Bennelongia Environmental Consultants

Lake Wells Potash Project

Subterranean Fauna Baseline Survey

Prepared for:

Australian Potash Limited

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Final Report

Short-Range Endemics | Subterranean Fauna

Waterbirds | Wetlands

Lake Wells Potash Project
Subterranean Fauna Baseline Survey

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EXECUTIVE SUMMARY

Australian Potash Limited proposes to develop the Lake Wells Potash Project at Lake Wells in the northeastern Yilgarn region of Western Australia. The Project will involve the extraction and concentration in solar evaporation ponds of naturally occurring potassium-rich brines underlying the Lake Wells salt lake system for the production of sulphate of potash.

This assessment aimed to determine the likelihood of subterranean fauna (stygofauna and troglofauna) occurring in the vicinity of the Project. This was done by assessing habitat characteristics and previous records of subterranean fauna through desktop review, and by further documenting the subterranean fauna in the Project area through field survey.

Four saline–hypersaline aquifers have been identified in the Project area by brine exploration drilling, occurring in surficial, upper sand, clay aquitard and basal sand units. The units are largely associated with the salt lake system and their high salinities are likely to preclude stygofauna. In addition, interstitial spaces in these aquifers are apparently small enough to exclude the occurrence of most stygofauna, while the shallow depth to the watertable (as well as high soil salinities) make it unlikely that troglofauna species occur. In contrast, the low salinity aquifers in alluvium, colluvium and fractured rock surrounding the main playa network are predicted to be moderately prospective for stygofauna. The proposed borefield for low salinity water will be located in aquifers to the south of Lake Wells.

No records of subterranean fauna in the vicinity of the Project were identified by desktop review. However, 60 stygofauna samples were collected in March and October 2017. Both net haul and pump sampling methods were used to collect stygofauna, depending on the infrastructure present in the bores. Troglofauna sampling occurred at six sites.

A total of 323 stygofauna specimens representing at least 27 species were collected. At least 14 species of stygofauna were collected from the estimated area of >3 m groundwater drawdown associated with the low salinity borefield, whereas at least 19 species were collected in surrounding areas. Six species of stygofauna have been collected only from within the proposed borefield. There is currently insufficient information to determine whether these species (four copepods and two syncarids) are likely to be more widespread, although one syncarid species may be represented outside the borefield by a juvenile animal.

Four troglofauna species were collected but it is unlikely the Project will impact on troglofauna because there will be no significant ground excavation associated with Project development.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

Australian Potash Limited proposes to develop the Lake Wells Potash Project (the Project) at Lake Wells, approximately 160 km northeast of Laverton, in the northeastern Yilgarn region of Western Australia (Figure 1). The Project will involve the extraction of naturally occurring potassium-rich groundwater brines underlying the Lake Wells salt lake system and their concentration in solar evaporation ponds for the production of sulphate of potash (potassium sulphate), an important plant fertiliser. Additional infrastructure is likely to include salt harvesting and treatment facilities, access and haul roads, an airstrip, accommodation and administration facilities, utility supplies and drainage, and a borefield to produce 'low salinity' groundwater for potash processing and domestic purposes. The final layout and impact footprint of the Project is yet to be determined but it is possible that groundwater drawdown associated with the Project may adversely affect subterranean fauna.

Although inconspicuous, subterranean fauna contribute markedly to the overall biodiversity of Australia. The Yilgarn and neighbouring Pilbara regions of Western Australia are recognised as hotspots of subterranean faunal biodiversity, with over 4,000 subterranean species likely to occur (Guzik et al. 2010), the majority of which remain undescribed. Nearly all subterranean species satisfy Harvey's (2002) criteria for short-range endemism (SRE), namely a range of less than 10,000 km^2, occurrence in discontinuous habitats, slow growth and low fecundity. Given that species with small ranges are more vulnerable to extinction following habitat degradation than wider ranging species (Ponder & Colgan 2002), it follows that subterranean species are highly susceptible to anthropogenic threats such as groundwater abstraction.

The Environmental Protection Authority (EPA) recognises the importance of subterranean fauna in Western Australia, and requires consideration of this component of the fauna as part of environmental impact assessment. Accordingly, this report provides the results of desktop and field surveys to determine the ecological and conservation values of subterranean fauna at Lake Wells. The specific aims of the work were:

1. To determine the likelihood that subterranean fauna (stygofauna and troglofauna) occur in the vicinity of the Project by assessing hydrogeology, potential habitat and previous records of subterranean fauna;
2. To document the assemblages and species of subterranean fauna present at Lake Wells by field survey; and
3. To evaluate the conservation values of subterranean fauna species and assemblages at Lake Wells in the context of proposed developments at the Project.

2. BACKGROUND

2.1. Conservation Framework

The requirement to consider impacts of developments on subterranean fauna conservation values in Western Australia is outlined in *Environmental Factor Guideline: Subterranean Fauna* (EPA 2016a) and can be further considered in the wider context of state and federal legislation for the protection of native flora, fauna and ecosystems. At the federal level, the Environmental Protection and Biodiversity Conservation (EPBC) Act 1999 provides a legal framework for the protection and management of threatened and endangered ecological communities, which includes some subterranean species and communities. For example, a species of stygal remipede crustacean, *Kumonga exleyi*, is listed as vulnerable on the EPBC Act List of Threatened Fauna. The natural environmental resources of Western Australia are also protected through state legislation, including the Wildlife Conservation (WC) Act 1950 and the Environmental Protection (EP) Act 1986. Following the passing of the Biodiversity Conservation (BC) Act in 2016, the WC Act will eventually be superseded by the BC Act.

Under the WC Act, special protection is granted to species listed as endangered, threatened or otherwise in need of special protection. The current notice includes many species of stygofauna and troglofauna, mostly crustaceans, arachnids and myriapods (and some fish). Additionally, the Department of Biodiversity, Conservation and Attractions maintains a list of priority fauna species that are of conservation importance, but for various reasons do not meet the criteria for listing as threatened. These priority species are treated as having high conservation status during environmental impact assessment.

In addition to the protection of species, the EPBC Act protects ecological communities – comprising groups of species occurring in association with each other – that are considered to be threatened. The WC Act has no provision for the listing of threatened ecological communities (TECs), although the new BC Act does. Currently, the Minister for the Environment has formally endorsed a list of TECs. Apparently threatened communities for which there is insufficient information to support listing have been listed as priority ecological communities (PECs) by DBCA. Several subterranean ecological communities in Western Australia are listed as TECs and over 80 subterranean communities (predominantly in calcretes) are listed as PECs.

2.2. Subterranean Fauna

With the exception of a small number of cave-dwelling fish species, Western Australian subterranean fauna are invertebrates and are divided into aquatic stygofauna and air-breathing troglofauna. Both groups typically lack eyes and are poorly pigmented due to lack of light. Other characteristic morphological and physiological adaptations such as vermiform bodies, elongate sensory structures, loss of wings, increased lifespan, a shift towards K-selection breeding strategies and decreased metabolism reflect low inputs of carbon and nutrients in subterranean habitats and the requirement to navigate enclosed spaces (Gibert and Deharveng 2002).

