Mesa H Project

Baseline Aquatic Ecosystem Survey
Wet Season Sampling 2016

Final Report
April 2017

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Wet Season Sampling 2016

Prepared for:

Astron Environmental Services Pty Ltd

129 Royal Street, east Perth, WA 6004
T: +61 8 9421 9600
E: perth@astron.com.au

by:

Wetland Research & Management

16 Claude Street, Burswood, WA 6100
T: +61 8 9361 4325
E: admin@WetlandResearch.com.au

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Frontispiece (left to right): freshwater mussels (*Velesunio* spp.) at RRU6, upstream of the Jimmawurrada-Robe confluence; RRD5 at Gnieraoora/Dthulurat; measuring milkfish (*Chanos chanos*) at RRD4 in the Medawandy Waters area.

Study Team

WRM

Project management: Jess Delaney & Chris Hofmeester
Field work: Adam Harman, Emma Thillainath & Fintan Angel
Macroinvertebrate identification: Bonita Clark, Kim Nguyen & Anton Mittra
Macroinvertebrate QA/QC: Alex Riemer, Anton Mittra & Chris Hofmeester
Report: Chris Hofmeester & Susan Davies
Internal review: Dr Andrew Storey

External Specialist Taxonomists

Dr Don H. Edward, The University of Western Australia (Chironomidae)
Dr Russell Shiel, The University of Adelaide (microinvertebrates)

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Disclaimer

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EXECUTIVE SUMMARY

This report summarises the results of a baseline sampling program for aquatic ecosystems of the Robe River system, both upstream and downstream of the proposed Mesa H iron ore development ("the Project"), managed by Rio Tinto on behalf of the Proponent (Robe River Mining Co. Pty Ltd) in the West Pilbara region of Western Australia. The aim of the sampling program was to document the current ecological condition of the Robe River prior to the implementation of the Mesa H development, which will require dewatering and surplus water discharge, which will result in a surface discharge footprint along the Robe River. The baseline survey included a number of named permanent pools in the Project area known to have ecological and cultural value, such as Gnieraoora (or Dthulurat) at Yeera Bluff. This report also includes a review of previous aquatic fauna surveys of the Robe River, and other nearby systems (*e.g.* Bungaroo Creek, Jimmawurrada Creek and Mungarathoona Creek), including conservation significant species known to occur in the vicinity of the Project area, which provides regional context for the sampling program.

The sampling design included six sites downgradient of the confluence of Jimmawurrada Creek and the Robe River (immediately upstream of the existing Mesa J operation) (RRD1 - 6), which are likely to fall within the zone of dewatering discharge (*i.e*. 'potentially exposed' sites), and six sites (RRU1 - 6) located upstream of the confluence (*i.e.* 'reference' sites). Sites were surveyed during the late wet season (April/May) 2016. The permanency and consistency of flow in the Robe River is already influenced by groundwater abstraction and dewatering discharge from the existing Mesa J mine operation, and so the current sampling program documents "current" ecological condition, more so than "natural" condition. Water quality, microinvertebrates (zooplankton), hyporheic fauna, macroinvertebrates and fish were successfully sampled at each of the 12 sites.

The main findings of the baseline survey were:

- Water quality was highly variable amongst sites, with salinity levels ranging from fresh (592 μS/cm) to brackish (1,700 μS/cm), pH from circum-neutral (6.9) to slightly alkaline (7.9) and dissolved oxygen from hypoxic (14.5%) to supersaturated (134.9%). There were no obvious longitudinal gradients in water quality parameters upstream or downstream. Site RRU6 (~1 km upstream of the Jimmawurrada-Robe confluence) and the downstream sites tended to have higher salinity (as electrical conductivity and total dissolved solids), alkalinity, hardness and concentrations of associated ions, than sites upstream. Some of this variability was attributed to differences in volume of the remnant pools sampled and evapoconcentration effects under recessional flows, however, higher concentrations of some ions downstream of the Jimmawurrada-Robe confluence (most notably magnesium and sulfate) was considered a possible artefact of current mining operations.
- Exceedances of ANZECC/ARMCANZ (2000) default trigger values for the protection of 95% of species in slightly-moderately disturbed tropical northern Australian systems were recorded for nitrogen nutrients (N-total, N-NO_x and N-NH_3) at most sites upstream and downstream of the Jimmawurrada-Robe confluence. Elevated background levels of N-NO_3 and N-NH_3 within the Project area are unsurprising, given that the Robe River catchment is already effected by current and historic pastoral practices, with groundwaters also appearing to be enriched. Elevated N-total and N-NO_x downstream of the Jimmawurrada-Robe confluence may also reflect discharge of nitrogen-enriched groundwater from existing mine operations, though the relative contribution of anthropogenic and natural sources to nitrogen enrichment in surface and groundwater of the Project area is unknown. The majority of heavy metal analytes, with the exception of dissolved zinc at RRU5 and RRD3, did not exceed ANZECC/ARMCANZ (2000) default 95% trigger values in the Project area.
- A total of 81 microinvertebrate taxa were recorded from the Project area, of which 46 were present at potentially exposed sites downstream of the Jimmawurrada-Robe confluence, and 69

were recorded at upstream reference sites. The microinvertebrate fauna was generally typical of that commonly recorded from tropical/sub-tropical freshwater systems, comprising Protista, Rotifera, Copepoda, Cladocera (water fleas) and Ostracoda (seed shrimp), with species from the family Lecanidae dominating within the Rotifera. There were no significant differences in total mean microinvertebrate taxa richness between reference and potentially exposed sites, nor was there any significant difference in richness of any of the major microinvertebrate groups (protists, rotifers, micro-crustaceans) between these sites. One microinvertebrate species listed for conservation significance, the copepod *Eodiaptomus lumholtzi* (IUCN Vulnerable), was recorded at potentially exposed site RRD6. The conservation listing of this species is considered in need of revision because it is known to occur at numerous locations across the Pilbara region, including sites along the Fortescue River, Coondiner Creek, Kalgan Creek, Weeli Wolli Creek, Mindy Mindy Creek, Koodaideri Springs, Caves Creek, Duck Creek and the Cane River, as well as Papua New Guinea.

- A total of 59 taxa were recorded from hyporheic samples, the majority of which were species not specially adapted to groundwater environments (stygoxene). Of these 59 taxa, 8% were considered stygobitic (obligate groundwater inhabitants), 31% occasional hyporheic stygophiles (species that use the hyporheic zone seasonally or during early life history stages), and 2% possible hyporheic taxa. There were no obvious longitudinal gradients or patterns in hyporheic taxa richness between reference and potentially exposed sites, though hyporheic taxa richness was relatively high at RRD1, RRU6, RRD2 and RRU4, suggesting strong connectivity between ground- and surface waters at these sites. Stygobitic taxa collected included the amphipod *Nedsia* sp., the thermosbaenacean *Halosbaena tulki,* and the ostracods *Candonopsis* cf. *tenuis* and *Vestalenula marmonieri.* Of these, *Nedsia* sp. is considered a potential short range endemic (SRE) species. *Nedsia* sp. was collected from sites potentially exposed to dewatering discharge (RRD1 – 4), as well as upstream reference sites (RRU3, RRU4 and RRU6).
- A total of 148 macroinvertebrate taxa were recorded from surface waters (117 from upstream reference sites, and 116 from downstream potentially exposed sites), with composition typical of freshwater systems throughout the world, being dominated by Insecta, in particular Diptera (true flies) and Coleoptera (aquatic beetles). There were no clear upstream/downstream gradients in macroinvertebrate richness within the Project area, with no significant difference in mean total taxa richness, or mean richness of most major macroinvertebrate groups, between reference and potentially exposed sites. Similarly, multivariate analysis detected no distinguishable separation of reference or potentially exposed sites based on macroinvertebrate species assemblage structure. One macroinvertebrate species listed for conservation significance, the Pilbara pin damselfly *Eurysticta coolawanyah* (IUCN Near Threatened), was recorded at potentially exposed downstream sites RRD3 and RRD4.
- A total of 3,515 individual fish, representing 11 species, were recorded in the Project area. True freshwater species included western rainbowfish, spangled perch, Pilbara tandan (eel-tailed catfish), Fortescue grunter, barred grunter, Terapontidae (grunter) hybrids and bony bream. Estuarine/marine vagrant fish species included milkfish, tarpon/ox-eye herring, mullet and banded scat/striped butterfish, the majority of which were recorded at the downstream reach. The conservation listed Fortescue grunter (*Leipotherapon aheneus*; IUCN Lower Risk/Near Threatened; Parks and Wildlife Priority 4) was the second most abundant fish species of the Project area, recorded at all upstream and downstream sites. Similar to other fauna indices, there was no significant difference in mean total abundance of fish between upstream and downstream sites, nor was there any significant difference in mean abundance of each individual species within the Project area. Healthy (breeding) populations of western rainbowfish, the most abundant fish species of the Project area, were recorded from upstream and downstream reaches; however, spangled perch and Pilbara tandan recruitment appeared to be low throughout the Project area.

1 INTRODUCTION

1.1 Background

Robe River Mining Co. Pty Ltd (the Proponent) is evaluating the potential development of the Mesa H iron ore deposit, located 16 km south-west of Pannawonica, in the West Pilbara region of Western Australia (Figure 1). The development envelope for Mesa H traverses the Robe River and lies adjacent to the existing Mesa J mine operation.

As part of the Mesa H development, dewatering of underlying groundwater will be required to allow mining of sections of ore (~20%) which occur below the water table (BWT). Options for disposal of excess dewatering water from the Mesa H development include discharge to an unnamed ephemeral tributary of the Robe River, between Mesa H and Mesa J, and/or discharge into Jimmawurrada Creek, east of Mesa J (Figure 1, or potentially an additional location north of Mesa H). The former two discharge points are currently used by the Mesa J operation.

