Bennelongia Environmental Consultants

Ningaloo Lighthouse Resort: Subterranean Fauna Desktop Assessment

Prepared for:

Tattarang

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Final Report

Short-Range Endemics I Subterranean Fauna

Waterbirds I Wetlands

Ningaloo Lighthouse Resort: Subterranean Fauna Desktop Assessment

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EXECUTIVE SUMMARY

The Ningaloo Lighthouse Resort is located near the Cape Vlamingh Lighthouse at the north-western tip of Exmouth Peninsula in Western Australia. The facility, which was formerly called the Lighthouse Holiday Park, was acquired by Tattarang Pty Ltd in 2018. It is planned to redevelop the holiday park with a greater range of accommodation and facilities. This will require access to additional relatively fresh groundwater to feed a reverse osmosis plant to provide potable water for the resort.

The Exmouth Peninsula has particularly rich populations of these aquatic animals (termed stygofauna) and also populations of earth-breathing species in caves and elsewhere underground (called troglofauna) and hence the objectives of this report are:

- To document the types of subterranean species likely to be present in the Project area, focussing particularly on the borefield;
- To assess the likely impact of groundwater abstraction from a new borefield on subterranean fauna; and
- To assess the likelihood of additional impact on subterranean fauna from proposed changes to wastewater disposal, including the operation of the wastewater treatment plant and possible irrigation of some areas with surplus treated water.

Two listed species of fish and nine listed species of invertebrate stygofauna occur on the peninsula. All but four of the species are confined to Bundera Sinkhole, 70 km south of the Project area.

Nine listed species of troglofauna occur, with all of them found to the south of the Project.

While Exmouth Peninsula is rich in stygofauna there is uncertainty about the suitability of the habitat in the borefield, and Project area, for this group of animals. Salinity is unlikely to be a constraint on stygofauna occurrence but lithology may constrain occurrence both through providing minimal habitat for stygofauna in terms of interstitial spaces and voids and also through allowing limited recharge of energy and nutrients, especially since the watertable is moderately deep. This uncertainty about habitat suitability means sampling is required to determine whether or not stygofauna occur in the proposed borefield and which, if any, species are present.

Suitable humidity and the occurrence of subterranean voids and fissures present are the main factors determining occurrence of troglofaunal. Results of drilling suggest significant subterranean spaces are likely to be presentabove the watertable in the Tulki limestone of the borefield. Accordingly, it would be expected that troglofauna occur in the borefield, although there has been no sampling to date to confirm occurrence.

The most obvious threat to subterranean for from Project development is groundwater drawdown associated with borefield operation. However, the overall reduction in volume of habitat for stygofauna will be no more than 0.5%. It is not known which, if any, stygofauna species occur in the borefield but it is highly unlikely that any species would have a range restricted to the vicinity of the borefield. Accordingly, the threat of borefield operations to stygofauna conservation values is low.

There is currently insufficient information to assess the potential impact of open space irrigation with wastewater, as well as leakage from the wastewater treatment plant on stygofauna conservation values. However, it should be noted that no species is likely to be confined to the WWTP and area of irrigation effect, meaning any threat is likely to be small.

The nature of borefield and wastewater operations mean that the likelihood of troglofauna conservation values being affected is low. Possible effects of wastewater treatment and irrigation are likely to be low but cannot be assessed with existing information..

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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, which was formerly called the Lighthouse Holiday Park, was acquired by Tattarang Pty Ltd in 2018. It is planned 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 access to additional relatively fresh groundwater to feed a reverse osmosis plant to provide potable water for the resort. Abstraction of groundwater, and the disposal of this water after use, has the potential to negatively affect species of invertebrates and fish that live in groundwater. The Exmouth Peninsula has particularly rich populations of these aquatic animals (termed stygofauna) and also populations of earth-breathing species in caves and elsewhere underground (called troglofauna).

The objectives of this report are:

- To document the types of subterranean species likely to be present in the Project area;
- To assess the likely impact of groundwater abstraction from a new borefield on subterranean fauna; and
- To assess the likelihood of additional impact on subterranean fauna from proposed changes to wastewater disposal.

2. PROJECT DETAILS

2.1. Location

The Project is located on Yardie Creek Road approximately 22 km north of Cape Range National Park and 16 km north of Exmouth (Figure 1). The ocean 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.

A proposed borefield to supply the Project with additional water (see below) lies in the extensive area of Unallocated Crown Land at the northern end of Exmouth Peninsula. The planned borefield will begin approximately 700 m south of the Project and run 1.1 km south 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.

The existing wastewater treatment plant (WWTP) for the holiday park is located on freehold land about 400 m south of the Project and almost 300 m east of the nearest production bore (Figure 1). It lies within an interdunal swale.

2.2. Water supply

For the purposes of water allocation, the proposed borefield lies within DWER's Exmouth North subarea. The aquifer in this subarea 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 licence 253728 from the Department of Water and Environmental Regulation (DWER), 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.