Geology influences the presence, richness and distribution of subterranean fauna by providing different types of habitat (Eberhard et al. 2005; Hose et al. 2015). Highly transmissive geologies support greater assemblages of subterranean fauna, both in terms of abundance and diversity, than consolidated ones. Alluvial deposits may host subterranean fauna in interstitial spaces between constituent sand and gravel, and coarser sediments tend to host greater assemblages than silty or clay-rich substrates (Korbel and Hose 2011). Physical and chemical weathering of consolidated strata can also provide fissures, vugs and caves for subterranean species to inhabit. High salinities have resulted in the precipitation of carbonates along many parts of the internal palaeoriver systems of Western Australia. The aquifers in these areas of calcrete, which may be quite karstic, provide excellent habitat for stygofauna. Calcrete also occurs above the watertable and may host troglofauna as well (Humphreys 2001).

Partly because prospective subterranean fauna habitats are often isolated, and also because below-ground movement of fauna is very restricted, there is a high incidence of short-range endemism in the Western Australian subterranean fauna. There is also a high incidence of cryptic (or at least morphologically very similar) species and comparatively high levels of genetic variability.

2.2.1. Stygofauna

Stygofauna are mostly crustaceans (especially copepods, amphipods, isopods, ostracods and syncarids) but also include earthworms, beetles, snails and various other groups with difficult-to-identify species, such as nematodes and rotifers (especially Bdelloidea).

In the Pilbara and Yilgarn, surveys of calcrete aquifers have revealed rich and endemic stygofaunal assemblages, while less transmissive geologies such as banded iron formations (BIF) and saprolite tend not to hold rich stygofaunal communities. Nevertheless, stygofauna have been recorded in geologies of relatively poor permeability (Ecologia 2009; GHD 2009).

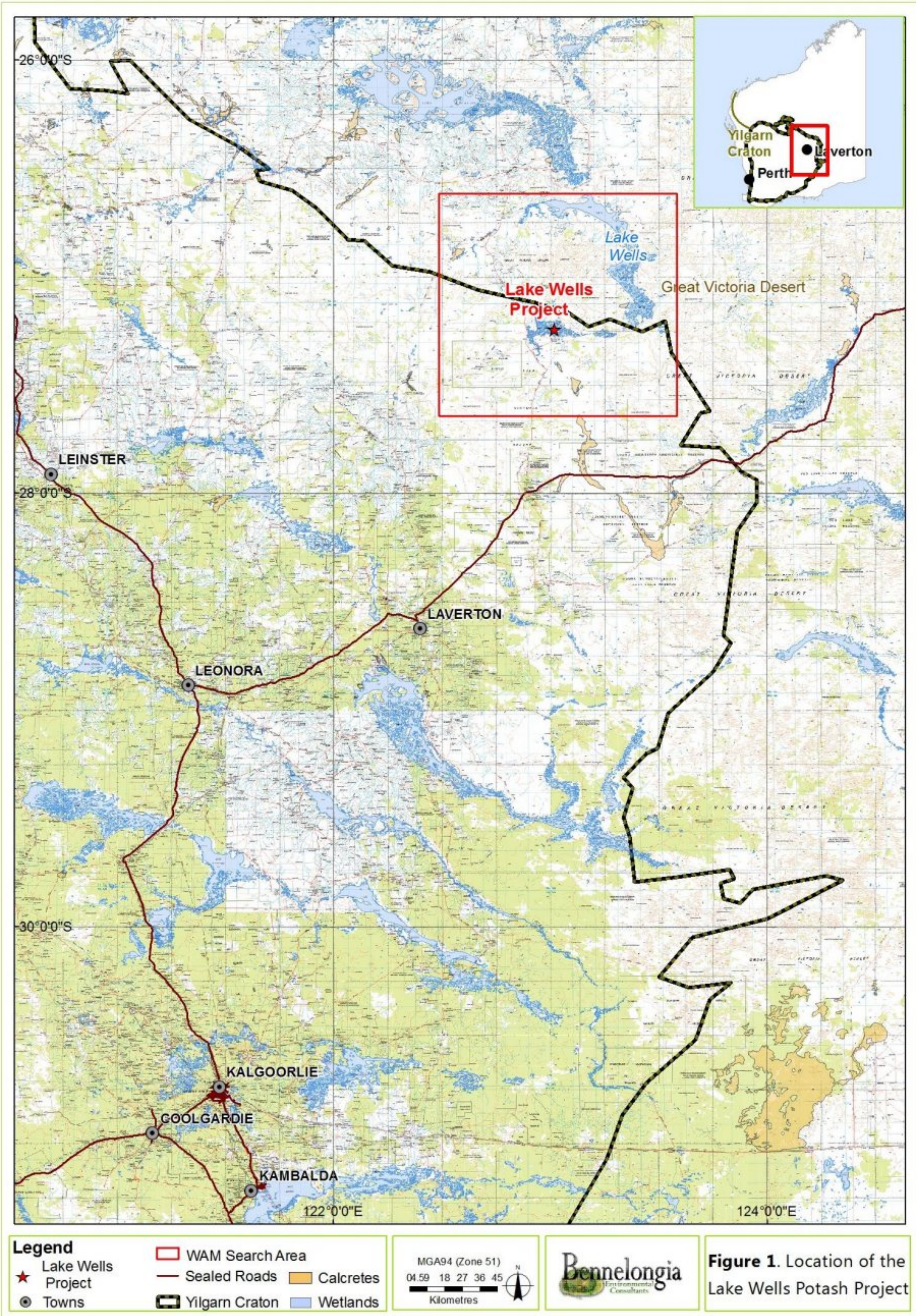

Figure 1. Location of the Lake Wells Potash Project.

The area covered by the database (WAM) and literature search for records of subterranean fauna is also shown.

Stygofauna occur in varying salinities, but are mostly found in fresh to saline waters with conductivities of less than 30,000 µS cm^{-1} (approximately 20,000 mg L^{-1} TDS), and are seldom found in hypoxic groundwater (<0.3 mg O_2 L^{-1}) (see Humphreys et al. 2009; Hose et al. 2015).

2.2.2. Troglofauna

Troglofauna include a wide variety of invertebrate groups including isopods, palpigrads, spiders, schizomids, pseudoscorpions, harvestmen, millipedes, centipedes, pauropods, symphylans, bristletails, silverfish, cockroaches, bugs, beetles and fungus-gnats. Troglofauna have been recorded throughout the Western Australian landscape, with the greatest diversity and abundance occurring in the Pilbara, where they occur widely in mineralised iron formations, calcretes and alluvial-detrital deposits (e.g. Biota 2006; Bennelongia 2008a, b; Edward and Harvey 2008).

Troglofauna surveys in the Yilgarn have been limited, and in most cases have recorded modest abundances and diversities of troglofauna in calcretes above the water table. Bennelongia (2015) notably recorded 45 species of troglofauna from the Yeelirrie calcrete, while Outback Ecology (2012) recorded 20 species in calcretes around Lake Way. These rich assemblages illustrate the suitability of calcrete as a habitat for troglofauna. Surveys in BIF in the Yilgarn at Koolyanobbing, Mt Jackson and Mt Dimmer have yielded depauperate to moderately rich troglofauna communities (Bennelongia 2008a; Bennelongia 2008b).