The permanency and consistency of flow in the Robe River is already influenced by groundwater abstraction and dewatering discharge from existing mine operations (Aquaterra 2004). Groundwater drawdown and discharge from Mesa H may also affect aquatic ecosystems in the local vicinity. This includes a number of named permanent pools known to have ecological and cultural value, such as Gnieraoora (or Dthulurat) at Yeera Bluff (Figure 1).

Astron Environmental Service Pty Ltd (Astron) commissioned *Wetland Research & Management* (WRM) to design and conduct a baseline sampling program encompassing aquatic ecosystems of the Robe River both upstream and downstream of the Mesa H development (the "Project area"). The aim of the sampling program is to document current ecological condition of the system, and procure benchmark aquatic fauna and water quality data against which any future changes may be assessed post-commencement of the Mesa H development, including cumulative effects from dewatering drawdown ('drying') and discharge (quality and quantity). The permanency and consistency of flow in the Robe River is already influenced by groundwater abstraction and dewatering discharge from the Mesa J mine, and so the current sampling program will document "current" ecological condition moreso than "natural" condition. Where possible, monitoring sites established by Streamtec Pty Ltd (Streamtec) and The University of Western Australia (UWA) on the Robe River (Figure 1) have been included in the program. Since 1991, annual sampling for fish and benthic macroinvertebrates has been conducted by Streamtec/UWA as part of long-term monitoring for the Mesa J Project (Streamtec 1996, 1999, 2003, 2007, 2009, 2010, 2012 and 2014, Dobbs and Davies 2009).

1.1.1 Legislative framework

At a State level, native aquatic fauna are protected under the *Wildlife Conservation Act 1950* (WC Act) and their environment is protected under the *Environmental Protection Act 1986* (EP Act). This includes freshwater turtles, frogs, fish and invertebrates (including hyporheic and stygal invertebrates). Hyporheic invertebrates inhabit subsurface interstitial spaces in coarse creek bed sediments. Stygal invertebrates are aquatic, obligate groundwater-dwelling species known to be present in a variety of rock types and are often also present in the hyporheos.

The EP Act provides for environmental impact assessment (EIA) of proposals (and schemes) likely to have a significant effect on the environment. As part of the EIA process, the Act requires the Environmental Protection Authority of Western Australia (EPA) to report on key environmental factors to the Minister for Environment. Environmental factors and associated objectives are the EPA's basis for assessing whether a proposal (or scheme's) impact on the environment is acceptable. Two key environmental factors relate to water resources:

i) Hydrological Processes - with the objective "To maintain the hydrological regimes of groundwater and surface water so that environmental values are protected".

ii) Inland Waters Environmental Quality - with the objective "To maintain the quality of groundwater and surface water so that environmental values are protected".

Proponents are required to provide baseline information on these two factors (and others) in order to inform the EIA process.

The WC Act provides for species and ecological communities to be specially protected and listed as either 'threatened' because they are under identifiable threat of extinction, or 'priority' because they are rare, or otherwise in need of special protection. This encompasses species with small distributions (occupying an area of less than 10, 000 km^2) defined as short range endemics, or SREs (Harvey 2002, EPA 2009). The EPA's Guidance Statement 20 (EPA 2009) requires that impacts on SRE invertebrates be considered during the EIA process.

It can be difficult to determine whether or not a species belonging to a SRE Group is actually a species with a range <10,000 km^2. The Western Australian Museum (WAM) uses a three-tier classification scheme for SRE species which we have applied to hyporheic fauna in this report:

- **Confirmed SREs** are species with a known distribution range <10,000 km^2. The taxonomy is well known and the group is well represented in collections and/or via comprehensive sampling.

- **Potential SREs** are species that belong to a group where there are gaps in our knowledge of the taxon, either because the group is not well represented in collections, taxonomic knowledge is incomplete, or the distribution is imperfectly understood because sampling has been patchy.

- **Widespread (not SRE) species** have a known distribution range >10,000 km^2. The taxonomy is well known and the species is well represented in collections and/or via comprehensive sampling.

WAM further uses five sub-categories if a species is determined to be a "Potential SRE". These sub-categories are:

1. Data deficient: There are insufficient data available to determine SRE status, either because there is a lack of geographic and taxonomic information, or because the individuals sampled cannot be identified to species level (*e.g.* wrong sex, juvenile, damaged);

2. Habitat Indicators: The status of a species can be elucidated through its association with a particular habitat and vice versa;

3. Morphological Indicators: The status of a species can be determined through its morphological characteristics;

4. Molecular Evidence: DNA sequence data reveal patterns congruent or incongruent with SRE status for a species; and

5. Research & Expertise: Available research data and/or WAM expertise provide the basis for a decision about the species' status.

The Department of Parks and Wildlife (Parks and Wildlife) also maintains a list of priority fauna species that are of conservation importance but, for various reasons, do not meet the criteria for listing as threatened. Parks and Wildlife uses the International Union for Conservation of Nature (IUCN) Red List criteria for assigning species and communities to threat categories. Not all Western Australian species listed by the IUCN are also listed by Parks and Wildlife.

Objectives for the management of potential impacts on water-dependent ecosystems are also outlined in the Western Australian Department of Water (DoW) Western Australian Water in Mining Guideline (DoW 2013) and include:

- Minimise the adverse effects of the abstraction and release of water on environmental, social and cultural values;
- Ensure the cumulative effects of mining operations are considered and managed;
- Use a monitoring and evaluation process, to adaptively manage the effects of abstractions and releases on the water resources;
- Maximise cooperation in water management activities between nearby water users, to reduce impacts on the environment;
- Plan for, and manage, the effects of climate variability and change.

At a Federal level, the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) provides for native fauna and their habitats to be specially protected and listed as nationally or internationally important. Relatively few aquatic species in Western Australia are listed as threatened or endangered under the WC Act or EPBC Act. Lack of knowledge of their distributions often precludes aquatic invertebrates for listing as threatened or endangered. The EPA has stated that listing under legislation should therefore not be the only conservation consideration in EIA (EPA 2004).

The current baseline sampling constituted a Level 1 survey for EIA, as described under the EPA's Environmental Assessment Guideline (EAG) No. 12 (EPA 2013), and in accordance with EAG No. 8 (EPA 2015), with the focus on hydrological processes and ecosystem maintenance. At the time of the survey (April/May 2016), the aforementioned EAGs were the most up-to-date EAGs availaible.

1.1.2 Other relevant policy - ANZECC/ARMCANZ (2000) Guidelines

The Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC/ARMCANZ 2000) "… provide an authoritative guide for setting water quality objectives required to sustain current, or likely future, environmental values (users) for natural and semi-natural water resources in Australia and New Zealand". These guidelines form part of the National Water Quality Management Strategy (NWQMS), a joint national approach to improving water quality in Australian and New Zealand waterways. The NWQMS was originally endorsed by two Ministerial Councils - the former Agriculture and Resources Management Council of Australia and New Zealand (ARMCANZ) and the former Australian and New Zealand Environment and Conservation Council (ANZECC).

State regulators have been known to apply the trigger values detailed in the ANZECC/ARMCANZ (2000) guidelines as compliance values for mining companies in the Pilbara, where developments may impact creeklines through dewatering and discharge operations. Yet, in some systems water quality data recorded during baseline surveys, conducted prior to any disturbance, do not actually meet the default ANZECC/ARMCANZ (2000) trigger values. Therefore, it is important to obtain adequate baseline water quality data and develop system-specific guidelines, as recommended in the ANZECC/ARMCANZ (2000) guidelines, to avoid issues with non-compliance as a result of inappropriate trigger values being used by regulators.

The ANZECC/ARMCANZ (2000) guidelines are currently under review and updates are provided by the Joint Steering Committee for the Revision on the Federal Department of the Environment and Energy website (www.environment.gov.au/water/quality/national; downloaded on 30 May 2016).

1.2 Scope of Works for Current Study

The scope of works for the current study was to establish riverine baseline monitoring sites, and to develop a robust dataset to allow statistical testing for potential change over time. Specifically, the scope of work included:

- Identification of baseline and future riverine monitoring sites, and where possible, include long-term monitoring sites established previously by Streamtec/UWA;
- Semi-qualitative sampling for aquatic fauna (microinvertebrates, hyporheic invertebrates, benthic macroinvertebrates, fish) and water quality to allow statistical comparison of any changes overtime;
- Qualitative visual assessment of general habitat conditions at all sites;
- Record opportunistic visual sightings of any turtle and frog species present;
- Identification of all specimens to the lowest taxonomic level practicable;
- An assessment of the conservation status of aquatic fauna recorded;
- Report water quality data against ANZECC/ARMCANZ (2000) guidelines for freshwater ecosystems;
- Preparation of a detailed technical report of all findings.

1.3 Rationale for Sampling Components of Aquatic Fauna

<u>Microinvertebrates</u>

Aquatic microinvertebrate fauna consists of microscopic fauna including micro-crustacea (ostracods, copepods and cladocera), protists and rotifers (nominally <53 μm in size). Aquatic microinvertebrates are used as bioindicators throughout the world for many reasons. The microinvertebrate community holds a strategic position in food webs (Bunn and Boon 1993, Zrum and Hann 1997, Jenkins and Boulton 2003). They provide a food source for higher trophic levels, such as macroinvertebrates (Bunn and Boon 1993, Jenkins and Boulton 2003), fish (King 2004, Vilizzi and Meredith 2009), and waterbirds (Crome 1985). Most fish species depend on microinvertebrates for their first feed after hatching (Geddes and Puckridge 1989). Therefore, any change in the microinvertebrate community will ultimately result in changes to the entire aquatic ecosystem. Microinvertebrates also have intimate contact with the surrounding environment, being planktonic, and continually exposed to the ambient water quality. Hence, they are vulnerable to environmental pollutants and can be a useful biomonitoring tool (Kaur and Ansal 1996).

