	1	No	Singleton, only known from Project area
	Cryptops sp. B42	1	No	Singleton, only known from Project area
Scolopendridae	*Cormocephalus* `CHI003`	1	No	Recorded throughout the central Pilbara. Previously called Cormocephalus `MH1`
Diplopoda				
Polyxenida				
Lophoproctidae	*Lophoturus madecassus*	68	No	Only known from Project area. Previously called Polyxenidae sp. (ecologia 2011) and Polyxenidae `PXD1` (Phoenix 2013)
Pauropoda	Pauropoda sp.	2	-	Higher order identification
Pauropodidae	Pauropodidae `MH1`	1	Yes	Singleton, only known from Project area
	Pauropodidae `MH2`	3	No	Only known from Project area, linear range 18.2 km
	Pauropodidae `MH3`	2	No	Only known from Project area, linear range 15 km
	Pauropodidae sp. B01	1	No	Recorded throughout the Pilbara
Symphyla				
Scutigerellidae	*Hanseniella* `MH1`	4	No	Only known from Project area
	Symphyella sp. B20	1	Yes	Singleton, only known from Project area

5.2.2 Stygofauna

At least 49 stygofauna species have been recorded within the Project area. Groups represented include worms (seven species), mites (one species), amphipods (three species), syncarids (eight species), copepods (18 species), ostracods (10 species), nematodes and rotifers (Table 2). Of the recorded species, 21 are known to occur outside the Project area, either because they were also collected in the Project vicinity or, more commonly, because other sampling programs have shown them to occur elsewhere in the Pilbara and occasionally even further afield (Table 2, notes on distribution). Eight belong to species complexes (containing multiple species that have not been systematically defined) and, therefore, these animals may have smaller ranges than listed for the complex and may even be restricted to the Project area. Two species (Nematoda spp. and Bdelloidea sp. 2:2) are reported but belong to groups (nematodes and rotifers) that, owing to very limited taxonomic and life history information, are excluded from the EIA process (EPA 2016d).

Seventeen stygofauna species have not been recorded outside of the Project area to date. Of these, six have been collected in only one sample from a single site, while the remaining 11 species are known from multiple locations and have linear ranges between 2.8 km and 20 km.

5.2.3 Troglofauna

Fifty-five species of troglofauna have been recorded within the Project area. Further comparisons of specimens collected in the 2013 and 2014 surveys are likely to reduce this number because multiple names may have been applied to the same species by different practitioners. Troglofauna were represented by 15 major groups: spiders (three species), palpigrads (three species), pseudoscorpions (five species), schizomids (four species), isopods (five species), diplurans (eight species), cockroaches (one species), beetles (six species), flies (one species), true bugs (two species), silverfish (five species), centipedes (five species), millipedes (one species), pauropods (four species) and symphylans (two species).

Forty-nine species are currently only known from the Project area and 18 of these are known only from within inferred resource outline, including 17 species recorded as singletons (only known from a single sample) and one species, Palpigradi sp. B18, known from two locations inside inferred resource outline. The two collection locations of Palpigradi sp B18 are interspersed by non-resource areas (reference or non-impacts areas) and thus the species is likely to occur outside inferred resource outline.

5.3 TECs, PECs and listed species

A search of Western Australian listed TECs and PECs revealed the closest of these to the Project area is the Priority 4 PEC *Stygofaunal community of the Western Fortescue Plains freshwater aquifer.* This PEC is situated approximately 160 km to the north west. There are also two Priority 1 PECs, *Subterranean invertebrate communities of mesas in the Robe Valley Region* and *Subterranean invertebrate community of pisolitic hills in the Pilbara*, located approximately 201 km and 240 km to the west of the Project, respectively. None of these PECs is considered to be threatened by any future Project development. A search of three databases - EPBC Protected matter search tool, DBCA's listed species (including NatureMap) and the ALA - did not identify any other listed subterranean species or communities within 100 km of the Project area.

5.4 Cumulative impacts

The Project lies approximately 10 km east of Fortescue's proposed Lower Fortescue Borefield (LFBF), which is currently the only known approved or proposed development nearby that may have an impact on subterranean fauna. With reference to Section 2.1 and Section 4, assessment of the potential impacts of this adjacent project cannot be made at this stage as it lies outside of the inferred groundwater drawdown area, and no information with respect to the project is currently available.

6. DISCUSSION

6.1 Species of significance

No listed species were identified within the Project area or the Project vicinity from Government database searches.

Although richer communities are known elsewhere in the Pilbara, the 48 and 55 species of stygofauna and troglofauna recorded within the Project area, respectively, represent relatively speciose subterranean fauna communities when compared with previous Pilbara survey results (Bennelongia 2015b), as well as in terms of various global comparisons (Moldovan *et al.* 2018).