3. POTENTIAL IMPACTS

The potential effects of the Project on subterranean fauna can be broadly divided into two categories:

1. Primary impacts – these are impacts that animals are unlikely to survive. The direct removal of habitat is the most obvious example of a primary impact. Depending on the spatial scale of habitat removal, it may threaten the local persistence of a widespread species or even cause extinction of a highly restricted species; and
2. Secondary impacts – these are impacts that will reduce animal fitness but which much of the population will survive. Secondary impacts are likely to reduce population density of a species but not to cause extinction. Most impacts fall into this category, including small changes in water chemistry, increased turbidity, very small scale release of hydrocarbons (fuel spills) and rapidly attenuating blast vibration.

3.1. Potential Impacts on Stygofauna

There are two areas of potential Project impact on stygofauna. First, the Project will abstract groundwater as a source of brine in which potassium sulphate can be concentrated. Second, the Project will abstract low salinity groundwater for processing of potassium sulphate. Drawdown of the water table in these borefields poses a potential primary threat to any stygofauna communities present.

3.2. Potential Impacts on Troglofauna

Direct habitat loss from excavation is the main threat to troglofauna in the Project area. The extent of habitat loss will depend on the area and depth of the excavation. Animals utilising small isolated pockets of habitat are more vulnerable to local (or complete) extinction than those inhabiting more extensive geologies, which will probably have ranges extending well beyond the impacted area.

4. DESKTOP ASSESSMENT

4.1. Regional Context

The Project is located among the network of salt lake playas and claypans of Lake Wells on the northeastern margin of the Yilgarn Craton, in the northern section of the Great Victoria Desert Shield sub-bioregion (GVD1; Barton and Cowan 2001) of Western Australia.

The climate is arid with the majority of total annual rainfall (ca. 300 mm) occurring in summer (Table 1). A significant volume of rainfall was received in the vicinity of Lake Wells in the weeks prior to field survey in March 2017, with approximately 177.2 mm and 98.4 mm falling in January and February, respectively, at Laverton Aero (BOM station no. 13035) (BOM 2017), resulting in localised flooding.

Table 1. Regional climate data for the study area.
Data for temperature and rainfall were taken from Laverton Aero (BOM weather station no. 12305, ~160 km south-southeast of the study area) and Delita Downs (BOM weather station 13035, ~60 km northwest of the study area), respectively. Red and blue text denotes maximum and minimum monthly values, respectively.

	Since	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean max. temp. (°C)	1991	35.5	33.8	30.4	26.7	22.2	18.3	18.3	20.8	24.5	28.6	31.3	33.8	27.0
Mean min. temp. (°C)	1991	21.5	20.7	18.2	14.9	10.5	7.0	5.9	7.2	10.4	14.3	17.1	19.7	14.0
Mean rainfall (mm)	1992	50.3	59.1	41.2	36.1	15.8	15.9	8.2	9.0	4.1	12.4	23.9	24.7	297.4

4.2. Hydrogeology

Geologically, the Lake Wells area is characterised by Quaternary aeolian deposits, depositional sheet wash and playa lake deposits. Basement rocks include Archaean granitic rocks rich in potassic and calcic feldspar, along with greenstone rocks including basalt, gabbro, felsic schists and chert-shale-BIF units. Historic and recent drilling programs have revealed a variable regolith horizon consisting of surficial or near-surface evaporite and sand/silt, silcrete (with or without laterite), common lake clays with some well sorted sand units and puggy lacustrine clays with minor sand/silt. Archaean basement rocks including transitional porphyry, granite, ultramafic and amphibolite types were logged at the end of some holes.

Thirty-two brine exploration drill holes have been drilled in the Project area. Consistent with the wider regional setting, drilling results show a deep Tertiary valley with predominantly lacustrine clays and minor sand interbeds at depths of up to 140 mbgl. The lacustrine clay is overlain by a variable, mixed alluvial sequence comprising sand, clay, evaporite and precipitate deposits. There is a reasonably consistent sand unit at the base of the alluvial sequence that has been intersected by 21 of the 32 drill holes at depths of between 29 mbgl and 77 mbgl. It is 1–15 m thick.

Aquifer units proposed for brine extraction in the Project area include:

- **Surficial aquifer:** Pliocene–Quaternary mixed alluvial/lacustrine sediments comprising clayey sands, calcrete, laterite and evaporite deposits (~0–30 mbgl);
- **Upper sand:** Pliocene, predominantly sand unit with variable clay content at the base of the surficial aquifer;
- **Clay with minor sand interbeds:** A low-permeability, low-yield Miocene clay aquitard comprising puggy lacustrine clay with sandy interbeds (~30–150 mbgl); and
- **Basal coarse sand:** an Eocene basal sand forming a major permeable aquifer and high yields of brine (>150 mbgl).

Freshwater aquifers occur in alluvium and colluvium, and in the underlying fractured rock, in areas surrounding the main playa network but the precise salinity, depth and connectivity of these aquifers is presently unclear (AQ2 2017). The proposed low salinity borefield will access freshwater aquifers to the south of Lake Wells.

4.2.1. Brine Borefield

The proposed brine borefield approximately bisects the main network of salt lake playas comprising Lake Wells. Permeability estimates for brine aquifers, combined with test pumping, indicate that brine can be pumped from the upper sand and basal sand units. Abstraction from the basal sand unit will facilitate depressurisation and under-drainage of the overlying clay aquitard, while abstraction from the upper sand will drain the overlying surficial aquifer. There is also the possibility to increase abstraction from the surficial aquifer through constructing drainage trenches (6–10 m deep) on playa surfaces (AQ2 2017).

The production rate of sulphate of potash is proposed to be 100,000 Tpa for the first five years, increasing to 200,000 Tpa thereafter. Based on these rates and mean-weighted averages of potassium concentrations in aquifers, the brine borefield must produce 46.4 ML day^{-1} (16.9 GL yr^{-1}) of brine continuously for the first five years and 102.2 ML day^{-1} (37.3 GL yr^{-1}) thereafter. Analysis suggests pumping water levels will fall below the base of the upper sand aquifer during the first year of operation but the depth and spatial extent of drawdown is undefined (AQ2 2017).

4.2.2. Freshwater Borefield

A fresh water borefield with a capacity for approximately 42 L s^{-1} pumping (1.3 GL yr^{-1}) is proposed to supply water to the process plant area at site. The proposed freshwater production bores are located to the south of Lake Wells, Nine potential production bores have been identified (Australian Potash 2017). While the extent of drawn as a result of the borefield as a whole has not been modelled, it is expected that drawdown of >3 m will extend 1-2 km from each bore (assuming circular drawdown, whereas the true shape is likely to be ellipsoidal).

4.3. Assessment of Habitat Prospectivity

In general, the available geological information suggests that Lake Wells has low prospectivity for subterranean fauna. Prevailing geologies are predominantly lacustrine deposits (clays, sands and playa lake deposits) that are unlikely to provide the subterranean matrix of interstices, vugs and holes required to host significant assemblages of stygofauna and troglofauna. Troglofauna habitat is further limited by shallow depths to groundwater (0.12–5 mbgl) through much of the Project area.

Stygofauna are unlikely to occur at salinities >50,000 mg L^{-1}, although there are records of stygofaunal amphipods and copepods at salinities around 100,000 mg L^{-1} near Wiluna (Outback Ecology 2012). Despite the Wiluna results, it is considered unlikely that stygofauna (and even more so troglofauna) occur underneath the playa surfaces that will host brine extraction because of unsuitable geology and hypersalinity.

