Bennelongia
Environmental Consultants

Greenbushes Subterranean Fauna Desktop Review and Assessment

Prepared for:

Talison Lithium Ltd

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Final Report

Short-Range Endemics I Subterranean Fauna

Waterbirds I Wetlands

Greenbushes Subterranean Fauna Desktop Review and 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

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Report Version	Prepared by	Reviewed by	Submitted to Client	
			Method	Date
Draft	Huon Clark	Stuart Halse	email	27 November 2019
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EXECUTIVE SUMMARY

Talison Lithium Ltd mines and processes lithium-bearing mineral spodumene at the Greenbushes Mine, located directly south of the Greenbushes townsite, approximately 250 km south of Perth, Western Australia. Talison is currently looking to construct of a third lithium processing plant and tailings retreatment facility, and to increase the area of mining (the Project).

As part of the associated environmental studies, Talison commissioned a desktop review of the likely impacts of the Project on subterranean fauna. The initial report was undertaken by Biologic Environmental Survey and updated by Bennelongia Environmental Consultants.

Subterranean fauna can be divided into aquatic stygofauna and air-breathing troglofauna. Both groups typically lack eyes and are poorly pigmented due to lack of light. With the exception of several species of stygofaunal fish and troglofaunal blind snakes in the north of the State, all subterranean fauna in Western Australia are invertebrates.

A database search of an area around the Proposal defined by 32.87°S, 115.06°E and 34.87°S, 117.06°E, based on limited survey effort in the Greenbushes area and surrounds, showed that at least low numbers of subterranean species may potentially occur in the Project. The species recorded in the search area were predominately found in cave systems and comprised two stygofauna species – the ostracod *Acandona admiratio* and copepod *Kinnecaris eberhardi* and four troglofauna species – the pseudoscorpions *Austrochthonius strigosu, Pseudotyrannochthonius giganteus*, *Protochelifer cavernarum* and harvestman *Calliuncus labyrinthus*. In addition, subterranean isopods occur in the search area (although it is not clear whether stygofauna or troglofauna), as well as probable troglofaunal symphylans and possible troglofaunal snails.

The geology of the Project is relatively complex but on the surface is dominated by undivided sediments and ferruginous duricrust (sand, loam, colluvium), with exposed granulite- gneiss and the eastern and western margins. There are two aquifers present: a shallow 'sand' aquifer and a deeper fractured rock aquifer in Granulite – gneiss. Little is known about the aquifers and much of the sand aquifer, and the habitat within it for subterranean fauna, has been removed by dredge mining for tin. It appears unlikely there is much habitat for troglofauna in the Project. There is probably less stygofauna habitat available currently than before tin mining commence.

The relatively low numbers of subterranean animals and species recorded in the search area is probably a reflection of relatively depauperate subterranean fauna communities occurring in the southwest; but may also reflect to varying degrees the limited survey effort applied to the area, narrow interests of collectors/researchers involved, and the lack of sampling outside caves in potentially prospective geologies.

While existing information suggests there unlikely to be significant subterranean fauna communities in the Project area, it is recommended that some subterranean fauna sampling should be undertaken to confirm the conclusion of this review that subterranean fauna conservation values are unlikely to be significantly affected by Project development.

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1. INTRODUCTION

Talison Lithium Limited (Talison) mines and processes lithium-bearing mineral spodumene at the Greenbushes Mine, located directly south of the Greenbushes townsite, approximately 250 km south of Perth, Western Australia (Figure 1). Mining consists of the traditional drill and blast method and ore is then sent to processing plants to produce a variety of lithium concentrates. Talison Lithium and its predecessor companies have been producing lithium from the Greenbushes lithium operations since 1983. Talison is currently looking to construct of a third lithium processing plant and tailings retreatment facility, and to increase the area of mining (the Project).

As part of the associated environmental studies, commissioned Biologic Environmental Survey to undertake a desktop review of the likely impacts of the Project on subterranean fauna within the area of proposed expansion, which will be contained within the Study Area (Figure). Bennelongia Environmental Consultants have updated this review. Where appropriate, the text and data provided in the Biologic report have been utilised in the review.

Some of the justification for assessing environmental impacts on subterranean fauna in Western Australia is based on the Pilbara and Yilgarn regions of the State being internationally recognised as areas of globally important subterranean fauna radiations. The very limited work to date in near coastal areas of south-western Australia has revealed nowhere near the same species richness and the conservation significance of the fauna is yet to be understood. In line with this, there is currently little information on which to base assessment of the likely richness of the subterranean fauna communities (stygofauna and troglofauna) within the Project.

Subterranean fauna species typically have very small ranges (Gibert and Deharveng 2002), and quite often have ranges that could potentially be encompassed by a mine pit or the associated dewatered zone. The potential threat of extinction faced by any highly restricted subterranean fauna species is the other justification for the Environmental Protection Authority (EPA) requiring subterranean fauna to be considered in environmental impact assessments (EIA) for mining developments and similar operations (EPA 2016a, b, c).

The purpose of this desktop review is to determine whether subterranean fauna communities of conservation significance are likely to exist in the vicinity of the Project, rather than to assess the level of threat to individual species.

2. SUBTERRANEAN FAUNA

Subterranean fauna can be 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 and Deharveng 2002). With the exception of several species of stygofaunal fish and troglofaunal blind snakes in the north of Western Australia, all subterranean fauna in the State are invertebrates.

Geology influences the presence, richness and distribution of subterranean fauna by providing different types of habitat (Eberhard *et al.* 2005; Hose *et al.* 2015). Geologies with an extensive network of internal spaces support larger assemblages of subterranean fauna, both in terms of abundance and diversity, than consolidated geologies.

Stygofauna communities tend to be richest in calcrete and alluvial aquifers (Humphreys 2001), while less transmissive geologies such as banded iron formations (BIF), saprolite, mafic and ultramafic usually contain depauperate communities (ecologia 2009; GHD 2009). It is unusual for silt and clay to support