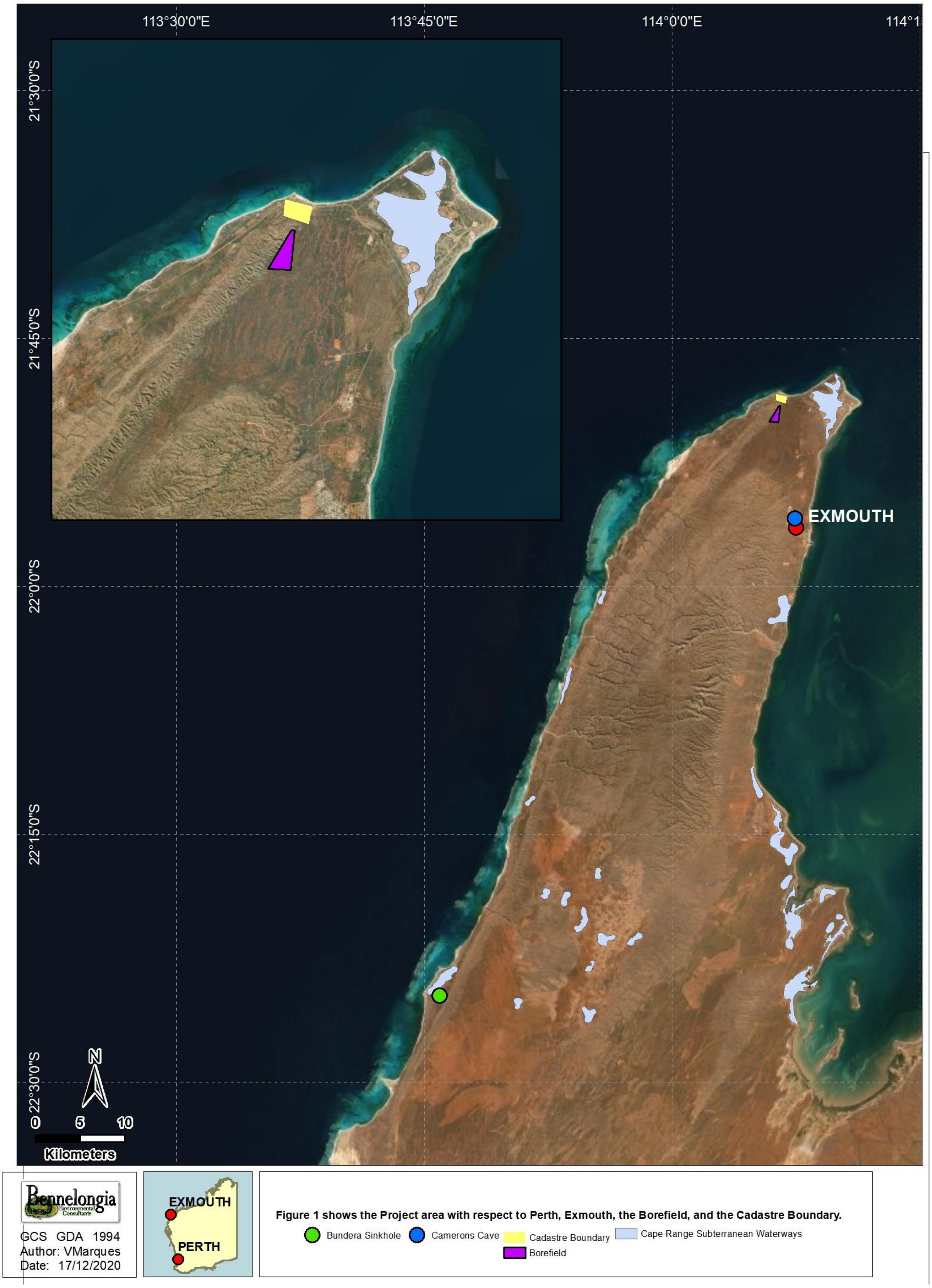

Figure 1. Exmouth Peninsula, showing the Project area (including borefield), Cape Range Subterranean Waterways and threatened ecological communities.

It is planned to obtain this groundwater from a borefield that begins about 2 km south of the Project on the east side of Cape Range. The borefield will comprise seven production bores (Pennington Scott 2020).

2.3. Wastewater

The Project will update the wastewater system used in the holiday park (ARUP 2019). The new system will recycle water on-site, with the recycled water being used for irrigation. The water treatment methods proposed include, with water treatment methods that include:

- Use of a membrane bioreactor (MBR);
- Ultra-violet (UV) disinfection; and
- Chlorine disinfection.

The treatment of wastewater will be to a standard that allows treated wastewater to be re-used for toilet flushing and open space irrigation.

3. GEOLOGY AND HYDROGEOLOGY

3.1. 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 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 east 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 fixed dunes over Tulki limestone (Figure 2).

Cape Range contains more than 300 caves in Tulki limestone, most of which are solution pipes with limited associated galleries (Finlayson and Hamilton-Smith 2003). Most of the caves are within the range but a few sink holes exist on the coastal plain, showing that quite cavernous areas can be found on the plain.

3.2. Hydrogeology

According to Allen (1993), the aquifer in the northern part of the peninsula is fresh (salinity <1000 mg/L TDS) and sits c. 100 m ASL in the central part of Cape Range (Figure 2). 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, varies from 2,900 to 14,000 mg/L based on pumping (Pennington Scott 2020, Table 5-1). Salinity within the aquifer increases with depth to a recorded maximum of 24,000 mg/L.

The fresh to saline aquifer of the peninsula is underlain by seawater, with the thickness of the aquifer increasing with distance from the coast and, concurrently, the depth to seawater below it increasing. The depth to groundwater in the proposed borefield varies from 30.8 mbgl to 50.9 mbgl. The aquifer is approximately 50 m thick

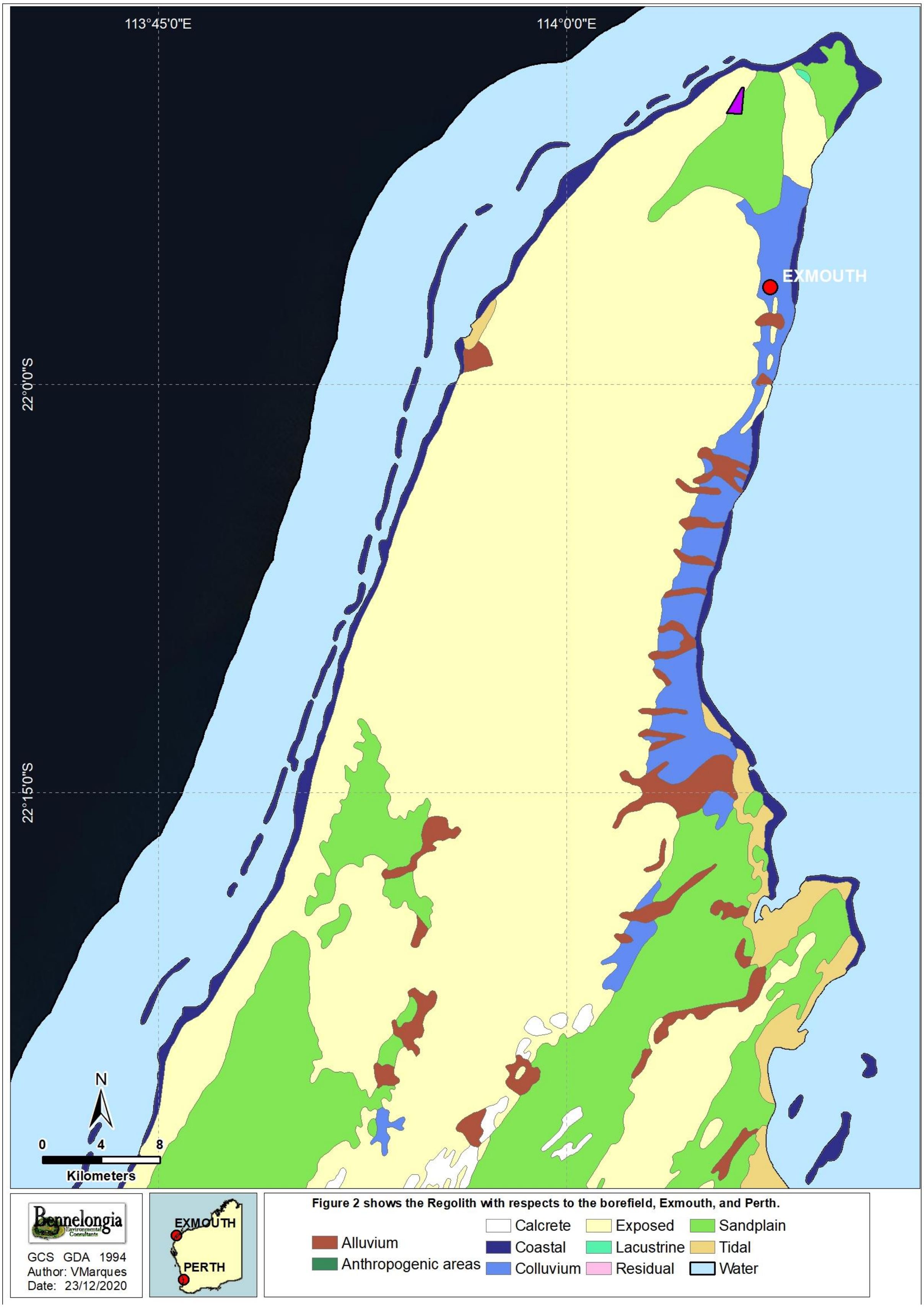

Figure 2. Regolith geology of Exmouth Peninsula. Cape Range runs up the centre of the peninsula and is shown as exposed rock.