While there is low prospectivity for subterranean fauna under the Lake Wells playa system, the low salinity aquifers external to Lake Wells (including the area proposed for low salinity water production outside the brine borefield) are predicted to be moderately prospective for stygofauna. The available information suggests the aquifer targeted for water production occurs predominantly in fractured rock but alluvium, colluvium and, possibly, calcrete are present in the surficial aquifer (AQ2 2017). Stygofauna have previously been recorded from fractured rock aquifers, although they are rarely speciose in such lithology, but alluvial and colluvial aquifers are prime stygofauna habitat (Halse et al. 2014; Bennelongia 2016a). This surficial aquifer unit is likely to form "a low-permeability unconfined aquifer although locally, calcrete and evaporites may be very permeable" (AQ2 2017) and may offer prospective stygofauna habitat. The precise locations and extent of these permeable areas are unknown.

4.4. Previous Records of Subterranean Fauna

Previous records of subterranean fauna in the vicinity of the Project were collated by searching available databases (Bennelongia, Western Australian Museum) and relevant literature for records of subterranean fauna within an area of ca. 10,000 km^2 (defined by 26.604°S, 122.489°E and 27.624°S, 123.57°E; Figure 1).

Neither stygofauna nor troglofauna have previously been recorded in the search area, at least partly because of lack of prior survey in the vicinity of Lake Wells. The closest records of subterranean fauna to the Project area come from the Yamarna Calcrete PEC in the Yeo Palaeochannel to the south of Lake Wells. The records from Yamarna, which hosts a rich stygofauna community (Bennelongia 2016b), are 75 km from the Lake Wells system but the habitat in the two areas is potentially similar.

5. FIELD SURVEY

5.1. Sampling Effort

In March 2017, 15 bores were sampled for stygofauna and six exploration holes were sampled for troglofauna (Table 2). For stygofauna, one bore in the proposed brine borefield (bore PLWDD004) and 14 bores that intercepted fresh or slightly saline groundwater to the north and south of the proposed brine field (except for bore LAGC047, which had a salinity similar to seawater) were sampled. Troglofauna litter traps were set at six sites over the same period. Two traps were deployed at each of two sites (LWHDH010 and TROG3), and three sites (TROG 1, TROG 2 and TROG 3) were also scraped for troglofauna. Traps from five sites were retrieved two months later by Jim Williams (Botanica Consulting). One troglofauna trap was unable to be retrieved due to damage to the hole (LAGC047) by earthmoving equipment. Scrape and trap samples within the same site were treated as sub-samples of a single sample for reporting purposes. A complete site list is given in Appendix 1.

In October 2017, 45 bores were sampled for stygofauna. Twenty-one of the bores had been recently drilled.

Table 2. Sampling effort for subterranean fauna at Lake Wells in March 2017.

	No. of Bores	Net	Pump	Scrape	Trap*
March 2017					
Stygofauna	15	8	7	-	-
Troglofauna	6	-	-	4	8
October 2017					
Stygofauna	45	38	7	-	-

*Two troglofauna litter traps were set at two sites (LWHDH010 and TROG3).

5.2. Methods

5.2.1. Stygofauna

At most sites, sampling for stygofauna followed the methods recommended by the EPA (2016b), whereby stygofauna were sampled at each bore using weighted plankton nets. Six hauls were taken at each site, three using a 50 µm mesh net and three with a 150 µm mesh net. The net was lowered to the bottom of the hole and jerked up and down to agitate the benthos (increasing the likelihood of collecting benthic species) and then slowly retrieved. Nets were washed between holes to minimise site-to-site contamination.

Net hauling was not possible at bores to which windmills were fitted. At these bores, the pump outflow was filtered mostly for between 20 and 40 minutes through a 150 µm mesh net. Outflow at one sampling site, Diorite Bore, was filtered for approximately 36 hours. Samples were preserved in 100% ethanol and refrigerated at a constant 4 °C. Previous work has shown that results from pumping and net hauling are similar in terms of the species collected (Eberhard et al. 2009; Hancock and Boulton 2009).

In situ water quality parameters – temperature, electrical conductance (EC) and pH – were measured at each site with a TPS WP-81 field meter. Standing water level and total depth of hole were also measured using a Solinst water level meter.

In the laboratory, samples were elutriated to separate out heavy sediment particles and sieved into size fractions using 250, 90 and 53 µm screens. All samples were sorted under a dissecting microscope and stygofauna specimens identified to species level where possible using available keys and species descriptions. When necessary for identification, animals were dissected and examined under a differential interference contrast compound microscope. If stygofauna did not represent a described species, they were identified to species/morphospecies using characters from species keys.

5.2.2. Troglofauna

Two sampling techniques were used to collected troglofaunal from drill holes. Cylindrical PVC traps (270 x 70 mm, entrance holes side and top) were baited with moist leaf litter (sterilised by microwaving) and lowered on nylon cord to the most suitable habitat within each drill hole. Holes were covered at the surface while traps were set to minimise the ingress of surface invertebrates. Scrapes were collected immediately prior to setting traps using a troglofauna net (weighted ring net, 150 µm screen, various apertures according to diameter of the hole) that was lowered to the bottom of the hole, or to the watertable, and scraped back to the surface along the walls of the hole. Each scrape comprised four sequences of lowering and retrieving the net. Samples were preserved in 100% ethanol and refrigerated at a constant 4 °C.

Upon return to the laboratory, troglofauna were extracted from the leaf litter in traps using Tullgren® funnels under incandescent lamps. The light and heat drives the troglofauna and other invertebrates out of the litter into the base of the funnel containing 100% ethanol which acts as a preservative. After about 72 hours, the ethanol and its contents were removed and sorted under a dissecting microscope. Litter from each funnel was also examined under a microscope for any remaining live or dead animals. Preserved scrapes were elutriated in the laboratory to separate animals from heavier sediment and screened into size fractions (250 and 90 µm) to remove debris and improve searching efficiency. Samples were then sorted under a dissecting microscope.

All fauna picked from scrapes or extracted from bait were examined for troglomorphic characteristics (lack of eyes and pigmentation, well developed sensory organs, slender appendages, vermiform body). Troglofauna specimens were, as far as possible, identified to species/morphospecies level, unless damaged, juvenile or the wrong sex for identification, using the same techniques employed for stygofauna.

5.3. Personnel

Field survey was undertaken by Michael Curran and Anton Mittra. Species identifications were completed by Jane McRae. Maps were produced by Mike Scanlon. Reporting was completed by Anton Mittra.

