



Caravel Copper Project:
Aquatic Ecosystem Survey

Biologic Environmental Survey
Report to Caravel Minerals Ltd.
December 2021



DOCUMENT STATUS				
Version No.	Author	Review / Approved for Issue	Approved for Issue to	
			Name	Date
1	A. Riemer, M. Lythe	J. Delaney	M. Klvac	22/12/2021
2				
Final				

“IMPORTANT NOTE”

Apart from fair dealing for the purposes of private study, research, criticism, or review as permitted under the Copyright Act, no part of this report, its attachments or appendices may be reproduced by any process without the written consent of Biologic Environmental Survey Pty Ltd (“Biologic”). All enquiries should be directed to Biologic.

We have prepared this report for the sole purposes of Caravel Minerals (“Client”) for the specific purpose only for which it is supplied. This report is strictly limited to the Purpose and the facts and matters stated in it do not apply directly or indirectly and will not be used for any other application, purpose, use or matter.

In preparing this report we have made certain assumptions. We have assumed that all information and documents provided to us by the Client or as a result of a specific request or enquiry were complete, accurate and up to date. Where we have obtained information from a government register or database, we have assumed that the information is accurate. Where an assumption has been made, we have not made any independent investigations with respect to the matters the subject of that assumption. We are not aware of any reason why any of the assumptions are incorrect.

This report is presented without the assumption of a duty of care to any other person (other than the Client) (“Third Party”). The report may not contain sufficient information for the purposes of a Third Party or for other uses. Without the prior written consent of Biologic:

- a) This report may not be relied on by a Third Party; and
- b) Biologic will not be liable to a Third Party for any loss, damage, liability, or claim arising out of or incidental to a Third-Party publishing, using, or relying on the facts, content, opinions, or subject matter contained in this report.

If a Third Party uses or relies on the facts, content, opinions, or subject matter contained in this report with or without the consent of Biologic, Biologic disclaims all risk, and the Third Party assumes all risk and releases and indemnifies and agrees to keep indemnified Biologic from any loss, damage, claim, or liability arising directly or indirectly from the use of or reliance on this report.

In this note, a reference to loss and damage includes past and prospective economic loss, loss of profits, damage to property, injury to any person (including death) costs and expenses incurred in taking measures to prevent, mitigate or rectify any harm, loss of opportunity, legal costs, compensation, interest and any other direct, indirect, consequential, or financial or other loss.

TABLE OF CONTENTS

EXECUTIVE SUMMARY	7
1. INTRODUCTION.....	9
1.1 Background and objectives	9
1.2 Guidance	11
2 ENVIRONMENT	12
2.1 Biogeography.....	12
2.2 Hydrology.....	12
2.3 Climate.....	12
3 METHODS	14
3.1 Desktop assessment	14
3.2 Field survey	17
3.2.1 Survey team	17
3.2.2 Survey timing and weather.....	17
3.3 Sampling sites	18
3.4 Habitat	18
3.5 Water quality.....	18
3.6 Micro-crustacea	20
3.7 Macroinvertebrates	21
3.8 Fish	22
3.9 Waterbirds	23
3.10 Other aquatic fauna	23
3.11 Data analysis.....	23
3.11.1 Water quality.....	23
3.11.2 Invertebrates.....	24
3.11.3 Fish.....	25
4 RESULTS.....	26
4.1 Desktop assessment	26
4.2 Habitat assessment	29
4.3 Water quality.....	33
4.3.1 <i>In situ</i>	33
4.3.2 Nutrients	34
4.3.3 Dissolved metals	35
4.4 Aquatic invertebrates.....	36
4.4.1 Taxa composition and richness.....	36
4.4.2 Conservation significant invertebrate taxa	37
4.4.3 Patterns in aquatic invertebrate assemblages	39
4.5 Fish	41
4.6 Waterbirds	41

4.7 Other vertebrate fauna 42

5 DISCUSSION 43

5.1 Habitat Assessment..... 43

5.2 Water quality..... 43

5.3 Aquatic invertebrates 44

5.4 Fish 45

5.5 Other vertebrate fauna 45

5.6 Final remarks 46

6 REFERENCES 47

APPENDICES..... 50

FIGURES

Figure 1.1: Study Area and regional location..... 10

Figure 2.1: Surface drainage of the Study Area and surrounds. 13

Figure 3.1: Location of previous aquatic sampling sites within the Search Area..... 15

Figure 3.2: Total and long-term average monthly temperature (°C) and rainfall (mm)..... 17

Figure 3.3: Locations of aquatic ecosystem sampling sites..... 19

Figure 4.1: Location of conservation significant fauna records..... 28

Figure 4.2: Electrical conductivity (EC; mS/cm) recorded in this study. 33

Figure 4.3: Dissolved oxygen (DO, % saturation) recorded in this study. 34

Figure 4.4: pH recorded in this study. 34

Figure 4.5: Total N (left) and total P (right) concentrations..... 35

Figure 4.6: Concentrations of selected dissolved metals 36

Figure 4.7: Aquatic invertebrate composition and richness from each site. 37

Figure 4.8: Location of conservation significant fauna *Parartemia extracta*. 38

Figure 4.9: nMDS of aquatic invertebrate assemblages, with samples identified by salinity category. 2D stress was low (0.05). 39

Figure 4.10: nMDS of aquatic invertebrate assemblages, with samples identified by site type (within Study Area vs reference). 40

Figure 4.11: Abundance of western minnows by age class..... 41

TABLES

Table 3.1: Databases searched in the desktop review. 14

Table 3.2: Literature sources used for the desktop assessment. 16

Table 3.3: Site information and sample locations. 18

Table 3.3: Standard lengths (mm) used for each age class. 25

Table 4.1: Summary of aquatic habitats sampled, including site photos. 30

Table 4.2: DistLM results examining correlations between invertebrate assemblages and environmental data. 40

Table 4.3: Waterbirds recorded during the survey..... 41

APPENDICES

Appendix A: Default ANZECC & ARMCANZ (2000) water quality guidelines 50

Appendix B: Habitat results..... 52

Appendix C: Water quality results 53

Appendix D: Aquatic invertebrate taxonomic list..... 54

Appendix E: Fauna Taking (Biological Assessment) License..... 58

GLOSSARY

ALA	Atlas of Living Australia
BOM	Bureau of Meteorology
DBCA	Department of Biodiversity, Conservation and Attractions
DGV	Default guideline value
DO	Dissolved oxygen
DPIRD	Department of Primary Industry and Regional Development
EC	Electrical conductivity
EPA	Western Australian Environmental Protection Authority
EPBC Act	<i>Environment Protection and Biodiversity Conservation Act 1999</i>
LOD	Limit of detection

EXECUTIVE SUMMARY

Biologic Environmental Survey (Biologic) was commissioned by Caravel Minerals Limited (Caravel) to undertake an aquatic ecosystem assessment of the lakes and claypans within and surrounding the Caravel Copper Project (hereafter referred to as the Study Area), located approximately 120 km north of Perth and 12 km south-west of Wongan Hills, in the Wheatbelt of WA. Aquatic ecosystem surveys were undertaken at nine sites, six within the Study Area, and three reference sites located outside the Study Area. Sampling was undertaken in September 2021. Surveys included habitat assessments and sampling of water quality, submerged macrophytes, aquatic invertebrates (including micro-crustacea) and fish. Methods followed those used in similar surveys, including the Western Australian Salinity Action Plan (WA SAP).

The Study Area comprises a number of brackish and salt lakes amongst open *Casuarina* sp. overstorey with samphire (saltbush) shrubs in the middle-storey. In-stream habitat diversity was higher in brackish sites compared to hypersaline sites, comprising complex heterogeneous substrates which provide better conditions with which to support aquatic fauna.

Water quality within the Study Area was characterised by brackish to hypersaline waters, with wide ranging dissolved oxygen saturation, circum-neutral to basic pH, and low dissolved metal concentrations. Total nitrogen (total N) and total phosphorus (total P) were variable across sites.

A total of 88 aquatic invertebrate taxa (including invertebrates and micro-crustacea) was recorded during the current study. Aquatic invertebrate composition was found to be related to salinity, with brackish sites recording the highest richness and diversity of aquatic invertebrates (20-39 taxa) and the most hypersaline site recording the lowest (six taxa). While most aquatic invertebrates were common, ubiquitous species, three species were considered to be of conservation or scientific significance including:

- the ostracod *Reticypriis* sp. (at CP05) is undescribed and likely to be new to science.
- the ostracod *Australocypris* sp. n. (at CP05, LN01 and LH01) is also potentially new to science.
- the fairy shrimp, *Parartemia extracta* (CP05, LH01 and an un-named wetland within the Study Area) is known from few populations (five).

Overall, there was a significant difference in aquatic invertebrate assemblages between saline and brackish sites, but not between Study Area and reference sites.

One native freshwater fish species, the western minnow *Galaxias occidentalis*, was recorded from two brackish sites within the Study Area (CP02 and CP03). The western minnow is a common and widespread species endemic to the south-west with a relatively high salinity tolerance. Site CP03 supported the highest abundance of western minnows, with 689 individuals recorded. More than half (52%) of the total fish population recorded were juveniles, indicating that the Study Area supports conditions conducive to breeding and recruitment. Although not a species of conservation significance, these records from the Wheatbelt are important given there are few populations of freshwater fish remaining in the region.

Eleven species of waterbird were recorded utilising sites within the Study Area, with the greatest richness at CP03 (eight taxa), followed by CP04. A large (10,000 individuals) feeding flock of banded stilt (*Cladorhynchus leucocephalus*) was also recorded at Lake Ninan. Two sites (CP03 and CP04) supported at least two frog species, including the banjo frog (*Limnodynastes dorsalis*).

Due to the widescale land clearing in the Wheatbelt, wetlands show varying degrees of salinity and degradation. As such, fresher wetlands and those not impacted by secondary salinisation are of particular ecological significance. The brackish sites sampled in the current study were found to support relatively rich aquatic invertebrate assemblage compared to hypersaline sites, as well as frogs, waterbirds and fish.

This study represents the first comprehensive aquatic ecosystem survey undertaken of the lakes and wetlands within and surrounding the Caravel Copper Project. Results from this survey provide an assessment of the current ecological values and health of aquatic systems within this Study Area.

1. INTRODUCTION

1.1 Background and objectives

Biologic Environmental Survey (Biologic) was commissioned by Caravel Minerals Limited (Caravel) to undertake an aquatic ecosystem assessment for the Caravel Copper Project (the Project). The lakes and claypans within and surrounding the Project were targeted for survey (hereafter referred to as the Study Area; Figure 1.1). The Study Area is located approximately 120 km north of Perth and 12 km south-west of Wongan Hills, in the Wheatbelt of Western Australia.

The overarching objective of the survey was to identify the aquatic fauna within salt lakes and claypan wetlands which have the potential to be impacted by the Project, and to determine the associated ecological values of aquatic fauna and habitats that may need to be considered for planning and environmental impact assessment (EIA).

The scope of works included:

- Assessment of key aquatic habitats in the vicinity of the Caravel Copper Project, including information on any historical changes to these habitats as a result of current land practices (such as salinisation);
- Undertake assessments of water quality (*in situ*, ions, nutrients, metals), aquatic habitat and aquatic fauna (fish and aquatic invertebrates) at appropriate sampling sites;
- Identification of all fauna specimens to lowest practicable level (species-level where possible);
- Assessment of the conservation status of the aquatic fauna recorded, with details of any listed or potential short-range endemic (SRE) species; and
- Analysis of spatial variability in the systems.

Figure 1.1: Study Area and regional location.

1.2 Guidance

Key environmental legislation and regulation relating to aquatic ecosystems include:

- Environmental Factor Guideline, Inland Waters (EPA, 2018);
- *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) (Cwlth);
- *Biodiversity Conservation Act 2016* (WA) (BC Act); and
- *Rights in Water and Irrigation Act 1914* (WA) (RIWI).

For the purposes of EIA, the Environmental Protection Authority (EPA) defines Inland Waters as:

“The occurrence, distribution, connectivity, movement, and quantity (hydrological regimes) of inland water including its chemical, physical, biological and aesthetic characteristics (quality)” (EPA, 2018).

The objective of the Inland Waters Environmental Factor is “to maintain the hydrological regimes and quality of groundwater and surface water so that environmental values are protected” (EPA, 2018). The EPA is primarily focused on impacts to significant ecosystems. In relation to the Pilbara, significant ecosystems include, (but are not limited to):

- Wetlands listed in the Directory of Important Wetlands in Australia;
- Wetlands protected by Environmental Protection Policies under Part III of the Environmental Protection Act 1986;
- Wild rivers, as identified by the Australian Heritage Commission and Department of Water and Environmental Regulation;
- Wetland types which may be poorly represented in the conservation reserves system;
- Springs and pools, particularly in arid areas;
- Ecosystems which support significant flora, vegetation and fauna species or communities, including migratory waterbirds, bats, and subterranean fauna; and,
- Ecosystems which support significant amenity, recreation, and cultural values.

There is currently (December 2021) no technical guidance applicable to the Inland Waters Environmental Factor; however, this survey was carried out in accordance with EPA guidelines and was consistent with the following:

- Environmental Factor Guideline, Inland Waters (EPA, 2018);
- Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZG, 2018);
- Technical Guidance, Sampling of Short-Range Endemic Invertebrate Fauna (EPA, 2016a);
- Technical Guidance, Terrestrial Fauna Surveys (EPA, 2016b);
- EPA Position Statement No. 3 Terrestrial Biological Surveys as an Element of Biodiversity Protection (EPA, 2002);
- Similar surveys, including the Western Australian Salinity Action Plan (WA SAP) (DPIRD, 1996).

2 ENVIRONMENT

2.1 Biogeography

The Study Area falls within the Avon-Wheatbelt biogeographical region as defined by the Interim Biogeographic Regionalisation of Australia (IBRA) (Thackway & Cresswell, 1995). The Avon-Wheatbelt bioregion, situated on the Yilgarn Craton is characterised by undulating landscapes of low relief on ancient lateritic uplands and derived sandplains (Thackway & Cresswell, 1995). Vegetation is predominantly mixed eucalypt, *Allocasuarina huegeliana* and Jam-York Gum woodlands on Quaternary alluvials and eluvials. There are two subregions within the Avon-Wheatbelt IBRA region, including the Merredin and Katanning subregions, of which the Study Area falls within the latter (Figure 1.1).

2.2 Hydrology

Agricultural land use within the Wheatbelt has resulted in significant hydrological imbalance as once perennial woodlands and shrubs were converted to annual crops (Clarke *et al.*, 2002). The flow on effect of rising water tables resulting in secondary salinisation of aquatic habitats is well documented (Halse *et al.*, 2004; Morgan *et al.*, 2003; Pinder *et al.*, 2004; Pinder *et al.*, 2005). The broad landscapes in the Wheatbelt are very flat and often filled with mosaics of saline, seasonally filled claypans/playas (Pinder *et al.*, 2004). Water levels are determined by a combination of surface run-off, subsurface flow and groundwater discharge as winter rains recharge aquifers (Pinder *et al.*, 2004). Most years, rainfall is insufficient to cause systems to flow, and the high rates of evaporation mean that many aquatic habitats are dry for much of the year. Although wetlands in the Wheatbelt are commonly saline, fresh and brackish wetlands can occur adjacent to highly saline systems. Such fresh systems provide an important refuge for freshwater aquatic fauna in the region.

The Study Area straddles two drainage catchments, Lake Ninan Catchment to the north and west, and Mortlock North Branch Catchment to the south and east (Figure 2.1). The ephemeral Lake Ninan lies within and adjacent to the Study Area, as do numerous smaller lakes (Figure 2.1). The Lake Ninan Catchment drains the surrounding area into Lake Ninan, which is managed as a Nature Reserve by the Department of Biodiversity, Conservation and Attractions (DBCA, 2019).

2.3 Climate

The climate of the Wheatbelt is semi-arid to warm Mediterranean, with hot dry summers and mild winters. Rainfall occurs predominately in the winter months, averaging 328 mm. Since the mid-1970s, the Wheatbelt has experienced significant decline in winter rainfall (Smith *et al.*, 2000). At the Bureau of Meteorology (BoM) Wongan Hills gauging station (number 008137), the average daily maximum temperature during summer is 33.8 °C, and average daily minimum is 17.3 °C. During winter, the average daily maximum is 17.8 °C and daily minimum is 7 °C.

