# LAKE MACKAY POTASH PROJECT: CONSOLIDATED SUBTERRANEAN FAUNA STUDY

PREPARED FOR **AGRIMIN LTD**

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Stantec

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# Executive Summary


**Background and Objective**

Agrimin Ltd (Agrimin) are proposing to develop the Mackay Potash Project (the Project) into a fertiliser operation. The Project is located on and surrounding Lake Mackay, approximately 450 km south of Halls Creek, in the Shire of East Pilbara, Western Australia. Stantec Australia Pty Ltd (Stantec) was commissioned by Agrimin to undertake a subterranean fauna study at Lake Mackay (the Study) and consolidate previous surveys. The objective was to increase understanding of subterranean fauna values within the Study Area.

**Sampling Effort**

The Study comprised five field surveys conducted in 2020 and 2021 (January, May/June, August and October 2020 and April 2021). It targeted a portion of the Study Area, including three Development Envelopes and the Southern Regional area. The sampling effort for the Study can be summarised as follows:

- On-Lake Development Envelope – On-LDE playa:
  - Nine stygofauna haul samples (including groundwater monitoring, where possible) collected from eight sites.
  - No troglofauna sampling (litter trapping) due to close proximity of groundwater to surface.
- On-Lake Development Envelope – On-LDE islands:
  - 23 stygofauna haul samples (typically including groundwater monitoring) and one hand auger sample collected from eleven sites.
- Southern Infrastructure Development Corridor (SIDE):
  - 12 stygofauna haul samples (including groundwater monitoring) collected from four sites within the proposed SIDE borefield.
  - Seven litter traps deployed across four sites.
- Southern Regional area – outside of development envelopes:
  - 14 stygofauna haul samples (including groundwater monitoring) collected from five sites.
  - 13 troglofauna litter traps deployed across seven sites.

Previous stygofauna surveys undertaken in the Study Area (a pilot survey and Level 1 survey completed in 2017) were also consolidated. The total sampling effort comprised 11 stygofauna samples for the On-LDE playa, 25 stygofauna samples for the On-LDE islands, 12 stygofauna samples for the SIDE and 31 stygofauna samples for the Southern Regional area. The total stygofauna sampling effort for the Study Area (79 samples) exceeded the recommended guidance for a Level 2 stygofauna survey (40 samples), with sampling undertaken across multiple seasons.

For troglofauna, the consolidated sampling effort totalled seven troglofauna litter trap samples for the SIDE and 17 troglofauna litter trap samples and two scrape samples for the Southern Regional area. These totals either approached or exceeded the recommended sampling effort for troglofauna pilot surveys (10 to 15 samples). Troglofauna litter trapping was not undertaken at the On-LDE playa or On-LDE islands during the Study or previous surveys.

**Results**

A total of 73 stygofauna/potential stygofauna specimens were recorded during the Study across the five field surveys, representing three higher level taxonomic groups. These included the oligochaete order Haplotaxida, the crustacean sub-class Copepoda and Bathynellacea of the superorder Syncarida.

Stygofauna specimens during the Study were recorded from the On-LDE islands (predominantly landform islands) and the Southern Regional area, with a potential stygofauna taxon, Enchytraeidae sp., recorded from the SIDE borefield. No stygofauna were recorded from the On-LDE playa, with habitat considered not prospective, comprising fine textured lacustrine sediments and hypersaline groundwater.

The majority of stygofauna taxa collected during the Study have been recorded during previous surveys, or where juvenile specimens were identified, are likely belong to an existing taxon from the Study Area. Of these, undescribed species including the parabathynellid *Atopobathynella* sp. 'mackay', and the cyclopoid copepod 'Mackaycyclops' sp. were recorded from the Southern Regional area. An undescribed species; the harpacticoid copepod *Schizopera* ?'bradleyi', was recorded from the On-LDE islands, although is considered likely to correspond with the previously identified *Schizopera* 'bradleyi'. The diversity of stygofauna was slightly higher within the Southern Regional area, which contains a large surficial calcrete aquifer system. The abundance was comparable between the Southern Regional area and On-LDE islands (predominantly landform islands).

A single potential troglofauna taxon; the dipluran Projapygidae-OES3, was collected from one of the On-LDE landform islands, as by-catch from a stygofauna net haul during the Study. There is a paucity of information on diplurans, making it difficult to determine whether the taxon is a troglobite (obligate troglofauna) or edaphofauna (soil-dwelling), although it is potentially endemic to the Study Area.

The results from this Study reflect those from previous surveys within the Study Area. The surficial calcrete unit of the Southern Regional area (outside of the Project's Development Envelopes), and the minor areas of calcrete outcropping on the On-LDE islands (not subject to direct impacts), intersecting low salinity groundwater, host stygofauna communities. This includes a number of undescribed species potentially endemic to the Study Area.

No stygofauna have been recorded from the On-LDE playa where Agrimin propose to develop their brine abstraction trench network. Despite the collection of the potential stygofauna Enchytraeidae sp. from the SIDE borefield, it is considered likely that this taxon is widely distributed within the broad alluvial unit and does not represent a significant stygofauna community. A summary of comparative subterranean fauna values (based on diversity, abundance and species significance of the consolidated dataset) is provided in **Table ES1**.

Table ES1: Summary of consolidated subterranean fauna values from Study Area.

| Area | Characterisation | Significant Species | Values |
|---|---|---|---|
| On-LDE Playa | Sand/silt/clay/gypsum with limited interconnected voids, groundwater close to surface, hypersaline (>100,000 mg/L) | None | Negligible |
| On-LDE Islands | Larger (landform) islands host some calcrete within the gypsiferous sands, with lower salinity water (<60,000 mg/L) | **Stygofauna**<br>*Schizopera* 'bradleyi'^<br>**Troglofauna**<br>Projapygidae-OES3^ | Moderate |
| SIDE Borefield | Clayey sandstone overlain by silty clay, fresh to brackish water (<6,500 mg/L) | None | Limited |
| Southern Regional Area | Calcrete and unconsolidated sediments, with lower salinity water (<50,000 mg/L) | New species of syncarid, copepods, ostracod and coleopterans | High |

*Note: grey text outside of Development Envelopes and no Project impacts expected; ^ potentially new and/or restricted.*

# Agrimin Ltd

## Lake Mackay Potash Project: CONSOLIDATED Subterranean Fauna STUDY

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# 1. Introduction

## 1.1 Project Background

Agrimin Limited (Agrimin) are proposing to develop the Mackay Potash Project (the Project) into a fertiliser Sulphate of Potash (SOP) operation. The Project is located on Lake Mackay, approximately 450 km south of Halls Creek (**Figure 1-1**) and comprises 12 tenements totalling 4,370 $km^2$ across the lake. Agrimin propose to extract hypersaline groundwater within the lakebed sediments, via a network of shallow trenches that will extend to an average depth of 3 m below the surface. Groundwater will flow along these trenches into a series of evaporation ponds located in the western part of the lake, to precipitate SOP-bearing salts. The salts will be wet harvested and pumped to an adjacent process plant, producing SOP as dry granular product, with distribution via a proposed port facility in Wyndham.

The Study Area for the Project is based on previous survey work across all environmental factors. It is large, at 443,985 ha, and incorporates four Development Envelopes (**Figure 1-2**). Stantec Australia Pty Ltd (Stantec) was commissioned by Agrimin to undertake a subterranean fauna study (the Study), comprising five field surveys, and consolidate the findings from previous subterranean fauna surveys. A portion of the Study Area was included, focusing on:

- **On-Lake Development Envelope (On-LDE)** – comprising the playa of Lake Mackay (Western Australian portion) and its islands. The former hosts the brine within lake-bed sediments where SOP will be abstracted, while some of the larger islands (outside of the development envelope) may host lower salinity groundwater within the island aeolian sediments.
- **Southern Infrastructure Development Corridor (SIDE)** – infrastructure corridor south of the lake, designated as a process and potable water supply area within alluvials, with a proposed borefield (SIDE borefield) to satisfy a process water demand of 3.5 GL/annum.
- **Southern Regional area** – south of the lake and east of the SIDE (outside proposed development envelopes), containing a large, surficial calcrete aquifer.

Pilot and Level 1 subterranean fauna surveys were completed in the Study Area in 2017 (Invertebrate Solutions 2017;2018). These surveys primarily targeted calcareous deposits within the Southern Regional area and beneath one large On-LDE island near the Northern Territory border. Stygofauna were recorded from both areas, including several undescribed genera and species. The surveys also targeted a small number of sites within the proposed On-LDE playa brine abstraction network, as well as the deep alluvial aquifer near the SIDE, with no subterranean fauna recorded from these areas. Subsequently, Agrimin commissioned Stantec to undertake this Study, which included additional sampling effort and consolidation of previous results.

## 1.2 Scope and Objectives

The objective of the Study was to increase understanding of subterranean fauna values in the Study Area, focusing on the On-LDE playa, On-LDE islands, SIDE borefield and Southern Regional area. Key tasks undertaken to address this objective comprised:

- sampling for stygofauna throughout the Study Area across five field surveys (January, May/June, August, October 2020 and April 2021);
- sampling for troglofauna in the SIDE borefield and Southern Regional area across two field surveys (January 2020 and August 2020);
- laboratory analysis of stygofauna and troglofauna samples and higher identification;
- characterisation of subterranean fauna habitat within the Study Area, based on available geological and hydrogeological information;
- analysis of subterranean fauna results in relation to habitat, known biological traits and findings of previous studies.

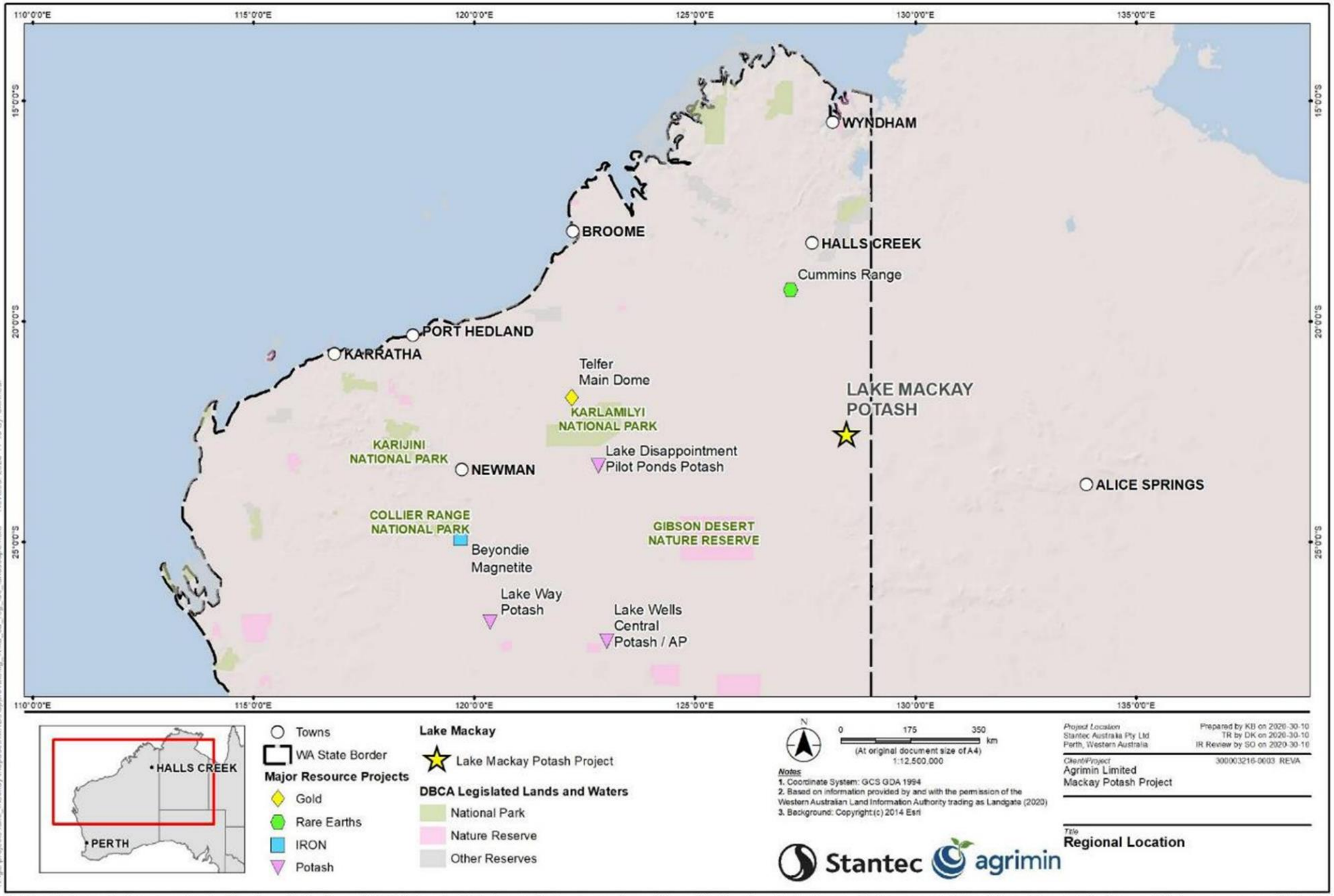


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Figure 1-1: Regional location of the Project in relation to other resource deposits and nature reserves.

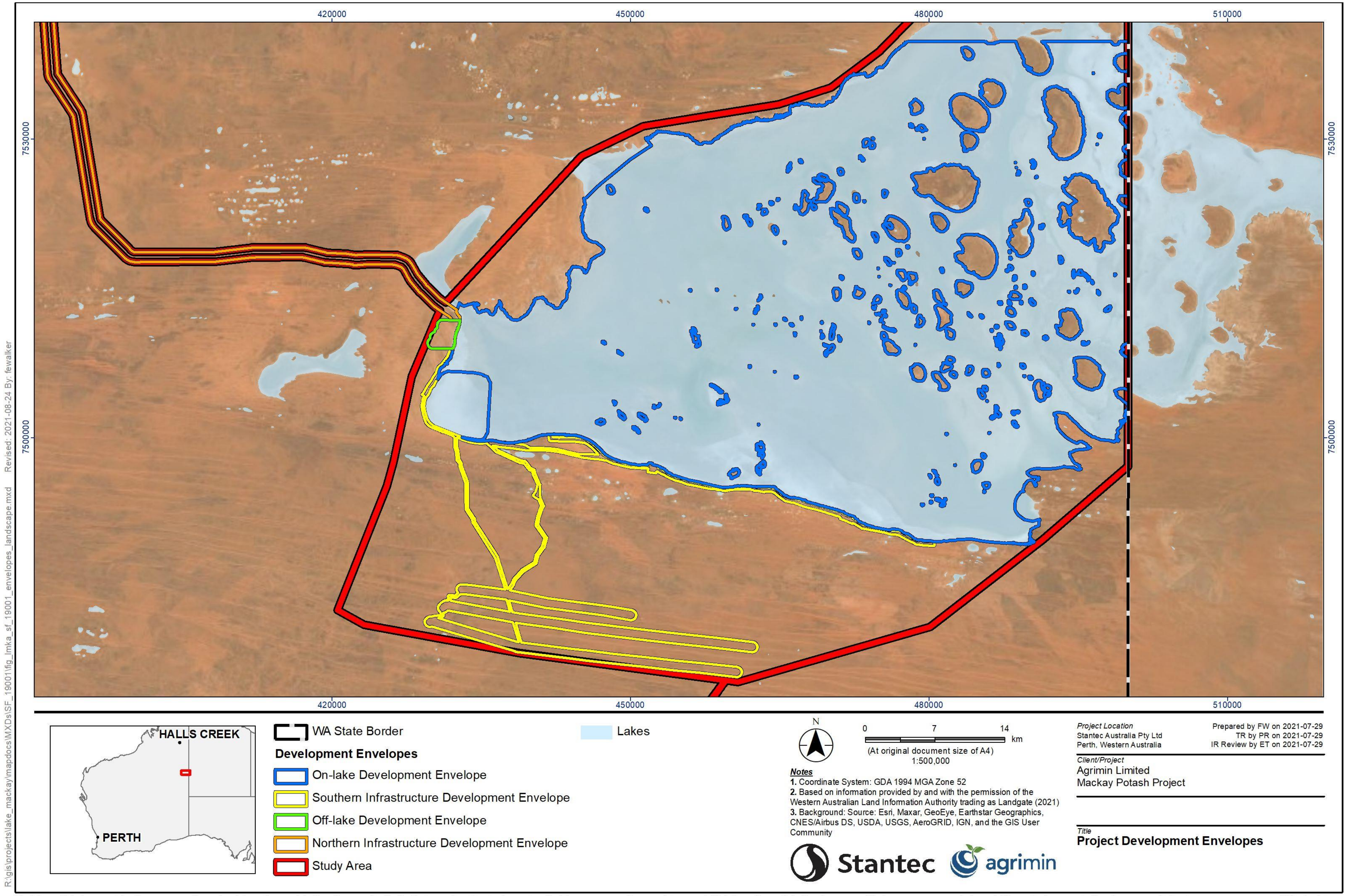


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Figure 1-2: Study Area indicating the four development envelopes of the Project (note the Off-LDE and NIDE were not part of this Study).

# 2. Existing Environment

## 2.1 Biogeographical Region and Land Use

The Project lies within the Great Sandy Desert (GSD02) Mackay subregion of the Great Sandy Desert bioregion, as defined by the interim Biogeographical Regionalisation for Australia (IBRA) classification system (Thackway and Cresswall 1995). The GSD02 is primarily located in Western Australia (75%) and extends into the Northern Territory (25%) encompassing 18,636,695 ha from the northern Pilbara coast across to the centre of the Northern Territory (Department of Agriculture Water and the Environment 2005).

The Project is located within the south east of the Western Australian portion of the subregion and is characterised by gently undulating plains, dominated by longitudinal dunes of varying frequency and lateritised uplands of shrub steppe such as *Acacia pachycarpa*. Calcrete and evaporite surfaces associated with palaeodrainage systems traverse the desert, including extensive salt lake chains with low samphire (*Tecticornia*) shrublands (Kendrick and McKenzie 2001).

The tenure of the Great Sandy Desert bioregion mostly consists of unallocated crown land, conservation reserves and aboriginal land with the main industries being mining and mineral exploration. Pastoral lands only comprise 7% of the bioregion (Department of Agriculture Water and the Environment 2005). In the vicinity of the Project, the predominant uses are traditional indigenous use, residual native cover, managed resource protection and conservation and natural environments (Kendrick 2001).

## 2.2 Climate

In the GSD02 Mackay subregion, the climate is characterised as arid tropical, with low, variable rainfall that is often unpredictable (Kendrick 2001). Rainfall is also influenced by tropical cyclones off the Pilbara and Kimberley coasts. Evaporation throughout the region is very high, averaging 2,800 to 3,200 mm per year.

The nearest Bureau of Meteorology (BOM) weather station to the Project with reliable long-term and recent climatic data is Walungurru Airport (station number 015664) (Kintore). Walungurru Airport station is located approximately 135 km south east of the Project and has been collecting rainfall data since 1998 and temperature data from 2001.

The mean long-term annual rainfall (2001 to 2021) for Walungurru Airport is approximately 280 mm (Bureau of Meteorology 2021a), with most rainfall occurring between December and March. In 2019, the total rainfall (30 mm) was well below the annual average, with less than 1% of the long-term average rainfall received during several months (**Figure 2-1**). The below-average rainfall followed a broader trend observed in most parts of Western Australia and nationally, with 2019 documented as the driest year on record (Bureau of Meteorology 2020). Subterranean fauna sampling at Lake Mackay commenced in January 2020, with subsequent field surveys in May/June, August and October 2020 and April 2021. In line with 2019, rainfall during this period was also substantially lower than the long-term monthly averages for most months. December 2020 was an exception, exceeding the long-term monthly average by 16 mm. Above average rainfall was also recorded in February and March 2021. The total for the latter (87 mm) was two-fold the long-term monthly average, with 59 mm received in a 24-hour period (Bureau of Meteorology 2021b).

A rainfall gauge installed by Agrimin on the edge of Lake Mackay in 2015 revealed a similar pattern. Rainfall in 2019 was consistently below average, with the total received in the 12 months prior to the first field survey of the Study equating to approximately 20% of the long-term average for the broader area. The trend continued in 2020. As with Wulungurru Airport, substantial rainfall was only recorded at the Agrimin weather station in December 2020. By comparison, rainfall in the three months preceding the April 2021 field survey totalled 180 mm, exceeding the long-term average for January to March by 60 mm.

Mean minimum and maximum temperatures at Wulungurru Airport (January 2019 to March 2021) were typically higher than the long-term mean monthly temperatures. The highest mean maxima were recorded in January 2019, February 2019 and December 2019 (>41 °C (**Figure 2-1**). On average, temperatures were lowest in June and July 2020 **(Figure 2-1).**

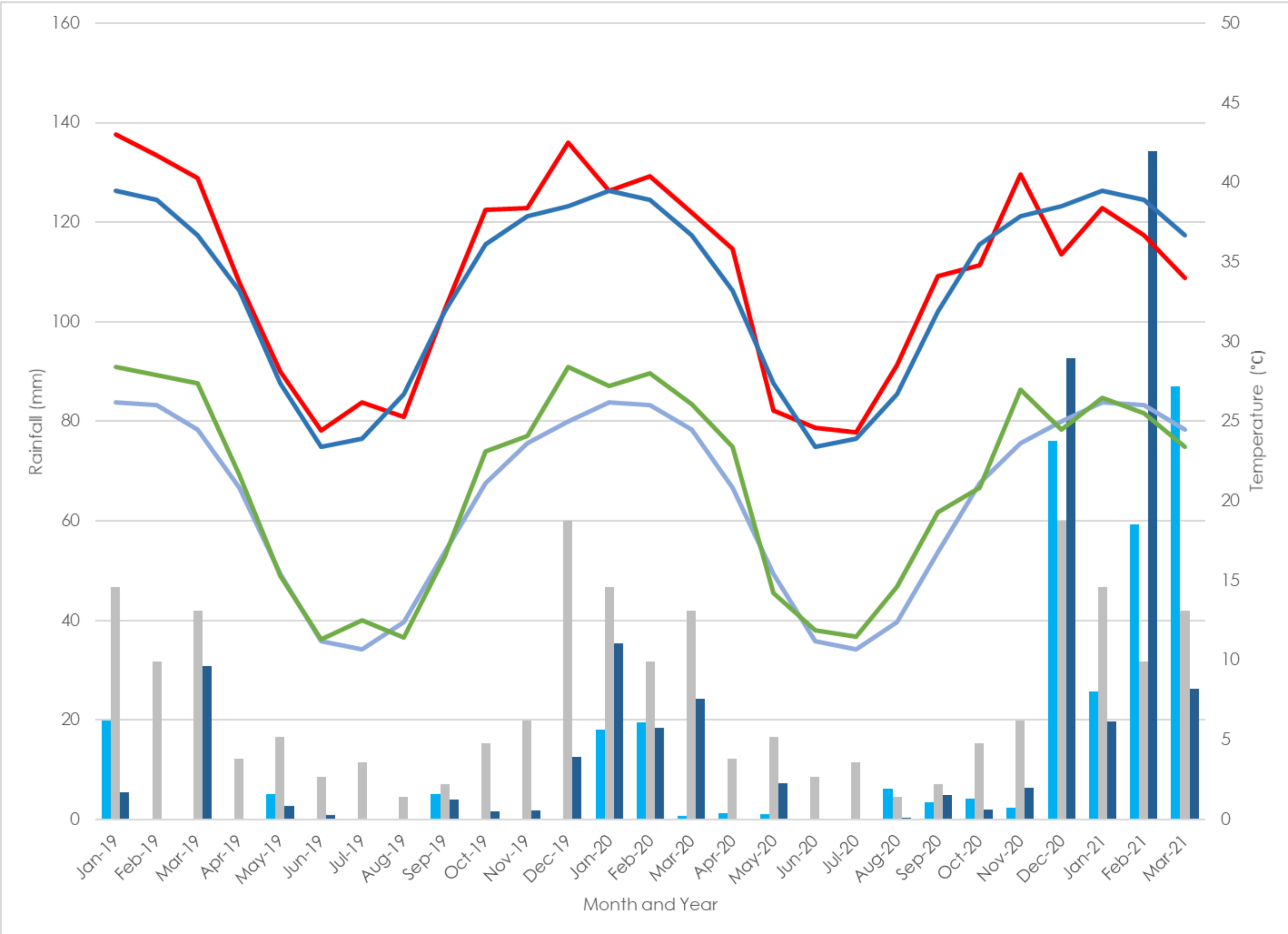


Figure 2-1: Monthly rainfall recorded at the Agrimin weather station, Lake Mackay (■) and Walungurru Airport (Station No. 15664) (■) and mean minimum (-) and maximum temperature (-) recorded at Walungurru Airport, compared to the long-term (1998-2021) mean monthly rainfall (■), long-term (2001-2021) mean monthly maximum temperature (-) and minimum temperatures (-) (Wulungurru Airport).

## 2.3 Geology

### 2.3.1 Lake Geology

The surface of Lake Mackay typically comprises a thin crust (<5 mm), of evaporitic material, predominantly halite (**Figure 2-2**). In the west of the lake halite coverage is more extensive than in the east, where it becomes patchy and interspersed with increasing proportions of gypsum and windblown quartz sands. The western halite crust typically forms a near horizontal surface, whereas the lakebed surface in the east is noticeably more undulating, and contains air filled vugs/void spaces. The halite crust has been observed to dissolve rapidly after rainfall and reprecipitate when flood waters evaporate.

Across much of the lake surface, the halite crust is underlain by variably decomposed organic material, which can be up to several centimetres thick and generally occurs at surface, or within ~5 cm of surface. This organic layer is often exposed in patches where surficial halite is not present. The relatively thin crust of halite and organics is underlain by a variable lakebed sequence which displays distinct characteristics east-west across the lake area.

The remaining lacustrine or lakebed sediment sequence of Lake Mackay is characterised into three broad lithological units, including:

- fine to coarse grained gypsum sand, with an approximate thickness of 1 m that varies laterally east-west across the lake. Gypsum sand horizons are noticeably thicker in the east. This unit progressively grades downward into clayey and silty sand approximately 3 m below ground level (mbgl);
- sandy and silty clay, containing discrete interbedded layers of evaporites (including granular/crystalline gypsum, halite and calcite), and organics continues to around 150 mbgl. The density of the clays increases with depth; and
- a palaeochannel unit in the southern section of the lake, comprising sands and gravels, with minor silt and clay continues to a known depth of 211 mbgl. The upper part of this unit contains discrete detrital iron, lignites and evaporite horizons. The lakebed sediments are unconformably underlain by highly weathered pelitic bedrock.

The shallow lakebed sediments are the primary geological unit of interest within the On-LDE and vary in composition from east to west due to varying depositional processes. This has been summarised in **Table 2-1**.

### 2.3.2 Island Geology

Lake Mackay is host to more than 270 islands within the On-LDE, which are not expected to be disturbed directly by the development of the Project. These range from small unvegetated formations to large formations that host extensive sand dunes. The islands range from less than 1 m in height to more than 13.5 m, with the larger islands providing the greatest topographic relief. Drilling investigations completed on six lake islands confirmed that they are surficial features of variable thickness underlain by lakebed sediments and are not linked to another subsurface geologic feature.

The lake islands are composed of unconsolidated aeolian sand at surface which is underlain by calcrete and gypsiferous sand (**Figure 2-2**). Clay content increases with depth and typically marks the transition from island sediments to the lakebed sediments. The thickness of the island sequences varies depending on the size of the island and topographical elevation.

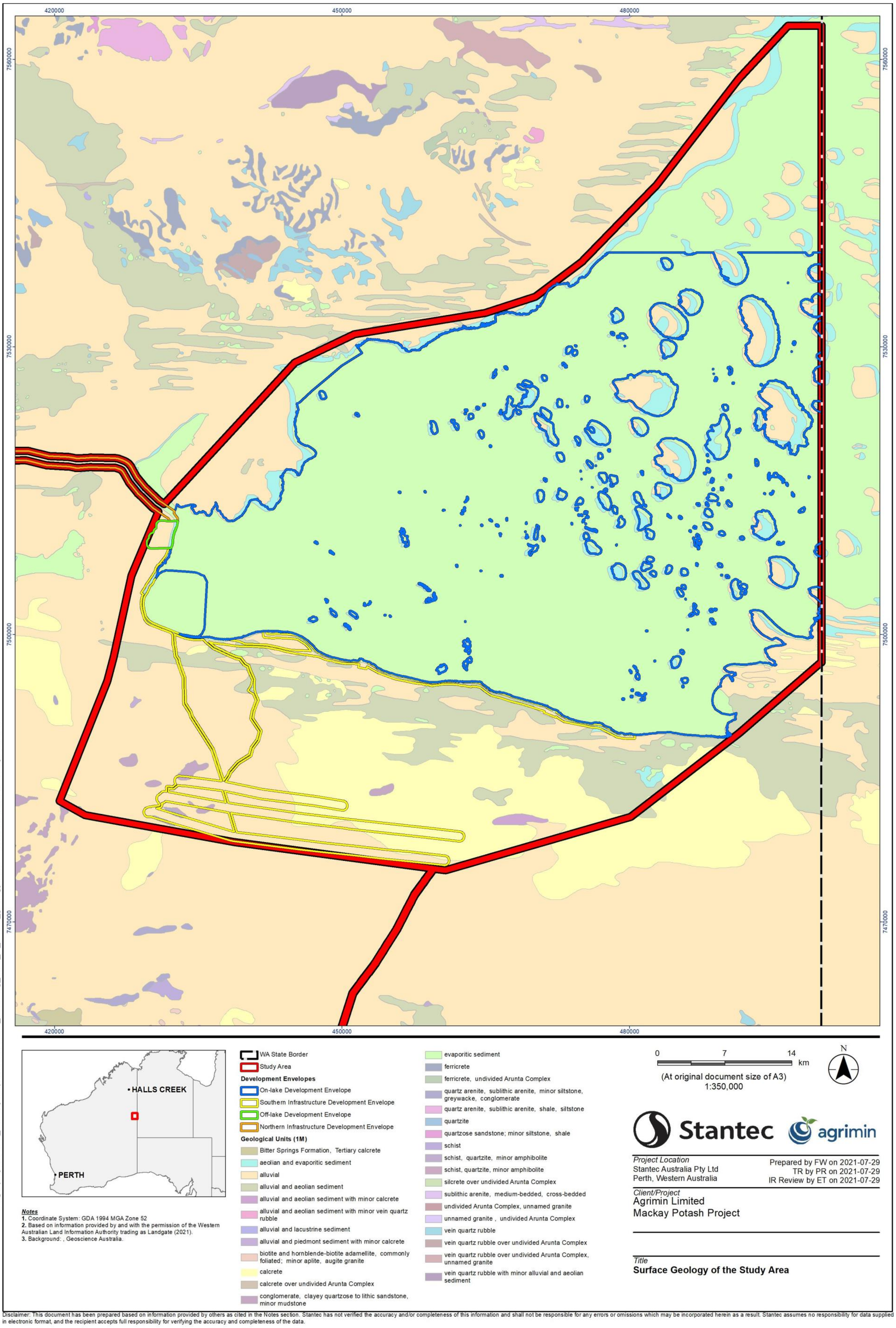


Figure 2-2: Surface geology of the Study Area.

