Bennelongia Environmental Consultants

Lake Wells Potash Project

Wetland Ecology Baseline Survey

Prepared for:

Australian Potash Limited

November 2017

Final Report

Short-Range Endemics I Subterranean Fauna

Waterbirds I Wetlands

Lake Wells Potash Project
Wetland Ecology Baseline Survey

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EXECUTIVE SUMMARY

Australian Potash Limited proposes to develop the Lake Wells Potash Project (the Project) at Lake Wells in Western Australia. The Project will involve extracting and concentrating potassium-rich brines in solar evaporation ponds for the production of sulphate of potash. The construction of evaporation ponds is the main potential threat to lake ecology at Lake Wells. This assessment provides baseline data on the ecological values of wetlands within the Lake Wells system, including values for aquatic invertebrates, diatoms, aquatic macrophytes and waterbirds.

Nine sites (six wet and three dry) in and around the Lake Wells system were sampled in March 2017. Sites included very shallow hypersaline pools in saline playas, freshwater pools in claypans and dry playas. Salinity (48–195,200 µS cm^{-1}) ranged from fresh (claypan pools) to hypersaline (pools in main saline playa) and water had mildly acidic to circumneutral pH. Sampling methods targeted aquatic invertebrates (sweep sampling and hatching trials), diatoms (scrapes of benthic mats or dry sediment), macrophytes and waterbirds (15 minute survey per site plus opportunistic sightings).

A total of 1,528 specimens of at least 64 invertebrate species were collected. Higher-order groups included flatworms, rotifers, roundworms, crustaceans and insects. Crustaceans were the most diverse group at order-level with seven orders (brine shrimp, clam shrimps, water fleas, shield shrimps, calanoid copepods, cyclopoid copepods and seed shrimps) and were diverse at species-level (21 species). Insects were the most diverse group at species-level, with 24 species of four orders (beetles, flies, true bugs, and dragon- and damselflies). Lake Wells appears to have a rich aquatic invertebrate fauna compared with many other inland saline lakes. Three species, the clam shrimp *Eocyzicus* sp. B01 and the ostracods *Bennelongia* nr *koendersae* and Bennelongia sp. BOS833 (*nimala* lineage) are currently known only from Lake Wells, although all three appear to occur outside the Project impact area and expected to be more widely distributed than the Lake Wells system alone. The other species recorded are all widespread.

A total of 707 diatom specimens of 55 species were collected. There was not a clear inverse relationship between species richness and salinity, as is commonly observed for diatom assemblages. Samples from both wet and dry sites yielded relatively high numbers of species. Results indicate that Lake Wells harbours a comparatively rich assemblage of diatoms. One species identified only to genus is known only from within the Project impact area but it is considered certain to occur more widely.

Two species of aquatic macrophyte, *Ruppia* sp. and *Marsilea* sp., were present during survey. As is typical of saline inland lakes, abundance and diversity of macrophytes were low.

Five waterbird and shorebird species (grey teal, white-necked heron, red-capped plover, black-tailed native-hen and Australian shelduck) were recorded in March and October 2017 (the latter period being a related stygofauna survey). When combined with results from a two-phase vertebrate survey, 16 species of waterbird and shorebird have been recorded at Lake Wells. The majority of species were seen at fresher claypans surrounding the main network of saline playas. The recorded species are widespread and most are common at arid zone saline lakes and fresher wetlands. It is likely that a higher abundance and diversity of waterbirds utilises Lake Wells shortly after major rainfall events.

Rather than hosting many rare or endemic species, the principal ecological value of Lake Wells is its function as a wetland that episodically hosts an abundant and speciose biota.

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1. INTRODUCTION

Australian Potash Limited proposes to develop the Lake Wells Potash Project (the Project) at Lake Wells, located approximately 160 km northeast of Laverton in the northeastern Yilgarn region of Western Australia (Figure 1). The Project will involve the abstraction of potassium-rich saline groundwater that underlies the Lake Wells system via bores. This groundwater will be fed into surrounding pans, which will act as evaporation ponds and then finally into a harvest pond, where sulphate of potash (K_2SO_4), will be collected. This is an important plant fertiliser. The construction and operation of evaporation ponds is a potential threat to aquatic ecology at Lake Wells. Additional infrastructure for the Project is likely to include processing facilities, salt storage areas, access and haul roads, an airstrip, accommodation and administration facilities, utility supplies and an associated borefield to supply processing water (Figure 2.)

This report provides results of a baseline field survey to determine the ecological and conservation values of wetland-dependent fauna and flora at Lake Wells. The specific aims of the study were to document:

- The composition of aquatic invertebrate fauna in and around Lake Wells;
- The composition of the diatom (benthic microalgae) community in and around Lake Wells;
- The aquatic macrophyte species present at the time of survey; and
- The waterbird species using the wetland system.

2. BACKGROUND

2.1. Regional Context

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

From a geological perspective, 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. Historical and recent drilling programs have revealed a variable regolith horizon consisting of surficial or near-surface evaporite and sand/silt, silcrete, common lake clays with some well sorted sand units and puggy lacustrine clays with minor sand/silt.

Local vegetation is characterised by samphire and saltbush steppes associated with the salt lake system, low mulga communities on hills and plains, spinifex grasslands on aeolian sand plains and *Eremophila* shrubland and mulga scrub on low ranges. 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. Total rainfall of 177.2 and 126.4 mm in January and 98.4 and 34.5 mm occurred in January and February, respectively, at Laverton Aero, 160 km to the south, and Delita Downs, 60 km to the northwest (BOM 2017). This rain resulted in localised flooding and pooling in the playas and claypans at Lake Wells but did not inundate the whole system.

Table 1. Regional climate data for the study area.
Temperature data are from Laverton Aero (BOM station 12305) and rainfall data are from Delita Downs (BOM station 13035). Red and blue text denote maximum and minimum average 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