Figure 2.1: Surface drainage of the Study Area and surrounds.

3 METHODS

3.1 Desktop assessment

A comprehensive desktop assessment was undertaken and reported separately (Biologic, 2021). The desktop assessment included a database search and literature review () to compile information on any aquatic species of conservation significance present or with the potential to be present, within the Study Area (Table 3.1, Table 3.2 and Figure 3.1). The literature review identified several surveys in the Wheatbelt which included aquatic ecosystem sampling to varying degrees (Biologic, 2021). While one study reported data for three named sites within the Search Area (Walyomourning Lake, Fraser Lake and Blue Gum Swamp) (Cale *et al.*, 2004), several other study sites which fell within the Search Area did not include site-specific species lists. As such, site-specific information was provided for three sites only, with general conclusions on community composition across the Search Area made for the remaining sites. Remaining sites included Boase’s Seep, Dambourning Lake, Mortijini NR Lake, Lake Ninan and Roach’s Lake (Blinn *et al.*, 2004). Other data sources referenced for the desktop assessment included the Australian Faunal Directory, and the Australian National Insect Collection Database.

Table 3.1: Databases searched in the desktop review.

Provider	Database	Reference	Search Area
Department of Biodiversity, Conservation and Attractions (DBCA)	NatureMap ¹	(DBCA, 2021a)	40 km radius centered on the coordinates: -30.8711° 116.5956°
Department of Agriculture, Water and Environment (DAWE)	Protected Matters Report	(DAWE, 2021)	80 km radius centered on the coordinates: -30.8711° 116.5956°
Atlas of Living Australia (ALA)	Species Occurrence	(ALA, 2021)	
Western Australian Museum (WAM)	Arachnids and Myriapods	(WAM, 2021a)	
	Crustaceans	(WAM, 2021b)	
	Molluscs	(WAM, 2021c)	

¹ NatureMap allows a maximum search radius of 40 km.

Figure 3.1: Location of previous aquatic sampling sites within the Search Area.

Table 3.2: Literature sources used for the desktop assessment.

Reference	Sites sampled	Sampling occasions	Sampling methods	Closest site to Study Area
Blinn et al. (2004) Diatom and micro-invertebrate communities and environmental determinants in the Western Australian wheatbelt: a response to salinisation	56 wetlands across the Wheatbelt region, including Dambouring Lake, Boase's Seep, Mortijini NR Lake, Lake Ninan and Roach's Lake located within the Search Area	Spring 1998 Spring 1999	Water Quality, Diatoms & Zooplankton	Lake Ninan (SPS159) <10 km from the Study Area
Cale et al. (2004) Wetland monitoring in the wheatbelt of south-west Western Australia: site descriptions, waterbird, aquatic invertebrate and groundwater data	25 wetlands across the Wheatbelt region, including Walyomourning, Fraser Lake and Blue Gum within the Search Area	Winter 1998 Spring 1998 Autumn 1999 Winter 2000 Spring 2000	Water Quality, Aquatic Flora, Fringing Vegetation, Waterbirds, Zooplankton & Macroinvertebrates	Walyomourning Lake 40 km from the Study Area
Pinder et al. (2004) Aquatic invertebrate assemblages of wetlands and river in the wheatbelt region of Western Australia	230 wetlands across the Wheatbelt region	Winter 1997 Winter 2000	Water Quality, Zooplankton & Macroinvertebrates	Lake Ninan <10 km from the Study Area
Lynas et al. (2006), ARL (2009) Buntine-Marchagee Natural Diversity Recovery Catchment (BMNDRC)	21 wetlands in the BMNDRC	Winter 2005 Winter 2006	Water quality, Habitat assessment, Zooplankton, Macroinvertebrates, Frogs, Waterbirds, Fish & Rehydrates	Catchment ~90 km north-west of the Study Area

3.2 Field survey

3.2.1 Survey team

The field survey was conducted by Biologic’s Senior Aquatic Ecologists Alex Riemer and Morgan Lythe, both with extensive experience undertaking aquatic ecosystem surveys in Western Australia. Fauna sampling for this survey was conducted under DBCA Fauna Taking (Biological Assessment Regulation 27) Licence BA27000505 issued to Jessica Delaney (Appendix E) and DPIRD Instrument of Exemption to the *Fish Resources Management Act 1994 Section 7 (2)* License EXEM3386 issued to Kim Nguyen. Macroinvertebrate fauna specimens were identified by Alex Riemer, Kim Nguyen, Siobhan Paget, and Vanessa Nici. Submerged macrophytes were identified by Morgan Lythe.

3.2.2 Survey timing and weather

The survey was undertaken between the 21st and 23rd of September 2021. Average maximum temperature for September 2021 (22.3°C) was higher than the long-term September average (20.8°C) for Wongan Hills (Bureau of Meteorology, station number 008137; Figure 3.2). Maximum daytime temperature reached 29.7°C during the survey period (BoM, 2021). In the months preceding the survey, Wongan Hills received 109.2 mm of rainfall in July, above the long-term average of 69.4 mm (Figure 3.2). September 2021 rainfall (11.8 mm) was below the monthly average (29.1 mm).

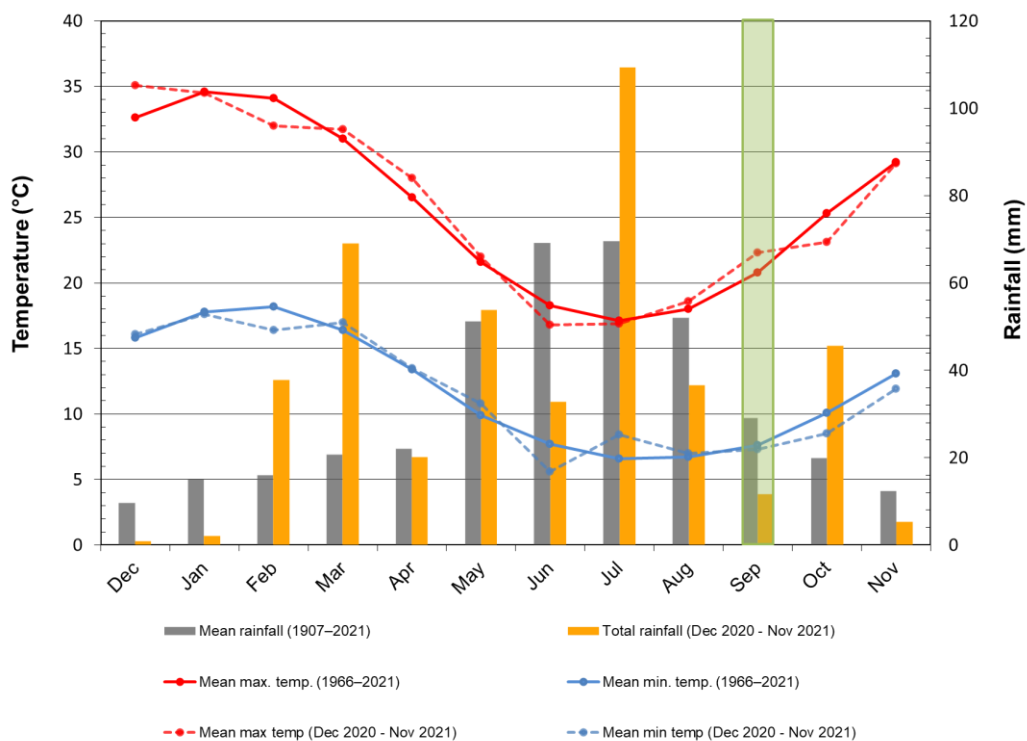


Figure 3.2: Total and long-term average monthly temperature (°C) and rainfall (mm) recorded from the Wongan Hills BoM station between September 2021. Green bar indicated timing of sampling event.

3.3 Sampling sites

Aquatic ecosystem surveys were conducted at six potential impact sites located within the Study Area and three reference sites (Table 3.3 and Figure 3.3).

Table 3.3: Site information and sample locations.

Site type	Site	Latitude	Longitude	Date Sampled
Study Area	CP01	22/09/2021	-30.9585	116.6171
	CP02	22/09/2021	-30.9617	116.6273
	CP03	23/09/2021	-30.9657	116.6305
	CP04	22/09/2021	-30.9693	116.6637
	CP06	22/09/2021	-30.9537	116.5641
	Lake Ninan	21/09/2021	-30.9519	116.6550
Reference	CP05	23/09/2021	-30.8247	116.5757
	CP07	23/09/2021	-30.7732	116.6014
	Lake Hinds	23/09/2021	-30.7764	116.5412

3.4 Habitat

Habitat characteristics were recorded at each site to provide information on the variability of aquatic habitat present, and to assist in explaining patterns in aquatic faunal assemblages. Details of in-stream habitat and sediment characteristics were recorded by the same team member for all sites to reduce the potential for habitat differences related to subjective recordings by different personnel. Habitat characteristics recorded included percent cover by inorganic sediment, submerged macrophyte, floating macrophyte, emergent macrophyte, algae, large woody debris (LWD), detritus, roots, and trailing vegetation. Details of substrate composition included percent cover by bedrock, boulders, cobbles, pebbles, gravel, sand, silt, and clay.

Submerged macrophytes, when present at a site, were collected, preserved in water, kept refrigerated and identified in the Biologic laboratory. Submerged macrophyte data were included in the habitat assessment.

3.5 Water quality

Water quality variables were recorded *in situ* from each site with a portable YSI Pro Plus multimeter. *In situ* variables included pH, electrical conductivity (EC), dissolved oxygen (DO), and water temperature. Undisturbed water samples were taken for laboratory analyses of ionic composition, nutrients, dissolved metals, and turbidity. All water quality analyses were undertaken by ALS, a NATA accredited chemical analysis laboratory.

Figure 3.3: Locations of aquatic ecosystem sampling sites.

Water quality variables measured included:

- *In situ* – pH, DO (% and mg/L), EC ($\mu\text{S}/\text{cm}$), and water temperature ($^{\circ}\text{C}$).
- Ionic composition – calcium (Ca), potassium (K), magnesium (Mg), sodium (Na), hydrogen carbonate (HCO_3), chloride (Cl), sulfate (SO_4), carbonate (CO_3), alkalinity and hardness (all mg/L).
- Water clarity – turbidity (NTU) and total suspended solids (TSS).
- Nutrients – nitrogen nitrite (N_{NO_2}), nitrogen nitrate (N_{NO_3}), nitrogen oxides (N_{NOx}), nitrogen ammonia (N_{NH_3}), total nitrogen (total N) and total phosphorus (total P; all mg/L).
- Dissolved metals – aluminium (Al), arsenic (As), boron (B), barium (Ba), cadmium (Cd), cobalt (Co), chromium (Cr), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo), nickel (Ni), lead (Pb), sulfur (S), selenium (Se), uranium (U), vanadium (V) and zinc (Zn) (all mg/L).

Samples collected for dissolved metals were filtered through $0.45\ \mu\text{m}$ Millipore nitrocellulose filters in the field. Nutrient samples were not filtered as ALS filters all nutrient samples in the laboratory as part of their analytical methods. Following best practice and to minimise any potential for contamination, all water samples were collected using clean Nalgene sample bottles, and clean/new filters and syringes (Ahlers *et al.*, 1990; Batley, 1989; Madrid & Zayas, 2007). All water quality sampling equipment was stored in polyethylene bags, and samplers wore polyethylene gloves whilst sampling water quality. All water samples were kept on ice in an esky while in the field, and either refrigerated (ions, dissolved metals, nutrients, general water), or frozen (total nutrients) as soon as possible for subsequent transport to the ALS laboratory.

3.6 Micro-crustacea

Micro-crustacea (ostracods, copepods and cladocera) form a vital component of aquatic food webs, feeding upon phytoplankton, bacteria, and detritus, and providing an important food source for higher invertebrate consumers and fish. They are generally poor swimmers, instead relying on flow for dispersal. Micro-crustacea can be useful bioindicators of water quality, eutrophication, productivity and disturbance because their development and distribution are subject to both abiotic (temperature, salinity, stratification, presence of pollutants, water flow) and biotic parameters (limitation of food, predation and competition) (Ramchandra *et al.*, 2006). Many species are known to be highly sensitive to a wide range of pollutants.

Micro-crustacea were sampled separately to other aquatic invertebrates as they are smaller, and therefore require a smaller mesh size, and are planktonic. However, all invertebrate taxa recorded were compiled into one taxonomic list for each site, and results reported together. Micro-crustacea samples were collected by gentle sweeping over an approximate 15 m distance with a $53\ \mu\text{m}$ mesh plankton net (Plate 3.1). Samples were preserved in 95% ethanol in the field and transported to the Biologic laboratory for processing. Sorting was conducted under a low power dissecting microscope. Specimens were identified to the lowest possible level (genus or species level) and enumerated to \log_{10} scale abundance classes (i.e., 1 = 1 individual, 2 = 2 - 10 individuals, 3 = 11 - 100 individuals, 4 = 101-1000

individuals, 5 = >1000). All micro-crustacea were identified by Alex Riemer to the lowest level possible. Where specific species names could not be assigned, voucher numbers were established.



Plate 3.1: Sampling the micro-crustacea at CP04.

3.7 Macroinvertebrates

Aquatic macroinvertebrates are used worldwide as indicators of ecosystem health for a number of reasons: they are ubiquitous; relatively easy to collect; have high species diversity and varying sensitivity to environmental disturbances; have relatively long life cycles; and are continuously exposed to environmental conditions and constituents of the surface water they inhabit (Bressler *et al.*, 2006; Cain *et al.*, 1992; Carew *et al.*, 2007; Hodgkinson & Jackson, 2005). In Australia, the inherent value in using aquatic macroinvertebrates as key biological indicators is evidenced by their inclusion in wetland health initiatives across the country, including the Salinity Action Plan (Halse *et al.*, 2004), studies of wetlands of the Swan Coastal Plain (Balla, 1994), and the Framework for the Assessment of River and Wetland Health (Norris *et al.*, 2007), to name a few.

Macroinvertebrate sampling was conducted with a 250 μm mesh D-net to selectively collect the macroinvertebrate fauna. At each site, sampling was undertaken across as many habitats as possible. This included sampling benthic habitat by vigorously disturbing sediments by kicking and sweeping through the resultant plume with the pond net (kick-sweep method) (Plate 3.2). The contents of the pond net were washed through a 250 μm sieve to remove fine sediment, with leaf litter and other coarse debris removed by hand. The net was thoroughly cleaned between sites to avoid cross contamination. Samples were preserved in 95% ethanol in the field and transported to the Biologic laboratory for processing. Sorting was conducted under a low power dissecting microscope. Specimens were identified to the lowest possible level (genus or species level) and enumerated to log₁₀ scale abundance classes (i.e., 1 = 1 individual, 2 = 2 - 10 individuals, 3 = 11 - 100 individuals, 4 = 101-1000 individuals, 5 = >1000). All macroinvertebrate groups were identified using in-house expertise.



Plate 3.2: Macroinvertebrate sampling at CP04.

3.8 Fish

Three baited box traps were set overnight at each site. Box traps were baited with chicken pellets and left half submerged to ensure air space for any potentially caught turtles or rakali. Two fine soft mesh fyke nets were set overnight at each site, where there was sufficient space to do so. DSEWPaC (2011) recommend their use because they are efficient for collecting galaxiids, while having minimal impact to fish caught. Fyke nets comprised a double 10 m leader/wing (4 - 6 mm mesh, 1.5 m drop) and a 5 m hoop. In accordance with the guidelines (DSEWPaC, 2011), a float was placed in the cod end of each net to ensure breathing space for turtles and rakali. Fish were identified in the field. Standard length (SL) measurements were taken, and then all individuals were released alive to the site where they were collected.



Plate 3.3: Fyke net set at CP04 to sample fish.

3.9 Waterbirds

A waterbird census was undertaken at each aquatic sample site. All species observed using the wetlands at the time of the survey were recorded, including abundance of each species.