<u>Hyporheic fauna</u>

The hyporheic zone, comprising subsurface interstitial spaces in coarse creek bed sediments, is recognised as a critical component of many streams and rivers (Edwards 1998). The hyporheic zone creates habitat and connectivity between surface and sub-surface (groundwater) zones, provides a rearing habitat and important refuge for aquatic invertebrates, and importantly in the context of the Pilbara region, buffering from floods (Palmer *et al.* 1992, Dole-Olivier and Marmonier 1992), disturbance in food supply (Edwards 1998) and drought (Cooling & Boulton 1993, Coe 2001, Hose *et al*. 2005). The aquatic fauna of hyporheic zones is collectively referred to as hyporheos. Typically, hyporheos have poor dispersal capabilities, are confined to discontinuous habitats, are highly seasonal (usually more active in the wet season following significant flows) and have low levels of fecundity, and are therefore commonly classified as SRE as defined by Harvey (2002)[1]. A number of taxa frequently encountered in hyporheic zones, including stygal amphipods, isopods and syncarids (crustaceans) are classified as SRE, and are therefore of high conservation value. The subterranean fauna of the Pilbara is characterised by high levels of diversity and short range endemism (Eberhard *et al*. 2005, Halse *et al*. 2014), with increasing aridity and cessation of surface flows over the last 60 – 70 million years causing once epigean

[1] Short range endemic as defined by Harvey (2002): a species occupying an area of less than 10, 000 km^2.

(surface dwelling) fauna to disperse and become isolated in groundwater environments (Finston *et al*. 2011).

Macroinvertebrates

Aquatic macroinvertebrates (nominally 53 - 250 μm in size) typically constitute the largest and most conspicuous component of aquatic invertebrate fauna in both lentic (still) and lotic (flowing) waters. Macroinvertebrates are used as a key indicator group in the bioassessment of the health of Australia's streams and rivers under the National River Health Program (Schofield and Davies 1996), and have inherent value for biological monitoring of water quality (ANZECC/ARMCANZ 2000). Macroinvertebrates are considered to be temporary residents if their life-cycle contains a winged-adult form (*e.g.* dragonflies, damselflies, mayflies, aquatic beetles, caddisflies, *etc.*), therefore being proficient in aerial dispersal between waterbodies (Gray and Fisher 1981). Permanent residents include those which can persist as larvae during periods of drought by aestivating or encysting in sediments (*e.g.* Baetidae, Simuliidae, Ceratopogonidae, Chironomidae), or produce desiccation-resistant propagules or eggs which hatch upon inundation (*e.g*. ciliates, rotifers, flatworms, nematodes, segmented worms and crustaceans) (Radzikowski 2013).

Fish

Historically, fish diversity has been used worldwide as an indicator of ecosystem health (*e.g.* Hugueny *et al*. 1996, Oberdoff *et al.* 2002, Pont *et al.* 2006). Because fish continually inhabit the receiving water, they integrate the chemical, physical and biological 'histories' of the watercourse. Most fish species have a long life span and therefore reflect both long-term and current water quality. Sampling fish assemblages can be used to assess a range of environmental disturbances, such as changes in habitat, water quality and land use (Hugueny *et al.* 1996). Fish also tend to be the most conspicuous biota in freshwater systems, have significant social amenity and are relatively easy to sample and identify.

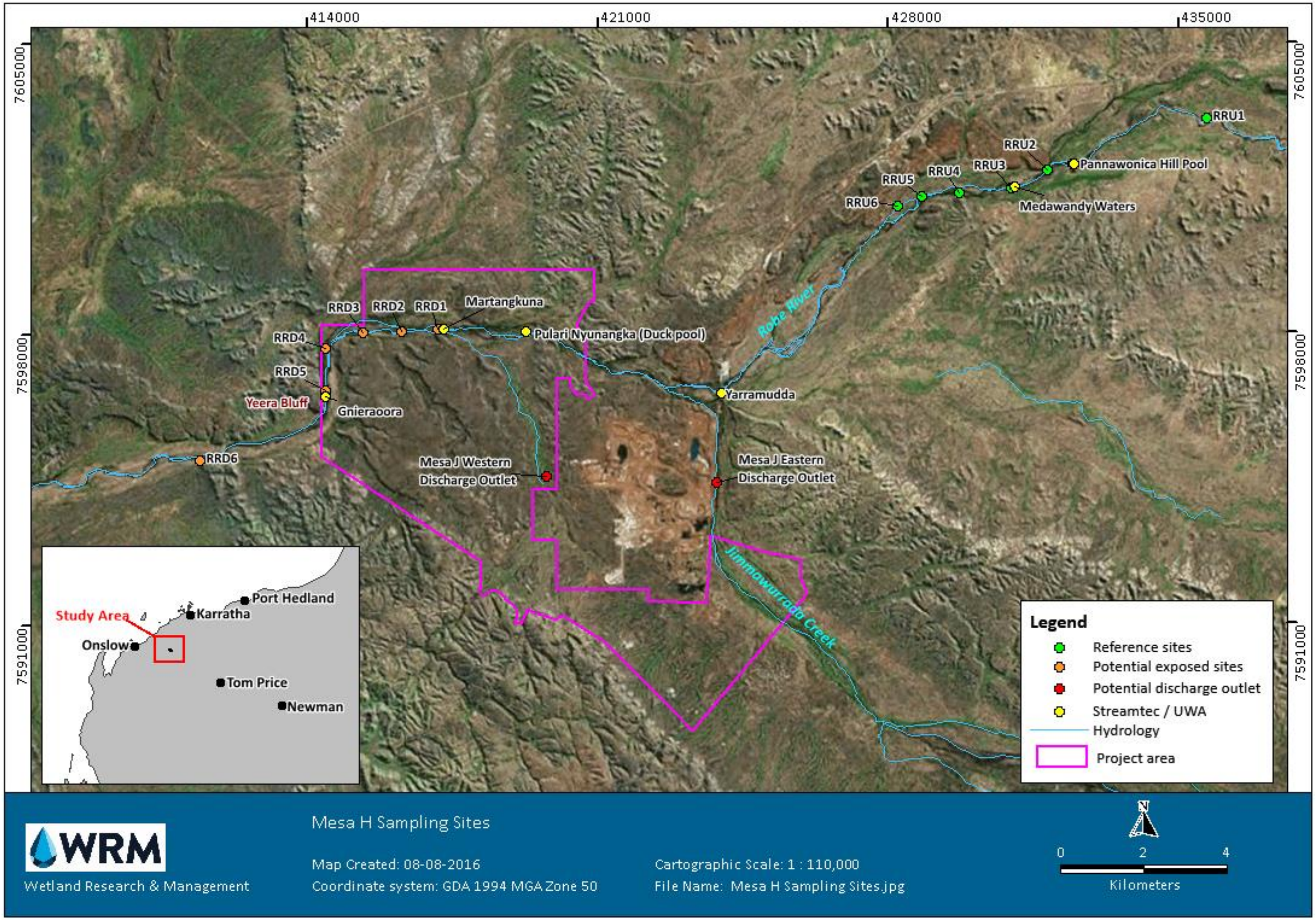

Figure 1. Location of Mesa H Project area and baseline aquatic ecosystem sampling sites (reference, potential exposed) and historic Streamtec/UWA sites ().

2 STUDY AREA

2.1 Climate

The Project area is located on the western edge of the Hamersley Ranges, approximately 100 km south-west of Karratha and south-west of Pannawonica. Climate of the region is semi-arid, with relatively dry winters and hot summers. The nearest long-term Bureau of Meteorology (BOM) gauging station is Pannawonica (no. 005069; 1971 - 2016), where total annual rainfall ranges from 113 to 700 mm, and monthly rainfall from 0 to 444 mm. Most rainfall occurs during the summer months (November to March) and is predominantly associated with cyclonic events; when flooding frequently occurs along creeks and rivers. Due to the nature of cyclonic events and thunderstorms, total annual rainfall in the region is highly unpredictable and individual storms can contribute several hundred millimetres of rain at one time.

Prior to sampling in April/May 2016, slightly above-average monthly rainfall was recorded in the latter part of 2015 (October & November) (Figure 2). However, total monthly rainfall was well below the 45-year average in the mid to late wet season of 2016, particularly during February, March and April (Figure 2). As such, there was no surface flow connecting pools along the Robe River at the time of sampling between 1st and 8th May. However, toward the end of the sampling period, a major storm event on the 5th - 6th May caused widespread flooding across the Robe River catchment, resulting in above average total rainfall for May (Figure 2). Pannawonica also recorded above average rainfall in June and July (Figure 2).

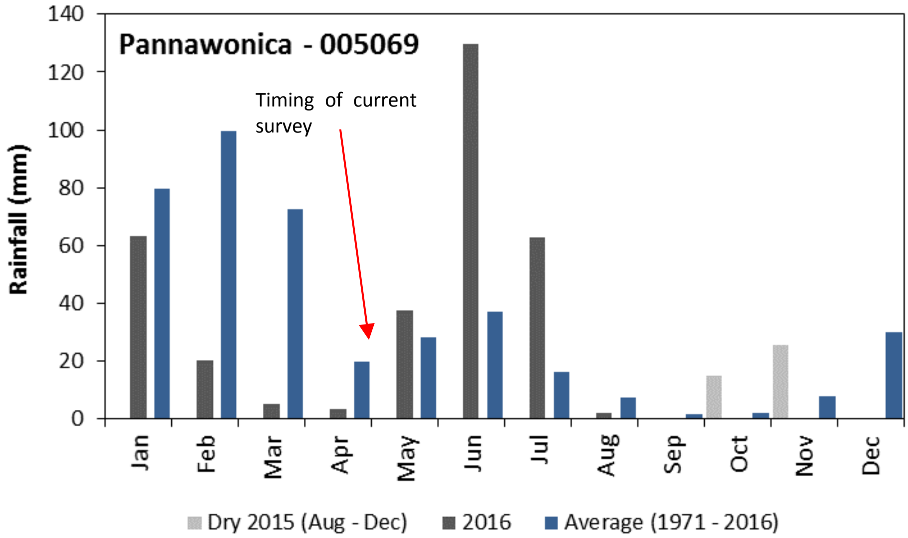

Figure 2. Average monthly rainfall (1971 – 2016) and total monthly rainfall (2016) for Bureau of Meteorology (BOM) Pannawonica Gauging Station (005069).

