Bennelongia Environmental Consultants

Ningaloo Lighthouse Resort: Stygofauna Survey Report

Prepared for:

Tattarang Pty Ltd

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Final Report

Short-Range Endemics I Subterranean Fauna

Waterbirds I Wetlands

Ningaloo Lighthouse Resort: Stygofauna Survey Report

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EXECUTIVE SUMMARY

Tattarang Pty Ltd plans to redevelop the Ningaloo Lighthouse holiday park with a greater range of accommodation and facilities (the Project). As a part of this, Tattarang has identified a requirement for additional water for the ongoing operations of the Project and plans to source this water from a borefield located approximately 700 m to the south of the Project.

Western Australia contains globally significant radiations of the two types of subterranean fauna: aquatic stygofauna and ground-dwelling troglofauna. This includes substantial radiation of subterranean fauna on the Exmouth Peninsula. Subterranean fauna across Western Australia occur predominantly in small underground voids, fissures or interstitial spaces across the broad landscape. In contrast, much of the troglofauna on Exmouth Peninsula has been collected from caves and the more significant stygofauna records have been collected from sinkholes that represent collapsed caves.

The extraction of water from the proposed Project borefield has the potential to impact upon any stygofauna species and communities in that area. Two rounds of stygofauna survey were conducted to document the stygofauna species and communities present within the aquifer being accessed by the borefield, so as to enable an assessment of borefield operations on stygofauna conservation values. The first sampling round (12-13 January 2021) focussed on bores within the borefield. The second round (15-18 March 2021) repeated the borefield sampling and also sampled of regional bores.

A total of 477 stygofauna specimens were collected during the two rounds of survey. The 10 samples from bores outside the borefield yielded 436 specimens belonging to 11 species, two of which also occurred in the borefield.

In contrast, the 30 samples collected from the borefield yielded only 41 specimens belonging to four species. Three species, a nematode worm, copepod crustacean *Diacyclops humphreysi* and oligochaete worm Enchytraeidae `3 bundle` s.l. (short sclero), have been collected or are considered to occur widely outside the borefield. The fourth species, copepod *Parastenocaris* `BHA286`, has been collected to date only within the borefield.

Existing knowledge of the distributions of copepod distributions suggests that *Parastenocaris* `BHA286` is almost certain to have a range extending well beyond the very small area of borefield drawdown. Other species in the borefield, which has a depauperate stygofauna community, have wide ranges. Therefore, the threat from Project borefield operations to stygofauna conservation values is low.

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1. INTRODUCTION

The Ningaloo Lighthouse Resort is located near the Cape Vlamingh Lighthouse at the north-western tip of Exmouth Peninsula in Western Australia (Figure 1). The facility was formerly called the Lighthouse Holiday Park and, after acquiring it in 2018, Tattarang Pty Ltd plans to redevelop the holiday park with a greater range of accommodation and facilities. Redevelopment of the holiday park and adjacent freehold land as Ningaloo Lighthouse Resort is referred to as the 'Project' and will require very minor land clearing to expand the original holiday park area. Tattarang has also identified a requirement for additional water for the ongoing operations of the Project and plans to source this water from a groundwater borefield located approximately 700 m to the south of the Project. Abstraction will eventually rise to 75,000 KL/year.

Extraction of groundwater has the potential to impact upon stygofauna species and communities living in the groundwater. Stygofauna is a term applied to aquatic animals, nearly all invertebrates, that occupy groundwater. This report follows from a desktop assessment of the likelihood of occurrence of stygofauna in the Project area (Bennelongia 2020) and presents the results of field survey undertaken to assess whether the operation of the Project borefield will have significant impacts on stygofauna.

The objectives of this report are to:

1. Compile and evaluate records of stygofauna species collected from two rounds of survey conducted from within the Project borefield and surrounding regional aquifer,
2. Assess the significance of stygofaunal species and/or communities collected from within the Project borefield area, and
3. Conduct an impact assessment on stygofauna species and/or communities in relation to operation of the borefield.

The potential for the Project to have impact on troglofauna was addressed by Bennelongia (2020), when it was concluded impact on this type of subterranean fauna was unlikely. Troglofauna is not considered further in this report. With both few species expected to occur in the borefield, and minimum drawdown and surface disturbance, the impact on any troglofaunal species would be negligible. No troglofaunal habitat will be removed or altered.

The potential for disposal of wastewater to lead to nutrient enrichment of groundwater was also addressed by Bennelongia (2020). No stygofauna sampling was undertaken with the objective of addressing the impacts of nutrient enrichment on stygofauna but the likely effects on stygofauna are discussed in this report.

1.1. Project Description

The Project is located on Yardie Creek Road, approximately 22 km north of Cape Range National Park and 16 km north of Exmouth. The ocean to the west of the Project lies within the inshore State, and more offshore Commonwealth, Ningaloo Marine Parks that form the bulk of the Ningaloo Coast World Heritage Area, while the beach lies within Jurabi Coastal Park, which is also part of the World Heritage area.

The proposed borefield to supply the Project with additional water lies in the extensive area of Unallocated Crown Land at the northern end of Exmouth Peninsula. The borefield begins approximately 700 m south of the Project and extends 1.1 km southwards along the eastern side of Cape Range. Additional monitoring bores will be placed up to 700 m south of the borefield itself. Production bores will be located at the base of the foothills of the eastern side of the range or in the swale between the foothills and the first red sand dune parallel to the range.

For the purposes of groundwater allocation, the proposed borefield lies within the Exmouth North subarea of the Department of Water and Environmental Regulations (DWER). The aquifer in this subarea

Figure 1. Location of the Project within Western Australia

is hyposaline and is currently considered to be over-allocated, with 200,000 KL per annum available for use and already licenced abstraction of 258,000 KL (WRC 1999).

The Project has an existing groundwater licence allocation of 32,000 KL per annum under DWER licence 253728, which covers an area more or less coincident with the Project area. The anticipated future groundwater requirement for the Project is 72,000 KL per annum (Pennington Scott 2020), and an additional 40,000 KL per annum of groundwater is required. Production bores at the Project are slotted to a depth of no more than 2 m below the water table (Pennington Scott 2020), limiting the maximum extent of drawdown that will be experienced at the borefield to <2 m.

2. GEOLOGY AND HYDROGEOLOGY

2.1. Geology

The Exmouth Peninsula essentially consists of limestone with overlying sands around the fringe. The peninsula is dominated by Cape Range, which runs almost its full length with a crest that is about 100 m above sea level (asl) at the northern end and about 300 m asl in the south. The range is flanked by a relatively narrow flat coastal plain to the west and a broader plain to the east (Allen 1993). The geological sequence of the eastern part of the range and associated coastal plain is mostly a moderately thin layer of Trealla limestone over Tulki limestone, with Manndu limestone below. There is also a small amount of Pilgramunna formation (a calcareous sandstone) that is younger than Trealla. Trealla limestone and Pilgramunna formation occur only on the range. On the coastal plain of most of the peninsula, Holocene sand deposits overlie the Tulki limestone. On the eastern side of the northern part of the range, instead of Holocene sands, there is an extensive Pleistocene sand sheet composed of silty red sand with stationary dunes over Tulki limestone (Figure 2).

Cape Range itself contains more than 300 caves in Tulki limestone, most of which are solution pipes with limited associated galleries (Finlayson and Hamilton-Smith 2003). There are also a few sink holes on the coastal plain, reflecting the occasional occurrence of cavernous areas below the surface of the plain.