3.10 Other aquatic fauna

Other vertebrate fauna (i.e., frogs) observed or caught during the aquatic survey was recorded for each site.

3.11 Data analysis

3.11.1 Water quality

Water quality data were compared against the ANZG (2018) water quality default guideline values (DGVs) for the protection of aquatic ecosystems in the southwest of Western Australia (see Appendix A for default values). For this purpose, sites sampled in the current study were classified as either wetlands or lakes depending on their size, morphology, hydrology, and habitat.

The primary objective of the guidelines is to “*provide authoritative guidance on the management of water quality in Australia and New Zealand and includes setting water quality and sediment quality objectives designed to sustain current, or likely future, community values for natural and semi-natural water resources*” (ANZG, 2018). DGVs are provided for a range of parameters designed to protect aquatic systems at a low level of risk but are not designed as pass or fail compliance criteria. Rather, exceedances of DGVs are triggers which can be used to inform managers and regulators that changes in water quality are occurring and may need to be investigated.

Differing levels of protection are provided within the guidelines, depending on the condition of the ecosystem in question:

- High conservation/ecological value systems - where the goal is to maintain biodiversity with no (or little) change to ambient condition. 99% species protection DGVs for toxicants apply².
- Slightly to moderately disturbed systems - where aquatic biodiversity has already been adversely impacted to a small but measurable degree by human activity. The aquatic ecosystem remains in a healthy condition and ecological integrity is largely retained. The aim is to maintain current biodiversity and ecological function. 95% species protection DGVs for toxicants apply.
- Highly disturbed systems - are measurably degraded and of lower ecological value. Guideline aims for these systems may be varied and more flexible, ranging from maintenance of the current yet modified ecosystem that supports management goals, to

² For toxicants, DGVs were derived using the species sensitivity distribution (SSD) approach; methods are described in ANZECC & ARMCANZ (2000). Refer to Warne *et al.* (2018) for updated GVs. Where the SSD approach could not be used, the less preferred ‘assessment-factor approach’ was used, following methods detailed in ANZECC & ARCMANZ (2000). For toxicants, DGVs relate to differing levels of species protection, i.e., the 99% GVs protect 99% of species, the 95% DGVs protect 95% of species present, and so on.

continual improvement in ecosystem condition. For toxicants, the 90% or 80% species protection DGVs may be applied.

All sites sampled in the current study show evidence of varying levels of impact from agricultural practices, including salinisation, and were classified as slightly to moderately disturbed systems. As such, the 95% DGVs applied. Comparisons were also made to the 99% DGVs in order to relate water quality results to known guidelines in the case where data were well below the 95% DGVs.

Two types of DGVs relating to nutrient concentrations are also provided within the default ANZG (2018) guidelines:

- A toxicity DGV above which direct toxic effects to aquatic biota can be expected (ammonia and nitrate); and
- A eutrophication DGV, above which nutrient concentrations are such that algal blooms and eutrophic conditions can be expected (nitrogen oxides, total nitrogen, and total phosphorus).

The guidelines have recently been updated to reflect a better understanding of physical and chemical stressors, the availability of additional monitoring data, the addition of recent toxicity data in DGVs for several toxicants, a weight of evidence approach, and the fact that water quality varies greatly across ecosystem types and regions (ANZG, 2018). The guidelines are now presented via an interactive online platform to improve usability and facilitate updates as new information becomes available. While information relating to management frameworks, background to derivation of DGVs, and approaches for sampling design and monitoring programs are available online, DGVs are not currently presented for all ecoregions. The Study Area falls within the Indian Ocean Inland Waters region, data for which is not currently available online. As such, data from the current study were compared against the ANZECC & ARMCANZ (2000) DGVs for systems within the southwest of Western Australia.

3.11.2 Invertebrates

All invertebrates collected were compared against appropriate threatened and priority species lists including the *Biodiversity Conservation Act 2016* (BC Act), the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act), the International Union for Conservation of Nature (IUCN), and Priority Fauna recognised by the DBCA. In addition, species were assigned to one of the following conservation categories based on species distributions:

- Cosmopolitan – species is found widely across the world
- Australasian – species is found across Australia, New Guinea and neighbouring islands, including those of Indonesia
- Australian endemic – species is only found in Australia
- Western Australian endemic – only known from W.A. (is restricted to, but is widely distributed across the state)
- Wheatbelt endemic - restricted to the Wheatbelt region of Western Australia
- Short range endemic (SRE) – an SRE is a species occupying an area of less than 10,000 km² (Harvey, 2002). Such species have traits which make them vulnerable to disturbance and changes in habitat, and affords them high conservation value

- Indeterminate distribution – taxa could not be assigned to one of the above, as there is currently insufficient knowledge on either its distribution or taxonomy to assess its level of endemism.

Invertebrate assemblage structure was analysed using multivariate techniques in PRIMER v7 (Clarke & Gorley, 2015), including cluster analysis and ordination. Ordination was by non-metric Multi-Dimensional Scaling (nMDS), which, unlike other ordination techniques uses rank orders, and therefore can accommodate a variety of different types of data. Ordination was based on the Bray-Curtis similarity matrix (Bray & Curtis, 1957). To test for significant difference in assemblages between salinity categories (saline vs brackish), one-factor PERMANOVA was conducted (Anderson *et al.*, 2008; Anderson & ter Braak, 2003). This analysis was also undertaken to assess whether there was a significant difference between site type (Study Area vs reference sites). SIMPER analysis was then used to determine which species were typical of a group by providing a list of taxa which were found consistently within most samples from that particular group (i.e., taxa representative of brackish sites in comparison to saline sites).

The relationship between invertebrate assemblages and environmental condition (water quality and in-stream habitat data) was assessed in PERMANOVA using a distance-based linear model (DistLM) (Anderson *et al.*, 2008). In order to undertake this analysis, water quality data had to first be transformed for those analytes which were not normally distributed (log transformation), and all water quality data were normalised.

3.11.3 Fish

Length-frequency analysis was undertaken for any fish species recorded, whereby fish were classified into four age classes based on body size (SL) mm. Age classes were determined from the literature (Allen *et al.*, 2002; Pen & Potter, 1991), and was based on knowledge of size of maturity (Table 3.4).

Table 3.4: Standard lengths (mm) used for each age class.

Age class	Western minnow
New recruit	≤ 30
Juvenile	30-49
Sub-adult	40-69
Adult	≥ 70

4 RESULTS

4.1 Desktop assessment

The database search indicated the lakes and wetlands within the Study Area have the potential to support several conservation significant or endemic fauna, including four invertebrates and 21 bird species (Biologic, 2021). These are:

Invertebrates:

- *Ilyodromus armacutis* (Ostracoda) - Potential SRE, currently known only from one location.
- *Parartemia extracta* (Anostraca) - Endemic to the Wheatbelt region, but currently known only from few populations, and with a highly disjunct distribution.
- *Parartemia boomeranga* (Anostraca) - Endemic to the Wheatbelt region, but very rare and hasn't been collected since 2008.
- *Daphnia jollyi* (Diplostraca) – Priority 1 (P1) species (DBCA, 2021b) and Vulnerable (IUCN, 2021). Endemic to the Wheatbelt region, with small disjunct populations (Figure 4.1).

Birds:

- Osprey *Pandion haliaetus* - Migratory (EPBC Act).
- Common sandpiper *Actitis hypoleucos* - Migratory (EPBC Act).
- Sharp-tailed sandpiper *Calidris acuminata* - Migratory (EPBC Act).
- Pectoral sandpiper *Calidris melanotos* - Migratory (EPBC Act).
- Wood sandpiper *Tringa glareola* - Migratory (EPBC Act).
- Common greenshank *Tringa nebularia* - Migratory (EPBC Act).
- Gull-billed tern *Gelochelidon nilotica* – Migratory (EPBC Act).
- Caspian tern *Hydroprogne caspia* – Migratory (EPBC Act).
- Bridled tern *Onychoprion anaethetus* – Migratory (EPBC Act).
- Greater crested tern *Thalasseus bergii* – Migratory (EPBC Act).
- Red-necked stint *Calidris ruficollis* – Migratory (EPBC Act) and Near Threatened (IUCN, 2021).
- Curlew sandpiper *Calidris ferruginea* – Migratory (EPBC Act), Critically Endangered (EPBC 1999, BC Act 2016), and Near Threatened (IUCN, 2021).
- Australian painted snipe *Rostratula australis* – Migratory (EPBC Act) and Endangered (EPBC 1999, BC Act 2016, IUCN, 2021).
- Hooded plover *Thinornis rubricollis* – Migratory (EPBC Act), Vulnerable (EPBC 1999, BC Act 2016, IUCN, 2021), and Priority 4 (P4) species (DBCA, 2021c).
- Greater sand plover *Charadrius leschenaultia* – Migratory (EPBC Act) and Vulnerable (EPBC 1999, BC Act 2016).
- Eastern curlew *Numenius madagascariensis* – Migratory (EPBC Act), Critically Endangered (EPBC 1999, BC Act 2016) and Endangered (IUCN, 2021).
- Fairy tern *Sternula nereis* – Vulnerable (EPBC 1999, BC Act 2016, IUCN, 2021).

- Australasian bittern *Botaurus poiciloptilus* – Endangered (EPBC 1999, BC Act 2016, IUCN, 2021).
- Australian little bittern *Ixobrychus dubius* – P4 species (DBCA, 2021).
- Black bittern *Ixobrychus flavicollis* (south-west Western Australian subpopulation) – Priority 2 (P2) species (DBCA, 2021).
- Blue-billed duck *Oxyura australis* – P4 species (DBCA, 2021c) and Near Threatened (IUCN, 2021).

The database search identified only one mammal of conservation significance, *Hydromys chrysogaster* (rakali, or water rat) (Figure 4.1). While widespread across northern and eastern Australia, the water rat population is more restricted in Western Australian where the species is listed as P4 (State BC Act). Oral histories have indicated that the presence and abundance of water rats declined in the Wheatbelt during the 1950s, to the point where they now no longer occur in wetlands in the region (Atkinson *et al.*, 2008). It was suggested that their decline was a result of reduced prey species (fish, frogs and crustaceans) due to the increasing salinity associated with increased agriculture in the region (Atkinson *et al.*, 2008).

The literature review indicated that, overall, invertebrate community composition (relative species richness) was strongly associated with salinity, with a decline in richness with increasing salinity (Blinn *et al.*, 2004; Cale *et al.*, 2004; Pinder *et al.*, 2004). Blinn *et al.* (2004) reported rotifers and cladocerans to be the most sensitive to high salinity. Geography, climate, habitat and water chemistry were also found to influence assemblages, but to a lesser extent (Cale *et al.*, 2004; Pinder *et al.*, 2004). Halse *et al.* (2004) also reported that many invertebrate species were new or recorded from a single site only.

Figure 4.1: Location of conservation significant fauna records.

4.2 Habitat assessment




A summary of the overall habitat assessment is provided in Table 4.1 and all raw data in Appendix B. Sites comprised brackish to hypersaline wetlands and lakes characterised by open *Casuarina* sp. overstorey and/ or samphire (saltbush) shrubs in the middle-storey.




Within the Study Area, sediments generally comprised a mix of sand, silt and clay. Sites CP04, CP06 and Lake Ninan were dominated by clay substrate, while CP01, CP02 and CP03 were predominantly sand. Reference sites CP05 and Lake Hinds comprised mostly clay substrate, while CP07 was dominated by sand.




In-stream habitat diversity within Study Area sites was generally poor, reflecting the high salinities, and comprised open sediment, submerged macrophytes, algae, large woody debris (LWD), detritus and roots. Habitat diversity at Lake Ninan was especially low and almost completely comprised of open inorganic sediment. Submerged macrophyte cover where present was highly variable, ranging from 20% cover (at CP03) to 68% (at CP04). Emergent macrophyte where present was generally sparse, ranging from 2% (at site CP04) to 20% (at CP06). Detritus was low, representing <10% cover at all sites except for CP02 (22% cover). Similarly, algae was mostly absent, with the exception of sites CP01 (50% algae cover) and CP06 (20%). Overall, in-stream habitat diversity was greater at the lower salinity (brackish) sites, which included including complex, heterogenous substrates with which to support aquatic fauna. Saline sites had very little in-stream habitat available for aquatic fauna.

Reference sites also recorded low habitat diversity and were dominated by inorganic substrate. Lake Hinds recorded moderate amounts of submerged macrophyte (40%). No algae cover was recorded from any reference sites.

Table 4.1: Summary of aquatic habitats sampled, including site photos.

Site	Habitat	Description	Site Photo
CP01	Salt Lake	<p>Hypersaline lake (241.5 mS/cm), too saline for macrophytes to be present. Clear waters. Inorganic sediment the dominant in-stream habitat, with large amounts of algae forming a crust on the upper layer. Sediments dominated by sand, with some silt and clay present.</p> <p>Maximum depth = 0.2 m.</p>	
CP02	Brackish Lake	<p>Brackish, tannin-stained lake (14.4 mS/cm). Vegetation dominated by <i>Casuarina</i> sp. and samphire shrubs abundant in the water and surrounds. High detritus cover in-stream. Sediments dominated by sand and silt, with some clay present.</p> <p>Maximum depth = 3.0 m.</p>	
CP03	Brackish Lake	<p>Brackish, tannin-stained lake (7.2 mS/cm). Surrounding vegetation dominated by <i>Casuarina</i> sp. Submerged macrophytes present, including samphire shrubs and <i>Ruppia</i> sp. Detritus and large woody debris (LWD) present in-stream. Sediments dominated by sand, with some silt and clay also present.</p> <p>Maximum depth = 1.5 m.</p>	

Site	Habitat	Description	Site Photo
CP04	Brackish Pool	<p>Fresh, small manmade dam (3.2 mS/cm). Surrounded by samphire and fringing grasses. Abundant in-stream vegetation dominated by submerged macrophytes <i>Ruppia polycarpa</i> and <i>Najas marina</i>. Detritus and roots also present in-stream. Sediment type dominated by clay.</p> <p>Maximum depth = 1.0 m.</p>	
CP05	Salt Lake	<p>Salt lake (109.1 mS/cm). Surrounding vegetation dominated by samphire. Inorganic sediment was the dominant in-stream habitat, with small proportions of detritus and LWD cover. Sediments dominated by clay with some sand and silt also present.</p> <p>Maximum depth = 1.0 m.</p>	
CP06	Salt Lake	<p>Salt lake (31.9 mS/cm). Surrounding vegetation dominated by samphire. In-stream vegetation comprising samphire and <i>Ruppia maritima</i> (abundant). Large areas of algae also present in-stream. Sediment composition dominated by clay.</p> <p>Maximum depth = 0.4 m.</p>	

Site	Habitat	Description	Site Photo
CP07	Salt Lake	<p>Salt lake (49.4 mS/cm). Surrounding vegetation dominated by samphire. Inorganic sediment the dominant in-stream habitat, but with small patches of detritus and LWD also present. Sediment composition dominated by sand, with some silt and clay. Maximum depth 2 m.</p>	
Lake Ninan	Salt Lake	<p>Large salt lake (141.6 mS/cm). Surrounding vegetation dominated by samphire. In-stream habitat dominated by open inorganic sediment, with small patches of detritus and LWD present. Substrates of clay, silt and sand. Maximum depth = 0.4 m.</p>	
Lake Hinds	Claypan	<p>Large claypan (141.4 mS/cm). Surrounding vegetation dominated by samphire. Inorganic open sediment dominating in-stream, with some <i>Ruppia tuberosa</i> present. Sediment composition dominated by clay, with some silt. Maximum depth = 0.2 m.</p>	

4.3 Water quality

All raw water quality data are provided in Appendix C.

4.3.1 *In situ*

Sampling sites ranged from brackish³ to hypersaline, with electrical conductivity (EC) ranging from 3.2 mS/cm (at CP04) to 241.5 mS/cm (at CP01, Figure 4.2). Overall, three sites were classed as brackish (CP02, CP03 and CP04) and six sites hypersaline (CP01, CP05, CP06, CP07, Lake Ninan and Lake Hinds). Unsurprisingly, all sites recorded EC in excess of the ANZG (2018) DGV for the protection of freshwater systems of the southwest (1.5 mS/cm).