Table 2-1: Lake Mackay summary of lithology descriptions.

| Lithology | Description |
|---|---|
| Surficial Halite | Surficial halite layer occurs as <5mm white crystalline evaporite layer in the western and central areas of the lake. In the east the surficial halite is intermixed with pale brown fine to medium gypsum sand and forms a brittle crust with many voids and vugs. |
| Organic Material | A dark grey organic layer (preserved material) ranges in thickness from 3 mm to 30 mm. This layer lies immediately below the salt crust in the western and central areas of the lake and is exposed at the surface in depressions where the surficial halite crust has been dissolved. In the east, this layer occurs at variable depths immediately above the water table and first occurrence of clay. |
| Gypsum Sand | Gypsum sand is widespread across the lake and occurs in the western and central areas as interbedded layers in silt and clay layers. Gypsum sand in the eastern region of the lake immediately underlies the brittle crust and makes up a major portion of the sediment profile. It varies from fine to coarse and is friable and unconsolidated. |
| Red Brown Clay | Red brown clay with interspersed bands of crystalline gypsum sand is the dominant lithology on the lake. It occurs within 0.1m of the surface in the west and up to 1.0 m from the surface in the east. |
| Crystalline Gypsum | Crystalline gypsum occurs as both interspersed crystals <50 mm in size at the lake water table and large laterally continuous horizons of consolidated crystal growths >100 mm at between 3 to 6 m depth, primarily encountered in the eastern region of the lake. |

### 2.3.3 SIDE and Southern Regional Geology

Within the SIDE, south of Lake Mackay, exploration has focussed on identifying a processing water supply for the Project. The geology in this region comprises rocks of the Amadeus Basin. The western portion of the SIDE is dominated by the Angas Hills Formation consisting of interbedded pebble and cobble conglomerate, sandstone, pebbly sandstone and siltstone, with a matrix of clayey sandstone and minor mudstone. The eastern portion of the SIDE hosts a sequence of sandstone, siltstone and shale and is consistent with the Carnegie/Pertatataka Formation.

These are overlain by Tertiary palaeochannel deposits of silty clay and clay over sand in some areas, and broad alluvial cover of Neogene age predominantly comprising a clayey sandstone, sand, quartz and silt/clay matrix (**Figure 2-2**). Historic logs from exploration targeting uranium and iron oxide copper gold mineralisation immediately east of the SIDE (Southern Regional area) identified clay and sand sequences overlain by a laterally extensive silcrete layer at 40 m and a similarly extensive calcrete layer at the surface (**Figure 2-2**) (Brooker and Fulton 2016).

## 2.4 Groundwater

The results of extensive groundwater investigations were used to develop an integrated groundwater flow and solute transport model for Lake Mackay, and a conceptual schematic cross section of groundwater associated with the playa and islands (**Figure 2-3**). Recharge, a key parameter investigated, is predominantly from direct rainfall onto the lake surface. Surface water contributions from the immediate catchment areas surrounding the lake are infrequent and only occur as a result of major rainfall events. As the lake is a terminal drainage point for the surrounding watershed, discharge is solely from evaporation and evapotranspiration.

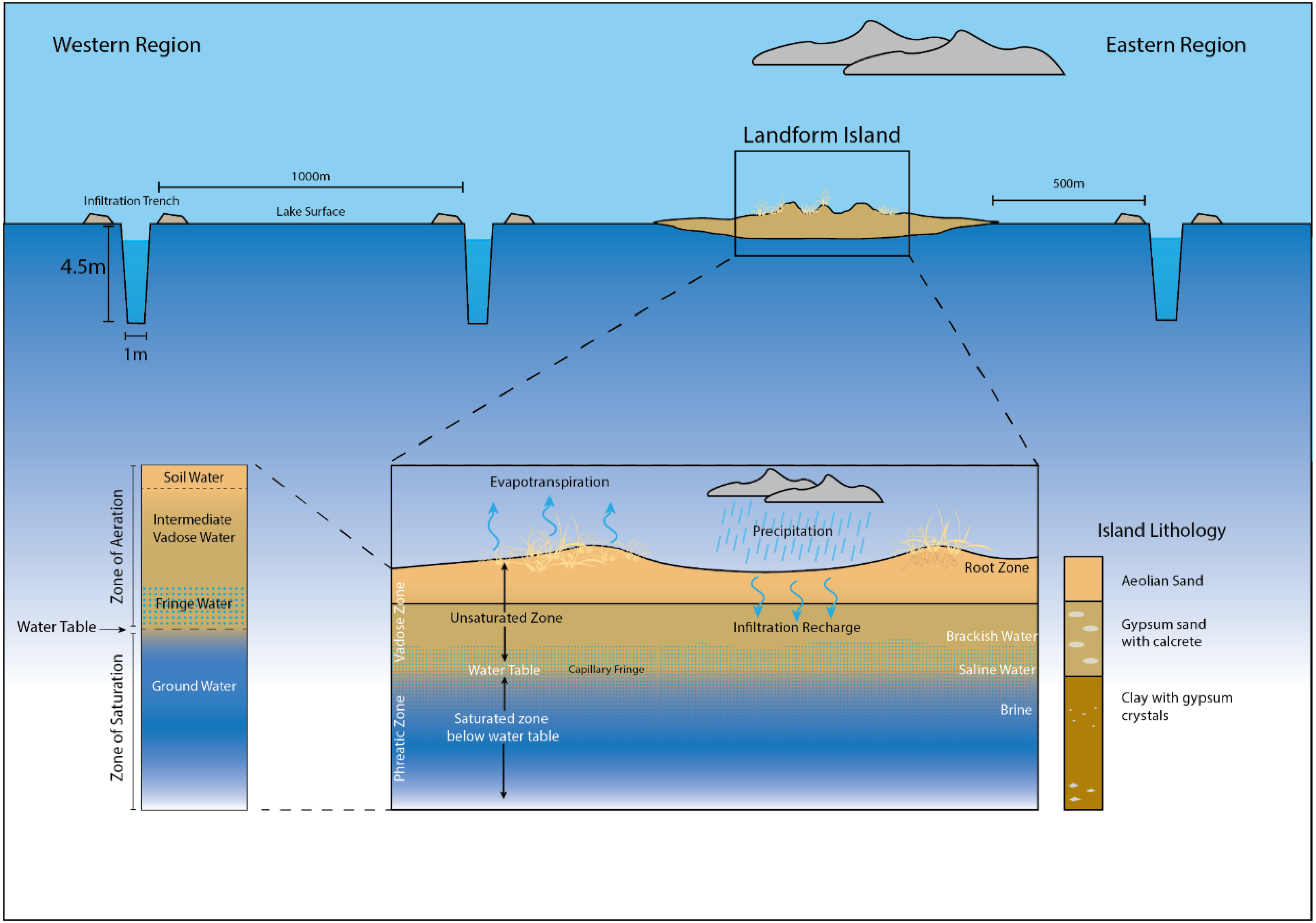


Figure 2-3: Conceptual schematic cross section of Lake Mackay and islands.

### 2.4.1 Lake Groundwater

Groundwater level monitoring across Lake Mackay, including monitoring of test trenches and piezometers, shows seasonal fluctuations ranging from 0.4 to 0.7 mbgl, with an average fluctuation of 0.3 m. Groundwater levels at monitoring bores also tend to increase rapidly in response to the first major rainfall event of the wet season. Levels subsequently decrease, and during extended dry conditions show an overall reduction across the lake (Agrimin 2020b).

Groundwater sampling and monitoring at Lake Mackay (Agrimin 2021) indicates the lakebed sediments are characterised by circumneutral pH (mean of 6.6), with naturally elevated nitrate concentrations. Groundwater salinity of lakebed sediments varies across the lake, although is typically greater than 200,000 mg/L, with a maximum of approximately 340,000 mg/L. In contrast, the major ionic constituents of the lakebed sediments are consistent, comprising a cation dominance of Na>K>Mg>Ca, and an anion sequence of $Cl>SO_4>HCO_3$. (**Appendix A**).

### 2.4.2 Island Groundwater

The depth to groundwater on the islands of Lake Mackay varies, depending on immediate topography, however, is typically less than 5 mbgl (Agrimin 2020a). Groundwater levels are influenced by a dynamic equilibrium between precipitation, evaporation and evapotranspiration.

The largest landform islands in the eastern portion of the lake also appear to host a lower salinity water (**Appendix A**), within the porous gypsiferous sands that overlay the clay dominant lakebed sediments (brine). The pH is typically circumneutral (mean 6.9), with naturally elevated nitrate concentrations. Salinities are typically below 60,0000 mg/L, with an ionic composition dominated by Na and Cl (**Appendix A**).

The lower salinity groundwater is likely associated with the infiltration of rainfall into the shallow, permeable aeolian sediments and where present, with calcrete outcrops. Seasonal fluctuations in water levels are expected on the islands, associated with both temporal water levels within the aeolian sands and the deeper lakebed sediments.

### 2.4.3 SIDE and Southern Regional Area

Groundwater modelling was undertaken to the south of Lake Mackay, targeting the SIDE borefield, to assess the prospectivity of aquifer units to meet processing water requirements for the Project. The aquifer units in the area include the alluvial Neogene deposits, Angas Hills Formation and Carnegie Formation. Tertiary paleochannel clay forms an aquitard, and where present separates aquifers within the Neogene Deposits and Angas Hills Formation. The Carnegie/Pertatataka Formation is an aquitard forming a basement to the overlying effective aquifers (CDM Smith 2020).

Two prospective aquifer units have been identified in the SIDE borefield between 5.8 and 8.2 mbgl, primarily intercepting the aquifer hosted within the shallow Neogene alluvials. Depth to water table corresponds, ranging between 5.8 mbgl and 8.2 mbgl (CDM Smith 2020). The units host groundwater characterised by circumneutral pH (mean 7.3), with salinity concentrations ranging from approximately 1,600 mg/L to 6,300 mg/L (**Appendix A**). In comparison, bores in the surrounding Southern Regional area range from less than 5,000 mg/L to approximately 47,000 mg/L, with concentrations decreasing with distance from the lake.

# 3. Subterranean Fauna

Subterranean fauna inhabit underground environments and are often relictual forms of surface dwelling (epigean) groups. They can be divided into stygofauna and troglofauna; the former are aquatic, occupying groundwater systems, with the latter persisting in air-filled voids. Both groups often display evolutionary adaptations according to their subterranean existence, including reduced pigmentation, poorly functioning or non-existent eyes, and the presence of extended locomotory and sensory appendages. Subterranean fauna comprise both invertebrate and vertebrates, with the former prevalent in Western Australia (Culver and Pipan 2009; Environmental Protection Authority 2016b). Both stygofauna and troglofauna have short-range endemic (SRE) species that have geographically restricted ranges of less than 10,000 $km^2$ and are considered vulnerable to extinction (Harvey *et al.* 2011).

## 3.1 Habitat

Prospective habitat for subterranean fauna (stygofauna and troglofauna) is dependent on the presence of sub-surface crevices, fractures and voids of suitable size and connectivity to satisfy biological requirements. Adequate interconnected spaces and associated high permeability allows for movement of subterranean fauna. They can also provide pathways for infiltration of resources such as oxygen and nutrients, key factors influencing subterranean fauna (Humphreys 2008; Strayer 1994).

For stygofauna, geologies with suitable secondary porosity can include karst, calcrete, coarse alluvium, fractured rock, pisolites and thin, rocky regoliths (Halse *et al.* 2014; Humphreys 2006a; Humphreys 2008; MWH 2016a;c; Outback Ecology 2014). Troglofauna occur in karstic and non-karstic geologies such as calcrete, alluvium, vuggy pisolite ore beds and fractured and weathered rock formations (Barranco and Harvey 2008; Bennelongia 2009; Halse *et al.* 2002; MWH 2014; Outback Ecology 2011a; Subterranean Ecology 2008). Humidity is also a key requirement for troglofauna existence (Environmental Protection Authority 2016a).

## 3.2 Stygofauna

Stygofauna predominantly comprise crustaceans (such as ostracods, copepods, amphipods and syncarids), while other invertebrate stygofauna groups can include gastropods (snails), insects, water mites and worms. In Western Australia, studies have shown that calcrete and alluvial aquifers associated with palaeodrainage channels of the arid and semi-arid zones can contain rich stygofauna communities. The Pilbara and to a lesser extent the Yilgarn regions, stand out as global hotspots for stygofauna diversity (Halse and Pearson 2014; Humphreys 2008).

Stygofauna can be classified according to their level of dependency on the subterranean environment:

- stygoxenes are animals that enter groundwaters passively or accidentally;
- stygophiles inhabit groundwaters on a permanent or temporary basis; and
- stygobites are obligate groundwater dwellers.

## 3.3 Troglofauna

Troglofauna include arachnids (pseudoscorpions, palpigrades, schizomids), insects and myriopods (such as millipedes and symphylans). Diverse troglofauna assemblages in Western Australia have been found in karst cave systems on Barrow Island and at Cape Range (Hamilton-Smith and Eberhard 2000; Humphreys and Harvey 2001). Calcrete and alluvial/colluvial deposits in palaeodrainage systems throughout the Pilbara and Yilgarn regions also provide habitat for troglofauna (Harrison *et al.* 2014; MWH 2015; Platnick 2008). However, there is still relatively little information on their distribution compared to stygofauna (Eberhard *et al.* 2007; Environmental Protection Authority 2016b).

Troglofauna can be divided into:

- troglophiles, which carry out most of their lifecycle underground but are able to survive in epigean habitats;
- trogloxenes, which can enter subsurface habitats passively or accidentally; and
- troglobites, which are obligate or permanent subterranean inhabitants (Thurgate *et al.* 2001) that generally lack pigmentation, are blind (or have reduced eyes), have elongated limbs and may possess enhanced non-visual sensory adaptations.

## 3.4 Relevant Legislation and Risk

Subterranean fauna are protected under State and Federal legislation including:

- *Biodiversity Conservation Act 2016* (WA) (BC Act);
- *Environmental Protection Act 1986* (WA) (EP Act); and
- *Environment Protection and Biodiversity Conservation Act 1999* (Cth) (EPBC Act).

The development and operation of mines in Western Australia poses multiple risks to subterranean fauna and their habitat, including:

- direct removal of, or disturbance to, habitats through mining excavation;
- lowering of the groundwater table via abstraction for pit dewatering and supply; and
- changes to water quality, which may exceed species tolerance limits.

Mining proposals that may impact on habitat that supports subterranean fauna requires environmental impact assessment (EIA) so that operations do not threaten significant communities or species. Proponents must demonstrate that any species existing within potential impact zones also occur outside this area. For taxa restricted to impact zones, a suitable management plan must be developed, which includes ongoing monitoring of subterranean fauna to ensure the persistence of the species.

## 3.5 Regulatory Guidance

The EPA's objective for subterranean fauna is to maintain representation, diversity, viability and ecological function at the species, population and assemblage level (Environmental Protection Authority 2016b). The EPA guidance (2016a) states that the appropriate level of survey depends on the likely presence of subterranean fauna, the degree of impact and survey adequacy for the EIA process. In areas where the likelihood is expected to be low, a level 1 (pilot) survey may be sufficient. The recommended Level 1 sampling effort, considered to provide a reliable indication of habitat prospectivity is:

- stygofauna – six to 10 samples; and
- troglofauna – 10 to 15 samples.

If subterranean fauna are recorded during the Level 1 survey or, in areas where the likelihood of subterranean fauna is considered high, a comprehensive baseline or Level 2 survey may be required. For a Level 2 stygofauna survey, the EPA recommend a minimum of 40 net samples should be collected from within a proposed impact area, across at least two survey seasons (2016a). For a Level 2 troglofauna survey, it is recommended that a minimum of 60 samples are deployed over two sampling rounds. Sampling of subterranean fauna from comparable habitat outside the impact area is also recommended (Environmental Protection Authority 2016a), to provide an understanding of species distribution.

# 4. Methods

## 4.1 Sampling

### 4.1.1 Overview of Sampling Effort

The Study comprised five subterranean fauna field surveys completed in 2020 and 2021. Areas investigated during the surveys included the On-LDE playa, On-LDE islands, SIDE borefield, and the Southern Regional area. A *Fauna taking (biological assessment) licence (*Regulation 27, Biodiversity Conservation Regulations 2018), was obtained from the Department of Biodiversity, Conservation and Attractions (DBCA) prior to the commencement of the field surveys (Licence number: BA27000199). The Study was led by Dr Fiona Taukulis (Ecology Team Lead at Stantec), with more than 20 years' experience. A summary of the Stantec and Agrimin personnel involved in sampling and laboratory analysis, including their qualifications and training is presented in **Table 4-1.**

An overview of the sampling effort for both stygofauna and troglofauna including timing, personnel, number of sites per area and sampling methods is presented in **Table 4-2**. A breakdown of sampling effort per site is summarised in **Table 4-3.** The consolidated sampling effort including previous surveys (2017) has also been outlined in **Table 4-2,** with the report (Invertebrate Solutions 2018) incorporating the results of the pilot and Level 1 surveys provided in **Appendix B**.

Table 4-1: Stantec and Agrimin personnel involved in the field surveys and laboratory analysis for the Study.

| Name | Organisation | Qualifications and Experience | Role |
|---|---|---|---|
| Dr Fiona Taukulis<br>(Team Lead – Ecology) | Stantec | BSc Environmental Biology<br>(Hons, PhD) (>20 yrs exp.) | Technical lead, survey design, technical report review |
| Thomas de Silva<br>(Aquatic Scientist) | Stantec | BSc Marine Biology and Environmental Biology<br>(9 yrs exp.) | Field survey<br>January 2020 |
| Michael Hartley*<br>(Principal Hydrogeologist) | Agrimin | BSc Hydrogeology (Hons)<br>(>20yrs exp.) | Field survey<br>May/June 2020, August 2020, October 2020<br>April 2021 |
| Nick Miles*<br>(Project Geologist) | Agrimin | BSc Coastal Marine Science and BSc Applied Geology<br>(5 yrs exp.) | Field survey<br>May/June 2020, August 2020, October 2020, April 2021 |
| Chris Hofmeester<br>(Senior Aquatic Scientist | Stantec | BSc Environmental Biology<br>(Hons) (10 yrs' exp.) | Technical report |
| Erin Thomas<br>(Technical Lead, Subterranean Ecology) | Stantec | BSc Environmental Biology<br>(Hons, PhD) (>20 yrs exp.) | Identification, technical report |

*Note: * Agrimin personnel were provided with extensive training by Dr Fiona Taukulis prior to undertaking field surveys.*

Table 4-2: Summary of the subterranean fauna sampling effort (stygofauna net haul, hand auger and troglofauna litter traps) for this Study and previous surveys.

| Survey | | Timing | Organisation | Number of Samples | | | | Total per Field Survey | Methods |
|---|---|---|---|---|---|---|---|---|---|
| | | | | On-LDE Playa | On-LDE Islands | SIDE | Southern Regional | | |
| Previous Surveys | 2017 Stygofauna Pilot Survey | 12 – 18 May 2017 | Invertebrate Solutions | - | - | - | 5 stygofauna | 5 stygofauna | Stygofauna net haul sampling, handpump sampling, groundwater quality |
| | 2017 Level 1 Stygofauna and Pilot Troglofauna Survey | 12 – 20 November 2017 | Invertebrate Solutions | 2 stygofauna | 1 stygofauna | - | 12 stygofauna<br>6 troglofauna* | 15 stygofauna<br>6 troglofauna | Stygofauna net haul sampling, groundwater quality, troglofauna litter traps |
| This Study | 1 | 10 - 12 January 2020<br>(traps retrieved by Agrimin, May 2020) | Stantec | - | 5 stygofauna | 4 stygofauna<br>3 troglofauna | 4 stygofauna<br>7 troglofauna | 13 stygofauna<br>10 troglofauna | Stygofauna net haul sampling, groundwater quality, troglofauna litter trap deployment |
| | 2 | 31 May - 5 June 2020 | Agrimin | - | NIL | 4 stygofauna | 5 stygofauna | 9 stygofauna | Stygofauna net haul sampling, groundwater quality |
| | 3 | 24 - 29 August 2020<br>(traps retrieved by Agrimin, October 2020) | Agrimin | 4 stygofauna | 5 stygofauna | 4 stygofauna<br>4 troglofauna | 5 stygofauna<br>6 troglofauna | 18 stygofauna<br>10 troglofauna | Stygofauna net haul sampling (including groundwater monitoring) and troglofauna litter trap deployment |
| | 4 | 12 - 14 October 2020 | Agrimin | 5 stygofauna | 9 stygofauna | - | - | 14 stygofauna | Stygofauna net haul sampling and hand auger |
| | 5 | 2 April 2021 | Agrimin | - | 5 stygofauna | - | - | 5 stygofauna | Stygofauna net haul sampling |
| Total Sampling Effort per Area | | | | 11 stygofauna | 25 stygofauna | 12 stygofauna<br>7 troglofauna | 31 stygofauna<br>19 troglofauna | - | |
| Total Consolidated Sampling effort | | | | 79 stygofauna<br>26 troglofauna | | | | | |

*Two troglofauna litter traps retrieved per site and one scrape sample collected at two sites, grey shading represents previous surveys

Table 4-3: Summary of the subterranean fauna sampling effort per site for the Study.

| Area and Site Name | | GPS Coordinates | | Survey | Sample Start Date | Sample End Date | Collection Method | | | Water Quality |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Easting | Northing | | | | Litter Trap | Auger | Net Hauling | |
| On-LDE Playa | MC09 | 492707 | 7524190 | Aug-20 | 27-08-20 | - | - | - | • | • |
| | | | | Oct-20 | 14-10-20 | - | - | - | • | - |
| | MC19 | 495002 | 7539591 | Aug-20 | 27-08-20 | - | - | - | • | • |
| | MC24 | 479945 | 7529990 | Aug-20 | 28-08-20 | - | - | - | • | • |
| | MC32 | 470014 | 7520051 | Oct-20 | 14-10-20 | - | - | - | • | - |
| | MC37 | 455015 | 7524980 | Oct-20 | 14-10-20 | - | - | - | • | - |
| | MC43 | 435003 | 7509993 | Oct-20 | 14-10-20 | - | - | - | • | - |
| | MC46 | 445760 | 7506086 | Aug-20 | 29-08-20 | - | - | - | • | • |
| | MC56 | 482373 | 7495002 | Oct-20 | 14-10-20 | - | - | - | • | - |
| Total Sampling Effort On-LDE Playa | | | | | | Sites | 0 | 0 | 8 | 4 |
| | | | | | | Samples | 0 | 0 | 9 | 4 |
| On-LDE Islands | LMISL1 | 494005 | 7530054 | Jan-20 | 11-01-20 | - | - | - | • | • |
| | | | | Aug-20 | 27-08-20 | - | - | - | • | • |
| | | | | Oct-20 | 14-10-20 | - | - | - | • | - |
| | | | | April 21 | 02-04-21 | - | - | - | • | - |
| | LMISL2 | 495393 | 7523588 | Jan-20 | 11-01-20 | - | - | - | • | • |
| | | | | Aug-20 | 27-08-20 | - | - | - | - | - |
| | | | | April 21 | 02-04-21 | - | - | - | • | - |
| | LMISL3 | 489207 | 7519847 | Jan-20 | 11-01-20 | - | - | - | • | • |
| | | | | Aug-20 | 28-08-20 | - | - | - | • | • |
| | | | | Oct-20 | 12-10-20 | - | - | - | • | - |
| | | | | April 21 | 02-04-21 | - | - | - | • | - |
| | LMISL9 | 463062 | 7499050 | Aug-20 | 29-08-20 | - | - | - | • | • |
| | | | | Oct-20 | 14-10-20 | - | - | - | • | - |
| | LMISL10 | 456668 | 7510184 | Oct-20 | 14-10-20 | - | - | - | • | - |
| | MC05 | 494087 | 7510174 | Jan-20 | 11-01-20 | - | - | - | • | • |
| | | | | Aug-20 | 28-08-20 | - | - | - | • | • |
| | | | | Oct-20 | 14-10-20 | - | - | - | • | - |
| | | | | April 21 | 02-04-21 | - | - | - | • | - |
| | MC13 | 494917 | 7530028 | Jan-20 | 11-01-20 | - | - | - | • | • |
| | | | | Oct-20 | 14-10-20 | - | - | - | • | - |
| | | | | April 21 | 02-04-21 | - | - | - | • | |
| | T13-H-011 | 495287 | 7530747 | Aug-20 | 27-08-20 | - | - | - | • | • |
| | T02A Island | 463158 | 7498699 | Oct-20 | 14-10-20 | - | - | • | - | - |
| | T02AH007 | 463158 | 7498699 | Oct-20 | 14-10-20 | - | - | - | • | - |
| | T02AH009 | 463365 | 7499406 | Oct-20 | 14-10-20 | - | - | - | • | - |
| Total Sampling Effort On-LDE Islands | | | | | | Sites | 0 | 1 | 10 | 7 |
| | | | | | | Samples | 0 | 1 | 23 | 10 |

| Area and Site Name | | GPS Coordinates | | Survey | Sample Start Date | Sample End Date | Collection Method | | | Water Quality |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Easting | Northing | | | | Litter Trap | Auger | Net Hauling | |
| SIDE | KTB1 | 429987 | 7481417 | Jan-20 | 10-01-20 | 31-05-20 | • | - | - | - |
| | | | | Aug-20 | 24-08-20 | 12-10-20 | • | - | - | - |
| | MWP10A | 436681 | 7482074 | Jan-20 | 10-01-20 | - | - | - | • | • |
| | | | | May/Jun-20 | 31-05-20 | - | - | - | • | • |
| | | | | Aug-20 | 24-08-20 | - | - | - | • | • |
| | MWP10B | 436672 | 7482065 | Aug-20 | 24-08-20 | 12-10-20 | • | - | - | - |
| | MWP11 | 436447 | 7479596 | Jan-20 | 10-01-20 | - | - | - | • | • |
| | | | | May/Jun-20 | 31-05-20 | - | - | - | • | • |
| | | | | Aug-20 | 24-08-20 | - | - | - | • | • |
| | MWP12A | 441500 | 7478517 | Jan-20 | 10-01-20 | - | - | - | • | • |
| | | | | May/Jun-20 | 31-05-20 | - | - | - | • | • |
| | | | | Aug-20 | 24-08-20 | - | - | - | • | • |
| | MWP12B | 441490 | 7478510 | Jan-20 | 10-01-20 | 31-05-20 | • | - | - | - |
| | | | | Aug-20 | 24-08-20 | 12-10-20 | • | - | - | - |
| | MWP13A | 446365 | 7477954 | Jan-20 | 10-01-20 | - | - | - | • | • |
| | | | | May/Jun-20 | 31-05-20 | - | - | - | • | • |
| | | | | Aug-20 | 24-08-20 | - | - | - | • | • |
| | MWP13B | 446355 | 7477945 | Jan-20 | 10-01-20 | 31-05-20 | • | - | - | - |
| | | | | Aug-20 | 24-08-20 | 12-10-20 | • | - | - | - |
| Total Sampling Effort SIDE | | | | | | Sites | 4 | 0 | 4 | 4 |
| | | | | | | Samples | 7 | 0 | 12 | 12 |
| Southern Regional | LD03 | 449111 | 7491138 | Jan-20 | 12-01-20 | 31-05-20 | • | - | - | - |
| | Nr LP008 | 448018 | 7491408 | Jan-20 | 12-01-20 | 31-05-20 | • | - | - | - |
| | | | | Aug-20 | 25-08-20 | 12-10-20 | • | - | - | - |
| | MWP1/5 | 466738 | 7488333 | Jan-20 | 12-01-20 | - | - | - | • | • |
| | | | | May/Jun-20 | 05-06-20 | - | - | - | • | • |
| | | | | Aug-20 | 25-08-20 | - | - | - | • | • |
| | MWP1B | 466726 | 7488334 | Jan-20 | 12-01-20 | 06-05-20 | • | - | - | - |
| | | | | Aug-20 | 25-08-20 | 12-10-20 | • | - | - | - |
| | MWP2 | 449028 | 7491200 | May/Jun-20 | 31-05-20 | - | - | - | • | • |
| | | | | Aug-20 | 25-08-20 | - | - | - | • | • |
| | MWP3 | 449015 | 7491215 | Jan-20 | 12-01-20 | 31-05-20 | • | - | - | - |
| | | | | Aug-20 | 25-08-20 | 12-10-20 | • | - | - | - |
| | MWP4 Deep | 442074 | 7492214 | Jan-20 | 12-01-20 | - | - | - | • | • |
| | | | | May/Jun-20 | 31-05-20 | - | - | - | • | • |
| | | | | Aug-20 | 25-08-20 | - | - | - | • | • |
| | LM0182 | 464058 | 7489688 | Jan-20 | 12-01-20 | 06-05-20 | • | - | - | - |
| | | | | Aug-20 | 25-08-20 | 12-10-20 | • | - | - | - |
| | LM0183 | 464050 | 7489687 | Jan-20 | 12-01-20 | 06-05-20 | • | - | - | - |
| | | | | Aug-20 | 25-08-20 | 12-10-20 | • | - | - | - |

| Area and Site Name | | GPS Coordinates | | Survey | Sample Start Date | Sample End Date | Collection Method | | | Water Quality |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Easting | Northing | | | | Litter Trap | Auger | Net Hauling | |
| | MWP6 | 440085 | 7485416 | Jan-20 | 10-01-20 | - | - | - | • | • |
| | | | | May/Jun-20 | 31-05-20 | - | - | - | • | • |
| | | | | Aug-20 | 24-08-20 | - | - | - | • | • |
| | MWP8 | 440080 | 7485420 | Jan-20 | 10-01-20 | 31-05-20 | • | - | - | - |
| | | | | Aug-20 | 24-08-20 | 12-10-20 | • | - | - | - |
| | MWP9 | 428324 | 7481082 | Jan-20 | 10-01-20 | - | - | - | • | • |
| | | | | May/Jun-20 | 31-05-20 | - | - | - | • | • |
| | | | | Aug-20 | 24-08-20 | - | - | - | • | • |
| Total Sampling Effort Southern Regional | | | | | | Sites | 7 | 0 | 5 | 5 |
| | | | | | | Samples | 13 | 0 | 14 | 14 |

### 4.1.2 Habitat Characterisation

A review of geological and hydrogeological information was undertaken to characterise potential stygofauna habitat and assess stygofauna prospectivity in the Study Area. Information reviewed included bore logs, hydrogeological cross section diagrams and mapping of interpreted aquifer extent provided by Agrimin and mapped geological units (surface and bedrock).

Stantec also completed a preliminary characterisation of the islands on Lake Mackay in 2020 and assigned broad categories, based on spatial data analysis, data and literature review. The categories include:

- Landform island
- Large island
- Intermediate island (Elevated Dune)
- Intermediate island (Low Dune)
- Small island (Alluvial); and
- Small island (Gypsiferous)

The detailed methods and findings, including mapping and key attributes for the island categories, are presented in an island characterisation memorandum (Stantec 2020).

### 4.1.3 Groundwater Monitoring

A suite of basic groundwater physicochemical parameters including electrical conductivity (EC), pH, water temperature (Temp.) were recorded *in-situ* during the January, May/June and August 2020 surveys. Dissolved oxygen (DO) and and reduction-oxidation potential (Redox) were only recorded during the initial (January 2020) survey. The parameters were measured from a groundwater sample collected by a bailer from the upper one to two metres of the bore column, using a calibrated YSI portable water quality meter.

Standing water levesl (SWLs) were measured as metres below ground level (mbgl) using a Solinst 101 water level meter. The end of hole depth (EoH) was calculated from the number of rotations of the stygofauna sampling winch reel (a known distance), which was required to retrieve the stygofauna nets.