2.2. Hydrogeology

According to Allen (1993), the aquifer under the range in the northern part of the peninsula is fresh (salinity <1000 mg/L TDS). Salinity of the aquifer increases towards the coast and the salinity in the upper part of the aquifer in the proposed borefield, which lies in the eastern foothills of Cape Range, mostly varies from 2,900 to 14,000 mg/L (Pennington Scott 2020). Salinity within the aquifer increases with depth to a recorded maximum of 24,000 mg/L. The depth to groundwater in the proposed Project borefield varies from about 30-50 mbgl. The aquifer is approximately 50 m thick.

The groundwater in the aquifer occurs principally in Tulki and Mandu limestones. It flows both eastwards and westwards from under the range. Flow is probably more rapid on the coastal plain than within the range because of higher permeability in the more transmissive Tulki limestone/coastal plain sediments than in the deeper Mandu limestone that comprises most of the aquifer under the range. Significant flow in Mandu limestone occurs only in joints and minor permeable interbeds. Recharge of the aquifer occurs mainly through direct infiltration after heavy rain.

Borehole logs compiled by Pennington Scott (2020) show that the upper aquifer across most of the borefield lies within a mixture of calcareous sand, gravel and limestone, with a predominance of sand (Appendix 1). Photographed chip trays for bores LH08P and LH02M show the geology comprises sand cover and then indurated Tulki limestone to a depth of 20 m or more, after which the Tulki limestone (which contains the borefield aquifer) is dominated by weakly cemented sand (Figure 3).

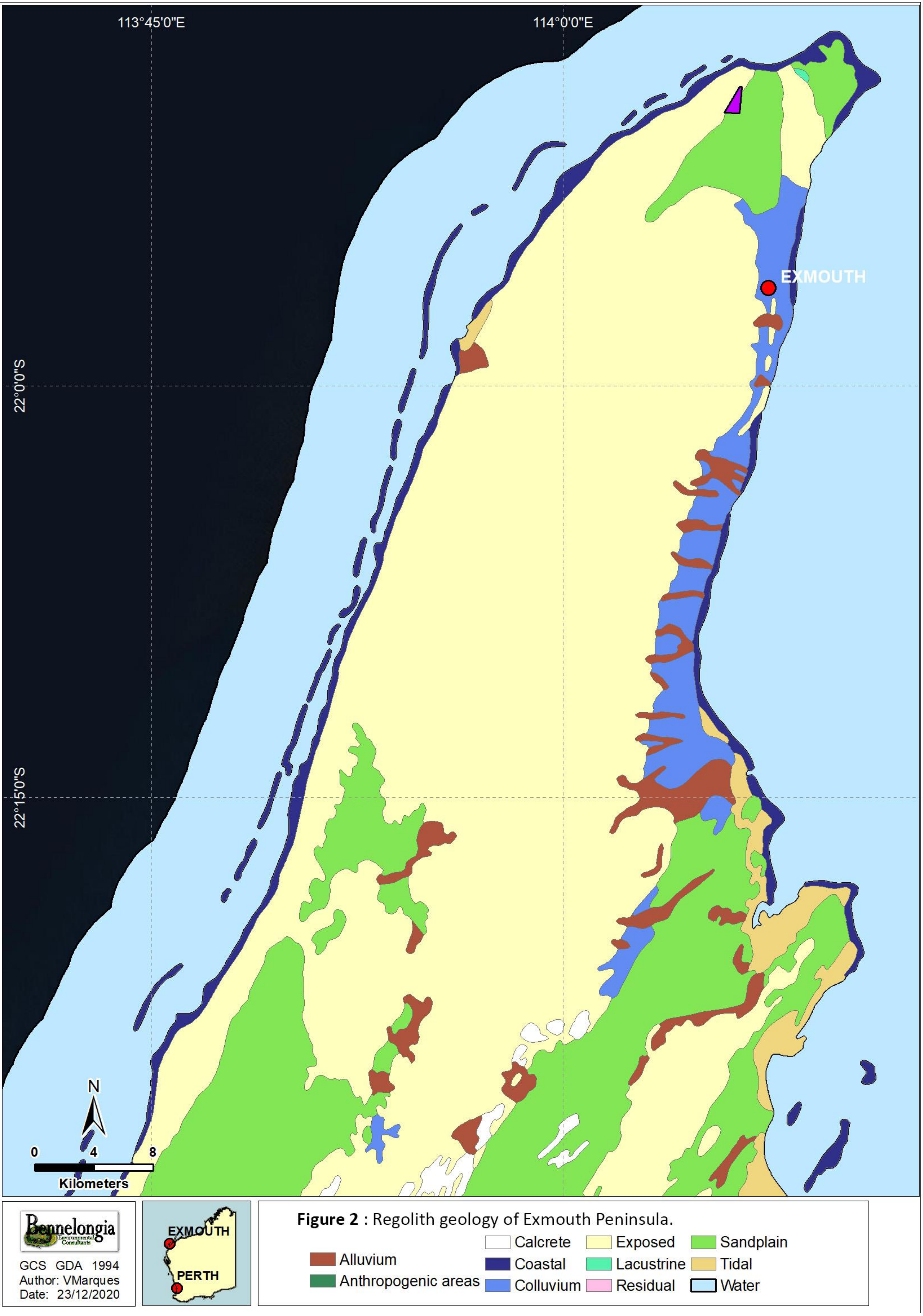

Figure 2 : Regolith geology of Exmouth Peninsula.

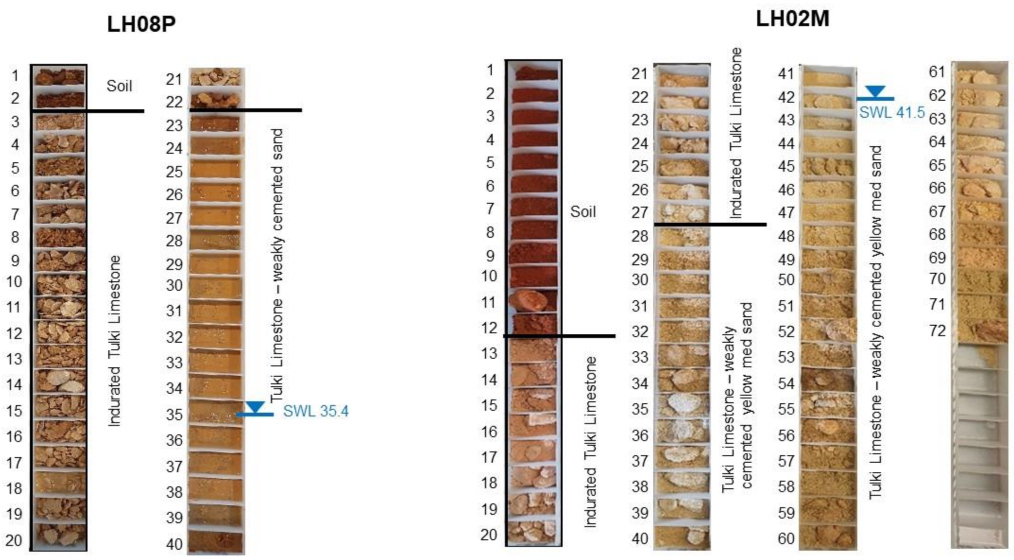

Figure 3. Chip trays showing lithology in borefield (from Pennington Scott 2020).

