Bennelongia Environmental Consultants

Smiths Beach Project, Yallingup - Coastal Tourism Village: Subterranean Fauna Desktop Assessment

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Strategen-JBS&G

October 2023

Final Report

Short-Range Endemics I Subterranean Fauna

Waterbirds I Wetlands

Smiths Beach Project, Yallingup - Coastal Tourism Village: Subterranean Fauna Desktop Assessment

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EXECUTIVE SUMMARY

The Smiths Beach Project, Yallingup – Coastal Tourism Village (the Project) is located approximately 250 km south-west of Perth, Western Australia. The total Project area is approximately 40 ha and, when developed, it will comprise low-density holiday homes, a hotel including wellness centre, campground and community hub, bakery, café, Cape to Cape headquarters, and surf club.

This report presents the results of a desktop review of habitat information and relevant biological records to document the likely values of subterranean fauna in the Project area and its surrounds and to assess the level of possible threat to subterranean fauna from development of the Project.

Geology influences the presence, richness, and distribution of subterranean fauna through its influence on the types of habitats present. The Project is located in the Leeuwin Complex, mostly with a thin veneer of sand overlying gneiss bedrock. Groundwater quality within the Proposal is well within the tolerances of stygofauna but the only groundwater present appears to be in small, perched aquifers. It is concluded on the available geological and hydrogeological information that the Project area habitat is not prospective for subterranean fauna.

A database and literature search of the Cape Naturaliste to Cale Leeuwin region found records of 21 species of probable stygofauna and 14 species of probable troglofauna. The stygofauna comprised 12 crustacean species, eight worms and one nematode. Ten of the species are formally described. The troglofauna list comprised 13 arachnid species and one millipede. Four species are described. Two species of stygofauna have been recorded from Northcote Grotto in the Yallingup area, although one of them is a nematode and does not have significant value in environmental assessment. Four species of troglofauna have been recorded from Ngilgi Cave, about 2 km north of the Project. Based on the database and literature search, no subterranean fauna species is known from the Project area and there are no records of subterranean species from the general landscape matrix in the search area, although this may reflect lack of sampling.

While no subterranean species are known from the Project area and available information on geology and hydrogeology suggests that habitat is not prospective for either stygofauna or troglofauna species, the information habitat is incomplete. LiDAR should be used to confirm that no caves are present and the potential for perched aquifers to yield stygofauna should be investigated further.

Irrespective of the occurrence of subterranean fauna, no large-scale ground excavation, nor groundwater abstraction, is planned in the Project area and it is expected that any potential impacts on subterranean fauna, if present, can be mitigated.

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1. INTRODUCTION

Smiths 2014 Pty Ltd is proposing to construct the Smiths Beach Project, Yallingup – Tourism Village (the Project) at Lot 4131, Smiths Beach Road, Yallingup (Figures 1 and 2).

The Project is located approximately 250 km southwest of Perth and is within the City of Busselton (Figure 1). The Development Envelope is 40.53 ha and is proposed to contain low-density holiday homes, a hotel including wellness centre, campground and community hub, bakery, café, Cape to Cape headquarters, and surf club.

The Project has been referred to the Environmental Protection Authority (EPA) and the Department of Climate Change, Energy, the Environment and Water (DCCEEW). Assessment was set at the level of Public Environmental Review and is being undertaken as an accredited assessment. One of the key environmental factors identified by the EPA is subterranean fauna (EPA 2016), In the absence of listed threatened species (as Matters of National Environmental Significance) subterranean fauna will not be assessed by the DCCEEW.

Subterranean fauna is a term used to describe species of animals (mostly invertebrates) that must have access to underground habitats for persistence. There are two types of subterranean species: stygofaunal species live in groundwater and troglofaunal species that live between the lower surface soil layers and the water table. Strategen-JBS&G has commissioned Bennelongia Environmental Consultants to conduct a desktop assessment of the likelihood of subterranean fauna occurrence at the Project and the likelihood of the Project affecting subterranean fauna conservation values.

Whether habitat likely to support subterranean fauna occurs in the Project area was determined using:

- Geological and hydrogeological mapping for the Project area provided by the client;
- Regional geological and hydrogeological information and mapping;
- Existing mapping of caves in the Yallingup area; and
- General information about the habitats used by subterranean fauna (EPA 2021; Sacco et al. 2022).