2.2 Hydrogeology

The Project area lies within the Robe River catchment, a significant river system in the region, with a catchment area of 7,571 km^2 and numerous braided tributaries (DoW 2012). The Robe River channel covers a linear distance of 190 km, 63% of which lies upstream of the Project area (EPA 1991). The immediate valley is 300 - 500 m wide. Jimmawurrada Creek is the only major tributary in the vicinity of the Project area, flowing northward along the eastern flank of Mesa J.

Jimmawurrada Creek joins the Robe River upstream of Mesa J (Figure 1). The Jimmawurrada Creek sub-catchment has an area of approximately 400 km^2 and constitutes the lower section of Bungaroo Creek catchment, with a combined area of around 1,261 km^2 (DoW 2012). Both the Jimmawurrada and Bungaroo Creek catchments are included in the Bungaroo Creek Water Reserve that protects the water resources in these catchments and underlying aquifer that supply the West Pilbara Water Supply Scheme (WPWSS) (RDA 2013). The WPWSS delivers public drinking water to the towns of Karratha, Dampier, Roebourne, Cape Lambert and Point Samson (DoW 2012).

Surface flow in the Robe and tributary rivers is naturally ephemeral, typically only occurring in response to significant rainfall events and continuing for one to two months. There is one DoW streamflow gauging station on Robe River; Yarraloola (no. 707 002; 1972 - 2016), at the North West Coastal Highway crossing, 36 km west of the Project area. The maximum total monthly river discharge for the period of record at Yarraloola is 773.9 GL (February 2009) and the maximum instantaneous discharge is 12,203 m^3/sec (February 2009). Low or no flow typically occurs from July to December, when the river is reduced to a series of isolated pools. The number and permanence of these pools is dependent on antecedent rainfall and groundwater levels (Antao & Braimbridge 2010). Since streamflow records began at Yarraloola in 1972, 14 zero-flow years have been recorded, including seven in the last two decades (2002, 2003, 2007, 2010, 2012, 2013 & 2014).

The major aquifer underlying the Robe River is the gravelly alluvium which has a saturated thickness of up to 15 m adjacent the main channel and extends laterally up to 5 km across the Robe River Valley (Antao & Braimbridge 2010). Groundwater flow through the gravels maintains permanent pools in the Robe River. The gravelly aquifer is underlain by fractured, permeable Trealla Limestone and highly transmissive Robe Pisolite. Robe Pisolite is an iron-enriched pisolitic alluvial sedimentary rock that fills the broad valley between ridges of the Brockman Iron Formation, originally as ancestral drainage channels (palaeochannels) of the Robe River (commonly known as a Channel Iron Deposits (CID), and forms the target ore deposit at Mesa H (and Mesa J).

Groundwater flow in the Pisolite is towards the Robe River and where the Pisolite is deepest, probably contributes to baseflow within the Robe River (Aquaterra 2005). The gravel and Pisolite aquifers are recharged primarily *via* river discharge. Modelling by DoW indicates the aquifers have the potential to absorb a significant percentage of river flow; however, due to the unpredictable flow regime, recharge is very low in two out of every five years (Antao & Braimbridge 2010). Near the Jimmawurrada-Robe confluence, the Pisolite is very shallow and unsaturated. Stream-aquifer interaction upstream in the Bungaroo and Jimmawurrada valleys contributes to recharge along with direct rainfall infiltration.

2.3 Water Quality

2.3.1 Surface water

Water quality monitoring has been conducted quarterly at five pools in the Robe River and at the existing dewatering discharge point on Jimmawurrada Creek. The Robe River pools are located upstream (Medawandy Waters), adjacent to (Yarramudda) and downstream (Japanese, Martangkuna, Gnieraoora) of the existing mine operation (refer Figure 1 & Section 3). Pools have been monitored for pH, conductivity (EC), total dissolved solids (TDS), nitrogen and phosphorus, turbidity, total suspended solids (TSS) and biological and chemical oxygen demand. Dewatering discharge has been monitored for pH, TDS, TSS and concentration of dissolved metals (Al, As, Cd, Cr, Cu, Fe, Mn, Ni, Pb, Zn). Unfortunately, the limit of reporting for most metals was not sufficiently low to allow comparison against ANZECC/ARMCANZ (2000) default trigger values (TVs) for the protection of freshwater ecosystems. In general, dewatering discharge to Jimmawurrada Creek appeared to be of low salinity (< 800 mg/L TDS), low TSS (< 5 NTU) and with a pH range of 6.2 - 8.5. The water is a predominantly sodium bicarbonate and calcium bicarbonate type, indicative of recharge water (Aquaterra 2004).

Available long-term quarterly monitoring data for the Robe River pools (1992 - 2004) indicates surface waters to be fresh (453 - 1,400 µS/cm EC; 300 - 904 mg/L TDS), with pH values typically in the range 7.0 - 9.0, and relatively low turbidity (< 10 NTU) under baseflow conditions. Maximum salinity levels recorded during quarterly monitoring were in 2003 following two years of low rainfall. Salinity generally tends to be lower in upstream pools than in pools adjacent to, and downstream of Mesa J. Background levels of total nitrogen (N-total) and nitrate-nitrogen (N-NO_3) often exceed default ANZECC/ARMCANZ (2000) TVs for protection against eutrophication (0.15 mg/L N-total; 0.03 mg/L N-NO_X), with levels of up 3.45 mg/L N-total and 3.1 mg/L N-NO_3 recorded at Medawandy waters, upstream of Mesa J. In general N-NO_3 appears to constitute most of the N-total present in surface waters in the pools. There are no data on dissolved metal concentrations in the pools.

Long-term annual monitoring of Robe River pools by Streamtec/UWA indicated similar physicochemical water quality characteristics to those identified from quarterly monitoring by the Proponent; fresh (EC < 1,200 µS/cm), slightly acidic to alkaline (pH 6.6 - 8.3) waters with relatively low turbidity during the dry season (< 8 NTU), becoming markedly more turbid following wet season flood events (often exceeding 70 NTU) (Dobbs & Davies 2009, Streamtec 2014). There was significant spatial and temporal variation in dissolved oxygen (DO) levels (< 2 mg/L to > 12 mg/L), depending on time of day sampled and permanency of pools. N-total and total phosphorus (P-total) often exceeded ANZECC/ARMCANZ (2000) default TVs (Dobbs & Davies 2009, Streamtec 2014).

2.3.1 Groundwater

At the time of reporting, groundwater quality sampling in the Project area had been conducted on three occasions, in December 2015 and twice during 2016. A comprehensive suite of parameters was sampled in 10 bores; MB15MEH001 to 4, 6 to 9, and 13 to 14. This sampling will be followed by more comprehensive groundwater assessment during 2016. The December 2015 sampling suggests groundwater quality in the majority of the bores to be similar to surface waters, *i.e.* fresh (489 - 1,110 µS/cm, 452 - 822 mg/L TDS), circum-neutral to slightly alkaline (pH 7.3 - 7.7) and with relatively high DO levels (7.2 - 9.1 mg/L). Two bores had brackish water; MB15MEH013 (3,040 µS/cm, 2,770 mg/L) and MB15MEH014 (1,920 µS/cm, 1,450 mg/L). Groundwaters in most bores (except MB15MEH001) were enriched in N-NO_3 relative to ANZECC/ARMCANZ (2000) default TVs for surface waters for protection against eutrophication. Maximum concentration was 23.9 mg/L N-NO_3 in MB15MEH014. Default TVs have yet to be developed for groundwaters. In their absence, ANZECC/ARMACANZ (2000) recommend that default TVs for surface waters be applied with caution, acknowledging that they may not be representative of natural background concentrations in groundwater.

In three bores, dissolved concentrations of chromium (Cr), manganese (Mn) and/or zinc (Zn) were also in exceedance of ANZECC/ARMCANZ (2000) default 95% species protection level TVs[2] for surface waters. This included MB15MEH001 (Mn, Zn), MB15MEH004 (Zn), MB15MEH013 (Cr, Zn) and MB15MEH004 (Cr).

2.4 Cultural and Ecological Values

The Project area is located within the Hamersley sub-region of the Pilbara Biogeographic Region as categorised under the national Interim Biogeographic Regionalisation for Australia (IBRA). Existing tenure in the area is a mixture of unallocated and leased Crown land. The Mesa H development would be implemented under Mining Lease ML248SA, which covers the Project area and other deposits

[2] Note, default TV for Ni should be modified for water hardness (as $CaCO_3$) at the time of sampling using algorithms provided in Table 3.4.3 of ANZECC/ARMCANZ (2000).

throughout the Robe River valley. In addition to ML248SA, the Project area lies substantially within Yarraloola Station pastoral lease (PL 3114-1127). The lease is held by Robe River Iron Associates joint venture through the Yarraloola Pastoral Company, and managed by Rio Tinto. The Station was established in 1916 as a sheep station, but currently runs cattle.

Numerous Aboriginal sites of significance have been identified within the Robe River valley. The Native Title Claim of the Kuruma Marthudunera Native Title Claimant Group covers 15,717 km^2 south of Karratha, incorporating the Project area and Yarraloola Station (YMAC 2011). The entire Robe River, also known as Jajiwarra, is of significant cultural value to the Kuruma and Marthudunera people, in particular permanent pools such as Yarramudda and Weedai immediately upstream of the Project area, Dthulurat (Gnieraoora) at Yeera Bluff, Joordi (or Jongardi) 14 km downstream of Yeera Bluff, and Chalyarn Pool on Mungarathoona Creek, a tributary of the Robe River.