3. SUBTERRANEAN FAUNA

3.1. Cape Range Subterranean Fauna

Western Australia contains globally significant radiations of the two types of subterranean fauna: stygofauna and troglofauna (Guzik *et al.* 2010; Halse 2018). Subterranean fauna species in Western Australia mostly occur in small underground voids, fissures or interstitial spaces across the broadlandscape. In contrast, much of the troglofauna on Exmouth Peninsula has been collected from caves and the more significant stygofauna records have been collected from sinkholes that represent collapsed caves under the coastal plain.

While a subterranean fish - the blind gudgeon *Milyeringa veritas* - was described early by Whitley (1945), scientific focus on the subterranean fauna of the Exmouth Peninsula did not begin until the late 1980s (Humphreys 1993). Subsequent survey and research have continued to increase the species list for the area and to improve understanding of the distributions of species and their degree of dependence on subterranean habitats (Bennelongia 2008; KBR 2005; Larson *et al.* 2013; Moore *et al.* 2018; Page *et al.* 2008; Tang *et al.* 2008)

Survey work has led to recognition under the Western Australian *Biodiversity Conservation Act 2016* (BC Act) of two Threatened Ecological Communities on the peninsula: the stygofauna-based Cape Range Remipede Community at Bundera Sinkhole on the west coast and the troglofauna based Cameron's Cave Troglobitic Community within Exmouth townsite. In addition, the Cape Range Subterranean Waterways, being groundwater in areas of potential karst scattered across the peninsula, are listed in the Directory of Important Wetlands in Australia (WA006) and on the Register of the National Estate.

The Exmouth Peninsula also contains the Ningaloo Coast World Heritage Area which lists the rich diversity of subterranean fauna found on the Exmouth Peninsula as one of the area's important features (DBCA 2019).

4. DESKTOP ASSESSMENT

Bennelongia (2020) conducted a desktop assessment of the possible presence of stygofauna within the Project area. This report found that the Exmouth Peninsula supports at least two native stygofaunal fish species and 69 species of invertebrate stygofauna. The two fish species are the blind gudgeon and the blind cave eel *Ophisternon candidum*, which are listed as Vulnerable species under the BC Act and the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). The gudgeon is restricted to Exmouth Peninsula (Larson *et al.* 2013) but the eel also extends into the Pilbara (Moore *et al*. 2018).

Eight threatened and one priority species (an informal state listing) of invertebrate stygofauna occur on the peninsula. Seven of the species occur at Bundera Sinkhole on the west coast and are listed as Critically Endangered or, in one case, Endangered under the BC Act. Only one of them, the remipede *Kumonga exleyi*, is listed (as Vulnerable) under the EPBC Act. The two species outside Bundera Sinkhole are the shrimps *Stygiocaris lancifera* and *S. stylifera*, which occur on the western and eastern coastal plains, respectively. *Stygiocaris lancifera* is listed as Vulnerable under the BC Act and *S. stylifera* is listed as a Priority 4 species.

The conclusion of the Bennelongia (2020) desktop assessment was that despite the known significance of the stygofauna community and species on Exmouth Peninsula, the impact of groundwater drawdown associated with the Project borefield is likely to be low because the physical habitat within the borefield aquifer does not look prospective for stygofauna, the depth to groundwater is large, and there is a lack of stygofauna records in the immediate vicinity (i.e. in the same habitat as the borefield). However, in recognition of the significance of Exmouth Peninsula for stygofauna (and troglofauna) a two-round field survey of stygofauna was recommended.

5. FIELD SURVEY

5.1. Water Quality

Electrical conductivity (as a measure of salinity), pH and temperature were measured in a water sample collected from the top 1 metre of groundwater using a bailer. Measurements were made using a TPS WP-81 meter.

Depth to groundwater was measured using a Solinst water level meter. The audio readings close to the water table can be difficult to interpret, leading to possible inaccuracies in some readings. Data on depth to groundwater, salinity and pH are also provided by Pennington Scott (2021).

Six of the sampled bores (LH01M, LH04P, LH07M, LH07P, LH09P and LH10P) had a smell of hydrogen sulphide one occasion when sampled, or both occasions in the case of LH07M. While the source of the hydrogen sulphide was not definitively determined, it is probably from either the nearby land fill site associated with the Light House Caravan Park or leakage from the historical sewerage ponds associated with the Park. Both facilities will be remediated as part of the development of the Ningaloo Lighthouse Resort.

5.2. Stygofauna

5.2.1. Sampling

Two rounds of stygofauna sampling were conducted at the Project borefield and surrounds. Round one focussed on sampling bores within the proposed borefield from 12-13 January 2021. The second round from 15-18 March 2021 repeated the borefield survey and also sampled some bores outside the borefield to provide context for the results of the borefield sampling.