### 4.1.4 Stygofauna Sampling

#### 4.1.4.1 Stygofauna Sampling Effort

A total of 59 stygofauna samples were collected from 28 sites across the five field surveys (**Figure 4-1, Table 4-2, Table 4-3**). Images of representative sites are included in **Appendix C**. Sampling of the On-LDE playa included nine samples from eight sites collected during the August and October 2020 surveys. Sampling of the On-LDE islands comprised 24 samples from 11 sites across January, August, October 2020 and April 2021 with some of the island sites inaccessible in May/June 2020. Twelve samples from four sites were collected from the SIDE borefield, and fourteen samples from five sites were collected from the Southern Regional area across the January, May/June and August 2020 surveys.

The previous surveys in the area were completed in 2017 (Invertebrate Solutions 2017;2018) and incorporated the Southern Regional area and one On-LDE landform island near the Northern Territory border. A consolidated figure of all sites sampled for stygofauna during this Study and/or previous surveys is presented in **Figure 4-2.**

#### 4.1.4.2 Stygofauna Sampling Method

Stygofauna samples were collected from piezometer and exploration bores (sites) using haul nets (**Plate 4-1**), though in one instance stygofauna were collected in a sample with a hand auger. Net haul sampling was consistent with the procedures outlined in the EPA guidance (2016a). The sampling method for net hauling was as follows:

- samples were collected using two weighted haul nets with mesh sizes of 150 µm and 50 µm, with each net fitted with a 70 ml plastic collection vial;
- the 150 µm net was lowered first, to the base of the bore (site);
- once at the base of the bore, the net was gently raised up and down to agitate the sediments;
- the net was then raised slowly, to minimise the 'bow wave' effect that may result in the loss of specimens, filtering the stygofauna from the water column on retrieval;
- once retrieved, the collection vial and net were rinsed into a collection pail;
- this process was repeated three times alternating with three hauls using the 50 µm net;
- following the final haul, the contents were filtered through a wide aperture 50 µm mesh net, rinsed with 100% undenatured ethanol and transferred to a 250 mL polypropylene vial for storage;
- to prevent cross-contamination, all sampling equipment was washed thoroughly with Decon 90 (2 to 5% concentration) and rinsed with potable water after sampling was completed at each site;
- samples were placed into eskies with ice bricks in the field, prior to being transferred into a refrigerated environment on-site at the end of each survey day; and
- samples were couriered back to the Stantec laboratory in Perth, where they were stored in 100% ethanol, at approximately minus 20°C.

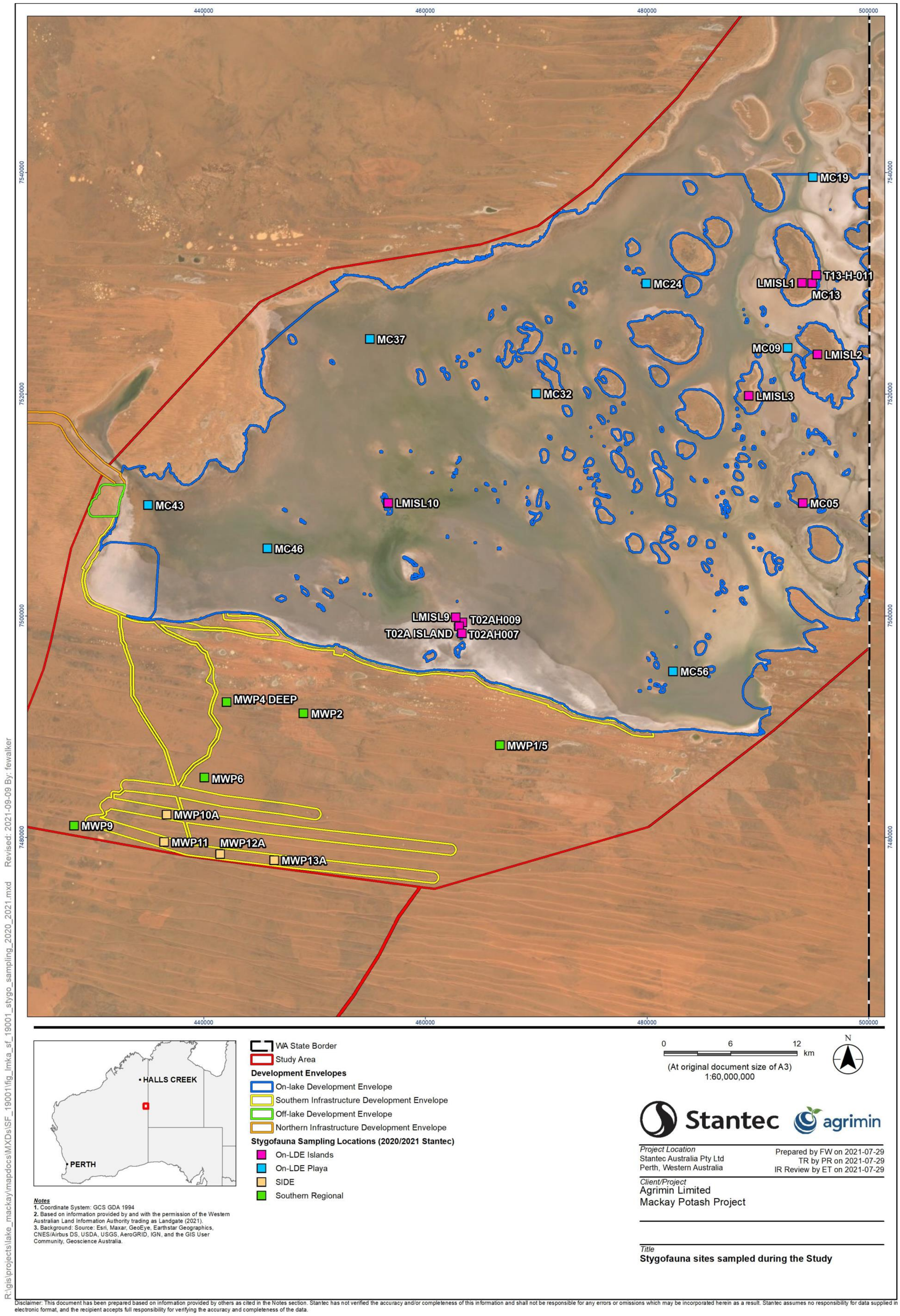


Figure 4-1: Stygofauna sites sampled during the Study.

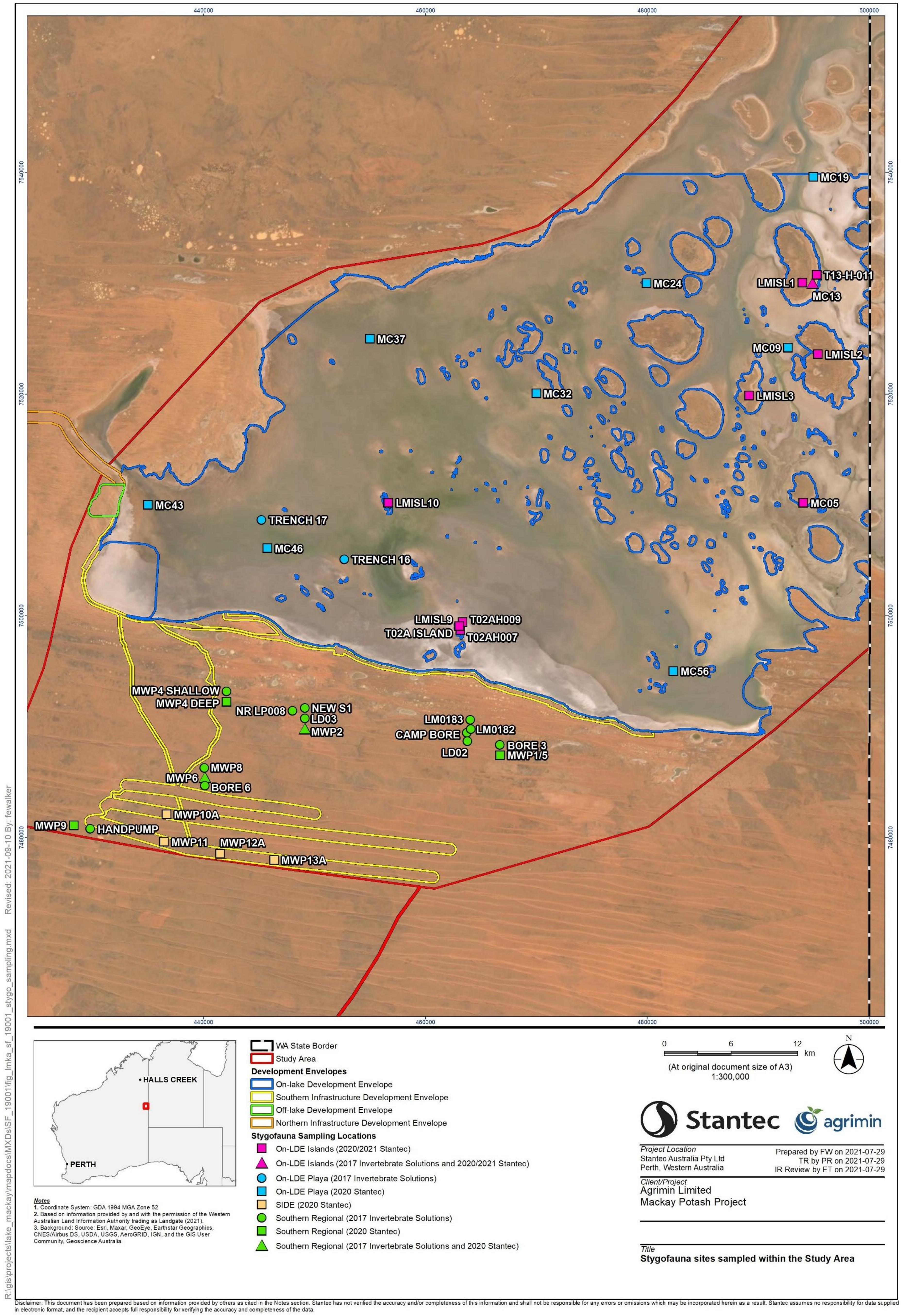


Figure 4-2: Stygofauna sites sampled during this Study (2020/2021) and previous surveys (2017) within the Study Area.

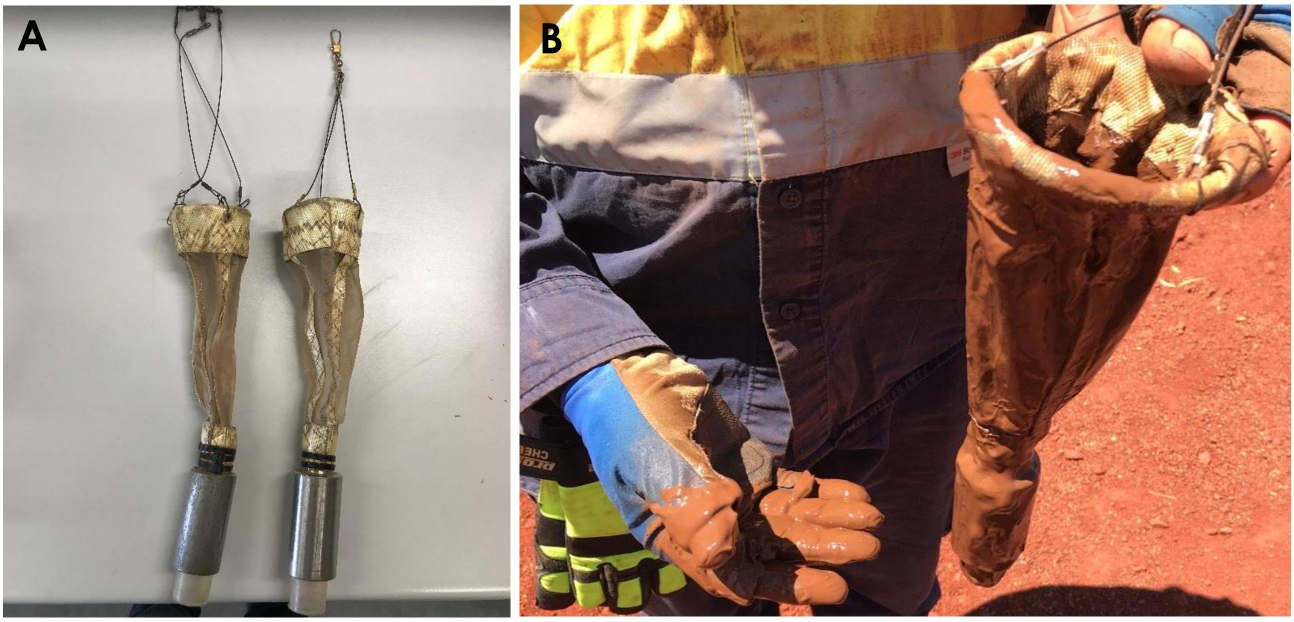


Plate 4-1: Examples of haul nets (A-B), used for sampling stygofauna.

### 4.1.5 Troglofauna Sampling

#### 4.1.5.1 Troglofauna Sampling Effort

In total, 20 troglofauna litter traps were deployed across 11 sites during the Study, with 10 samples collected in January and August 2020, respectively**.** Seven troglofauna traps were deployed at four sites in the SIDE and 13 traps at seven sites in the Southern Regional area, across the two field surveys**.** No traps were deployed at sites On-LDE (playa) (**Figure 4-3**), due to the close proximity (typically 0.5 m below surface) of groundwater to the surface.

Previous sampling in the area was undertaken in 2017 (Invertebrate Solutions 2017;2018), comprising two scrape samples and four litter traps* from two sites in the Southern Regional area. A consolidated figure of all sites sampled for troglofauna during this Study and/or the previous survey is presented in **Figure 4-4**.

#### 4.1.5.2 Troglofauna Sampling Method

Troglofauna were sampled using litter traps as follows:

- litter traps were packed with sterilised organic material and sealed to maintain moist, sterile conditions prior to field deployment;
- traps were then moistened with water prior to deployment in sites;
- once installed in the sites, traps were left in place for eight weeks (21 weeks in some cases, see Study Limitations below) to allow adequate time for colonisation by troglofauna; and
- on retrieval, traps were sealed in zip lock bags, labelled, and couriered to the Stantec laboratory in Perth for sorting and identification.

In the laboratory, troglofauna specimens were extracted from the litter using Tullgren funnels. Litter was placed into funnels, and light and low heat was applied from overhead lamps to create a temperature gradient of approximately 14°C in the litter. This method was applied to encourage any troglofauna, which are light sensitive and prefer humid conditions, to migrate downwards through the litter as it dried. Troglofauna specimens then fell through a mesh layer into collection vials at the base of the funnels, containing 100% ethanol. After collection of troglofauna in the vials (if present), the litter was removed from the funnels and manually searched under magnification for any troglofauna specimens that may remain (**Plate 4-2**).

**six litter traps were deployed across two sites but only two from each site were retrieved (Invertebrate Solutions 2018).*

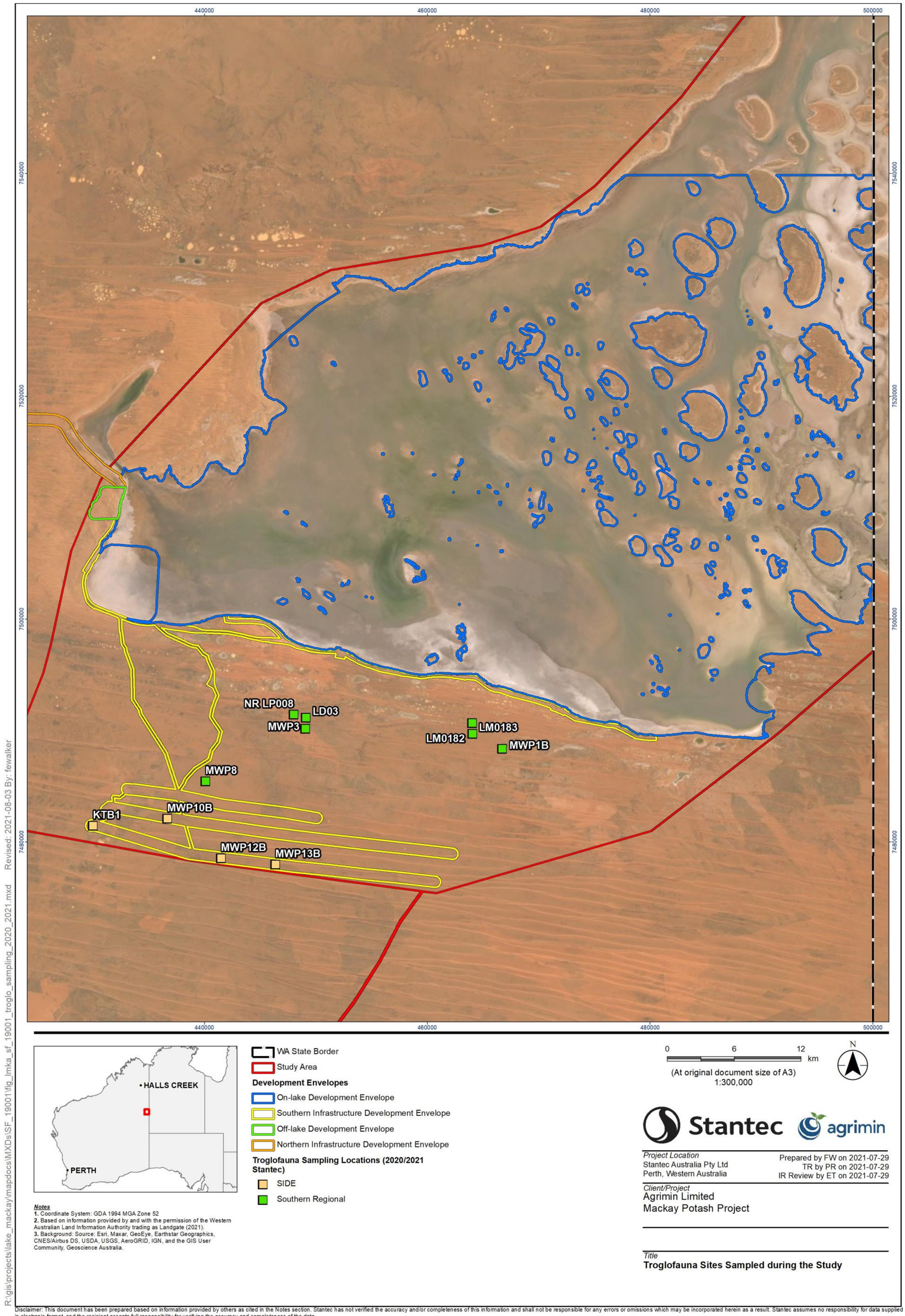




Figure 4-3: Troglofauna sites sampled during the Study.

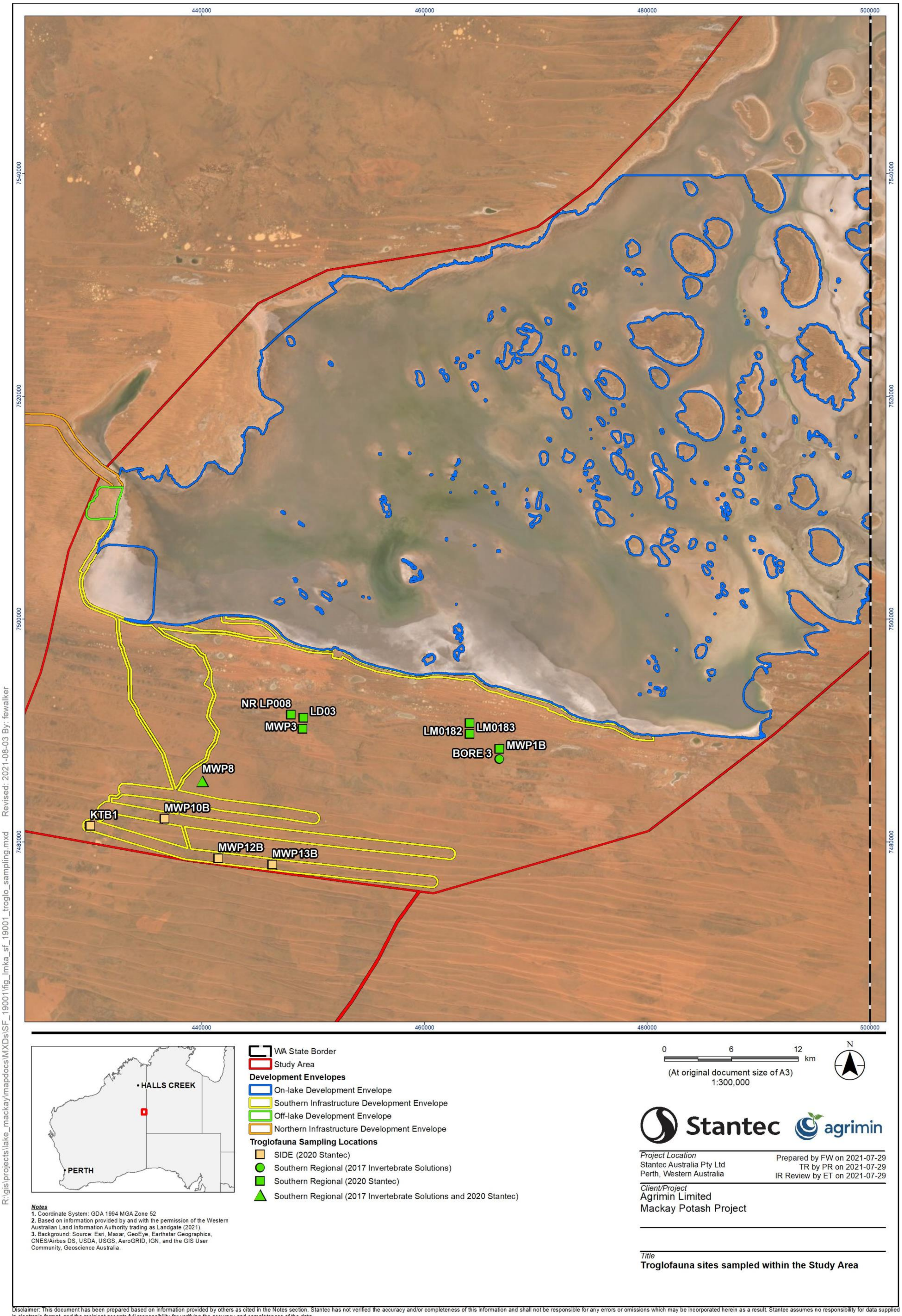


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Figure 4-4: Troglofauna sites sampled during this Study (2020/2021) and previous surveys (2017) in the Study Area.


Plate 4-2: Troglofauna collection and extraction methods. (A) Litter trap, and (B) Tullgren funnels.

## 4.2 Laboratory

### 4.2.1 Laboratory Sorting and Identification of Specimens

Preserved subterranean fauna samples were sorted in the Stantec laboratory using Leica stereomicroscopes at a suitable magnification by Stantec aquatic scientist Emma Dobinson (5 years' experience) and graduate aquatic scientist Madison Brown (2 years' experience), with quality assurance and quality control (QAQC) provided by invertebrate specialists' Dr Nick Stevens and Dr Erin Thomas (both of Stantec), with over 20 years' invertebrate taxonomic experience, specialising in subterranean fauna.

Identification of copepods was completed by Jane McRae (Bennelongia Environmental Consultants), with input from copepod specialist, Dr Tomislav Karanovic (Hanyang University). Preliminary identification of Bathynellacea was undertaken by Jane McRae. Higher identification, based on morphological comparison with Western Australian Museum material, was completed by Dr Erin Thomas. Identification of dipluran material was completed by Dr Nick Stevens.

## 4.3 Study Limitations

Several subterranean fauna surveys have been undertaken at Lake Mackay, targeting the On-LDE playa, ON-LDE islands and SIDE borefield. While most of the habitat associated with these areas is not prospective to subterranean fauna, calcareous geology on the On-LDE landform islands appears to support stygal and potentially troglofauna communities.

For stygofauna, the total sampling effort in the Study Area (79 samples) exceeded the guidance for Level 2 surveys (40 samples). The troglofauna sampling effort approached or exceeded guidance for pilot studies (10 to 15 troglofauna samples) (Environmental Protection Authority 2016a) in the two areas sampled.

Sampling efforts in 2020 were also hindered by COVID-19 travel restrictions, delaying the retrieval of troglofauna traps and preventing additional subterranean fauna survey work from being undertaken in the early part of the year. Subsequently, in late 2020 and early 2021, further sampling was undertaken on the ON-LDE playa and On-LDE islands.

Specialist taxonomic identification was also affected by these travel restrictions. However, every effort was made to access suitably qualified local specialists to complete morphological identification.

# 5. Results

## 5.1 Habitat Characterisation

### 5.1.1 On-LDE Playa

Lacustrine deposits such as clay and silt, which host hypersaline groundwater (>100,000 mg/L), comprising the lakebed sediments of Lake Mackay (**Table 5-1**), are considered to have a low prospectivity for subterranean fauna. Although stygofauna and troglofauna can occupy a diverse range of geological settings, such as karstic landscapes, fractured rock, vuggy pisolites and unconsolidated alluvial sediments, their presence is typically dependent on the occurrence of interconnected or sub-surface crevices, fractures and voids, which lacustrine sediments do not provide (Subterranean Ecology 2010a).

In addition to restricting movement, inadequate interconnected void spaces and associated low permeability limit pathways for infiltration of resources such as oxygen and carbon, key factors influencing subterranean fauna persistence and distribution (Subterranean Ecology 2010a). Further, although there are records of stygofauna occupying groundwaters with salinity levels up to 100,000 mg/L in the northern Yilgarn region of WA, and some species are salt tolerant, the majority of species appear to be restricted to salinities below 25,000 mg/L (Halse 2018).

### 5.1.2 On-LDE Islands

The most prospective subterranean habitat exists on the larger landform islands of Lake Mackay, where calcareous material intercepts the low salinity capillary fringe (vadose zone), although calcrete is not immediately evident in the core photos (**Plate 5-1, Plate 5-2**). Prospective subterranean habitat likely exists within the largest (landform) islands in the eastern portion of the lake, due to the presence of some calcrete within the gypsiferous sands, and low salinity groundwaters. Calcrete aquifer systems are recognised as providing optimal habitat for stygofauna in the Pilbara and Yilgarn regions, typically hosting more diverse stygofauna assemblages than regolith or fractured rock associated aquifers (Halse *et al.* 2014) Humphreys 2006a; Humphreys 2008; MWH 2016a;c; Outback Ecology 2014).

The vadose (unsaturated) zone of calcrete units are similarly recognised as important habitat for troglofauna, providing suitably sized and extensively connected crevices and cavities, that remain relatively humid, an important condition considered to be a key requirement for troglofauna existence (Barranco and Harvey 2008; Bennelongia 2009; Halse *et al.* 2002; MWH 2014; Outback Ecology 2011a; Subterranean Ecology 2008).

### 5.1.3 SIDE Borefield and Southern Regional Area

In WA, studies have shown that alluvial aquifers associated with palaeodrainage channels of arid and semi-arid zones can contain rich stygofauna (Halse *et al.* 2014; Humphreys 2006a; Humphreys 2008; MWH 2016a;c; Outback Ecology 2014) and troglofauna (MWH 2014; Outback Ecology 2011a; Subterranean Ecology 2008). As opposed to calcrete units, unconsolidated alluvial aquifers provide interstitial habitats between clastic sediments (primary porosity), with coarser sediments supporting a more diverse range of fauna. Greater hydraulic connectivity also increases supply rates of organic carbon, oxygen, and nitrogen, essential for the subterranean lifecycle (Subterranean Ecology 2010a).

While the SIDE borefield occurs in the saturated Neogene alluvials hosting fresh to low salinity groundwaters, the relatively fine textured lithology is likely to restrict subterranean fauna (**Plate 5-3**). However, to the northeast of the SIDE and within the Southern Regional area, more prospective subterranean fauna habitat exists within unconfined calcrete and unconsolidated sediments hosting brackish groundwaters.

As mentioned in **Section 5.1.2**, calcrete aquifer systems provide optimal habitat for subterranean fauna (Halse *et al.* 2014; Humphreys 2006b;2008; MWH 2016b; Outback Ecology 2014) and troglofauna (Harrison *et al.* 2014; MWH 2015; Outback Ecology 2011b;2012a;b; Platnick 2008). This is supported by results from Invertebrate Solutions' 2017 surveys of the surficial calcrete aquifer, with a diverse stygofauna assemblage identified, including 10 species of copepod, one species of syncarid, one oligochaete, one ostracod and three species of diving beetle (Invertebrate Solutions 2018).

Table 5-1: Summary of the geology and groundwater salinity for each area, taken from representative bore logs.

| Area | | Geological Unit | Depth (mbgl) | Description | Salinity (TDS mg/L) |
|---|---|---|---|---|---|
| Playa | Western and Central | Lake Sediment | 0-0.5 | Unsaturated sequence with an average thickness of 0.5m made up of a thin (<2mm) white evaporite crust and a layer of fine gypsum silt and dark grey organic mud (30mm). Remainder of unit is composed of a soft red-brown silty clay. | 102,946 to 314,965 |
| | | | 0.5-0.6 | Saturated layer of gypsum crystals in a matrix of red brown silty clay and minor coarse gypsum sand. | |
| | | | 0.6-6.5 | Red-brown clay, very well sorted, stiff, plastic, minor interspersed gypsum crystals. | |
| | Eastern | Lake Sediment | 0-0.5 | Unsaturated sequence with an average thickness of 0.5m made up of a brittle crust of evaporite cemented fine to medium gypsum and quartz sand (40mm) followed by coarse porous gypsum sand. The base of the unit is marked by a thin dark grey organic clay layer. | 186,319 to 255,109 |
| | | | 0.5-0.6 | Saturated red brown clay with medium to coarse gypsum sand and minor gypsum crystals. | |
| | | | 0.6-6.5 | Red-brown clay, minor medium gypsum sand, stiff, plastic, minor interspersed gypsum crystals. | |
| | | | 6.0-12.7 | Red-brown clay, very well sorted, stiff, plastic, minor interspersed gypsum crystals. | |
| Islands | Island (description from LMISL1 logging) | Aeolian Sand | 0-0.6 | Very fine-grained red-brown sand, well sorted. | 6,331 to 56,113 |
| | | Calcrete | 0.6-3.0 | Beige-white calcrete with minor gypsum sand, increasingly silty clay content with depth. | |
| | | Lake Sediment | 3.0-6.0 | Well sorted fine grained gypsiferous sand, increasing silty clay content with depth | |
| | | | 6.0-12.7 | Red-brown clay, very well sorted, stiff, plastic, minor interspersed gypsum crystals. | |
| SIDE | MWP9-13 (description from MWP13 logging) | Clayey Sandstone | 0-45 | Red brown sand, very fine to granular (<3mm), dominantly fine to medium, poorly sorted, sub angular quartz; silt/clay matrix ~10%, poorly consolidated. | 1,567 to 6,300 |
| | | Clay | 45-70 | Pale beige-brown to dark grey grey-purple. | |
| | | Silty Sand | 70-102 | Pale grey-brown to yellow brown, very fine to fine grained, moderately sorted, angular to sub angular quartz sand with abundant silt matrix; poorly consolidated. | |
| | | Sandstone | 102-109 | Sandstone, Brown, fine grained, well sorted, subangular quartz with minor dark hard mineral, well consolidated. | |
| Southern Regional | MWP1-MWP7 (description from MWP2 logging) | Alluvium | 0-2.0 | Orange-brown silt with minor fine to medium grained sand. | 7,483 to 47,118 |
| | | Calcrete | 2.0-4.0 | Beige-white to grey calcrete with trace fine to coarse grained sand, weathered, well consolidated. | |
| | | Clay | 4.0-34 | Tan-brown to orange-brown clay, firm moderately plastic. | |
| | | Sand | 34-38 | Creamy grey-brown sand, coarse to very coarse grained, moderately sorted. | |
| | | Clay | 38-86 | Grey-purple to pale green clay, soft and slightly plastic. | |
| | | Sand | 86-132 | Pale beige white to grey sand with minor clay matrix. | |


Plate 5-1: Lakebed sediment core photos (T02AH-012). (A) 0.0 to 3.0 m, and (B) 3.0 to 6.0 m.