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 coastal plain than within the range because of higher permeability in the cavernous Tulki limestone/coastal plain sediments than in the deeper Mandu limestone that comprises most of the aquifer under the range that has significant flow 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 of most bores lies with a mixture of calcareous sand, gravel and limestone. Photographed chip trays for bores LH08P and LH02M show the geology to comprise a sand cover and then indurated Tulki limestone to a depth of 20 m or more, after which the Tulki limestone is dominated by weakly cemented sand (Figure 3).

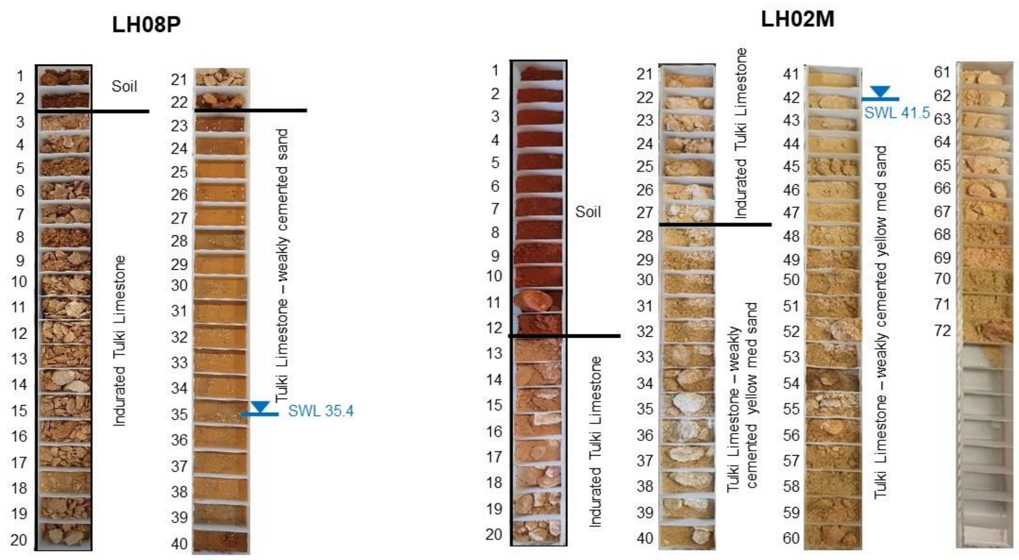

Figure 3. Chip trays showing lithology in borefield (from Pennington Scott 2020).

4. LEGISLATION

Native flora and fauna in Western Australia are protected at both State and Commonwealth levels. At the state level, the *Biodiversity Conservation Act 2016* (BC Act) provides a legal framework for protection of species, particularly those listed by the Minister for the Environment as threatened. Less formal protection for additional species is provided by DBCA maintaining lists of priority fauna species that are of conservation importance but, for various reasons, do not meet the criteria for listing as threatened. At the national level, the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) provides a legal framework to protect and manage nationally and internationally important species as well as threatened ones. Several subterranean fauna species from Exmouth Peninsula are listed as threatened under both acts (see below).

Both the EPBC and BC Acts also provide frameworks for the protection of threatened ecological communities (TECs). Within Western Australia, DBCA also informally recognises communities of potential conservation concern, but for which there is little information, as priority ecological communities (PECs). AS with the list of threatened species, the list of TECs recognised under the BC Act is larger than the EPBC Act list and has much greater focus on subterranean communities.

5. CAPE RANGE SUBTERRANEAN FAUNA

Western Australia contains globally significant radiations of the two groups of subterranean fauna: stygofauna and troglofauna (Guzik *et al*. 2010; Halse 2018). Subterranean fauna in Western Australia mostly occur 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.

While 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 ed). Subsequent survey and research has continued to increase the species list for the area and has improved understanding of the distributions of species and their degree of dependence on subterranean habitats (e.g. KRB 2005; Bennelongia 2008, Page *et al*. 2008, 2016; Tang et al. 2008; Larson *et al*. 2013; Moore et al. 2018).

Survey work has led to recognition under the BC Act of two TECs 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 areas of groundwater in potentially 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. This comprises the State and Commonwealth Ningaloo Marine Parks, Cape Range National Park and the Learmonth Air Weapons Range. The World Heritage Area was listed under two criteria:

- containing areas of incredible natural beauty; and
- containing the most important and significant natural habitats for in situ conservation of biological diversity.

Among the features representing these criteria is the rich diversity of subterranean fauna found only on the Exmouth Peninsula (DBCA 2019)

5.1. Stygofauna

The Exmouth Peninsula supports at least two native stygofaunal fish species (Figure 4) and 69 species of invertebrate stygofauna (Figure 5, Appendix 1). This estimate was compiled using records in Western Australian Museum databases and a more informal database of stygofauna records maintained by Dr W.F. Humphreys, as well as records of monitoring by the Water Corporation (see Bennelongia 2008), results of sampling by Bennelongia (2018, 2019) and recent scientific literature. The list of species has some uncertainty because differing levels of taxonomic knowledge have led to a variety of names being applied at times to what are probably single species, while it is possible that other species treated as single units are multiple units (as shown by some recent genetic studies (*Page et al. XXX, 2013*).is likely to be a significant underestimate of the actual number of species present. Sampling by Bennelongia in two locations substantially increased the number of species collected, partly because the earlier work by the Museum focussed on fish shrimps and the community in the anchialine ecosystem at Bundera Sinkhole south of Yardie Creek.

Both species of stygofaunal fish known from Western Australia are found on the peninsula. Both the blind gudgeon *Milyeringa veritas* and the blind cave eel *Ophisternon candidum* are listed as Vulnerable species under the BC and EPBC Acts (Table 1). Locations of these species have been mapped using Museum records (including those of Bill Humphreys) for *M. veritas* and Museum records and sight observations reported by Moore et al. (2018) for *O. candidum*. *Milyeringa veritas* is restricted to Exmouth Peninsula (Larson *et al*. 2013) but *O. candidum* also extends into the Pilbara.