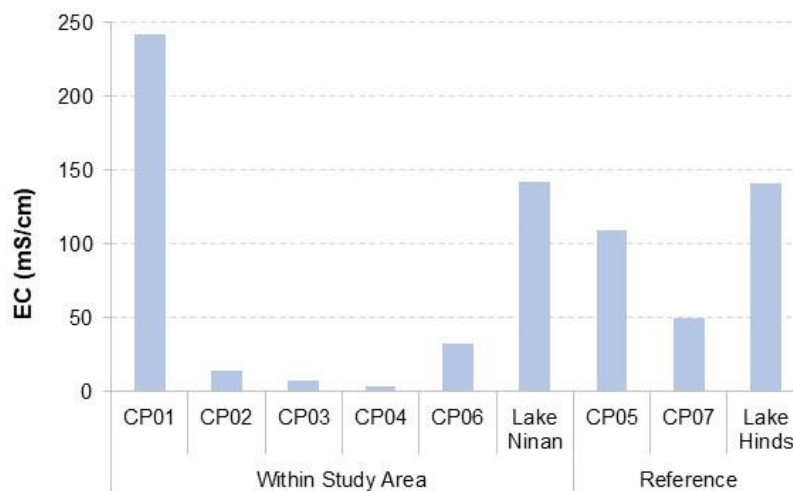


Figure 4.2: Electrical conductivity (EC; mS/cm) recorded in this study.

Dissolved oxygen (DO) ranged from 19.9% (at LH01) to 130.9% (at CP03, Figure 4.3). While several sites recorded DO saturation below the lower ANZG (2018) DGV (CP01, CP05, CP07 and LH01), only Land Hinds recorded DO sufficiently low as to potentially result in ecological harm. Two sites recorded super-saturated DO which exceeded the upper DGV for wetlands (>120%), CP03 and CP06.

Surface waters at all sampling sites were neutral to basic, with pH ranging from 7.40 (at CP01) to 10.18 (at CP04, Figure 4.4). Although, four sites exceeded the upper pH DGV (CP02, CP03, CP04 and CP06), Basic pH has been recorded from wetlands and lakes of the Wheatbelt previously (ARL, 2009; Cale *et al.*, 2004; Lyons *et al.*, 2004).

³ Salinity categories are based on the Department of Water and Regulation classification system, where fresh/marginal < 1,000 mg/L (~1.5 mS/cm), brackish = 1,000 mg/L – 2,000 mg/L (~1.5 mS/cm to 3.0 mS/cm), saline = 2,000 mg/L – 10,000 mg/L (~ 3.0 mS/cm – 15.0 mS/cm), and hypersaline > 10,000 mg/L (> 15.0 mS/cm) (Mayer *et al.*, 2005).

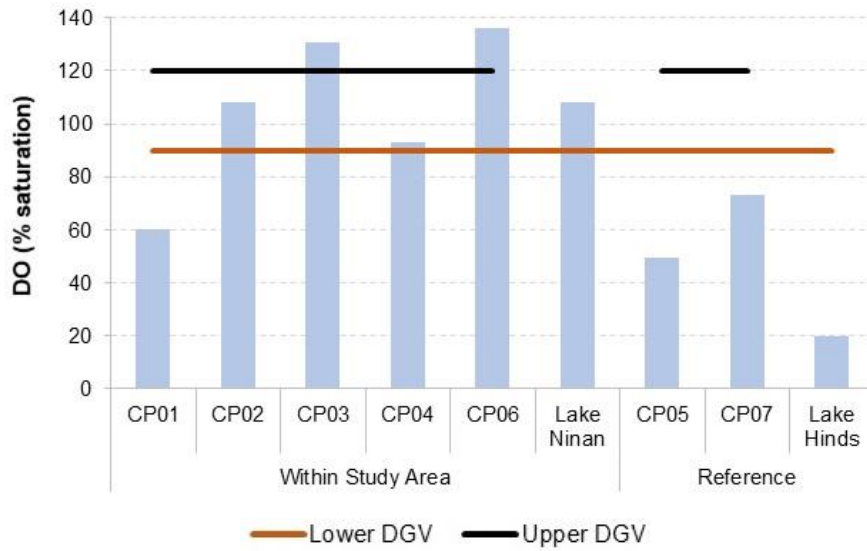


Figure 4.3: Dissolved oxygen (DO, % saturation) recorded in this study.

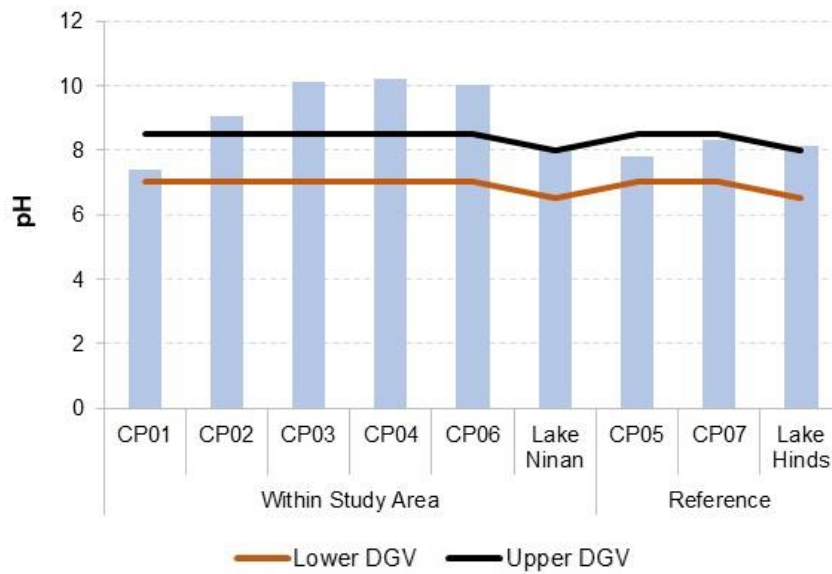


Figure 4.4: pH recorded in this study.

4.3.2 Nutrients

While nitrogen ammonia (N_{NH₃}) concentrations were generally low, concentrations recorded from Lake Ninan were in excess of the 99% toxicity DGV (0.66 mg/L), and CP05 were in excess of the 95% toxicity DGV (2.26 mg/L). Nitrate nitrate (N_{NO₃}) concentrations were low, with most sites recording values below the limit of detection (LOD, < 0.01 mg/L), and all concentrations being well below the 99% and 95% DGVs. Nitrogen oxide (N_{NO_x}) concentrations were similarly low, with most sites recording values below the LOD (< 0.01 mg/L). No sites recorded N_{NO_x} concentrations in excess of the eutrophication DGVs.

Concentrations of total nitrogen (total N) were variable, ranging from 0.78 mg/L (at CP03) to 4.21 mg/L (at Lake Ninan, Figure 4.5). Most sites were in excess of the eutrophication DGVs (of 1.50 mg/L for wetlands and 0.35 mg/L for Lakes), with the exception of CP01 (1.46 mg/L) and CP03 (0.78 mg/L).

Concentrations of total P were also variable and ranged from 0.017 mg/L (at CP03) to 0.112 mg/L (at Lake Hinds; Figure 4.5). Four sites recorded total P concentrations greater than eutrophication DGVs, including CPO1, Lake Ninan, CP05 and Lake Hinds (Figure 4.5).

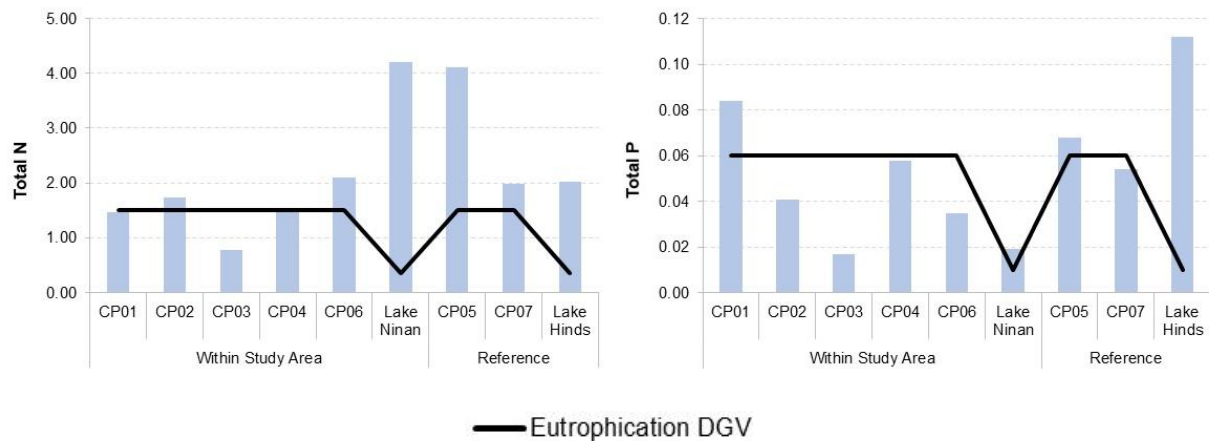


Figure 4.5: Total N (left) and total P (right) concentrations (mg/L) recorded in this study.

4.3.3 Dissolved metals

Dissolved metal concentrations were generally low, with some analytes recording concentrations below LODs at several sites. However, some analytes could not be compared against DGVs for some sites, as the LODs were greater than LODs. This was generally only the case for highly saline sites, and included dAs, dCd, dCr, dSe, and dZn. Of the metals that could be directly compared with DGVs, most recorded concentrations below the corresponding DGVs, at most sites. Exceptions to this included:

- dAs – was elevated in comparison to the 99% toxicity DGVs for As (III) at four sites (CP02, CP05, CP07 and Lake Hinds). It must be noted, however, that the ANZG (2018) DGV relates to arsenic III, while the concentrations reported here are for total arsenic. Analysis of specific arsenic valencies was outside the scope of this study.
- dB – exceeded the 99% toxicity DGV at Lake Ninan, CP05 and Lake Hinds. No concentrations were in excess of the 95% DGV.
- dCu – was high at all sites except CP04. All eight remaining sites, all recorded dCu concentrations greater than the 59% toxicity DGV except CP03 which was in excess of the 99% DGV.
- dPb – one site (CP01) recorded elevated dPb, which was greater than the 99% DGV, but lower than the 95% toxicity DGV.
- dZn – of the sites which had sufficiently low LODs for comparison against DGVs, only one (CP03) recorded a concentration greater than the 99% toxicity DGV. All were lower than the 95% DGV (Figure 4.6).

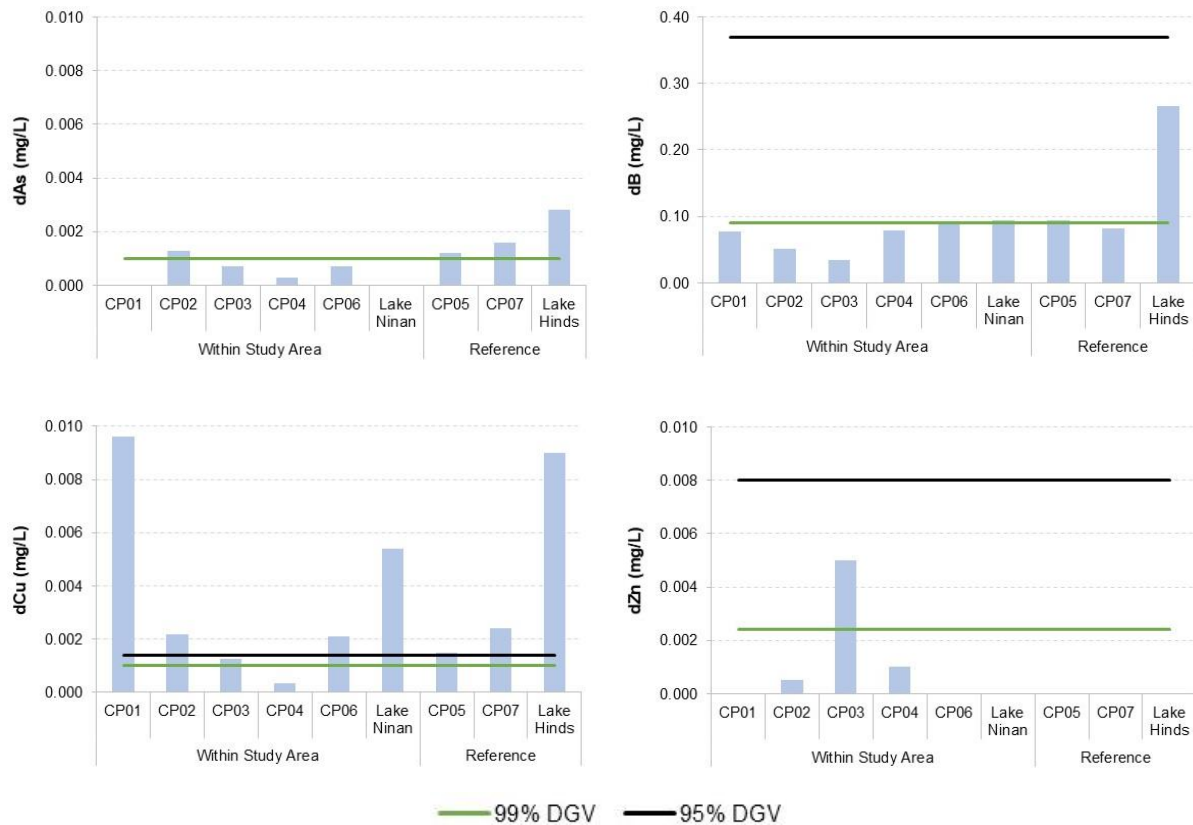


Figure 4.6: Concentrations of selected dissolved metals (mg/L) recorded in this study. NB: some concentrations are blank, indicating the LOD was above the DGV.

4.4 Aquatic invertebrates

4.4.1 Taxa composition and richness

A total of 88 aquatic invertebrate taxa was recorded during the current study (see Appendix D for the full taxonomic list). Aquatic invertebrate taxa comprised Nematoda (round worms; one taxon), Oligochaeta (aquatic segmented worms; two taxa), Gastropoda (aquatic snails; one taxon), Acarina (water mites; three taxa), Amphipoda (side swimmers; one taxon), Anostraca (fairy shrimp; four taxa), Diplostraca (water fleas; five taxa), Ostracoda (seed shrimp; 11 taxa), Copepoda (copepods; six taxa), Coleoptera (beetles; 17 taxa), Diptera (two winged flies; 19 taxa), Hemiptera (true bugs; six taxa), Lepidoptera (aquatic moth larvae; one taxon), Thysanoptera (thrips; one taxon), Odonata (dragonflies and damselflies; eight taxa), and Trichoptera (caddisflies; two taxa, Figure 4.7).

Of the 88 taxa recorded, 55 were singletons and recorded from one sample only (one site). More common taxa, recorded from five or more sites, included the amphipod *Austrochiltonia subtenuis*, ostracods *Mytilocypris ambiguosa* and *Cyprididae* sp., the diving beetle *Necterosoma penicillatum* and non-biting midges *Tanytarsus barbitarsus* and *Procladius paludicola*.

The highest invertebrate richness was recorded from brackish sites CP02 (20 taxa), CP03 (27 taxa) and CP04 (39 taxa), while hypersaline site CP01 (six taxa) recorded the lowest richness (Figure 4.7). The remaining saline sites (CP05, CP06, CP07, Lake Ninan and Lake Hinds) also recorded low taxa

richness and were generally dominated by salt tolerant Diptera (*Tanytarsus barbitarsus*) and Crustacea taxa (Ostracoda, Anostraca and Copepoda) (Figure 4.7).