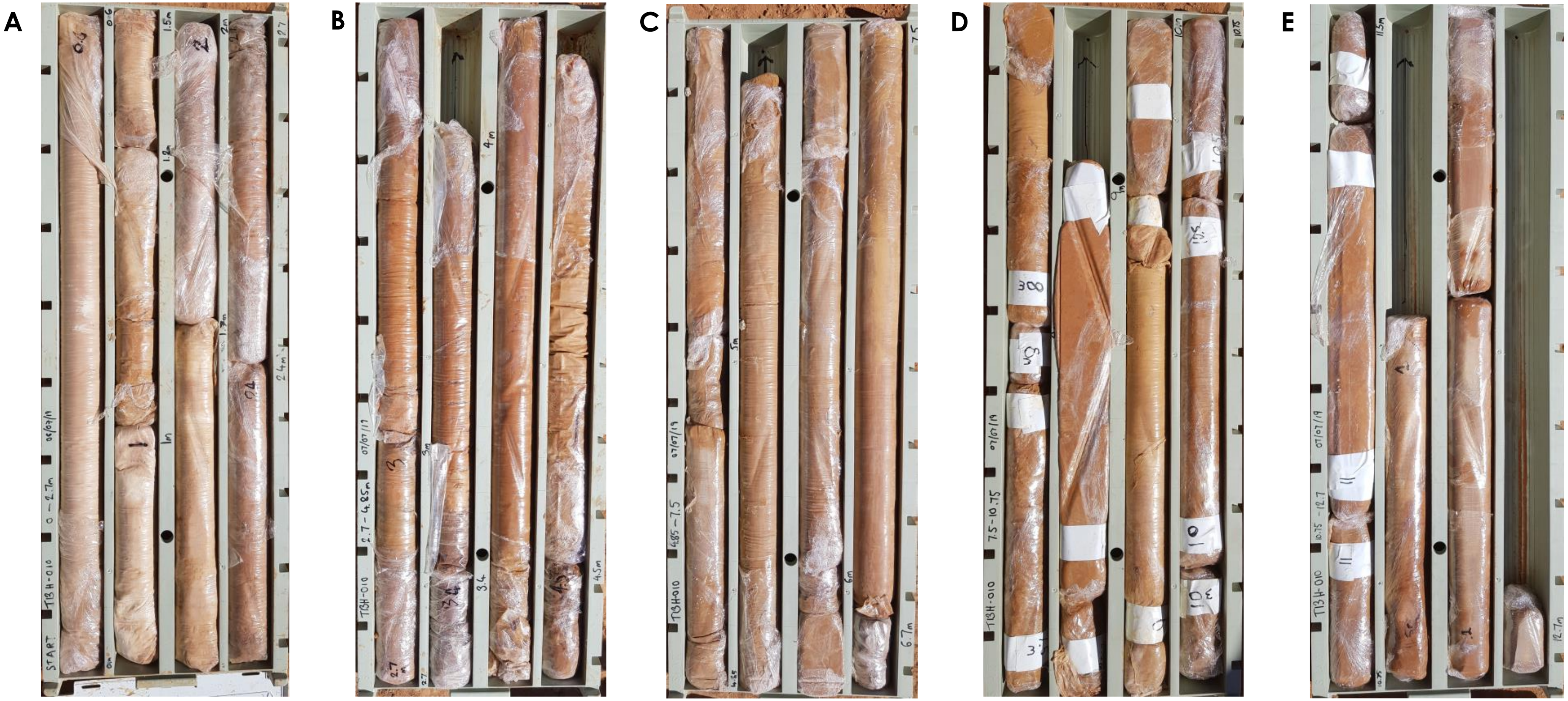


Plate 5-2: Landform island core photos (LMISL-001). (A) 0.0 to 2.70 m, (B) 2.70 to 4.85 m, (C) 4.85 to 7.50 m, (D) 7.50 to 10.75 m, (E) 10.75 to 12.7 m.

Plate 5-3: SIDE monitoring bore chip tray photo (MWP13), 0.0 to 109 m.

## 5.2 Groundwater Monitoring

Groundwater levels associated with the On-LDE playa were typically shallow, with standing water levels (SWLs) ranging from 0.86 to 1.54 mbgl (**Table 5-2**). Within the On-LDE islands, the maximum recorded depth to groundwater was also relatively shallow (1.54 to 4.6 mbgl), likely attributed to infiltration of rainfall through porous gypsiferous sands (Stantec 2020). Groundwater in the SIDE were recorded at depths ranging from 5.85 to 8.87 mbgl, coinciding with a clayey sandstone alluvial unit (**Table 5-1**). The depth to groundwater in the Southern Regional area varied from 3.75 to 11.10 mbgl (**Table 5-2**).

The pH of groundwater ranged from acidic (<6.5) to alkaline (>7.5) (Foged 1978) but was typically circumneutral (6.5 to 7.5) across most of the areas (**Table 5-2**). This is considered typical of groundwater associated with salt lakes in Western Australia (Gregory 2007) and is generally within the pH range known to support stygofauna (Glanville *et al.* 2016; Humphreys 2008; Reeves *et al.* 2007).

Groundwater salinity at the On-LDE playa sites exceeded 200,000 mg/L, reflecting the hypersaline brine. For the On-LDE islands, salinity ranged from 1,601 to 145,446 mg/L and was categorised as freshwater (<3,000 mg/L) to hypersaline (≥50,000 mg/L) (Hammer 1986), demonstrating the influence of rainfall recharging porous gypsiferous sands, in the vadose zone (Agrimin 2018). In the SIDE, salinity ranged from freshwater (<3,000 mg/L) to hyposaline (3,000 to 20,000 mg/L) (Hammer 1986), and freshwater to mesosaline (20,000 to 50,000 mg/L) in the Southern Regional area (**Table 5-2**), similar to previous hydrogeological investigations (**Table 5-1**). Significant stygofauna communities are generally associated with groundwater salinities <60,000 mg/L (Environmental Protection Authority 2016a). However, there are records of stygofauna from salinities in excess of 100,000 mg/L (Outback Ecology 2011b;2012c).

Table 5-2: Groundwater quality recorded from sites during the Study.

| Area and Site Name | | Date | SWL (mbgl) | pH (unit) | TDS (mg/L)* | EC (µS/cm) | DO (mg/L) | Redox (mV) | Temp. (°C) |
|---|---|---|---|---|---|---|---|---|---|
| On-LDE Playa | MC09 | Aug-20 | 1.54 | 7.06 | 253,334 | 210,700 | - | - | 26.4 |
| | MC19 | Aug-20 | 0.86 | 7.3 | 201,800 | 191,200 | - | - | 29.6 |
| | MC24 | Aug-20 | 1.32 | 7 | 258,384 | 214,900 | - | - | 27.5 |
| | MC46 | Aug-20 | 0.94 | 8 | 258,504 | 215,000 | - | - | 30 |
| On-LDE Islands | LMISL1 | Jan-20 | 3.79 | NA | 1,601 | 2,911 | 3.27 | -135.4 | 31.2 |
| | | Aug-20 | 4.6 | NA | 2,750 | 5,000 | - | - | 30 |
| | LMISL2 | Jan-20 | 3.5 | 6.78 | 51,496 | 69,823 | 1.46 | 25.5 | 32.5 |
| | LMISL3 | Jan-20 | 3.8 | 7.06 | 39,161 | 55,469 | 0.74 | -42.7 | 31.5 |
| | | Aug-20 | 4.45 | 7.02 | 45,309 | 62,300 | - | - | 29.8 |
| | LMISL9 | Aug-20 | 1.54 | 7.5 | 128,952 | 143,500 | - | - | 30 |
| | MC05 | Jan-20 | 2.89 | 6.95 | 145,446 | 162,800 | 1.38 | -279 | 31 |
| | | Aug-20 | 3.55 | 6.93 | 126,938 | 141,200 | - | - | 29.6 |
| | MC13 | Jan-20 | 2.99 | 6.38 | 81,803 | 101,649 | 0.41 | 35 | 33.1 |
| | T13-H-011 | Aug-20 | 2.38 | 8.01 | 53,101 | 72,000 | - | - | 29.5 |
| SIDE | MWP10A | Jan-20 | 8.02 | 6.99 | 2,756 | 5,011 | 1.56 | 49.2 | 32 |
| | | May/Jun-20 | 8 | 7.17 | 2,420 | 4,400 | - | - | 28.4 |
| | | Aug-20 | 8.87 | 7.1 | 1,892 | 3,440 | - | - | 30 |
| | MWP11 | Jan-20 | 5.85 | 6.98 | 5,796 | 9,502 | 4.9 | 65.8 | 31.5 |
| | | May/Jun-20 | 6 | 7.48 | 5,770 | 9,460 | - | - | 26 |
| | | Aug-20 | - | 7 | 5,728 | 9,390 | - | - | 30.1 |
| | MWP12A | Jan-20 | 6.35 | 7.09 | 2,093 | 3,805 | 2.8 | 48.7 | 31.9 |
| | | May/Jun-20 | 6.2 | 7.66 | 1,964 | 3,570 | - | - | 28.2 |
| | | Aug-20 | 7.08 | 5.21 | 1,930 | 3,510 | - | - | 30.3 |
| | MWP13 | Jan-20 | 7.48 | 7.13 | 1,757 | 3,195 | 3.38 | 55.9 | 30.7 |
| | | May/Jun-20 | 7.46 | 7.55 | 1,892 | 3,440 | - | - | 24.3 |
| | | Aug-20 | 8.21 | 5.91 | 1,782 | 3,240 | - | - | 28.7 |
| Southern Regional | MWP1/5 | Jan-20 | 8.02 | 6.99 | 48,917 | 67,286 | 1.56 | 49.2 | 32 |
| | | May/Jun-20 | 8.65 | NA | 40,224 | 56,100 | - | - | 27 |
| | | Aug-20 | 11.1 | 7.19 | 36,430 | 51,600 | - | - | 28.2 |
| | MWP2 | May/Jun-20 | 7.5 | 7.6 | 6,942 | 11,380 | - | - | 26.5 |
| | | Aug-20 | 8.33 | 7.73 | 6,588 | 10,800 | - | - | 28.9 |
| | MWP4 - Deep | Jan-20 | 3.78 | 7.02 | 40,317 | 56,230 | 0.4 | -68 | 31 |
| | | May/Jun-20 | 4 | 7.94 | 35,300 | 50,000 | - | - | 27.2 |
| | | Aug-20 | 4.59 | 7.5 | 35,300 | 50,000 | - | - | 31 |
| | MWP6 | Jan-20 | 5.45 | 7.72 | 559 | 1,017 | 1.75 | 38.9 | 31.2 |
| | | May/Jun-20 | 5.5 | 7.7 | 592 | 1,077 | - | - | 30.1 |
| | | Aug-20 | 6.18 | 7.51 | 6,454 | 10,580 | - | - | 31 |
| | MWP9 | Jan-20 | 7.2 | 7.02 | 3,491 | 6,347 | 0.4 | -68 | 31 |
| | | May/Jun-20 | 7.22 | 7.4 | 3,575 | 6,500 | - | - | 26 |
| | | Aug-20 | 8.1 | 6.3 | 3,470 | 6,310 | - | - | 27.8 |

**TDS (mg/L) was converted from electrical conductivity (EC) (µS/cm) based on Williams (1998) for values >8,200 µS/cm. Values <8,200 µS/cm were multiplied by 0.55.*

## 5.3 Stygofauna

A total of 73 stygofauna and potential stygofauna specimens were recorded during the Study across the five field surveys, representing three higher level taxonomic groups. These included the oligochaete order Haplotaxida, the crustacean sub-class Copepoda and Bathynellacea of the superorder Syncarida (**Table 5-3**). With the exception of the On-LDE playa, at least one stygofauna or potential stygofauna specimen was recorded from each area (**Figure 5-1, Table 5-3**), however, abundance and diversity were relatively low. In comparison, during the previous (2017) stygofauna surveys, 18 species were identified, 14 of which were undescribed and are considered new to science (Invertebrate Solutions 2018). The majority of these were collected from the surficial calcrete aquifer in the Southern Regional area, with just two copepod species recorded from one of the On-LDE landform islands, at site MC13. Detailed discussion of the taxa recorded during this Study is provided in subsequent sections.

### 5.3.1 Crustacea: Malacostraca: Bathynellacea

A single Bathynellacea specimen (family Parabathynellidae) was recorded during the Study. The specimen was collected from MWP2, a site within the surficial calcrete aquifer of the Southern Regional area, during the May/June 2020 survey (**Figure 5-1**, **Table 5-3**). It was identified as *Atopobathynella* sp. 'mackay' (**Plate 5-4**), a new, unpublished species first recorded from the area during the 2017 surveys (Invertebrate Solutions 2018). The designation of the specimen from this Study was based on morphological comparison with 2017 material lodged at the Western Australian Museum.

Bathynellaceans are stygobitic, with the family Parabathynellidae documented from groundwaters of the Pilbara, Yilgarn and Kimberley regions of Western Australia, typically from calcrete or alluvial aquifers (Cho *et al.* 2005; Guzik *et al.* 2008). Invertebrate Solutions (2018) recorded a high abundance of *Atopobathynella* sp. 'mackay' from the bore Nr LP008 (85 specimens across the two 2017 surveys), located approximately 1 km from MWP2. Both sites form part of the same surficial calcrete aquifer within the Southern Regional area, and are characterised by alkaline and hyposaline groundwaters (Invertebrate Solutions 2018).


Plate 5-4: Lateral view of Parabathynellidae: *Atopobathynella* sp. 'mackay' from island site MWP2.

Table 5-3: Stygofauna recorded from Lake Mackay during the Study (note no stygofauna were recorded from the On-LDE).

| Stygofauna Taxa | Survey | On-LDE Islands | | | | SIDE | Southern Regional | | Comments |
|---|---|---|---|---|---|---|---|---|---|
| | | LMISL2 | LMISL3 | MC13 | T02A Island | MWP13 | MWP1/5 | MWP2 | |
| **Annelida: Clitellata** | | | | | | | | | |
| Oligochaeta | | | | | | | | | |
| Haplotaxida | | | | | | | | | |
| Enchytraeidae sp. | Jan-20 | 1 | - | - | - | 2 | - | - | Family known from terrestrial and aquatic systems. specimens may be semi-aquatic. |
| **Arthropoda: Crustacea** | | | | | | | | | |
| Malacostraca | | | | | | | | | |
| Bathynellacea | | | | | | | | | |
| *Atopobathynella* sp. 'mackay' | May/June-20 | - | - | - | - | - | - | 1 | Potentially endemic to the Lake Mackay area. |
| Maxillopoda | | | | | | | | | |
| Copepoda | | | | | | | | | |
| Copepoda sp. | May/Jun-20 | - | - | - | - | - | 1 | - | Damaged specimen; further ID not possible. |
| Cyclopoida | | | | | | | | | |
| 'Mackaycyclops' sp. | May/Jun-20 | - | - | - | - | - | - | 2 | Likely to belong to previously recorded species. Potentially endemic to the Lake Mackay area. |
| *Halicyclops kieferi* | Jan-20 | - | - | 1 | - | - | - | - | Previously recorded. Widespread in the Yilgarn region although may represent multiple cryptic species. |
| | Aug-20 | | | | | | 31 | | |
| | Oct-20 | | | | 1 | | | | |
| | Apr-21 | 27 | 4 | | | | | | |
| Harpacticoida | | | | | | | | | |
| *Schizopera* ?'bradleyi' | Apr-21 | 2 | | | | | | | Unique robust claw on lateral setae of caudal rami and length of caudal rami consistent with *Schizopera* 'bradleyi'. Slight difference noted in shape of posterior half of caudal rami. Likely to be *Schizopera* 'bradleyi' |

### 5.3.2 Crustacea: Maxillipoda: Copepoda

Copepods were recorded from the groundwaters of the On-LDE islands and Southern Regional area during the Study. The order Cyclopoida was represented by 66 specimens from two taxa, while two specimens from one taxon were recorded from the order Harpacticoida. The remaining material (one specimen) has been identified to the subclass Copepoda only. No further identification was possible for this specimen, collected from the Southern Regional area in June 2020, due to specimen damage.

Representatives of both cyclopoid taxa were recorded from the Southern Regional area during the Study. Previous sampling at Lake Mackay in 2017 (Invertebrate Solutions 2018) has demonstrated that the surficial calcrete aquifer within Southern Regional area hosts a diverse copepod assemblage, with 10 taxa identified, eight of which represent new and potentially endemic species (Invertebrate Solutions 2018).

By comparison, the On-LDE islands yielded one cyclopoid and one harpacticoid taxon during the Study. Based on collective data from this Study and the 2017 surveys, at least three copepod taxa have been documented from the On-LDE islands, including the undescribed harpacticoid species *Schizopera* 'bradleyi', (Invertebrate Solutions 2018). Further details of the identified copepod (cyclopoid) taxa collected during the Study are outlined below.

***Halicyclops kieferi***

The cyclopoid copepod *Halicyclops kieferi* was recorded from four sites within the On-LDE islands area (including small, large and landform islands), totalling 33 specimens (**Figure 5-1**, **Table 5-3**). The taxon was also collected from one site (MWP1/5) in the Southern Regional area (31 specimens). *Halicyclops kieferi* is considered widespread, with numerous records from bores in the Murchison and Yilgarn regions, where it typically occurs in association with calcrete (Karanovic 2004). It was previously recorded from Camp Bore at Lake Mackay (as *Halicyclops* cf. *kieferi*), within the surficial calcrete aquifer (Invertebrate Solutions 2018).

Molecular work on *Halicyclops* in other regions of WA found that representatives of this genus in separate calcrete systems typically represent cryptic species. Detailed comparative morphological work and DNA would be required to confirm whether *Halicyclops kieferi*/*Halicyclops* cf. *kieferi* at Lake Mackay represents a cryptic species, potentially endemic to the Lake Mackay area (Invertebrate Solutions (2018). However, the identification of another widespread cyclopoid copepod, *Fierscyclops fiersi,* from the On-LDE islands site MC13 during the November 2017 survey (Invertebrate Solutions 2018) highlights the potential for the dispersal of this species more broadly.

**'Mackaycyclops' sp.**

Two specimens belonging to the new, unpublished genus 'Mackaycyclops' (**Plate 5-5**) were recorded from MWP2 within the Southern Regional area (May/June 2020) (**Figure 5-1, Table 5-3**). The first records of this genus came from the previous (2017) surveys (Invertebrate Solutions 2018). 'Mackaycyclops' was originally designated using morphological features including the segmentation and armature of the swimming legs and the absence of outer principal setae on the caudal rami. Based on the 2017 material, two species were recognised; 'Mackaycyclops bradleyi' and 'Mackaycyclops mouldsi' (Invertebrate Solutions 2018).

'Mackaycyclops bradleyi' was represented by five specimens from MWP08 in the surficial calcrete aquifer of the Southern Regional area in 2017. The specimens were comparatively smaller than 'Mackaycyclops mouldsi' and had a proportionately longer female genital double somite. 'Mackaycyclops mouldsi' was recorded from three sites, also within the surficial calcrete aquifer of the Southern Regional area (38 specimens) (Invertebrate Solutions 2018).

The 'Mackaycyclops' specimens recorded during this Study were immature and could not be identified to species level. However, it is likely the specimens belong to one of the undescribed 'Mackaycyclops' species already known from the surficial calcrete aquifer of the Southern Regional area.

***Schizopera* ?'bradleyi'**

Two specimens of *Schizopera* ?'bradleyi' were identified from the On-LDE island site of LMISL2 during the April 2021 survey of the Study. The specimens exhibited a unique robust claw on the lateral setae of the caudal rami, consistent with *Schizopera* 'bradleyi' (Jane McRae pers. comm. 2021). This feature was not observed in any of the other 100 species of *Schizopera* described in this genus (Karanovic and McRae 2013). While a slight difference was noted in the shape of the posterior half of the caudal rami, the specimens are considered likely to belong to *Schizopera* 'bradleyi'.

### 5.3.3 Annelida: Clitellata: Oligochaeta: Haplotaxida

The family Enchytraeidae was the only oligochaete group represented during the Study (**Table 5-3**). Enchytraeids are known to occur in a wide range of habitats including terrestrial, marine and freshwater ecosystems (Dumnicka *et al.* 2020; Pinder 2010). The taxonomic framework for this group is poorly resolved in Australia (Pinder 2010).

In total, three enchytraeid specimens were recorded during the Study. Two specimens were collected from MWP13 in the SIDE, with the third specimen collected from the On-LDE island site LMISL2. The specimens recorded during the Study were considered potential stygofauna. However, the degree of affinity of this group to groundwater remains uncertain, with some enchytraeids classified as semi-aquatic (Dumnicka 2014). Regardless, the extent of comparable geological units and associated groundwaters in the area implies a wider distribution of enchytraeids throughout the broader area.


Plate 5-5: 'Mackaycyclops' sp. specimen recorded during the Study.

## 5.4 Troglofauna

One potential troglofauna taxon belonging to the order Diplura was collected as by-catch from a stygofauna net haul during the January 2020 survey. The taxon, identified as Projapygidae-OES3, was recorded as a singleton from island site LMISL2 (**Figure 5-1**). This site is situated on one of the landform islands on the eastern edge of the On-LDE, with geology consisting of mostly of aeolian sands and areas of calcrete outcropping (Stantec 2020). No troglofauna were recorded from litter traps deployed in the SIDE or Southern Regional area in January 2020 and August 2020. The absence of troglofauna in litter traps is consistent with previous investigations at Lake Mackay (Invertebrate Solutions 2018).

The family Projapygidae has been recorded from a range of geological units including alluvial/colluvial profiles (Outback Ecology 2009;2011b), sandstone and iron formations (Subterranean Ecology 2010b) throughout Western Australia. All diplurans are largely unpigmented and lack eye development. The majority are known to be soil dwelling (edaphofauna) in mesic environments (Naumann 1991). Information on the group is limited, making it difficult to determine the ecological preference (troglobite or edaphofauna) of this specimen.

It should be noted that the traps deployed in January 2020 remained *in situ* for almost six months due to COVID-19 travel restrictions. This is longer than the six to eight week deployment period recommended in the technical guidance (Environmental Protection Authority 2016a).

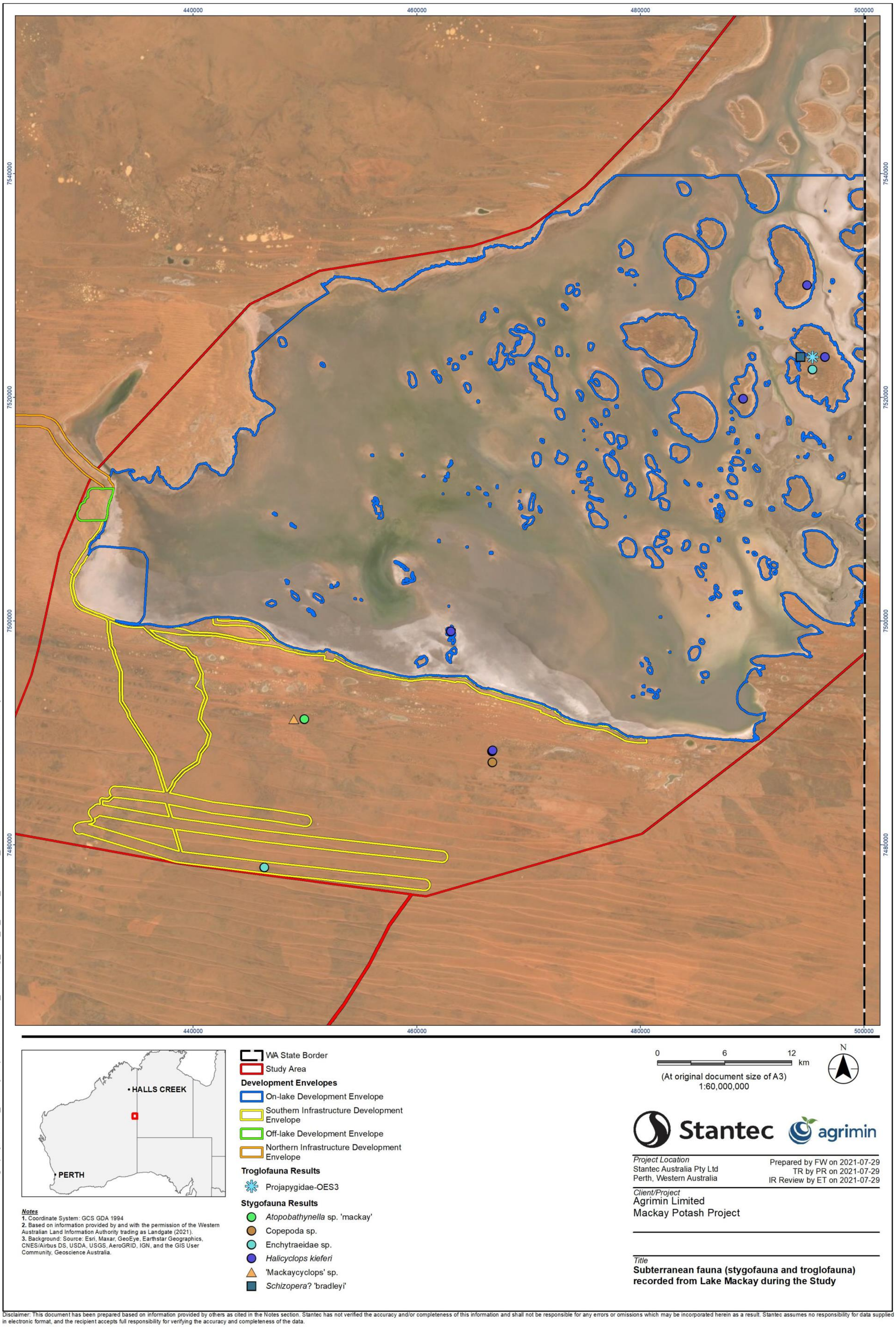


Figure 5-1: Subterranean fauna (stygofauna and troglofauna) recorded from Lake Mackay during the Study.

## 5.5 Summary of Subterranean Fauna Values

To date, at least 18 stygofauna species, one potential stygofauna species, and one potential troglofauna species have been recorded from the Study Area across the seven field surveys (consolidated dataset), completed in 2017, 2020 and 2021 (**Table 5-4**). No species have been recorded from lakebed sediments on the On-LDE playa of Lake Mackay (**Figure 5-2**). This habitat is not considered prospective for subterranean fauna, due to hypersaline groundwater and limited interconnected voids. Similarly, the SIDE borefield was also not considered prospective for significant stygofauna communities, with the area characterised by relatively fine textured alluvial lithology, likely to restrict stygofauna and troglofauna (**Figure 5-3**).

The On-LDE islands, predominantly the landform islands in the eastern portion of the lake, host stygofauna within the calcrete and gypsiferous sands that comprise lower salinity groundwater. However, this habitat is comparatively less diverse than the Southern regional area (**Figure 5-2**, **Figure 5-3**). Three stygal copepod species have been recorded from the On-LDE islands, including one undescribed species that may be restricted; *Schizopera* 'bradleyi' (**Table 5-4**). The only potential troglofauna species recorded was the dipluran Projapygidae-OES3 (**Table 5-4**).

The majority of stygofauna records from the Study Area were associated with the surficial calcrete aquifer in the Southern Regional area (beyond the SIDE borefield and outside the Project's Development Envelopes). Sixteen species were recorded from this area, including 13 undescribed species (**Table 5-4**, **Figure 5-2**). Only one potential stygofauna taxon (affinity to groundwater unknown); Enchytraeidae sp., was recorded from the alluvial aquifer of the SIDE borefield (**Figure 5-3**), although is likely more widely distributed throughout the region.