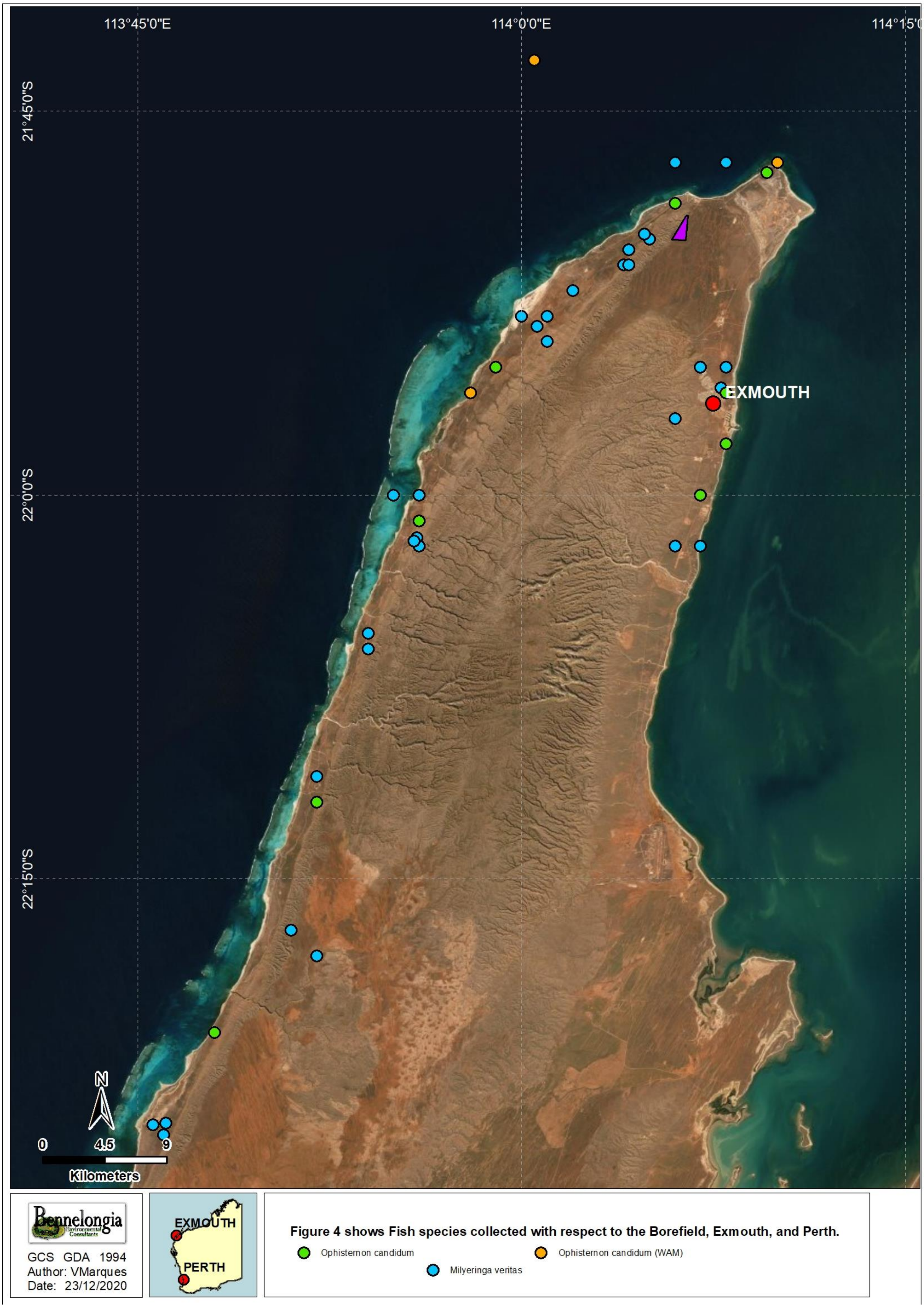

Figure 4. Distribution of stygofaunal fish species on Exmouth Peninsula, including site records of *O. candidum*.
Note that there are small coordinate errors in Museum database for some records.

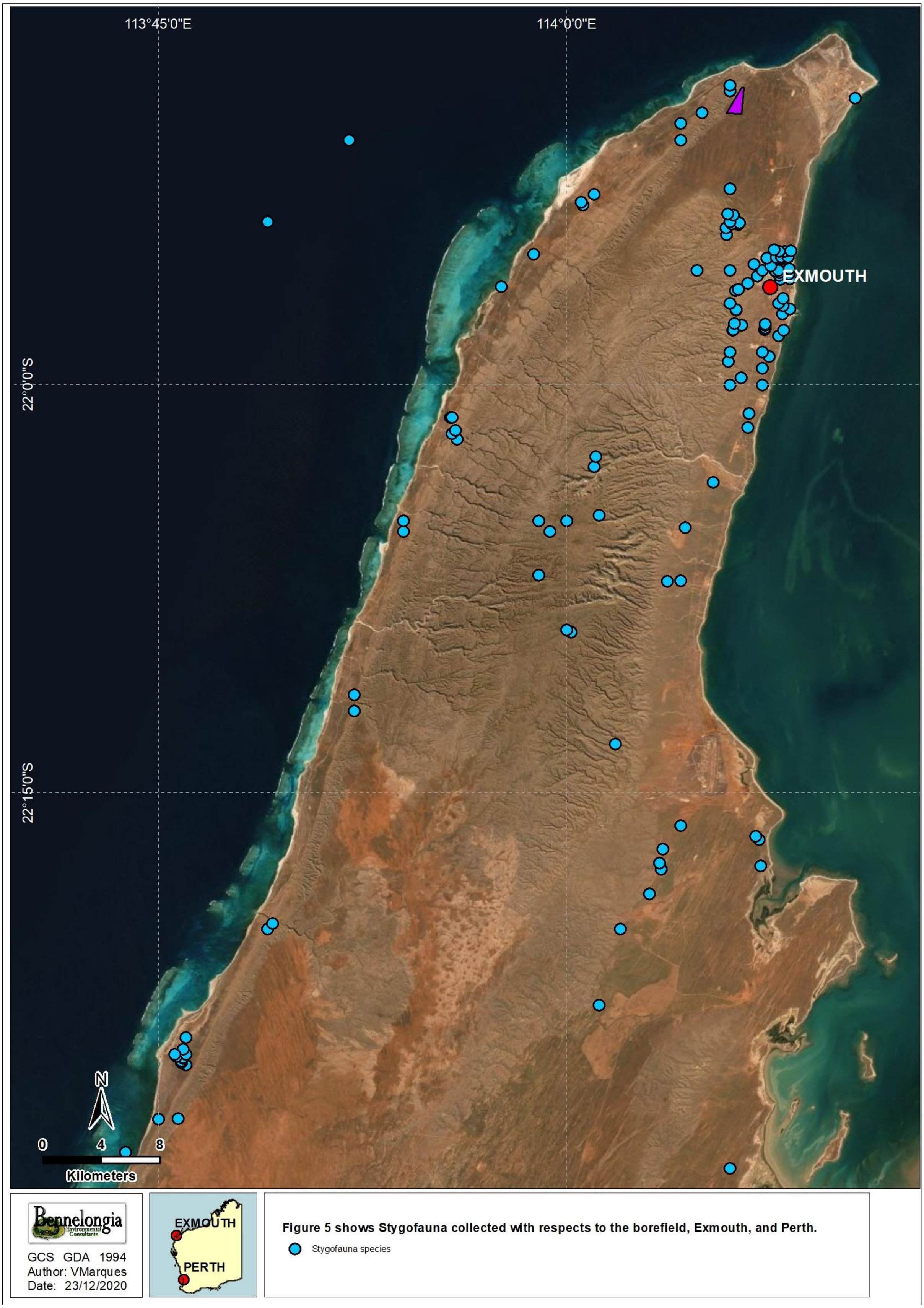

Figure 5. Distribution of invertebrate stygofauna on Exmouth Peninsula.
Note that there are small coordinate errors in Museum database for some records.

Figure 6. Distribution of listed invertebrate stygofauna species.
Note that *Stygiocaris* sp. Bundera is been recognised genetically and is shown, although not currently listed.

Table 1. Listed subterranean species on Exmouth Peninsula.