As the Pilbara has an arid and variable climate with irregular episodic rainfall events, sources of water are of high ecological value. The permanent pools of the Robe River are an important component of the river ecosystem, supporting a diverse range of aquatic fauna and specialised flora such as yellow bladderwort (*Utricularia australis*) and water chestnut (*Eleocharis dulcis*). The pools act as refuges for fauna during periods of drought (EPA 1991). The riparian zone in the vicinity of the Project area also supports woodlands of silver cadjeput (*Melaleuca argentea*) and eucalypt (*Eucalyptus camaldulensis*, *E. victrix*). Lower tree and shrub layers in these woodlands are atypical of the Fortescue Botanical District, and as such, warrant conservation (EPA 1991). Cyclonic events and associated rainfall can severely affect the riparian vegetation, re-arrange braided channels and alter the size and position of permanent pools through scouring and aggradation (Dobbs & Davies 2009). In March 2004 for example, a rain depression in the wake of tropical cyclone Monty resulted in record rainfalls (376.6 mm) that caused widespread flooding throughout the Robe River valley and its surrounding catchments (Aquaterra 2004). High flows and flash flooding associated with cyclone Monty uprooted much of the Cadjeput woodland along the river channel in the vicinity of the Jimmawurrada-Robe confluence.

A number of potential short range endemic (SRE) aquatic invertebrates are known from the vicinity of the Project area and potentially occur within drawdown and dewatering impact zones. These species include stygal amphipods, isopods and syncarids, which are also known to occur in the hyporheic zones of the Robe River and/or tributary rivers. Further discussion of these species is provided in Section 3.

3 REVIEW OF PREVIOUS AQUATIC FAUNA AND STYGOFAUNA SURVEYS

The most comprehensive surveys of aquatic fauna within the Project area are those of Streamtec/UWA, who have conducted annual sampling of Robe River pools since 1992 (Dobbs & Davies 2009, Streamtec 1996 - 2014). Other recent studies include the Parks and Wildlife Pilbara Biological Survey (PBS); a region-wide survey of aquatic invertebrates conducted between 2003 and 2006, as part of a broader biodiversity survey (see Pinder *et al.* 2010). The PBS featured a number of ephemeral, long-term and permanent waterbodies within the vicinity of the Project area, including Mungarathoona Creek to the west, Myannore Creek and Yarraloola Station Claypan to the north-west, Nyeetbury Spring on upper Bungaroo Creek to the south-east, Kumina Creek in the upper Robe, and two pools on the Cane River to the south-west (Pinder *et al*. 2010). Morgan and Gill (2004) studied the distribution of fishes in inland waters of Pilbara, sampling 171 sites across 21 river systems between 2000 and 2002. Nearby sites included two pools on the Robe River close to the Project area; two on the lower Robe west of Mesa A/Warramboo, two on the lower Fortescue River to the north-west, and one on the Cane River. WRM previously sampled aquatic invertebrates and fish at Nyeetbury Spring (2009 - 2015) and Yalleen Pool (2010 - 2011) on Bungaroo Creek under the Proponent's Regional Aquatic Fauna Program (see WRM 2016). In 2008 and 2009, baseline surveys for the Australian Premium Iron (API) West Pilbara Iron Ore Project (WPIOP) were conducted, including sites on Mungarathoona Creek, Red Hill Creek and the Cane River (WRM 2009).

Additionally, stygofauna[3] have been sampled by Biota Environmental Sciences in the Mesa A/Warramboo Yarraloola Borefield to the west (Biota 2006a), and within the Ken's Bore and Cardo Bore areas along Red Hill Creek to the south-west (Biota 2010). Bennelongia Environmental Consultants surveyed stygofauna within the Bungaroo Creek catchment in the Buckland Hills area (Bennelongia 2013). Stygofauna were also surveyed by Parks and Wildlife as part of the PBS, including 36 bores within the Robe River catchment, sampled between 2002 and 2005 (see Eberhard *et al*. 2009, Halse *et al.* 2014).

A review of previous aquatic fauna surveys conducted within 100 km of the Project area, including sites sampled, methods used, and notable fauna found, is presented in the following sub-sections. A summary of the studies is provided in Table 1 and the sampling locations are shown in Figure 3. Studies referenced in this review were either conducted by WRM for the Proponent, or were publicly available, or records sourced from the Parks and Wildlife database NatureMap (http://naturemap.dpaw.wa.gov.au). In addition, direct requests were therefore made to Parks and Wildlife in order to obtain additional information on distribution of threatened, priority and vulnerable aquatic fauna.

For each species, conservation significance was assessed by reference to the IUCN Red List of Threatened Species, Parks and Wildlife Threatened and Priority Fauna Lists, as well as The Australian Faunal Directory, The Australian National Insect Collection Database and WRM's in-house database for distribution and occurrence information. Collectively, the previous studies have identified a number of species of conservation significance and/or scientific interest, which have the potential to reside, either seasonally or permanently, within the Project area and its expected drawdown zone and/or dewatering discharge footprint (acknowledging hydrological modelling for drawdown and dewatering discharge was not completed at the time of the survey or reporting).

A summary of aquatic species (including hyporheic species) of conservation and/or scientific value known to occur, or likely to occur within the Project area, is provided in Table 2, at the end of Section 3.

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[3] Obligate inhabitants of groundwater environments, *e.g.* aquifers, caves and hyporheic (interstitial) spaces. Morphological adaptations to such environments include reduced body size, lack of pigmentation, reduced or absent eyes, and elongated appendages (*e.g.* antennae).

Table 1. Summary of previous recent aquatic fauna studies (invertebrates and fish) conducted within a 100 km radius of the Mesa H Project area, together with methodologies. Studies are listed in chronological order. Stygofauna assessments appropriate to the Project area are also included. Codes for 'Fauna sampled': Macro = macroinvertebrate; Micro = microinvertebrate; Hypo = hyporheos; Stygo = stygofauna).

Program	Sampled by	Locations sampled	Fauna sampled	Methods used	Taxonomic level	Sampling dates	Reference
Aquatic Fauna (Surface Water and Hyporheos)							
Proponent Mesa J Project Aquatic Ecosystem Study (long-term)	Streamtec / UWA	Robe River pools: • Gnieraoora, Martangkuna, Pulari-Nyunangka, Japanese pool, Yarramudda, Medawandy Waters, Pannawonica Hill pool, Chundy Pool, Ngalooin, Mussel Pool.	Macro Fish	• Macro – kick sampling (250 µm net) all habitats, • Fish – seine net and visual observation (mask and snorkel).	Species	Annually between Nov - Mar, 1991 - 2013.	Streamtec (1996, 1998, 2002, 2007-2009, 2011, 2014); Dobbs and Davies (2009)
Fish Fauna of Pilbara inland waters	Murdoch Uni	• Robe River near Mesa H and J, • Lower Robe River, west of Mesa A/Warramboo, • Lower Fortescue River (40 km NE), • Cane River (75 km SW).	Fish	• Fish – seine nets, gill nets, cast nets, rod and line, and visual observation (mask and snorkel).	Species	Once between Dec 2000 - Nov 2002.	Morgan and Gill (2004)
Hyporheos of five Pilbara springs	Parks and Wildlife	• Nyeetbury Spring on Bungaroo Creek, Robe River catchment (33 km SE).	Hypo	• Stirring up sediments and sweeping with a 250 µm mesh dip net, • Digging up sediments to a depth of 30 cm and collecting fauna caught with 50 µm and 250 µm mesh nets (Karaman-Chappuis method).	Species	Sep 2001.	Halse *et al.* (2002)
Pilbara Biological Study (PBS)	Parks and Wildlife	• Chalyarn Pool, Mungarathoona Creek, Robe River catchment (20 km W), • Red Hill Creek Pool, Robe River catchment (30 km SW), • Nyeetbury Spring on Bungaroo Creek (33 km SE), • Duck Creek Pool on Duck Creek, Ashburton River catchment (46 km SE), • Myannore Creek (49 km NNW), • Yarraloola Station Claypan (65 km NNW), • 2 sites on Cane River; House Pool and Creek Pool (70-75 km SW), • Kumina Creek (74 km SW).	Macro Micro	• Macro - kick sampling (250 µm net) all habitats, • Micro – sweep netting (50 µm mesh).	Species	Aug/Sep 2003, Aug/Sep 2004, May 2005, May 2006.	Pinder *et al.* (2010)

Program	Sampled by	Locations sampled	Fauna sampled	Methods used	Taxonomic level	Sampling dates	Reference
Aquatic Fauna (Surface Water and Hyporheos)							
API WPIOP Baseline Aquatic Fauna Survey	WRM	• 2 sites on Mungarathoona Creek (20 km W), • 6 sites on Red Hill Creek, (40 km SW).	Macro Micro Hypo Fish	• Macro – kick sampling (250 µm net) all habitats, • Micro – sweep netting (53 µm net) water column, • Hypo – Karaman-Chappuis method (53 µm net), • Fish – seine nets and gill nets.	Species	Dec 2008, Apr 2009.	WRM (2009)
Proponent Regional Aquatic Program (long-term)	WRM	• Yalleen Pool on Bungaroo Creek (23 km SE), • Nyeetbury Spring on Bungaroo Creek (33 km SE).	Macro Micro Hypo Fish	• Macro – kick sampling (250 µm net) all habitats, • Micro – sweep netting (53 µm net) water column, • Hypo – Karaman-Chappuis method (53 µm net), • Fish – seine nets and gill nets.	Species	Ongoing, wet and dry seasons since 2009.	WRM (2013, 2016)
Stygofauna							
Pilbara Biological Study (PBS)	Parks and Wildlife	• 36 bores across the Robe River catchment	Stygo	• Replicate hauls with weighted plankton nets (50 µm and 150 µm mesh).	Species	3 wet and 3 dry season occasions 2002 - 2005.	Eberhard *et al.* (2005, 2009); Halse *et al.* (2014)
Robe River Mining Co. Mesa A/Warramboo Baseline Stygofauna Assessment	Biota	• 21 bores within the Warramboo area, Robe River catchment (45 km W) • 20 bores within the Yarraloola area, Robe River catchment (40 km W)	Stygo	• Hauls with weighted plankton nets (150 µm mesh).	Species	Oct 2005.	Biota (2006a)
API WPIOP Baseline Stygofauna Assessment	Biota	• 58 bores within the WPIOP tenement areas, Red Hill Creek catchment (40 km SW)	Stygo	• Hauls with weighted plankton nets (70 µm mesh).	Species	Jun 2008, Sep 2009.	Biota (2010)
Iron Ore Holdings Bungaroo South Subterranean Fauna Assessment	Bennelongia	• 61 bores within Bungaroo South tenement, immediately south of the Project area.	Stygo	• Replicate hauls with weighted plankton nets (50 µm and 150 µm mesh).	Species	Jul 2012, Oct 2012.	Bennelongia (2013)