Table 5-4: Summary of all subterranean fauna recorded in the Study Area.

| Area | Higher ID | Species | Bore Records | Date Records | Distribution and Context |
|---|---|---|---|---|---|
| **Stygofauna** | | | | | |
| On-LDE Islands | Copepoda | *Schizopera* 'bradleyi' | MC13 | Nov 2017 | New, undescribed species, only recorded from a landform island |
| | | *Schizopera ?* 'bradleyi'^ | LMISL2 | Apr 2021 | Likely to belong to previously recorded species |
| | | *Fierscyclops fiersi* | MC13 | Nov 2017 | Widespread outside of the Study Area |
| | | *Halicyclops kieferi* | LMISL2, LMISL3, MC13, T02A Island | Jan 2020, Oct 2020, Apr 2021 | Species widespread within and outside of the Study Area however could represent cryptic species |
| | Oligochaeta | Enchytraeidae sp. | LMISL2 | Jan 2020 | Unknown affinity to groundwater, likely widespread |
| SIDE | Oligochaeta | Enchytraeidae sp. | MWP13 | Jan 2020 | Unknown affinity to groundwater, likely widespread |
| Southern Regional Area | Copepoda | *Schizopera* 'medifurca' | Camp Bore | Nov 2017 | New, undescribed species, only recorded from the Southern Regional area |
| | | *Schizopera* 'paracooperi' | Camp Bore | Nov 2017 | New, undescribed species, only recorded from the Southern Regional area |
| | | *Halicyclops* cf. *kieferi*^ | Camp Bore | May 2017, Nov 2017 | Widespread outside of the Study Area however could represent cryptic species |
| | | *Halicyclops kieferi* | MWP1/5 | Aug 2020 | Widespread outside of the Study Area however could represent cryptic species |
| | | *Halicyclops* 'mackay' | Camp Bore | May 2017, Nov 2017 | New, undescribed species, only recorded from the Southern Regional area |
| | | *Parapseudoleptomesochra* 'mackay' | Camp Bore, Bore 3 | May 2017, Nov 2017 | New, undescribed species, only recorded from the Southern Regional area |
| | | 'Mackaynitocrella mouldsi' | Camp Bore, Nr LP008 | May 2017, Nov 2017 | New undescribed genus and species, only recorded from the Southern Regional area |
| | | 'Mackaycyclops mouldsi' | Camp Bore, Nr LP008, MWP8 | May 2017, Nov 2017 | New, undescribed genus/species, only recorded from the Southern Regional area |
| | | *Nitokra lacustris pacifica* | MWP8 | Nov 2017 | Widespread in Oceania |
| | | 'Mackaycyclops bradleyi' | MWP8 | Nov 2017 | New, undescribed genus/species, only recorded from the Southern Regional area |
| | | *Schizopera* 'mackay' | Nr LP008 | May 2017, Nov 2017 | New, undescribed species, only recorded from the Southern Regional area |
| | | 'Mackaycyclops' sp. ^ | MWP2 | May/Jun 2020 | New undescribed genus. Likely to belong to previously recorded undescribed species. Likely endemic to the Study Area |
| | | Copepoda sp.^ | MWP1/5 | May/June 2020 | No further identification possible for one specimen |
| | Syncarida | *Atopobathynella* sp. 'mackay' | Nr LP008, MWP2 | May 2017, Nov 2017, May/Jun 2020 | New, undescribed species, only recorded from the Southern Regional area |
| | Ostracoda | *Abcandonopsis* 'mackay' | Nr LP008 | May 2017 | New, undescribed species, only recorded from the Southern Regional area |
| | Coleoptera | *Paroster* sp. 'mackay large' | Camp Bore, Nr LP008 | May 2017, Nov 2017 | New, undescribed species, only recorded from the Southern Regional area |
| | | *Paroster* sp. 'mackay medium' | Nr LP008 | Nov 2017 | New, undescribed species, only recorded from the Southern Regional area |
| | | *Paroster*? sp. 'mackay small' | Nr LP008 | Nov 2017 | New, undescribed species, only recorded from the Southern Regional area |
| | Oligochaeta | Phreodrilidae? sp. | Nr LP008 | May 2017 | Damaged specimen |
| Troglofauna | | | | | |
| On-LDE Islands | Diplura | Projapygidae-OES3 | LMISL2 | Jan 2020 | Considered a possible troglofauna, very little known about their ecological status. Only recorded from a landform island |

*Note: * Orange highlight indicates new species only recorded from the islands; ^ these taxa have been excluded from total species diversity (likely to be already represented in the taxon list).*

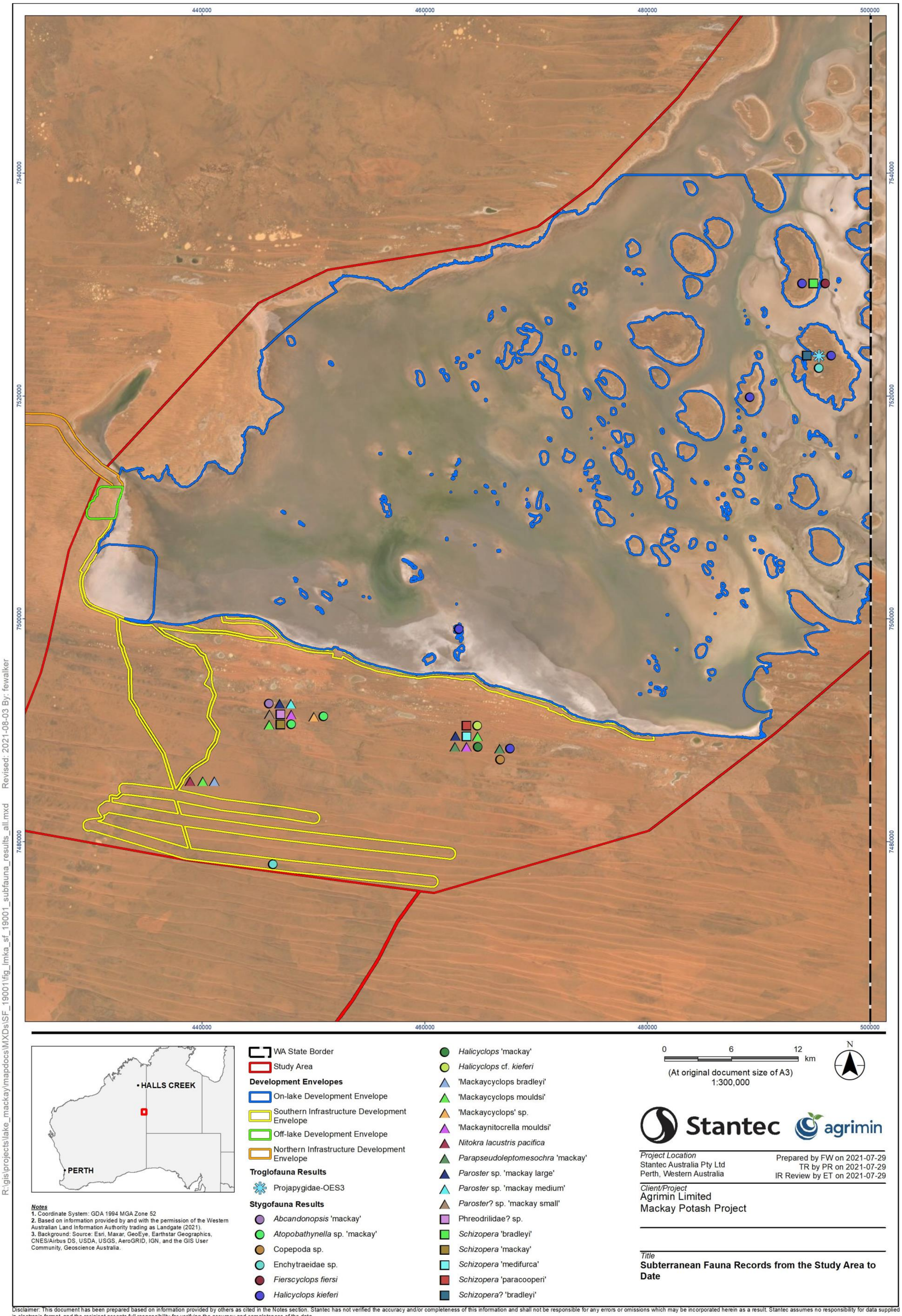




Figure 5-2: Subterranean fauna records from the Study Area to date, based on consolidated data (2017-2021).

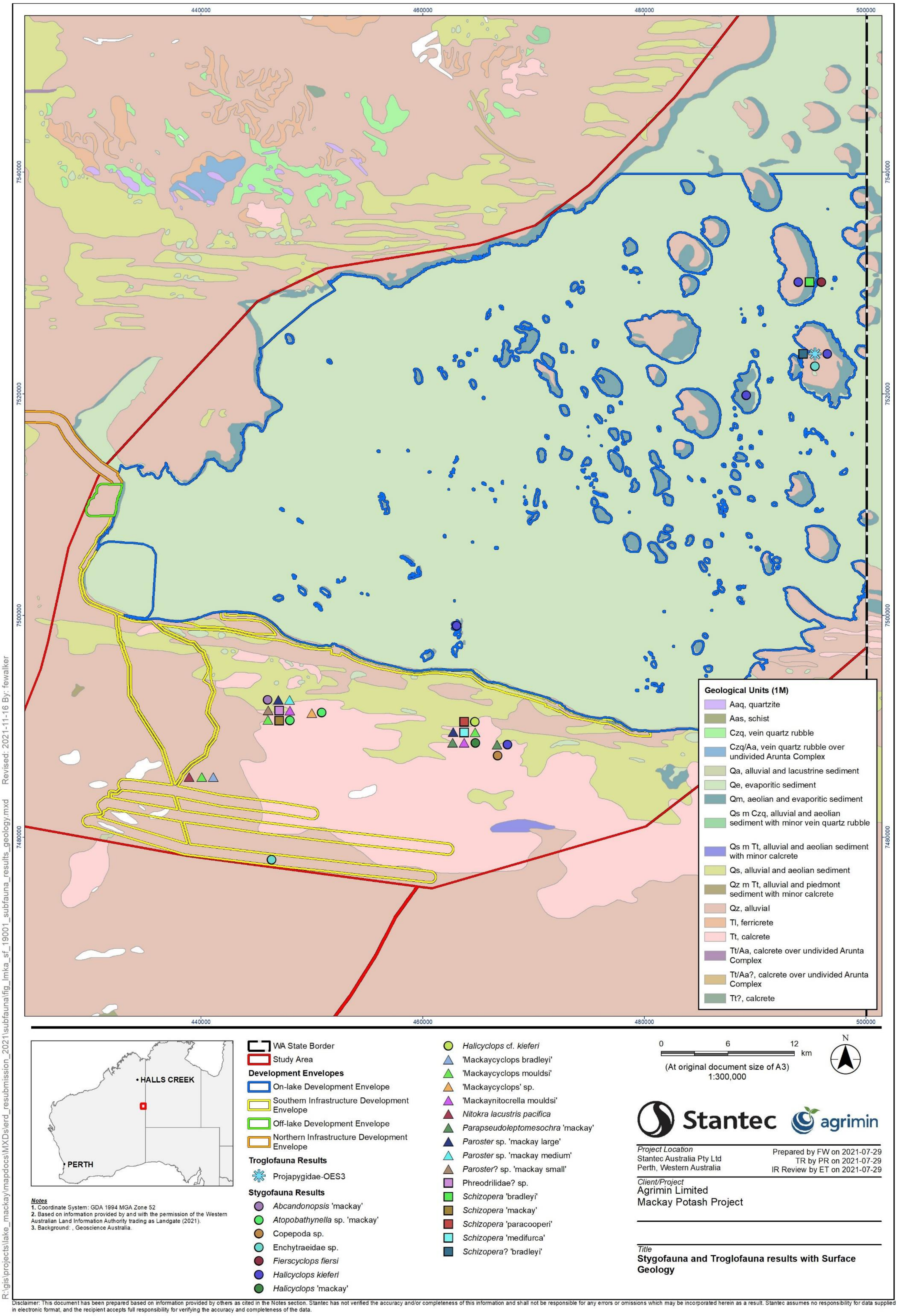


Figure 5-3: Subterranean fauna records from the Study Area to date, based on consolidated data (2017-2021), in relation to surface geology.

# 6. Conclusion

A total of 73 stygofauna and potential stygofauna specimens were recorded during the Study across the five field surveys, representing three higher level taxonomic groups. These included the oligochaete order Haplotaxida, the crustacean sub-class Copepoda and Bathynellacea of the superorder Syncarida.

Stygofauna specimens during this Study were recorded from the On-LDE islands and the Southern Regional area, with a potential stygofauna taxon, Enchytraeidae sp., recorded from the SIDE borefield. No stygofauna were recorded from the On-LDE playa, with habitat considered not prospective, comprising fine textured lacustrine sediments and hypersaline groundwater.

The majority of stygofauna taxa collected during the Study have been recorded during previous surveys, or where juvenile specimens were identified, likely belong to an existing taxon from the Study Area. Of these, undescribed species including the parabathynellid *Atopobathynella* sp. 'mackay', and the cyclopoid copepod 'Mackaycyclops' sp. were recorded from the Southern Regional area. An undescribed species; the harpacticoid copepod *Schizopera* ?'bradleyi', was recorded from the On-LDE islands, although is considered likely to correspond with the previously identified *Schizopera* 'bradleyi'. The diversity of stygofauna was slightly higher within the Southern Regional area, which contains a large surficial calcrete aquifer system. The abundance was comparable between the Southern Regional area and On-LDE islands (predominantly landform islands).

A single potential troglofauna taxon, the dipluran Projapygidae-OES3, was collected from one of the On-LDE landform islands as by-catch from a stygofauna net haul during the Study. There is a paucity of information on diplurans, making it difficult to determine whether the taxon is a troglobite (obligate troglofauna) or edaphofauna (soil-dwelling), although it is potentially endemic to the Study Area.

The results from this Study reflect those from previous surveys within the Study Area. The surficial calcrete unit of the Southern Regional area (outside of the Project's Development Envelopes), and the minor areas of calcrete outcropping on the On-LDE islands (not subject to direct impacts), intersecting low salinity groundwater, host stygofauna communities. This includes a number of undescribed species potentially endemic to the Study Area.

No stygofauna have been recorded from the On-LDE playa where Agrimin propose to develop their brine abstraction trench network. Despite the collection of the potential stygofauna Enchytraeidae sp. from the SIDE borefield, it is considered likely that this taxon is widely distributed within the broad alluvial unit and does not represent a significant stygofauna community. A summary of comparative subterranean fauna values (based on diversity, abundance and species significance) is provided in **Table 6-1**.

Table 6-1: Summary of subterranean fauna values from Study Area.

| Area | Characterisation | Significant Species | Values |
|---|---|---|---|
| On-LDE Playa | Sand/silt/clay/gypsum with limited interconnected voids, groundwater close to surface, hypersaline (>100,000 mg/L) | None | Negligible |
| On-LDE Islands | Larger (landform) islands host some calcrete within the gypsiferous sands, with lower salinity water (<60,000 mg/L) | **Stygofauna**<br>*Schizopera* 'bradleyi'^<br>**Troglofauna**<br>Projapygidae-OES3^ | Moderate |
| SIDE Borefield | Clayey sandstone overlain by silty clay, fresh to brackish water (<6,500 mg/L) | None | Limited |
| Southern Regional Area | Calcrete and unconsolidated sediments, with lower salinity water (<50,000 mg/L) | New species of syncarid, copepods, ostracod and coleopterans | High |

*Note: grey text outside of Development Envelopes and no Project impacts expected; ^ potentially new and/or restricted.*

# 7. References


Agrimin. (2018). Hydrology and Hydrogeology of the Lake Mackay Sulphate of Potash (SOP) Project, Western Australia.

Agrimin. (2020a). Island characterisation memorandum. Consolidated island information.

Agrimin. (2020b). Regional lake groundwater levels memorandum.

Agrimin. (2021). Groundwater sampling and analysis memorandum.

Barranco, P. and Harvey, M. S. (2008). The first indigenous palpigrade from Australia: a new species of Eukoenenia (Palpigradi : Eukoeneniidae). *Invertebrate Systematics* 22: 227-233.

Bennelongia. (2009). Yilgarn Iron Ore Project: Carina Deposit, Subterranean Fauna Assessment. . Report prepared for Polaris Metals NL, Western Australia.

Brooker, M. and Fulton, A. (2016). Lake Mackay process water evaluation (version 2D). Memo by Hydrominex Geoscience and Groundwater Exploration Services prepared for Agrimin.

Bureau of Meteorology (2020). Annual Climate Statement 2019: Periods of extreme heat in 2019 bookend Australia's warmest and driest year on record. Available online at.

Bureau of Meteorology (2021a). Climate Statistics - Walungurru Airport (Station number 15664 Kintore). Available online at http://www.bom.gov.au/jsp/ncc/cdio/cvg/av.

Bureau of Meteorology (2021b). Walungurru / Kintore, Northern Territory March 2021 Daily Weather Observations. Available online at http://www.bom.gov.au/climate/dwo/202103/html/IDCJDW8054.202103.shtml.

CDM Smith. (2020). Water Supply Assessment for Mackay SOP Project Groundwater Modelling Report. Prepared for Agrimin Limited.

Cho, J., Park, J. and Humphreys, W. F. (2005). A new genus and six new species of the Parabathynellidae (Bathynellacea, Syncarida) from the Kimberly region, Western Australia. *Journal of Natural History* 39(24): 2225-2255.

Culver, D. C. and Pipan, T. (2009). The Biology of Caves and Other Subterranean Habitats. Oxford University Press, Oxford, United Kingdom.

Department of Agriculture Water and the Environment (2005). Great Sandy Desert Bioregion Available online at.

Dumnicka, E. (2014). Stygobitic oligochaetes (Annelida, Clitellata( in Poland with remarks on their distribution in Central Europe. *Subterranean Biology* 14: 15-24.

Dumnicka, E., Galas, J., Krodkiewska, M. and Pociecha, A. (2020). The diversity of annelids in subterranean waters: a case study from Poland. *Knowledge & Management of Aquatic Ecosystems* 421(16).

Eberhard, S. M., Halse, S. A., Williams, M., Scanlon, M. D., Cocking, J. S. and Barron, H. J. (2007). Exploring the relationship between sampling efficiency and short range endemism for groundwater fauna in the Pilbara region, Western Australia. *Freshwater Biology* 54: 885-901.

Environmental Protection Authority. (2016a). Technical Guidance Sampling Methods for Subterranean Fauna Survey. Environmental Protection Authority, Western Australia.

Environmental Protection Authority. (2016b). Technical Guidance Subterranean Fauna Survey. Environmental Protection Authority, Western Australia.

Foged, N. (1978). Diatoms in Eastern Australia. *Bibliotheca Phycologica* 41: 1-242.

Glanville, K., Schulz, C., Tomlinson, M. and Butler, D. (2016). Biodiversity and biogeography of grounndwater invertebrates in Queensland, Australia. *Subterranean Biology* 17: 55-76.

Gregory, S. J. (2007). The classification of inland salt lakes in Western Australia. Masters. Curtin University of Technology.

Guzik, M. T., Abrams, K. M., Cooper, S. J. B., Humphreys, W. F., Cho, J.-L. and Austin, A. D. (2008). Phylogeography of the ancient Parabathynellidae (Crustacea:Bathynellacea) from the Yilgarn region of Western Australia *Invertebrate Systematics* 22: 205-216.

Halse, S. and Pearson, G. B. (2014). Troglofauna in the vadose zone: comparison of scraping and trapping results and sampling adequacy. *Subterranean Biology* 13: 17-34.

Halse, S., Scanlon, M., Cocking, J., McRae, J. and Pinder, A. (2002). A survey of the biodiversity of groundwater habitats of the Pilbara IBRA bioregion.

Halse, S. A. (2018). Subterranean Fauna of the Arid Zone. In: E. Lambers (ed) On the Ecology of Australia's Arid Zone. Springer Nature

Halse, S. A., Scanlon, M. D., Cocking, j. S., Barron, H. J., Richardson, J. B. and Eberhard, S. (2014). Pilbara stygofauna: deep groundwater of an arid landscape contains globally significant radiation of biodiversity. *Records of the Western Australian Museum. Supplement* 78: 443-483.

Hamilton-Smith, E. and Eberhard, S. (2000). The diversity of the karstic and pseudokarstic hypogean habitats in the world. In: H. Wilkens, D. C. Culver and W. F. Humphreys (eds) Subterranean Ecosystems. Elsevier, Amsterdam, The Netherlands, pp 647-664

Hammer, U. T. (1986). Saline Lake Ecosystems of the World. Dr. W. Junk Publishers, Dordrecht.

Harrison, S. E., Guzik, M. T., Harvey, M. S. and Austin, A. D. (2014). Molecular phylogenetic analysis of Western Australian troglobitic chthoniid pseudoscorpions (Pseudoscorpiones : Chthoniidae) points to multiple independent subterranean clades. *Invertebrate Systematics* 28: 386-400.

Harvey, M. E., Rix, M. G., Volker, W. F., Hamilton, Z. R., Johnson, M. S., Teale, R. J., Humphreys, G. and Humphreys, W. F. (2011). Protecting the innocent: studying short-range endemic taxa enhances conservation outcomes. *Invertebrate Systematics* 25: 1-10.

Humphreys, G. (2006a). BHPBIO Pilbara operations regional stygofauna programme - 2006 annual report. Biota Environmental Sciences Pty Ltd, Perth.

Humphreys, W. F. (2006b). Aquifers: the ultimate groundwater-dependent ecosystems. *Australian Journal of Botany* 54: 115-132.

Humphreys, W. F. (2008). Rising from Down Under: developments in subterranean biodiversity in Australia from a groundwater fauna perspective. *Invertebrate Systematics* 22: 85–101.

Humphreys, W. F. and Harvey, M. S. (ed) (2001). Subterranean biology in Australia 2000 edn). Records of the Western Australian Museum Western Australian Museum, Perth, Western Australia.

Invertebrate Solutions. (2017). Pilot Survey for Subterranean Fauna for the Lake Mackay SOP Project, Western Australia. . Invertebrate Solutions, Perth, Western Australia. .

Invertebrate Solutions. (2018). Phase 1 Survey for Subterranean Fauna for the Lake Mackay SOP Project, Western Australia. Invertebrate Solutions, Perth, Western Australia. .

Karanovic, T. (2004). Subterranean copepods from arid Western Australia. Crustaceana Monographs, 3. Koninklijke, Brill, Leiden, The Netherlands.

Karanovic, T. and McRae, J. M. (2013). The genus *Schizopera* (Copepoda, Harpacticoida) in the Pilbara region of Western Australia, with description of a new species and its molecular and morphological affinities. *Records of the Western Australian Museum* 28: 119-140.

Kendrick, P. (2001). Great Sandy Desert 2 (GSD2 - Mackay subregion). Available online at.

Kendrick, P. and McKenzie, N. (2001). A Biodiversity Audit of Western Australia's 53 Biogeographical Subregions in 2002. Pilbara. Available online at.

MWH. (2014). McPhee Creek Iron Ore Project Subterranean Fauna Environmental Impact Assessment. Report prepared for Atlas Iron Limited.

MWH. (2015). Wiluna Uranium Project: Millipede Targeted Subterranean Fauna Assessment. Report prepared for Toro Energy Ltd.

MWH. (2016a). Ethel Gorge Stygofauna Monitoring Program: 2016. Report prepared for BHP Billiton Iron Ore.

MWH. (2016b). Mount Keith Satellite Operations Subterranean Fauna Assessment. Report prepared for BHP Billiton Nickel West.

MWH. (2016c). Salinity Tolerance of Ethel Gorge Stygofauna TEC. Report prepared for BHP Billiton Iron Ore.

Naumann, I. D. (ed) (1991). The Insects of Australia. A textbook for students and research workers (Second edn). Melbourne University Press, Carlton.

Outback Ecology. (2009). Assessment of the Troglofauna within the Hope Downs 4 Study Area. Internal report for Pilbara Iron Services, Hope Downs 4, Perth, Western Australia.

Outback Ecology. (2011a). BHP Billiton Nickel West NDS1 Mine and Corridor Project Subterranean Fauna Assessment. Prepared for BHP Billiton NIckel West, Perth, Western Australia.

Outback Ecology. (2011b). Wiluna Uranium Project Subterranean Fauna Assessment, March 2011. Prepared for Toro Energy Ltd, Perth, Western Australia.

Outback Ecology. (2012a). BHP Billiton Nickel West NDS1 Project: Lake Way Borefield Subterranean Fauna Assessment. Prepared for BHP Billiton NIckel Wes, Perth, Western Australia.

Outback Ecology. (2012b). Lake Maitland Uranium Project Level 2 Troglofauna Assessment. Prepared for Mega Lake Maitland Pty Ltd, Perth, Western Australia.

Outback Ecology. (2012c). Lake Maitland Uranium Project Stygofauna Assessment. Prepared for Mega Lake Maitland Pty Ltd.

Outback Ecology. (2014). Browns Range Project Subterranean Fauna Assessment. Report prepared for Northern Minerals Ltd, Perth, Western Australia.

Pinder, A. M. (2010). Tools for identifying Australian aquatic oligochaetes (Clitellata: Annelida). *Museum Victoria Science Reports* 13: 1-26.

Platnick, N. I. (2008). A new subterranean ground spider genus from Western Australia (Araneae:Trochanteriidae) *Invertebrate Systematics* 22: 295-299.

Reeves, J. M., De Deckker, P. and Halse, S. A. (2007). Groundwater Ostracods from the arid Pilbara region of northwestern Australia: distribution and water chemistry. *Hydrobiologia* 585: 99–118.

Stantec. (2020). Lake Mackay Island Characterisation

Strayer, D. L. (1994). Limits to biological distributions in groundwater. In: J. Gibert, D. L. Danielopol and J. A. Stanford (eds) Groundwater Ecology. Academic Press, San Diego, pp 287-310

Subterranean Ecology. (2008). Abydos DSO Project Troglofauna Survey. Prepared for Atlas Iron Ltd.

Subterranean Ecology. (2010a). Gold Fields, St Ives Gold Mines: Stygofauna Desktop Assessment. Unpublished report for Gold Fields Pty Ltd.

Subterranean Ecology. (2010b). Gold Fields, St Ives Gold Mines: Troglofauna Desktop Assessment. Unpublished report for Gold Fields Pty Ltd.

Thackway, R. and Cresswall, I. D. (1995). An interim biogeographic regionalisation for Australia: a framework for setting priorities in the national reserves system cooperative program. Department of the Environment and Water Resources. Available online at http://www.environment.gov.au/parks/nrs/ibra/version4-0/framework/ibrintro.html#ch1. Accessed on 20/06/07.

Thurgate, M. E., Gough, J. S., Spate, A. and Eberhard, S. (2001). Subterranean biodiversity in New South Wales: from rags to riches. *Records of the Western Australian Museum Supplement No.* 64: 37-47.

Williams, W. D. (1998). Guidelines of lake management, Volume 6. Management of inland saline waters. International Lake Environment Committee, United Nations Environment Programme, Shiga, Japan.

# Appendices

# Appendix A Groundwater Quality Summary Tables (Agrimin 2021)

Table A1: Summary of groundwater quality from lakebed sediments from monitoring bores and trenches.

| Parameter | Records | Min. | Mean | Median | Max. |
|---|---|---|---|---|---|
| pH (units) | 32 | 5.34 | 6.63 | 6.68 | 7.22 |
| Salinity (TDS) | 349 | 6,569 | 214,678 | 228,456 | 339,995 |
| Magnesium | 213 | 57 | 2,551 | 2,240 | 6,790 |
| Calcium | 213 | 140 | 598 | 602 | 1,220 |
| Sodium | 213 | 6,823 | 88,786 | 89062 | 134,348 |
| Potassium | 213 | 390 | 3,088 | 3080 | 9,640 |
| Chloride | 213 | 164 | 131,987 | 132050 | 186,950 |
| Sulphate | 213 | 3,870 | 19,688 | 19325 | 60,900 |
| Bicarbonate | 28 | 10 | 37 | 20 | 210 |
| Nitrates | 32 | 4 | 31 | 11 | 151 |

*Note: all parameters are mg/L, except where shown.*

Table A2: Summary of groundwater quality from the islands during drilling.

| Parameter | Records | Min. | Mean | Median | Max. |
|---|---|---|---|---|---|
| pH (units) | 2 | 6.83 | 6.87 | 6.87 | 6.90 |
| Salinity (TDS) | 2 | 41,864 | 48,988 | 48,989 | 56,113 |
| Magnesium | 2 | 373 | 446 | 446 | 520 |
| Calcium | 2 | 1,080 | 1,135 | 1,135 | 1,190 |
| Sodium | 2 | 12,450 | 14,675 | 14,675 | 16,900 |
| Potassium | 2 | 325 | 418 | 418 | 510 |
| Chloride | 2 | 20,425 | 24,738 | 24,738 | 29,050 |
| Sulphate | 2 | 5,295 | 5,573 | 5,573 | 5,850 |
| Bicarbonate | 2 | 40 | 105 | 105 | 170 |
| Nitrates | 2 | 8 | 38 | 38 | 68 |

*Note: all parameters are mg/L, except where shown.*

Table A3: Summary of groundwater quality from the SIDE borefield during drilling.

| Parameter | Records | Min. | Mean | Median | Max. |
|---|---|---|---|---|---|
| pH (units) | 3 | 7.2 | 7.27 | 7.3 | 7.30 |
| Salinity (TDS) | 3 | 1,567 | 3,465 | 2,528 | 6,300 |
| Magnesium | 7 | 35 | 69 | 55 | 180 |
| Calcium | 7 | 55 | 118 | 95 | 264 |
| Sodium | 7 | 350 | 695 | 600 | 1,622 |
| Potassium | 7 | 30 | 49 | 40 | 124 |
| Chloride | 7 | 326 | 867 | 950 | 1,290 |
| Sulphate | 7 | 240 | 503 | 390 | 1,312 |
| Bicarbonate | 3 | 296 | 345 | 315 | 424 |

*Note: all parameters are mg/L, except where shown.*

# Appendix B Invertebrate Solutions Subterranean Fauna Survey (2018)

# Phase 1 Survey for Subterranean Fauna for the Lake Mackay SOP Project, Western Australia.

Report by Invertebrate Solutions for Agrimin Ltd on behalf of 360 Environmental Pty Ltd

**April 2018**

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Report Number 2017ISJ07_F03_20180410

Prepared for: Agrimin Ltd, on behalf of 360 Environmental Pty Ltd

Frontispiece: A stygobiontic bathynellid, *Atopobathynella* sp. 'mackay' from a calcrete aquifer south of Lake Mackay.

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# Executive Summary

Agrimin Limited (Agrimin) is developing its Lake Mackay Sulphate of Potash (SOP) Project and requires a number of baseline biological assessments to be carried out. The SOP Project includes 12 tenements covering the majority of Lake Mackay over a total area of 3,500 square kilometres. Lake Mackay is a seasonally inundated salt lake located on the Western Australia (WA) – Northern Territory (NT) border, with most of the lake located within WA.

In May 2017 Invertebrate Solutions was requested by 360 Environmental Pty Ltd (360 Environmental) on behalf of Agrimin to undertake a pilot survey for stygofauna, with eight new species, and two new genera of stygofauna recorded from five sampled bores located within the surficial calcrete aquifer to the south of Lake Mackay.

A subsequent level 2 stygofauna survey was commenced in November 2017 in the various aquifers to the south of Lake Mackay and on Lake Mackay itself. This survey has begun sampling in the surficial calcrete aquifer and the underlying deep alluvial aquifer, located to the south of Lake Mackay, and the perched aquifers associated with the islands in Lake Mackay. A pilot survey for troglofauna within the surficial calcrete deposits also commenced in November 2017, sampling two available uncased bores using both scrape and litter trap sampling techniques. No troglofauna has been recorded at present.

The results of the November 2017 stygofauna sampling has recorded stygofauna in both the surficial calcrete aquifer and the aquifers associated with the islands in Lake Mackay. No stygofauna has been recorded from the deep alluvial aquifer or from the hypersaline water within Lake Mackay situated away from islands.

Currently, the surficial calcrete aquifer shows the greatest diversity, with five classes, six orders, 7 families and 16 species present, whilst the single sampling location within the island aquifer has recorded two additional species. The stygofauna recorded in the Lake Mackay aquifers is significant in that it contains three new species of dytiscid diving beetle (*Paroster* spp.?*),* a new species of parabathynellid (*Atopobathynella* sp. '*mackay'*), and multiple new species of Copepoda, some of which show extremely primitive morphological characters (*Mackaycyclops mouldsi* n. g. & sp. and *Schizopera mackay* n. sp.) and may be important in the evolutionary history of Australian stygofauna.

Fourteen of the 18 species recorded (78%) from both the surficial calcrete and island aquifer are undescribed species and 10 species (56%) are currently only recorded from single bores, although this is invariably due to the lack of suitable sampling locations. These results are not entirely unexpected due to the location of the sampling being many hundreds of kilometres from any other subterranean fauna sampling locations. Currently, most of these new species are known from single bores.

The following recommendations are made with regard to the potential development of the Lake Mackay SOP Project:

- Due to the presence of a stygofaunal community within the surficial calcrete aquifer located within the southern proposed borefield area, a Level 2 survey for stygofauna should be undertaken with regard to EPA Technical Guidance – subterranean fauna survey (EPA2016a) and EPA Technical Guidance – sampling methods for subterranean fauna (EPA2016b);

- The Level 2 survey for stygofauna will require, at a minimum, 40 samples from each impacted aquifer within the proposed borefield area (EPA2016b);
- Genetic sequencing of the stygobitic Dytiscid beetles and Bathynellids should be undertaken to confirm the current morphological identifications and the distribution of individual species within the Project area. Confirmation of the same species geographically across the project area will enable a more accurate assessment of potential impacts to stygofaunal communities to be determined;
- The deep alluvial aquifer currently presents an environment unfavourable to stygofauna and preliminary sampling of this aquifer has recorded no stygofauna. Additional sampling of this aquifer should be undertaken to obtain sufficient samples to provide a pilot survey level of field sampling before a final assessment regarding the presence or absence of stygofauna within this aquifer can be undertaken;
- A troglofauna pilot survey has commenced in the proposed borefield area and should be continued until the requirements of EPA Guidance (2016a) are met. This would be a minimum of 10 – 15 bores to be sampled. No troglofauna has currently be recorded from the proposed borefield area;
- The stygofauna pilot survey of the island aquifers within Lake Mackay should be continued in all available bores until an assessment of the stygofauna present and the potential for impact to this stygofaunal community can be determined more accurately. This sampling should include all island areas that may be potentially impacted by drawdown associated with trenching; and
- Newly constructed bores should be constructed suitable for stygofauna and/or troglofauna sampling.