Group	Family	Species	Listing
Stygofauna			
Polychaeta	Spionidae	*Prionspio thalanji*	CR^{BC}
Remipedia	Kumongidae	*Kumonga exleyi*	CR^{BC},VU^{EPBC}
Calanoida	Epacteriscidae	*Bunderia misophaga*	CR^{BC}
	Pseudocyclopidae	*Stygocyclopia australis*	CR^{BC}
Misophrioida	Speleophridae	*Speleophria bunderae*	CR^{BC}
Ostracoda	Thaumatocyprididae	*Welesina kornickeri*	CR^{BC}
Amphipoda	Hadziidae	*Liagoceradocus branchialis*	EN^{BC}
Decapoda	Atyidae	*Stygiocaris lancifera* (includes *S.* sp. Bundera)	VU^{BC}
	Atyidae	*Stygiocaris stylifera*	P4
Pisces	Eleotricae	*Milyeringa veritas*	$VU^{BC,EPBC}$
	Synbranchidae	*Ophisternon candidum*	$VU^{BC,EPBC}$
Troglofauna			
Diplopoda	Paradoxosomatidae	*Stygiochiropus isolatus*	VU
		Stygiochiropus peculiaris	CR
		Stygiochiropus sympatricus	VU
Pseudoscorpiones	Hyidae	*Indohya damocles*	CR
Schizomida	Hubbardiidae	*Bamazomus subsolanus*	EN
		Bamazomus vespertinus	EN
		Draculoides brooksi	EN
		Draculoides julianneae	VU
Blattodea	Nocticolidae	*Nocticola flabella*	P4

Eight threatened and one priority species of invertebrate stygofauna occur on the peninsula (Table 1). Seven of the species occur at Bundera Sinkhole (Figure 6) 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 other two species, the shrimps *Stygiocaris lancifera* and *S. stylifera* (Figure 4), are listed as Vulnerable under the BC Act and as a Priority 4 species, respectively.

5.2. Troglofauna

Subterranean records of troglofauna on Exmouth Peninsula are nearly all from caves. There are also a few records from drill holes across the landscape that are sampling small voids and fissures in the underground matrix above the watertable. Many of the animals occurring in caves also occur in surrounding areas and it is frequently difficult to determine the extent of subterranean dependence in the apparent cave records themselves, especially as cave records frequently do not distinguish between occurrence immediately outside the cave, in the cave entrance or deeper in the cave. As a result, assignment as 'troglofauna' in Appendix 2 is accompanied by significant uncertainty in some cases. This variation in occurrence has been recognised in ecological classifications and species with subterranean affinity can be divided, somewhat artificially, into troglophiles that occur in the twilight zone near the entrance of caves (and sometimes outside) and troglobites that occur deeper in caves where it is dark, humidity is high and temperatures are relatively stable (Sket 2008). There are also various categories for species that use caves but have minimal dependence on them.

Figure 7. Distribution of troglofauna on Exmouth Peninsula**.**

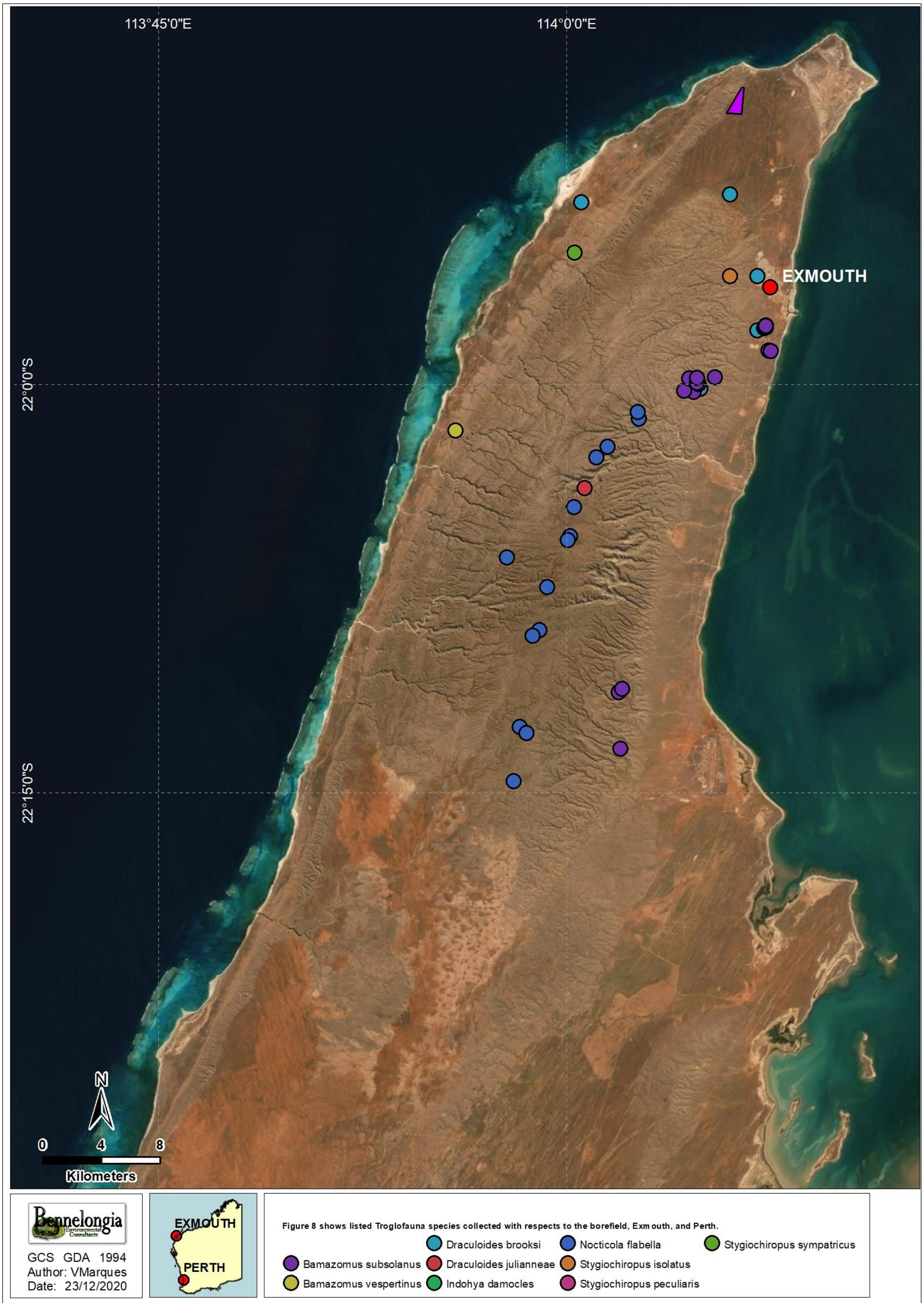

Figure 8. Distribution of listed troglofauna species**.**

Western Australian Museum taxonomic databases contain records of specimens belonging to at least 59 species that are considered likely to be troglobites or troglophiles (Figures 7 and 8, Appendix 2). The true number of troglofauna species is likely to be higher than recorded because, particularly for isopods, there has been limited taxonomic investigation and multiple species are likely to have been as a single taxon. The more comprehensive subterranean database of Dr W.F. Humphreys was not accessed for troglofauna. In addition, literature on troglofauna of the peninsula is quite dispersed and has not been used greatly in compiling the species list in Appendix 2, although papers such as Humphreys and Shear (1993) highlight the incompleteness of the records presented in this report for individual species as not all occurrences lead to specimens in the Western Australian Museum. Other papers by Humphreys et al. (1989), Humphreys and Collis (1990) and Humphreys (1991) provide ecological information that increases understanding of how communities function underground.