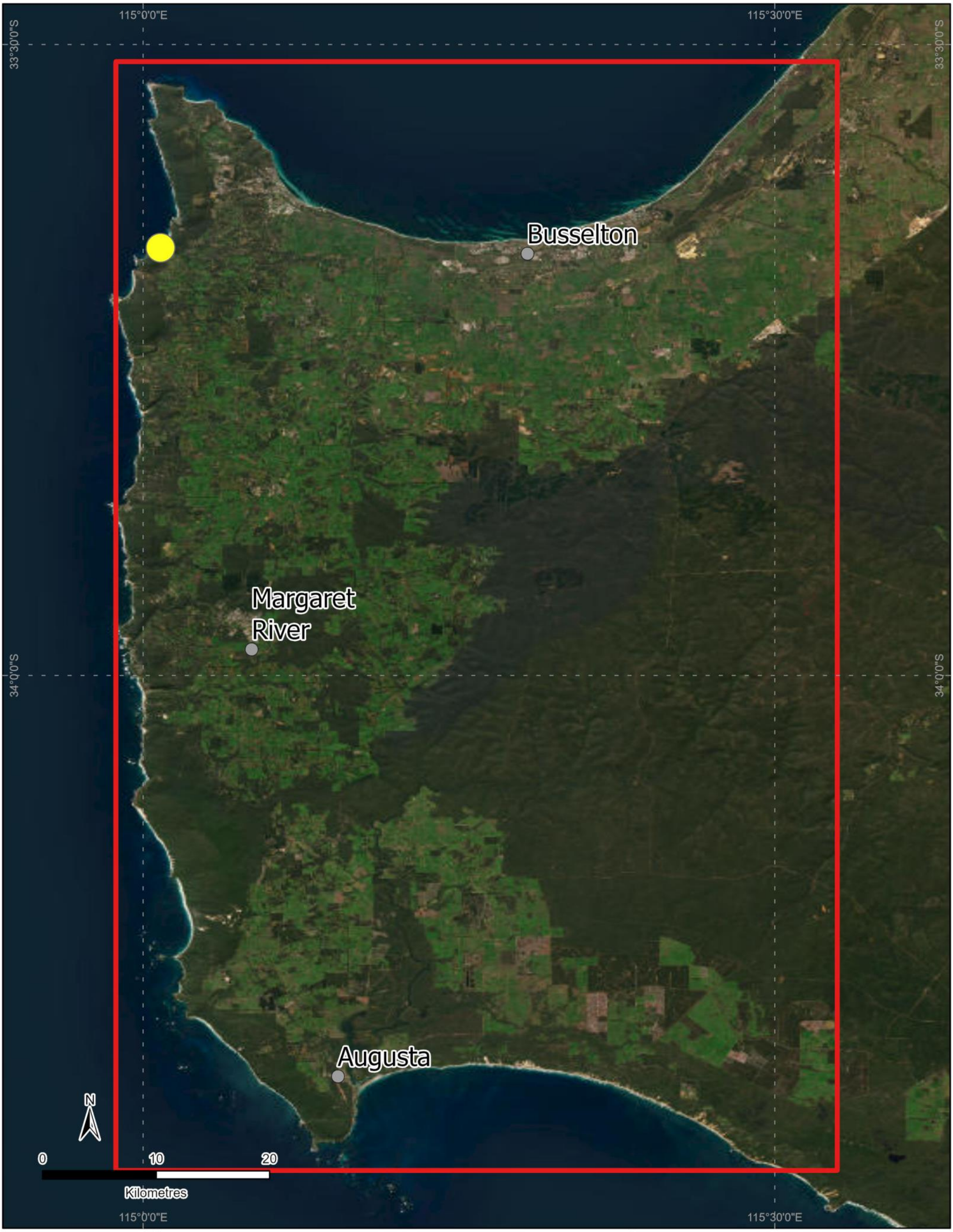
The subterranean fauna communities likely to occur in the Project area, and their taxonomic composition, were determined by collating previous sampling records of subterranean fauna in the Cape Naturaliste to Cape Leeuwin region using:

- Databases of the Western Australian Museum, Commonwealth Protected Matters Search Tool, Department of Biodiversity, Conservation and Attractions (DBCA), and Bennelongia; and
- Scientific literature and previous subterranean fauna survey reports.

2. SUBTERRANEAN FAUNA AND LEGISLATIVE FRAMEWORK

Subterranean species characteristically have reduced or absent eyes and are poorly pigmented owing to lack of light. They often have vermiform bodies and elongate sensory structures, as well as physiological adaptations such as the loss or reduction of wings, increased lifespan, a shift towards K-selection breeding strategy and lower metabolic rate (Gibert and Deharveng 2002). Except for a few species of fish and snakes, all subterranean fauna species in Western Australia are invertebrates.

Although inconspicuous, subterranean fauna contributes markedly to the overall biodiversity of Australia. The Pilbara, Yilgarn and neighbouring regions of Western Australia are globally important for subterranean fauna, with an estimated 4,500 or more subterranean species likely to occur (Halse 2018a), the majority of which remain undescribed. Diversity is lower in the south-west of Western Australia Most subterranean species satisfy Harvey's (2002) criteria for short-range endemism (SRE), having total range size of less than 10,000 km^2 and occupying discontinuous or fragmented habitats.



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GCS GDA 1994
Author: mfulcher
Date: 30/01/2023

Legend

- Desktop Search Area
- Major Towns
- Project Location

Figure 1. The Project location, major towns, and desktop search area.

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Development Envelope

Figure 2. Smiths Beach Project, Yallingup - Coastal Tourism Village.

Many subterranean fauna species spend their entire life cycles below ground (stygobites and troglobites). Other species may have a surface life-stage, usually when they mate, but spend the remainder of their life cycle below ground (stygophiles and troglophiles). As with stygobites and troglobites, stygophiles and troglophiles require access to subterranean habitat for persistence. In most cases, species that come to the surface at some stage have larger ranges than entirely subterranean species because of greater opportunity for dispersal when on the surface.

Given that species with small ranges are more vulnerable to extinction following habitat degradation than wider ranging species (Ponder and Colgan 2002), it follows that many subterranean species are highly susceptible to anthropogenic threats.

2.1. Legislation

Recognising that subterranean fauna is vulnerable to large-scale developments, the (requires consideration of subterranean fauna as part of environmental impact assessments (EPA 2016, 2021), although the legislation providing protection for species is contained in the Western Australian *Biodiversity Conservation Act 2016* (BC Act) and, potentially, the Commonwealth *Environment Protection and Biodiversity Conservation Act 1996* (EPBC Act) if there are Matters of National Environmental Significance.