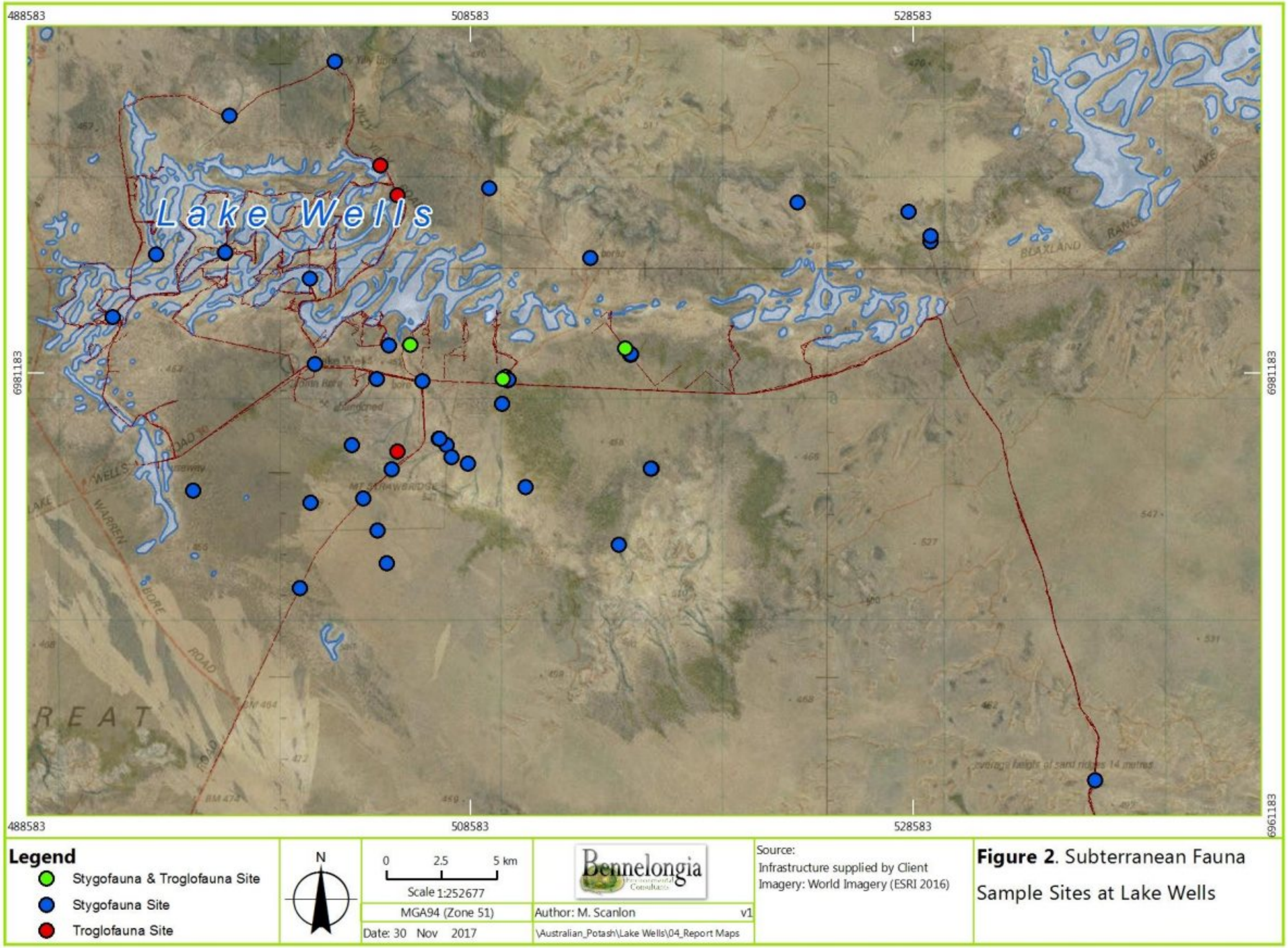

Figure 2. Locations of sampling sites for stygofauna and troglofauna at Lake Wells in March and October 2017.

6. RESULTS

6.1. Stygofauna

6.1.1. General Results

A total of 323 specimens of stygofauna representing at least 27 species were recorded from 19 of the 50 sites sampled for stygofauna, and site TROG3 sampled for troglofauna (Table 3). Higher-order identifications were not included in estimates of species richness unless they belonged to taxa that were not otherwise represented and thus constituted discrete species (e.g. Oligochaeta sp. was not included in counts of species as it may in fact align with *Enchytraeus* AP PSS1 sp.).

Major groups recorded included earthworms (Oligochaeta), roundworms (Nematoda), amphipods (Amphipoda), syncarids (Syncarida), cyclopoid copepods (Cyclopoida), seed shrimps (Ostracoda) and, harpacticoid copepods (Harpacticoida). Harpacticoid copepods comprised the most speciose and abundant group. A total of 184 specimens of 12 harpacticoid species were recorded at seven sites (Table 3). Harpacticoids are often the most abundant group within stygofaunal communities and often show diverse radiations (e.g. Bennelongia 2015). The most abundant species was *Nitocrellopsis* sp. B15 (Ameiridae), of which 60 specimens were recorded from a single bore (LGRB100) in March, Altogether, seven species were recorded at this bore. *Nitocrellopsis* sp. B13 was also recorded in relatively high numbers, with 51 individuals collected from two bores (LGAC043 and LWHDH010) in March. Other species were collected in low-to-moderate abundance. Four species stood out as occurring at a relatively large number of bores (although this was a low proportion of the bores sampled). The more frequent species were the worm *Enchytraeus* AP PSS1 sp. (6 bores), ostracod *Sarscypridopsis* sp. BOS1017 (5 bores), worm Nematoda sp. (probably several species) (4 bores) and harpacticoid *Nitocrellopsis* sp. B14 (3 bores). Nineteen species were collected from only one bore.

Stygofauna were collected mostly from salinities in the range of 600–26,000 µS cm^{-1} (ca. 390–16,500 mg L^{-1}) but ostracod valves were collected from bore LWFRM014 at a salinity of 68,200 µS cm^{-1}. Recorded salinities in holes from which stygofauna were collected are similar to most other Yilgarn studies where stygofauna have been recorded (e.g. Bennelongia 2016). Most stygofauna species were collected from south of the playa system (Figure 3 and 4).

At least 14 species of stygofauna were collected from the estimated area of >3 m groundwater drawdown associated with the low salinity borefield, whereas at least 19 species were collected in surrounding areas. Six species are known only from the area of drawdown, although this may represent a precautionary evaluation of impact based on an over-estimate of the low salinity borefield footprint. In addition, most of the recently drilled bores sampled in October were shown by laboratory testing to be contaminated with cyclohexanol or related compounds and did not yield stygofauna (Appendix 1). More effective sampling of these bores would almost certainly have shown wider distributions of many species.

Brief evaluations of the likely ranges of the species known only from the low salinity borefield are provided below.

6.1.2. Species Accounts

<u>Copepoda</u>

Copepods form a major component of stygofaunal diversity in Western Australia and are commonly the most abundant and speciose group collected. This was the case at Lake Wells, where nine species of *Nitocrellopsis* were collected, two of which (*Nitocrellopsis* sp. 16 and *Nitocrellopsis* sp. 17) are potentially restricted to the borefield. All but one of the species occurs on the south side of Lake Wells.

Table 3. Stygofauna recorded at Lake Wells in March 2017.

Bore numbers from Appendix 1, T3 = scrap sub-sample. Higher order identifications not included in final estimate of species richness are indented.