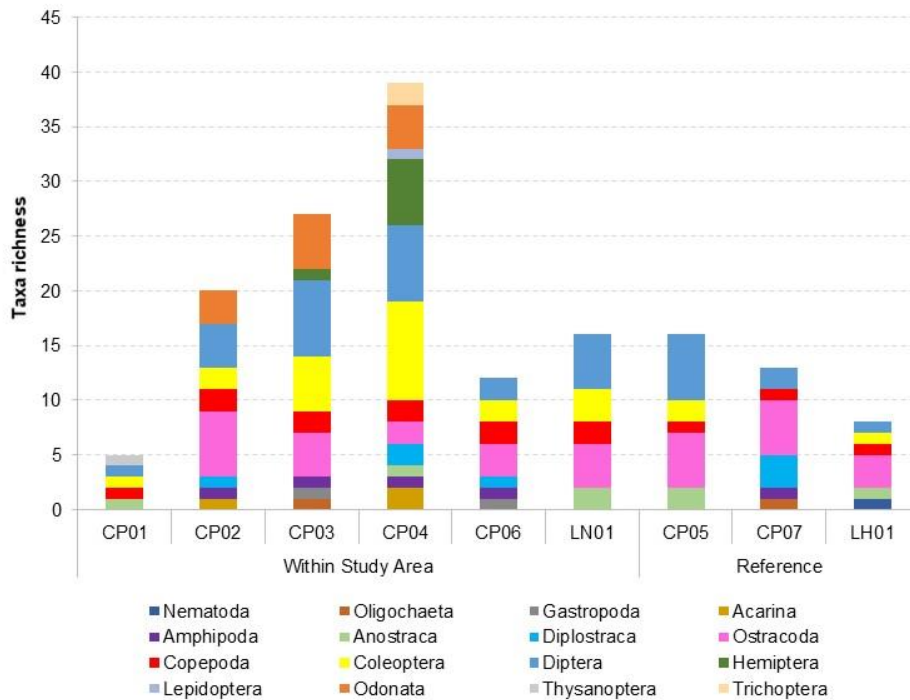


Figure 4.7: Aquatic invertebrate composition and richness from each site.

4.4.2 Conservation significant invertebrate taxa

The majority of aquatic invertebrates recorded during the current study were common, ubiquitous species. Other than taxa which could not be assigned a distribution status due to insufficient information or taxonomy (juveniles/damaged specimens; indeterminate taxa), most have distributions extending across Australia (31%), Australasia (5%) and the world (cosmopolitan species; 6%). Taxa endemic to Western Australia accounted for 4% of the total invertebrate fauna. Two ostracod taxa and one fairy shrimp were categorised as potential Wheatbelt endemics (3%). These three taxa are discussed in further detail below.

Anostraca

The fairy shrimp, *Parartemia extracta* is known from only five populations, most of which occur within the intensive agricultural zone of the central Wheatbelt region (Figure 4.8). Its distribution includes small lakes near Jurien in the north, to Tammin and southwards to Lake Grace. Early records suggest it occurred further east, near Minnivale and Koorda, but recent surveys have failed to record *P. extracta* from these areas (Timms *et al.*, 2009). In the current study, *P. extracta* was recorded from CP05 and LH01. Individuals were also collected from an un-named claypan inside the Study Area, near CP01, which was visited but not sampled as part of the current study (Figure 4.8).

Figure 4.8: Location of conservation significant fauna *Parartemia extracta*.

Ostracoda

Reticypriis sp. recorded from CP05 is an undescribed species, potentially new to science. This genus of ostracod is known throughout the Wheatbelt, occurring at secondarily saline wetlands (Pinder *et al.*, 2002). The *Reticypriis* genus is considered in need of taxonomic revision, with Pinder *et al.* (2005) recording six species throughout the Wheatbelt, four of them being new, undescribed taxa.

The other ostracod, *Australocypris* sp. n., is also potentially a new species. Morphological characters of the male features differed from all species described by Halse and McRae (2004). *Australocypris* sp. n. was recorded from CP05, LN01 and LH01.

4.4.3 Patterns in aquatic invertebrate assemblages

Patterns were evident in the invertebrate assemblage nMDS ordination (Figure 4.9). As would be expected, macroinvertebrate assemblages separated by salinity category, with saline samples sitting apart from brackish samples in ordination space (Figure 4.9Figure 4.10). CP01 separated from all other sites, including the other saline sites (Figure 4.9Figure 4.10). This was the most hypersaline site of all sampled, with only six invertebrate taxa recorded. Patterns were not so evident between site type, with considerable overlap of Study Area sites with reference sites within the nMDS (Figure 4.10).

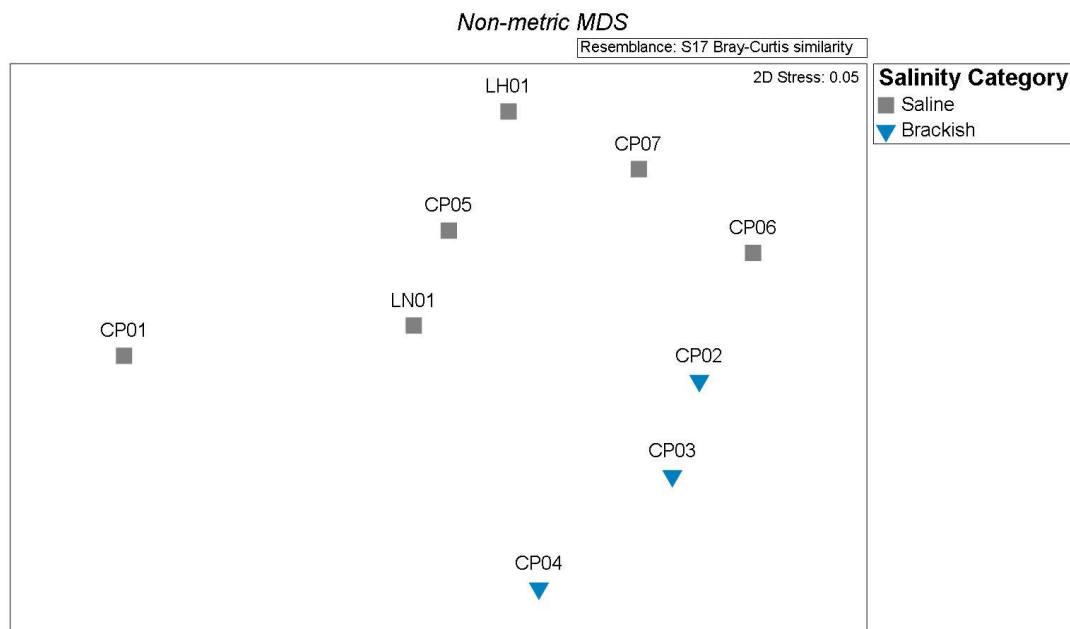


Figure 4.9: nMDS of aquatic invertebrate assemblages, with samples identified by salinity category. 2D stress was low (0.05).

Overall, there was a significant difference in macroinvertebrate assemblages between saline and brackish sites (One-factor PERMANOVA; $df = 1$, Pseudo-F = 2.51, $p = 0.013$), but not between site type (One-factor PERMANOVA; $df = 1$, Pseudo-F = 1.61, $p = 0.132$).

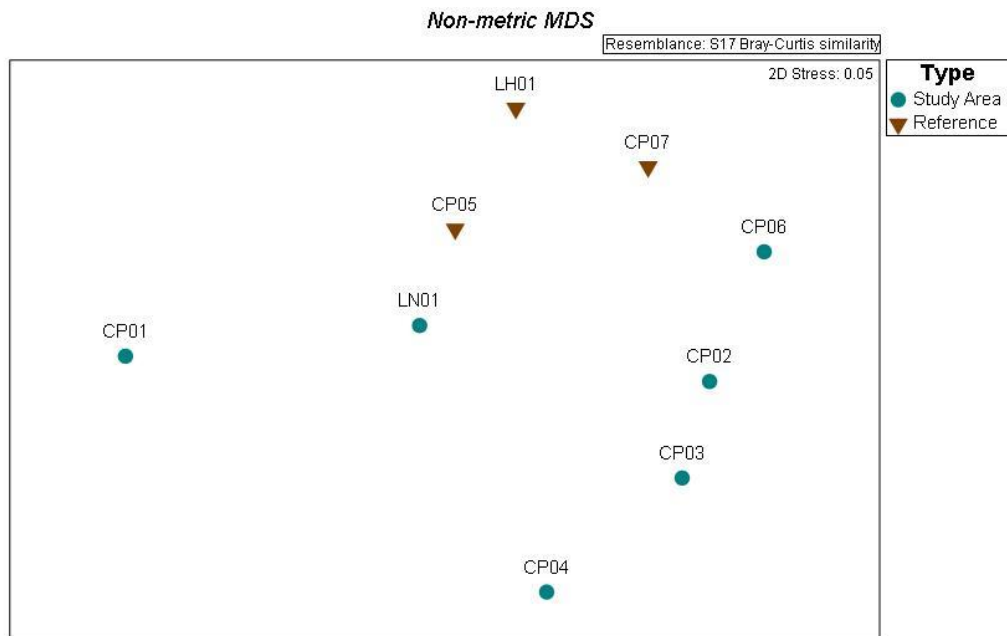


Figure 4.10: nMDS of aquatic invertebrate assemblages, with samples identified by site type (within Study Area vs reference).

SIMPER (analyses of similarity) indicated a large difference between saline and brackish invertebrate assemblages (only 14.09% similarity). This difference was largely due to the presence of species recorded at brackish sites, which were not present at saline/hypersaline sites. Such taxa included the amphipod *Austrochiltonia subtenuis*, copepod *Boeckella triarticulata*, the ostracod *Mytilocypris mytiloides* and the non-biting midge *Procladius paludicola*. There were some species recorded from saline sites, which were not supported by the brackish wetlands, including the copepod *Pescecyclus cf. arnaudi*, the brine shrimp *Artemia franciscana*, and the ostracods *Australocypris* sp. n. and *Platycypris baueri*.

Correlations between invertebrate assemblages and environmental data (water quality and habitat) were investigated using DistLM. A model with a strong correlation ($r = 0.92$) between invertebrate assemblages and four predictor variables (EC, pH, DO and dB) was produced (Table 4.2). Together these variables explained over 95% of the total variation amongst invertebrate assemblages. Interestingly, all were water quality variables, with no habitat parameters contributing to the model.

Table 4.2: DistLM results examining correlations between invertebrate assemblages and environmental data.

Variable	Pseudo-F	p-value	% variance explained
EC	2.69	< 0.001	27.77
pH	2.38	0.008	25.41
DO	1.92	0.037	21.50
dB	1.88	0.024	21.21
Total % variation explained			95.89%

4.5 Fish

One freshwater fish species was recorded in the current study, the western minnow *Galaxias occidentalis*. Western minnows were recorded from two sites within the Study Area, 84 individuals from CP02 and 689 individuals from CP03. Western minnows are common in streams, lakes, and wetlands across south-west Western Australia. Their distribution extends from Arrowsmith, 250 km north of Perth, to Albany (Morgan *et al.*, 1998). Primarily, their diet comprises terrestrial insects and small aquatic crustaceans (Pen & Potter, 1991).

Western minnows attain a maximum size of approximately 130 mm SL, but more commonly grow to 85 to 100 mm SL. Individuals from a range age classes were recorded from both sites, with juveniles being the most abundant (52.5%; Figure 4.11). This indicates recent breeding and recruitment within the Study Area wetlands.

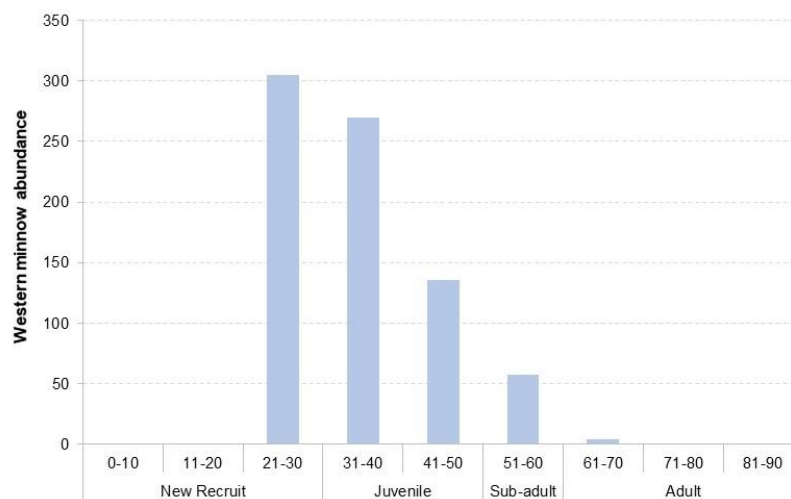


Figure 4.11: Abundance of western minnows by age class.

4.6 Waterbirds

Eleven species of waterbird were recorded during the survey, at five out of the nine sites (Table 4.3). The highest abundance of waterbirds was recorded at Lake Ninan, where a huge feeding flock of banded stilt (*Cladorhynchus leucocephalus*) was observed (Plate 4.1). Highest species richness was recorded from CP03 (eight species observed). Australian shelduck (*Tadorna tadornoides*) was the most common species, being recorded at five sites.

Table 4.3: Waterbirds recorded during the survey.

Site	CP01	CP02	CP03	CP04	CP05	CP06	CP07	Lake Hinds	Lake Ninan	# Sites recorded
Black swan			9			3				2
Australian shelduck		4	20	16		3			41	5
Pacific black duck			3	2						2
Grey teal		3	2			18			2	4
Hardhead			10							1
Hoary-headed grebe		6	6	3						3

Site	CP01	CP02	CP03	CP04	CP05	CP06	CP07	Lake Hinds	Lake Ninan	# Sites recorded
Pied stilt				9						1
Banded stilt									10000	1
Red-necked avocet				1						1
White-faced heron		1	1							2
Eurasian coot			60							1
Species richness	0	4	8	5	0	3	0	0	3	



Plate 4.1: Banded stilt feeding flock at Lake Ninan.

4.7 Other vertebrate fauna

Banjo frogs (*Limnodynastes dorsalis*) were observed at CP04. Banjo frogs are found throughout the south-west, where they utilise permanent and temporary freshwater sources for breeding, including farm dams such as CP04. At least two frog species were observed at CP03, however these could not be identified in the field due to immaturity (Plate 4.2).



Plate 4.2: Juvenile frogs observed at CP03

5 DISCUSSION

5.1 Habitat Assessment

The Study Area consists of a range of wetland habitats, including brackish wetlands, saline lakes and hypersaline claypans most of which were characterised by open *Casuarina* sp. overstorey and/ or samphire (saltbush) shrubs in the middle-storey. In-stream habitat diversity was greater at the lower salinity (brackish) sites, which included including complex, heterogenous substrates with which to support aquatic fauna. Such habitat included submerged and emergent macrophytes, algae, large woody debris (LWD), detritus and roots. Saline sites supported very little in-stream habitat for aquatic fauna.

5.2 Water quality

Unsurprisingly, all sites recorded EC in excess of the ANZG (2018) DGV and the level of ecological stress; the level at which freshwater systems experience stress (1.5 mS/cm). Three sites were classed as brackish (CP02, CP03 and CP04) and six sites were hypersaline (CP01, CP05, CP06, CP07, Lake Ninan and Lake Hinds). The Wheatbelt region has been heavily impacted by agricultural development resulting in secondary salinisation across much of the area (Cale *et al.*, 2004; Pinder *et al.*, 2004; Pinder *et al.*, 2005; Pinder *et al.*, 2002). Increased salinity is associated with a reduction in taxa diversity, particularly for those that have low salt tolerances (Halse *et al.*, 2004; Pinder *et al.*, 2002).

Dissolved oxygen (DO) was variable. While several sites recorded DO saturation below the lower ANZG (2018) DGV (CP01, CP05, CP07 and LH01), only Lake Hinds recorded DO sufficiently low as to potentially result in ecological harm (<20%). DO is influenced by factors such as salinity, biological activity and the rate of atmospheric transfer (ANZG, 2018). Oxygen needs of aquatic biota differ between species and life history stage. However, low DO saturation is known to increase the toxicity of certain toxicants including Zn, Cu and NH₃. Two sites recorded super-saturated DO which exceeded the upper DGV for wetlands (>120%); CP03 and CP06. Submerged macrophytes and algae were abundant at these sites which would explain the high DO recorded due to high levels of photosynthesis.

Surface waters at all sampling sites were neutral to basic. While four sites exceeded the upper pH DGV (CP02, CP03, CP04 and CP06), pH was considered typical of salt lakes in the Wheatbelt (Lynas *et al.*, 2006).