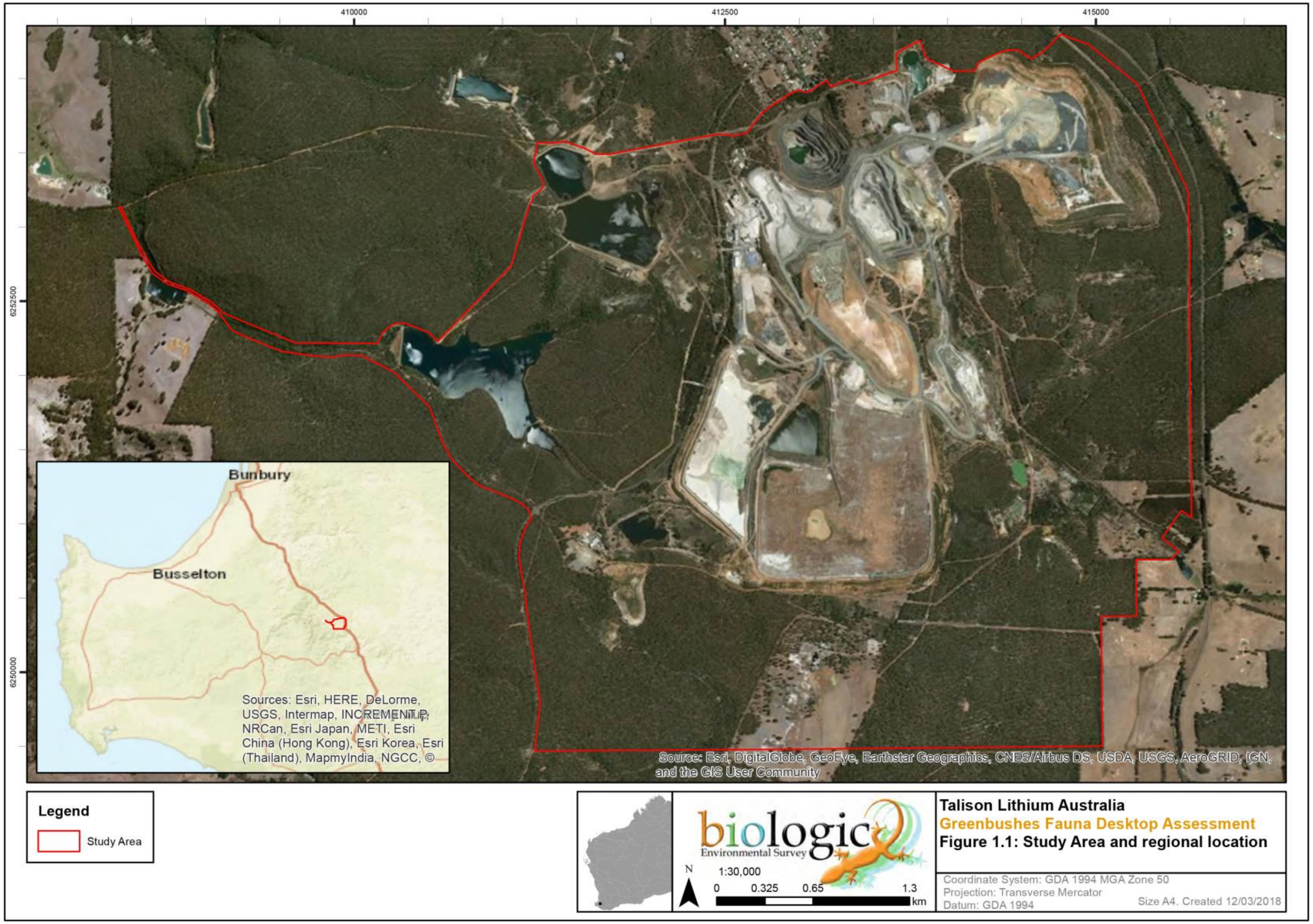

Figure 1. Location of the Project and surrounding Study Area.

stygofauna because of the lack of interstitial spaces and the associated absence of an aquifer (Korbel and Hose 2011).

Caves on the coastal plain in southwestern Australia are known to support some stygofauna species (e.g.Karanovic 2003; Karanovic 2005). Other surveys that have recorded stygofauna in coastal plain aquifers in southwestern Australia include surveys of aquifers in the Gnangara Mound (Tang and Knott 2009), Bassendean Sand at Kensington in Perth (Bennelongia 2015) and in limestone sands at Pt Grey beside the Harvey Estuary near Mandurah (Bennelongia 2009).

Troglofauna have been found to occur widely in mineralised iron formations, calcretes and alluvial-detrital deposits in the Pilbara (Halse 2018). Troglofauna surveys in Western Australia outside the Pilbara have been limited but surveys in ironstone ranges in the Yilgarn at Koolyanobbing, Mt Jackson and Mt Dimmer have yielded depauperate to moderately rich troglofauna communities (Bennelongia 2008a, b), while significant communities have been recorded in calcretes of the Yilgarn, Records of the occurrence of troglofauna in more coastal areas of south-western Australia are few and mostly from caves (Moulds 2007), although two species thought to be potential troglofauna were collected close to the Project at Ludlow by Biota (2005). More generally, the likely richness and frequency of occurrence of troglofauna outside caves in the southwest remains unclear.

3. GEOLOGICAL SETTING

3.1. Local Geology

The Project is located within the Darling Plateau, which consists of an undulating dissected peneplain with gravelly, pale orange soils. Deep steeply-sided valleys occur throughout the area, occasionally punctuated by dome-shaped granite outcrops (Water Corporation 2004). Soils are predominantly gravels with occasional block laterite outcrops and some elevated areas of sands and sandy loams. In the deeper valleys, the soils are heavier alluvium (Water Corporation 2004).

The Greenbushes area has historically been a major source of alluvial tin and, subsequently, tin from weathered pegmatite (Partington 1990). Three broad surface geology types have been mapped (Figure 2, Table 1) across the Study Area. Undivided sediments and ferruginous duricrust (sand, loam, colluvium), which are sedimentary in nature, cover most of the Study Area but on the eastern and western margins there is granulite - gneiss. Under the surface geology, five bedrock geologies of metamorphic and igneous origin have been recognised in the Study Area (Table 1).

3.2. Local Hydrogeology

A shallow aquifer, much of it coincident with a former water course and the historical dredge mining operation for alluvial tin, runs through parts of the Study Area, including the tailings dams. This shallow 'sand' aquifer has surface connections (GHD 2014). Information on the occurrence of this aquifer is incomplete but it appears to lie largely within undivided sediments. The aquifer (in channels of sand) is often incised into an underlying 20-50 m thick layer of weathered material (mainly clay) that acts as an aquitard, although there is some connection between the surface aquifer and the bedrock aquifer below this weathered material. The shallow sand aquifer has been removed from many areas where tin was dredge-mined and now occurs as a limited network across the Study Area, although it is inferred to be up to 20 m thick in places (see Figures 9-12 in GHD 2014). The deeper bedrock aquifer has more uniform occurrence across the Study Area, albeit in a mix of geologies (Figure 3).

3.3. Presence of Habitat within Search Area

The suitability of the geological and hydrological units of the Project has been assessed in a preliminary way in Table 1.

Table 1. Geology and hydrology of the Study Area.