The BC Act covers general protection for all species in Western Australia and the listing of threatened species and communities by the Minister of the Environment for special protection. Some other species and communities that are considered to be at risk are informally listed by DBCA as priority species and communities. The EPBC Act supports special protection of slightly smaller lists of Western Australian threatened species and communities, especially in relation to subterranean habitats.

3. POTENTIAL HABITAT

3.1. Habitat Requirements

Geology influences the presence, richness and distribution of subterranean fauna by providing different types of habitat (Hose *et al.* 2015). Geologies containing extensive networks of internal spaces support larger assemblages of subterranean fauna, both in terms of abundance and diversity, than those without spaces (e.g. fresh rock) or with extremely small interstitial species (e.g. silt, laterite).

Early records of subterranean fauna were centred around cave environments (Holthuis 1960; Schneider and Culver 2004; Skubała *et al.* 2013; Whitley 1945) and there are many caves between Cape Naturaliste and Cape Leeuwin, including the Yallingup area. Caves are potentially important habitat for subterranean fauna if they are deep, and hence dark with a saturated atmosphere (Howarth and Moldovan 2018). However, since the late 1990s, it has become clear that subterranean species also inhabit voids outside caves and throughout the landscape matrix, with these smaller spaces often supporting more species (Eberhard *et al.* 2005; Halse 2018a).

Troglofauna is outcompeted by surface soil species in the uppermost soil layers across the landscape but can be abundant at depth, where relative humidity is high (Halse 2018). Troglofauna species are common in vuggy (e.g. weathered iron ore) and karstic (e.g. calcrete) geologies but are also found various detritals, including colluvium. Some species of stygofauna occur in streambeds (in the interstitial species of alluvium) or springs but, across most of Western Australia, stygofauna is more common in groundwater aquifers that are not directly connected to the surface.

The extent of subterranean fauna occurrence in the south-west and mid-west coast of Western Australia is still being evaluated although communities of low to moderate richness appear to be widely distributed across the extensive aquifers of the Swan Coastal Plain, and cave systems between Cape Naturaliste and Cape Leeuwin (Eberhard 2004; Sacco *et al.* 2022).

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3.2. Project Geology and Hydrogeology

3.2.1. Occurrence of caves

The Ngilgi Cave (previously called Yallingup Cave) has been a tourist attraction for the past 100 years. It is located near Caves House, approximately 2 km from the Project. There are 11 other named and 37 explored but un-named caves in the Yallingup area in the Tamala Limestone known as the Leeuwin-Naturaliste Ridge (Moulds and Thomas 2017). The Western Australian Speleological Group (*in litt.*) is aware of a couple of caves about 300 m south of the Project. There has been no walking survey for evidence of caves in the project area in the last 40 or 50 years.

Ngilgi Cave is much larger than other caves in the Yallingup area, with a length of 750 m and depth of 39 m. There is no free water in the cave but the deeper environment is damp. The other 11 named caves vary in length from 24-174 m and mostly have unknown (but shallow depths). Ketaluck Cave, which is 174 m long has a depth of 36 m. Only one cave, Northcote Grotto, which is 157 m long and 18 m deep contains a stream. Warrigal Cave, which is 30 m long and 9 m deep, contained a stream in a previous geological era.

3.3. General landscape

The Project lies west of the Dunsborough Fault in an area known geologically as the Leeuwin Complex. The geology of the Development Envelope consists of Quaternary sand (with some clay) overlying Archaean gneiss (hydro$_2$o 2021). There is minor outcropping of Tamala Limestone in surrounding area, although the main Tamala Limestone ridge is further inland. A fractured rock aquifer is present in the basement gneiss at depth, as well as a perched surficial aquifer in detritals and the thin zone of sand overlying surficial deposits.

There are no long-term monitoring bores within the Project area and its surrounds and no nearby regional Department of Water and Environmental Regulation bores or mapping of groundwater levels for the area. Hydrogeological information relevant to stygofauna is sparse. ATA Environmental (2007) reported that groundwater was encountered in only two of 35 holes drilled for geotechnical mapping. At these holes in the north-western end of the Project development envelope, groundwater occurred at depths >7 m below ground level. There are also areas of perched groundwater relatively close the surface where water infiltrating from the surface through sand encounters clay (hydr2o 2021). While the spatial extent and permanence of the perched groundwater is unknown, hydro2o (2021) suggests there is 1 m of annual variation in water table depth, which implies little downward flow and perhaps greater permanence of the perched aquifer than would be expected., Convention suggests small perched aquifers are unlikely to host significant stygofauna because they are unlikely to be permanent over the appropriate (geological) timeframe.

3.4. Assessment of Habitat Prospectivity

Whether caves occur in the Project area is unknown, although probably unlikely according to existing geological information (Golder 2021).

The dominant feature of the coastal corner of south-western Australia is its fine, unconsolidated sandy soils deposited on a stable, predominantly granitic basement. This is shown clearly in Appendices 1 and 2, but this information comes from a small area at the northern extent of the Project. It should be noted that all holes further south were put in with a hand-auger in sand, mostly to a depth much less than 10 m. Most coastal aquifers are in sand, although sometimes interspersed with semi-contiguous units of limestone or with clay-rich units that on occasion act as local regional aquitards or create small and shallow perched aquifers.