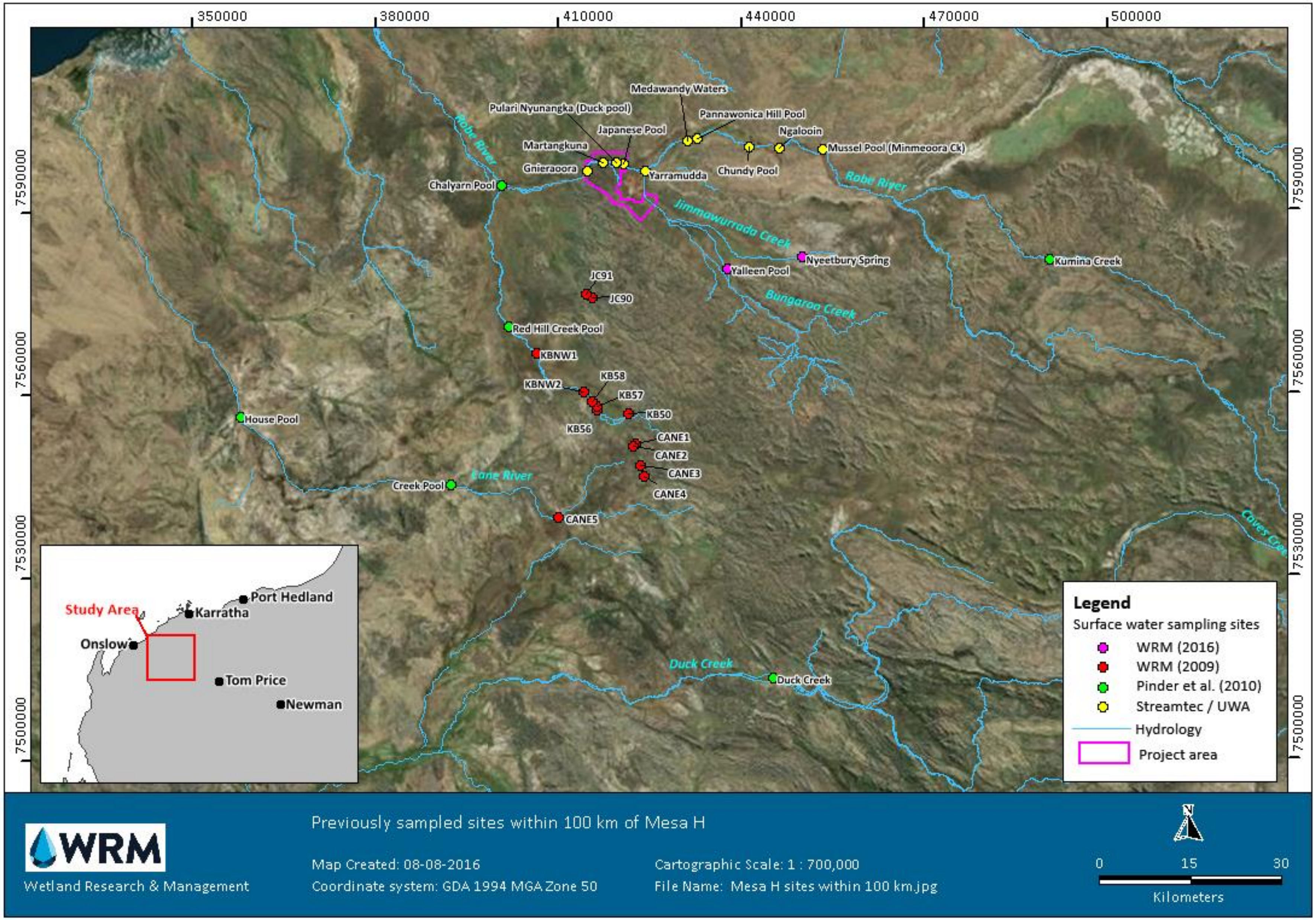


Figure 3. Locations previously sampled for aquatic invertebrates (Streamtec/UWA 1991 - 2014, WRM 2009 - 2016, Pinder *et al.* 2010) and fish (Streamtec 1991 – 2014) within 100 km of the Mesa H project area. Note, individual groundwater bores sampled for stygofauna (Biota 2006a, 2010, Eberhard 2009, Bennelongia 2013, Halse *et al.* 2014) are not detailed. Morgan and Gill (2004) did not provide GPS co-ordinates for their study of Robe River fish fauna.

3.1 Microinvertebrates (zooplankton)

The microinvertebrate fauna within the vicinity of the Project area is poorly known. Eight sites within 100 km of the Project area were sampled for microinvertebrates as part of the Parks and Wildlife PBS (Table 1). Pools sampled within the Robe River catchment included Chalyarn Pool (Mungarathoona Creek) and pools along Red Hill Creek, Myannore Creek, Kumina Creek, Nyeetbury Spring, Yalleen Pool and an ephemeral claypan on Yarraloola Station (Figure 3). Locations sampled outside the Robe River catchment included two pools on the Cane River to the south-west, and one on Duck Creek in the Ashburton River catchment (Figure 3). A combined total of 216 microinvertebrate taxa were recorded from these sites both within and outside of the Robe River catchment, sampled in August and September 2003/2004 (dry season) and May 2005/2006 (wet season). Wet season sampling appeared to favour microinvertebrate richness, with some of the most specious samples taken in May 2005 at House Pool on the Cane River (45 taxa), Red Hill Creek (42 taxa) and Chalyarn Pool (35 taxa).

WRM (2009) surveyed microinvertebrates in Mungarathoona Creek (two sites adjacent to the Jewel Cochrane development, to the south-east) and Red Hill Creek (six sites adjacent to Ken's Bore development) to the south east, as part of baseline aquatic surveys for API's WPIOP (Figure 3). A total 135 microinvertebrate taxa were recorded across two sampling events, conducted in December 2008 and April 2009 (WRM 2009).

WRM also conducts an ongoing aquatic fauna surveys under the Rio Tinto Pilbara Regional Program, which has previously included the microinvertebrate fauna of Yalleen Pool and Nyeetbury Spring on Bungaroo Creek (Figure 3). Biannual surveys collected a total 45 microinvertebrate taxa from Yalleen Pool, sampled between 2010 and 2011 (WRM 2013), and 160 taxa from Nyeetbury Spring, sampled between 2009 and 2016 (WRM 2016).

In each study, the microinvertebrate fauna was generally found to be typical of systems in the arid tropics (*e.g.* Koste and Shiel 1983, Tait *et al.* 1984, Smirnov and De Meester 1996, Segers *et al*. 2004). For example, in the nine featured PBS sites within the Robe River catchment (Table 1), species from the family Brachionidae (Rotifera) were poorly represented (14 taxa). This family tends to dominate temperate rotifer plankton, but is largely replaced by Lecanidae in tropic zones, as appears to be the case in the Pilbara (27 taxa; Pinder *et al.* 2010).

Microinvertebrate fauna of note (*i.e*. of conservation or scientific value) recorded from these studies included the stygal ostracod *Vestalenula matildae*, the rotifers *Colurella oblonga* and *Lecane noobijupi* and the cyclopoid copepod *Paracyclops* sp. 6. All these species have been recorded from within the Robe River catchment.

Vestalenula matildae was recorded at Mungarathoona Creek (Chalyarn Pool) during the PBS (Pinder *et al*. 2010). *V. matildae* is a recently described stygal species of ostracod known from groundwater (bores and wells) in the Ashburton River catchment (Government Well, Divide Well), DeGrey River catchment (Kylena Well, Home Well), and Sherlock River (Muorena Well). It has been recorded from hyporheic zones in the Ashburton (Yindabiddy Pool) and Fortescue River catchments (Weeli Wolli Spring), as well as surface waters in the Ashburton (Horrigans Pool), Fortescue (Gregory Gorge) and DeGrey (Coppin Gap, Chinaman Spring, Running Waters) (Martens and Rosetti 2002, Halse *et al*. 2002, Pinder *et al.* 2010, Schön *et al*. 2010). It appears to be endemic to the Pilbara, with no record to date of occurrence outside the region.

Colurella oblonga was collected at Nyeetbury Spring by WRM in 2012. This constituted the first record of *Colurella oblonga* from the Australian continent. This species is previously known from the southwest islands of Japan and from Europe (Dr Russel Shiel, University of Adelaide, pers. comm.).