Unit Code	Description	Suitability to subterranean fauna (generalised)
Surface Geology		
Granulite, gneiss 74316	High-grade metamorphic rock (felsic granulite, mafic granulite) - Mafic and felsic granulites: hornblende-plagioclase-hypersthene granulite, quartz-feldspar-biotite gneiss with lenses of schist, amphibolite, ultramafic rock, banded iron formation, quartzite; quartz-feldspar-hornblende layered	Low – unlikely to provide sufficient voids/ spaces (except possibly where fractured/ faulted)
Undivided sediments 74488	Sedimentary, regolith (sedimentary rock, colluvial sediment, weathered material - unknown origin, sand - residual, silt - unknown origin) – Undivided poorly consolidated sediments: colluvium, weathered rocks, alluvium, sand, silt, clay, lacustrine and swamp deposits; silcrete, ferricrete, calcrete; shallow-marine sediments	Med - poorly consolidated sediments (colluvium, alluvium, shallow marine sediments) and weathered rock (silcrete, calcrete, ferricrete); clays less likely to be habitable. Likelihood of stygofauna/ troglofauna depends on habitat extent relative to water table.
Ferruginous duricrust 38498	Regolith (lateritic duricrust) - Pisolitic, nodular or vuggy ferruginous laterite; some lateritic soils; ferricrete; magnesite; ferruginous and siliceous duricrusts and reworked products, calcrete, kaolinised rock, gossan; residual ferruginous saprolite	Med - vuggy ferruginous laterite, reworked ferruginous/ siliceous duricrust, and likely weathered rock (calcrete, ferricrete). Likelihood of stygofauna/ troglofauna depends on habitat extent relative to water table.
Bedrock Geology		
A-gp-YSW	Igneous granitic (Syntectonic, synmetamorphic zoned rare-metal pegmatite (includes Greenbushes Pegmatite)	Low – unlikely to provide sufficient voids/ spaces (except possibly where fractured/ faulted)
A-mgn-YSW	Meta-igneous felsic intrusive (Granitic gneiss)	Low – unlikely to provide sufficient voids/ spaces (except possibly where fractured/ faulted)
A-mwa-YSW	Meta-igneous mafic (Amphibolite)	Low – unlikely to provide sufficient voids/ spaces (except possibly where fractured/ faulted)
A-xmno-mni-YSW	Metamorphic (Granulite and migmatite; high-grade metamorphic rock)	Low – unlikely to provide sufficient voids/ spaces (except possibly where fractured/ faulted)
A-xmo-ma-YSW	Meta-igneous mafic intrusive (Metagabbro and metaperidotite, includes mafic/ultramafic igneous complexes)	Low – unlikely to provide sufficient voids/ spaces (except possibly where fractured/ faulted)
Dolerite dykes	Numerous dolerite dykes are known to occur throughout the bedrock, in some cases extending to the surface (not shown on map)	Negligible – assumed to be impermeable and likely to provide potential barriers to species dispersal.
Aquifers		
Sand	Shallow aquifer in sand and clay – connected local aquifer, extending into weathered rock	Moderate – should have suitable spaces for stygofauna, extent and saturation of aquifer unknown
Ano	Fractured and weathered rocks – spatially extensive local aquifer, degree of connection to surface unknown, degree of saturation and extent/ type of spaces unknown. Depth to aquifer may restrict occurrence of stygofauna (Granitoid gneiss, migmatite and minor schist; weathered at base)	Low – limited or very localised groundwater resources (in fractured rocks) assumed to correspond to low suitability habitat for stygofauna

Subterranean fauna habitat may occur wherever small subterranean fauna spaces are present. Such spaces are likely to occur in two broad geologies in the Study area: the 'sand' of the shallow aquifer and wherver there has been fracturing or secondary weathering in rock geologies, especially at the base of the greenstone and granite.

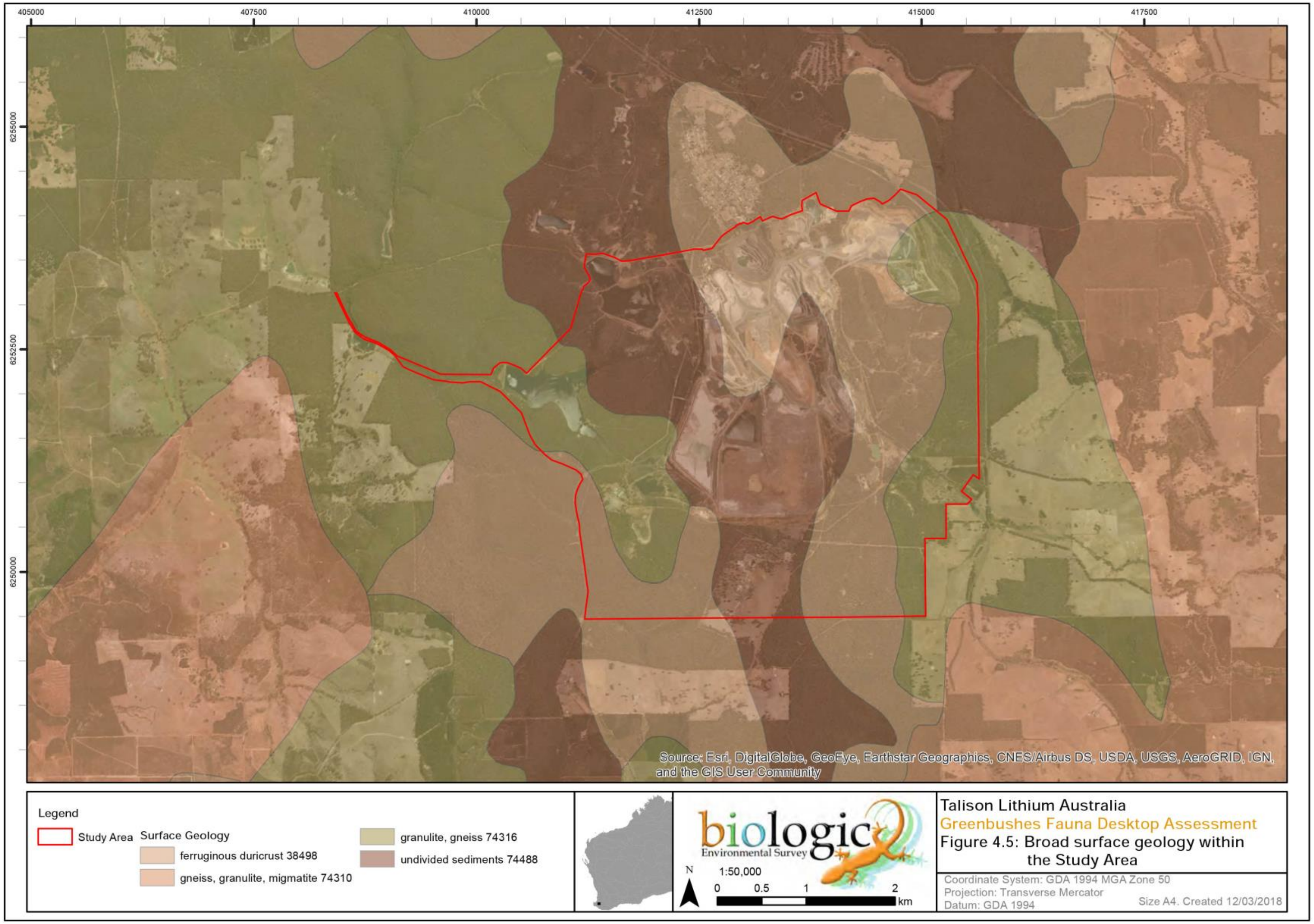

Figure 2. Surface geology at the Project and surrounds.