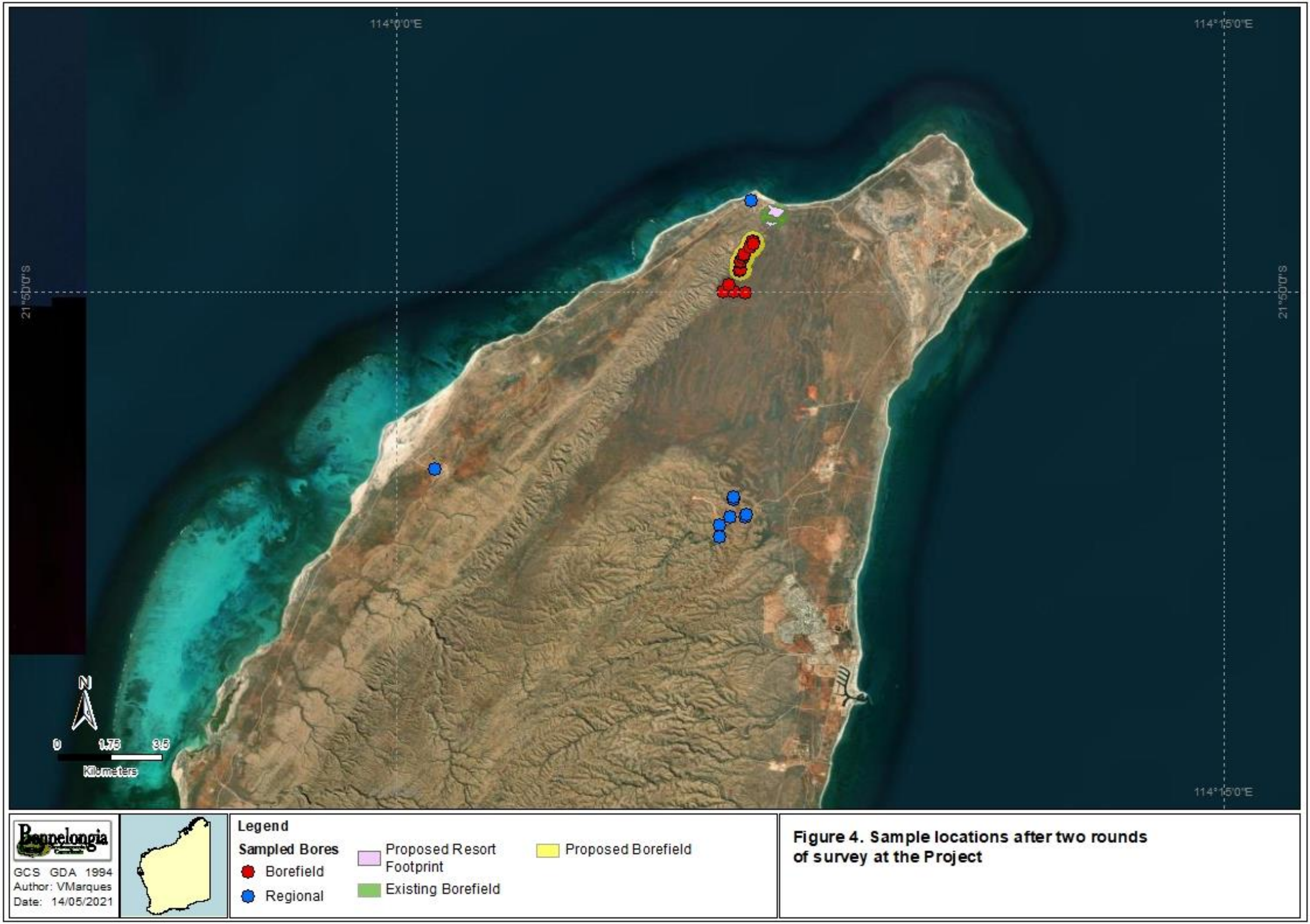

Figure 4. Sample locations after two rounds of survey at the Project

Sampling was conducted according to the general principles laid out for subterranean fauna sampling by the Environmental Protection Authority (EPA) in *Environmental Factor Guideline – subterranean fauna* (EPA 2016a), *Technical Guidance – subterranean fauna survey* (EPA 2016c) and *Technical Guidance – sampling methods for subterranean fauna* (EPA 2016b).

Stygofauna were collected by net-hauling. At each hole, a small, weighted plankton net was lowered to the bottom of the hole and then agitated vigorously to stir benthic and epibenthic fauna into the water column, where animals were then captured as the net was slowly retrieved. Six separate net hauls were made (three with 50 µm mesh net and three with 150 µm mesh net). The contents of the net were transferred to cold 100% ethanol for preservation after each haul (EPA 2016b). Contamination between sites was avoided by washing the nets between the sampling of different drill holes.

5.2.2. Sampling Effort

Forty stygofauna samples were collected in the two rounds of survey (Table 1, Figure 4). Thirty samples were taken from 17 bores within the borefield and 10 samples were collected from nine 'regional' bores outside the borefield in the northern part of the peninsula (Appendix 1). Monitoring bores were made of 50 mm PVC slotted from the water table to end of the bore, while production bores were made of 150 mm PVC slotted from the water table to approximately 3 m below it. Slotting aperture was 1 mm,

Table 1: Stygofauna survey effort at the Project.

Survey Round	Sample Location	
	Borefield	Regional
1	15	1
2	15	9

5.2.3. Laboratory Processing

All samples were returned to the laboratory in Perth for sorting. Stygofauna net samples were elutriated to separate animals from sediment and put through sieves to fractionate the contents according to size (53, 90 and 250 µm) to improve searching efficiency. All potential stygofauna animals were removed from these samples for species or morphospecies level identification. Surface animals were identified to Order level and classified as by-catch.

Stygofauna identification was conducted using published, unpublished and informal taxonomic keys, as well as species descriptions in the scientific literature. Morphospecies were established using the characters of existing species keys, and the lowest level of identification possible was reached given the constraints of sex, maturity of the specimens (juveniles and females often cannot be identified to species level) and possible damage to body parts. Dissecting and compound microscopes were used during the sorting and identification processes, with specimens dissected as required. After the taxonomic assessment was completed, representative animals were lodged with the Western Australian Museum.

5.2.4. Laboratory Processing

The first round of fieldwork was conducted by Huon Clark and Sam Chidgzey and the second round was conducted by Bruno Buzatto and Vitor Marques. Sample sorting was conducted by Jane McRae, Melanie Fulcher, Melita Pennifold, Heather McLetchie and Jim Cocking. Species identifications were performed by Jane McRae. Report writing was done by Huon Clark and Stuart Halse, while maps were prepared by Huon Clark and Vitor Marques.

6. FIELD SURVEY RESULTS

6.1. Water Quality

Electrical conductivity of water in the top meter of groundwater in the proposed borefield varied from 1450 - 31,900 µScm^{-1} (Appendix 1). This equates approximately to salinities of 900 – 19,000 mgL^{-1} total dissolved solids.

Values of pH were consistently neutral and varied from only 6.8-7.6, reflecting strong buffering of groundwater. Temperature varied from 26.9-31.7 ºC, which is more variation that would be expected in groundwater and most likely reflects time the sample was on the surface before temperature was measured.

6.2. Stygofauna

A total of 477 specimens of at least 13 species of stygofauna were collected over two rounds over survey in borefield and surrounding area (Table 2, see also Appendix 2). Forty-one specimens of stygofauna were collected from the 30 samples taken from the borefield. Of these, 34 specimens were identified as four species, while the other seven specimens could not be identified to species level.

One of the four borefield species, the copepod crustacean *Parastenocaris* `BHA286`, is known only from the borefield. The other three borefield species, a nematode worm, oligochaete worm Enchytraeidae `3 bundle` s.l. (short sclero) and copepod *Diacyclops humphreysi*, were collected from 'regional' bores as well as from the borefield. It is possible, but unlikely, that some of the seven specimens that could not be identified to species level represent additional species. This report assumes there are only four borefield species.

The 10 samples collected outside the borefield yielded 11 species consisting of one worm species, three amphipods, one shrimp, one thermosbaenacid, two copepods and one rotifer, as well the worm Enchytraeidae `3 bundle` s.l. (short sclero) and copepod *Diacyclops humphreysi* that were also found in the borefield (Table 2). Even though sampling effort was low, the results of 'regional' sampling reflects the richness and composition of the stygofauna community previously documented on the eastern side of the Exmouth Peninsula (Bennelongia 2008; KBR 2005).

6.3. Species Collected from Borefield

More information about the four species collected from the borefield is provided below. The collection location of the single species known only from the borefield is shown in Figure 5.

Enchytraeidae `3 bundle` s.l. (short sclero)

One specimen of Enchytraeidae `3 bundle` s.l. (short sclero) was collected from a monitoring bore (LH02M) at the southern extent of the borefield. A fragment of another Enchytraeid specimen (not identified to species) was also collected from a monitoring bore (LH04M) to the north of the borefield.
Enchytraeidae `3 bundle` s.l. (short sclero) is a member of a species complex that has been collected widely across the Pilbara. It has been suggested most enchytraeid species are widespread (*Brown et al*. 2015) and it is very unlikely that Enchytraeidae `3 bundle` s.l. (short sclero) contains a localised species restricted to the borefield. The species is treated here as having at least an Exmouth Peninsula distribution.

Parastenocaris `BHA286`

Six specimens of *Parastenocaris* `BHA286` were collected from a single bore (LH07M, Figure 5) within the proposed borefield during the first round of survey. Harpacticoid species in the Pilbara have variable ranges (Karanovic 2006), with most occupying one of two sub-regions (see Halse *et al*. 2014) and consequently having ranges that are orders of magnitude larger than the proposed borefield. While

Table 2: Stygofauna species collected over two rounds of sampling at the Project.