Eight threatened and one priority species of troglofauna occur on the peninsula (Figure 8). All of these species are listed only under the BC Act, with two species listed as Critically Endangered, three as Endangered and three as Vulnerable (Table 1).

6. PROJECT AREA SUBTERRANEAN FAUNA

6.1. Stygofauna

No species of stygofauna or troglofauna has been recorded from the proposed borefield area, although one record of the listed blind cave eel *Ophisternon candidum* is very close to the Project area (Figure 4). The lack of records from near the borefield is probably because no sampling has occurred in this or adjacent areas. Based on distribution of records, *O. candidum* and the other listed fish species *Milyeringa veritas* appear likely to occur in the borefield, as well as the shrimp *Stygiocaris stylifera* (Figure 6), assuming that habitat there is suitable.

Other stygofauna species collected nearby include the copepods *Phyllopodopsyllus wellsi* and *Nitokra humphreysi* collected on the western side of the range and the worm Enchytraeidae sp. B16, which although well east is in the tip of the peninsula (see Figure 5).

The main determinants of occurrence of stygofauna are depth to groundwater, salinity and suitability of habitat (Mokany *et al*. 2019), although the latter is often difficult to determine. The depth to goundwater in the borefield varies from 30-50 m across the borefield. In many situations, this is sufficient depth to suggest the borefield is unlikely to host a rich stygofauna community. For example, Halse et al. (2014) collected large numbers of animals in the Pilbara only when depth to groundwater was <32 m and large numbers of species only at depth <19 m. However, depth to groundwater in the Water Corporation's water supply borefield for Exmouth varies from 33-54 m across most of the borefield and monitoring has shown that a rich stygofauna community occurs (KBR 2005). It is therefore unlikely that depth to groundwater will constrain stygofauna occurrence in the proposed borefield, although this assumes that the borefield has relatively high recharge from the surface that washes nutrients and carbon into the aquifer after rainfall. The relationship between depth to groundwater and stygofauna occurrence principally reflects the extent of hydraulic connectivity with the surface (Hahn and Fuchs 2009). Locally, stygofauna abundance in the Yilgarn has been shown to vary according to the quantity of recharge (Sacco *et al*. 2020).

The effect of salinity on groundwater occurrence is strongly influenced by natural salinity levels in the region, which set the 'background' tolerance level of the fauna. However, most Pilbara species are restricted to salinities of <10,000 µS/cm and most Yilgarn species to <25,000 µS/cm, although occasional species have greater tolerances (Halse 2018). In the coastal setting of the Exmouth Peninsula, most species would be expected to tolerate the salinities of the borefield, where upper groundwater salinity varies from 2,900-14,000 µS/cm across the borefield and increases at depth to about 24,000 µS/cm. It is therefore unlikely that groundwater salinity in the proposed borefield will constrain stygofauna occurrence.

As a general rule of thumb, aquifers that are transmissive enough to support a borefield will also have the interstitial spaces or voids to support stygofauna occurrence. Stygofauna respond to small-scale changes in lithology as well as broader geological and hydrogeological patterns (Hose *et al.* 2017). Recognising the foregoing, the chip tray samples from bores in the proposed borefield provide do not provide definite information about the occurrence of potential stygofauna habitat. However, samples from some bores appear to lack the interstitial spaces necessary to host stygofauna (Figure 2, LH08P), while elsewhere the habitat looks more prospective (Figure 2, LH02M).

There are no comparable chip samples from the Water Corporation's Exmouth water supply borefield that can be compared with those of the proposed but the generalised geology of the Exmouth Peninsula suggests the lithology in the proposed borefield and the water supply borefield are likely to be similar, with the aquifers being hosted by Tulki limestone in both cases (Figure 9; see also Allen 1993). This suggests a rich stygofauna community should occur in the proposed borefield. However, pump tests show the aquifer of the proposed borefield has an average transmissivity of 80 m^2/day (Pennington Scott 2020), which is an order of magnitude less than for the water supply borefield (WRC 1999). Thus, possibly the lithology of the proposed borefield aquifer constrains the occurrence of stygofauna. In addition to providing less habitat, the lower transmissivity of the proposed borefield may also reduce recharge of energy and nutrients.

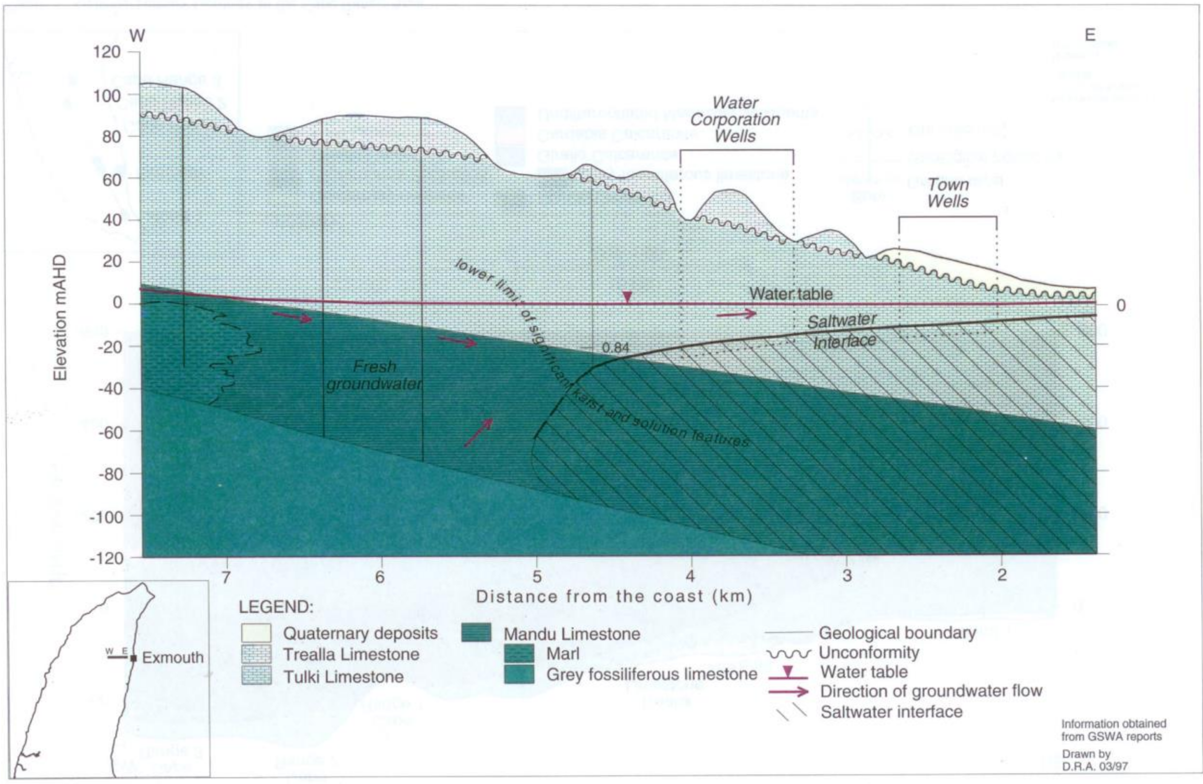

Figure 9. Generalised geology on the coastal plain near Exmouth (from WRC 1999).