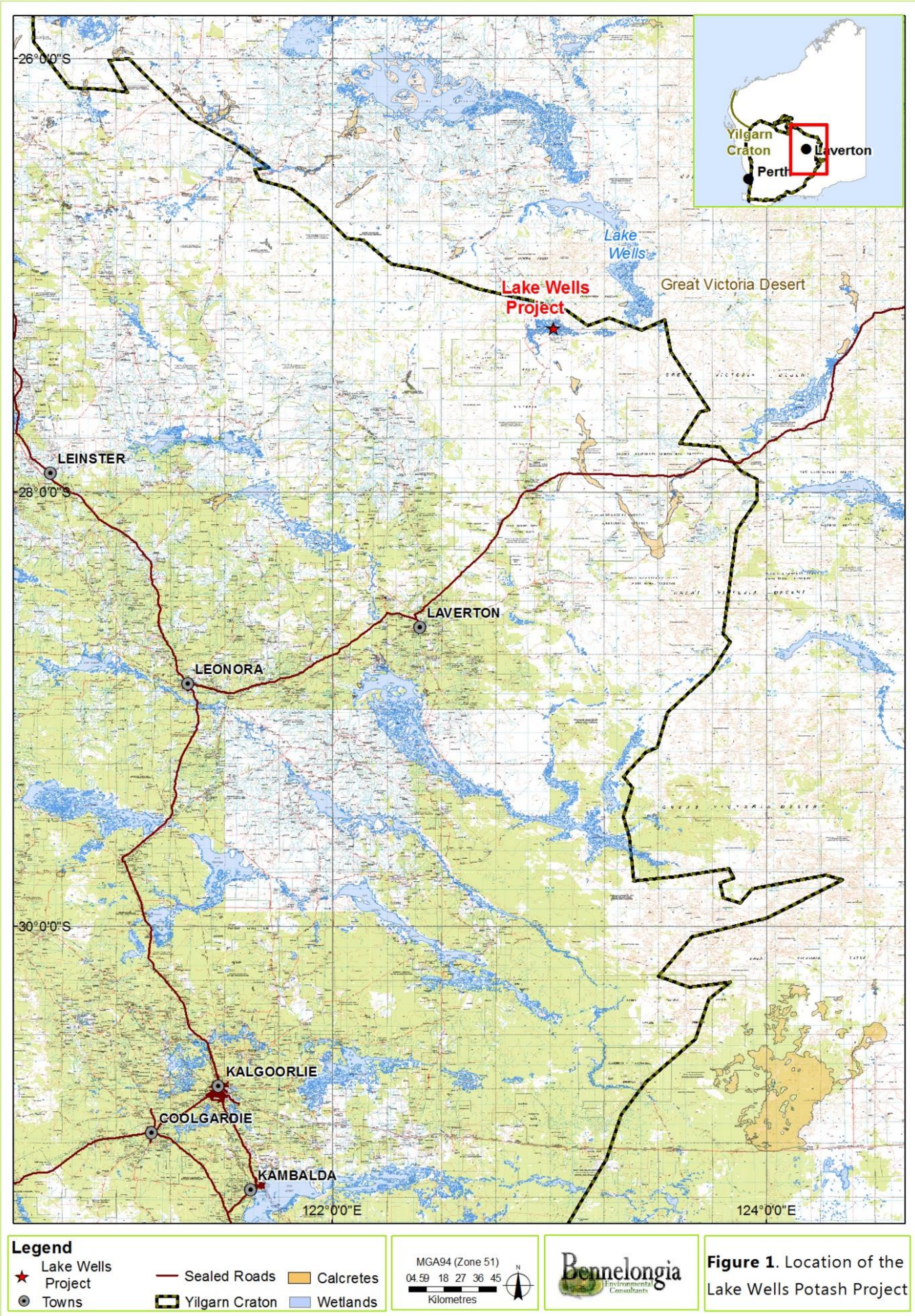

Figure 1. Location of the Lake Wells Potash Project.
Locations of calcretes are derived from the Geological Survey of Western Australia (GSWA).

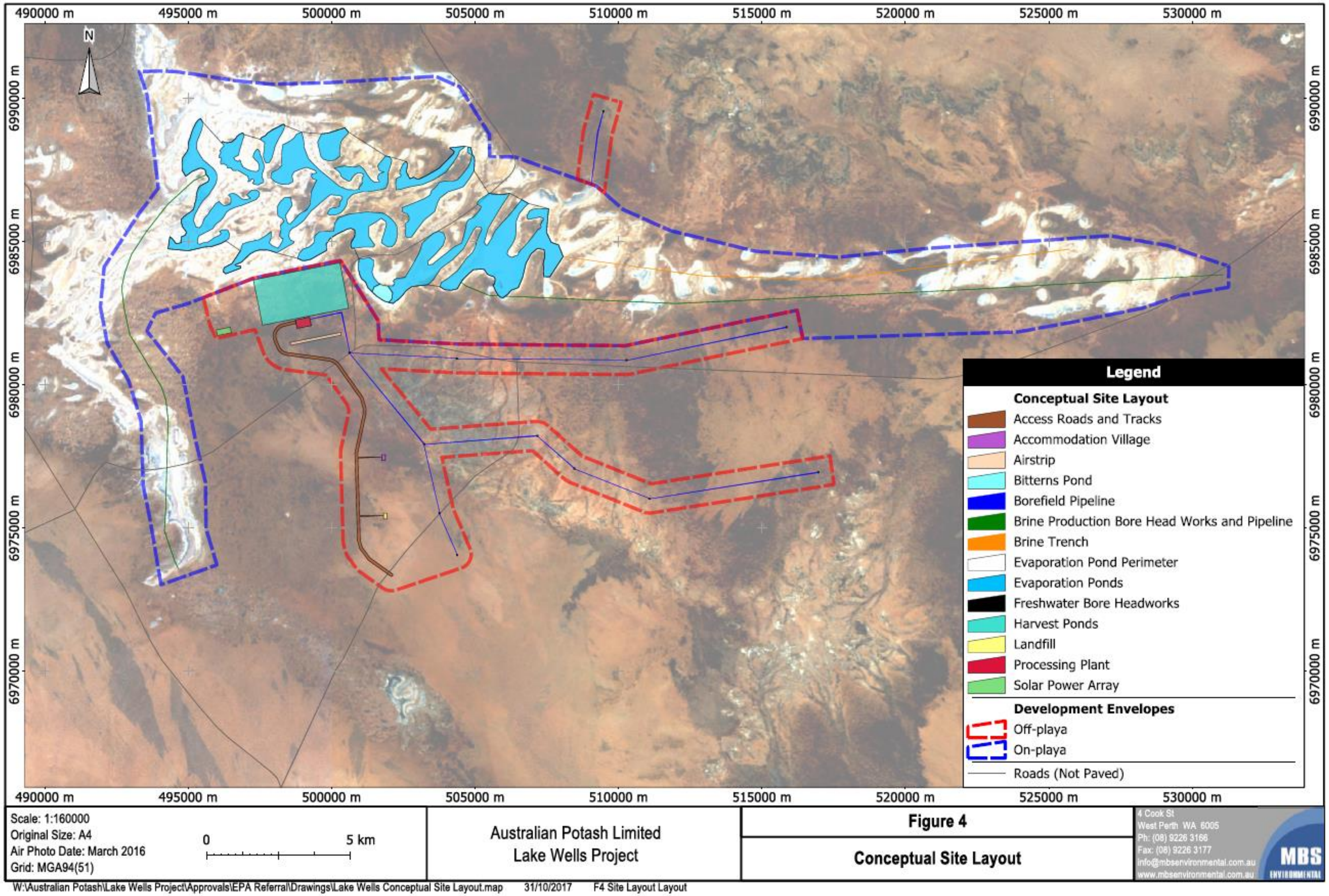

Figure 2. Conceptual site layout and development envelopes (off-playa and on-playa) of the Project (provided by MBS Environmental).

2.2. Sampling Dry Wetlands

Sampling surface water in ephemeral wetlands is not always practical because of sporadic, unpredictable flow regimes and logistical constraints. This is the case at Lake Wells, which is rarely inundated due to low rainfall and high rates of evaporation. However, some aquatic invertebrates survive adverse environmental conditions through various mechanisms of dormancy, reactivating with the onset of favourable conditions (Radzikowski 2013). This means hatching trials, in which dry wetland sediments are rehydrated under laboratory conditions to encourage hatching of drought-resistant eggs and spores, provide an alternative method of assessing aquatic invertebrate communities. Hatching trials enable monitoring to continue during periods when surface water is absent, although it provides results for only part of the community (some crustacean groups and rotifers, in particular).