Higher Order Identification	Lowest Identification	Borefield	Regional
Annelida			
Clitellata			
Oligochaeta			
Enchytraeida			
Enchytraeidae	Enchytraeidae `3 bundle` s.l. (short sclero)	1	
	Enchytraeidae sp.	1	
Haplotaxida			
Tubificina			
Tubificidae	Tubificidae `BOL065`		4
	Oligochaeta sp.	2	6
Arthropoda			
Crustacea			
Malacostraca			
Eumalacostraca			
Amphipoda			
Bogidiellidae	Bogidiella `BAM203`		1
Eriopisidae	Nedsia `sculptilis Cape Range`		9
	Nedsia sp.		1
Paramelitidae	Paramelitidae sp.		1
Decapoda			
Atyidae	Stygiocaris stylifera		7
Thermosbaenacea			
Thermosbaenacidae	Halosbaena sp. CRE		60
Maxillopoda			
Copepoda			
Calanoida			
Ridgewayiidae	Stygoridgewayia trispinosa		69
Cyclopoida			
Cyclopidae	Diacyclops h. humphreysi	1	30
	Metacyclops mortoni		24
Harpacticoida			
Parastenocarididae	Parastenocaris `BHA286`	6	
	Parastenocaris sp.	4	
Nematoda	Nematoda sp.	26	124
Rotifera			
Eurotatoria			
Bdelloidea	Bdelloidea sp. 2:2		100
Grand Total		**41**	**436**

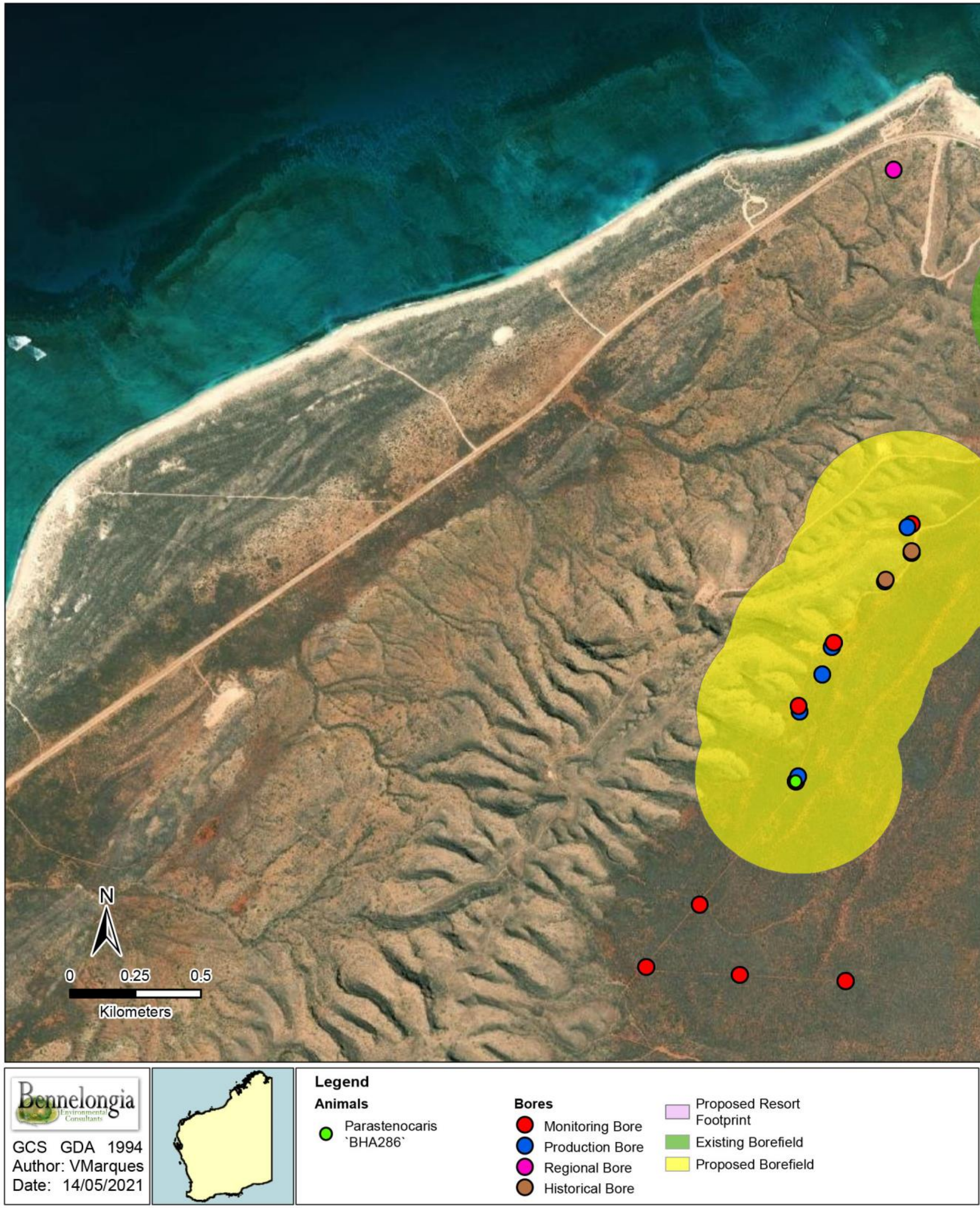

Figure 5. Locations of animals currently only known from the project area

Parastenocaris `BHA286` is expected to have a range extending well beyond the borefield, it is currently treated as potentially restricted to the area of groundwater drawdown associated with the borefield.

A further four specimens of *Parastenocaris* sp. were collected from LH07M in the second round of survey. They were female (males are required for species level identification) but most likely are *Parastenocaris* `BHA286`.

Diacyclops humphreysi humphreysi
One specimen of *Diacyclops h. humphreysi* was collected from bore LH11P inside the borefield and 30 specimens were collected from regional bores 19 and MB3 outside. This species occurs widely on the Exmouth Peninsula (Pesce and De Laurentiis 1996) and the species will not be impacted by borefield operations.

Diacyclops humphreysi is also widespread in the Pilbara, with an additional southern population on the Naruraliste Ridge, south of Busselton. Recent genetic work has shown that *Diacyclops humphreysi* in the Pilbara is a separate species from *Diacyclops h. humphreysi* on the peninsula.

Nematoda sp.
Little can be said about the distribution of Nematoda sp. other than it was collected from bore LH07M in the borefield and three regional bores (19, Shire, Windmill). There is essentially no framework for ready identification of free-living nematodes to species level and, consequently, the EPA framework for stygofauna assessment excludes them (EPA 2016b).

Higher Level Identifications
It is possible, although considered unlikely, that there are additional borefield species among the seven specimens identified only to higher levels. These specimens are:

- A single enchytraeid from bore LH04M. It is treated in this report as most likely to be Enchytraeidae `3 bundle` s.l. (short sclero).
- Two oligochaete specimens from bores LH07M and LH10P. It is considered most likely they are Enchytraeidae `3 bundle` s.l. (short sclero), Tubificidae 'BOL065' (collected from regional bores) or the same species as other unidentified oligochaetes collected from regional bore 19.
- Four *Parastenocaris* sp. specimens from bore LH07M, which are probably *Parastenocaris* 'BHA286' as discussed above.

7. DISCUSSION

7.1. Absence of the Blind Cave Eel and Blind Gudgeon

The nearest known occurrence of the listed blind cave eel is about 1.3 km north of the proposed borefield near the coast. It is close to the planned Project accommodation and landscaping. While uncertain, the collecting location is probably what is referred to in this report as Shire bore. This bore was sampled twice during the survey and contained fresh groundwater but there was extensive organic matter load from the bore being in poor condition. No eel was collected although it can be inferred the species occurs in the area (Bennelongia 2020).

The listed blind gudgeon has been collected about 3.5 km west of the southern end of the proposed borefield. As with the eel, it can be inferred the gudgeon occurs along the coast in the vicinity of the Project. Existing records suggest that occurrence of either the eel or gudgeon immediately east of Cape Range in the proposed borefield is unlikely; the distribution of both species is coastal.