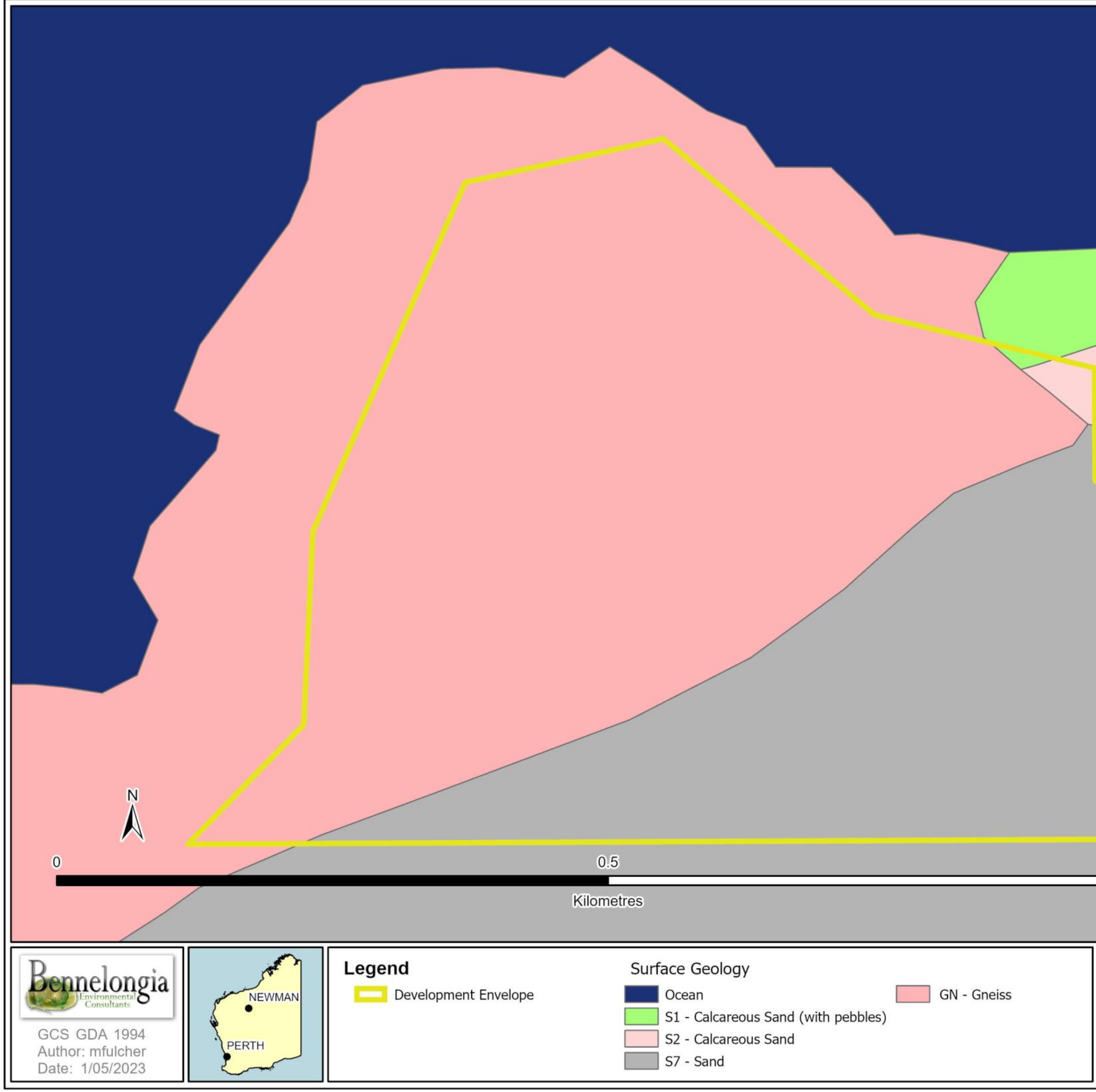


Figure 3. Surface Geology of the Project area (Development Envelope) and surrounding area.

Coastal aquifers have some prospectivity for stygofauna, with stygofauna known to occur in the greater Busselton area and north of Perth in karstified Quaternary limestone and porous sandy aquifers (Tang and Knott 2009; Sacco *et al.* 2022). While one of two species of troglofauna have been collected from sand habitats during some surveys near the coast on the Swan Coastal Plain (Biota 2005; Bennelongia 2009), overall sampling results suggested coastal sands habitats are not suitable for troglofauna even when some limestone is present.

Karst ecology in general suggests that large, karstified areas of outcropping limestone will provide suitable habitat for troglofauna (Moldovan *et al*. 2018). However, even caves in the south-west have few troglofauna species, with some or most of the species recorded to date as troglophiles actually being surface species (Moulds 2007). Based on results from areas such as Point Grey (Bennelongia 2009), it is considered very unlikely that small areas of limestone in the Project development envelope support troglofauna. Areas of gneiss at the Project are even less likely to provide habitat for troglofauna because the geology is too consolidated (see cores in Appendix 2).

The numbers of stygofauna species in individual caves of the south-west is low (English *et al.* 2003; Eberhard 2004; Knott *et al.* 2007, 2008, 2009). No groundwater was encountered by hyd$_2$o (2021) when drilling to depths up to 16.5 m in gneiss or when hand auguring in sand at depths up to 3 m (although water was considered likely to be present in sand at slightly greater depths at one hole). Various other surveys have reported groundwater in sand (ATA Environmental 2007; MP Rogers & Associates 2007) but the aquifer in sand appears to be perched and disconnected from the regional aquifer in fractured gneiss.

The documented salinity of groundwater (1800 mg/L TDS) at the Project (hyd$_2$o 2021) is suitable for stygofauna. However, while water quality could support stygofauna, the very limited extent of both the sand aquifer and the deeper gneiss aquifer suggest that the Project area and its surrounds are not prospective for stygofauna.