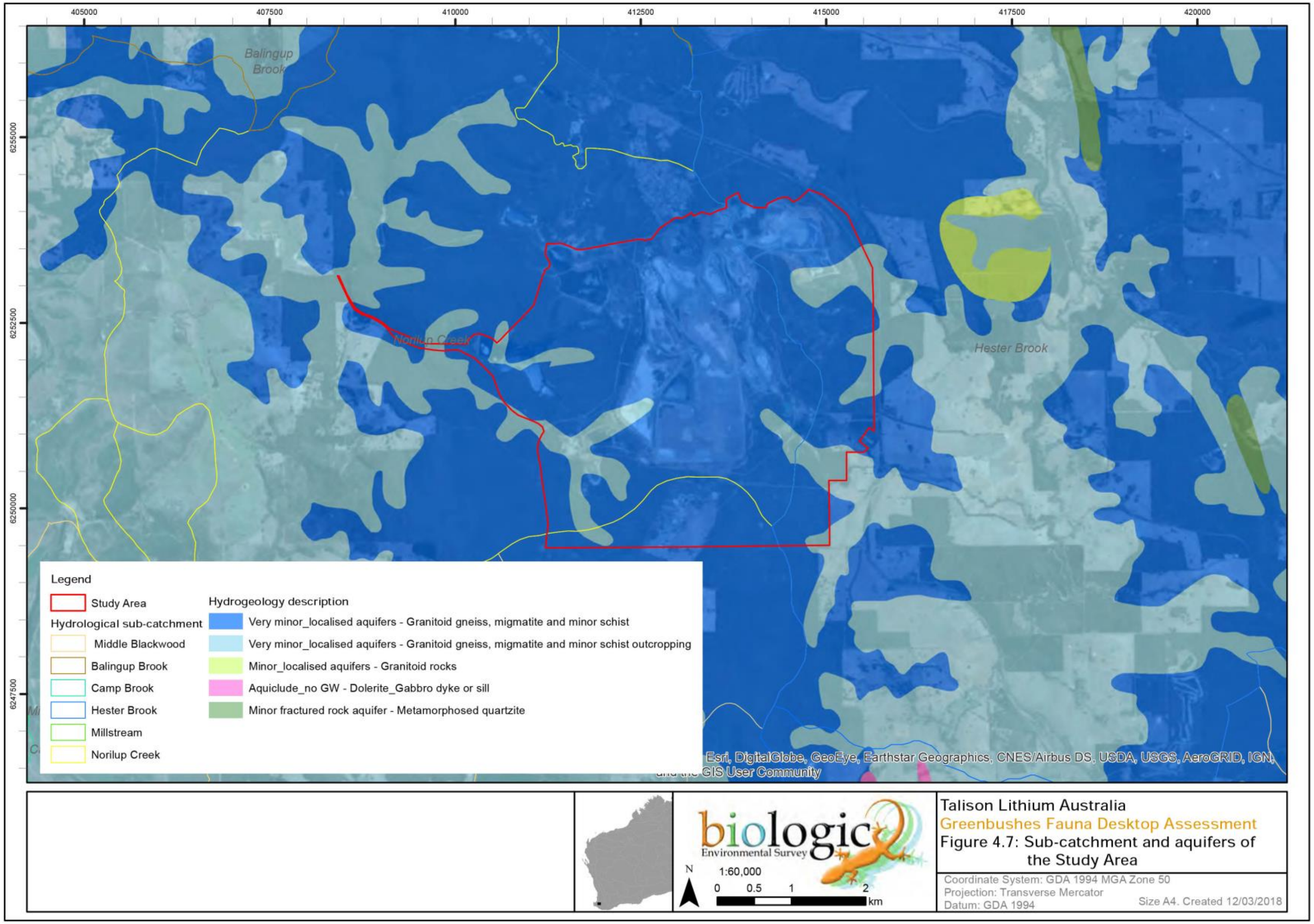

Figure 3. Geology in areas of occurrence of deeper aquifer in the Study Area and surrounds.

Interstitial and other small subterranean spaces above the watertable that might be used by troglofauna are frequently filled-in by detritus but groundwater flow below the watertable can maintain these spaces for stygofauna to a much greater extent (Howarth and Moldovan 2018). Overall, however, the undivided sediments and duricrust ('sand') that cover most of the Study Area are unlikely to support rich subterranean fauna communities. The duricrust offers very limited potential habitat for troglofauna because of likely filling of subterranean spaces, while the surface aquifer within it is not extensive and may have been considerably further reduced in extent by historical mining activity. The deeper gneiss – granulite and related geologies are unlikely to support much subterranean fauna because of the reduced surface connection as a consequence of the overlying aquitard. Furthermore, fracturing and weathering is likely to be limited to the base of the gneiss – granulite.

The caveat that must be added to the above habitat conclusions is that no quantitative information about groundwater (including depth to watertable) was available at the time of writing, no drill cores or bore logs were available, and geological information is oriented towards interpretation of mineral prospectivity and the likelihood of leakage from tailings storage facilities rather than subterranean fauna habitat.

4. PREVIOUS SUBTERRANEAN FAUNA SURVEYS

Records of subterranean fauna were compiled from Western Australian Museum (WAM) and Bennelongia databases for a square search area of approximately 2 decimal degrees surrounding the Proposal (defined by 32.87°S, 115.06°E and 34.87°S, 117.06°E). Published research papers, available environmental reports and online resources such as the Atlas of Living Australia (ALA 2018) and the Australian Faunal Directory (ABRS 2009) were also reviewed.

4.1. Previously reported records

Databases and scientific literature were specifically searched for references to subterranean environments to ensure that reported species represent subterranean fauna. This resulted in 40 records of at least eight species of confirmed subterranean fauna within the search area (Table 2). A complete list of details associated with these records is provided in Appendix 1 and a map of species locations with respect to the Project is provided in Figure 4. Of the 40 records, 12 records belong to two species of stygofauna and 26 records belong to five species of troglofauna (Table 2). In addition, there are two higher order records of Isopoda 'sp.', for which it is indicated the animals were subterranean but there is no guidance as to whether they were stygofauna or troglofauna.

4.1.1. Stygofauna

Species of stygofauna known from the search area are *Acandona admiratio* (nine records) and *Kinnecaris eberhardi* (three records). *Acandona admiratio* is an ostracod, while *Kinnecaris eberhardi* is a harpacticoid copepod. The records in the search area were from caves, although both species either also occur, or are likely to occur, at depth in the broader landscape.

Acandona admiratio

Eight of the nine records of *Acandona admiratio* were found in Easter Cave, Margaret River and one specimen was collected from Jewel Cave, near Margaret River. This species was described by Karanovic (2003) as a new genus. Specimens were collected by sweeping hand nets through pools containing roots in caves in the Margaret River region.

Kinnecaris eberhardi

Karanovic (2005) described *Kinnecaris eberhardi* from subterranean waters in two small caves in the Margaret River region. Records from the WAM database indicate that this species has been found in monitoring wells at Strongs Cave. Karanovic (2005) also collected material from Kudjal Yolgah Cave. Both Tang and Knott (2009) and Bennelongia (2009) have recorded the species 250 km to the north in Perth; the former at Yanchep and the latter at Kensington.