A number of hatching trials have been undertaken in arid regions of Western Australia to inform environmental approval processes for mining developments or as part of ecological monitoring programs (e.g. Bennelongia 2012, 2016; Rodman et al. 2016). The success of these trials has varied owing to the technical difficulties of simulating complex natural conditions and encouraging the activation and growth of dormant stages in the laboratory (see Cáceres and Schwalbach 2001). Although improved techniques may lead to diverse suites of fauna being recorded in laboratory hatching trials, it is noted that *in situ* sampling of aquatic fauna during inundation is likely to yield a more thorough representation of actual diversity.

3. METHODS

3.1. Sampling Effort

Nine wetland sites in and around the Lake Wells system were sampled for aquatic biota between 4 and 7 March 2017. Sites included very shallow hypersaline pools in saline playas, freshwater pools in claypans and dry playas. Sites were classified as 'internal', 'peripheral' or 'external' based on their position relative to the proposed evaporative pond network (Table 2; Figure 3). Internal sites are all hypersaline playa sites that will be included within the evaporative pond network. The peripheral site LW5 is in a small hypersaline playa outside the proposed pond system but it is sufficiently close to the pond system that it is likely to experience additional salinity. The external LW7 is a hypersaline playa site that will not be affected by the proposed evaporative ponds, while the other external sites are in surrounding swales and can be regarded as fresh or hyposaline pans.

The aquatic invertebrate fauna at dry sites (LW7, 8, 9) was sampled by collecting lake sediments for laboratory hatching trials (Section 3.2). *In situ* water quality parameters (temperature, pH and electrical conductance) were measured at wet sites using a calibrated TPS WP-81 field meter. A summary of sampling effort is provided in Table 2. Site locations are shown in Figure 3 and full site descriptions and photographs are given in Appendix 1.

3.2. Aquatic Invertebrates and Hatching Trials

At sites holding surface water, aquatic invertebrates were collected *in situ* by kick-sweep sampling through all available habitat types with pond nets. Two mesh sizes (50 µm and 250 µm) were used to optimise sampling efficiency with the objective of collecting all species present at each site. Additional targeted collections were made by hand, pipette or pond net for scarce, conspicuous or fast-moving taxa. Observations of perished aquatic invertebrates were made at dry sites and on the outskirts of wet sites. These observations were included in final estimates of richness (number of species), but did not contribute to abundance values. Samples were preserved in ethanol, refrigerated and freighted to the laboratory where they were sorted under dissecting microscopes and identified using available taxonomic keys.

Table 2. Summary of sampling effort, water chemistry and sampling methods at each wetland site at Lake Wells in March 2017.
Sites for which no water chemistry data are presented were dry at the time of survey.

Site	Latitude	Longitude	Position	Description	Temp. (°C)	pH	EC (µS/cm)	Depth (mm)	Invertebrates
LW1	-27.2678	123.0301	Internal	Hypersaline film in saline playa	26.6	6.49	195,200	5	*In situ*
LW2	-27.2733	123.0154	Internal	Hypersaline film in saline playa	30.2	6.89	176,200	30	*In situ*
LW3	-27.2375	123.2444	External	Freshwater claypan pool	27.7	6.78	390	150	*In situ*
LW4	-27.2477	123.2102	External	Brackish claypan pool	28.0	7.44	2,990	100	*In situ*
LW5	-27.2653	122.9499	Periphery	Saline claypan pool	20.3	7.35	5,820	300	*In situ*
LW6	-27.2444	122.9837	Internal	Dry saline playa	-	-	-	-	Hatching trial
LW7	-27.2058	123.0381	External	Dry claypan	-	-	-	-	Hatching trial
LW8	-27.3282	122.9251	External	Freshwater claypan pool	20.3	6.27	48	100	*In situ*
LW9	-27.2538	123.0103	Internal	Dry saline playa	-	-	-	-	Hatching trial

Where surface water was absent, hatching trials were conducted to document aquatic invertebrate communities. The top 1–2 cm of sediment, including salt crust and underlying soil, was collected from multiple spots within each site and stored into plastic takeaway containers with lids perforated to allow airflow. Samples within each site were predominantly taken from depressions and potential pools to maximise the likelihood of capturing an adequate representation of the resting fauna present. In the laboratory, approximately 1 tbsp of sediment from each sample was placed in an aluminium tray and rehydrated with approximately 1 L of deionised water. Trays were kept under an east-facing window (approximately 12.2–12.3 h light per day) and equipped with air stones for aeration. Electrical conductance (EC) was measured in each container after 24 hours and water added as necessary to formulate an environment that would encourage hatching in a range of species, with the rationale that excessive salinity may preclude hatching in some fauna. Water was topped up every 1–2 days to account for evaporation and to maintain constant salinity. Hatching and development of animals was monitored daily by pipetting small volumes of water, as well as any visible animals, into petri dishes and examining the water and animals under a microscope. Trays were monitored for approximately two weeks or until additional hatchings ceased. Animals in each tray were then counted, preserved in ethanol and identified to species-level where possible.

3.3. Diatoms

Diatoms were sampled at each site by extracting the topmost benthic layer with a pipette (wet sites) or by scraping approximately 0.25 teaspoons of lake sediment (dry sites). The uppermost portion of salt crust was removed prior to sampling at dry sites. Samples were preserved in ethanol, refrigerated and freighted to Professor Peter Gell at Federation University, Victoria, for sorting and identification.

3.4. Avifauna

Surveys for waterbirds and shorebirds were undertaken at each sampling site using binoculars and spotting scopes. Fifteen minutes were allocated to observations at each site and additional opportunistic sightings made while other components of the biota, as well as during a stygofauna field trip in October 2017. Results from a related vertebrate fauna survey at Lake Wells (Harewood 2017) were also included.