In summary, while Exmouth Peninsula is rich in stygofauna there is uncertainty about the suitability of the habitat in the borefield for this group of animals. Salinity is unlikely to be a constraint on stygofauna occurrence but lithology may constrain occurrence both through providing minimal habitat for stygofauna in terms of interstitial spaces and voids and also through allowing limited recharge of energy and nutrients, especially since the watertable is moderately deep. This uncertainty about habitat suitability means sampling is required to determine whether or not stygofauna occur in the proposed borefield and which, if any, species are present.

6.2. Troglofauna

No species of stygofauna or troglofauna has been recorded from the proposed borefield area. However, the spiders *Yardiella humphreysi* and *Trichocyclus nigropunctatus* occur near the coast to the west of the borefield and the schizomid *Draculoides brooksi* occurs about 6 km directly south (see Figures 7 and 8).

The main determinants of troglofauna occurrence are suitable habitat in terms of subterranean spaces, high relatively humidity and a source of energy and carbon. The latter is usually provided by recharge from the surface or direct transport into caves. In most cases, relative humidity is maintained at depth by processes within the vadose zone (Hong Shou *et al*. 2011). Thus, lithology and the types and size of subterranean voids and fissures present can be the critical factors in determining occurrence of troglofauna (Howarth and Moldovan 2018).

Chip trays from bores within the proposed borefield (Figure 3) suggest that significant subterranean spaces are likely to be present in Tulki limestone above the watertable in this area. This fits the pattern across Exmouth Peninsula as a whole where numerous caves occur in the Tulki limestone. Accordingly, it would be expected that troglofauna occur in the borefield. In the Pilbara, more troglofauna is found hills, breakaways and other elevated areas where karstic or weathered rocks containing voids are exposed or have very little soil cover (Mokany *et al*. 2018). The same pattern appears to occur on the peninsula (Figure 7) but this could also be interpreted as reflecting the areas where larger caves occur and sampling has been greatest.

Given the above information, some troglofauna species are expected to occur in the borefield although the likely richness of the community is unknown.

7. THREAT TO SUBTERRANEAN FAUNA

There are two potential threats to subterranean fauna associated with development of the proposed new borefield and the changes to the wastewater system (ARUP 2019): lowering of the water table in the borefield reduces the volume of habitat potentially available to stygofauna, while open space irrigation with wastewater, as well as leakage from the WWTP, will increase nutrient concentrations in groundwater.

Troglofauna will not be affected by lowering of the watertable in the borefield, or by the activities associated with borefield construction and surface operation. Relative humidity is unaffected by small increases in depth to water and groundwater abstraction has little or no potential to affect other components of troglofauna habitat. Irrigation and increases in nutrients may affect troglofauna occurrence but any changes are likely to be small and there is insufficient information to assess small effects. It is considered likely that the threat of the proposed new borefield and wastewater issues to troglofauna conservation values will be low.

7.1. Groundwater Abstraction

The maximum drawdown around the production bores in the proposed borefield is predicted to be 0.4-0.6 m (Pennington Scott 2020). Drawdown is likely to extend almost 400 m from the borefield but in most of the area the lowering of the watertable will be very small.

The thickness of the borefield aquifer is approximately 30 m, with water in the upper layers ranging from subsaline to hyposaline and that at the base of the aquifer being mesosaline. All sections of the aquifer have salinities suitable for stygofauna and the species in the more saline sections of surface water will tolerate the mesosaline conditions in the deeper aquifer.

The overall reduction in volume of the habitat for stygofauna within the borefield itself will be reduced by no more than 0.5%. While the aim of abstraction is to skim off the fresher groundwater, which may result in loss of the small areas of subsaline (500-3000 µS/cm) water, overall very little habitat change will occur as a result of borefield operations.

It is not known which, if any, stygofauna species occur in the borefield but current knowledge of species ranges on the peninsula suggests it is highly unlikely that any species would have a range restricted to the vicinity of the borefield unless it represented a unique hydrogeological feature (see Figure 6). This is not the case because the borefield lies in an area of continuous Tulki limestone. While it is possible that listed stygofauna species may occur in the borefield, all of the species with potential to do so have wide ranges on the peninsula and their conservation status would not be threatened by borefield operations. Species of the Bundera Sinkhole community, the only listed stygofauna community on the peninsula, will not be found in the borefield because it requires an anchialine setting, which clearly does not occur there. The other recognised 'community', the Cape Range Subterranean Wetlands occurs north-east of the borefield (and elsewhere) but will not be affected by borefield operation. Accordingly, the threat of borefield operations to stygofauna conservation values is low.

7.2. Wastewater disposal

There is currently insufficient information to assess the potential impact of open space irrigation with wastewater, as well as leakage from the WWTP, on stygofauna conservation values. This is likely to increase nutrient concentrations in groundwater to an unknown extent, although the WWTP ponds will be lined. In studies elsewhere, high nutrient levels associated with sewerage have been shown to alter the composition of stygofauna communities, with inferences that some species are affected deleteriously (Hartland *et al.* 2011; Korbel and Hose 2011). However, it appears that in general stygofauna species are likely to be no more sensitive than to nutrients surface species (see Hose 2005). Elevated levels of organic matter have also been shown to change stygofauna community structure while Total N concentrations remained low (Sinton 1984; Graening and Brown 2003).

Surveys in the vicinity of Exmouth suggest that total nitrogen values (usually the main contamination from WWTPs together with increased biological oxygen demand) of up to 15 mg/L N do not adversely affect stygofauna occurrence (Bennelongia 2018).

8. CONCLUSIONS

Stygofauna and troglofauna probably occur in the borefield and nearby Project area, although habitat evaluation produces uncertain inference about the occurrence of both groups and there is no knowledge of any species occurring there.

The nature of borefield and wastewater operations mean that the likelihood of troglofauna conservation values being affected is low. Possible effects of wastewater treatment and irrigation are likely to be low but cannot be assessed with existing information.

The effect of groundwater drawdown, as a result of borefield operations, on stygofauna conservation values will be low. There is currently insufficient information to assess the likely impact of wastewater treatment and irrigation on stygofauna conservation values. However, it should be noted that no species is likely to be confined to the WWTP and area of irrigation effect.

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APPENDICES

Appendix 1. Stygofauna species on Exmouth Peninsula according to Museum records and literature.