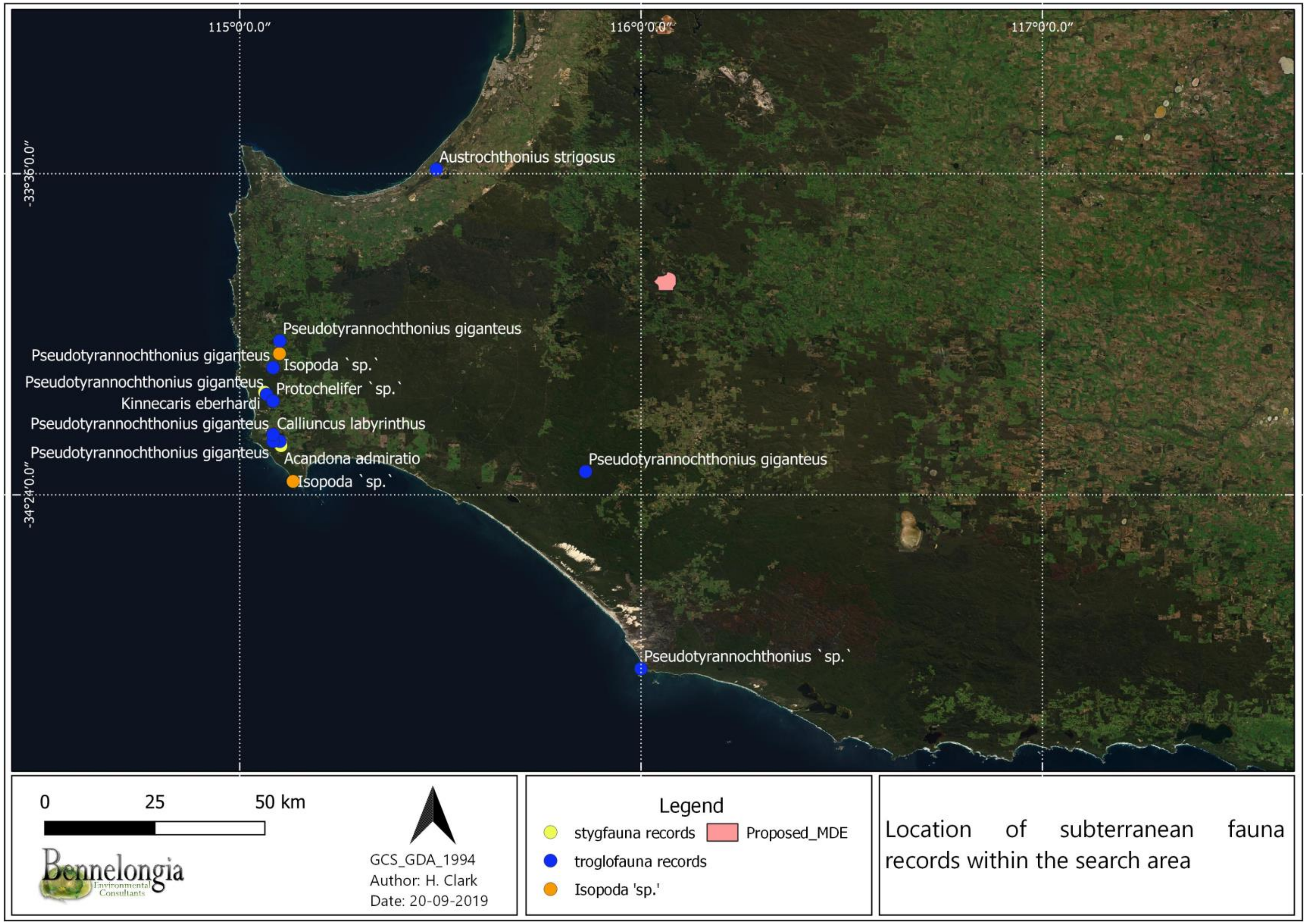

Figure 4. Location of subterranean fauna records within the search area.

Table 2: Records of subterranean fauna within the search area.

Order	Family	Species	Site	Habitat	Category
Podocopida	Candonidae	*Acandona admiration*	Tiffanys Lake, Easter Cave, Margaret River		Stygofauna
Podocopida	Candonidae	*Acandona admiration*	Tiffanys Lake, Easter Cave, Margaret River		Stygofauna
Podocopida	Candonidae	*Acandona admiration*	Lake Roots, Easter Cave, Margaret River		Stygofauna
Podocopida	Candonidae	*Acandona admiration*	Tiffanys Lake, Easter Cave, Margaret River		Stygofauna
Podocopida	Candonidae	*Acandona admiration*	Mouse Hole 1, Easter Cave, Margaret River		Stygofauna
Podocopida	Candonidae	*Acandona admiration*	Mouse Hole 2, Easter Cave, Margaret River		Stygofauna
Podocopida	Candonidae	*Acandona admiration*	Mouse Hole 2, Easter Cave, Margaret River		Stygofauna
Podocopida	Candonidae	*Acandona admiration*	Flat Roof 2, Jewel Cave, Margaret River		Stygofauna
Podocopida	Candonidae	*Acandona admiration*	Tiffanys Lake, Easter Cave, Margaret River		Stygofauna
Pseudoscorpiones	Chthoniidae	*Austrochthonius strigosus*	Ludlow region (site LDMB2) [33.58921503°S, 115.4904651°E]	borehole, approx. 5 m depth	Troglofauna
Opiliones	Triaenonychidae	*Calliuncus labyrinthus*	Moondyne Cave, Au-11	tree roots at base of column, dark zone	Troglofauna

Order	Family	Species	Site	Habitat	Category
Opiliones	Triaenonychidae	*Calliuncus labyrinthus*	Moondyne Cave, Au-11	tree roots at base of column, dark zone	Troglofauna
Opiliones	Triaenonychidae	*Calliuncus labyrinthus*	Easter Cave, AU-14	tree roots on damp sand, dark zone	Troglofauna
Opiliones	Triaenonychidae	*Calliuncus labyrinthus*	Easter Cave, AU-14	tree roots near pool, dark zone	Troglofauna
Opiliones	Triaenonychidae	*Calliuncus labyrinthus*	Easter Cave, AU-14	tree roots near pool, dark zone	Troglofauna
Opiliones	Triaenonychidae	*Calliuncus labyrinthus*	Easter Cave, AU-14	tree root mat, dark zone	Troglofauna
Opiliones	Triaenonychidae	*Calliuncus labyrinthus*	Easter Cave, AU-14	tree root mat, dark zone	Troglofauna
Isopoda		Isopoda `sp.`	Calgalup Cave Market River		
Isopoda		Isopoda `sp.`	Cape Leeuwin, Skull Cave		
Harpacticoida	Parastenocarididae	*Kinnecaris eberhardi*	Monitoring Well, Strongs Cave, Margaret River		Stygofauna
Harpacticoida	Parastenocarididae	*Kinnecaris eberhardi*	Monitoring Well, Strongs Cave, Margaret River		Stygofauna
Harpacticoida	Parastenocarididae	*Kinnecaris eberhardi*	Monitoring Well, Strongs Cave, Margaret River		Stygofauna
Pseudoscorpiones	Cheliferidae	*Protochelifer* `sp.`	Witchcliffe region, Nannup Cave (WI-60)	dead on stalactite in doline, outside dripline, daylight	Troglofauna
Pseudoscorpiones	Cheliferidae	*Protochelifer* `sp.`	Witchcliffe region, Nannup Cave (WI-60)	from stalactite in doline, outside dripline, daylight z	Troglofauna