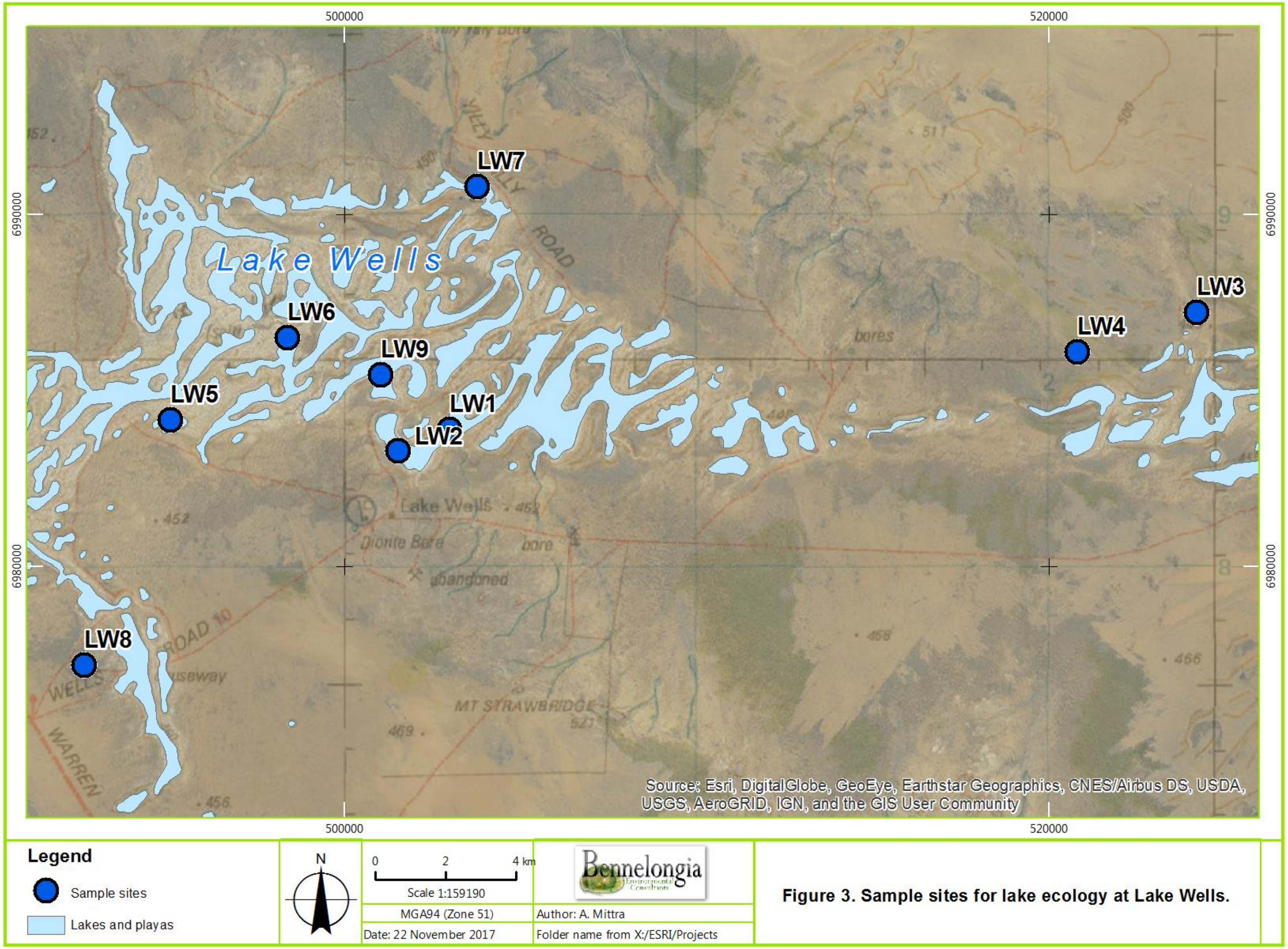

Figure 3. Location of sampling sites in and around Lake Wells in March 2017.

3.5. Aquatic Vegetation

Specimens of aquatic macrophyte species present were collected by hand from wet sites (and from dry sites where possible), preserved in ethanol or by pressing and identified using keys in Sainty and Jacobs (1994).

3.6. Personnel

Fieldwork was completed by Michael Curran and Anton Mittra. Hatching trials were run by Anton Mittra. Sorting of aquatic invertebrates was done by Jane McRae and identification by Jane McRae and Stuart Halse. Maps were compiled by Mike Scanlon and reporting was done by Anton Mittra.

4. RESULTS AND DISCUSSION

4.1. Aquatic Invertebrates and Hatching Trials

Aquatic invertebrate sampling yielded 1,528 specimens from at least 64 species (Table 3). Actual species richness is likely to exceed estimated richness because some taxa (e.g. Nematoda sp.) could not identified to species-level and may represent several species. To avoid artificial inflation, higher-order identifications were not included in final estimates of species-richness unless they belonged to otherwise unrecorded taxonomic units.

With the exception of the terrestrial salt lake tiger beetle *Megacephalini* sp. (one individual at LW5), all recorded species are aquatic. *Megacephalini* sp. is included in this report because of its potential, but uncertain, conservation significance. The systematics of the carabid tribe Megacephalini is under ongoing review and many species are salt lake specialists that appear to be range restricted (N. Guthrie, pers. comm. October 2017; López-López et al. 2016). Recent studies have revealed considerable cryptic diversity (McCairns et al. 1997; Sumlin 1997; López-López et al. 2016). Genetic work would be required to determine the identity of the specimen from Lake Wells.

Hatching trials contributed only a small amount to documenting the overall aquatic invertebrate abundance and richness at Lake Wells, with a total of 61 animals of eight species being recorded in sediment samples from three sites (LW1, LW7 and LW9). Species of rotifer, nematode, cladoceran and ostracod hatched. Two species, the rotifer Bdelloidea sp. 2:2 and the cladoceran *Alona rigidicaudis* s.l., were only recorded in hatching trials.

Major higher-level groups that were recorded included flatworms (Platyhelminthes: Turbellaria), rotifers (Rotifera), roundworms (Nematoda), crustaceans (Crustacea) and insects (Insecta). Crustaceans were the most diverse group at the rank of order, with seven orders recorded: brine shrimp (Anostraca), clam shrimp (Conchostraca), water fleas (Diplostraca: Cladocera), shield shrimp (Notostraca), calanoid copepods (Calanoida), cyclopoid copepods (Cyclopoida) and seed shrimp (Ostracoda). Crustacea were considerably diverse at species level, with at least 21 species recorded. However, insects were the most speciose group with 24 species belonging to four orders. The most abundant taxa were seed shrimps (525 specimens across eight sites); larvae of the non-biting midge *Procladius* (*Procaldius*) *paludicola* (Chironomidae; 119 specimens across four sites); larvae of the biting midge *Monohelea* sp. (Ceratopogonidae; 102 specimens across four sites); and the diving beetle *Allodessus bistrigatus* (Dytiscidae; 72 specimens across two sites). Twelve species were recorded as singletons (Table 3).

Although the current survey of Lake Wells is unlikely to have captured all aquatic invertebrate species that use the system during flooding, the species collected probably provide a reasonably complete characterisation of the aquatic invertebrate community at Lake Wells. It is a community with a species richness towards the higher end of the documented spectrum of richness at inland Australian salt lakes Table 4). The high richness is largely attributable to the inclusion of a number of substantial ephemeral

Table 3. Aquatic and semi-aquatic invertebrates recorded in surface water sampling at Lake Wells.
Int =internal saline site within proposed evaporative ponds; Peri = peripheral saline site likely outside ponds but likely to be impacted by higher salinity; Ext = external relatively fresh site away from ponds..
Values are absolute abundance. Higher-order identifications denoted by '*' were not included in final estimates of richness. Presence of a species based on visual observations of perished animals is denoted by '#'.

Higher Classification	Lowest Identification	Site									Total Abundance
		Int	Int	Ext	Ext	Peri	Int	Ext	Ext	Int	
		LW1	LW2	LW3	LW4	LW5	LW6	LW7	LW8	LW9	
Platyhelminthes											
Turbellaria	Turbellaria sp.		2			10					12
Rotifera											
Eurotatoria											
Bdelloidea	Bdelloidea sp. 2:2			10						5	15
Monogononta											
Flosculariacea											
Filiniidae	*Filinia longiseta*				10						10
Flosculariidae	Flosculariidae sp.				10						10
Testudinellidae	*Testudinella patina*				50						50
Ploima											
Asplanchnidae	*Asplanchna sieboldii*								50		50
Brachionidae	*Brachionus bidentatus*			5							5
	Brachionus ibericus		1								1
	Brachionus lyratus				50						50
	Brachionus plicatilis s.l.	2									2
	Brachionus rotundiformis	2	2								4
Dicranophoridae	*Dicranophorus grandis*					1					1
Lecanidae	*Lecane bulla*	1									1
	Lecane curvicornis					1					1
Lepadellidae	*Colurella* sp.					1					1
Synchaetidae	*Polyarthra dolichoptera*				3						3
Trichocercidae	*Trichocerca rattus*					2					2
	Trichocerca ruttneri				2						2
Nematoda	Nematoda sp.	1	2	10	2	1				5	21
Arthropoda											
Crustacea											
Branchiopoda											
Anostraca											
Branchiopodidae	*Parartemia laticaudata*		17								17
Conchostraca											
Cyzicidae	*Eocyzicus* sp. B01					2					2