Group	Species	Borefield impact area											Unimpacted surrounds								
		10	3	11	15	20	23	25	27	34	42	T3	2	4	5	6	12	43	44	46	50
Rotifera	Bdelloidea sp. 2:2																1				12
Nematoda	Nematoda sp.			2										3		4	11				
Aphaneura	*Aeolosoma* sp. S01																		1		
Oligochaeta	Enchytraeus AP PSS1 sp.		1	11	12		1											5	1		
	Tubificoid Naididae AP 5 sp.		4																		
	Oligochaeta sp.	1																			
Ostracoda	*Riocypris* sp.												1								
	Sarscypridopsis sp. BOS1017	5				1		2			10		15								
	Sarscypridopsis sp. BOS1018																			1	
	Ostracoda sp. BOS834																6				1
	Ostracoda sp. unident.	3							2												
Copepoda	*Dussartcyclops (Dussartcyclops) uniarticulatus*																2		1		
	Nitocrellopsis sp. B12			15								1						10			
	Nitocrellopsis sp. B13			1														50			
	Nitocrellopsis sp. B14			1												1	2				
	Nitocrellopsis sp. B15																60				
	Nitocrellopsis sp. B16			10																	
	Nitocrellopsis sp. B17			10																	
	Nitocrellopsis sp. B18																		7		
	Nitocrellopsis sp. B19															2					
	Nitocrellopsis sp. Bx20															2					
	Nitocrellopsis sp.			10																	
	Parastenocaris sp.		1																		
	Schizopera sp. B31		1																		
	Schizopera sp. B32														1						
Syncarida	*Atopobathynella* sp. B26	1																			
	Kimberleybathynella sp. B08									2											
	Kimberleybathynella sp. B09																		2		
	Kimberleybathynella sp.													1							
	Syncarida sp.				1																
	Yilgarniella sp. B04																10				
	Yilgarniella sp.																		1		
	No of species	**4**	**4**	**8**	**2**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**2**	**2**	**1**	**4**	**7**	**3**	**6**	**1**	**2**

The first specimens of *Nitocrellopsis* found in Australia were described by Karanovic (2010) and the genus appears to be widespread across Western Australia, having been recorded in both the Pilbara and Yilgarn. While the genus is widespread, many species belonging to it are not and little can be inferred about the likely ranges of the two apparently 'restricted' species of *Nitocrellopsis*. The extensive radiation of the genus at Lake Wells suggests the animals are in a calcrete aquifer but according to the available hydrogeological information the amount of calcrete in the area is small.

Six of the nine species of *Nitocrellopsis* are known from single bores (Figure 3). Of the species with multiple occurrences, *Nitocrellopsis* sp. B12, B13 and B14 have known linear ranges of approximately 6, 6 and 12 km and occur both inside and outside the borefield.

A further two copepod species (*Schizopera* sp. B31 and *Parastenocaris* sp.) are known only from the low salinity borefield (Figure 3). The genus *Schizopera* is known to be hugely diverse in the Yilgarn region, with many sympatric species often occurring within single aquifers (or sections of an aquifer), and many species remain undescribed (Karanovic and Cooper 2012). The genus *Parastenocaris* (and related species in the family Parastenocaridae) is also speciose in Western Australian aquifers, with many species being range-restricted and sometimes occurring only in sections of an aquifer (Karanovic and Cooper 2011). Estimating the ranges of species recorded as singletons is difficult and the likely ranges of *Schizopera* sp. B31 and *Parastenocaris* sp. are unclear.

Syncarida

Syncarids are diverse in Western Australian aquifers. The syncarid *Atopobathynella* sp. B26 was recorded as a singleton at Lake Wells Bore (Figure 4). The closest congeneric record comes from the Carnegie Downs calcrete at a hole more than 190 km to the north of Lake Wells Bore. Stygofaunal syncarids usually have small ranges, although some syncarid species have been recorded from continuous alluvial aquifers (Bennelongia 2016c). The likely range of *Atopobathynella* sp. B26 is unclear, although it is unlikely to extend beyond the local area and its distribution within this area is probably determined by salinity (and perhaps pore size) within the local aquifer system.

Although *Kimberleybathynella* sp. B08 is known only from within the borefield, a juvenile specimen of *Kimberleybathynella* was collected from Erics Bore outside the borefield. It is likely to be the same species, which could be confirmed genetically (there has been insufficient time for any genetic analysis).

6.1.3. Implications of the Project for Stygofauna

In general, the main factors causing loss of stygofauna habitat are groundwater drawdown (and ground excavation below the watertable).

Given the salinity of the hypersaline groundwater under Lake Wells, and physical properties of the lithologies hosting it, stygofauna are unlikely to occur in areas proposed for brine abstraction. Brine abstraction is not considered a threat to stygofauna conservation values unless the drawdown associated with this abstraction propagates into surrounding low salinity aquifers.

In contrast, the low salinity aquifers to the south of the Lake Wells host a relatively abundant and moderately speciose stygofauna community that contains an amphipod species, syncarids and a extensive radiation of harpacticoid copepods. Documentation of the stygofauna community in the proposed low salinity borefield and surrounding areas was hindered by the contamination of holes drilled specifically for the purpose of stygofauna sampling. A further round of stygofauna sampling is proposed in early 2018 after contamination issues have been resolved. Genetic work will also be undertaken to confirm uncertain identifications.

At present, up to six (but probably five) species have been collected only from the proposed low salinity borefield.