Concentrations of nitrogen ammonia (N_NH₃), nitrogen nitrate (N_NO₃) and nitrogen oxide (N_NOx) were generally low across all sites. However, N_NH₃ concentrations at Lake Ninan exceeded the 99% toxicity DGV and at CP05 were greater than the 95% toxicity DGV. Total nitrogen (total N) concentrations were varied, with most sites in excess of the eutrophication DGVs. Total P concentrations were also in excess of eutrophication DGVs at four sites (CPO1, Lake Ninan, CP05 and Lake Hinds). The eutrophication DGV is designed to protect aquatic ecosystems from the effects of nuisance algal and macrophyte growth. Excessive plant growth can physically smother aquatic invertebrates, as well as deplete oxygen in the water, due to increased biological oxygen demand as plants decay and are decomposed by bacteria. The relationship between nitrate-enrichment and

enhanced algal growth in freshwaters is well documented, often resulting in very high density/abundance but low species richness (Camargo & Alonso, 2006; Wagenhoff *et al.*, 2011). While the idea that phosphorus (as FRP or total P) is the primary limiting factor for algal growth in freshwaters has been challenged as too simplistic (Beck & Hall, 2018; Elser *et al.*, 2007; Muhid & Burford, 2012), the fact that both total N and total P are naturally enriched in wetlands and lakes within the Study Area, suggests that any additional nutrient inputs would increase the risk of eutrophication.

Dissolved metal concentrations were generally low. However, some analytes (dAs, dCd, dCr, dSe and dZn) could not be compared against DGVs, as LODs were above the DGVs, particularly for sites that were hypersaline. Of the metals that could be directly compared with DGVs, most concentrations were below the corresponding DGVs at most sites. Exceptions to this included:

- dAs – was elevated in comparison to the 99% toxicity DGVs for As (III) at four sites (CP02, CP05, CP07 and Lake Hinds).
- dB – exceeded the 99% toxicity DGV at Lake Ninan, CP05 and Lake Hinds. No concentrations were in excess of the 95% DGV.
- dCu – was high at all sites except CP04. Of the eight remaining sites, all recorded dCu concentrations greater than the 95% toxicity DGV except CP03 which was in excess of the 99% DGV.
- dPb – one site (CP01) recorded elevated dPb greater than the 99% DGV, but lower than the 95% toxicity DGV.
- dZn – of the sites which had sufficiently low LODs for comparison against DGVs, only one (CP03) recorded a concentration greater than the 99% toxicity DGV.

Concentrations of dCu were generally elevated during the current survey. However, the acute toxicity of copper decreases with increased salinity (ANZG, 2018). The generally high salinity should help to ameliorate any toxic effects of dCu to aquatic biota throughout the Study Area.

5.3 Aquatic invertebrates

A total of 88 aquatic invertebrate taxa were recorded during the current study. Aquatic invertebrate composition was found to be related to salinity, with brackish sites recording the highest richness and diversity of aquatic invertebrates (20-39 taxa). The most hypersaline site CP01 had the lowest species richness (six taxa). Hypersaline sites were low in species richness and generally dominated by salt tolerant Diptera (*Tanytarsus barbitarsus*) and Crustacea (Ostracoda, Anostraca and Copepoda).

While most aquatic macroinvertebrates were common, ubiquitous species, three species were of conservation significance or scientific interest, including:

- The ostracod *Reticypriis* sp. (CP05). This taxon is undescribed, and potentially new to science.
- The ostracod *Australocypris* sp. n. (CP05, LN01 and LH01). This taxon is also potentially new to science.

- The fairy shrimp, *Parartemia extracta* (CP05, LH01 and an un-named claypan near CP01 which was visited during the current study). This species is known from very few populations (five), most of which occur within the intensive agricultural zone of the central Wheatbelt region.

Overall, there was a significant difference in invertebrate assemblages between saline and brackish sites, but not between reference and Study Area sites. Four water quality variables were found to be significantly correlated with the invertebrate assemblages; EC, pH, DO and concentrations of dissolved boron.

5.4 Fish

One freshwater fish species was recorded from the Study Area, the western minnow *Galaxias occidentalis*. The general lack of freshwater fish is not surprising given the salinity levels recorded from these sites, to which most freshwater fish species endemic to the south-west are extremely sensitive (Morgan *et al.*, 2011). Western minnows are one of the most common and widespread endemic freshwater fishes in south-western Australia. Their broad distribution is facilitated by a tolerance to elevated salinity; western minnows have been recorded from sites with EC up to 40 mS/cm in the Blackwood River (Morgan *et al.*, 2003). In the current study, western minnows were only recorded from brackish sites (CP02 and CP03). These sites supported a high proportion of juveniles, indicating the importance of sites within the Study Area for breeding and recruitment of this species.

Although western minnows are not of conservation significance, records from the current study, are of note as they represent one of the last, few records of freshwater fish in Wheatbelt wetlands currently. Habitat loss through salinisation is one of the greatest threats to freshwater fish in Australia's south-west, with several native fish species experiencing population decline and even localised extinction from catchments (Morgan *et al.*, 2003).

5.5 Other vertebrate fauna

Eleven species of waterbird were recorded utilising the Study Area. Frogs were also recorded from sites CP03 and CP04, including the banjo frog. Several other vertebrate species are likely to occur within the Study Area, based on results from the desktop assessment. These include:

Frogs

- Motorbike frog (*Litoria moorei*)
- Bleating frog (*Crinia pseudinsignifera*)
- Slender tree frog (*Litoria adelaidensis*).

None of the aforementioned species are restricted or listed for conservation significance. All are relatively widespread throughout the south-west.

5.6 Final remarks

This study represents the first comprehensive aquatic ecosystem survey undertaken in the Study Area, other than some work within Lake Ninan. Results from this survey provide an assessment of the current ecological values and health of aquatic systems within the Caravel Project.

6 REFERENCES

- Ahlers, W. W., Reid, M. R., Kim, J. P., & Hunter, K. A. (1990). Contamination-free sample collection and handling protocols for trace elements in natural fresh waters. *Australian Journal of Marine and Freshwater Research*, 41, 713-720. doi:<https://doi.org/10.1071/MF9900713>
- ALA, Atlas of Living Australia. (2021). Occurrence search (custom search). Retrieved 2021 <http://www.ala.org.au/>
- Allen, G. R., Midgley, S. H., & Allen, M. (2002). *Field Guide to the Freshwater Fishes of Australia*. Melbourne, Australia: CSIRO Publishing.
- Anderson, M. J., Gorley, R. N., & Clarke, K. R. (2008). *Permanova + for PRIMER: guide to software and statistical methods*. Plymouth, UK: PRIMER-E Ltd.
- Anderson, M. J., & ter Braak, C. J. F. (2003). Permutation tests for multi-factorial analysis of variance. *Journal of Statistical Computation and Simulation*, 73, 85-113.
- ANZECC, & ARMCANZ. (2000). *Australian and New Zealand Guidelines for Fresh and Marine Water Quality*. Canberra:
- ANZG. (2018). Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Retrieved from www.waterquality.gov.au/anz-guidelines
- ARL. (2009). *Buntine-Marchagee Natural Diversity Recovery Catchment (BMNDRC). Wetland Invertebrate Fauna Sampling: 2009*. Crawley, WA:
- Atkinson, C. A., Lund, M. A., & Morris, K. D. (2008). Biblio rakali: the Australian water rat, *Hydromys chrysogaster* Geoffroy, 1804 (Muridae: Hydromyinae), a subject-specific bibliography. *Conservation Science Western Australia*, 7(1), 65-71.
- Balla, S. (1994). *Wetlands of the Swan Coastal Plain volume 1: Their nature and management* (Vol. 1). Perth, Western Australia: Water Authority of Western Australia and the Western Australian Department of Environmental Protection.
- Batley, G. E. (1989). Collection, preparation and storage of samples for speciation analysis. In G. E. Batley (Ed.), *Trace Element Speciation: Analytical Methods and Problems* (pp. 1-24). Boca Raton: CRC Press, Inc.
- Beck, W. S., & Hall, E. K. (2018). Confounding factors in algal phosphorus limitation experiments. *PLoS ONE*, 13.
- Biologic. (2021). *Caravel Copper Project – Aquatic Ecology Desktop Assessment DRAFTv1*. East Perth, W.A.:
- Blinn, D. W., Halse, S. A., Pinder, A. M., Shiel, R. J., & McRae, J. M. (2004). Diatom and micro-invertebrate communities and environmental determinants in the western Australian wheatbelt: a response to salinization. *Hydrobiologia*, 528, 229-248.
- BoM, Bureau of Meteorology. (2021). Climate Data Online. Retrieved 2021 <http://www.bom.gov.au/climate/data/index.shtml>
- Bray, J. R., & Curtis, J. T. (1957). An ordination of the upland forest communities of Southern Wisconsin. *Ecological Monographs*, 27(4), 325-349.
- Bressler, D., Stribling, J., Paul, M., & Hlcks, M. (2006). Stressor tolerance values for benthic macroinvertebrates in Mississippi. *Hydrobiologia*, 573, 155-172.
- Cain, D. J., Luoma, S. N., Carter, J. L., & Fend, S. V. (1992). Aquatic insects as bioindicators of trace element contamination in cobble-bottom rivers and streams. *Canadian Journal of Fisheries and Aquatic Sciences*, 49, 2141-2154.
- Cale, D. J., Halse, S. A., & Walker, C. D. (2004). Wetland monitoring in the Wheatbelt of south-west Western Australia: site descriptions, waterbird, aquatic invertebrate and groundwater data.
- Camargo, J., & Alonso, A. (2006). Ecological and toxicological effects of inorganic nitrogen pollution in aquatic ecosystems: A global assessment. *Environment International*, 32, 831-849.
- Carew, M. E., Pettigrove, V., Cox, R. L., & Hoffman, A. A. (2007). The response of Chironomidae to sediment pollution and other environmental characteristics in urban wetlands. *Freshwater Biology*, 52, 2444-2462.
- Clarke, C. J., George, R. J., Bell, R. W., & Hatton, T. J. (2002). Dryland salinity in south-western Australia: its origins, remedies, and future research directions. *Australian Journal of Soil Research*, 40, 93-113.
- Clarke, K. R., & Gorley, R. N. (2015). *PRIMER v7: User Manual/Tutorial*. Plymouth, United Kingdom: Primer.
- DAWE, Department of Agriculture, Water and the Environment. (2021). Protected Matters Search Tool (custom search). Retrieved 2021 www.environment.gov.au/erin/ert/epbc/index.html
- DBCA, Department of Biodiversity, Conservation and Attractions. (2019). *Wheatbelt Region Parks and Reserves Draft Management Plan*. Perth, WA:

- DBCA, Department of Biodiversity, Conservation and Attractions. (2021a). NatureMap: Mapping Western Australia's biodiversity (custom search). Retrieved 2021 <http://naturemap.dec.wa.gov.au/default.aspx>
- DBCA, Department of Biodiversity, Conservation and Attractions. (2021b). Threatened and Priority fauna database (custom search). from Department of Biodiversity, Conservation and Attractions <https://www.dpaw.wa.gov.au/plants-and-animals/threatened-species-and-communities/threatened-animals>
- DBCA, Department of Biodiversity, Conservation and Attractions. (2021c). Threatened and Priority Fauna List. from Department of Biodiversity, Conservation and Attractions <https://www.dpaw.wa.gov.au/plants-and-animals/threatened-species-and-communities/wa-s-threatened-ecological-communities>
- DPIRD, Department of Primary Industries and Regional Development. (1996). Department of Agriculture and Food, Western Australia (1996) "Salinity action plan,". *Journal of the Department of Agriculture, Western Australia*, 37(4), 122-123.
- DSEWPaC, Department of Sustainability, Environment, Water, Population and Communities. (2011). *Survey guidelines for Australia's threatened fish: Guidelines for detecting fish listed as threatened under the Environment Protection and Biodiversity Conservation Act 1999*. Department of Sustainability, Environment, Water, Population and Communities.
- Elser, J. J., Bracken, M. E. S., & Cleland, E. E. (2007). Global analysis of nitrogen and phosphorus limitation of primary producers in freshwater, marine, and terrestrial ecosystems. *Ecology Letters*, 10, 1135-1142.
- EPA, Environmental Protection Authority. (2002). *Position Statement No. 3: Terrestrial Biological Surveys as an Element of Biodiversity Protection*. Perth, Western Australia:
- EPA, Environmental Protection Authority. (2016a). *Technical Guidance: Sampling of Short-range Endemic Invertebrate Fauna*. Perth, Western Australia: Environmental Protection Authority.
- EPA, Environmental Protection Authority. (2016b). *Technical Guidance: Terrestrial Fauna Surveys*. Perth, Western Australia: Environmental Protection Authority.
- EPA, Environmental Protection Authority. (2018). *Environmental Factor Guideline: Inland Waters*. Perth, Western Australia: Environmental Protection Authority.
- Halse, S. A., Lyons, M. N., Pinder, A. M., & Shiel, R. J. (2004). Biodiversity patterns and their conservation in wetlands of the Western Australian wheatbelt. *Records of the Australian Museum*, 67, 337-364.
- Halse, S. A., & McRae, J. M. (2004). New genera and species of 'giant' ostracods (Crustacea: Cyprididae) from Australia. *Hydrobiologia*, 524, 1-52.
- Harvey, M. S. (2002). Short range endemism in the Australian fauna: some examples from non-marine environments. *Invertebrate Systematics*, 16, 555-570.
- Hodkinson, I. D., & Jackson, J. K. (2005). Terrestrial and aquatic invertebrates as bioindicators for environmental monitoring, with particular reference to mountain ecosystems. *Environmental Management*, 35(5), 649-666.
- IUCN, International Union for the Conservation of Nature and Natural Resources. (2021). The IUCN Red List of Threatened Species. Retrieved from www.iucnredlist.org
- Lynas, J., Storey, A. W., & Shiel, R. L. (2006). *Buntine-Marchagee Natural Diversity Recovery Catchment (BMRC): Wetland Invertebrate Fauna Monitoring: August 2005*.
- Lyons, M. N., Gibson, N., Keighery, G. J., & Lyons, S. D. (2004). Wetland flora and vegetation of the Western Australian wheatbelt. *Records of the Australian Museum*, 67, 39-89.
- Madrid, Y., & Zayas, Z. P. (2007). Water sampling: Traditional methods and new approaches in water sampling strategy. *Trends in Analytical Chemistry*, 26(4), 293-299.
- Mayer, X. M., Ruprecht, J. K., & Bari, M. A. (2005). *Stream salinity status and trends in south-west Western Australia. Report No. SLUI38*.
- Morgan, D. L., Beatty, S. J., Klunzinger, M. W., Allen, M. G., & Burnham, Q. F. (2011). *A Field Guide to Freshwater Fishes, Crayfishes and Mussels of South-Western Australia*. Beckenham, WA: SERCUL.
- Morgan, D. L., Gill, H. S., & Potter, I. (1998). Distribution, identification and biology of freshwater fishes in the south-western Australia. *Records of the Western Australia Museum, Supplement*, 56, 1-97.
- Morgan, D. L., Thorburn, D. C., & Gill, H. S. (2003). Salinization of the southwestern Western Australian Rivers and the implications of the inland fish fauna – the Blackwood River, a case study. *Pacific Conservation Biology*, 9, 161-171.
- Muhid, P., & Burford, M. A. (2012). Assessing nutrient limitation in a subtropical reservoir. *Inland Waters*, 2, 185-192.