Higher Classification	Lowest Identification	Site									Total Abundance
		Int	Int	Ext	Ext	Peri	Int	Ext	Ext	Int	
		LW1	LW2	LW3	LW4	LW5	LW6	LW7	LW8	LW9	
	Conchostraca sp. unident.*			1	1			#			2
Diplostraca											
Chydoridae	*Alona rigidicaudis* s.l.							1			1
	Ovalona pulchella							25			25
Macrothricidae	*Macrothrix breviseta*				40	1		17			58
Moinidae	*Moina micrura* s.l.								24		24
Neothricidae	*Neothrix* cf. *armata* (SAP)				2						2
Notostraca											
Triopsidae	*Triops australiensis australiensis*	#			4	#	#	#			4
Maxillopoda											
Calanoida											
Centropagidae	*Boeckella triarticulata*				40	2					42
	Calamoecia ampulla var. P1 (PSW)				15						15
Cyclopoida											
Cyclopidae	*Apocyclops dengizicus*	3				10					13
	Mesocyclops brooksi			50							50
	Mesocyclops sp.*								1		1
Ostracoda											
Cyprididae	*`Trilocypris horwitzi`* ms	18	100			100		1		1	220
	Bennelongia sp. BOS833 (*nimala* lineage)			5							5
	Bennelongia nr *koendersae*				100				1		101
	Bennelongia sp.*							1			1
	Cypretta sp. BOS822				35				3		38
	Cypretta sp. BOS829			50							50
	Cyprinotus kimberleyensis					4			20		24
	Cyprinotus sp. BOS830			1							1
	Ilyodromus sp. BOS821				35				5		40
Ilyocyprididae	*Ilyocypris australiensis (*Cue form *sensu* De Deckker)			40					5		45
Hexapoda											
Insecta											
Coleoptera											
Carabidae	*Megacephalini* sp. (salt lake floor species)					1					1
Dytiscidae	*Allodessus bistrigatus*			48					24		72
	Eretes australis			1	12						13
	Hydroglyphus grammopterus			21					3		24
	Hydroglyphus orthogrammus			1							1
	Sternopriscus multimaculatus			1							1

Higher Classification	Lowest Identification	Site									Total Abundance
		Int	Int	Ext	Ext	Peri	Int	Ext	Ext	Int	
		LW1	LW2	LW3	LW4	LW5	LW6	LW7	LW8	LW9	
Hydrophilidae	Berosus sp.					1					1
	Enochrus (Methydrus) elongatulus			8							8
Diptera											
Ceratopogonidae	*Monohelea* sp.	65	14	2		21					102
Chironomidae	*Cryptochironomus griseidorsum*					3					3
	Dicrotendipes `CA1` Pilbara type 2 (PSW)					1					1
	Polypedilum (Polypedilum) nubifer				1	1					2
	Polypedilum sp.*				2						2
	Procladius (Procladius) paludicola			33	15	50			21		119
	Tanytarsus fuscithorax/semibarbitarsus					40					40
Culicidae	*Anopheles annulipes* s.l.			1					5		6
Hemiptera											
Corixidae	*Agraptocorixa parvipunctata*			3							3
	Agraptocorixa sp.*			13							13
Notonectidae	*Anisops* sp.*			8							8
	Anisops thienemanni					5					5
Odonata											
Aeshnidae	*Anax papuensis*			3							3
Coenagrionidae	*Ischnura aurora aurora*			10							10
	Xanthagrion erythroneurum			29							29
Hemicorduliidae	*Hemicordulia tau*					12			1		13
Lestidae	*Austrolestes aridus*			7							7
	Austrolestes sp.*					1					1
Libellulidae	*Diplacodes bipunctata*			1		7					8
	Pantala flavescens					10					10
Total abundance		92	138	362	429	288	-	45	163	11	1528
Total no. of species		8	7	24	18	25	1	7	13	3	62

Table 4. Comparison of aquatic invertebrate species richness at inland Australian lakes.
Overall richness combines records within the main saline playa with surrounding claypans.

System	Location	Overall richness	Saline playa richness	Salinity ($\mu S\ cm^{-1}$)	Sites	Samples
Lake Disappointment[1]	Pilbara, WA	195	14	66-99,300	31	52
Lake Carey[2]	Goldfields, WA	107	10	313-83,300	31	66
Lake Wells	Goldfields, WA	64	10	48–195,200	9	9
Lake Torrens[3]	SA	27	27	20-391	5	25
Lake Eyre[4]	SA	17	17	39-427	1	15
Lake Weelarrana[5]	Pilbara, WA	14	14	59	1	1
Lake Cowan[6]	Wheatbelt, WA	7	6	184,000–234,000	4	4
Lake Way[7]	Goldfields, WA	3	3	Dry (hatching trial)	6	18

[1]Bennelongia 2017 [2]Timms *et al.* 2006; [3]Williams *et al.* 1998; [4]Williams and Kokkinn 1988; [5]Pinder *et al.* 2010; [6]Bennelongia 2016; [7]Bennelongia 2016c.

pools in the sampling program, in addition to the two sites within the main network of the saline playa where a remnant film of water remained (Table 2; Figure 3). When only the internal sites are considered, richness within Lake Wells (10) is exceeded by Lake Torrens, Lake Eyre and Lake Weelarrana, which were much fresher than Lake Wells and were sampled more intensively (Table 4). The species richness of the main saline playa at Lake Wells is typical of large saline playa with that salinity level (approximately 180,000 $\mu S\ cm^{-1}$) (see Pinder et al. 2004)

4.1.1. Patterns in Aquatic Invertebrate Communities

Species richness at individual sites ranged from one species at the dry internal, hypersaline site LW6, which was sampled by hatching trial, to at least 24 species at the fresher subsaline site LW4 and hyposaline site LW5 (Table 3). Salinity categories of Beadle (1943) are used.