# 1. Introduction

Agrimin Limited (Agrimin) is developing its Lake Mackay Sulphate of Potash (SOP) Project and requires a number of baseline biological assessments to be carried out. The SOP Project includes 12 tenements covering the majority of Lake Mackay over a total area of 3,500 square kilometres. Lake Mackay is a seasonally inundated salt lake located on the Western Australia (WA) – Northern Territory (NT) border, with most of the lake located within WA.

In May 2017, Invertebrate Solutions was requested by 360 Environmental Pty Ltd (360 Environmental) on behalf of Agrimin to undertake a pilot survey for stygofauna, with eight new species, and two new genera of stygofauna recorded from five sampled bores located within the surficial calcrete aquifer to the south of Lake Mackay.

The proposed water supply for the Lake Mackay SOP Project is expected to be sourced from various aquifers within the general area to the south of Lake Mackay.  Invertebrate Solutions has subsequently been engaged by 360 Environmental on behalf of Agrimin to undertake a Level 2 survey for subterranean fauna (stygofauna and troglofauna) with regard to EPA Technical Guidance – subterranean fauna survey (EPA2016a) and EPA Technical Guidance – sampling methods for subterranean fauna (EPA2016b).

## 1.1 Purpose of this Report

360 Environmental has requested Invertebrate Solutions to undertake the following scope of works for the Lake Mackay SOP Project area, Western Australia:

- Undertake a Level 2 field survey for stygofauna in the surficial calcrete aquifer located within the proposed borefield area;
- Undertake a pilot survey for stygofauna in the deep alluvial aquifer within the proposed borefield area;
- Undertake a pilot survey for stygofauna in the Lake Mackay Island aquifers;
- Undertake a pilot survey for stygofauna in the trenches in Lake Mackay;
- Undertake a pilot survey for troglofauna in the proposed borefield area;
- Provide recommendations to minimise potential impacts and any suggested requirements for further work to comply with relevant legislation; and
- Provide a written report containing the above items.

## 1.2 Project Area

The Project includes 12 tenements covering the majority of Lake Mackay over a total area of 3,500 square kilometres. Lake Mackay is a seasonally inundated salt lake located on the Western Australia (WA) – Northern Territory (NT) border, with most of the lake located within WA and is shown in Figure 1.


# Legend

- Project Boundary
- Proposed Infrastructure Boundaries
- Existing Road
- Existing Track
- Proposed Track

## Stygofauna Sampling Locations

- Deep Alluvial Aquifer
- Lake Mackay Island
- Lake Mackay trench
- Surficial calcrete

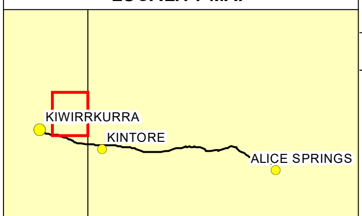
0 5 10 15 20

Kilometers

1:500,000 @ A4

- NOTE THAT POSITION ERRORS CAN BE >5M IN SOME AREAS

**LOCALITY MAP**




- LOCALITY MAP SOURCED FROM LANDGATE 2017
- AERIAL PHOTOGRAPHY SOURCED ESRI 2017
(DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community)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| PROJECT ID | | | DATE |
|---|---|---|---|
| 2188 | | | 15/02/2018 |
| HORIZONTAL DATUM AND PROJECTION | | | |
| GDA 1994 MGA Zone 52 | | | |
| CREATED | CHECKED | APPROVED | REVISION |
| DV | TM | FJ | 0 |

**Agrimin Limited**
**Lake Mackay SOP Project**
**Phase 1 Survey for Subterranean Fauna for the Lake Mackay SOP Project, Western Australia**

**Figure 1**
**Stygofauna Sampling Locations**

K:\Projects\1.0 EBS\2188 Eco Surveys Lake Mackay\Figures\SRE and Aquatic Macroinverts\2188 SRE Figure 2 Stygofauna updated 01 Feb 2018.mxd

## 1.3 Survey Effort and Timing

Invertebrate Solutions completed a pilot survey for stygofauna in the borefield areas in May 2017. A total of five samples were collected from bores within the borefield area (Table 1), however, one sample collected using an *in situ* handpump does not meet the required sampling requirements for a pump sample and is for reference only (refer Section 2.2). Some of the bores (Table 1) that were sampled in the Phase 1 sampling in November 2017 were drilled in September 2017 and so were within the six month settling period (EPA 2016a). These bores will be resampled following the settling period to confirm the results of the current sampling.

**Table 1 Bores sampled for Stygofauna in the proposed borefield**

| Bore ID | Pilot Phase | Phase 1 | Aquifer sampled |
|---|---|---|---|
| Camp Bore | X | X | Surficial calcrete |
| BORE 3* | | X | Surficial calcrete |
| BORE 6* | | X | Deep Alluvial Aquifer |
| Handpump | X | | Surficial calcrete |
| LD02 | X | X | Surficial calcrete |
| LD03 | X | X | Surficial calcrete |
| LM0182 | | X | Surficial calcrete |
| LM0183 | | X | Surficial calcrete |
| MC13* | | X | Lake Mackay Island |
| MWP2* | | X | Deep Alluvial Aquifer |
| MWP4 SHALLOW* | | X | Deep Alluvial Aquifer |
| MWP6* | | X | Deep Alluvial Aquifer |
| NEW S1* | | X | Deep Alluvial Aquifer |
| Nr LP008 | X | X | Surficial calcrete |
| TRENCH16 | | X | Lake Mackay trench |
| TRENCH17 | | X | Lake Mackay trench |

***Newly drilled bore, sampled within the six month settling period.**

The stygofauna sampling effort for each aquifer currently identified within the Project area is shown in Table 2. Currently the most survey effort has been within the surficial calcrete aquifer to the south of Lake Mackay with 12 samples obtained, mainly from historic exploration bores. Two stygofauna samples have been taken from the test trenches in Lake Mackay in order to confirm the absence of stygofauna from these hypersaline environments. No samples have currently been taken in known non-impact areas.

**Table 2 Sample effort for aquifers in the Lake Mackay SOP Project**

| Aquifer sampled | Pilot Phase | Phase 1 | Total |
|---|---|---|---|
| Surficial calcrete | 4 | 7 | 11 |
| Deep Alluvial Aquifer | 0 | 5 | 5 |
| Lake Mackay Island | 0 | 1 | 1 |
| Lake Mackay trench | 0 | 2 | 2 |
| Reference samples (non-impact areas) | 0 | 0 | 0 |


## Legend

- Project Boundary
- Proposed Infrastructure Boundaries
- Existing Road
- Existing Track
- Proposed Track
- Troglofauna Sampling Locations

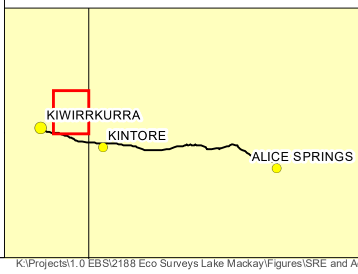
0 5 10 15 20

Kilometers

1:500,000 @ A4

- NOTE THAT POSITION ERRORS CAN BE >5M IN SOME AREAS

**LOCALITY MAP**




- LOCALITY MAP SOURCED FROM LANDGATE 2017
- AERIAL PHOTOGRAPHY SOURCED ESRI 2017
(DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community)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| PROJECT ID | DATE |
|---|---|
| 2188 | 15/02/2018 |

**HORIZONTAL DATUM AND PROJECTION**
GDA 1994 MGA Zone 52

| CREATED | CHECKED | APPROVED | REVISION |
|---|---|---|---|
| DV | TM | FJ | 0 |

**Agrimin Limited**
**Lake Mackay SOP Project**
**Phase 1 Survey for Subterranean Fauna for the Lake Mackay SOP Project, Western Australia**

**Figure 2**
**Troglofauna Sampling Locations**

K:\Projects\1.0 EBS\2188 Eco Surveys Lake Mackay\Figures\SRE and Aquatic Macroinverts\2188 SRE Figure 2 Troglofauna Sampling Locations.mxd

The pilot survey of troglofauna commenced in November 2017 and has included two scrape samples and the placement of six litter traps in the two bores suitable for troglofauna sampling (Table 3). The litter traps will be retrieved during subsequent field surveys. Additional uncased bores suitable for troglofauna sampling are anticipated to be constructed in the future.

**Table 3 Bores sampled for troglofauna in the proposed borefield**

| Bore ID | Easting | Northing | Scraped | Litter Trap | Date Sampled |
|---|---|---|---|---|---|
| **BORE 3** | 466729 | 7488333 | X | 3 | 17/11/2017 |
| **BORE 5 (MWP8)** | 440076 | 7485415 | X | 3 | 19/11/2017 |

A map showing the locations of the bores sampled for troglofauna and stygofauna is shown in Figure 2.

## 1.4 Introduction to Subterranean Fauna

Subterranean fauna are comprised of stygofauna (aquatic subterranean dependent species) and troglofauna (air breathing subterranean dependent species) which are known to be relatively diverse on a worldwide scale in Western Australia. Stygofauna and troglofauna are known to occur widely in the Pilbara, Yilgarn and Ngalia basins. Many species of subterranean fauna have highly restricted ranges due to habitat connectivity issues and evolutionary history.

The high degrees of local endemism and lack of habitat connectivity makes subterranean fauna susceptible to high levels of impact from sometimes localised projects, with species' extinction a real possibility if they are not adequately considered during project planning phases.

An extensive amount of jargon is associated with subterranean fauna and multiple forms of classification have been used historically. The most commonly accepted and used terms divide troglofauna into categories that describe a particular species' degree of dependence upon the subterranean environment. Due to the reliance upon ecological information to determine if a species is a troglobite, the concept of troglomorphy (Christiansen 1962) - specific morphological adaptations to the subterranean environment - is used to define obligate subterranean species. The term troglomorphy, initially confined to morphology, has since been used to describe both morphological or behavioural adaptations (Howarth 1973). This combination provides a practical system, easily applied in the field and with a minimum of detailed ecological study required. The level of subterranean dependency for different ecological groupings is described below:

- Troglobiont: animals that are obligate subterranean species and mostly show morphological adaptation to subterranean habitats (troglomorphisms) including depigmentation, loss or reduction of eyes, elongation of appendages, absent or reduced wings and extra sensory hairs;
- Troglophiles: animals that can complete their entire lifecycle within a cave but possess no specific adaptations to the cave environment. These species are capable of living outside caves in suitably dark and moist epigean habitats; and

- Trogloxenes: animals that use the subterranean environment but require surface environments to complete part of their lifecycle (generally either feeding or breeding). Common trogloxenes are cave dwelling bats, cave swiftlets and cave crickets that leave subterranean habitats to feed.

The aforementioned terms refer to stygofauna when the prefix is altered to stygo (Humphreys 2000).

Species which inhabit the deep soil habitat (Edaphophiles) often exhibit convergent morphological adaptations to those animals found exclusively within caves, such as reduced or absent eyes, body flattening, loss of pigmentation, etc. Soil dwelling species commonly do not show highly restricted distributions as they are less easily isolated in evolutionary timeframes, thus only true troglobitic animals are the focus of surveys for subterranean fauna. Taxa discussed in this study were assessed on their combination of loss/reduction of eyes, reduction in pigmentation and wing development, and elongation of appendages to assess if a taxa was an edaphophile or truly reliant upon the subterranean habitat (Troglobiont).

## 1.5 Conservation Legislation and Guidance Statements

Subterranean fauna are protected under state legislation via the Wildlife Conservation (WC) Act (1950), the Environmental Protection Act (1986) and federally under the Environment Protection and Biodiversity Conservation (EPBC) Act (1999). The assessment of subterranean fauna for environmental impact assessment (EIA) is undertaken in Western Australia with regard to the Technical Guidance – Subterranean Fauna Survey (EPA2016a), Technical Guidance – Sampling Methods for Subterranean Fauna (EPA2016b) and the Environmental Factor Guideline – Subterranean Fauna (EPA 2016c).

At the State level, the WC Act provides a list of species that have special protection as species listed under the Wildlife Conservation (Specially Protected Fauna) Notice 2018 (DBCA 2018). This notice is updated periodically by the Department of Biodiversity, Conservation and Attractions (DBCA) (formerly the Department of Parks and Wildlife (DPaW) and the current list (January 2018) includes numerous subterranean species mainly from the Cape Range and Pilbara regions. Included in the list are crustaceans, arachnids and myriapods that are considered to be “rare or likely to become extinct, as critically endangered fauna, or are declared to be fauna that is in need of special protection” (DPaW 2015). In addition to the specially protected fauna, DBCA also maintains a list of Priority fauna that are considered to be of conservation significance but do not meet the criteria for formal listing under the WC Act as Scheduled species. The Priority fauna list is irregularly updated by DBCA and, although it offers no formal legislative protection, these species are generally considered in the EIA process.

There is no current ability for the state government of Western Australia to formally list Threatened or Priority Ecological Communities (TECs/PECs), however, a list of such communities is maintained by DBCA and overseen by the Minister for the Environment. Several subterranean ecological communities are recognised as Threatened including the Bundera Cenote Anchialine community on Cape Range, Cameron’s Cave near the townsite of Exmouth on Cape Range, stygal root mat communities in both the Yanchep and Margaret River regions and stygobionts in the Ethel Gorge aquifer in the Pilbara. Communities that are not considered by DBCA to be threatened but may be vulnerable to future impacts are classed as PECs and include numerous calcrete aquifers in the Yilgarn region where each calcrete has been shown to contain an endemic stygal community.

The WC Act is expected to be imminently replaced by the new Biodiversity Conservation Act that has yet to be enacted into law. This new act has been passed by the lower house of the State parliament and will be capable of protecting both species and ecological communities under legislation.

The federal EPBC Act protects both species and ecological communities. The most relevant listings for subterranean fauna include the Bundera Cenote on the western side of the Cape Range which contains a unique anchialine ecosystem including the stygal Cape Range Remipede *Kumonga exleyi* that is listed as Vulnerable. The Cape Range gudgeon *Milyeringa veritas* and the Cape Range blind eel *Ophisternon candidum* are also listed as Vulnerable species from subterranean habitats on the Cape Range.

## 1.6 Survey Staff Qualifications

Field sampling for invertebrates was undertaken by experienced ecologists and comprised of:

- Dr Timothy Moulds BSc (Hons) Geol., PhD. Invert. Ecol.
- Gerry Bradley BSc (Hons) Zool. (Agrimin Sustainability Manager).

Invertebrate extraction and sorting was completed by Dr Timothy Moulds.

Survey work was undertaken under the collection licences issued by the Department of Biodiversity, Conservation and Attractions:

- 08-001304-1; Licensee Dr Tim Moulds; Valid from 9/11/2017.

The pilot survey sampling for stygofauna was undertaken between 12$^{th}$ – 18$^{th}$ May 2017 and Phase 1 sampling was undertaken between 12$^{th}$ – 20$^{th}$ November 2017.

## 1.7 Report Limitations and Exclusions

This study was limited to the written scope provided to the client by Invertebrate Solutions (8$^{th}$ August 2016) and in Section 1.1. This study was limited to the extent of information made available to Invertebrate Solutions at the time of undertaking the work. Information not made available to this study, or which subsequently becomes available, may alter the conclusions made herein. Assessment of potential impacts to subterranean fauna was based on proposed infrastructure plans provided by Agrimin Ltd.

The opinions, conclusions and any recommendations in this report are based on conditions encountered and information reviewed at the date of preparation of the report. Invertebrate Solutions has no responsibility or obligation to update this report to account for events or changes occurring subsequent to the date that the report was prepared.

The opinions, conclusions and any recommendations in this report are based on assumptions made by Invertebrate Solutions described in this report (this section and throughout this report). Invertebrate Solutions disclaims liability arising from any of the assumptions being incorrect.

Invertebrate Solutions has prepared this report on the basis of information provided by 360 Environmental for Agrimin Ltd and others (including Government authorities), which Invertebrate Solutions has not independently verified or checked beyond the agreed scope of work. Invertebrate Solutions does not accept liability in connection with such unverified information, including errors and omissions in the report which were caused by errors or omissions in that information.

Site conditions may change after the date of this report. Invertebrate Solutions does not accept responsibility arising from, or in connection with, any change to the site conditions. Invertebrate Solutions is also not responsible for updating this report if the site conditions change.

Species were identified to the lowest practical taxonomic level, taking into consideration that the taxonomic framework of many invertebrate groups is incomplete and often in need of substantial revision to enable accurate identification. Insufficient information exists for many invertebrate species due to specimens being juvenile, the wrong sex to allow identification, damaged, or inadequate taxonomic frameworks, precluding identification.

Field surveys for subterranean fauna require multiple seasonal surveys to fully record all species that may be present in an area and additional surveys at different times of the year may record additional species.

# 2. Methods

Invertebrate Solutions undertook the following tasks for the pilot survey of the Lake Mackay Project area:

- Desktop subterranean fauna assessment;
- Stygofauna Phase 1 field survey of the surficial calcrete aquifer within the proposed borefield;
- Stygofauna pilot survey of the deep alluvial aquifer within the proposed borefield;
- Stygofauna pilot survey of the Island aquifers;
- Stygofauna pilot survey of the trenches in Lake Mackay;
- Troglofauna pilot survey of the proposed borefield.

The survey program was undertaken with regard to the Technical Guidance – Subterranean Fauna Survey (EPA2016a), Technical Guidance – Sampling Methods for Subterranean Fauna (EPA2016b) and the Environmental Factor Guideline – Subterranean Fauna (EPA 2016c).

## 2.1 Subterranean Fauna Desktop Methodology

The likelihood of stygofauna and troglofauna species occurring in the Study Area was assessed using a combination of regional information, geological, hydrogeological and database searches including:

- Analysis of published and unpublished reports concerning subterranean fauna from the region;
- Available geological maps;
- Geological, geotechnical and hydrogeological information available for the Study area;
- Records of fauna held by the Western Australian Museum.

Based on the analysis of all available information, the study area was assigned a level of likelihood to support subterranean fauna of either 'Low', 'Moderate', 'High', or 'Definite'.

## 2.2 Stygofauna Sampling Methods

Stygofauna was sampled using modified plankton nets in accordance with the Environmental Protection Authority (EPA) Technical Guidance – Subterranean Fauna Survey (EPA2016a) and EPA Technical Guidance – Sampling Methods for Subterranean Fauna (EPA2016b). Bores were sampled for stygofauna using a plankton net of suitable diameter (32 mm to 90 mm) to match the bore/well. The net (either 125 µm or 50 µm mesh), with a weighted vial attached, was lowered into the bore and then hauled up through the water column.

The net was dropped to the base of the bore then agitated up and down (±1 m) several times to disturb the bottom sediment and any stygofauna contained within. Six hauls of the entire water column were undertaken at each bore. Depths to the water table and the bottom of bores were calculated using the number of rotations of the fishing reel. Three hauls were undertaken with both the 125 µm and the 50 µm mesh nets. Each net haul sample was transferred to a labelled polycarbonate container and preserved in 100% alcohol. Samples with large quantities of sediment were elutriated prior to preservation. To minimise the possibility of stygofauna cross contamination, the nets were treated with a decontamination solution and thoroughly rinsed in water and air-dried.

Sampling of the handpump site was undertaken by pumping water through a 50 µm mesh net into bucket of known volume. Approximately 165 L of water was pumped from the bore through the stygofauna net prior to the well going temporarily dry. This volume is well below the recommended volume of 300 L or three times the bore volume (EPA 2016b) and so this sample should not be regarded as an indication that stygofauna is absent from this bore.

## 2.3 Troglofauna sampling methods

### 2.3.1 Litter traps

Troglofauna was sampled using litter traps suspended in drill holes following EPA Technical Guidance – sampling methods for subterranean fauna (EPA2016b).

The traps comprise 50 mm diameter PVC pipe cut to a length of 140 mm. Leaf litter comprising mainly of spinifex (*Triodia* sp.) was soaked in water and irradiated for 10 minutes in a microwave set on high power, to kill any terrestrial invertebrates present. The sterilised litter was packed inside the traps with one end of the tube covered with 10 mm mesh. The packed traps were sealed in garbage bags to retain moisture and sterile conditions prior to deployment.

The traps were suspended in the holes using venetian blind cord. Where possible, the traps were aligned at depths corresponding to recorded cavities in drill logs. Traps were left in place for 16 weeks to allow colonisation by subterranean fauna. When traps are recovered the condition (moist or dry) of the hole environment and the litter in each trap is recorded. The traps from each drill hole were sealed in zip lock bags for transport to the laboratory.

### 2.3.2 Scraping

In addition to placing troglofauna litter traps in the bores the innovative scraping technique was used at each bore. This involved scraping a modified stygofauna haul net up the sides of unlined bores to scrape off any troglofauna that is present. This was repeated at least three times at each hole and the sample stored in an ethanol filled vial for sorting in the laboratory. This technique allows a more rapid determination if troglofauna are present within an area compared with the use of litter traps, although litter traps are required in order to meet EPA Technical Guidance – subterranean fauna survey (EPA2016a) and Technical Guidance – sampling methods for subterranean fauna (EPA2016b).

## 2.4 Water Quality

Water samples were collected in conjunction with stygofauna sampling and analysed *in situ* using a Hanna HI 9811-5 water quality meter. Water samples were collected from the upper 1 - 2 m of the water column prior to stygofauna sampling using a bailer. Four parameters (Temperature, Total

Dissolved Solids, Electrical conductivity and pH) were recorded from each bore where a stygofauna sample was collected.

#### 2.3.1 Temperature

The temperature of ground water in arid Australia is generally fairly constant throughout the year and reflects the average surface temperature of the area. Ground water temperature was measured in degrees Celsius (°C). Stygofauna have been recorded from a variety of temperatures in the Ngalia Basin, and in the Yilgarn and Pilbara cratons, and currently no direct correlation has been detected between temperature and either presence, diversity or abundance of stygofauna.

#### 2.3.2 Total Dissolved Solids

Total dissolved solids (TDS) was measured in milligrams per litre (mg/L) and provides a measure of all organic and inorganic substances such as calcium, magnesium, potassium, sodium, bicarbonates, chlorides, and sulfates dissolved in groundwater. The measurement provides a general indication of the quality of the water with lower values (less than 500 mg/L) associated with high quality drinking water while seawater is approximately 35,000 mg/L. Stygofauna have been detected in a wide variety of water qualities from completely fresh to groundwater that is equivalent to seawater. Species response to TDS cannot be generalised and will be species specific (Leijs 2009).

#### 2.3.3 Electrical Conductivity

Electrical conductivity was measured in milli Siemens per centimetre (mS/cm) and provides an indication of salinity. Stygofauna have been detected in a wide variety of salinities from completely fresh to groundwater that is equivalent to seawater. Species response to salinity cannot be generalised and will be species specific (Leijs 2009).

#### 2.3.4 pH

The concentration of hydrogen ions (H+) is shown as a logarithmic scale where a low value indicates a high concentration and higher values indicate a more basic solution. The neutral value of 7 is more likely to support stygofauna, however, communities of stygofauna have previously been found to occur in a wide variety of pH values.

## 2.5 Sorting and Curation

Sorting for all samples occurred in the Invertebrate Solutions laboratory using an Amscope 45x dissecting microscope and was undertaken by Dr Timothy Moulds. Each taxon was identified to the lowest practical taxonomic rank using published keys and descriptions, and the numbers of each taxon recorded. Each identified taxon was kept in a separate labelled vial and assigned a specimen tracking code. Specimen and site collection data were recorded in an Excel spreadsheet. At the conclusion of the study, all specimens will be lodged at the Western Australian Museum.

## 2.6 Taxonomy and Nomenclature

Identification of collected invertebrate material was undertaken by Dr Timothy Moulds. The level of specimen identification achievable is dependent on the level of taxonomic knowledge and expertise available. The majority of the taxonomic expertise relating to subterranean taxa resides with the staff of the Western Australian Museum, while some groups are also worked on by researchers within other government departments and academic institutions. Taxonomic treatments are available for some invertebrate groups, but not all. The EPA expects that invertebrates collected for identification will be identified to the lowest taxonomic level possible. Ideally, this is to the species level, but there will be limits due to the nature of specimens and the availability of taxonomic keys.

Taxonomic groups known to contain troglobitic or stygobitic representatives were examined in more detail to determine if the specimens collected in this study are subterranean or non-subterranean forms. Obligate subterranean forms were distinguished by the possession of troglomorphic characters such as depigmentation, reduction or loss of eyes, elongation of appendages and sensory structures. Troglobitic/stygobitic status was assigned after comparison with the morphology of other close relatives in the group, and current knowledge on their distribution and ecology where known. Identifications of copepods and ostracods were undertaken by Drs Tomislav Karanovic and Ivana Karanovic, respectively. Identification of bathynellid specimens was undertaken by Dr Kym Abrams.

# 3. Desktop Assessment

## 3.1 Subterranean Fauna in Central Australia

There has been limited sampling for subterranean fauna in central Australia with stygofauna recorded from calcretes in the Ngalia basin north of the MacDonnell Ranges near Alice Springs in the Northern Territory (Balke *et al*. 2004; Taiti and Humphreys 2001; Watts and Humphreys 2006, Leys and Watts 2008, Humphreys 2008). The stygofauna recorded has included multiple species of Dytiscid diving beetles, similar to the fauna recorded in the Yilgarn calcretes, along with a diverse assemblage of stygobiont oniscoid isopods from the genus *Haloniscus,* and Bathynellids from the genus *Atopobathynella* (Cho *et al*. 2006). There has been some sampling of calcretes beyond the Ngalia basin near Nolans Bore approximately 135 km to the north of Alice Springs associated with a rare earth element project (GHD 2010), however, no stygofauna were recorded from this area. Calcrete aquifers have been shown throughout arid and semi-arid Australia to be highly likely to contain stygofauna, hence, if this habitat is likely to be impacted upon during Project development activities (i.e. dewatering or borefield operation) there is a high risk of significant impacts being caused to local stygofauna communities.

There are no records of any subterranean fauna studies being previously undertaken in the vicinity of Lake Mackay and no subterranean specimens are held in the records of the Western Australian Museum (WAM 2017a, 2017b).

## 3.2 Troglofauna Desktop Assessment

No previous records of troglofauna are present in the databases of the Western Australian Museum (WAM 2017a, 2017b). Suitable habitat for troglofauna is highly likely to occur in the calcrete areas (Figure 3) to the south of Lake Mackay (Bureau of Mineral Resources 1976). The upper unsaturated portions of the calcrete provide suitable conditions for troglofauna in the extensive interconnected void networks found in calcrete outcrops (Plate 1).

## 3.3 Stygofauna Desktop Assessment

No previous records of stygofauna are present in the databases of the Western Australian Museum (WAM 2017a, 2017b).

Stygofauna are known from the Ngalia basin to the south east of Lake Mackay with significant diversity present including bathynellids, isopods, copepods, ostracods and subterranean dytiscid diving beetles. The calcrete outcrops identified in the Webb 1:250,000 geological map (Bureau of Mineral Resources 1976) provide suitable habitat for stygofauna. The islands on Lake Mackay may also have some calcrete deposits or horizons within halite and gypsum units (Figure 3, Plate 2). The extent of these calcrete horizons is unknown although, if of a suitable size, they may provide habitat for stygofauna if saturated, however, the salinity of any such groundwater would be anticipated to be very high and thus may reduce the likelihood of any stygofauna being present. It should be noted that high salinity does not necessarily preclude the presence of stygofauna (Leijs 2009).

**Plate 1 Exposure of calcrete within a quarry on the southern side of Lake Mackay showing micro and meso caverns that provide suitable habitat for stygofauna (when saturated) and troglofauna.**

**Plate 2 Exposure of calcrete on an island of Lake Mackay that may provide suitable habitat for stygofauna (when saturated) and troglofauna.**

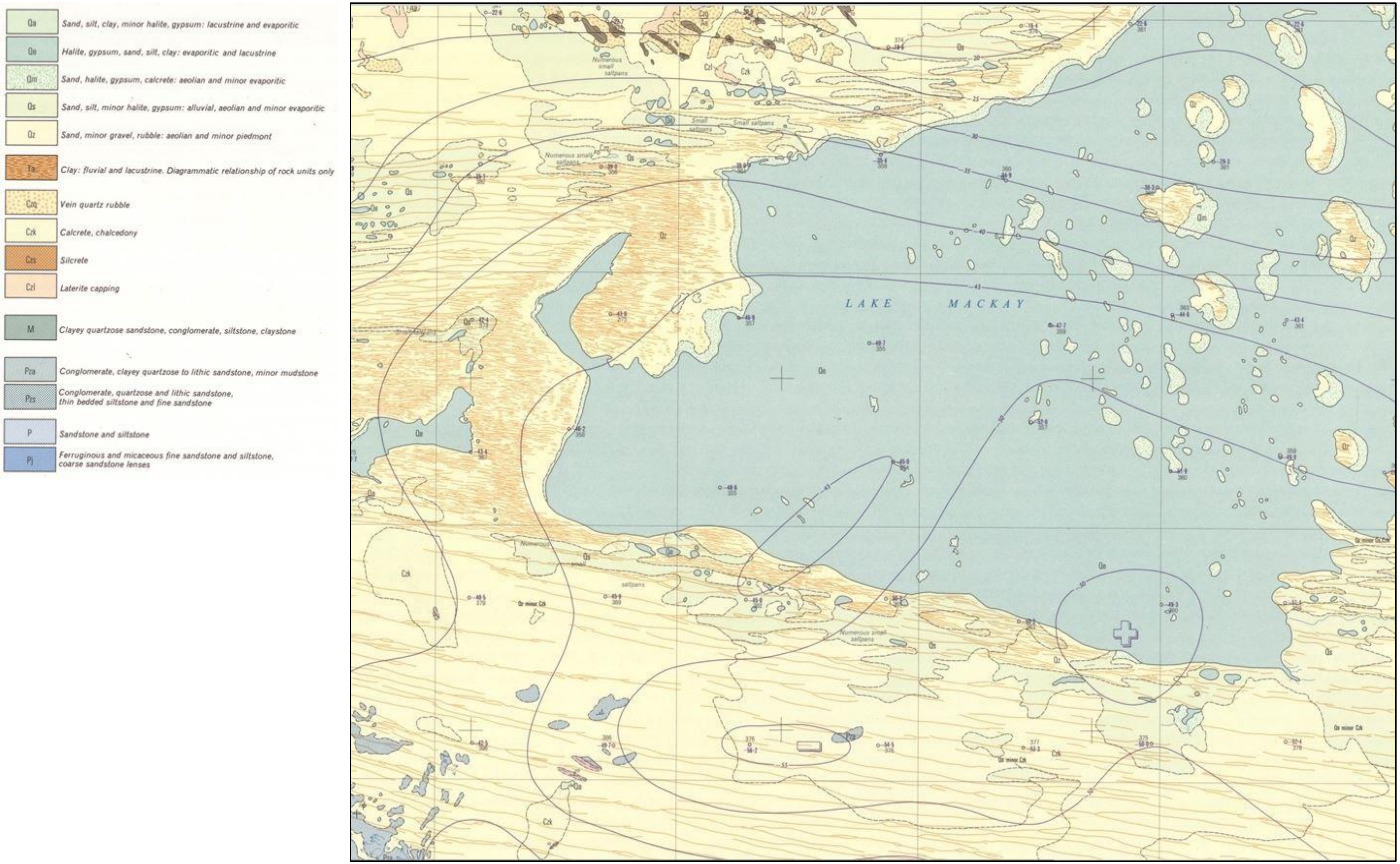


**Figure 3 Extract from 1:250,000 Geological Map of Lake Mackay (Webb SF5210, Bureau of Mineral Resources WA 1976) showing extensive calcrete (Czk) present on the southern side of the lake. It is likely that the individual calcrete surface expressions on the southern side of the lake form a continuous outcrop with intermittent surface cover by sand dunes.**

# 4. Stygofauna Survey Results

## 4.1 Pilot Survey – Surficial Calcrete Aquifer

The stygofauna pilot survey of the surficial calcrete aquifer in May 2017 recorded 10 species and 121 individuals of stygofauna from two of the five bores sampled within the proposed borefield area (Table 4, Table 5, Appendix 3). The samples included three classes, six orders, seven families and nine genera. The greatest diversity was among the copepods with two orders, three families, five genera and six species recorded, including two new genera and five new species (Karanovic and Karanovic 2017).