Lecane noobijupi was collected from Nyeetbury Spring by WRM in 2011 and 2012, and from Red Hill Creek in 2009. This species is endemic to Western Australia, and appears to have a highly disjunct distribution. It was described from specimens collected from a wetland in the Muir-Unicup catchment in the south-west of the state (Lake Noobijup), and it had been thought to be restricted to that catchment (Segers and Shiel 2003). WRM has since recorded *Lecane noobijupi* from a number of locations throughout the Pilbara region, including Weeli Wolli Creek, Marillana Creek, Coondiner Creek, Mindy Mindy Creek and Kalgan Creek and (WRM 2016). Pinder *et al*. (2010) also recorded it from the DeGrey River. It would now appear that the Pilbara may be the normal locality of this species, and the Muir location in the south-west was an isolated occurrence.

Closer to the Project area, *Paracyclops* sp. 6 was collected from Chalyarn Pool, as well as Nyeetbury Spring and Kumina Creek (Pinder *et al*. 2010). This species is endemic to the Pilbara and is known from only 20 locations across the region, including the Ashburton River (Bobswim Pool, Fork Spring, Whiskey Pool, Cheela Spring, Paperbark Spring, Innawally Pool), Fortescue River (Palm Pool, Gregory Gorge, Palm Spring near Millstream, Joffre Creek), DeGrey River (Pelican Pool, Glen Herring Pool, Chinaman Spring, Minigarra Creek pools, Skull Springs and Bonnie Pool), Harding River (Springs Creek, Harding River Pool) and Sherlock River (Erawallana Spring and Pool Spring) (Pinder et al. 2010, WRM unpub. data).

Of the above-mentioned species, *Lecane noobijupi, Vestalenula matildae* and *Paracyclops* sp. 6 potentially occur within the Project area and its immediate vicinity but have a widespread distribution across the Pilbara.

3.2 Hyporheos

The hyporheos was not sampled by Streamtec/UWA during their long-term study of Robe River pools upstream, nor during the PBS (Pinder *et al.* 2010, Halse *et al.* 2014). However, biannual surveys of the hyporheos of upper Bungaroo Creek by WRM recorded a total of 22 hyporheic taxa from Yalleen Pool (WRM 2013) and 103 from Nyeetbury Spring (WRM 2016). Halse *et al.* (2002) recorded 62 hyporheic taxa from Nyeetbury Spring during one-off sampling in 2001. WRM (2009) also sampled the hyporheos of upper-Mungarathoona Creek and Red Hill Creek in 2008/2009, recording a combined total of 45 taxa.

Fauna of note collected during these studies included stygal amphipods and isopods that are likely SREs. Amphipods from the family Paramelitidae were collected from Yalleen Pool (WRM 2013), one site on Mungarathoona Creek, and three sites on Red Hill Creek (WRM 2009). These specimens were not able to be identified further than family level due to immaturity of life stage; however, they were considered likely to be SREs, given that most stygal Paramelitidae species are restricted to a small number of river systems within close geographical proximity to one-another (Finston *et al.* 2011).

At least three large isopod species are known from the subsurface zone of the Robe River catchment; *Pygolabis* sp. (Tainisopidae), *Tainisopus* sp. (Tainisopidae) and *Pilbarophreatoicus platyarthricus* (Amphisopodidae). Keable and Wilson (2006) documented *Pygolabis* sp. as occurring in the Robe River catchment but did not disclose the specific locality. Bennelongia (2013) also recorded P*ygolabis* sp. from two groundwater bores in the Bungaroo South area. All species of *Pygolabis* appear to be restricted to groundwaters and/or hyporheic zones of one or several creek drainages of the Pilbara region (Fortescue, Ashburton or Robe River catchments) (Keable and Wilson 2003) and at least some appear to be restricted to single sub-basins (Finston *et al.* 2009). Another undescribed, but closely related species, *Tainisopus* sp., is known to occur in the hyporheos of Nyeetbury Spring (Halse *et al.* 2002), as is *Pilbarophreatoicus platyarthricus* (WRM 2016). *P. platyarthricus* was first identified by Knott and Halse (1999) from Robe River specimens (including Chalyarn Pool), which were exclusively collected during the wet season “under cobbles in slow-flowing riffles … maintained by groundwater discharge.” This species was also collected in surface water samples at Chalyarn Pool during the PBS (Pinder *at al.* 2010).

Although not specifically targeting hyporheic fauna, there have been a number of surveys of stygal communities in the vicinity of the Project area. These communities have taxa frequently encountered in hyporheic zones including SRE amphipods and isopods. These species may potentially occur in hyporheic zones within dewatering and drawdown zones in the Project area and the immediate vicinity.

The PBS sampled a total of 507 wells and drill holes across the Pilbara between 2002 and 2005, including 36 within the Robe River catchment area (Eberhard *et al.* 2005, 2009, Halse *et al.* 2014). A total of 110 stygal invertebrate taxa were recorded from bores in the Robe River catchment, including taxa belonging to the groups Oligochaeta (segmented worms), Polychaeta (bristle worms), Nematoda (round worms), Turbellaria (flat worms), Gastropoda (snails), Acarina (mites), Rotifera (wheel animals), Copepoda (copepods), Ostracoda (seed shrimps), Isopoda (aquatic slaters), Amphipoda (amphipods/side swimmers), Syncarida (syncarids) and Themosbaenacea (thermosbaenaceans). These taxa are also likey to occur within hyporheic zones of the Robe River. Out of the 110 taxa captured in the Robe River area, 83 were recorded from three or less bores (*i.e*. present at < 10% of bores), while just eight taxa were recorded from more than eight bores (*i.e.* present at > 20% of bores). It is possible that many of the uncommonly recorded stygofauna in this study are SREs.

Biota (2006a) sampled stygofauna from 21 bores within the Mesa A/Warramboo Project area and 20 bores in the Yarraloola area during 2005. In this study, a number of species which are occasionally encountered in hyporheic zones, such as stygal amphipods, copepods, and the themosbaenacean *Halosbaena tulki* were recorded, though it was noted that "there appears to be little in the way of a stygal community present at Warramboo". DNA sequencing delineated four new stygal amphipod species (Melitidae spp.), including two from the bores within the Mesa A/Warramboo Project area (Melitidae sp. A and sp. F), which currently are known only from the Mesa A/Warramboo Project area (Biota 2006a).

Biota (2010) sampled 58 bores in the Cardo East and Ken's Bore areas of the Red Hill Creek catchment. A number of potential SREs were recorded, including Paramelitidae (*Pilbarus* nr *millsi*, Paramelitidae sp. 2 and sp. 6), Melitidae (*Nedsia* spp., nr *Norcapensis* sp.), isopods (*Haptolana yarraloola*, *Kagalana tonde*, *Pygolabis* sp., *Pilbarophreatoicus platyarthricus*) and syncarids (*Bathynella* spp., Billibathynella sp. *Hexabathynella* sp. *Notobathynella sp.*).

Bennelongia (2013) sampled stygofauna in 61 bores within the Bungaroo South area in July and October 2012. Potential SREs recorded included Paramelitidae (Genus 2 sp. B12), Melitidae (*Nedsia* spp.), Neoniphargidae (nr *Wesniphargus*), the isopod *Pygolabis* sp. and syncarids (*Bathynella* spp., *Billibathynella* sp.).

3.3 Macroinvertebrates

Since 1991, Streamtec/UWA have conducted annual surveys for macroinvertebrates at seven long-term pools on the Robe River (Streamtec 1996 - 2014, Dobbs and Davies 2009). Pools include Medawandy Waters, Yarramudda, Japanese Pool, Martangkuna, Pannawonica Hill Pool, Pulari-Nyunangka, Gnieraoora (Figures 1 and 3). Four additional pools were included in the program during the 1990s; Chundy Pool, A1, Ngalooin and Mussel Pool (Figure 3). To date, over 112 macroinvertebrate taxa from 64 families have been recorded by Streamtec/UWA from 16 sampling occasions between February 1991 and December 2013. The most commonly encountered groups were the segmented Oligochaeta, Atyidae (freshwater prawns), Ephemeroptera (mayflies), Chironomidae (non-biting midges) and Dytiscidae (diving beetles). Streamtec/UWA noted that caddisflies (Trichoptera) were susceptible to changes in flow regime and water quality, with a decline in the number of species recorded following 1993, 2005, and 2012 cyclone events (Streamtec 2014).

The macroinvertebrate fauna of Chalyarn Pool (Mungarathoona Creek) was sampled during the PBS (Pinder *et al.* 2010). A total of 70 macroinvertebrate taxa were recorded at Chalyarn Pool in the wet season (May 2005), and 97 taxa were recorded in the dry season (August 2003). Other locations surveyed for macroinvertebrates in the vicinity of the Project area during the PBS included Red Hill Creek pools, Myannore Creek Pool and the Yarraloola Station claypan (Figure 3). A total of 196 macroinvertebrate taxa were recorded across these sites, sampled in August 2003/2004/2005 (dry season) and May 2003/2005/2006 (wet season). The most specious samples among these were collected at Red Hill Creek, with 90 taxa collected in both the wet and dry seasons (Pinder *et al.* 2010).

Macroinvertebrates from Mungarathoona Creek and Red Hill Creek were also sampled as part of baseline aquatic surveys for API's WPIOP area (WRM 2009). A total of 128 macroinvertebrate taxa were recorded across two sampling events; dry season (December) 2008 and wet season (April) 2009 (WRM 2009). The taxonomic list comprised Nematoda (roundworms), Hydrozoa (freshwater hydra), Oligochaeta (segmented worms), Gastropoda (snails and bivalves), Acarina (aquatic mites), Ephemeroptera (mayflies), Odonata (dragonflies and damselflies), Hemiptera (true bugs), Coleoptera (aquatic beetles), Diptera (aquatic fly larvae, including Chironomidae/midges), Trichoptera (caddisflies) and Lepidoptera (aquatic caterpillars).