The occurrence of species in the Lake Wells system exhibits considerable spatial heterogeneity, with 47 species (78.3%) recorded at single sites, only four species (6.67%) recorded at four sites or more and no species recorded at more than seven sites (Figure 4). It should be recognised, however, that this hetero-

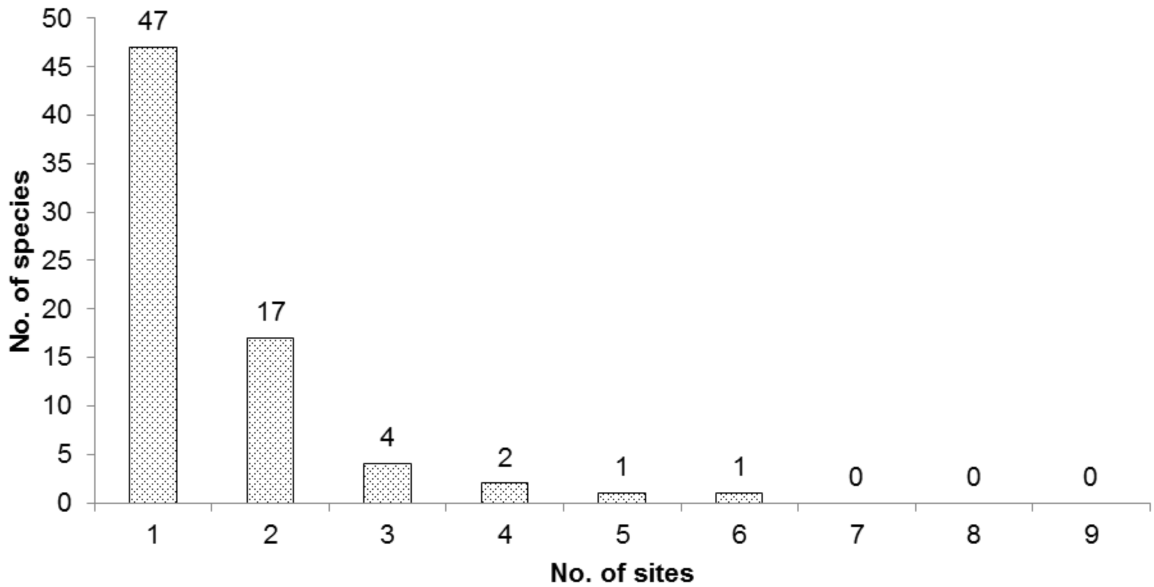

Figure 4. Frequency of occurrence of aquatic invertebrate species across sampling sites in and around Lake Wells.

geneity was probably somewhat accentuated by survey conditions and the range of wetland types. Dry sites yielded low species richness (one, three and six species at LW6, LW7 and LW9 respectively) in hatching trials, although when flooded these sites probably have richness that is comparable to other similar sites. Use of hatching trials to estimate the actual diversity species richness of wetlands (or even relative richness) provides valuable data when sites are dry but the results are inconsistent and underestimate richness. Groups, such as insects, that do not produce resting stages are not recorded and even some crustacean groups hatch poorly.

Inland, ephemeral saline playas in Western Australia are typically considered to host relatively depauperate invertebrate faunas (Table 4). Consistent with this trend, only 1-9 species were recorded at sites within the saline playas at Lake Wells (i.e. those within the main salt lake system - LW1, LW2, LW6 and LW9). The saline playa site LW7, which is outside the proposed evaporative ponds, yielded a similar number of species. These sites were typical of saline playa pools: shallow depressions on uniformly flat areas, with saline to hypersaline water quality and low habitat diversity. In contrast, the deeper (100–300 mm), fresher (390–5,820 µS cm^{-1}) sites LW3, LW4 and LW5, which had greater habitat diversity, including debris, organic matter and macrophyte cover, hosted richer invertebrate assemblages (18–25 species) (Table 2; Appendix 1).

4.1.2. Species Distributions

Most of the aquatic invertebrate species collected are widespread and common. Some species are endemic to central and north-western Australia, while others have Australia-wide or cosmopolitan distributions. Three species (*Eocyzicus* sp. B01, *Bennelongia* nr *koendersae*, *Bennelongia* sp. BOS833 [*nimala* lineage]) have probably been recorded to date only at Lake Wells.

The clam shrimp *Eocyzicus* sp. B01 was recorded from the peripheral site LW5, while additional higher-order clam shrimps (Conchostraca sp. unident.) that were too immature to identify to species level were collected at LW3, LW4 and LW7 (the latter were visual observations of perished animals). Salinity at these sites was variable (390–5,820 µS cm^{-1}; LW7 was dry). All of these sites occur in playas or claypans outside the areas proposed for the development of evaporation ponds. Two species of this genus are currently formally described, however genetic work has shown that at least eleven distinct genetic lineages, some of which may contain multiple species, occur in Australia. *Eocyzicus* sp. B01 is a new species, although it may possibly correspond with a previously collected genetic lineage. Some *Eocyzicus* species are likely to have restricted distributions (Schwentner et al. 2013). The nearest records of *Eocyzicus* are from Lake Carey, approximately 200 km south and these animals are considered to belong to a different species from those at Lake Wells (B. Timms, pers. comm.). It is expected that *Eocyzicus* sp. B01 occupies ephemeral pools throughout the Lake Wells system and may be more widely distributed.

The ostracod *Bennelongia* nr *koendersae* appears to be a new species known only from current records at Lake Wells. Other species in the genus have ranges that vary from being confined to isolated rock outcrop pools to being Australia-wide in the case of *Bennelongia dedeckkeri*. Considering the extensive ranges of most surface water ostracods, it is likely that *Bennelongia* nr *koendersae*, which belongs to the *nimala* lineage of *Bennelongia* species, is at least moderately widespread. This lineage contains five described species in the Pilbara and Murchison-Gascoyne (Martens et al. 2015). All species have known linear ranges of more than 100 km and it is expected that *Bennelongia* nr *koendersae* occurs in the parts of the Lake Wells system with suitable salinity, as well as more widely in the surrounding region. It was collected at LW4, which is outside the areas proposed for the development of evaporation ponds.

The ostracod *Bennelongia* sp. BOS833 (*nimala* lineage) is also likely to be a new species. As with *Bennelongia* nr *koendersae*, it is expected that *Bennelongia* sp. BOS833 (*nimala* lineage) occurs in the parts of the Lake Wells system with suitable salinity, as well as more widely in the surrounding region. It was recorded at LW3, which is outside the areas proposed for the development of evaporation ponds.

4.2. Diatoms

A total of 707 diatom specimens of 55 species were recorded across the nine sampling sites in the Lake Wells system (Table 5; Appendix 2). All but three taxa (*Chaetaceros* sp., *Nitzschia* cf. *vasta*, *Seminavis* sp.) could be assigned to described or figured species (e.g. *Nitzschia* cf. *hantzschiana*) and the affinity of *Nitzschia* cf. *vasta* is clear. All the described species are relatively widespread. *Seminavis* sp. is known only from the Project impact area at site LW1 but the distribution pattern of the other diatom species it is likely to be more widespread than the Lake Wells system (and certainly to occur beyond the Project impact area).

The number of species at individual sites ranged from three species at LW7 to 21 at LW4. Somewhat surprisingly, there was not a clear inverse relationship between richness and salinity as is commonly observed for diatom assemblages and 37 species were recorded in the main saline playa network, 17 species were recorded from intermediate sites and 34 species were recorded at sites external to the main network.

Lake Wells supports a comparatively rich assemblage of diatom species. Lakes in the Wheatbelt of Western Australia have yielded 1–24 species (51 sites, ca. 203–241,000 µS cm^{-1}; Taukulis and John 2006), while 33 taxa were recorded at Lake Eyre (ca. 39,100–391,000 µS cm^{-1} when wet; Blinn 1991). Other large salt lakes in inland north-western Australia have been sampled via hatching trials that have yielded substantially fewer species with, for example, seven species recorded at Lake Austin (Rodman et al. 2016) and 13 species at Lake Way near Wiluna (Bennelongia 2016a).

A range of ecological indicator species were recorded (Table 6; Appendix 1), including nine acidophiles, five aerophiles species (requiring frequent wetting and drying cycles), six nitrophiles and seven halophiles. The distribution of ecological indicator species generally reflected known habitat characteristics of the waterbodies at Lake Wells, with higher numbers of halophiles and aerophiles within the main saline playa indicating higher salinity and less inundation.