4. SUBTERRANEAN FAUNA RECORDS

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 supporting globally important radiations of subterranean fauna. In contrast, the relatively limited work to date in near coastal areas of south-western Australia has revealed only moderate richness of subterranean fauna (Moulds 2007; Bennelongia 2009; Sacco *et al*. 2022).

Information about the likely stygofauna and troglofauna communities at the Project area was gathered by collating records of fauna in a search area of 100 km x 100 km centred on the Project (decimal degree coordinates of search area, top left: -33.513°S: 114.978°E, bottom right -34.394°S: 115.551°E). Most records were obtained from sampling caves. Very little, if any, sampling for subterranean fauna in the general landscape matrix has been conducted (and reported).

Collation of existing records provides only an indication of the level of subterranean species richness that might be expected within the Project area; it will not document the communities in the Project area unless there has been previous sampling within that area.

4.1. Stygofauna

Twenty-one species of stygofauna have been recorded in caves of the search area. The Western Australian Museum database contains records of three described species of stygofauna in the search area (*Acandona admiratio, Australoeucyclops darwini, Kinnecaris eberhardi*; Table 1, Figure 4). English and Blyth (2000). in a threatened community recovery plan, provide records of a nematode and an oligochaete from near the Project, while Eberhard (2004) lists 19 aquatic species in caves of the Margaret

River - Augusta area that are confirmed or probable stygofauna, albeit that some of the species also to have nearby surface populations.

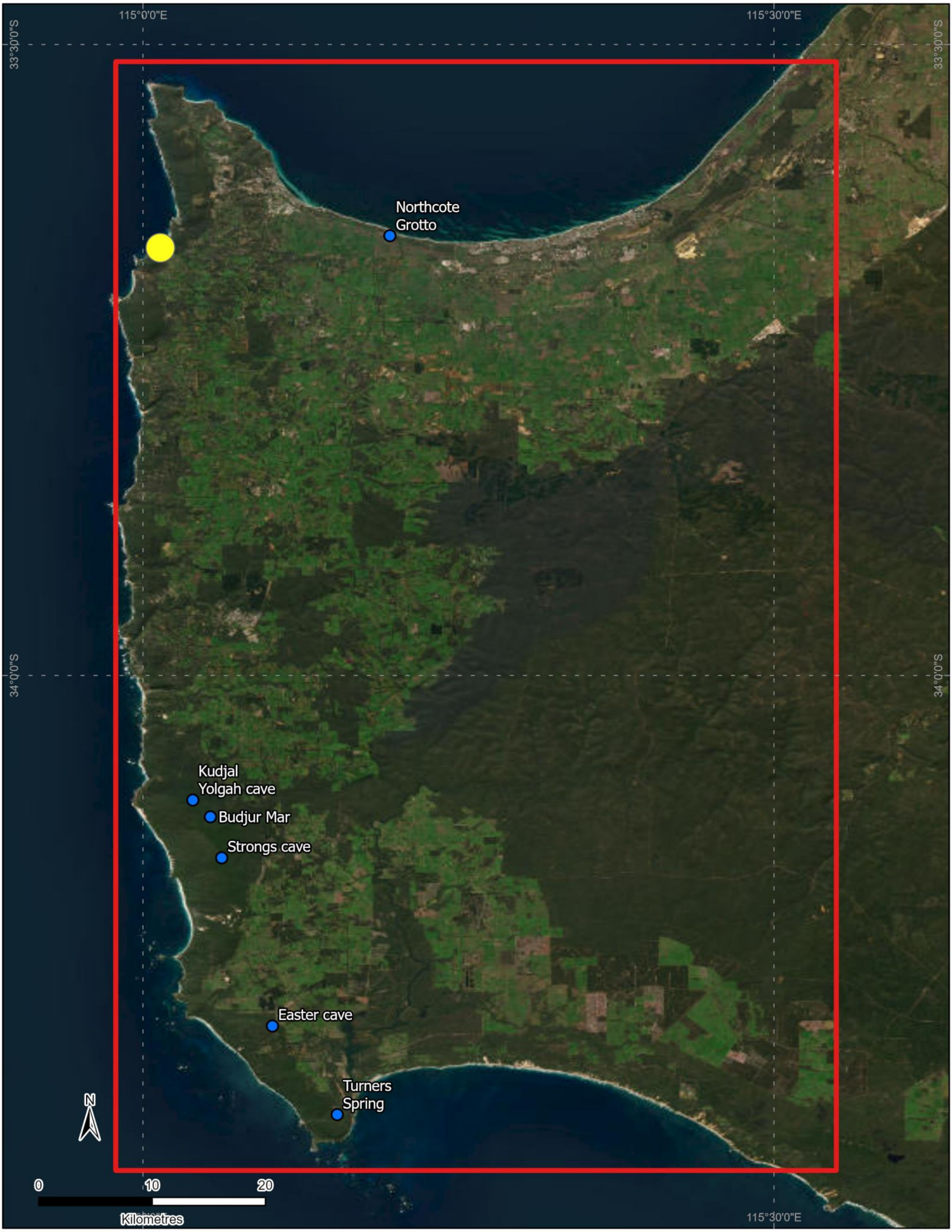
Table 1: Stygofauna records from the search area.
# indicates specimens present.