Based on existing information, 17 species of stygofauna appear to have been collected to date only from the Project area. In addition, eight stygofauna 'species' known more widely actually belong to species-complexes and populations of these taxa within the Project area may also comprise species known only from the Project area (rather than widespread species as currently assumed). Thus, there are possibly as many as 25 species known only from the Project area, although it is unlikely all eight species complexes are represented by restricted species. Any species known only from the Project area has the potential to be of conservation concern.

Using existing identifications, 49 troglofauna species have been collected to date only from the Project area, of which 18 have been found only within inferred resource outline. Further comparison of specimens from different surveys is likely to reduce this number of potentially restricted (and thus possibly conservation-significant) species. Given there is currently no mine plan, all troglofauna species known only from the Project area have the potential to be of conservation concern, although it is assumed that the 18 species from the inferred resource outline have the greatest likelihood of being conservation-significant.

Several of the taxonomic groups known from the Project area contain mostly species that are likely to have tight local ranges (i.e. linear ranges of a few kilometres at most). A brief description of these animal groups is given below. Species in other groups may also have limited ranges.

Stygofauna

Annelid worms

Information garnered in recent years about the phylum Annelida has made identification of the species within this phylum more complex than was recognised when these surveys were conducted. Molecular work is now routinely undertaken for this group, so that the true number of worm species in the Project area is likely to be substantially higher than reported, although taxonomic alignment of the material collected over five years ago is likely to be difficult due to specimen age, condition and accessibility. The likelihood of restricted species with distributions confined to the Project area may be low, however, as Brown *et al.* (2015) found that many annelid worms appear to have catchment-scale distributions.

Syncarids

Syncarids are very small shrimp-like crustaceans that are exclusively groundwater inhabitants in Western Australia. The Western Australian syncarid fauna is significantly diverse (Guzik *et al.* 2008; Perina *et al.* 2018) and this is also the case in aquifers at Mulga East, with at least eight species recorded. All eight species are currently known only from the Project area, are likely to have confined geographic distributions and none has been formally described. The ranges of stygal syncarid species are typically small with many species restricted to single aquifers or part thereof (Guzik *et al.* 2008). Of the syncarids collected, two species were represented as singletons (in both cases being the only known record of the species) and one species was represented by two individuals.

Copepods
Copepods are small crustaceans of teardrop or cylindrical shape and are very diverse in the Pilbara. A substantial proportion of the cyclopoid copepod species in the Pilbara are stygophiles that occur widely in groundwaters of this region, while harpacticoid copepods usually have small ranges. Six of the eight species recorded in the Project area currently appear to be range-restricted, including one cyclopoid and five harpacticoids.

Ostracods
Ostracods are the most speciose group of animals in the Pilbara stygofauna community and most species are restricted to single sub-regions (Halse *et al.* 2014). Two of the 10 species of ostracod in the Project area may be new species and therefore are possibly range-restricted.

Troglofauna

Spiders
The spiders have one of the lowest median ranges, as calculated by Halse and Pearson (2014), with a median range of 3.7 km^2. Three spider species have been identified from previous surveys, all are currently only known from the Project area and one, Gnaphosidae sp. B03, is a singleton from within the resource outline. Of the other two species, one is a singleton and the other from four specimens with a linear range of 14.7 km.

Pseudoscorpions
Five pseudoscorpion species have been identified within the Project area, although one is unlikely to be substantially subterranean (*Indohya* ?`PSE002`) because of its probable alignment with a surface species (*Indohya* `PSE002). The remaining four species are only known from the Project area and three only from within inferred resource outline. Three of these species belong to the genus *Tyrannochthonius* and may in fact comprise two species (further specimen comparison is required). Small ranges are possible for these species because 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 (Edward and Harvey 2008). Of the five species, four were singletons with the fifth being represented by four individuals.

Schizomids
Short-tailed whipscorpions are one of the troglofaunal groups identified as having particularly small ranges (Framenau *et al.* 2018; Halse and Pearson 2014; Harms *et al.* 2018; Harvey *et al.* 2008). The median range of schizomids calculated by Halse and Pearson (2014) was 5.4 km^2. Up to four schizomid species have been identified from within the Project area and vicinity, none of which has been recorded elsewhere. Three of the four schizomids were found as singletons, each being the only known record of that species, and one species was represented by three individuals. Further taxonomic work may possibly reduce the number of species from four to two.

Isopods
Slaters are one of the more speciose groups of troglofauna in the Pilbara and the median range for species in this group was calculated by Halse and Pearson (2014) as 2.5 km^2. Previous surveys have identified five isopod species from within the Project area and these are the only known records of these species. Three species are singletons, one is represented by two specimens and another by three specimens. Two species are currently only known from the resource outline.

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8. 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 watertable 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 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.