Order	Family	Species	Site	Habitat	Category
Pseudoscorpiones	Cheliferidae	*Protochelifer cavernarum*	Witchcliffe region, Acoustic (Pit) Cave (WI-67)	off shelf by west wall of doline, 20 m into shaded dayl	Troglofauna
Pseudoscorpiones	Pseudotyrannochthoniidae	*Pseudotyrannochthonius* \`sp.\`	Windy Harbour region, cave S.17 (Inland Cliffs Cave)	under rock, dark zone	Troglofauna
Pseudoscorpiones	Pseudotyrannochthoniidae	*Pseudotyrannochthonius giganteus*	Witchcliffe Karst: Mill Cave (WI-59)		Troglofauna
Pseudoscorpiones	Pseudotyrannochthoniidae	*Pseudotyrannochthonius giganteus*	Witchcliffe Karst: Mill Cave (WI-59)		Troglofauna
Pseudoscorpiones	Pseudotyrannochthoniidae	*Pseudotyrannochthonius giganteus*	Kudjal Yolgah Cave, Witchcliffe, western streamway chamber	from root mat and clay substrate near roof	Troglofauna
Pseudoscorpiones	Pseudotyrannochthoniidae	*Pseudotyrannochthonius giganteus*	Easter Cave, AU-14, Tiffanys Lake		Troglofauna
Pseudoscorpiones	Pseudotyrannochthoniidae	*Pseudotyrannochthonius giganteus*	Kudgal Yolgah Cave, Witchcliffe, western streamway chamber, deep zone		Troglofauna
Pseudoscorpiones	Pseudotyrannochthoniidae	*Pseudotyrannochthonius giganteus*	Windjand Cave, WI-113, Witchcliffe	on sand in dark zone	Troglofauna
Pseudoscorpiones	Pseudotyrannochthoniidae	*Pseudotyrannochthonius giganteus*	Augusta Karst: Labyrinth Cave (AU-16)	dark zone, under muddy piece of stalagmite	Troglofauna
Pseudoscorpiones	Pseudotyrannochthoniidae	*Pseudotyrannochthonius giganteus*	Strongs Cave (WI-63)		Troglofauna

Order	Family	Species	Site	Habitat	Category
Pseudoscorpiones	Pseudotyrannochthoniidae	*Pseudotyrannochthonius giganteus*	Witchcliffe area, Kudjal Yolgah, cave WI-9, left hand chamber, eastern	cave floor, fine tree roots	Troglofauna
Pseudoscorpiones	Pseudotyrannochthoniidae	*Pseudotyrannochthonius giganteus*	Beedelup National Park: Sevens Road, off Vasse Highway	Tullgren funnel	Troglofauna
Pseudoscorpiones	Pseudotyrannochthoniidae	*Pseudotyrannochthonius giganteus*	Witchcliffe area, Kudjal Yolgah, cave WI-9, right hand chamber, western streamway	cave floor, fine tree roots	Troglofauna
Pseudoscorpiones	Pseudotyrannochthoniidae	*Pseudotyrannochthonius giganteus*	Easter Cave, AU-14	organic matter on damp sand, dark zone	Troglofauna
Pseudoscorpiones	Pseudotyrannochthoniidae	*Pseudotyrannochthonius giganteus*	Nannup Cave, cave WI-60, near Witchcliffe		Troglofauna

4.2. Troglofauna

Toglofauna species known from the search area are *Austrochthonius strigosus* (one record), *Calliuncus labyrinthus* (seven records), *Protochelifer cavernarum* (one record), and *Pseudotyrannochthonius giganteus* (13 records). All of these species are pseudoscopions except for *Calliunicus labyrinthus*, which is a harvestman. Each of these is discussed in more detail below.

Austrochthonius strigosus

The database search revealed one record of *Austrochthonius strigosus* within the search area at a borehole in the Ludlow region at approximately 5 m depth (Table 2). This species was described by Harvey and Mould (2006), who noted that the specimen exhibited strong troglomorphic characteristics including loss of eyes, elongated appendages, and a loss of pigment (Harvey and Mould 2006). This species was collected by Biota (2005) in an environmental impact assessment. The symphylan collected by Biota at the same time, and thought to be troglofauna also, did not come up in the search of Museum databases.

Calliuncus labyrinthus

There were seven records of *Calliuncus labyrinthus* in the Museum databases, five individuals from Easter Cave and two from Moondyne Cave in the Margaret River region. This species was described by Hunt (1972), and it was noted the specimens exhibited morphological adaptations associated with cave and subterranean environments. Hunt (1972), describes the location of three individuals (one from Strongs Cave and two from Labyrinth Cave). They were found in the entrance doline and in the dark zone of the caves.

Protochelifer cavernarum

Protochelifer cavernarum is represented by a single record and is known from Acoustic (Pit) Cave in the Witchcliffe region. According to Moulds (2007), *Protochelifer cavernarum* is widespread and can be considered a troglophile, i.e. an animal that has part of its life cycle outside subterranean environments or that can complete all its life cycle within subterranean environments but is not dependent on such environments.

Pseudotyrannochthonius giganteus

Thirteen specimens of *Pseudotyrannochthonius giganteus* have been collected in the search area, all from various caves from within the Margaret River/Witchcliffe region. This species inhabits surface environments as well as cave systems, with cave specimens often exhibiting subterranean adaptations such as pigment loss in some body parts. (Harms 2018). As a result, this species has been described as an epigean troglophile (Harms 2013).

4.2.1. Other Records

There were also two higher order identifications of Isopoda 'sp.', one from Calgalup Cave near Margaret River and the other from Skull Cave, Cape Leeuwin (Table 2). Little is known about these records and, since isopods have representatives in both the troglofauna and stygofauna groups, they could not be categorically assigned to either groups. They are likely, however, to have at least some dependence of subterranean habitats.

Another group identified within the Margaret River caves is the snail family Bothriembryontidae. There are records of two species, *Bothriembryon leeuwinensis* and *Bothriembryon sayi*, either within or associated with the caves (usually dolines or cave entrances or near caves). The family is known to contain troglofauna species and B. *leeuwinensis* and *B. sayi* may have subterranean affinities, although they are not listed in Table 1.

In addition, it should be noted that Biota (2005) recorded a probable troglofaunal symphylan species at Ludlow.

5. IMPACT ASSESSMENT

While subterranean fauna (troglofauna and stygofauna) probably occur across most landscapes in Western Australia, there is considerable variation in species density at both regional and local scales. A framework for determining the likely presence of subterranean fauna within a region (and local geology) has been summarised in an EPA (2016c) technical guidance. It is suggested that for most geologies of the South-West (with the exception of karst), the probability that a rich subterranean fauna assemblage exists is low.

The limited sampling to date supports this conclusion, although moderately rich stygofauna communities have been collected from groundwater aquifers at Kensington (25 species, Bennelongia 2015), Pt Grey (15 species, Bennelongia 2009) and the larger area of Gnangara Mound (up to 15 species of copepods, Tang and Knott 2009).

The almost complete lack of records of stygofauna and troglofauna species outside caves in the vicinity of the Project is, at least to some extent, an artefact of limited survey effort and the taxonomic bias of surveys. It is often the case that when one or two troglofaunal or stygofaunal species are collected from a region, further survey reveals numerous other species. This was shown clearly by Tang and Knott's work on copepods of the relatively well studied Swan coastal plain, where six of the 15 species reported were new. The other frequently observed phenomenon is that some groups are regularly overlooked. This is likely to be the case in the search area with syncarids, which are one of the most common groups found in moderately rich to depauperate stygofauna communities in coastal areas of Australia (Camacho and Hancock 2012; Little *et al.* 2016). No syncarids have been reported in the search area.