7.2. Extent of Drawdown

Pennington Scott (2021) calculated the area of measurable drawdown around the proposed borefield as <6 km^2. Within this area the maximum drawdown around each bore will be 0.6-0.8 m. However, in conjunction with this small amount of drawdown, there is likely to be an increase in salinity of groundwater near the watertable as the fresher surface water is removed by pumping. Salinity is expected to return to pre-pumping conditions after significant recharge events (manly cyclones or heavy monsoonal rain) (Pennington Scott 2021).

This increase in salinity in the upper part of the aquifer has the potential to remove habitat for stygofauna with a preference for freshwater, even the though the proposed extent of drawdown is small and the physical structure of the aquifer habitat is otherwise homogeneous. Definitive statements about the salinity preferences of the one stygofauna species collected only from the borefield, *Parastenocaris* 'BHA286', cannot be made. However, assuming the *Parastenocris* individuals collected from LH07M in March also belong to *Parastenocaris* 'BHA286, which was collected from LH07M in January, the species has a salinity tolerance of at least 22,300 µS cm^{-1} (approximately 13,500 mgL^{-1} TDS). Borefield operations are unlikely to raise salinity much above this level (Pennington Scott 2021).

7.3. Wastewater and nutrient enrichment

The existing wastewater treatment plant (WWTP), which served the former holiday park, is located on freehold land almost 300 m east of the nearest production bore. As part of the Project, this WWTP will be remediated and a new WWTP will be constructed (ARUP 2019). The new system will treat wastewater to a standard whereby it can be re-used for toilet flushing and open space irrigation. Approximately 6 ha of vegetation will be irrigated with 40,000 KL/year (Appendix 4).

It is anticipated that the concentration of phosphorus in the wastewater will be <1 mg L^{-1} and nitrogen as nitrate will be <6 mg L^{-1} (Appendix 4). Phosphorous will bind to the calcareous soils of the Project and is unlikely to reach the water table. In contrast, nitrogen will pass through to the water table except to the extent it is taken up by plant roots. Context for the operation of the Project WWTP and associated irrigation is provided by the old Exmouth WWTP. Concentrations of nitrogen in groundwater around this WWTP are 35 mg L^{-1}, whereas background levels in the area are 1 mg L^{-1} (Bennelongia 2018) or 0.2 mgL-1 (Humphreys and Adams 1991). Concentrations of nitrogen are 0.07 mg L^{-1} compared with background levels in the area of 0.01 mg L^{-1}.

A survey of stygofauna occurrence in relation to nutrient levels near the Exmouth WWTP suggested that nitrogen concentrations had little effect, if any, on stygofauna at concentrations of 15 mg L^{-1}. However, particular species, such as the shrimp *Stygiocaris stylifera* and the copepod *Stygoridgewayia trispinosa*, were found only where nitrogen concentrations were low (Bennelongia unpublished data). Calculations to determine likely concentrations under irrigated areas are complex and depend largely on how vegetation and irrigation are managed; concentrations are expected to be substantially lower than around the old Exmouth WWTP (Appendix 4). More generally, however, changes in stygofaunal community structure as a result of sewerage effluent were demonstrated by Sinton (1984), who showed changes in both species composition and abundance in New Zealand. Nitrate concentrations (usually 8-10 mg/L) did not appear to be the factor controlling these changes, which matches observations in the USA where elevated levels of organic matter changed stygofaunal community structure while nitrogen concentrations remained low (Graening and Brown 2003).

While the above results from Exmouth and elsewhere show there is possible potential for operation of the Project WWTP and irrigation to affect stygofauna, nutrient concentrations can addressed through management plans. The calculations to determine likely concentrations of nitrogen under irrigated areas are complex and depend largely on how vegetation and irrigation are managed (Appendix 4). Whether nitrogen will impact any stygofauna at the concentrations at which it will occur under irrigated Project areas is unclear but impact is probably unlikely for most species.

7.4. Regional Context of Stygofauna

The stygofauna and troglofauna communities of the Exmouth Peninsula have been described in Bennelongia (2020). In summary, the peninsula supports rich communities of both types of subterranean fauna. In contrast to the rich stygofauna community found more generally on the peninsula, the proposed borefield appears to contain a depauperate stygofauna despite quite intensive sampling. It contains probably four species of stygofauna compared with 77 now known from the peninsula, although there was greater taxonomic effort applied to the borefield survey than across most surveyed parts of the peninsula. The other 11 species collected during the survey were in areas outside the borefield.

Thirty species were collected in a similar-sized survey at Exmouth with similar taxonomic effort to that of the borefield survey. The crustaceans species that characterise the stygofauna of the peninsula and support most taxonomic interest are largely absent from the borefield.

8. CONCLUSION

After two rounds of stygofauna survey and the collection of 30 samples, only four species of stygofauna were recorded in the proposed borefield (Table 2). This represents a depauperate stygofauna community. There is a significant contrast between the rich stygofauna community found in much of the Exmouth Peninsula (Bennelongia 2020; KBR 2005), which was reflected even in the 10 regional samples collected during this field survey, and the depauperate community of the proposed borefield.

The low number of stygofauna species in the borefield is probably the result of the watertable in the borefield being deep (30-50 mbgl) and the borefield aquifer being in Tulki limestone that consists mostly of weakly cemented sand, rather than containing caverns (Bennelongia 2020).

Only one stygofauna species, the copepod *Parastenocaris* \`BHA286\`, has currently not been collected outside of the borefield. The borefield has an area of measurable drawdown of approximately 6 km^2. Although smaller ranges have been inferred for stygofauna species occurring in confined landscapes (Pipan and Culver 2007), stygofaunal copepods of open landscapes do not have ranges as small as 6 km^2 (Galassi *et al*. 2009; Halse *et al*. 2014). There is an extensive area of similar habitat to the north, south and east of the borefield. Accordingly, the threat from proposed borefield operations to *Parastenocaris* \`BHA286\` and, more generally, to stygofauna conservation values in the Project area is considered to be low.

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Appendix 1. Summary of log information from bores within proposed borefield (Pennington Scott 2021).

Bore	Main Lithology	Bore Log Summary
LH01M	Sand	Little gravel at c. 10 m, medium coarse sand below water table with limestone chips, fine gravel below 50 m
LH02M	Sand	Gravel at c. 10 m, some gravel to 25 m, sand below water table with limestone chips at depth
LHOM3	Sand	Gravel at 10 and 25 m, sand below water table with limestone chips
LHOM4	Sand	Gravel 7-8 m, clay 8-18 m, then sand with some gravel, sand below water table with limestone chips
LHOMP	Sand	Gravel 4-8 m, sand with traces of gravel and clay to water table, fine sand below water table
LH05M	Sand	Little gravel 10-40 m, sand below water table with minor limestone chips
LH06M	Sand	Gravel to 10 m, sand and gravel to 15 m, then sand, sand below water table with limestone chips
LH06P	Sand	Gravel to 10 m, sand with trace of gravel to water table, medium or fine sand below water table,
LH07M	Sand	Gravel at c. 10 m and 25 m and 40 m, sand below water table with limestone chips
LH07P	Sand	Gravel at 12-17 m, sand with fine gravel to 20 m, sand to water table, gravelly sand below water table
LH08M	Sand	Gravel at 5-20 m, clay to 25 m, sand to water table, sand below water table
LH08P	Sand	Gravel at 3-22 m, sand with trace of gravel to 25 m, sand to water table, sand below water table
LH09P	Sand	Gravel at 1-9 m, sand with fine gravel to 18 m, sand to water table, coarse sand below water table
LH10P	Sand	Gravel to 19 m, sand to water table, sand below water table
LH11P	Sand	Gravel at 5-12 m, sand to water table, sand below water table

Appendix 2. Bores sampled, dates and water quality.