- Norris, R., Dyer, F. J., Hairsine, P. B., Kennard, M., Linke, S., Merrin, L., . . . Williams, D. (2007). *Australian Water Resources 2005. Assessment of River and Wetland Health: A Framework for Comparative Assessment of the Ecological Condition of Australian Rivers and Wetlands*. Canberra, ACT.:
- Pen, L. J., & Potter, I. C. (1991). Biology of the western minnow, *Galaxias occidentalis* Ogilby (Teleostei: Galaxiidae), in a south-western Australian river 2. Size and age composition, growth and diet. *Hydrobiologia*, 211, 89-100.
- Pinder, A. M., Halse, S. A., McRae, J. M., & Shiel, R. J. (2004). Aquatic invertebrate assemblages of wetlands and rivers in the wheatbelt region of Western Australia. *Records of the Western Australian Museum*, 67, 7-37.
- Pinder, A. M., Halse, S. A., McRae, J. M., & Shiel, R. J. (2005). Occurance of aquatic invertebrates of the wheatbelt region of Western Australia in relation to salinity. *Hydrobiologia*, 543, 1-24.
- Pinder, A. M., Halse, S. A., Shiel, R. J., Cale, D. J., & McRae, J. M. (2002). Halophile aquatic invertebrates in the wheatbelt region of south-western Australia. *Verh. In. Ver. Limnol.*, 28, 1-8.
- Ramchandra, T. V., Rishiram, R., & Karthik, B. (2006). *Zooplankton as bioindicators: hydrobiological investigations in selected Bangalore lakes*. Bangalore:
- Smith, I. N., McIntosh, P., Ansell, T. J., Reason, C. J. C., & McInnes, K. (2000). Southwest Western Australian Winter Rainfall and its association with Indian Ocean climate variability. *International Journal of Climatology*, 20, 1913-1930.
- Thackway, R., & Cresswell, I. D. (1995). *An interim biogeographic regionalisation for Australia: A framework for setting priorities in the National Reserves System Cooperative Program*. Canberra, Australian Capital Territory: Australian Nature Conservation Agency.
- Timms, B. V., Pinder, A. M., & Campagna, V. S. (2009). The biogeography and conservation status of the Australian endemic brine shrimp *Parartemia* (Crustacea, Anostraca, Parartemiidae). *Conservation Science Western Australia*, 7(2), 413-427.
- Wagenhoff, A., Townsend, C. R., Phillips, N., & Matthaei, C. D. (2011). Subsidy-stress and multiple-stressor effects along gradients of deposited fine sediment and dissolved nutrients in a regional set of streams and rivers. *Freshwater Biology*, 56, 1916-1936.
- WAM, Western Australian Museum. (2021a). Arachnida and Myriapoda Collection Database (custom search). from WAM,, Western Australian Museum <http://www.museum.wa.gov.au>
- WAM, Western Australian Museum. (2021b). Crustacea Collection Database (custom search). from WAM,, Western Australian Museum <http://www.museum.wa.gov.au>
- WAM, Western Australian Museum. (2021c). Mollusca Collection Database (custom search). from WAM,, Western Australian Museum <http://www.museum.wa.gov.au>
- Warne, M. S., Batley, G. E., van Dam, R. A., Chapman, J. C., Fox, D. R., Hickey, C. W., & Stauber, J. L. (2018). *Revised Method for Deriving Australian and New Zealand Water Quality Guidelines Values for Toxicants*. Canberra:

APPENDICES

Appendix A: Default ANZECC & ARMCANZ (2000) water quality guidelines

Default trigger values for some physical and chemical stressors for south-west Australia for slightly disturbed ecosystems (TP = total phosphorus; FRP = filterable reactive phosphorus; TN = total nitrogen; NO_x = total nitrates/nitrites; NH₄⁺ = ammonium). Data derived from trigger values supplied Western Australia (ANZECC & ARMCANZ, 2000).

Aquatic Ecosystem	Analyte						
	TP mg/L	FRP mg/L	TN mg/L	NO _x mg/L	NH ₄ ⁺ mg/L	DO % saturation ⁱ	pH
Upland River ^f	0.02	0.010	0.45	0.20	0.06	90-na	6.5-8.0
Lowland River ^f	0.06	0.040	1.20	0.15	0.08	80-120	6.5-8.0
Lakes & Reservoirs	0.01	0.005	0.35	0.01	0.01	90-no data	6.5-8.0
Wetlands ^d	0.06	0.030	1.50	0.10	0.04	90-120	7.0 ^e -8.5 ^e

na = not applicable;

e = in highly coloured wetlands (gilven >52 g_{440m}⁻¹) pH typically ranges 4.5-6.5;

f = all values derived during base river flow conditions, not storm events;

i = dissolved oxygen values were derived from daytime measurements. Dissolved oxygen concentrations may vary diurnally and with depth. Monitoring programs should assess this potential variability.

Default trigger values for salinity and turbidity for the protection of aquatic ecosystems, applicable to slightly disturbed ecosystems in south-west Australia (ANZECC & ARMCANZ, 2000).

Salinity	(µs/cm)	Comments
Aquatic Ecosystem		
Upland & lowland rivers	120-300	Conductivity in upland streams will vary depending on catchment geology. Values at the lower end of the range are typically found in upland rivers, with higher values found in lowland rivers. Lower conductivity values are often observed following seasonal rainfall.
Lakes, reservoirs & wetlands	300-1,500	Values at the lower end of the range are observed during seasonal rainfall events. Values even higher than 1,500 µScm ⁻¹ are often found in saltwater lakes and marshes. Wetlands typically have conductivity values in the range of 500-1,500 µScm ⁻¹ over winter. Higher values (>3,000 µScm ⁻¹) are often measured in wetlands in summer due to evaporative water loss.
Turbidity	(NTU)	
Aquatic Ecosystem		
Upland & lowland rivers	10-20	Turbidity and SPM are highly variable and dependent on seasonal rainfall runoff. These values representative of base river flow in lowland rivers.
Lakes, reservoirs & wetlands	10-100	Most deep lakes have low turbidity. However, shallow lakes have higher turbidity naturally due to wind-induced re-suspension of sediments. Wetlands vary greatly in turbidity depending on the general condition of the catchment, recent flow events and the water level in the wetland.

Guideline values for toxicants at alternative levels of protection (in mg/L). Values in grey shading are applicable to typical *slightly-moderately disturbed systems* (ANZG, 2018).

Chemical	Guideline values for freshwater mg/L			
	Level of protection (% species)			
	99%	95%	90%	80%
Metals and metalloids				
Aluminium pH > 6.5	0.027	0.055	0.08	0.15
Aluminium pH < 6.5	ID	ID	ID	ID
Arsenic (As III)	0.001	0.024	0.094 ^C	0.36 ^C
Arsenic (AsV)	0.0008	0.013	0.042	0.14 ^C
Boron	0.09	0.37 ^C	0.68 ^C	1.3 ^C
Cadmium H	0.00006	0.0002	0.0004	0.0008 ^C
Chromium (Cr III) H	ID	ID	ID	ID
Chromium (Cr IV)	0.00001	0.001 ^C	0.006 ^A	0.04 ^A
Cobalt	ID	ID	ID	ID
Copper H	0.001	0.0014	0.0018 ^C	0.0025 ^C
Iron G	ID	ID	ID	ID
Lead H	0.001	0.0034	0.0056	0.0094 ^C
Manganese	1.2	1.9 ^C	2.5 ^C	3.6 ^C
Mercury (inorganic) B	0.00006	0.0006	0.0019 ^C	0.0054 ^A
Mercury (methyl)	ID	ID	ID	ID
Molybdenum	ID	ID	ID	ID
Nickel H	0.008	0.011	0.013	0.017 ^C
Selenium (Total) B	0.005	0.011	0.018	0.034
Selenium (SeIV) B	ID	ID	ID	ID
Uranium	ID	ID	ID	ID
Vanadium	ID	ID	ID	ID
Zinc H	0.0024	0.008 ^C	0.015 ^C	0.031 ^C
Non-metallic inorganics				
Ammonia D	0.32	0.9 ^C	1.43 ^A	2.3 ^A
Chlorine E	0.0004	0.003	0.006 ^A	0.013 ^A
Nitrate J	1.0	2.4	3.4 ^C	17 ^A

Notes:

Most guideline values listed here for metals and metalloids are *High Reliability* figures, derived from field or chronic NOEC data (see 3.4.2.3). The exceptions are *Moderate Reliability* for freshwater aluminium (ph>6.5) and manganese.

Most non-metallic inorganics are *Moderate Reliability* figures, derived from acute LC50 data (see section 3.4.2.3). The exception is *High Reliability* for freshwater ammonia.

A = Figure may not protect key test species from acute toxicity (and chronic) (Section 8.3.4.4).

B = Chemicals for which possible bioaccumulation and secondary poisoning effects should be considered (see Sections 8.3.3.4 and 8.3.5.7).

C = Figure may not protect key test species from chronic toxicity (this refers to experimental chronic figures or geometric mean for species) - check Section 8.3.7 for spread of data and its significance.

D = Ammonia as TOTAL ammonia as [NH₃_N] at pH 8. For changes in trigger value with pH refer to Section 8.3.7.2

E = Chlorine as Total Chlorine, as [Cl]; see Section 8.3.7.2

F = Figures protect against toxicity and do not relate to eutrophication issues. Refer to Section 3.3 if eutrophication is a concern.

G = There were insufficient data to derive a reliable guideline value for iron. The current Canadian guideline level is 0.3 mg/L which could be used as an interim working level. However, further data are required to establish a figure appropriate for Australian and New Zealand waters.

H = Chemicals for which algorithms have been provided in table 3.4.3 to account for the effects of hardness. The values have been calculated using a hardness of 30 mg/L CaCO₃. These should be adjusted to the site-specific hardness (see Section 3.4.3).

J = Figures relate to toxicity (not eutrophication). The ANZECC & ARMCANZ (2000) DGVs for nitrate have been found to be erroneous (ANZG, 2018). In the absence of updated values, ANZG (2018) suggest reference is made to current New Zealand nitrate toxicity guidelines, specifically the 'Grading' GVs published in the 'Updating Nitrate Toxicity Effects on Freshwater Aquatic Species' report (NIWA, 2013). These New Zealand Grading DGVs for N₂O₃ are provided above.

Appendix B: Habitat results

Percentage cover by each of the in-stream habitat types.

	Site	Inorganic Sediment	Submerged Macrophytes	Emergent Macrophytes	Algae	Large Woody Debris	Detritus	Roots	Habitat Diversity
Study Area	CP01	50	0	0	50	0	0	0	2
	CP02	25	25	10	0	8	22	0	5
	CP03	60	20	7	0	5	8	0	5
	CP04	37	68	2	0	0	1	2	5
	CP06	10	40	20	20	5	5	0	6
	Lake Ninan	98	0	0	0	1	1	0	3
Reference	CP05	97	0	0	0	1	2	0	3
	CP07	90	2	2	0	4	2	0	5
	Lake Hinds	60	40	0	0	0	0	0	2

Percentage cover by each of the in-stream sediment types.

	Site	Sand	Silt	Clay
Study Area	CP01	60	20	20
	CP02	40	40	20
	CP03	60	20	20
	CP04	0	0	100
	CP06	0	0	100
	Lake Ninan	20	30	50
Reference	CP05	15	15	70
	CP07	60	20	20
	Lake Hinds	0	20	80

Appendix C: Water quality results

Highlighted cells refer to values which are in excess of: ■ > the 99% ANZECC DGV, and ■ > the 95% DGV.

Analyte	LOR	Unit	ANZG DGVs (Wetlands)	ANZG DGVs (Lakes)	ANZG toxicity DGVs		Within Study Area						Reference		
					99% DGV	95%	CP01	CP02	CP03	CP04	CP06	Lake Ninan	CP05	CP07	Lake Hinds
Temp		°C					25.4	19.8	17.6	14.4	19.4	19.9	22.9	18.3	25.5
EC		mS/cm	1.5	1.5			241.5	14.4	7.2	3.2	31.9	141.6	109.1	49.4	141.4
Salinity		ppt					226.1	9.4	4.7	2.1	22.6	126.6	84.8	37.6	109.7
pH		pH units	7.0 - 8.5	6.5 - 8.0			7.40	9.04	10.12	10.18	10.02	8.00	7.81	8.31	8.14
DO		%	90-120	90 (lower limit)			60.4	107.9	130.9	92.8	136.0	108.2	49.6	73.3	19.9
Turbidity	0.1	NTU	10	100			8.8	3.0	1.3	4.1	3.1	1.5	2.5	4.8	38.0
TSS	1	mg/L					34	5	1	5	4	19	8	9	163
Alkalinity	1	mg/L					54	175	129	51	86	135	109	124	136
Hardness	1	mg/L					13300	1330	704	303	4840	13400	12800	7420	22100
CO ₃	1	mg/L					<1	31	91	16	84	<1	<1	<1	<1
HCO ₃	1	mg/L					54	144	38	36	2	135	109	124	136
Cl	1	mg/L					144000	5540	2460	1190	13200	67200	44700	20400	63200
Ca	0.1	mg/L					697	59.3	27.9	26	464	449	1060	746	1580
Mg	0.1	mg/L					2800	287	154	57.8	895	2970	2460	1350	4420
K	0.1	mg/L					556	105	48.7	15.6	144	452	536	240	1430
Na	0.1	mg/L					95200	3210	1430	634	7200	43900	27400	12600	35600
SO ₄	0.1	mg/L					7270	534	298	132	1860	5170	6290	3380	10800
S	0.1	mg/L					2520	205	113	49.5	744	2060	2480	1230	4250
N_NH ₃	0.01	mg/L	0.90	0.90	0.32		<0.10	<0.01	0.02	0.03	0.03	0.66	2.26	0.01	0.09
N_NO ₃	0.01	mg/L	2.40	2.40	1.00		0.02	<0.01	<0.01	0.02	<0.01	<0.01	<0.01	<0.01	<0.01
N_NOx	0.01	mg/L	0.10	0.01			0.02	<0.01	<0.01	0.03	<0.01	<0.01	<0.01	<0.01	<0.01
N_total	0.01	mg/L	1.50	0.35			1.46	1.74	0.78	1.53	2.09	4.21	4.10	1.98	2.03
P_total	0.005	mg/L	0.06	0.01			0.084	0.041	0.017	0.058	0.035	0.019	0.068	0.054	0.112
Al	0.005	mg/L			0.027	0.055	<0.050	<0.005	<0.005	0.015	<0.005	<0.025	0.012	0.007	<0.025
As	0.005	mg/L			0.001	0.024	<0.0050	0.0013	0.0007	0.0003	0.0007	<0.0025	0.0012	0.0016	0.0028
B	0.001	mg/L			0.09	0.37	0.078	0.0516	0.0350	0.0788	0.089	0.094	0.094	0.082	0.266
Ba	0.1	mg/L					1.53	1.45	0.99	0.53	4.28	3.76	1.61	3.47	13.70
Cd	0.002	mg/L			0.00006	0.0002	<0.0020	<0.00005	<0.00005	<0.00005	<0.0002	<0.0010	<0.0004	<0.0002	<0.0010
Cr	0.005	mg/L			0.00001	0.001	<0.0050	<0.0002	<0.0002	<0.0002	<0.0005	<0.0025	<0.0010	<0.0005	<0.0025
Co	0.0002	mg/L					0.0024	0.0002	0.0002	0.0004	0.0004	0.0005	<0.0002	0.0010	0.0008
Cu	0.0002	mg/L			0.0010	0.0014	0.0096	0.00216	0.00124	0.00032	0.0021	0.0054	0.0015	0.0024	0.0090
Fe	0.05	mg/L			0.300*		<0.050	0.017	0.003	0.088	<0.005	<0.025	<0.010	0.009	<0.025
Pb	0.001	mg/L			0.001	0.0034	0.0119	<0.0001	<0.0001	<0.0001	<0.0002	<0.0010	<0.0004	<0.0002	<0.0010
Mn	0.0025	mg/L			1.20	1.90	0.4410	0.0015	0.0009	0.0072	0.0115	0.0217	0.0337	0.0494	<0.0025
Mo	0.0001	mg/L					0.0029	0.0034	0.0020	0.0002	0.0030	0.0026	0.0008	0.0027	0.0069
Ni	0.0005	mg/L			0.008	0.011	<0.0050	0.0007	<0.0005	<0.0005	0.0011	0.0035	0.0058	0.0050	0.0067
Se	0.01	mg/L			0.005	0.011	<0.020	0.0007	0.0006	0.0002	<0.002	<0.010	<0.004	<0.002	<0.010
U	0.0001	mg/L					<0.0010	0.00061	0.00018	0.00023	0.0050	0.0059	0.0013	0.0081	0.0451
V	0.005	mg/L					<0.0050	0.0029	0.0032	0.0004	0.0035	0.0035	0.0012	0.0014	0.0088
Zn	0.05	mg/L			0.0024	0.008	<0.050	<0.001	0.005	0.001	<0.005	<0.025	<0.010	<0.005	<0.025

Appendix D: Aquatic invertebrate taxonomic list.