Table 5. Summary of diatom abundance and richness across sampling sites at Lake Wells.

Site	EC (µS cm^{-1})	Total Abundance	Total No. of Species
LW1	195,200	203	17
LW2	176,200	11	8
LW3	390	72	13
LW4	2,990	145	21
LW5	5,820	65	17
LW6	dry	103	17
LW7	dry	29	3
LW8	48	41	11
LW9	dry	38	12
Total		707	55

Table 6. Distribution of ecological indicator species of diatom in and around Lake Wells.

Ecology	Site Position		
	Internal	Intermediate	External
Acidophile	7	2	6
Aerophile	4	2	3
Nitrophile	3	1	3
Halophile	6	5	3

4.3. Aquatic Vegetation

Two macrophytes, *Ruppia* sp. and *Marsilea* sp., were collected. It was not possible to identify either taxon to species level because of the absence of the fruiting bodies that are required for species identification. The observed abundance of macrophytes was also low, which is typical of inland saline lake systems.

Ruppia is a widespread genus of perennial aquatic herb. The genus is native but not endemic to Australia. Four Australian species are recognised (Jacobs and Brock 1982), all but one of which have been recorded in arid inland Western Australia (*Ruppia maritima*, *Ruppia megacarpa* and *Ruppia polycarpa*). The fourth species, *Ruppia turbosa*, is seemingly confined to coastal and inland-southwestern waters. *Ruppia* species occur in fresh to hypersaline waters and are frequently recorded in salt lake assessments, including hatching trials (Rodman et al. 2016). In the current study, *Ruppia* sp. was recorded at LW2 and also at LW7 in hatching trials. It is likely to also occur at other sites and throughout the Lake Wells system.

Marsilea is a widespread but relatively uncommon native aquatic fern with clover-shaped leaves (Sainty and Jacobs 1994). Seven species occur in Australia, four of which have been recorded in inland Western Australia (*Marsilea drummondii*, *Marsilea exarata*, *Marsilea hirsuta* and *Marsilea mutica*). During the current survey *Marsilea* sp. was recorded at the small, muddy, freshwater claypan at LW8.

4.4. Avifauna

Five species of waterbird or shorebird were observed at three sites during survey in March 2017 and October 2017 (Table 7). The low number of sightings reflects conditions at the time of survey, with most saline playas being dry or covered in only a thin film of water. Species present during survey were grey teal, white-necked heron, red-capped plover, black-tailed native-hen and Australian shelduck. All observed species occur across Australia, are common at ephemeral inland lakes and have secure conservation status.

Table 7. Waterbirds observed during survey at Lake Wells by Bennelongia.

Species	Common Name	Sites (abundance)	Comments
Anas gracilis	Grey teal	LW5 (5)	Foraging/swimming on saline pool
Ardea pacifica	White-necked heron	LW5 (1)*	Foraging in fresh claypan pool
Charadrius ruficapillus	Red-capped plover	LW1 (2), LW5 (15)	Foraging at edges of pools and amongst fringing samphire
Gallinula ventralis	Black-tailed native-hen	LW3 (3)*	Foraging in fresh claypan pool
Tadorna tadornoides	Australian shelduck	LW5 (2)	Foraging/swimming on saline pool

*Recorded in October 2017 during stygofauna survey.

An independent two-phase fauna survey by Harewood (2017) recorded a further eleven species of waterbird and shorebird including chestnut teal *Anas castanea*, Australian wood duck *Chenonetta jubata*, black swan *Cygnus atratus*, pink-eared duck *Malacorhynchus membranaceous*, hoary-headed grebe *Poliocephalus poliocephalus*, white-faced heron *Ardea novaehollandiae*, marsh sandpiper *Tringa stagnatilis*, black-winged stilt *Himantopus himantopus*, red-knecked avocet *Recurvirostra novaehollandiae*, red-kneed dotterel *Erythrogonys cinctus* and banded lapwing *Vanellus tricolor*. The total number of waterbird and shorebird species recorded at Lake Wells by Bennelongia and Harewood (2017) is 16. To the north of Lake Wells, the Lake Carnegie System is recognised as a wetland of national significance due to its importance as a breeding site for the black swan *Cygnus atratus*, as well as 23 other waterbird species (Cowan 2001).

The marsh sandpiper *Tringa stagnatilis* was recorded by Harewood (2017) at a large freshwater lake near the northwest boundary of the Project area in April 2017. This species is not threatened, but as a migratory shorebird, is listed under the WC Act (Schedule 5) and international agreements. It probably only occurs in wetland areas of the Project after significant rainfall events. It has also been noted (Harewood 2017) that several other migratory waders, all of which breed in the northern hemisphere, have the potential to occur at Lake Wells but that the presence of suitable habitat relies on unpredictable, episodic rainfall.

Overall, a moderate number of waterbird and shorebird species have been recorded at Lake Wells, with observations coming predominantly from fresher claypans surrounding the main saline playa system. Water levels in the main saline playa system were low during all survey events, so that the significance of the main playa for waterbirds and shorebirds remains uncertain. Significant use of the playa system by waterbirds and/or shorebirds would certainly be limited to periods after heavy rainfall and subsequent flooding (e.g. Lane and Chapman 2001).

5. CONCLUSIONS

This study aimed to determine the ecological values of Lake Wells including the compositions of aquatic invertebrate, diatom, macrophyte and waterbird communities. Given that the ecologies of episodic inland lakes vary greatly according to the stage of the hydrocycle when the system is sampled, assessments of the values of lake systems often contain a considerable element of uncertainty and this is the case with Lake Wells.

The nine sites sampled in the Lake Wells system included very shallow hypersaline pools in saline playas, freshwater pools in claypans and dry playas. Salinity ranged from fresh (external claypan pools) to hypersaline (main saline playas). pH values ranged from mildly acidic to circumneutral.

The March 2017 survey took place relatively soon after significant rainfall in January and February and the aquatic invertebrate, diatom and macrophyte results are considered likely to provide a reasonable snapshot of the value of the lake for these components of its ecology. By the time survey occurred, the value of the main saline playa system for waterbirds and shorebirds was low. However, combining results of this and other surveys showed that a moderate number of waterbird and shorebird species use the fresher surrounding claypans after rainfall.

At least 64 invertebrate species of aquatic invertebrates were collected. The higher-level groups recorded were flatworms, rotifers, roundworms, crustaceans and insects. Crustaceans were the most diverse of these groups, with 21 species collected that encompassed seven orders recorded (brine shrimps, clam shrimps, water fleas, shield shrimps, calanoid copepods, cyclopoid copepods and seed shrimps). Insects were the most speciose group, however, with 24 species from four orders (beetles, flies, true bugs, and dragon- and damselflies). Lake Wells appears to have a rich invertebrate fauna compared with most other inland saline playa systems, although comparisons between studies need to take account of differences in conditions at the time of sampling, scope and sampling methods.

Most of the invertebrates collected belong to widespread species. Collection of three species at Lake Wells may possibly represent the first time these species have been recorded. They are the clam shrimp *Eocyzicus* sp. B01 and ostracods *Bennelongia* nr *koendersae* and Bennelongia sp. BOS833 (*nimala* lineage). It is considered likely that the ranges of all three species extend beyond the Lake Wells system.