LCP, Lighthouse Caravan Park; SWL, depth to water table (m); EOH depth to end of bore (m); Temp, temperature ºC; EC, electrical conductivity μS cm^{-1}, * Likely error.

Bore	Lat.	Long.	Site Type	Purpose	SWL	EOH	Slotting	Date	Temp	EC	pH
Bore E LCP	-21.81	114.11	Impact	Monitoring	36.4	38.3		16-Mar-21	28.3	1907	7.13
Bore F LCP					37.7	40		16-Mar-21	26.9	2360	7.55
LH01M	-21.83	114.11	Impact	Monitoring	29.7	54	41.5-53.5	12-Jan-21	30.4	31900	7
LH01M					30.2	54		15-Mar-21	30.3	31700	6.99
LH02M	-21.83	114.10	Impact	Monitoring	*23.6	72	41-53	12-Jan-21	31.1	17400	6.8
LH02M					32	66		15-Mar-21	30.9	17100	6.97
LH03M	-21.83	114.10	Impact	Monitoring	52	66	50.5-65.6	12-Jan-21	30.3	16300	7.07
LH03M					50.6	66		15-Mar-21	30.4	14500	7.08
LH04M	-21.82	114.10	Impact	Monitoring	47	56	41-53	13-Jan-21	29.2	5840	7.18
LH04M					43.3	50		15-Mar-21	29.5	6950	6.89
LH04P	-21.82	114.10	Impact	Production	43	47.8	43.5-46.5	13-Jan-21	27	9110	7.23
LH04P					43.5	47.8		15-Mar-21	28.3	11490	6.98
LH05M	-21.83	114.10	Impact	Monitoring	50	60	47-59	12-Jan-21	29.5	18700	7.11
LH05M					47.3	60		15-Mar-21	29.8	17800	7.04
LH06M	-21.82	114.11	Impact	Monitoring	36	54	41-53	13-Jan-21	31.9	10700	7.58
LH06M					39.3	54		16-Mar-21	26.9	8700	7.44
LH06P	-21.82	114.11	Impact	Production	36	44	37.7-43.7	13-Jan-21	30.6	960	7.56
LH06P					36.6	44		16-Mar-21	27	1022	7.34
LH07M	-21.83	114.10	Impact	Monitoring	47	65	41-59	12-Jan-21	28	11700	7.5
LH07M					46.8	56		15-Mar-21	29.4	22300	7.11
LH07P	-21.83	114.10	Impact	Production	46.6	50.7	46.3-50.3	12-Jan-21	28.9	21800	6.97
LH07P					46.5	50.7		15-Mar-21	30.2	21200	6.86
LH08M	-21.82	114.11	Impact	Monitoring	35.9	48	36-48	13-Jan-21	30.2	1809	7.31
LH08P	-21.81	114.11	Impact	Production	35.8	39.9	35.6-38.6	13-Jan-21	30.5	10200	7.21
LH08P					35.8	39.9		16-Mar-21	28.9	1186	7.31
LH09P	-21.82	114.11	Impact	Production	37.8	41.8	37.5-40.5	13-Jan-21	29.7	7980	7.53
LH10P	-21.82	114.11	Impact	Production	36.5	39.5	36.2-38.2	13-Jan-21	31.7	6730	7.6
LH10P					36.6	39		16-Mar-21	28.9	1403	7.22
LH11P	-21.82	114.10	Impact	Production	42	44.6	41.3-43.3	13-Jan-21	29.8	3610	7.04

Bore	Lat.	Long.	Site Type	Purpose	SWL	EOH	Slotting	Date	Temp	EC	pH
LH11P					41.68	44.6	41.7	16-Mar-21	27.2	3660	6.97
Bore 19	-21.90	114.10	Reference	N/A	20.51	24.5	20.5	18-Mar-21	28.9	1508	7.97
MB1	-21.90	114.1	Reference	N/A	19.35	32	19.4	18-Mar-21	29.1	722.6	7.29
MB2	-21.90	114.10	Reference	N/A	20.48	25	20.5	18-Mar-21	29.6	2650	7.25
MB3	-21.91	114.1	Reference	N/A	23.98	27	24.0	18-Mar-21	28.4	3060	7.08
MB4	-21.90	114.10	Reference	N/A	20.06	30	20.1	18-Mar-21	30.2	2960	7.45
MB5					18.57	27	18.6	18-Mar-21	30.8	1448	7.86
Shire Bore	-21.81	114.11	Reference	N/A	11.15		11.2	13-Jan-21	31.5	2040	7.38
Shire Bore					11.1	13	11.1	18-Mar-21	29.8	1845	7.34
WCUNK02	-21.90	114.10	Reference	N/A	17.58	19	17.6	18-Mar-21	30	1185	7.26
Windmill	-21.89	114.01	Reference	N/A	1.49	2	1.49	18-Mar-21	28.8	6260	7.25

Appendix 3. Stygofauna species collected during sampling.

Bore Code	Date	Phylum	Family	Species	Number.
Shire Bore	18-Mar-21	Rotifera		Bdelloidea sp. 2:2	100
Bore 19	18-Mar-21	Nematoda		Nematoda sp.	3
Bore E LCP	16-Mar-21	Nematoda		Nematoda sp.	1
LH07M	12-Jan-21	Nematoda		Nematoda sp.	15
LH07M	15-Mar-21	Nematoda		Nematoda sp.	10
Shire Bore	13-Jan-21	Nematoda		Nematoda sp.	20
Shire Bore	18-Mar-21	Nematoda		Nematoda sp.	100
Windmill	18-Mar-21	Nematoda		Nematoda sp.	1
Bore 19	18-Mar-21	Annelida		Oligochaeta sp.	6
LH07M	15-Mar-21	Annelida		Oligochaeta sp.	1
LH10P	16-Mar-21	Annelida		Oligochaeta sp.	1
LH02M	12-Jan-21	Annelida	Enchytraeidae	Enchytraeidae `3 bundle` s.l. (short sclero)	1
LH04M	13-Jan-21	Annelida	Enchytraeidae	Enchytraeidae sp.	1
MB3	18-Mar-21	Annelida	Tubificidae	Tubificidae `BOL065`	3
MB4	18-Mar-21	Annelida	Tubificidae	Tubificidae `BOL065`	1
MB2	18-Mar-21	Arthropoda	Bogidiellidae	Bogidiella `BAM203`	1
Bore 19	18-Mar-21	Arthropoda	Eriopisidae	Nedsia `sculptilis Cape Range`	8
WCUNK02	18-Mar-21	Arthropoda	Eriopisidae	Nedsia `sculptilis Cape Range`	1
MB3	18-Mar-21	Arthropoda	Eriopisidae	Nedsia sp.	1
MB2	18-Mar-21	Arthropoda	Paramelitidae	Paramelitidae sp.	1
Bore 19	18-Mar-21	Arthropoda	Ridgewayiidae	Stygoridgewayia trispinosa	31
MB2	18-Mar-21	Arthropoda	Ridgewayiidae	Stygoridgewayia trispinosa	1
MB3	18-Mar-21	Arthropoda	Ridgewayiidae	Stygoridgewayia trispinosa	30
MB4	18-Mar-21	Arthropoda	Ridgewayiidae	Stygoridgewayia trispinosa	4
MB5	18-Mar-21	Arthropoda	Ridgewayiidae	Stygoridgewayia trispinosa	3
LH11P	13-Jan-21	Arthropoda	Cyclopidae	Diacyclops h. humphreysi	1
Bore 19	18-Mar-21	Arthropoda	Cyclopidae	Diacyclops h. humphreysi	5
MB3	18-Mar-21	Arthropoda	Cyclopidae	Diacyclops h. humphreysi	20
MB2	18-Mar-21	Arthropoda	Cyclopidae	Diacyclops h. humphreysi	1
MB4	18-Mar-21	Arthropoda	Cyclopidae	Diacyclops h. humphreysi	4
Windmill	18-Mar-21	Arthropoda	Cyclopidae	Metacyclops mortoni	24
Bore 19	18-Mar-21	Arthropoda	Atyidae	Stygiocaris stylifera	5
MB4	18-Mar-21	Arthropoda	Atyidae	Stygiocaris stylifera	2
LH07M	12-Jan-21	Arthropoda	Parastenocarididae	Parastenocaris `BHA286`	6
LH07M	15-Mar-21	Arthropoda	Parastenocarididae	Parastenocaris sp.	4
Bore 19	18-Mar-21	Arthropoda	Thermosbaenacidae	Halosbaena sp. CRE	30
MB3	18-Mar-21	Arthropoda	Thermosbaenacidae	Halosbaena sp. CRE	22
MB5	18-Mar-21	Arthropoda	Thermosbaenacidae	Halosbaena sp. CRE	7
Windmill	18-Mar-21	Arthropoda	Thermosbaenacidae	Halosbaena sp. CRE	1