Values are log abundances (i.e., 1=1 individual, 2 = 2-10, 3 = 11-100, 4 = 101-1000).

Phylum/Class/Order	Family	Lowest taxon	Cons. Cat.	Within Study Area						Reference				
				CP01	CP02	CP03	CP04	CP06	LN01	CP05	CP07	LH01		
NEMATODA		Nematoda sp.	I											3
ANNELIDA														
	Oligochaeta													
	Tubificida	Naididae	C			1								
		<i>Pristina osborni</i>	I										3	
		Oligochaeta sp. (earthworm)												
MOLLUSCA														
	Gastropoda	Pomatiopsidae	I			3		4						
		<i>Coxiella</i> sp.												
CRUSTACEA														
	Malacostraca													
	Amphipoda	Chiltoniidae	AE		4	5	5	2					2	
		<i>Austrochiltonia subtenuis</i>												
	Branchiopoda													
	Anostraca		I				4							
		Artemiidae	C	3						5	5			
		<i>Artemia</i> sp. Indet.	I							5				
		Parartemiidae	WA								2		3	
		<i>Parartemia extracta</i>												
	Diplostraca		I				3							
		Daphniidae	I		1								4	
		<i>Daphnia</i> sp. Indet.												
		<i>Daphnia australis</i>	AE										4	
		<i>Daphnia pusilla</i>	AE					5					5	
		<i>Simocephalus vetulus elisabethae</i>	AE				4							
	Maxillopoda													
	Calanoida	Centropagidae	AE		5	4	3							
		<i>Boeckella triarticulata</i>												
		<i>Calamoecia</i> sp.	I	2										
	Cyclopoida	Cyclopidae	C						3					
		<i>Apocyclops dengizicus</i>												

Phylum/Class/Order	Family	Lowest taxon	Cons. Cat.	Within Study Area						Reference			
				CP01	CP02	CP03	CP04	CP06	LN01	CP05	CP07	LH01	
		<i>Mesocyclops brooksi</i>	WA				3						
		<i>Pescecyclus cf. arnaudi</i>	AE							3	4	5	4
	Harpacticoida	Harpacticoida sp.	I		3	2		2		2			
	Ostracoda												
	Podocopida	Cyprididae											
		Ostracoda Indet.	I				3			1			
		<i>Alboa worooa</i>	AE		4	2							
		<i>Australocypris insularis</i>	WA								4	3	
		<i>Australocypris</i> sp. n.	I							2		4	4
		Cyprididae sp.	I		4			4		2	3	4	4
		<i>Cyprinotus cingalensis</i>	A		4	3							
		<i>Mytilocypris ambiguosa</i>	AE		4	2		4		1	2		
		<i>Mytilocypris mytiloides</i>	AE		4	2		4				4	
		<i>Platycypris baueri</i>	AE								3	4	3
		<i>Reticypris</i> sp.	I								4		
		<i>Sarscypridopsis aculeata</i>	C		3		3						
	ARTHROPODA												
	Arachnida												
	Sarcoptiformes	Oribatida sp.	I		2								
	Trombidiformes	Arrenuridae						2					
		Hydrachnidae						1					
	Insecta												
		Staphylinidae											
		Staphylinidae sp.	I	2							1		
		Carabidae					1						
		Carabidae sp. (A)	I										
		Curculionidae											
		Curculionidae sp. (A)	I							1			
		Dytiscidae											
		<i>Allodessus bistrigatus</i>	AE				2						
		<i>Antiporus gilberti</i>	AE				1						
		<i>Hyphydrus</i> sp. (L)	I				2						
		<i>Megaporus howitti</i>	AE				1						

Phylum/Class/Order	Family	Lowest taxon	Cons. Cat.	Within Study Area						Reference			
				CP01	CP02	CP03	CP04	CP06	LN01	CP05	CP07	LH01	
		<i>Necterosoma penicillatum</i>	AE		3	3	3			2	2		2
		<i>Necterosoma</i> sp. (L)	I		3	3	2						
		<i>Rhantus suturalis</i>	C				2						
		<i>Sternopriscus multimaculatus</i>	AE				1						
	Heteroceridae	Heteroceridae sp. (A)	I						1				
	Hydrophilidae	<i>Berosus approximans</i>	AE								1		
		<i>Berosus discolor</i>	AE			1							
		<i>Berosus munitipennis</i>	AE						1				
		<i>Berosus</i> sp. (L)	I			3							
		<i>Limnoxenus</i> sp. (L)	I				1						
Diptera	Cecidomyiidae	Cecidomyiidae sp.	I	1									
	Ceratopogonidae	Ceratopogonidae sp. (P)	I				2						
		Ceratopogoninae sp.	I				3						
		Ceratopogoninae sp. (L)	I								2		
		Chironomidae sp. (P)	I		2	2					2		
		<i>Chironomus alternans</i>	A		3								
		<i>Cryptochironomus griseidorsum</i>	AE				1						
		<i>Dicrotendipes</i> cf. <i>cumberlandensis</i>	I			3							
		<i>Dicrotendipes</i> sp.	I			4	2				4		
		nr. <i>Gymnometriochnemus</i> sp.	I							1			
		<i>Polypedilum</i> sp.	I			3					3		
		<i>Procladius paludicola</i>	AE		3	3	2	2				2	
		<i>Procladius</i> sp. P1	I			3							
		<i>Tanytarsus barbatarsis</i>	AE		3	3	3	2		3	4	4	
		<i>Tanytarsus</i> sp.	I										1
	Ephydriidae	Ephydriidae sp.	I								3		
		Ephydriidae sp. (L)	I							3			

Phylum/Class/Order	Family	Lowest taxon	Cons. Cat.	Within Study Area						Reference			
				CP01	CP02	CP03	CP04	CP06	LN01	CP05	CP07	LH01	
		Ephydriidae sp. (P)	I							2			
	Muscidae	Muscidae sp. (L)	I				1			1			
Hemiptera	Corixidae	<i>Agraptocorixa eurynome</i>	AE				3						
	Corixoidea	Corixoidea sp. (imm)	I			2	2						
	Micronectidae	<i>Micronecta annae</i>	AE				3						
	Notonectidae	Anisops sp.	I				3						
		<i>Anisops thienemanni</i>	AE				3						
		Notonectidae sp. (imm)	I	1			2						
Lepidoptera	Nymphalidae	Nymphalinae sp. (imm)	I				2						
Odonata													
Anisoptera	Aeshnidae	Aeshnidae sp. (imm)	I		3								
		<i>Hemianax papuensis</i>	A			2	2						
		Anisoptera sp. (imm)	I			3							
Zygoptera	Coenagrionidae	<i>Ischnura heterosticta</i>	A				1						
	Corduliidae	<i>Hemicordulia tau</i>	AE			2							
	Lestidae	<i>Austrolestes annulosus</i>	AE		2	2	3						
	Libellulidae	<i>Orthetrum caledonicum</i>	A				2						
		Zygoptera sp. (imm)	I		2	3							
Thysanoptera		Thysanoptera sp.	I	1									
Trichoptera	Leptoceridae	Leptoceridae sp. (imm)	I				2						
		<i>Triplectides australis</i>	AE				2						

Appendix E: Fauna Taking (Biological Assessment) License



Department of Biodiversity,
Conservation and Attractions

FAUNA TAKING (BIOLOGICAL ASSESSMENT) LICENCE

Regulation 27, Biodiversity Conservation Regulations 2018

Licence Number: BA27000505
Licence Holder: Ms Jessica Delaney
Biologic Environmental Survey
24-26 Wickham Street
EAST PERTH WA 6004
Date of Issue: 10/09/2021
Date Valid From: 20/09/2021
Date of Expiry: 19/09/2022

LICENSED ACTIVITIES

Subject to the terms and conditions on this licence, the licence holder may –

1. Take and disturb fauna for Caravel Minerals Aquatic Fauna Survey for a baseline aquatic ecosystem assessment of the lakes and claypans around a mining project surrounding Wongan Hills within the Wheatbelt which is required to provide sufficient information for planning and inform environmental impact assessment. Box traps to capture fish and crayfish, Dip / D-frame / sweep nets, fyke nets, plankton nets, collection of sediment samples for rehydration trials in the lab and visual observational waterbird census. All invertebrate fauna (macroinvertebrates, hyporheic species and zooplankton) will be euthanised on site in 100% ethanol and Fish species will be identified in the field and standard length measurements taken before being released alive to the site where they were collected.

LOCATIONS

1. Within Western Australia's central wheatbelt, approximately 120km north of Perth. The survey includes lakes and claypans around Lake Ninan, southwest of Wongan Hills.

AUTHORISED PERSONS

The following persons or persons of the specified class may assist in carrying out the licensed activities:

1. Kim Nguyen
2. Morgan Lythe
3. Alex Riemer
4. Syngeon Rodman
5. Anton Mittra
6. Siobhan Paget
7. Isabelle Johansson
8. Courtney Wilkins

CONDITIONS

1. Fauna must not be taken on CALM land, (as defined in the Conservation and Land Management Regulations 2002), unless authorised by a written notice of a lawful authority issued under regulations 4 and 8 of the Conservation and Land Management Regulations 2002.



Department of Biodiversity,
Conservation and Attractions

2. If persons, other than the licence holder, are authorised to carry out/assist in carrying out the activities under the licence, the licence holder must ensure those persons have read and understand the licence terms and conditions.
3. The written authorisation of the person in possession or occupation of the land accessed and upon which fauna is taken, as required under regulation 101(2) and referred to in "Additional information" below, must:
 - a) state location details (including lot or location number, street/road, suburb and local government authority);
 - b) state land owner or occupier name, and contact phone number;
 - c) specify the time period that the authorisation is valid for;
 - d) be signed and dated; and
 - e) be attached to this licence at all times.
4. This licence, and any written authorisation or lawful authority which authorises the take of fauna on specified locations must be carried at all times while conducting licensed activities and be produced on demand by a wildlife officer.
5. If a species of fauna listed as a threatened species under Section 19 of the *Biodiversity Conservation Act 2016* is inadvertently captured, that species is to be released immediately at the point of capture. If the fauna is injured or deceased, the licence holder shall contact the DBCA Wildlife Licensing Section (wildlifelicensing@dbca.wa.gov.au) for advice on treatment or disposal. Details of any capture of threatened fauna must be included in the "Return of Fauna Taken."
6. The licence holder must not:
 - a) release any fauna in any area where it does not naturally occur;
 - b) transfer fauna to any other person or authority (other than the Western Australian Museum) unless approved in writing by the CEO; or
 - c) dispose of the remains of fauna in any manner likely to interfere the natural or present day distribution of the species.
7. The licence holder must not take and remove more than ten specimens of any one protected species of fauna from any location less than 20km apart. Where exceptional circumstances make it necessary to take a larger number of specimens from a particular location in order to obtain adequate statistical data, the collector must proceed with circumspection and justify their actions to the Director General in advance.
8. All holotypes and syntypes and a half share of paratypes of species or subspecies permitted to be permanently taken under this licence must be donated to the Western Australian Museum. Duplicates (one pair in each case) of any species collected, which represents a significant extension of geographic range must be offered to the Western Australian Museum.
9. All specimens and material retained under the authority of this licence must be offered to the Western Australian Museum for loan, for inclusion in its collection, or on request be made available to other persons involved in relevant scientific studies.
10. The licence holder must create, compile and maintain records and information as required in a DBCA approved "Return of Fauna Taken" of all fauna taking activities as they occur.
11. A DBCA approved "Return of Fauna Taken" must be completed in full (including nil taking details) and submitted to DBCA Wildlife Licensing Section (wildlifelicensing@dbca.wa.gov.au) prior to the end of each annual period of the licence (from the valid from date) (refer to "Additional Information" section below).



Department of Biodiversity,
Conservation and Attractions



Danny Stefoni
LICENSING OFFICER
WILDLIFE PROTECTION BRANCH

Delegate of CEO

ADDITIONAL INFORMATION

1. It is an offence to take any species of fauna listed as a threatened species under Section 19 of the *Biodiversity Conservation Act 2016* unless the person is authorised under Section 40. The penalty ranges between \$300 000 and \$500 000; Section 150 Biodiversity Conservation Act 2016.
2. Regulation 82 empowers the CEO to add, substitute or delete a term or condition of a licence or to correct errors. Such power may be exercised on application of a licence holder or by the CEO's own initiative. If an amendment to a licence term or condition is required, please contact the CEO or the Licensing Section on wildlifelicensing@dbca.wa.gov.au in the first instance. The licence holder, if adversely affected by a condition imposed in this licence, may apply to the State Administrative Tribunal for review of the decision of the CEO to impose that condition on a licence: regulation 89(2) Biodiversity Conservation Regulations 2018.
3. A person must not contravene a condition of a licence. The penalty for an offence involving the contravention of a condition of a licence is a fine of \$10 000: regulation 84 of the Biodiversity Conservation Regulations 2018.
4. It is an offence for persons authorised by this licence to enter land that is not in their possession or under their control without first having the *prior* written authorisation of the current owner or occupier of the land to:
 - a) enter the land; and
 - b) carry out the activity authorised by this licence.The penalty for this offence is a fine of \$5 000: regulation 101(2) of the Biodiversity Conservation Regulations 2018.
5. The licence holder must be able to produce for inspection upon request any information or records required by regulation 85(2) of the Biodiversity Conservation Regulations 2018 Penalty \$10 000. It is an offence to knowingly include false or misleading information or make statements in records: regulation 85(3) of the Biodiversity Conservation Regulations 2018 Penalty \$10 000. It is an offence to include any information or make any statement in a return that the licence holder knows to be false or misleading in a material particular: regulation 86 (2) of the Biodiversity Conservation Regulations 2018 Penalty \$10 000.
6. The approved DBCA "Return of Fauna Taken" data file can be downloaded from the DBCA webpage (<https://www.dpaw.wa.gov.au/plants-and-animals/licences-and-authorities>).



Department of Biodiversity,
Conservation and Attractions



Danny Stefoni
LICENSING OFFICER
WILDLIFE PROTECTION BRANCH

Delegate of CEO

ADDITIONAL INFORMATION

1. It is an offence to take any species of fauna listed as a threatened species under Section 19 of the *Biodiversity Conservation Act 2016* unless the person is authorised under Section 40. The penalty ranges between \$300 000 and \$500 000; Section 150 Biodiversity Conservation Act 2016.
2. Regulation 82 empowers the CEO to add, substitute or delete a term or condition of a licence or to correct errors. Such power may be exercised on application of a licence holder or by the CEO's own initiative. If an amendment to a licence term or condition is required, please contact the CEO or the Licensing Section on wildlifelicensing@dbca.wa.gov.au in the first instance. The licence holder, if adversely affected by a condition imposed in this licence, may apply to the State Administrative Tribunal for review of the decision of the CEO to impose that condition on a licence: regulation 89(2) Biodiversity Conservation Regulations 2018.
3. A person must not contravene a condition of a licence. The penalty for an offence involving the contravention of a condition of a licence is a fine of \$10 000: regulation 84 of the Biodiversity Conservation Regulations 2018.
4. It is an offence for persons authorised by this licence to enter land that is not in their possession or under their control without first having the *prior* written authorisation of the current owner or occupier of the land to:
 - a) enter the land; and
 - b) carry out the activity authorised by this licence.The penalty for this offence is a fine of \$5 000: regulation 101(2) of the Biodiversity Conservation Regulations 2018.
5. The licence holder must be able to produce for inspection upon request any information or records required by regulation 85(2) of the Biodiversity Conservation Regulations 2018 Penalty \$10 000. It is an offence to knowingly include false or misleading information or make statements in records: regulation 85(3) of the Biodiversity Conservation Regulations 2018 Penalty \$10 000. It is an offence to include any information or make any statement in a return that the licence holder knows to be false or misleading in a material particular: regulation 86 (2) of the Biodiversity Conservation Regulations 2018 Penalty \$10 000.
6. The approved DBCA "Return of Fauna Taken" data file can be downloaded from the DBCA webpage (<https://www.dpaw.wa.gov.au/plants-and-animals/licences-and-authorities>).