Identification	Location
Nematoda	
Rhabditidae sp. 1	Northcote Grotto
Oligochaeta	
Antarctodrilus micros	Budjur Mar, Kudjal Yolgah
Insulodrilus lacustris s.l.	Strongs, surface waters
Phreodrilidae WA25 sp. n.	Budjur Mar
Phreodrilidae WA26 sp. n	Easter
Aktedrilus leeuwinensis	Budjur Mar
?*Ainudrilus* (WA14) sp. n.	Easter, Strongs
Tubificidae WA12 sp. n.	Jewel
Tubificidae sp. 3	Northcote Grotto
Copepoda	
Cyclopoida	
Australoeucyclops darwini	Turners Spring, surface waters
Diacyclops humphreysi	Jewel, Easter
Macrocyclops albidus	Strongs, Budjur Mar, Kudjal Yolgah, surface waters
Mesocyclops brooksi	Many caves, surfaces waters
Harpacticoida	
Nitokra lacustris pacifica	Jewel
'Kudjalmoraria nana' ms	Kudjal Yolgah
Kinnecaris eberhardi	Strongs, Kudjal Yolgah
Ostracoda	
Acandona admiratio	Jewel, Easter
Syncarida	
Bathynellidae sp.	Strongs
Parabathynellidae sp.	Strongs, Kudjal Yolgah
Amphipoda	
Perthia sp. 1	Jewel, Easter, Crystal, surface water
Uroctena sp.	Jewel

The harpacticoid copepod *Kinnecaris eberhardi* and ostracod *Acandona admiratio* were collected from caves with free water 50 km to 77 km from the Project area. The cyclopoid copepod *Australoeucyclops darwini* was collected from a single spring and is known to inhabit both subterranean and surface environments. *Australoeucyclops darwini* is known only from Margaret River area; both *Australoeucyclops darwini* and *Kinnecaris eberhardi* occur from the search arear to north of Perth to Yanchep (Karanovic 2005, 2009; Tang and Knott 2009).

The amphipod *Perthia* sp. 1 is widespread between Cape Naturaliste and Cape Leeuwin and occurs in surface water as well as caves. The Jewel Cave population appears to have been isolated from surface water populations for 250,000 years (Eberhard *et al*. 2005). The amphipod *Uroctena* sp. represents an undescribed species known to date only from Jewel Cave.

The nematode Rhabditidae sp. 1 and oligochaete worm Tubificidae sp. 3 were collected from Northcote Grotto, a cave with free water relatively close to the Project (English and Blyth 2000). Whether the worms



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Legend

- Desktop Search Area
- Project Location
- Stygofauna records

Figure 4. Stygofauna records in the desktop search area.

in Table 1 also occur in surface waters is uncertain in most cases and some have wide distributions (Pinder and Brinkhurst 1997; Pinder *et al*. 2006). The occurrence of syncarids in caves is expected; both families present are restricted to groundwater.

There are no records of stygofauna species from aquifers in the general landscape matrix in the search area.

4.2. Troglofauna

The Western Australian Museum contains records of 14 species of probable troglofauna (Table 2, Figure 5). There are nine species of spiders, three pseudoscorpions, one harvestman and one millipede.

The spiders *Proshemacha* sp., *Opopaea* sp. and *Pelicinus* sp. and the pseudoscorpion *Austrochthonius* sp. were collected from Ngilgi Cave 2 km north of the Project. Other species were collected from caves in the Margaret River - Augusta area.

Table 2: Troglofauna records from the search area.

Identification	Location
Araneae	
Proshemacha sp.	Ngilgi
Baiami tegenarioides	Margaret River, Witchcliffe caves, forest
Pholcomma sp.	Strongs
Argyrodes sp.	Strongs, Easter
Theridiidae sp.	Giants, Cardup, Nannup, Kudjal-Yolgah
Theridiosomatidae	Dingo
Orsolobidae sp.	Kudjal-Yolgah
Opopaea sp.	Ngilgi
Pelicinus sp.	Ngilgi
Opiliones	
Calliuncus labyrinthus	Moondyne, Easter
Pseudoscorpiones	
Pseudotyrannochthonius giganteus	Easter, Winjand, forest
Protochelifer cavernarum	Quininup Lake Cave, Acoustic, Nannup
Austrochthonius sp.	Ngilgi
Diplopoda	
?*Akamptogonus* sp.	Kudjal-Yolgah

Some, or most of the species in the search area have surface, as well as cave, occurrences. The spider *Baiami tegenarioides* and pseudoscorpion *Pseudotyrannochthonius giganteus* occur in forests in south-western Australia (Gray 1973; Harms 2018). The harvestman *Calliuncus labyrinthus* and pseudoscorpion *Protochelifer cavernarum* are, however, troglobitic (Hunt 1972; Moulds *et al*. 2007).

There are no records of troglofauna species from the general landscape matrix in the search area.

5. POTENTIAL IMPACTS ON SUBTERRANEAN FAUNA

The major impacts to subterranean fauna are usually derived from the direct loss of habitat through activities such as ground excavation and groundwater abstraction (including de-watering of the subterranean landscape to facilitate mining or construction) (EPA 2016; Halse 2018b). Sometimes pollution, the alteration of energy and water inputs such as can occur below hard surfaces, or substantial changes to surface topography, can also impact on subterranean fauna communities.