Group	Species	Source[1]	Probable synonyms
Fish[2]			
Eleotricae	*Milyeringa veritas*	1	
Synbranchidae	*Ophisternon candidum*	2,3	
Oligochaeta			
Naididae	*Dero furcata*	1	
Tubificidae	*Aktedrilus parvithecatus*	1	*Aktedrilus* n. sp. 2 (WA18)
	Pectinodrilus ningaloo	1	*Pectinodrilus* n. sp. 1 (WA19)
Enchytraeidae	Enchytraeidae sp. B16	4	
	Enchytraeidae sp. B17	4	
Phreodrilidae	Phreodrilidae D sp. B11	4	
	Phreodrilidae S sp. B12	4	
Polychaeta			
Spionidae	*Prionospio thalanji*	1	
Syllidae	*Erinaceusyllis centroamericana*	1	*Sphaerosyllis centroamericana*
	Syllis cf. *broomensis*	1	*Typosyllus (Ehlersia)* cf. *broomensis*
Crustacea			
Remipede			
Speleonectidae	*Kumonga exleyi*	1	*Lasionectes exleyi*
Thermosbaenacaea			
Halosbaenidae	*Halosbaena tulki*	1	
	Halosbaena sp. CRE	5	
Ostracoda			
Limnocytheridae	*Gomphodella* sp.		
Candonidae	*Candonopsis tenuis*	1	
	Phlyctenophora mesembria	1	
	Humphreyscandona 'BOS630'	4	
	Humphreyscandona 'BOS639'	4	*s*
	Humphreyscandona 'BOS642'	4	
	Candonidae 'BOS628'	4	
Thaumatocyprididae	*Welesina kornickeri*	1	*Danielopolina kornickeri*
Cypridopsidae	*Sarscypridopsis ochracea*	4	
Copepoda			
Epacteriscidae	*Bunderia misophaga*	7	
Pseodocyclopidae	*Stygocyclopia australis*	1	
	Stygoridgewayia trispinosa	6	'Stygoridgewayia westaustraliensis'
Speleophridae	*Speleophria bunderae*	1	
	Speleophria 'BCA002'		
Cyclopidae	*Apocyclops dengizicus*	1	
	Diacyclops humphreysi	1	
	Dussartcyclops sp. B12	4	
	Halicyclops longifurcatus	1,8	
	Halicyclops spinifer	1	
	Orbuscyclops westaustraliensis	4	
	Metacyclops mortoni	1	
	Microcyclops varicans	1	
	Neocyclops 'BCY058'	12	
Ameiridae	*Ameira* 'BHA250'	12	
	Megastygonitocrella unispinosa	4	
	Nitokra fragilis	1	
	Nitokra humphreysi	1	
	Nitokra lacustris	1	
	Nitokra 'BHA251'		
	nr *Neonitocrella* sp. B01	4	

Group	Species	Source[1]	Probable synonyms
Ectinomatidae	*Ectinosoma* 'BHA244'		
Paramesochridae	*Apodopsyllus* 'BHA255'		
Miraciidae	*Amphiascoides subdebilis*	1	
Laophontidae	*Onychocamptus bengalensis*	1	
Tetragonicipitidae	*Phyllopodopsyllus wellsi*	1	
Phyllognathopodidae	*Phyllognathopus* sp. B01	4	
Canthocamptidae	*Australocamptus* nr *hamondi*	4	
Parastenocaridae	*Parastenocaris* sp. B36	4	
Syncarida			
Parabathynellidae	*Brevisomabathynella* sp.	1	\`Australobathynella brooksi\`
	Hexabathynella sp. B12	1,4	
Bathynellidae	*Bathynella* sp. B28	4	
Amphipoda			
Eriopisidae	*Norcapensis mandibulis*	1	*Elasmopus ?yunde*; Melitidae gen. nov.; *Psammogammarus/Victoriopisa* sp.; Melitidae gen. nov. nr *Norcapensis, Wesniphargus*
Hadziidae	*Hadzia branchialis*	1	*Liagoceradocus branchialis*
Melitidae	*Nedsia douglasi*	1,9	
	Nedsia 'sculptilis Cape Range'	4,12	*Nedsia* sp. B07 (*douglasi* grp)
Paramelitidae	Paramelitidae sp.	4	
Isopoda			
Cirolanidae	*Haptolana pholeta*	1,2	
Philosciidae	Philosciidae genus? sp. A	1	
	Philosciidae genus? sp. B	1	
Decapoda			
Aytidae	*Stygiocaris lancifera*	1,3,10	
	Stygiocaris stylifera	1,3,10	
	Stygiocaris sp. Bundera	1,11	
Mollusca			
Iravadidae	*Iravadia* sp.	1	
Thiaridae	*Melanoides ?tuberculata*	1	
Pupillidae	*Gastrocopta* CW1 sp. nov.	1	

[1] Source: 1 Western Australian Museum and W.F. Humphreys databases); 2 Knott (1993); 3 Humphreys and Adams (2001); 4 Bennelongia (2018); 5 Page *et al.* (2016); 6 Tang *et al.* (2008); 7 Jaume and Humphreys (2001); 8 Pesce *et al.* (1996); 9 Barnard and Williams (1995); 10 Holthuis (1960); 11 Page *et al.* (2008); 12 Bennelongia (2019)
[2] The introduced fish *Poecilia reticulata* has been recorded on the eastern coastal plain.

Appendix 2. Troglofauna[1] species on Exmouth Peninsula according to Museum records.

Group	Species
Acari	
Ascidae	*Cheiroseius* `sp. 1`
	`Genus indet.` `sp. 1`
Laelapidae	`Genus indet.` `sp. 2`
Araneae	
Corinnidae	*Nyssus albopunctatus*
Ctenidae	*Bengalla bertmaini*
	Janusia `sp. 2`
Deinopidae	*Deinopis* `sp. indet. (juvenile)`
Filistatidae	*Wandella barbarella*
	Wandella humphreysi
	Wandella waldockae
	Yardiella humphreysi
Gallieniellidae	*Oreo* `sp.`
Lamponidae	*Notsodipus capensis*
	Pseudolampona marun
Linyphiidae	*Chthiononetes tenuis*
	Dunedinia occidentalis
	`Genus indet.` `sp. indet. (juvenile)`
Oonopidae	*Opopaea* `Exmouth sp. 1`
	Prethopalpus alexanderi
	Prethopalpus infernalis
Pholcidae	*Trichocyclus nigropunctatus*
	Trichocyclus septentrionalis
Symphytognathidae	*Anapistula troglobia*
Isopoda	
Armadillidae	Armallidae sp.
Philosciidae	Philosciidae sp.
Pseudoscorpiones	
Chthoniidae	*Austrochthonius easti*
	Tyrannochthonius brooksi
	Tyrannochthonius butleri
	Tyrannochthonius `sp. nov.`
Hyidae	*Indohya damocles*
	Indohya humphreysi
Syarinidae	*Ideoblothrus papillon*
	Ideoblothrus woodi
Schizomida	
Hubbardiidae	*Bamazomus subsolanus*
	Bamazomus vespertinus
	Draculoides brooksi
	Draculoides julianneae
	Draculoides vinei

Group	Species
	Draculoides `SCH112`
	`SCHAAA` `SCH056`
	`SCHAAA` `SCH091`
Collembola	
Entomobryidae	*Sinella tropicalis*
Diplura	
Campodeidae	'Cocytocampa humphreysi' ms
Archaeognatha	
Meinertellidae	*Machilelloides incoloratus*
Thysanura	
Nicoletiidae	*Trinemura troglophila*
Blattodea	
Nocticolidae	*Nocticola flabella*
Orthoptera	
Gryllidae	*Ngamarlanguia luisae*
Hemiptera	
Reduviidae	Reduviidae sp.
Meenoplidae	*Phaconeura prosperina*
Coleoptera	
Carabidae	Lebiinae sp.
	Clivina sp.
Staphylinidae	Pselaphinae sp.
	Anabaxis sp.
	Durbos sp.
	Eupines sp.
Diplopoda	
Paradoxosomatidae	*Stygiochiropus communis*
	Stygiochiropus isolatus
	Stygiochiropus peculiaris
	Stygiochiropus sympatricus
Lophoproctidae	*Lophoturus madecassus*

[1]Likely troglobites and troglophiles, based on collection information