The same observations apply to troglofauna. In most troglofauna surveys where pseudoscorpions and spiders have been collected, silverfish, diplurans and isopods are also found (see Moulds 2007). The absence of these groups from Table 1 suggests documentation of the fauna in the search area is very incomplete. It should also be noted that the collection of the pseudoscorpion *Austrochthonius strigosus* from a borehole in the Ludlow region at a depth of approximately 5 m, coupled with the collection of a probably troglofaunal symphylan (Biota 2005), highlights that troglofauna are unlikely to be restricted to cave systems near the Project.

5.1. Potential Impacts on Stygofauna

Open cut and underground mining often require a dewatering program to enable access to the mineral resource and to prevent the mine being flooded. Abstracted groundwater is typically also used in ore processing. The consequent drawdown of aquifers may potentially threaten the persistence of stygofauna communities that occur within the dewatering footprint. In particular, any species with a distribution that is restricted to the cone of groundwater drawdown may face possible extinction. Besides dewatering, the excavation of the pit itself causes 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 may disrupt connectivity between populations on either side of the disturbance.

Based on the depauperate occurrence of stygofauna in the search area, the apparently limited suitability of the aquifers in the Project for stygofauna and the likely greater range of any stygofauna species than the spatial extent of groundwater drawdown, it is considered unlikely that the Project will adversely affect stygofauna conservation values. However, documentation of the aquifers and their suitability for stygofauna s incomplete and there has been no sampling of stygofauna of aquifers in the vicinity of the Project to provide a sound framework for assessing the likelihood of stygofauna occurrence.

5.2. Potential Impacts on Troglofauna

The direct habitat loss from mine pit excavation is the primary mine-related threat to troglofauna in the Greenbushes area. As with stygofauna, the persistence of troglofauna communities that occur within the mine pit areas may be threatened. This especially applies to any species with distributions that are restricted to the mine pits. While in general animals utilising small isolated geologies are likely to be more vulnerable than those inhabiting more extensive geologies, many troglofauna species have highly restricted distributions within spatially extensive geologies. Species ranges can be determined by innate characteristics of the species or small-scale physical barriers or breaks in geological habitat.

The proposed area of mine pit excavation is 3.06 km^2 which is a 38% increase on the existing 2.22km^2. It is considered very few troglofauna species in the broad landscape of southern-western Australia are likely to have ranges this small. Based on the depauperate troglofauna community reported in the search area, it may be considered that few, if any, troglofaunal species will occur at the Project and, therefore, it is unlikely that the Project will adversely affect troglofauna conservation values. However, there has been no sampling of troglofauna in the vicinity of the Project to provide a sound framework for assessing the likelihood of stygofauna occurrence. The existing information from caves is unlikely to be a reliable indication of the abundance and richness of troglofauna in the broad landscape.

6. CONCLUSION

This desktop review examined the occurrence of both stygofauna and troglofauna species within the search area of the Project, mostly associated with cave environments. The troglofauna species known to occur include spiders, pseudoscorpions, and a harvestman species (as well as probably a symphylan), while the only known stygofauna are ostracods and copepods. Isopods that are likely to be subterranean (though whether stygofauna or troglofauna is unclear) have also been collected, as well as snails that may have cave affinities.

The low numbers of animals and species in the search area likely reflects the relatively depauperate nature of subterranean fauna communities in the southwest; but it may also reflect to varying degrees the limited survey effort applied to the area, narrow interests of collectors/researchers involved, and the lack of access to possibly more prospective geologies in the broader landscape. There is uncertainty about how well the search area information reflects the structure of subterranean fauna communities in the broad landscape around the Project.

While it is considered Project development is unlikely to threaten stygofauna and troglofauna conservation vales, a pilot-scale level of survey of subterranean fauna should undertake within the Project and its immediate surrounds to determine more conclusively whether or not significant subterranean fauna communities occur. In addition, there should be more detailed evaluation of the structure of the habitat above and below the watertable, and the nature of the aquifers present, to provide habitat information to support the evaluation of the prospectivity of the Project for stygofauna and troglofauna.

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Appendix 1 – Complete list of subterranean fauna and possible fauna with subterranean affinities

WAM Reg No	Class	Subclass	Order	Infraorder	Family	Lowest ID	Latitude	Longitude	Group
C28396			Podocopida		Candonidae	Acandona admiratio	-34.278	115.103	Stygo
C28397			Podocopida		Candonidae	Acandona admiratio	-34.278	115.103	Stygo
C28403			Podocopida		Candonidae	Acandona admiratio	-34.278	115.103	Stygo
C28395			Podocopida		Candonidae	Acandona admiratio	-34.278	115.103	Stygo
C28399			Podocopida		Candonidae	Acandona admiratio	-34.277	115.101	Stygo
C28400			Podocopida		Candonidae	Acandona admiratio	-34.277	115.101	Stygo
C28401			Podocopida		Candonidae	Acandona admiratio	-34.277	115.101	Stygo
C28402			Podocopida		Candonidae	Acandona admiratio	-34.273	115.103	Stygo
C28398			Podocopida		Candonidae	Acandona admiratio	-34.278	115.103	Stygo
T65550			Pseudoscorpiones		Chthoniidae	Austrochthonius strigosus	-33.589	115.49	Trog
S9236	Gastropoda	Heterobranchia			Bothriembryontidae	Bothriembryon \`Eventus\` n.sp.	-33.95	115.067	
S72511	Gastropoda	Heterobranchia			Bothriembryontidae	Bothriembryon leeuwinensis	-34.167	115.083	
S4208	Gastropoda	Heterobranchia			Bothriembryontidae	Bothriembryon leeuwinensis	-34.2	115.117	
S2985	Gastropoda	Heterobranchia			Bothriembryontidae	Bothriembryon leeuwinensis	-34.2	115.117	
S2988	Gastropoda	Heterobranchia			Bothriembryontidae	Bothriembryon leeuwinensis	-34.2	115.117	
S2993	Gastropoda	Heterobranchia			Bothriembryontidae	Bothriembryon leeuwinensis	-34.317	115.167	