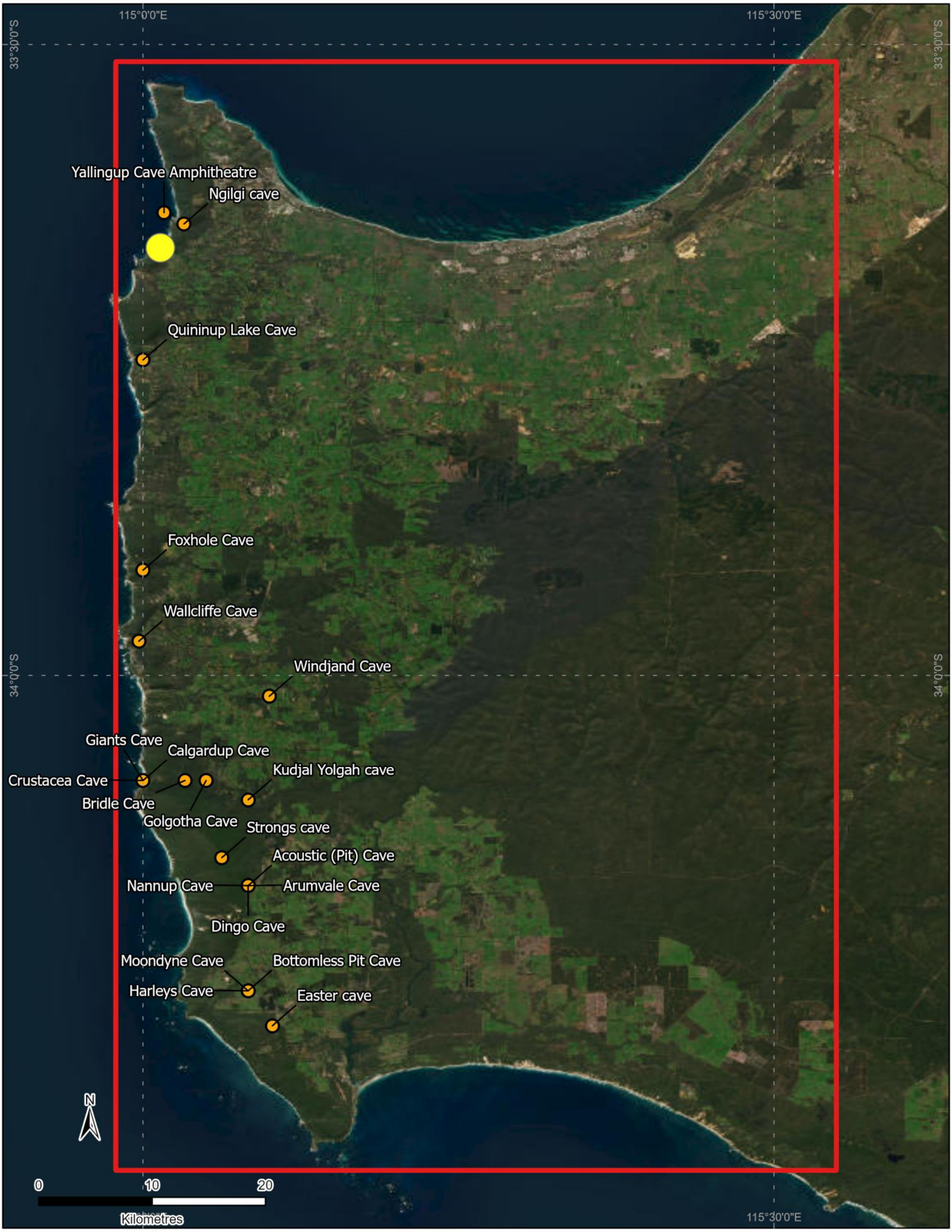
No large-scale ground excavation, nor groundwater abstraction, is planned in the Project area. It is also considered that the probability of significant subterranean fauna communities occurring is low because of the probable absence of caves supporting stygofauna and troglofauna species in the Project area. However, this conclusion about the absence of caves should be confirmed using LiDAR to locate any sinkholes or cave entrances in the Project area or close surrounds (the underground passages of caves with nearby entrances may extend into the Project area). An appropriate search area is illustrated in Appendix 3.

It should also be recognized that the geology and hydrologeology of the Project area indicate there is low prospectivity of any subterranean fauna community occurring in the general below-ground matrix, although it is possible the perched aquifers are more permanent than concluded in section 3.3. Moderate numbers of stygofauna species have sometimes been collected from near-coast situations, such as Point Grey on the Harvey Estuary (Bennelongia 2009), although in larger aquifers. Geological cores from the Project area suggest soils are shallow and underlain by gneiss that lacks prospectivity for stygofauna (Appendices 1 and 2) but these cores were taken from a small area on the northern boundary of the project area (Appendix 3). There is deeper sand and clay to the south. Following more detailed description of the geology and hydrogeology of the Project area, there should be consideration of whether basic stygofauna sampling is required to confirm the absence of significant stygofauna.

6. CONCLUSION

Records of subterranean fauna species from the search area surrounding the Project area showed that moderate numbers of species may occur in caves, although few of these species have obligate underground occurrence. There are no records of subterranean species from the general landscape matrix, although this probably reflects sampling effort being low rather than a total absence of subterranean species. There are no records of subterranean species from within the Project area.

No large-scale ground excavation, nor groundwater abstraction, is planned in the Project area and it is expected that Project development will not impact subterranean fauna and the available information on geology and hydrogeology suggest that habitat is not prospective for either stygofauna or troglofauna species. However, the information habitat is incomplete. LiDAR should be used to confirm that no caves are present and the potential for perched aquifers to yield stygofauna should be investigated further.



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Legend

- Desktop Search Area
- Project Location
- Troglofauna records

Figure 5. Troglofauna records in the desktop search area.