The 55 diatom species collected in the Lake Wells system also appear to represent a relatively rich assemblage for an inland saline playa system. There was not a clear inverse relationship between richness and salinity, as is commonly observed for diatom assemblages, with 37 species recorded from sites in the main saline playa. All species are likely to be widespread.

Two species of aquatic macrophyte, *Ruppia* sp. and *Marsilea* sp., were collected. It was not possible to identify either taxa to species-level due to the absence of fruiting bodies that are required for further identification.

Only three species of waterbird (grey teal, red-capped plover and Australian shelduck) were seen in March 2017 but white-necked heron and black-tailed native-hen were recorded in October 2017 during a stygofauna survey by Bennelongia. A two-phase vertebrate survey recorded an additional 11 species. All the waterbird and shorebird species recorded at Lake Wells are widespread and are frequently recorded at inland saline lakes. Indications were that the period of significant inundation was too short to support much, if any, waterbird breeding in early 2017 and whether the system occasionally has high waterbird values after flooding is unknown. All recorded species are widespread.

Overall, the wetland conservation values of Lake Wells appear to be relatively high but all (or nearly all) recorded species are widespread and have ranges extending well beyond the Lake Wells system. Rather than hosting rare or endemic species, the principal ecological value of Lake Wells is the episodic occurrence of an abundant and speciose biota.

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7. APPENDICES

Appendix 1.

Photographs and descriptions of sampling sites at Lake Wells in March 2017.

LW1

Location: -27.2678, 123.0300
Water depth: 5 mm
Invertebrate sample: *in situ*
Temperature: 26.6
EC: 195,200 $\mu S\ cm^{-1}$
pH: 6.49
Position: Internal
Description: Transient hypersaline film on salt lake playa

LW2

Location: -27.2733, 123.0154
Water depth: 30 mm
Invertebrate sample: *in situ*
Temperature: 30.2
EC: 176,000 $\mu S\ cm^{-1}$
pH: 6.89
Position: Internal
Comments: Transient hypersaline film on salt lake playa

LW3

Location: -27.2375, 123.2444
Water depth: 150 mm
Invertebrate sample: *in situ*
Temperature: 27.7
EC: 390 $\mu S\ cm^{-1}$
pH: 6.78
Position: External
Comments: Freshwater claypan pool

LW4

Location: -27.2477, 123.2102
Water depth: 100 mm
Invertebrate sample: *in situ*
Temperature: 28.0
EC: 2,990 $\mu S\ cm^{-1}$
pH: 7.44
Position: External
Comments: Brackish claypan pool

LW5

Location: -27.2653, 122.9499
Water depth: 300 mm
Invertebrate sample: *in situ*
Temperature: 20.3
EC: 5,820 $\mu S\ cm^{-1}$
pH: 7.35
Position: Intermediate
Comments: Saline claypan pool

LW6

Location: -27.2443, 122.9836
Water depth: dry
Invertebrate sample: *in situ*
Temperature: -
EC: -
pH: -
Position: Internal
Comments: Dry salt lake playa

LW7

Location: -27.2056, 123.0381
Water depth: dry
Invertebrate sample: *in situ*
Temperature: -
EC: -
pH: -
Position: Intermediate
Comments: Dry claypan playa

LW8

Location: -27.3282, 122.9251
Water depth: 100 mm
Invertebrate sample: *in situ*
Temperature: 20.3
EC: 48 $\mu S\ cm^{-1}$
pH: 6.27
Position: External
Comments: Freshwater claypan pool

LW9

Location: -27.2538, 123.0103
Water depth: dry
Invertebrate sample: *in situ*
Temperature: -
EC: -
pH: -
Position: External
Comments: Dry salt lake playa

Appendix 2. Distribution of diatom species at Lake Wells.

Ecological classifications: Ac= acid indicator; Ae= aerophilous (frequent wet sediment); N= nutrients; S = high salinity (P. Gell, pers. comm., June 2017).

Species	Ecology	LW1	LW2	LW3	LW4	LW5	LW6	LW7	LW8	LW9	Abundance	No. of sites present
Actinocyclus sp.				3							3	1
Amphora borealis	S	10	2		1	1					14	4
Amphora coffeaeformis	S			1							1	1
Amphora subcapitata					1						1	1
Aulacoseira alpigena						1	5	4	1	2	13	5
Brachysira styriaca	Ac		1			5	4		2		12	4
Chaetoceros sp.	S	2							1		3	2
Craticula cuspidata				2							2	1
Craticula halophila		1			6						7	2
Encyonema silesiaca		1									1	1
Eolimna minima	N	2									2	1
Eunotia bilunaris	Ac									1	1	1
Eunotia exigua	Ac									1	1	1
Eunotia minor	Ac	2					1				3	2
Fragilaria tenera									1		1	1
Frustulia rhomboides	Ac	1			3	2	6	2	4	3	21	7
Gomphonema gracile										3	3	1
Hantzschia amphioxys	Ae	1		6	9						16	3
Hantzschia petitiana	S						47				47	1
Hantzschia virgata	Ae					2					2	1
Luticola mutica	Ae, N			6	7	1	2				16	4
Luticola muticopsis	Ae, N						1				1	1
Mayamaea atomus	N				1						1	1
Navicula incertata	S	43	1			8					52	3
Navicula leptostriata		7	1	12	13	6	13	23	20	20	115	9
Navicula krasskei					2					2	4	2
Navicula cf *molestiformis*		14		8					1		23	3
Navicula perminuta	S	11				7	4				22	3
Navicula cf *pseudobryophila*									3	1	4	2
Navicula recens						1					1	1
Navicula salinicola	S	77	1			1	1				80	4
Navicula subtillissima										1	1	1
Navicula tenelloides	S					9					9	1
Nitzschia commutata			1		5	1					7	3

Species	Ecology	LW1	LW2	LW3	LW4	LW5	LW6	LW7	LW8	LW9	Abundance	No. of sites present
Nitzscchia graciliformis					1						1	1
Nitzschia cf *hantzschiana*				1							1	1
Nitzschia palea	N			6	3						9	2
Nitzschia paleaceae					8						8	1
Nitzschia sociabilis					7						7	1
Nitzschia tubicola	N	1			4						5	2
Nitzschia cf *vasta*		8									8	1
Pinnularia appendiculata	Ac				3						3	1
Pinnularia borealis	Ae			1	5		1				7	3
Pinnularia divergentissima	Ac				2						2	1
Pinnularia microstauron						11				2	13	2
Pinnularia subcapitata	Ac		3	5	39		1			1	49	5
Sellaphora laevissima							5				5	1
Sellaphora seminulum	N					6	3				9	2
Seminavis sp.		21									21	1
Stauroneis anceps comb.				18							18	1
Stauroneis obtusa					21					1	22	2
Staurosira subsalina			1	3	4	2	5		6		21	6
Staurosira venter							2		1		3	2
Stenopterobia delicatissima						1					1	1
Tabellaria flocculosa	Ac	1					2		1		4	3
Total Abundance		**203**	**11**	**72**	**145**	**65**	**103**	**29**	**41**	**38**	**707**	
Total No. of Species		**17**	**8**	**13**	**21**	**17**	**17**	**3**	**11**	**12**	**55**	