WAM Reg No	Class	Subclass	Order	Infraorder	Family	Lowest ID	Latitude	Longitude	Group
S2994	Gastropoda	Heterobranchia			Bothriembryontidae	Bothriembryon leeuwinensis	-34.317	115.167	
S2999	Gastropoda	Heterobranchia			Bothriembryontidae	Bothriembryon leeuwinensis	-34.317	115.167	
S3002	Gastropoda	Heterobranchia			Bothriembryontidae	Bothriembryon leeuwinensis	-34.317	115.167	
S28094	Gastropoda	Heterobranchia			Bothriembryontidae	Bothriembryon leeuwinensis	-34.267	115.117	
S4314	Gastropoda	Heterobranchia			Bothriembryontidae	Bothriembryon leeuwinensis	-34.2	115.15	
S72689	Gastropoda	Heterobranchia			Bothriembryontidae	Bothriembryon leeuwinensis	-34.25	115.083	
S3404	Gastropoda	Heterobranchia			Bothriembryontidae	Bothriembryon sayi	-34.367	115.133	
S3408	Gastropoda	Heterobranchia			Bothriembryontidae	Bothriembryon sayi	-34.367	115.133	
S3418	Gastropoda	Heterobranchia			Bothriembryontidae	Bothriembryon sayi	-34.167	115.083	
S3442	Gastropoda	Heterobranchia			Bothriembryontidae	Bothriembryon sayi	-34.317	115.167	
S3446	Gastropoda	Heterobranchia			Bothriembryontidae	Bothriembryon sayi	-34.15	115.067	
S4217	Gastropoda	Heterobranchia			Bothriembryontidae	Bothriembryon sayi	-34.167	115.083	
S3454	Gastropoda	Heterobranchia			Bothriembryontidae	Bothriembryon sayi	-33.95	115.067	
S3457	Gastropoda	Heterobranchia			Bothriembryontidae	Bothriembryon sayi	-33.95	115.067	
S3463	Gastropoda	Heterobranchia			Bothriembryontidae	Bothriembryon sayi	-33.95	115.067	
S3464	Gastropoda	Heterobranchia			Bothriembryontidae	Bothriembryon sayi	-33.95	115.067	
S4234	Gastropoda	Heterobranchia			Bothriembryontidae	Bothriembryon sayi	-34.15	115.067	

WAM Reg No	Class	Subclass	Order	Infraorder	Family	Lowest ID	Latitude	Longitude	Group
S3469	Gastropoda	Heterobranchia			Bothriembryontidae	Bothriembryon sayi	-33.95	115.067	
S4317	Gastropoda	Heterobranchia			Bothriembryontidae	Bothriembryon sayi	-34.317	115.167	
S4321	Gastropoda	Heterobranchia			Bothriembryontidae	Bothriembryon sayi	-33.95	115.067	
S4323	Gastropoda	Heterobranchia			Bothriembryontidae	Bothriembryon sayi	-34.25	115.15	
S9239	Gastropoda	Heterobranchia			Bothriembryontidae	Bothriembryon sp.	-34.367	115.133	
S9250	Gastropoda	Heterobranchia			Bothriembryontidae	Bothriembryon sp.	-34.317	115.15	
S9316	Gastropoda	Heterobranchia			Bothriembryontidae	Bothriembryon sp.	-33.95	115.067	
S9320	Gastropoda	Heterobranchia			Bothriembryontidae	Bothriembryon sp.	-33.95	115.067	
S9322	Gastropoda	Heterobranchia			Bothriembryontidae	Bothriembryon sp.	-34.367	115.133	
S12707	Gastropoda	Heterobranchia			Bothriembryontidae	Bothriembryon sp.	-34.083	115.083	
S9156	Gastropoda	Heterobranchia			Bothriembryontidae	Bothriembryon sp.	-34.483	116.05	
S3702	Gastropoda	Heterobranchia			Bothriembryontidae	Bothriembryon sp.	-34.833	116	
S5888	Gastropoda	Heterobranchia			Bothriembryontidae	Bothriembryon sp.	-34.304	115.171	
S9236	Gastropoda	Heterobranchia			Bothriembryontidae	Bothriembryon sp.	-33.95	115.067	
T29623			Opiliones		Triaenonychidae	Calliuncus labyrinthus	-34.25	115.083	Trog
T29624			Opiliones		Triaenonychidae	Calliuncus labyrinthus	-34.25	115.083	Trog
T29625			Opiliones		Triaenonychidae	Calliuncus labyrinthus	-34.25	115.083	Trog

WAM Reg No	Class	Subclass	Order	Infraorder	Family	Lowest ID	Latitude	Longitude	Group
T29626			Opiliones		Triaenonychidae	Calliuncus labyrinthus	-34.25	115.083	Trog
T29627			Opiliones		Triaenonychidae	Calliuncus labyrinthus	-34.25	115.083	Trog
T29628			Opiliones		Triaenonychidae	Calliuncus labyrinthus	-34.25	115.083	Trog
T29629			Opiliones		Triaenonychidae	Calliuncus labyrinthus	-34.25	115.083	Trog
C54707			Isopoda			Isopoda `sp.`	-34.048	115.099	Unk
C54712			Isopoda			Isopoda `sp.`	-34.367	115.133	Unk
C28618			Harpacticoida		Parastenocarididae	Kinnecaris eberhardi	-34.144	115.062	Stygo
C28620			Harpacticoida		Parastenocarididae	Kinnecaris eberhardi	-34.144	115.062	Stygo
C28619			Harpacticoida		Parastenocarididae	Kinnecaris eberhardi	-34.144	115.062	Stygo
T62107			Pseudoscorpiones	Panctenata	Cheliferidae	Protochelifer `sp.`	-34.167	115.083	Trog
T62108			Pseudoscorpiones	Panctenata	Cheliferidae	Protochelifer `sp.`	-34.167	115.083	Trog
T62162			Pseudoscorpiones	Panctenata	Cheliferidae	Protochelifer cavernarum	-34.167	115.083	Trog
T89511			Pseudoscorpiones		Pseudotyrannochthoniidae	Pseudotyrannochthonius `sp.`	-34.833	116	Trog
T120610			Pseudoscorpiones		Pseudotyrannochthoniidae	Pseudotyrannochthonius giganteus	-34.15	115.067	Trog
T120611			Pseudoscorpiones		Pseudotyrannochthoniidae	Pseudotyrannochthonius giganteus	-34.15	115.067	Trog
T82476			Pseudoscorpiones		Pseudotyrannochthoniidae	Pseudotyrannochthonius giganteus	-34.083	115.083	Trog

WAM Reg No	Class	Subclass	Order	Infraorder	Family	Lowest ID	Latitude	Longitude	Group
T82480			Pseudoscorpiones		Pseudotyrannochthoniidae	Pseudotyrannochthonius giganteus	-34.267	115.1	Trog
T82481			Pseudoscorpiones		Pseudotyrannochthoniidae	Pseudotyrannochthonius giganteus	-34.083	115.083	Trog
T22357			Pseudoscorpiones		Pseudotyrannochthoniidae	Pseudotyrannochthonius giganteus	-34.017	115.1	Trog
T120456			Pseudoscorpiones		Pseudotyrannochthoniidae	Pseudotyrannochthonius giganteus	-34.267	115.083	Trog
T89490			Pseudoscorpiones		Pseudotyrannochthoniidae	Pseudotyrannochthonius giganteus	-34.167	115.083	Trog
T142233			Pseudoscorpiones		Pseudotyrannochthoniidae	Pseudotyrannochthonius giganteus	-34.083	115.083	Trog
T146841			Pseudoscorpiones		Pseudotyrannochthoniidae	Pseudotyrannochthonius giganteus	-34.342	115.862	Trog
T142234			Pseudoscorpiones		Pseudotyrannochthoniidae	Pseudotyrannochthonius giganteus	-34.083	115.083	Trog
T29631			Pseudoscorpiones		Pseudotyrannochthoniidae	Pseudotyrannochthonius giganteus	-34.25	115.083	Trog
T83394			Pseudoscorpiones		Pseudotyrannochthoniidae	Pseudotyrannochthonius giganteus	-34.167	115.083	Trog