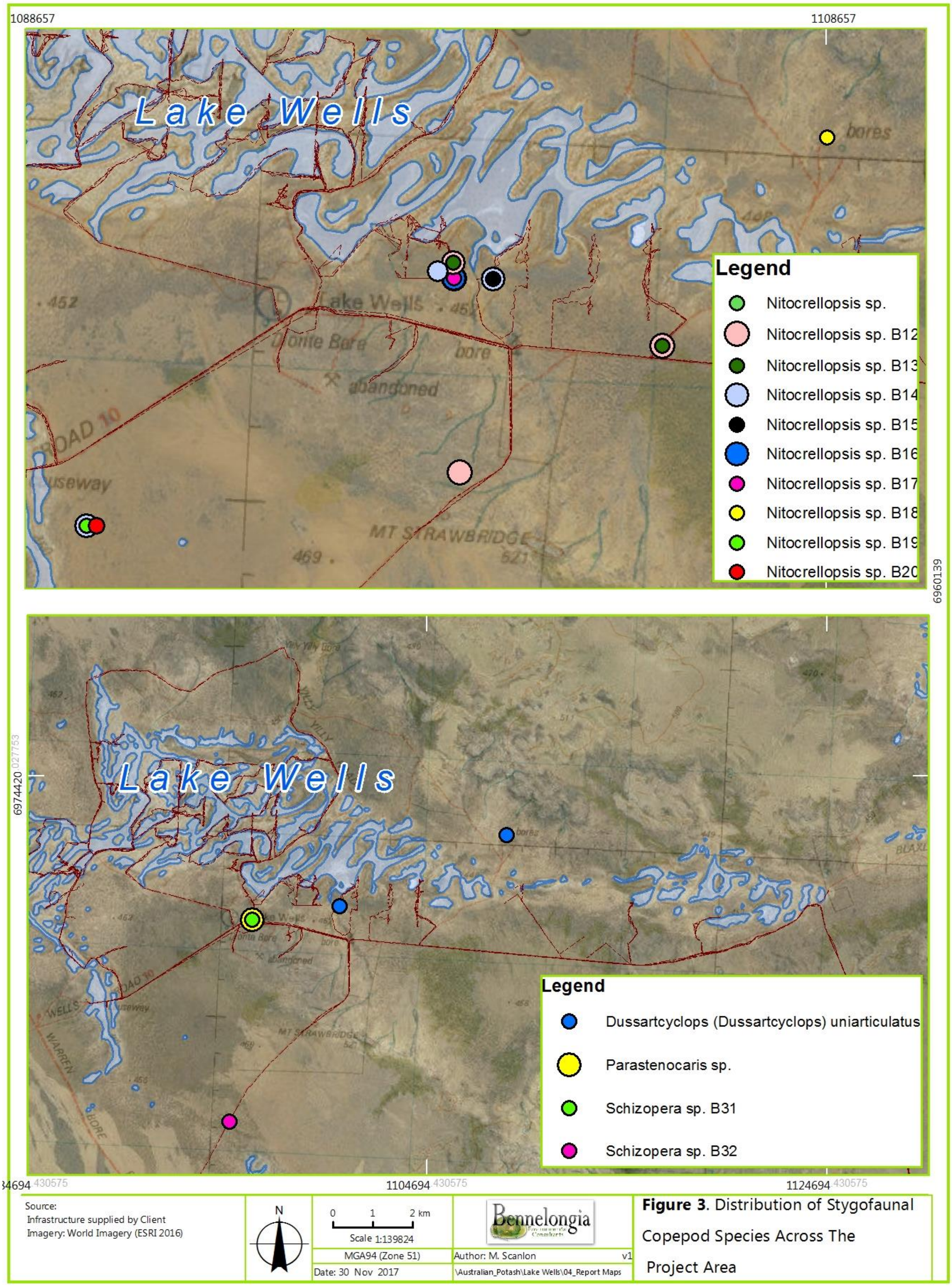

Figure 3. Distribution of copepod species across the Project area and surrounds.

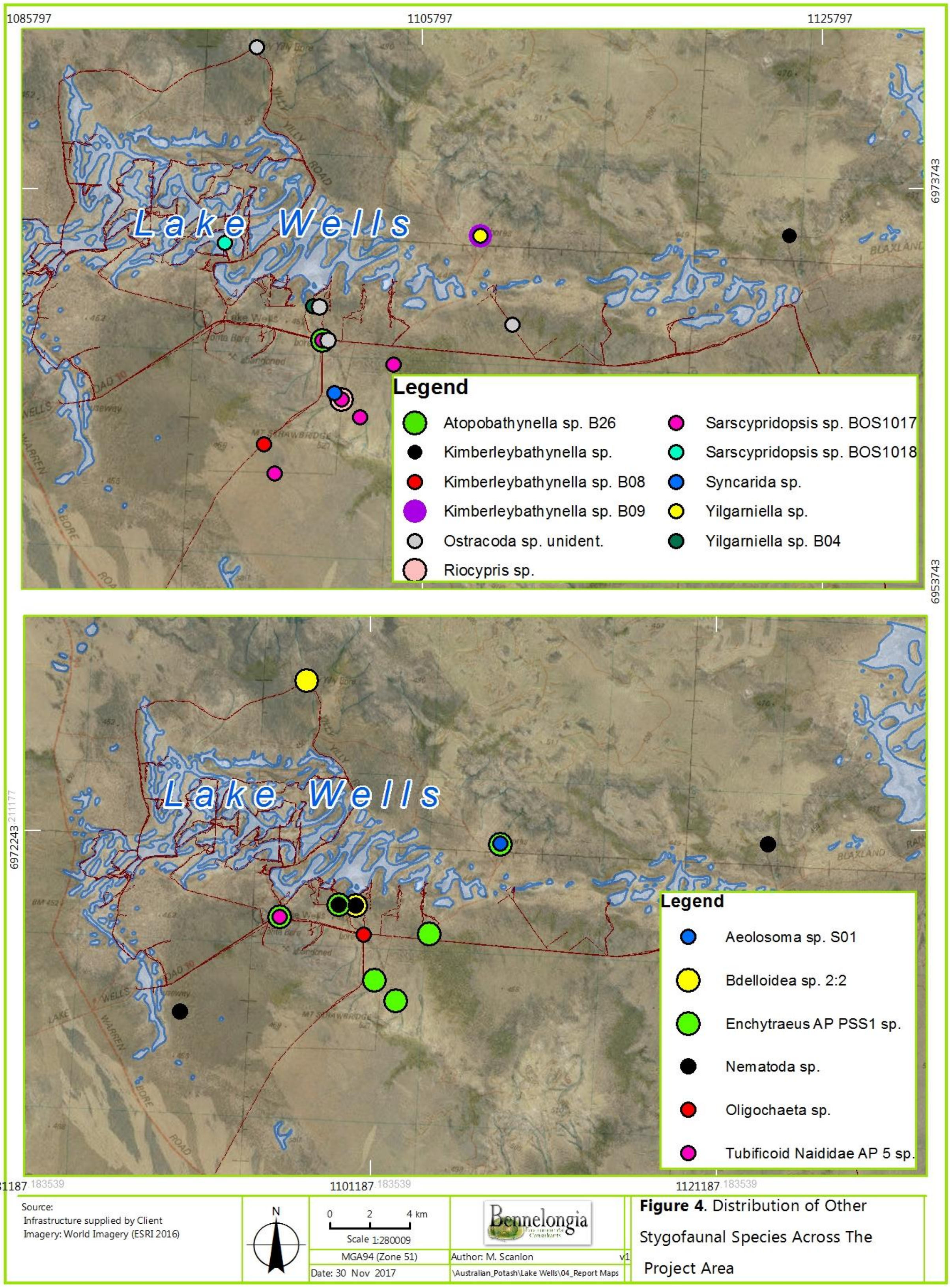

Figure 4. Distribution of other stygofauna species across the Project area and surrounds.

6.2. Troglofauna

Four troglofaunal species were collected during troglofauna and stygofauna sampling (Table 4). This represents a depauperate troglofauna community but sampling effort was low. The species collected belong to groups that are typical of Yilgarn troglofauna.

Given there will be no excavation of troglofauna habitat in the Project (i.e. there will be no 'mining' pits), the level of disturbance to troglofauna will be very low and no conservation impact on troglofauna is expected.

Table 4. Species of troglofauna collected at the Project.

Group	Species	Gibson Bore	Golden Bore	LWHDH010
Isopoda	Armadillidae sp. B12	1	3	
	Trichorhina sp.	1		
Diplura	Japygidae sp. B41			1
Hemiptera	*Phaconeura* sp.	1		

7. CONCLUSIONS

This assessment used desktop review and a field survey to evaluate whether subterranean fauna may occur in the Project area and to assess whether the Project may threaten the conservation values of any subterranean fauna species and communities present. The following conclusions were drawn:

- The Project area, particularly within the salt lake playa network of Lake Wells, is for the most part of low prospectivity for subterranean fauna due to a lack of suitable lithology and high salinities. The suitability of habitat for troglofauna is further limited by the shallow depth to groundwater throughout the area.
- Low salinity aquifers around Lake Wells were predicted to be moderately prospective for stygofauna and 323 specimens of 27 stygofauna species were collected during field survey, mostly from south of the lake. This represents a moderately rich stygofauna assemblage, especially when the relatively low intensity of the sampling effort is taken into account because of bore contamination.
- Six species of stygofauna were collected only from within the likely area of>3 m groundwater drawdown associated with the low salinity borefield south of Lake Wells. There is currently insufficient information to determine whether these species (four copepods and two syncarids) are likely to be more widespread, although one syncarid species may be represented outside the borefield by a juvenile animal.
- Four species of troglofauna were recorded during survey but the Project is unlikely to threaten troglofauna species because of lack of ground disturbance.