Abundance data for each bore is shown in Appendix 3.

## 4.2 Pilot Survey – Deep Alluvial Aquifer

The preliminary stygofauna survey of the deep alluvial aquifer has currently recorded no stygofauna. It should be noted that additional samples are required in order to satisfy the minimum requirements for a pilot survey (EPA 2016b). The bores sampled within the deep alluvial aquifer during Phase 1 were drilled in September 2017 and so were within the six month settling period (EPA 2016a). These bores will be resampled following the settling period to confirm the results of the current sampling.

## 4.3 Pilot Survey – Lake Mackay Trenches

Two of the test trenches (Trench 16 and 17) constructed by Agrimin were sampled for stygofauna. No stygofauna was obtained from either trench.

## 4.4 Pilot Survey – Lake Mackay Islands

The preliminary stygofauna survey of the Lake Mackay island aquifers is currently based on a single sample from bore MC013. This sample recorded two species from two orders of Copepoda. One of the species *Fierscyclops fiersi* (De Laurentiis *et al*., 2001) is a widespread stygophilic species whilst the other, *Schizopera bradleyi* is an undescribed species and currently only known from this location.

## 4.5 Phase 1 – Surficial Calcrete Aquifer

The Phase 1 sampling of the surficial calcrete aquifer in November 2017 recorded 16 species and 222 individuals of stygofauna from two of the five bores sampled within the proposed borefield area (Table 4, Table 5, Appendix 3). The samples included three classes, four orders, five families and nine genera. The greatest diversity was among the copepods with two orders, three families, seven genera and 12 species recorded, including two previously unrecorded genera for the Project and four species new to science, not previously recorded form the Project area (Karanovic 2018).

Abundance data for each bore is shown in Appendix 3.

Table 4 Stygofauna recorded from the Lake Mackay SOP Project area by survey phase

| Higher Order | Genus and species | Pilot Survey | Phase 1 | Notes |
|---|---|---|---|---|
| **Annelida: Oligochaeta** | *Phreodrilidae?* sp. | X | | Damaged specimen |
| **Crustacea: Bathynellacea: Parabathynellidae** | *Atopobathynella* sp. *'mackay'* n. sp. | X | X | New species, likely endemic |
| **Crustacea: Ostracoda: Podocopida: Candonidae** | *Abcandonopsis mackay* n. sp. | X | | New species, likely endemic |
| **Crustacea: Copepoda: Harpacticoida: Ameiridae** | *Mackaynitocrella mouldsi* n. gen., n. sp. | X | X | New genus and species, likely endemic |
| | *Parapsuedoleptomesochra mackay* n. sp. | X | X | New species, likely endemic |
| | *Nitokra lacustric pacifica* Yeatman, 1983 | | X | Widespread in Oceania |
| **Crustacea: Copepoda: Harpacticoida: Miraciidae** | *Schizopera bradleyi* n. sp. | | X | New species, likely endemic |
| | *Schizopera mackay* n. sp. | X | X | New species, likely endemic |
| | *Schizopera medifurca* n. sp. | | X | New species, likely endemic |
| | *Schizopera paracooperi* n. sp. | | X | New species, likely endemic |
| **Crustacea: Copepoda: Cyclopoida: Cyclopidae** | *Fierscyclops fiersi* (De Laurentiis *et al*., 2001) | | X | Widespread, stygophilic species |
| | *Halicyclops cf. kieferi* | X | X | Widespread in the Yilgarn but likely cryptic species complex |
| | *Halicyclops mackay* n. sp. | X | X | New species, likely endemic |
| | *Mackaycyclops bradleyi* n. g. & sp. | | X | New species, likely endemic |
| | *Mackaycyclops mouldsi* n. gen., n. sp. | X | X | New genus and species, likely endemic |
| **Insecta: Coleoptera: Dytiscidae** | *Paroster* sp. *'mackay large'* n. sp. | X | X | New species, likely endemic |
| | *Paroster* sp. *'mackay medium* n. sp. | | X | New species, likely endemic |
| | *Paroster?* sp. *'mackay small'* n. sp. | | X | New species, likely endemic |

Table 5 Stygofauna recorded from the Lake Mackay SOP Project area by aquifer

| Higher Order | Genus and species | Surficial Calcrete Aquifer | | | | Island Aquifer |
|---|---|---|---|---|---|---|
| | | Camp Bore | Nr LP008 | MWP08 | Bore 3 | MC013 |
| **Annelida: Oligochaeta** | *Phreodrilidae?* sp. | | X | | | |
| **Crustacea: Bathynellacea: Parabathynellidae** | *Atopobathynella* sp. *'mackay'* n. sp. | | X | | | |
| **Crustacea: Ostracoda: Podocopida: Candonidae** | *Abcandonopsis mackay* n. sp. | | X | | | |
| **Crustacea: Copepoda: Harpacticoida: Ameiridae** | *Mackaynitocrella mouldsi* n. gen., n. sp. | X | X | | | |
| | *Parapsuedoleptomesochra mackay* n. sp. | X | | | X | |
| | *Nitokra lacustric pacifica* Yeatman, 1983 | | | X | | |
| **Crustacea: Copepoda: Harpacticoida: Miraciidae** | *Schizopera bradleyi* n. sp. | | | | | X |
| | *Schizopera mackay* n. sp. | | X | | | |
| | *Schizopera medifurca* n. sp. | X | | | | |
| | *Schizopera paracooperi* n. sp. | X | | | | |
| **Crustacea: Copepoda: Cyclopoida: Cyclopidae** | *Fierscyclops fiersi* (De Laurentiis *et al*., 2001) | | | | | X |
| | *Halicyclops cf. kieferi* | X | | | | |
| | *Halicyclops mackay* n. sp. | X | | | | |
| | *Mackaycyclops bradleyi* n. g. & sp. | | | X | | |
| | *Mackaycyclops mouldsi* n. gen., n. sp. | X | X | X | | |
| **Insecta: Coleoptera: Dytiscidae** | *Paroster* sp. *'mackay large'* n. sp. | X | X | | | |
| | *Paroster* sp. *'mackay medium* n. sp. | | X | | | |
| | *Paroster?* sp. *'mackay small'* n. sp. | | X | | | |

## 4.6 Water Quality

Water quality parameters were collected from each bore sampled for stygofauna using a Hanna HI 9811-5 water quality meter. Samples were analysed in the field to provide a measure of temperature, total dissolved solids (TDS), electrical conductivity (EC) and pH. Results for the pilot and Phase 1 surveys are shown in Table 6 and for Phase 1 in Table 7.

Water quality was found to be near fresh to brackish in most shallow bores accessing calcrete aquifers, the deep alluvial aquifer was substantially more saline, with stygofauna recorded only from the bores slotted or accessing the surficial calcrete aquifer or the island aquifer.

**Table 6 Water quality in Borefield bores sampled for stygofauna in May 2017**

| Bore ID | Temperature ˚C | pH | TDS mg/L | EC µS/cm | Depth to Water (m) | Water Depth (m) | Total Depth (m) |
|---|---|---|---|---|---|---|---|
| **Camp Bore** | 29.3 | 6.7 | 320 | 660 | 5 | 33 | 38 |
| **LD02** | 27.7 | 8.2 | >1310 | >2500 | 9 | 32 | 41 |
| **LD03** | 29.5 | 8.7 | >1310 | >2500 | 7 | 30 | 37 |
| **Nr LP008** | 29.5 | 8.6 | 3710 | 7460 | 2 | 20 | 22 |
| **Handpump** | 28.8 | 8.1 | 100 | 210 | - | - | - |

**Table 7 Water quality in Borefield bores sampled for stygofauna in November 2017**

| Bore ID | Temperature ˚C | pH | TDS mg/L (ppm) | EC µS/cm | Depth to Water (m) | Water Depth (m) | Total Depth (m) |
|---|---|---|---|---|---|---|---|
| **Camp Bore** | 31.6 | 6.6 | 30 | 80 | 5 | 33 | 38 |
| **BORE 3** | 29.5 | 7.3 | >1310 | >2500 | 5 | 5 | 10 |
| **BORE 6** | 30.0 | 6.8 | >1310 | >2500 | 5 | 82 | 87 |
| **LD02** | 29.3 | 7.3 | >1310 | >2500 | 9 | 32 | 41 |
| **LD03** | 30.6 | 8.3 | >1310 | >2500 | 7 | 30 | 37 |
| **LM0182** | 30.4 | 6.5 | 70 | 150 | 4 | 93 | 97 |
| **LM0183** | 31.8 | 6.9 | >1310 | >2500 | 6 | 73 | 79 |
| **MC13** | 33.6 | 6.6 | 30 | 80.79* | 3 | 7 | 10 |
| **MWP2** | 30.7 | 7.7 | 7,289* | >2500 | 1 | 41 | 42 |
| **MWP4 SHALLOW** | 28.6 | 8.6 | >1310 | >2500 | 3 | 39 | 42 |
| **MWP6** | 28.6 | 7.4 | 15,999* | >2500 | 3 | 97 | 100 |
| **NEW S1** | 28.9 | 7.5 | >1310 | >2500 | 5 | 92 | 97 |
| **Nr LP008** | 30.8 | 7.9 | 2980 | 6030 | 2 | 20 | 22 |
| **TRENCH16** | 29.4 | 6.9 | ~200,000* | >2500 | - | 6 | - |
| **TRENCH17** | 27.8 | 6.9 | ~200,000* | >2500 | - | 6 | - |

* Lab analysis results obtained by Agrimin ltd.

# 5. Troglofauna Survey Results

The two scrape samples obtained in November 2017 contained no fauna exhibiting obligate subterranean characteristics. The litter traps remain *in situ* and the results of these will be reported once the traps have been retrieved and any specimens identified. This is anticipated to occur in late March or April 2018.

# 6. Discussion

The results of the pilot and Phase 1 survey have revealed a diverse stygofauna community within the surficial calcrete aquifer to the south of Lake Mackay. The extent and distribution of this habitat is shown in Plate 3 with the calcrete units representing habitat with a high likelihood of containing stygofauna whilst the underlying palaeochannel aquifers also potentially support stygofauna communities, especially when salinity levels are low.

Preliminary sampling for stygofauna within the underlying deep alluvial aquifer has currently not recorded any stygofauna, however, these bores have been sampled prior to the full six month bore settling period and additional sampling will be required in these bores to exclude the presence of stygofauna. The deep alluvial aquifer is substantially more saline than the surficial calcrete aquifer, with laboratory analysis of water samples by Agrimin showing TDS levels between 7,000 – 58,000 with an average of 33,000 TDS which is close to sea water salinity (refer Appendix 4).

The islands within Lake Mackay also host aquifers, although the extent, depth and connectivity of these aquifers is unknown. Although initially suggested by Ecologia (2016) that stygofauna would be absent, or consist only of widespread stygophilic species, a single sample from bore MC013 has found a possibly endemic species of *Shizopera* copepod. These island aquifers should continue to be sampled until a proper understanding of their connectivity, diversity and level of endemicity can be established.

## 5.1 Stygofauna Assessment

A pilot survey for stygofauna within the proposed Project borefield recorded 10 species of stygofauna. At least eight of these species are new to science and likely endemic to the individual calcrete situated to the south of Lake Mackay (Figure 3) due to the repeated pattern of endemism found in the Yilgarn and Ngalia basin calcretes (Leys *et al*. 2003, Watts and Humphreys 2006, 2009, Watts and Leys 2005).

The presence of stygofauna within the calcrete to the south of Lake Mackay from the sampling of 5 bores would indicate that a stygofaunal community is present, although its complete diversity and distribution is currently unknown beyond the two bores where stygofauna was identified (Camp Bore and Nr LP008, refer). A discussion of the individual species recorded is below.

### 5.1.1. Annelida: Oligochaeta: Pheodrilidae? sp.

A single specimen of Pheodrilid oligochaete was recorded from bore Nr LP008. The specimen was damaged and so unable to be identified further than family level. Additional collecting from this bore in the future may enable further identification.

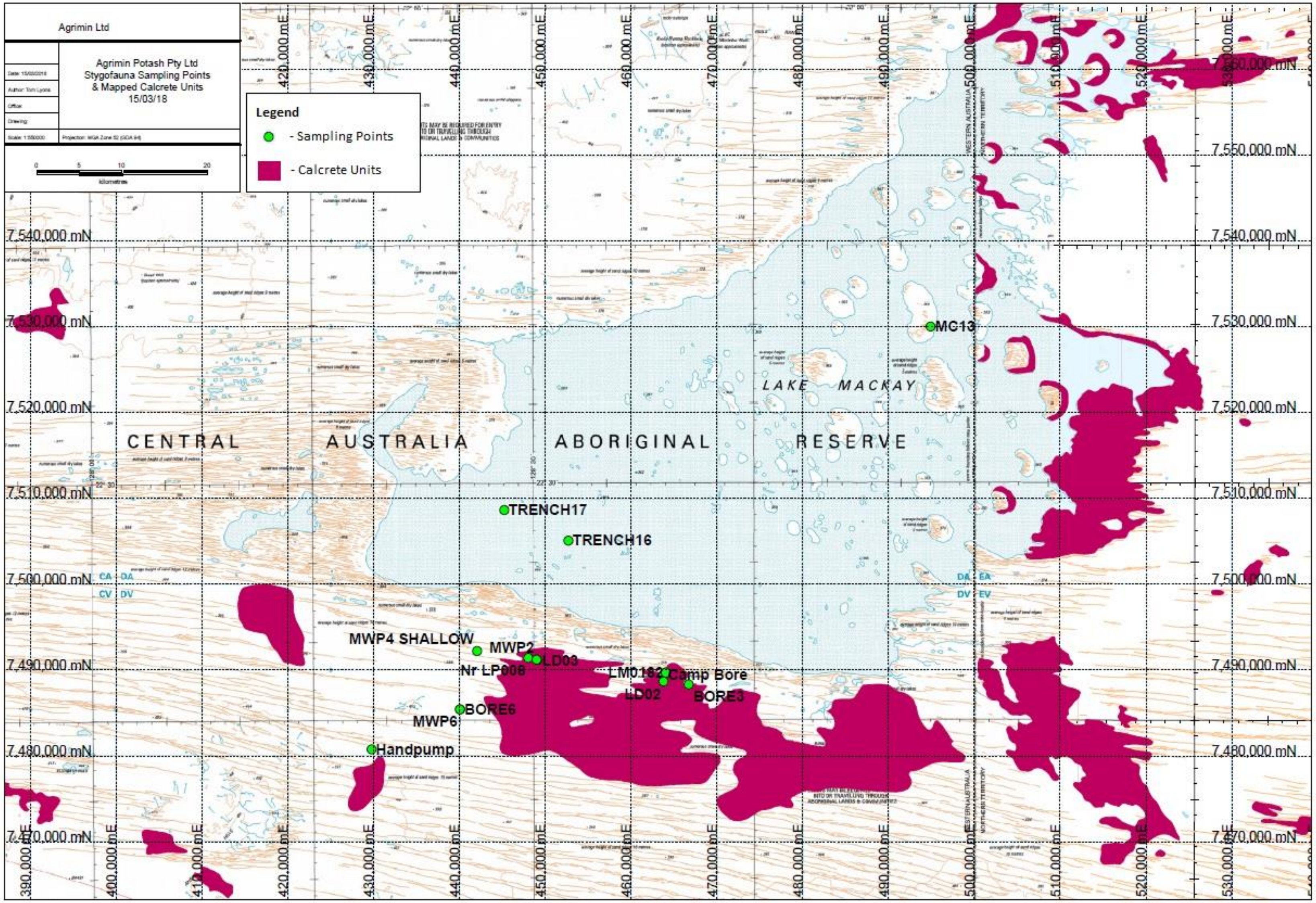


**Plate 3** Stygofauna habitat map with surface expression of calcrete shown in purple. Additional stygofauna habitat potentially occurs in underlying palaeochannels.

### 5.1.2. Crustacea: Bathynellacea: Parabathynellidae:

***Atopobathynella*? sp. *'mackay'* n. sp.**

Bathynellids are small, groundwater crustaceans that have a worldwide distribution in freshwater environments. There are over 35 genera and 120 species of parabathynellids described worldwide (Cho 2005). The genus *Atopobathynella* was first erected in 1973 and is now one of 10 genera of Parabathynellids in Australia. The genus contains nine described specimens, three from surface waters in Victoria and Tasmania, with the remainder being stygobitic from subterranean waters in Western Australia (Cho, Humphreys and Lee 2006). The specimen recorded from bore Nr LP008 shows morphological differences in the structures of the uropod and pleotelson to other described species of *Atopobathynella*, and so is regarded as a new species (Plate 4). This species has been recorded in both the Pilot and Phase 1 surveys but only from a single location. Genetic sequencing of the Bathynellids is recommended as it will confirm the current morphological identifications and also enable a more accurate assessment of potential impacts to stygofaunal communities to be determined.

**Plate 4 Lateral view of Parabathynellidae: *Atopobathynella* sp. '*mackay'* from bore Nr LP008. Scale approximately 1mm.**

### 5.1.3. Crustacea: Ostracoda: Podocopida: Candonidae

***Abcandonopsis mackay* n. sp.**

Ostracods are aquatic micro-crustaceans distributed worldwide in virtually every imaginable aquatic habitat, both fresh and saline. This trapezoid species is similar to some congeners from the Murchison region (Karanovic I. 2004) and exhibits a smooth shell surface, pronounced asymmetry in valve shape and size. Details of soft part morphology were not checked, as only one specimen was available, but it is clearly distinct from other congeners in shell shape and ornamentation (Karanovic and Karanovic 2017).

### 5.1.4. Crustacea: Copepoda: Cyclopoida:

***Fierscyclops fiersi (De Laurentiis* et al., *2001)***

This is a widely distributed species in the Murchison region and probably a stygophile rather than a stygobiont (Karanovic 2004).

***Halicyclops cf. kieferi* Karanovic, 2004**

This species is large (refer Plate 5) and is clearly distinct from its small-sized congener. It was first described by Karanovic T. (2004) from several bores in the Murchison region and has been commonly recorded in multiple locations since, often with another smaller congener in the same bore. There are parallels in niche partitioning by size class, similar to that of diving beetles in the Yilgarn region (Watts and Humphreys 2006). To be sure that these specimens from Lake Mackay are indeed *H. kieferi*, comparative morphology and possible DNA would have to be studied in detail. Other molecular work on this genus (from other regions of WA) suggest that, in most cases, we are dealing with cryptic species in separate large calcretes (Karanovic and Karanovic 2017).

***Halicyclops mackay* n. sp.**

This species is small (refer Plate 5) and very similar to *H. eberhardi* De Laurentiis, Pesce & Humphreys, 2001, which was also redescribed from several bores in the Murchison region by Karanovic T. (2004). This new species differs mostly by longer (more slender) caudal rami and larger lateral wings on the genital double somite (Karanovic and Karanovic 2017).

**Plate 5 Dorsal view of two adult females of *Halicyclops mackay* n. sp. on the left and two adult females of *Halicyclops cf. kieferi* Karanovic, 2004 on the right. Note the pronounced size differentiation. Image by T. Karanovic. Scale bar approximately 350 µm.**

### *Mackaycyclops bradleyi* n. g. & sp.

This species differs from *Mackaycyclops mouldsi* n. sp. mostly in size (it is much smaller, refer Plate 5). It also has a proportionately longer female genital double somite. Other characters, that are unique to this new genus, include the segmentation and armature of the swimming legs, and the absence of outer principal seta on caudal rami (also long dorsal seta). This is another case of two closely related species living together in the same habitat and differing mostly in size (as it is common with *Halicyclops* species and also with diving beetles in this region), resulting probably from niche partitioning.

### *Mackaycyclops mouldsi* n. g. & sp.

This cyclopoid is extremely primitive and unlike modern species. It has a unique segmentation of the swimming legs (2/2, 2/2, 3/2, 3/3) and completely reduced outer principal seta on the caudal rami. Other characters include: antennule 11-segmented; antenna without exopod; fifth leg 2-segmented, inner apical element in between genera *Diacyclops* and *Thermocyclops* in size, but a seta is present instead of a spine; genital somite with pronounced lateral corners (as in *Acanthocyclops vernalis*). This species represents an important discovery for Australian copepoda (Karanovic and Karanovic 2017).


**Plate 6 Photograph of two adult females of *Mackaycyclops bradleyi* n. sp. on the right and two adult females of *Mackaycyclops mouldsi* n. sp. on the left. Notice the pronounced size differentiation. Insert: one female *of M. bradleyi* enlarged.**

### 5.1.5. Crustacea: Copepoda: Harpacticoida:

#### *Mackaynitocrella mouldsi* n. g. & sp.

This new genus of ameirid harpacticoid is somewhat similar to the genus *Nitocrella* (which has several unusual representatives in Australia), but with important differences in the armature of the swimming legs (Exp3P1 and Exp3P2 with 3 outer elements). The most important morphological characters are the P1-P4 armature formula (exp/enp) 0.1.023/1.0.3, 0.1.123/1.2, 0.1.122/1.3, 0.1.222/1.3; Enp1P1 reaching midlength of Exp3P1; ExpA2 with 3 setae; Fu short; female fifth leg similar to *Nitocrella trajani* but with longer setae; no additional rows of spinules on anal somite; male fifth leg with 4 setae on exopod and only 1 on endopodal lobe.

#### *Nitokra lacustric pacifica Yeatman, 1983*

This is a widely distributed species and certainly not a stygobiont; its morphological characters (Plate 7) are the same as those reported in Karanovic (2004). It was reported from crab holes in Western Samoa, Tonga, and Fiji (Yeatman 1983), temporary brackish pools in Papua New Guinea (Fiers 1986), and numerous bores in the Murchison regions of Western Australia (Karanovic 2004 and unpublished data).


**Plate 7 Adult female and male of *Nitokra lacustris pacifica* Yeatman, 1983.**

### *Parapsuedoleptomesochra mackay* n. sp.

Several species of this genus have already been described from the Murchison region (Karanovic T. 2004) and several more have been discovered but remain unpublished. This one differs from them all in a unique armature formula of EnpP2-P4. It is relatively similar to *P. rouchi*, but, in addition to different armature formula, it has only one row of spinules on the anal somite (Karanovic and Karanovic 2017).

### *Schizopera bradleyi* n. sp.

This harpacticoid is a very slender species, with caudal rami about as long as anal somite and cylindrical in the anterior half but conical in the posterior half. This species exhibits a unique morphological character where the anterior lateral seta on the caudal rami has been transformed into a laterally reaching robust claw, unseen in any of the other 100 species described in this genus (Karanovic & McRae 2013).

### *Schizopera paracooperi* n. sp.

This is a very small species, cylindrical but not very slender, with very short cylindrical caudal rami similar to the shape of this structure in the majority of marine members of this genus. This species is similar in its appearance to *S. cooperi* described from the Pilbara region (Karanovic & MacRae 2013), and to several species identified from the vicinity of Lake Way in Western Australia (T. Karanovic, unpublished).

### *Schizopera mackay* n. sp.

This harpacticoid is another extremely primitive species from the Lake Mackay area. The genus is very common in arid Western Australia, with most diversity in the Murchison region (Karanovic T. 2004; Karanovic and Cooper 2012) but a few species also in the Pilbara (Karanovic 2006; Karanovic & McRae 2013). This new species differs from them all in having extremely long caudal rami (maybe twice as long as in *S. jundeei*) and the outer principal seta are reduced to a minute hair (smaller than inner principal seta). It is unusual to find a character reduced in the same way in two completely unrelated copepods in the same habitat (refer to *Mackaycyclops mouldsi*), and this could plausibly be some kind of convergent adaptation for this specific habitat (Karanovic and Karanovic 2017), although it is very unusual morphologically.

### *Schizopera mediafurca* n. sp.

This is a large species for the genus (about twice as long as the syntopic *S. paracooperi*), with very long caudal rami, although their elongation is resulting from elongation of the posterior portion, meaning therefore, that the dorsal and anterior lateral seta are inserted almost at mid-length. This is a very unusual feature on this genus. Unfortunately, only one male was collected, so the female characters are unknown.

### 5.1.6. Insecta: Coleoptera

**Dytiscidae: *Paroster* spp.**

Sampling within the surficial calcrete aquifer has recorded at least three species of stygobiontic diving beetles from the genus *Paroster* in two separate bores (Nr LP008 and Camp Bore). The diving beetle genus *Paroster* currently contains 43 species known to occur in Australia, with the majority being stygobiont species from calcrete aquifers in Western Australia (Leys *et al*. 2003, Watts and Humphreys 2006, 2009, Watts and Leys 2005). Every stygobiont species of *Paroster* known are endemic to individual calcrete aquifers in the Ngalia Basin and Yilgarn Craton (Watts and Humphreys 2006, 2009, Humphreys 2008). Every calcrete also shows an amazing repeated morphological adaptation where the diving beetles differentiate into three size classes (small, medium and large) sympatrically within the same aquifer. Due to the often extreme morphological conservatism in the characters used to identify dystiscid diving beetles genetic barcoding is required in order to comprehensively determine individual species delimitation.

All three species currently known from bores Nr LP008 and Camp Bore are considered endemic (Plate 8).

**Plate 8 Dorsal view of Dytiscidae: *Paroster* sp. '*mackay large*' from bore Nr LP008. Scale approximately 1mm.**

## 5.2 Troglofauna Assessment

The desktop assessment has identified suitable habitat in the form of unsaturated calcrete. Troglofauna, if present, may be impacted by borefield development through drawdown reducing available habitat with a saturated humidity upon which troglofauna rely.

No troglofauna has been recorded from the two available scrape samples collected in November 2017. The litter traps remain *in situ* and will be retrieved in March or April 2018.

## 5.3 Potential Impacts to Subterranean Fauna

The potential impacts of resource development including, developing a borefield in the region to the south of Lake Mackay, trenching of the lake bed to collect potash rich brine, and general construction activities on subterranean fauna may be categorised as being either direct or indirect impacts.

Direct impacts are the obvious and unavoidable destruction or degradation of habitat that occurs in excavating voids such as for trenching and adjacent terrain, including associated aquifer dewatering. The development of a borefield to the south of Lake Mackay has the potential to drawdown the regional watertable to varying amounts, although generally greater drawdown will occur in the vicinity of production bores. The hydrogeological nature of the area to the south of Lake Mackay is currently being investigated by Agrimin, but there are currently two identified aquifers; the surficial calcrete aquifer at the surface (up to ~10m depth) and the deep alluvial aquifer beneath this (Hydrominex Geoscience 2016). It is currently unknown if there is a hydrological connection between these two aquifers or if they are separated by an aquitard layer. The identified stygofaunal community is currently only recorded from the surficial calcrete aquifer and abstraction from the deep alluvial aquifer will directly affect stygofauna if there is a connection, even in part between these two aquifers.

The trenching system to abstract potash-rich brine from Lake Mackay will generally be at least five kilometres from lake islands, however, there are several locations where passing close to islands is unavoidable (Knight Piesold 2018). The larger islands occupy approximately 214 $km^2$, of which approximately 1.2% of the island surface is within the zone of influence of the trench drawdown area (Knight Piesold 2018). The fresh to brackish aquifers that underlay the lake islands support in at least one instance unique stygofauna (Bore MC013) and further investigation is required to determine what impacts may occur to the affected islands and their biota.

Indirect impacts are generally gradational, and more difficult to predict and manage because they may occur at moderate to large distances from the Project footprint. These impacts may be expressed some time after Project development has begun. Some examples include changes to hydrology, nutrient and microclimate regimes, contamination, reduced habitat area, water quality, and population viability. The zone of influence for indirect impacts may be considerably larger than the immediate area of the trenches or disturbance area. Potential indirect impacts of excavation include:

- Alteration of surface hydrology that affects groundwater recharge regimes, sedimentation, and water quality (e.g. under and adjacent to remediation areas, roads and infrastructure);
- Changes to subterranean microclimate in the zone of influence of groundwater abstraction from bores for construction or operational water requirements (causing drying of habitat);
- Dewatering that removes support and leads to physical damage to karstic geology types from the slumping of strata in calcrete aquifers (Humphreys 1999);
- Surface and groundwater contamination from plant equipment and infrastructure (e.g. chemical pollutants, hydrocarbons or waste water of lower quality);
- Salinisation of groundwater systems caused by changes to surface and subsurface hydrology;
- Reduction in organic inputs beneath areas cleared of vegetation and sealed surfaces;

- Vibration disturbance from construction and operational activities; and
- Risk of species extinction from reduction and/or fragmentation in habitat.

# 7. Conclusions and Recommendations

The desktop assessment for subterranean fauna identified suitable habitat in the form of a large continuous calcrete unit on the southern side of Lake Mackay. There is also the potential for subterranean fauna to occur in the smaller calcrete outcrops located on the islands within Lake Mackay. This habitat was confirmed as present by the preliminary sampling in the augered bore MC013, however, the extent of this habitat is unknown without additional subsurface information (such as from drilling, augering or test pits).

The pilot survey for subterranean fauna at the Lake Mackay SOP Project was undertaken in May 2017. Five stygofauna samples were obtained from the surficial calcrete aquifer to the south of Lake Mackay. Stygofauna was identified in two of the five samples (Camp Bore and Nr LP008) with 10 species present.

A subsequent level 2 stygofauna survey was commenced in November 2017 in the various aquifers to the south of Lake Mackay and on Lake Mackay itself. This survey has begun sampling in the surficial calcrete aquifer and the underlying deep alluvial aquifer, located to the south of Lake Mackay, and the perched aquifers associated with the islands in Lake Mackay. A pilot survey for troglofauna within the surficial calcrete deposits also commenced in November 2017, sampling two available uncased bores using both scrape and litter trap sampling techniques. No troglofauna has been recorded at present.

The results of the November 2017 stygofauna sampling has recorded stygofauna in both the surficial calcrete aquifer and the aquifers associated with the islands in Lake Mackay. No stygofauna has been recorded from the deep alluvial aquifer or from the hypersaline water within Lake Mackay situated away from islands.