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Appendix 1. Geology of drill holes (Golder 2021).

Location of Boreholes (red circles) in Development Envelope.

BH1

Depth (m)	Material	Description
0	Sand & gravel	Sand & gravel
0.5		
1		Core loss
1.5	Gneiss	Medium to coarse grained, massive brown, grey, pale red and black, fractured with clayey sand infill
2		
2.5		
3		
3.5		
4		
4.5	Sandy clay/clayey sand	Sandy clay/clayey sand
5	Gneiss	Medium to coarse grained, massive, mottled pale blue, dark blue and grey
5.5		
6		
6.5		

BH2

Depth (m)	Material	Description
0	Sand & gravel	Sand & gravel
0.5		
1	Gneiss	Medium to coarse grained, mottled brown, grey pale red, fractured with sand/clay infill, inferred boulder
1.5	Clayey sand	Fine to coarse grained, red brown, orange, grey, weakly to moderately cemented with iron cementing
2		
2.5	Gneiss	Medium to coarse grained, massive, red brown, orange, grey
3		
3.5	Gneiss	Medium to coarse grained, red brown, dark grey, slighty fractured
4		
4.5		
5		
5.5		
6		
6.5		
7		
7.5		

BH3

Depth (m)	Material	Description
0	Sand	Fine to medium grained, pale grey
0.5		
1		
1.5	Silty sand	Fine to medium grained, dark grey black
2		
2.5		
3		
3.5	Gneiss	Medium to coarse grained, mottled brown, pale red, dark grey, highly fractured, inferred boulder
4	Clayey sand	Fine to coarse grained, red brown and grey, weakly to moderately cemented with iron cementation
4.5		
5		Core loss
5.5	Gneiss	Medium to coarse grained, massive, mottled red brown and grey
6		
6.5		
7		
7.5		Core loss
8	Gneiss	Medium to coarse grained, massive, mottled red brown and grey
8.5		
9		
9.5		
10		
10.5		
11		
11.5		
12		

BH4

Depth (m)	Material	Description
0	Sand & gravel	Sand & gravel
0.5		
1	Sand	Fine to medium grained, pale grey
1.5		
2		
2.5		
3		
3.5	Clayey sand	Fine to coarse grained, pale brown, about 20-25% medium plasticity clay
4		
4.5		
5		
5.5		
6		
6.5		
7		
7.5		
8	Sandy clay	Medium plasticity, brown, grey, ple blue and pale red, fine to coarse sand, variable cementation, iron cemented
8.5		
9		
9.5		
10		
10.5		
16	EOH at 16m. Core lost; no groundwater observed.	

BH5

Depth (m)	Material	Description
0	Sand & gravel	Sand & gravel
0.5		
1	Sand	Fine to medium grained, pale grey
1.5		
2		
2.5		
3		
3.5		
4	Gneiss	Medium to coarse grained, red brown, grey, inferred boulder
4.5		Core loss inferred weak zone
5	Clayey sand/sandy clay	Brown, red, orange and grey, moderately cemented with iron cementation in parts
5.5		
6		
6.5		
7	Clay	Mottled grey, blue and black, stiff to very stiff
7.5	Gneiss	Medium to coarse grained, massive, mottled red brown, grey, pale red
8		
8.5		
9		
9.5		
10		
10.5		

BH6

Depth (m)	Material	Description
0	Sand	Fine to medium grained, pale grey, white, quartz and calcareous sand
0.5		
1		
1.5	Gneiss	Fine to coarse grained, inferred boulder, mottled blue, grey and dark grey, slightly weathered, high strength
2	Clayey sand/sandy clay	Grey brown, orange, red, fine to coarse grained sand, medium plasticity, moderately cemented in parts
2.5	Clay	Medium plasticity, grey, red brown
3	Gneiss	Fine to coarse grained, massive, grey, brown, red
3.5		
4		
4.5		
5		
5.5		
6		

BH7

Depth (m)	Material	Description
0	Sand	Fine to medium grained, pale grey, white, quartz and calcareous sand
0.5		
1		
1.5		
2	Gneiss	Fine to coarse grained, massive, brown, red, dark grey, fractured with clay/sand infill
2.5		
3		
3.5		
4		Blue, green, grey, red-brown, slightly fractured
4.5		
5		
5.5		
6		

BH8

Depth (m)	Material	Description
0	Sand	Fine to medium grained, pale grey
0.5		
1		
1.5		
2		
2.5		
3		
3.5		
4		
4.5		
5		
5.5		
6	Gneiss	Fine to coarse grained, red brown, cemented clayey sand
6.5		
7		
7.5		
8		
8.5	Gneiss	Fine to coarse grained, massive, red brown and grey, slightly fractured
9		
9.5		
10		
10.5		

Appendix 2. Core photographs (Golder 2021).

Figure 1. Core photograph BH1.

Figure 2. Core photograph BH2.

Figure 3. Core photograph BH3, 2-7m.

Figure 4. Core photograph BH3, 7-12m.

Figure 5. Core photograph BH4, 0-8m.

Figure 6. Core photograph BH4, 8-13m.

Figure 7. Core photograph BH5, 0-8m.

Figure 8. Core photograph BH5, 8-13m.

Figure 9. Core photograph BH6.

Figure 10. Core photograph BH7.

Figure 11. Core photograph BH8, 0-10m.

Figure 12. Core photograph BH8, 10-10.5m.

Appendix 3. Recommended area for LiDAR survey.

Legend

Boundary of survey area

Appendix 3. Recommended LiDAR survey area.