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9. APPENDICES

Appendix 1. Sampling sites and effort for subterranean fauna in the Project area in 2017.

Field notes about contamination (which were incomplete) summarised in right hand column. Laboratory testing by mpl Laboratories for semi-volatile or volatile organic compounds suggested cyclohexanol was the main such compound in water from three contaminated bores.

STYGOFAUNA

	Site Identification	Latitude	Longitude	Date	Sample Method	EC (µS cm^{-1})	pH	Contamination
1	Big Les's Bore	-27.216	123.095	19/10/2017	Net	4580	7.03	
2	Corner Bore	-27.322	123.076	7/03/2017	Net	817	7.06	
2	Corner Bore			19/10/2017	Pump	1719	7.47	
3	Diorite Bore	-27.288	123.015	6/03/2017	Pump			
3	Diorite Bore			17/10/2017	Pump	4120	7.5	
4	Eric's Bore	-27.238	123.296	4/03/2017	Pump	4,030	6	
4	Eric's Bore			17/10/2017	Pump	3310	7.44	
5	Gibson Bore	-27.380	123.009	7/03/2017	Net	16,530	5.83	
5	Gibson Bore			19/10/2017	Net	15000	7.47	
6	Golden Bore	-27.340	122.960	7/03/2017	Net	23,790	5.67	
6	Golden Bore			20/10/2017	Net	26400	6.37	
7	Greg's Bore	-27.2363	123.296	4/03/2017		3,470	6.03	
8	Grimwoods Bore	-27.187	122.976	4/03/2017	Pump	5,100	5.77	
8	Grimwoods Bore			18/10/2017	Pump	4860	7.18	
9	LAGC047	-27.285	123.160	6/03/2017	Net	60,900	6.18	
10	Lake Wells Bore	-27.295	123.064			9,140	6.95	
10	Lake Wells Bore					8800	7.08	
11	LGAC043	-27.281	123.050	6/03/2017	Net	16,610	6.34	
11	LGAC043			19/10/2017		15080	7.49	
12	LGRB100	-27.281	123.059	6/03/2017	Net	20,480	6.2	
13	LWDRM003	-27.243	122.975	18/10/2017	Net	167.2	5.32	
14	LWDRM005	-27.244	122.943	18/10/2017	Net	176.6	5.66	
15	LWFRM001	-27.3190	123.072	18/10/2017	Net	2950	6.82	

	Site Identification	Latitude	Longitude	Date	Sample Method	EC (µS cm^{-1})	pH	Contamination
16	LWFRM002	-27.326	123.078	19/10/2017	Net	1430	7.51	
17	LWFRM004	-27.331	123.050	19/10/2017	Net	1694	7.34	
18	LWFRM005	-27.321	123.0326	19/10/2017	Net	1732	7.56	Contaminated
19	LWFRM006	-27.370	123.048	19/10/2017	Net	15400	7.03	Contaminated
20	LWFRM007	-27.3566	123.044	19/10/2017	Net	2610	7.25	
21	LWFRM008	-27.3436	123.0380	19/10/2017	Net	2820	6.91	
22	LWFRM009	-27.3452	123.013	19/10/2017	Net	5770	7.65	
23	LWFRM010	-27.329	123.085	18/10/2017	Net	1611	7.86	
24	LWFRM011	-27.2950	123.104	17/10/2017	Net	55200	6.87	
25	LWFRM012	-27.3049	123.101	18/10/2017	Net	159.2	6.13	Contaminated
26	LWFRM013	-27.331	123.169	17/10/2017	Net	17000	7.38	Contaminated
27	LWFRM014	-27.2846	123.159	17/10/2017	Net	68200	6.88	Contaminated
28	LWFRM014R (Redrill)	-27.284	123.160	17/10/2017	Net	142.1	6.57	Contaminated
29	LWFRM015	-27.226	123.286	17/10/2017	Net	3620	7.6	Contaminated
30	LWFRM016	-27.457	123.372	17/10/2017	Net	6870	7.29	Contaminated
31	LWFRP001	-27.319	123.072	18/10/2017	Net	1674	7.61	
32	LWFRP002	-27.321	123.032	19/10/2017	Net	1677	8.12	
33	LWFRP003	-27.3566	123.044	19/10/2017	Net	2790	6.52	
34	LWFRP004	-27.3435	123.037	19/10/2017	Net	2970	7.7	
35	LWFRP005A	-27.338	123.111	18/10/2017	Net	1770	7.43	
36	LWFRP005B	-27.338	123.111	18/10/2017	Net	1700	7.67	
37	LWFRP006	-27.295	123.103	17/10/2017	Net	136.4	6.55	Okay?
38	LWFRP007	-27.331	123.169428	17/10/2017	Net	3650	7.24	Possibly
39	LWFRP008	-27.284	123.159	19/10/2017	Net	131.2	6.33	Possibly
40	LWFRP009	-27.226	123.286	17/10/2017	Net	6430	6.81	
41	LWFRP010	-27.294	123.04	16/10/2017	Net	4740	7.73	
42	LWFRP012	-27.329	123.085	18/10/2017	Net	1687	7.44	
43	LWHDH010	-27.294	123.103	6/03/2017	Net	25,700	6.04	-
44	Mt Barrett`s bore	-27.245	123.141	20/10/2017	Pump	10800	7.28	
45	Pete`s pool	-27.362	123.155	19/10/2017	Pump	1534	7.21	
46	PLAC018	-27.254	123.014	18/10/2017	Net	185.1	7.2	
47	PLAC026	-27.269	122.924	18/10/2017	Net	153.3	5.61	
48	PLWDD004	-27.243	122.975	5/03/2017	Net	156,000	5.95	-

	Site Identification	Latitude	Longitude	Date	Sample Method	EC (µS cm^{-1})	pH	Contamination
49	Twin Spinner	-27.223	123.236	4/03/2017	Pump	2,620	6.53	-
49	Twin Spinner			17/10/2017		2780	6.79	
50	Yilly Yilly Bore	-27.166	123.025	6/03/2017	Pump	604	6.06	-
50	Yilly Yilly Bore			18/10/2017		2000	7.38	

TROGLOFAUNA

Site identification	Latitude	Longitude	Date	SWL (m)	EOH (m)	Scrape#	Trap (m)
TROG1	-27.208	123.045	5/03/2017	3		Yes	2
TROG2	-27.220	123.054	5/03/2017	4.2		Yes	3
TROG3	-27.324	123.053	7/03/2017		9	Yes	3, 8
LAGC047	-27.285	123.160	6/03/2017	6.6	73	-	5*
LGRB100	-27.281	123.059	6/03/2017	3.1	3.8	-	3
LWHDH010	-27.294	123.103	6/03/2017	5.9	26	-	4, 5

*Unable to be retrieved.

#Sites that were not scraped were sampled for stygofauna by net hauling, which may be viewed as analogous to troglofauna scraping.