Currently, the surficial calcrete aquifer shows the greatest diversity, with five classes, six orders, 7 families and 16 species present, whilst the single sampling location within the island aquifer has recorded two additional species. The stygofauna recorded in the Lake Mackay aquifers is significant in that it contains three new species of dytiscid diving beetle (*Paroster* spp.?*),* a new species of parabathynellid (*Atopobathynella* sp. '*mackay'*), and multiple new species of Copepoda, some of which show extremely primitive morphological characters (*Mackaycyclops mouldsi* n. g. & sp. and *Schizopera mackay* n. sp.) and may be important in the evolutionary history of Australian stygofauna. The diversity of copepoda stygofauna in the Lake Mackay region is potentially very high. Currently, from a pilot survey and phase 1 sampling rounds, there are four very different species of *Schizopera,* and some of them are even syntopic (Karanovic 2018). This is a much higher diversity than is commonly encountered in this genus, with only Yeelirrie exhibiting a similar diversity. (Karanovic & Cooper 2012).

Genetic sequencing of the stygobitic Dytiscid beetles and Bathynellids will confirm the current morphological identifications and the distribution of individual species within the Project area. Confirmation of the same species geographically across the Project area will enable a more accurate assessment of potential impacts to stygofaunal communities to be determined.

Fourteen of the 18 species recorded (78%) from both the surficial calcrete and island aquifers are undescribed species and 10 species (56%) are currently only recorded from single bores, although this is invariably due to the lack of suitable sampling locations. These results are not entirely unexpected due to the location of the sampling being many hundreds of kilometres from any other subterranean fauna sampling locations. Currently, most of these new species are known from single bores.

## 6.1 Recommendations

The following recommendations are made with regard to the potential development of the Lake Mackay SOP Project:

- Due to the presence of a stygofaunal community within the surficial calcrete aquifer located within the southern proposed borefield area, a Level 2 survey for stygofauna should be undertaken with regard to EPA Technical Guidance – subterranean fauna survey (EPA2016a) and EPA Technical Guidance – sampling methods for subterranean fauna (EPA2016b);
- The Level 2 survey for stygofauna will require, at a minimum, 40 samples from each impacted aquifer within the proposed borefield area (EPA2016b);
- Genetic sequencing of the stygobitic Dytiscid beetles and Bathynellids should be undertaken to confirm the current morphological identifications and the distribution of individual species within the Project area. Confirmation of the same species geographically across the Project area will enable a more accurate assessment of potential impacts to stygofaunal communities to be determined;
- The deep alluvial aquifer currently presents an environment unfavourable to stygofauna and preliminary sampling of this aquifer has recorded no stygofauna. Additional sampling of this aquifer should be undertaken to obtain sufficient samples to provide a pilot survey level of field sampling before a final assessment regarding the presence or absence of stygofauna within this aquifer can be undertaken;
- A troglofauna pilot survey has commenced in the proposed borefield area and should be continued until the requirements of EPA Guidance (2016a) are met. This would be a minimum of 10 – 15 bores to be sampled. No troglofauna has currently be recorded from the proposed borefield area;
- The stygofauna pilot survey of the island aquifers within Lake Mackay should be continued in all available bores until an assessment of the stygofauna present and the potential for impact to this stygofaunal community can be determined more accurately. This sampling should include all island areas that may be potentially impacted by drawdown associated with trenching; and
- Newly constructed bores should be constructed to be suitable for stygofauna and/or troglofauna sampling.

# 8. References


Balke, M., Watts, C. H. S., Cooper, S. J. B., Humphreys, W. F., and Vogler, A. P. (2004). A highly modified stygobitic diving beetle of the genus *Copelatus* (Coleoptera, Dytiscidae): taxonomy and cladistic analysis based on mtDNA sequences. Systematic Entomology 29: 59–67. doi:10.1111/j.1365-3113.2004.00229.x

Bureau of Mineral Resources WA (1976). 1:1250,000 Geological Map Sheet SF52-10 Webb.

Cho, J.-L. (2005). A primitive representative of the Parabathynellidae (Bathynellacea, Syncarida) from the Yilgarn Craton of Western Australia. *Journal of Natural History* **39**, 3423–3433

Cho, J-L., Humphreys, W. F., and Lee, S-D. (2006). Phylogenetic relationships within the genus *Atopobathynella* Schminke, 1973 (Bathynellacea, Parabathynellidae): with the description of six new species from Western Australia. Invertebrate Systematics 20: 9–41. doi:10.1071/IS05019

Christiansen, K. A. (1962). Proposition pour la classification des animaux cavernicoles. Spelunca Mem. 2: 76-78.

Ecologia (2017). Mackay SOP Project. Subterranean fauna risk assessment. Unpublished report to Agrimin Ltd, p11.

EPA (2016a). Technical guidance subterranean fauna survey. Environmental Protection Authority: Perth. 24 pp.

EPA (2016b). Technical guidance Sampling methods for subterranean fauna. Environmental Protection Authority: Perth. 37 pp.

EPA (2016c). Environmental factor guideline. Subterranean Fauna. Environmental Protection Authority: Perth. 5 pp.

Fiers F. (1986). New and interesting copepods (Crustacea, Copepoda) from brackish waters of Laing Island (Northern Papua New Guinea). Bulletin de l'Institut Royal des Sciences Naturelles de Belgique Biology 56: 99-120.

GHD (2010). Nolans Mine EIS Stygofauna Pilot Survey. Unpublished report to Arafura Resources Ltd, 16p.

Howarth, F. G. (1973). The cavernicolous fauna of Hawaiian lava tubes, 1. Introduction. Pacific Insects 15: 139-151.

Humphreys, W.F. (1999). Relict stygofaunas living in sea salt, karst and calcrete habitats in arid northwestern Australia contain many ancient lineages. In: The other 99%. The conservation and biodiversity of invertebrates. Ed W. Ponder and D. Lunney Transactions of the Royal Zoological Society of New South Wales, Mosman. Pp.219-227

Humphreys, W. F. (2000). Background and glossary. Ecosystems of the world. Subterranean ecosystems. Wilkens, H., Culver, D. C. and Humphreys, W. F. Amsterdam, Elsevier. 30: 3-14.

Humphreys, W.F. (2008). Rising from Down Under: developments in subterranean biodiversity in Australia from a groundwater fauna perspective. Invertebrate Systematics, 22: 85–101.

Hydrominex Geoscience (2016). Lake Mackay process water evaluation. Unpublished report to Agrimin Ltd, 15p.

Karanovic, I. (2004) Towards revision of Candoninae (Crustacea, Ostracoda): on the genus *Candonopsis* Vavra, with descriptions of new taxa. Subterranean Biology 2: 91–108.

Karanovic, T. (2004) Subterranean Copepoda from arid Western Australia. Crustaceana Monographs, 3: 366pp.

Karanovic, T. (2006) Subterranean copepods (Crustacea, Copepoda) from the Pilbara region in Western Australia. Records of the Western Australian Museum, Supplement 70: 1–239.

Karanovic T. and Cooper S.B.J. (2012) Explosive radiation of the genus *Schizopera* on a small subterranean island in Western Australia (Copepoda : Harpacticoida): unravelling the cases of cryptic speciation, size differentiation and multiple invasions. Invertebrate Systematics 26: 115–192.

Karanovic, T. and Karanovic, I. (2017). Lake Mackay Copepoda and Ostracoda identification report. Unpublished report to Invertebrate Solutions, October 2017.

Karanovic, T. (2018). Lake Mackay Copepoda identification report. Unpublished report to Invertebrate Solutions, January 2018.

Karanovic T. and McRae J. (2013) The genus *Schizopera* (Copepoda, Harpacticoida) in the Pilbara region of Western Australia, with description of a new species and its molecular and morphological affinities. Records of the Western Australian Museum 28: 119–140.

Knight Piesold (2018). Brine Collection, Evaporation Ponds and Residue Disposal Pre-Feasibility Study, January 2018. Unpublished report to Agrimin Ltd.

Leys, R. and Watts, C.H. (2008). Systematics and evolution of the Australian subterranean hydroporine diving beetles (Dytiscidae), with notes on *Carabhydrus*. Invertebrate Systematics, 22: 217–225.

Leys R, Watts C.H.S, Cooper S.J.B and Humphreys W.F. (2003). Evolution of subterranean diving beetles (Coleoptera: Dytiscidae: Hydroporini, Bidessini) in the arid zone of Australia. Evolution 57: 2819– 2834.

Leijs, R. (2009). Potential effects of managed aquifer recharge on stygofauna communities. Appendix 3 in Dillon, P., Kumar, A., Kookana, R., Leijs, R., Reed, D., Parsons, S. and Ingerson, G. (2009). Managed Aquifer Recharge - Risks to Groundwater Dependent Ecosystems - A Review. Water for a Healthy Country. Flagship report to Land & Water Australia, 2009.

Taiti, S., and Humphreys, W.F. (2001). New aquatic Oniscidea (Crustacea, Isopoda) from groundwater calcretes of Western Australia. Records of the Western Australian Museum Supplement 64: 133–151.

Watts, C. H. S., and Humphreys, W. F. (2006). Twenty-six new Dytiscidae (Coleoptera) of the genera *Limbodessus* Guignot and *Nirripirti* Watts and Humphreys, from underground waters in Australia. Transactions of the Royal Society of South Australia 130: 123–185.

Watts C.H.S. and Humphreys W.F. (2009). Fourteen new Dytiscidae (Coleoptera) of the genera *Limbodessus* Guignot and *Paroster* Sharp and *Exocelina* Broun from underground waters in Australia. Transactions of the Royal Society of South Australia 133: 62–107.

Watts C.H.S. and Leys R. (2005). Review of the epigean species of Australian *Limbodessus* Guignot (Insecta: Coleoptera: Dytiscidae). Transactions of the Royal Society of South Australia 129, 1–13.

Western Australian Museum (WAM). (2017a). Arachnida and Myriapoda database search April 2017.

Western Australian Museum (WAM). (2017b). Crustacea database search April 2017.

Yeatman H.C. (1983) Copepods from microhabitats in Fiji, Western Samoa, and Tonga. Micronesica 19: 57–90.

# Appendix 1

Location of Bores sampled for Stygofauna (May and November 2017)

| Bore ID | Easting | Northing | Pilot survey sample date | Phase 1 sample date |
|---|---|---|---|---|
| **Camp Bore** | 463762 | 7489435 | 12/05/2017 | 14/11/2017 |
| **BORE3** | 466729 | 7488333 | | 17/11/2017 |
| **BORE6** | 440099 | 7485405 | | 20/11/2017 |
| **Handpump** | 429786 | 7480760 | 18/05/2017 | - |
| **LD02** | 463802 | 7488674 | 18/05/2017 | 13/11/2017 |
| **LD03** | 449111 | 7491138 | 18/05/2017 | 13/11/2017 |
| **LM0182** | 464058 | 7489688 | | 17/11/2017 |
| **LM0183** | 464050 | 7489687 | | 14/11/2017 |
| **Nr LP008** | 448025 | 7491415 | 18/05/2017 | 12/11/2017 |
| **MC13** | 494917 | 7530028 | | 15/11/2017 |
| **MWP2** | 449028 | 7491199 | | 13/11/2017 |
| **MWP4 SHALLOW** | 442075 | 7492213 | | 16/11/2017 |
| **MWP6** | 440085 | 7485416 | | 16/11/2017 |
| **NEW S1** | 449014 | 7491206 | | 13/11/2017 |
| **TRENCH16** | 452712 | 7505086 | | 16/11/2017 |
| **TRENCH17** | 445232 | 7508636 | | 16/11/2017 |

# Appendix 2

Department of Parks and Wildlife Conservation Codes (November 2015)

Department of Parks and Wildlife

# CONSERVATION CODES

## For Western Australian Flora and Fauna

Specially protected fauna or flora are species* which have been adequately searched for and are deemed to be, in the wild, either rare, at risk of extinction, or otherwise in need of special protection, and have been gazetted as such.

Categories of specially protected fauna and flora are:

**T** **Threatened species**

Published as Specially Protected under the *Wildlife Conservation Act 1950,* and listed under Schedules 1 to 4 of the Wildlife Conservation (Specially Protected Fauna) Notice for Threatened Fauna and Wildlife Conservation (Rare Flora) Notice for Threatened Flora (which may also be referred to as Declared Rare Flora).

***Threatened fauna*** is that subset of 'Specially Protected Fauna' declared to be 'likely to become extinct' pursuant to section 14(4) of the Wildlife Conservation Act.

***Threatened flora*** is flora that has been declared to be 'likely to become extinct or is rare, or otherwise in need of special protection', pursuant to section 23F(2) of the Wildlife Conservation Act.

The assessment of the conservation status of these species is based on their national extent and ranked according to their level of threat using IUCN Red List categories and criteria as detailed below.

**CR** **Critically endangered species**

Threatened species considered to be facing an extremely high risk of extinction in the wild. Published as Specially Protected under the *Wildlife Conservation Act 1950,* in Schedule 1 of the Wildlife Conservation (Specially Protected Fauna) Notice for Threatened Fauna and Wildlife Conservation (Rare Flora) Notice for Threatened Flora.

**EN** **Endangered species**

Threatened species considered to be facing a very high risk of extinction in the wild. Published as Specially Protected under the *Wildlife Conservation Act 1950,* in Schedule 2 of the Wildlife Conservation (Specially Protected Fauna) Notice for Threatened Fauna and Wildlife Conservation (Rare Flora) Notice for Threatened Flora.

**VU** **Vulnerable species**

Threatened species considered to be facing a high risk of extinction in the wild. Published as Specially Protected under the *Wildlife Conservation Act 1950,* in Schedule 3 of the Wildlife Conservation (Specially Protected Fauna) Notice for Threatened Fauna and Wildlife Conservation (Rare Flora) Notice for Threatened Flora.

**EX** **Presumed extinct species**

Species which have been adequately searched for and there is no reasonable doubt that the last individual has died. Published as Specially Protected under the *Wildlife Conservation Act 1950,* in Schedule 4 of the Wildlife Conservation (Specially Protected Fauna) Notice for Presumed Extinct Fauna and Wildlife Conservation (Rare Flora) Notice for Presumed Extinct Flora.

**IA** **Migratory birds protected under an international agreement**

Birds that are subject to an agreement between the government of Australia and the governments of Japan (JAMBA), China (CAMBA) and The Republic of Korea (ROKAMBA), and the Bonn Convention, relating to the protection of migratory birds. Published as Specially Protected under the *Wildlife Conservation Act 1950,* in Schedule 5 of the Wildlife Conservation (Specially Protected Fauna) Notice.

**CD Conservation dependent fauna**

Fauna of special conservation need being species dependent on ongoing conservation intervention to prevent it becoming eligible for listing as threatened. Published as Specially Protected under the *Wildlife Conservation Act 1950,* in Schedule 6 of the Wildlife Conservation (Specially Protected Fauna) Notice.

**OS Other specially protected fauna**

Fauna otherwise in need of special protection to ensure their conservation. Published as Specially Protected under the *Wildlife Conservation Act 1950,* in Schedule 7 of the Wildlife Conservation (Specially Protected Fauna) Notice.

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**P Priority species**

Possibly threatened species that do not meet survey criteria, or are otherwise data deficient, are added to the Priority Fauna or Priority Flora Lists under Priorities 1, 2 or 3. These three categories are ranked in order of priority for survey and evaluation of conservation status so that consideration can be given to their declaration as threatened flora or fauna.

Species that are adequately known, are rare but not threatened, or meet criteria for near threatened, or that have been recently removed from the threatened species or other specially protected fauna lists for other than taxonomic reasons, are placed in Priority 4. These species require regular monitoring.

Assessment of Priority codes is based on the Western Australian distribution of the species, unless the distribution in WA is part of a contiguous population extending into adjacent States, as defined by the known spread of locations.

**1 Priority 1: Poorly-known species**

Species that are known from one or a few locations (generally five or less) which are potentially at risk. All occurrences are either: very small; or on lands not managed for conservation, e.g. agricultural or pastoral lands, urban areas, road and rail reserves, gravel reserves and active mineral leases; or otherwise under threat of habitat destruction or degradation. Species may be included if they are comparatively well known from one or more locations but do not meet adequacy of survey requirements and appear to be under immediate threat from known threatening processes. Such species are in urgent need of further survey.

**2 Priority 2: Poorly-known species**

Species that are known from one or a few locations (generally five or less), some of which are on lands managed primarily for nature conservation, e.g. national parks, conservation parks, nature reserves and other lands with secure tenure being managed for conservation. Species may be included if they are comparatively well known from one or more locations but do not meet adequacy of survey requirements and appear to be under threat from known threatening processes. Such species are in urgent need of further survey.

**3 Priority 3: Poorly-known species**

Species that are known from several locations, and the species does not appear to be under imminent threat, or from few but widespread locations with either large population size or significant remaining areas of apparently suitable habitat, much of it not under imminent threat. Species may be included if they are comparatively well known from several locations but do not meet adequacy of survey requirements and known threatening processes exist that could affect them. Such species are in need of further survey.

**4 Priority 4: Rare, Near Threatened and other species in need of monitoring**

(a) Rare. Species that are considered to have been adequately surveyed, or for which sufficient knowledge is available, and that are considered not currently threatened or in need of special protection, but could be if present circumstances change. These species are usually represented on conservation lands.
(b) Near Threatened. Species that are considered to have been adequately surveyed and that are close to qualifying for Vulnerable, but are not listed as Conservation Dependent.
(c) Species that have been removed from the list of threatened species during the past five years for reasons other than taxonomy.

*Species includes all taxa (plural of taxon - a classificatory group of any taxonomic rank, e.g. a family, genus, species or any infraspecific category i.e. subspecies or variety, or a distinct population).

# Appendix 3

Species and abundance data by collection phase (Pilot and Phase 1)

| Higher Order | Genus and species | Pilot Survey | | Phase 1 | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Surficial Calcrete | | Surficial Calcrete | | | | Island |
| | | Nr LP008 | Camp bore | Nr LP008 | Camp bore | Bore 3 | MWP8 | MC013 |
| **Annelida: Oligochaeta** | *Phreodrilidae?* sp. | **1** | | | | | | |
| **Crustacea: Bathynellacea: Parabathynellidae** | *Atopobathynella* sp. *'mackay'* n. sp. | **30** | | **45** | | | | |
| **Crustacea: Ostracoda: Podocopida: Candonidae** | *Abcandonopsis mackay* n. sp. | **1 male** | | | | | | |
| **Crustacea: Copepoda: Harpacticoida: Ameiridae** | *Mackaynitocrella mouldsi* n. gen., n. sp. | **3 females** | | **16** | | | | |
| | *Parapsuedoleptomesochra mackay* n. sp. | | **1 male, 2 females** | | | **4** | | |
| | *Nitokra lacustric pacifica* Yeatman, 1983 | | | | | | **4** | |
| **Crustacea: Copepoda: Harpacticoida: Miraciidae** | *Schizopera bradleyi* n. sp. | | | | | | | **21** |
| | *Schizopera mackay* n. sp. | **9 females, 1 juv.** | | **22** | | | | |
| | *Schizopera medifurca* n. sp. | | | | **1** | | | |
| | *Schizopera paracooperi* n. sp. | | | | **2** | | | |
| **Crustacea: Copepoda: Cyclopoida: Cyclopidae** | *Fierscyclops fiersi* (De Laurentiis *et al*., 2001) | | | | | | | **28** |
| | *Halicyclops cf. kieferi* | | **3 males, 8 females** | | **58** | | | |
| | *Halicyclops mackay* n. sp. | | **3 males, 3 females, 1 juv** | | **6** | | | |
| | *Mackaycyclops bradleyi* n. g. & sp. | | | | | | **5** | |
| | *Mackaycyclops mouldsi* n. gen., n. sp. | **44 male, 9 female, 9 Juv** | **2 females** | **7** | **30** | | **1** | |
| **Insecta: Coleoptera: Dytiscidae** | *Paroster* sp. *'mackay large'* n. sp. | **1** | | **3** | **1** | | | |
| | *Paroster* sp. *'mackay medium* n. sp. | | | **3** | | | | |
| | *Paroster?* sp. *'mackay small'* n. sp. | | | **4** | | | | |

# Appendix 4

Drilling and laboratory water quality data for bores constructed in September 2017 in the Deep Alluvial Aquifer.

| Bore ID | Type | Location | Easting | Northing | Casing Depth | Casing Diameter (mm) | Blank casing | Slotted Casing | Airlift (L/s) | Lab TDS |
|---|---|---|---|---|---|---|---|---|---|---|
| **MWP1** | MB | Drill Pad 1 | 466737 | 7488337 | 36 | 50 | 0-12 & 33-36 | 12 - 33 | 2 | 14,896 |
| **MWP2** | MB | Drill Pad 3 | 449026 | 7491202 | 42 | 50 | 0-24 & 36-42 | 24-36 | 2 | 7,289 |
| **MWP3** | PB | Drill Pad 3 | 449026 | 7491202 | 102 | 150 | 0-48, 54-84 & 96-102 | 48-54 & 84-96 | sand inflow | 97,766 |
| **MWP4_S** | MB | Drill Pad 4 | 442075 | 749221 | 42 | 50 | 0-24, 36-42 | 24-36 | | ? |
| **MWP4_D** | MB | Drill Pad 4 | | | 96 | 50 | 0-66, 90-96 | 66-90 | 2 | 58,000 |
| **MWP5** | MB | Drill Pad 1 | | | 108 | 50 | 0-60, 105-108 | 60-105 | 2 | 46,518 |
| **MWP6** | MB | Drill Pad 5 | 440098 | 74855422 | 100 | 50 | 0-40, 97-100 | 40-97 | 2 | 15,599 |
| **MWP7 (BORE6)** | PB | Drill Pad 5 | | | 96 | 150 | 0-60, 90-96 | 60-90 | 3.6 - 5.5 | 21,400 |
| **MWP8** | Stygo Hole | Drill Pad 5 | | | 2 | 150 | drilled to 15m | open hole | NA | NA |
| **MWP9** | MB | Drill Pad 6 | 428274 | 7481083 | 72 | 50 | 0-23, 69-72 | 23-69 | 1 | 2,780 |

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25 June 2018
Dr Tim Moulds
Director Invertebrate Solutions
PO Box 14
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**Troglofauna litter trap samples from Lake Mackay**

Attention: Gerry Bradley
Sustainability Manager
Agrimin Ltd

Dear Gerry

This letter is an update to the existing report Phase 1 Survey for Subterranean Fauna for the Lake Mackay SOP Project, Western Australia, April 2018. Unpublished report to Agrimin Ltd, on behalf of 360 Environmental Pty Ltd. Invertebrate Solutions Report Number 2017ISJ07_F03_20180410.

Six troglofauna litter traps were set in two bores within the area immediately to the south of Lake Mackay in November 2017 and these traps were retrieved in June 2018. Two traps were irretrievable (one from each bore). The remaining four troglofauna litter traps were transported to Perth and potential troglofauna specimens were extracted in tullgren funnels in the Invertebrate Solutions laboratory between 21-25th June 2018 until the litter was completely dry. The samples were the sorted using an Amscope 45x dissecting microscope and was undertaken by Dr Timothy Moulds.

No specimens exhibiting troglomorphisms were identified from the samples with only limited abundance of surface forms present.

The two sampling locations Bore 3 and Bore 5 (MWP8) represent the initial sampling of a pilot survey for troglofauna and an additional eight to 13 troglofauna litter samples will be required to meet the EPA Technical Guidance – Subterranean Fauna Survey (EPA2016a), Technical Guidance – Sampling Methods for Subterranean Fauna (EPA2016b) and the Environmental Factor Guideline – Subterranean Fauna (EPA 2016c).

Invertebrate Solutions

Sincerely


Dr Tim Moulds
Director and Principal Ecologist
Invertebrate Solutions
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# Appendix C Representative Site Images

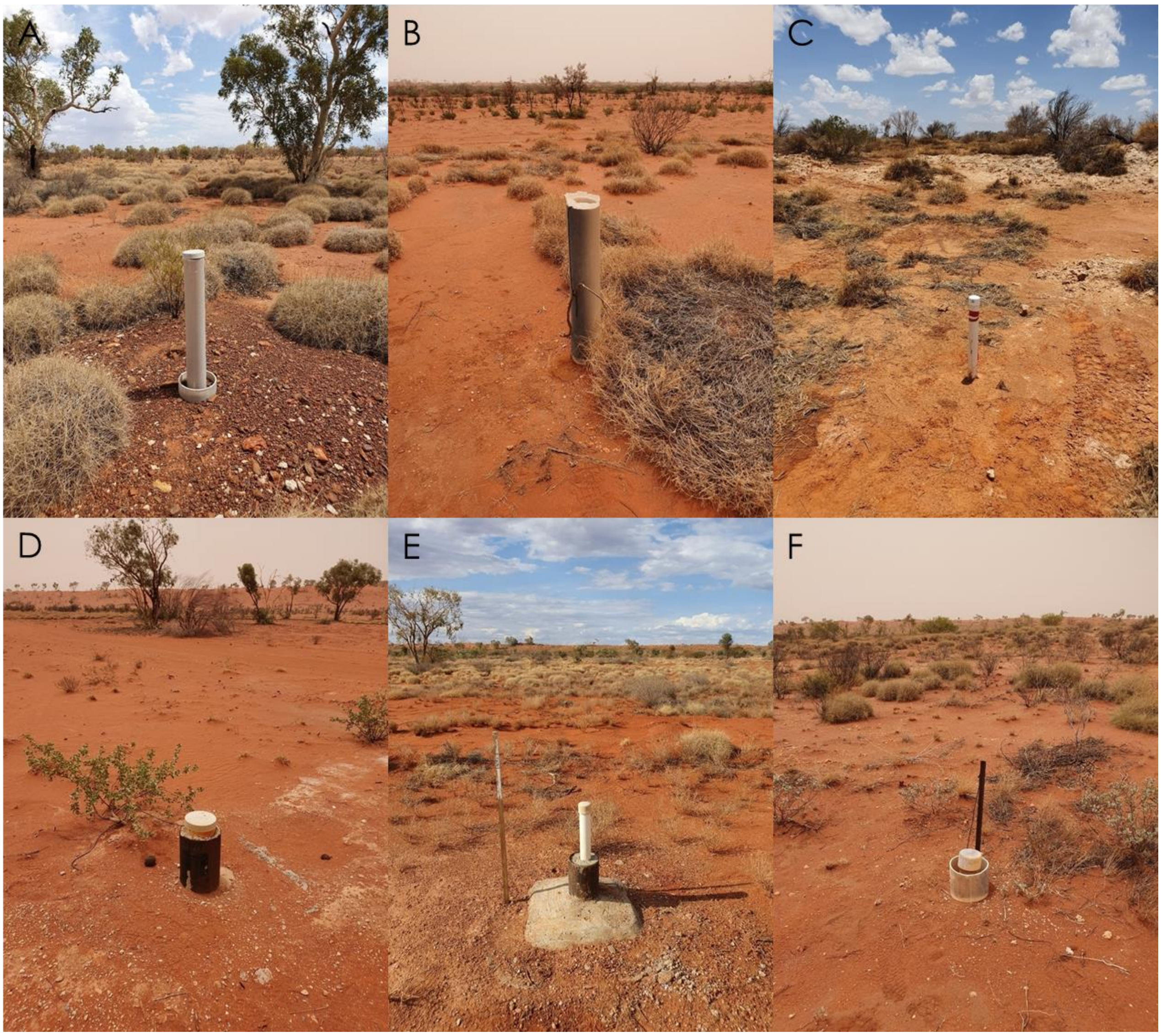


Plate C1: Representative site images A) KTB1, B) LD03, C) LMISL5, D) MWP3, E) MWP9, F) Nr LP008.

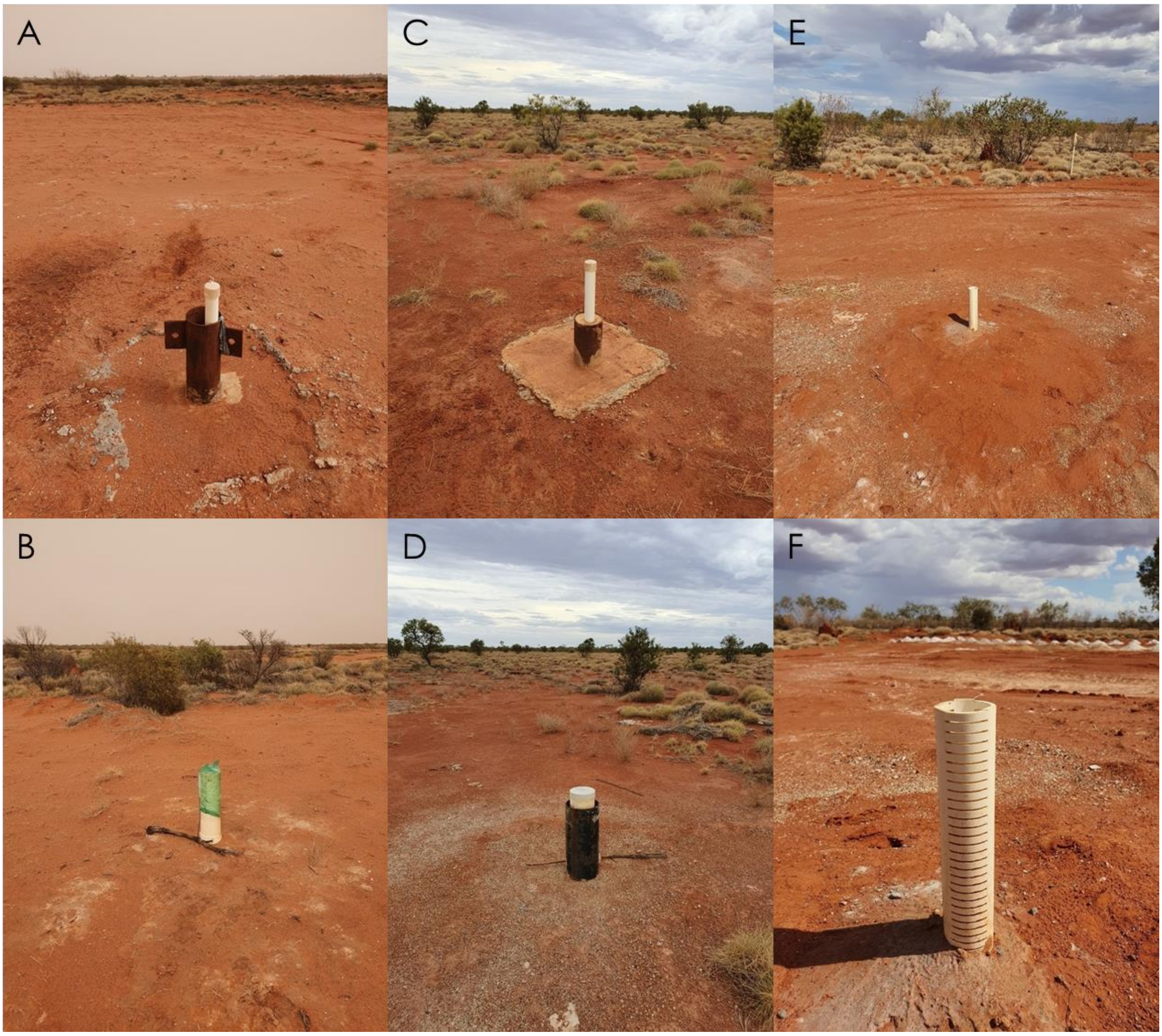


Plate C2: Representative site images, where a second bore had been drilled for Troglofauna traps A-B) MWP1/5 and the troglofauna site MWP1b, C-D) MWP6 and E-F) MWP10.

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