Appendix 4. Technical Memorandum from Pennington Scott.

TECHNICAL memorandum

Lighthouse Resort Nutrients in Groundwater

Title:	Irrigation of Treated Waste Water at the Ningaloo Lighthouse Resort Project
For:	Z1Z Resorts Pty Ltd
Date:	13 May 2021
Ref:	2298 Lighthouse Resort Nutrients in Groundwater Tech Memo Rev 0

Z1Z Resorts Pty Ltd (**the Proponent**) is seeking to develop the Lighthouse Holiday Resort at Exmouth Western Australia to accommodate up to 726 guests and staff. On March 31st 2021 the Proponent submitted a Development Application (**DA**) to the Environmental Protection Authority (**EPA**) for assessment under Section 38A(1) of the Environmental Protection Act 1986. On 23 April 2021, the EPA responded with a request for further information on several aspects of the DA including stygofauna, marine fauna and social surroundings.

One of the EPA's requests for clarification with respect to stygofauna, was that ***"the referral information states that an increase in nutrient levels in groundwater is not known to affect subterranean fauna. Please provide further information to support this statement."*** The request relates to comments made in Appendix D of the DA (Bennelongia (2020 pp 355 to 360) which says that the Project's proposed wastewater irrigation and leakage from the wastewater treatment plant (**WWTP**) could potentially increase groundwater nutrients, which might in turn affect subterranean fauna occurrence. However, while there may be some information deficiencies, Bennelongia are confident the risk is low because of the following known mitigating factors:

- the groundwater in the Tulki Limestone aquifer beneath the Resort is known to be naturally elevated in nitrate;
- previous studies by Bennelongia in Exmouth have shown that the elevated background levels of nitrates don't apparently adversely affect subterranean fauna occurrence (Bennelongia 2018);
- in the event that nitrate levels in the irrigation water from the Lighthouse WWTP are elevated above the natural groundwater, it is unlikely to be by much; and
- whatever the nutrient levels are with the irrigation water, these levels would be reduced by plant uptake before any water leaches to groundwater.

The following sections provide supporting evidence for these assertions.

Naturally occurring nutrient levels

Nitrogen is an abundant naturally occurring nutrient, comprising 69% of the atmosphere. In the nitrogen cycle, nitrogen fixing plants (legumes, such as acacias) capture atmospheric nitrogen and store it within the soil zone, where other plant species may access it. Some of the nitrogen leaches to groundwater through plant decay processes, particularly where termites are active.

Bennelongia (2018, 2020) said that the natural groundwater in the Tulki Limestone on the Cape Range is up to 15 mg/L (NO_3/N). This is consistent bore water quality measurements by Pennington Scott

(2020) around the Lighthouse Resort, which showed nitrate levels ranging from 0.5 to 11.3 mg/L (NO_3/N). It is also consistent studies from other arid zone regions of Australia, where naturally occurring groundwater nitrate levels up to 17 mg/L (NO_3/N) are common (Jacobson *et al*. 1991, and Barnes *et a*l. 1992).

Phosphorus (P) is an essential component in all living organisms. The main sources of P in the natural environment are through the decomposition of apatite minerals found in volcanogenic (greenstone) rocks. Guano from seabirds is another significant source of phosphorus in coastal environments, such as the Cape Range.

Nutrient levels in the WWTP irrigation stream

The proposed Lighthouse Resort WWTP will be a best practice tertiary plant, similar those to established at other resorts located along the west coast at Ningaloo, Monkey Mia and Rottnest Island. **Table 1** summarises the key quality parameters in the treated effluent stream from these WWTPs.

Reference to this table shows that the salinity could be expected to be potable, neutral acidity/alkalinity, and have nitrate levels less than 6 mg/L (NO_3/N), while total phosphorus would be below 1 mg/L.

Table 1 Typical treated water outputs from WWTP vs local groundwater at Lighthouse

Parameter	Rottnest	Monkey Mia	Local Groundwater Quality	Estimated treated Water quality for DA
pH	6.5 – 7.5	7 – 8	7.4	6.5 – 8.0
TDS (mg/L)	600 –1000	500 – 1000	7000 – 10000	1000
NO3-N (mg/L)	-	2 – 6	< 15	<6
Total P (mg/L)	0.1 – 0.8	0.5 – 2		<1

Soil and plant uptake of nutrients

The Lighthouse WWTP is expected produce up to 40,000 kL/year of treated water, which would be used to irrigate 6 ha of indigenous parks and gardens around the resort. A full species list is provided in the Landscape Architecture Statement of the DA (McGregor Coxall, 2020).

The growth of the three main species (*Eucalyptus victrix*, *Eucalyptus xerothermica*, *Brachychiton obtusilobus*, and *Banksia ashbyi*.) in the natural environment is limited by the low availability of soil nutrients but thrive with the addition of nutrients. Eucalyptus victrix, especially, grows best when in a community with nitrogen fixing plants such as acacias (Cromer *et al.* 1984, Florentine and Fox, 1997). However, plant uptake is not the only source of nutrient loss:

- nitrates are also lost through denitrification, volatilisation, and immobilisation processes in the soil zone (Di and Cameron (2000); and
- phosphates tend to be relatively immobile in limestone soil environments, being adsorbed onto soil particles and reacting with calcium in the limestone to form immobile calcium phosphate minerals, dicalcium phosphate and octacalcium phosphate (Von Wandruszka, 2006).

Summary

Pennington Scott concurs with Bennelongia (2020) that there is low risk that nutrients from the Project would affect subterranean fauna because:

- the groundwater in the Tulki Limestone aquifer beneath the Resort is known to be naturally elevated nutrients, with nitrogen levels up to 15 mg/L (total N);
- previous studies by Bennelongia in Exmouth have shown that the elevated background levels of nitrates don't apparently adversely affect stygofauna occurrence (Bennelongia 2018);
- based on outputs from other WWTPs along the coast, nitrate levels in the irrigation water from the Lighthouse WWTP are likely to be less than 6 mg/L (NO_3/N) and phosphorus less than 1 mg/L (PO_4/P); and
- whatever the nutrient levels are with the irrigation water, these levels are going to be reduced by plant uptake and other soil processes before any water leaches to groundwater.

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