The macroinvertebrate fauna of Yalleen Pool and Nyeetbury Spring on Bungaroo Creek have been sampled as part of the ongoing Pilbara Regional Aquatic Program for the Proponent (see WRM 2016). A total of 83 macroinvertebrate taxa were collected from Yalleen Pool from a total three sampling occasions; wet (March) and dry season (October) 2010 and wet season (March) 2011 (WRM 2013). A total of 190 macroinvertebrate taxa were recorded from Nyeetbury Spring from a total 13 occasions during biannual sampling (wet and dry seasons) between and October 2009 and May 2016 (WRM 2016).

The composition of macroinvertebrate taxa recorded during all of the above studies was typical of freshwater systems throughout the world (Hynes 1970), being dominated by Insecta (insects), within which Diptera (flies) and Coleoptera (beetles) were particularly well represented.

Of the macroinvertebrate fauna recorded from the Robe River catchment, two species are listed for conservation significance (IUCN Red List), and six are of scientific interest, being Pilbara endemics and/or relatively new to science. All potentially occur within the Project area. Three other Pilbara endemics have the potential to occur within the Project area (having been recorded within 100 km), and based on their known dispersal capabilities (*i.e.* with winged-adult forms with strong capacity for flight). These species are as follows:

- Conservation listed species recorded from the Robe River catchment:
  Eurysticta coolawanyah (Pilbara pin damselfly) (IUCN Near Threatened);
  Hemicordulia koomina (Pilbara emerald dragonfly) (IUCN Near Threatened);

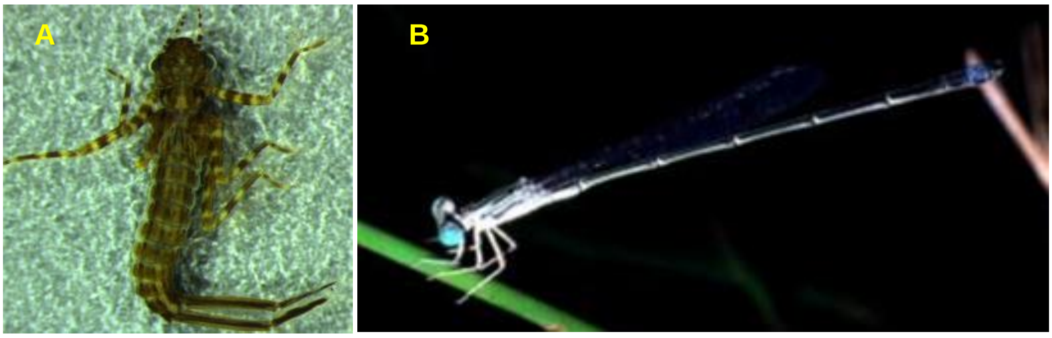
- Pilbara endemic species recorded from the Robe River catchment:
  Agriocnemis kunjina (Pilbara wisp damselfly);
  Ictinogomphus dobsoni (Pilbara tiger dragonfly);
  Nannophlebia injibandi (Pilbara archtail dragonfly);
  Tiporus tambreyi (diving beetle);
  Laccobius billi (water scavenger beetle);
  Haliplus halsei (crawling water beetle);

- Pilbara endemic species recorded from other locations within 100 km of the Project area:
  - *Sternopriscus pilbaraensis* (diving beetle);
  - *Tiporus lachlani* (diving beetle);
  - *Haliplus pilbaraensis* (crawling water beetle).

The Pilbara pin damselfly, *Eurysticta coolawanyah* (Plate 1A-B), is restricted to the Pilbara region, where it prefers riverine pools with an abundance of perching mediums (*e.g.* emergent reeds or overhanging riparian vegetation). *E. coolawanyah* has been collected from Robe River pools by Streamtec/UWA, and from Bungaroo Creek by WRM (2013, 2016). It has also been previously recorded at Chalyarn Pool (Pinder *et al.* 2010). *E. coolawanyah* is listed as Near Threatened[4] on the IUCN Red List of Threatened Species (IUCN 2016), based on its (initially recorded) restricted distribution to an area of less than 500 km^2, and it being thought to occur at less than five locations (Millstream Station, Nanuturra Pools, Palm Pool and the Millstream area); however, it has since been recorded from over 40 locations throughout the Pilbara (Pinder *et al*. 2010). Hawking (2009a) lists no known threats currently, or in the near future, to this species. WRM has encountered *E. coolawanyah* in habitats with a range in frequency of inundation and degree of persistence, including permanent/semi-permanent pools, permanent springs, ephemeral pools and sites permanently inundated and flowing due to dewatering discharge operations, for example at Weeli Wolli Spring.

The Pilbara emerald dragonfly, *Hemicordulia koomina* (Plate 1C-D), has been recorded by Streamtec/UWA from the Robe River, and from Red Hill Creek by Pinder *et al.* (2010). It is known to prefer large, permanent/semi-permanent pools. *H. koomina* is currently listed as Near Threatened on the IUCN Red List (IUCN 2016) but this listing is in need of revision given its more recent collections from numerous localities across several river catchments, including the Fortescue River (Hamersley Gorge, Fortescue Falls, Kalgan Creek), DeGrey River (Bamboo Springs, Minigarra Creek), Ashburton River system (Moreton Pool, Creek Pool near Mt Amy, Henry River pools, Pool at Gorge Junction), Sherlock River (Pool Spring) and Shaw River (Panorama Spring). Despite its widespread occurrence, *H. koomina* is infrequently collected, likely due to its preference for large, permanent pools, which are somewhat uncommon in the Pilbara region and inherently difficult to sample. The major threat to this species is considered to be loss of habitat (*i.e.* drying of permanent pools/waterways) through groundwater abstraction (Hawking 2009b).

Both of these species, particularly the large dragonfly *H. koomina*, are likely to have excellent dispersal capabilities in their winged-adult form (see Plate 1). Dispersal (the movement of individuals from one site to another) is an integral factor in determining the composition of biological communities (Palmer et *al*. 1996, Leibold *et al*. 2004). Aerial dispersal by winged-adult invertebrate fauna (*e.g.* Odonata, Coleoptera, Hemiptera, Ephemeroptera, Diptera and Trichoptera, *etc*.) has been recognised as the most important pathway for colonisation in arid and semi-arid wetlands (Gray and Fisher 1981). Heavy rainfall during the wet season also serves as a cue for many aquatic invertebrate taxa to migrate from perennial wetlands to colonise more ephemeral bodies of water (Lytle and Poff 2004). Given their proficient dispersal capabilities, and the record of these species at multiple locations within close proximity to the Project area, it is considered likely that macroinvertebrate sampling could reveal the presence of one or both of *E. coolawanyah* or *H. koomina* within the Project area.



[4] A species is listed under the IUCN Red List as Near Threatened when it has been evaluated against the criteria but does not qualify for Critically Endangered, Endangered or Vulnerable now, but is close to qualifying for or is likely to qualify for a threatened category in the near future (IUCN 2016).

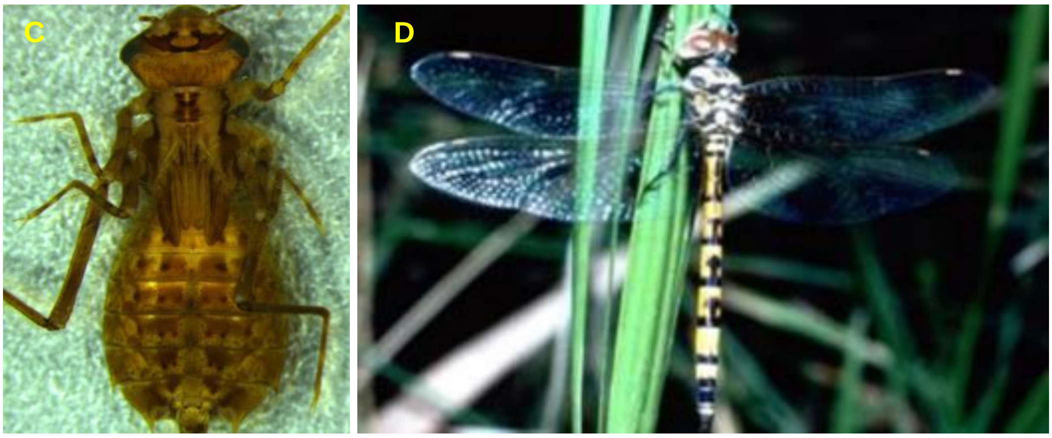


Plate 1. Pilbara pin damselfly, *Eurysticta coolawanyah* (A) nymph and (B) adult, and Pilbara emerald dragonfly *Hemicordulia koomina* (C) nymph and (D) adult (photos A and D courtesy of Jan Taylor ©).

The endemic Pilbara tiger dragonfly, *Ictinogomphus dobsoni*, is recorded infrequently and in low abundances from permanent still or sluggish waters of the Pilbara region (Watson 1991). It is known from a number of sites along the Fortescue, Robe, Ashburton, Yule, DeGrey and Sherlock rivers (DEC 2009, Pinder *et al*. 2010, CSIRO 2015). Near the Project area, *I. dobsoni* has been recorded from pools along the Robe River (Streamtec/UWA), Mungarathoona Creek (Chalyarn Pool) and Red Hill Creek (Pinder *et al*. 2010).

The Pilbara archtail dragonfly, *Nannophlebia injibandi*, is also restricted to the Pilbara region. This species was recorded infrequently during the PBS at Millstream Delta and Gregory Gorge in the Fortescue River catchment (Pinder *et al.* 2010). Within the vicinity of the Project area, *N. injibandi* has been recorded from Robe River pools near Mesa H (Streamtec/UWA) and from Red Hill Creek (WRM 2009).

The Pilbara wisp damselfly *Agriocnemis kunjina,* is a Pilbara endemic rarely encountered. It is previously known from Millstream, Harding River, and Tanberry Creek (ANIC Database); however, it was not recorded during the PBS (Pinder *et al.* 2010). *A. kunjina* is known from both still and flowing waters (Theischinger and Hawking 2006), and has been recorded from Robe River pools in the vicinity of the Project area (Streamtec/UWA) and from Yalleen Pool (WRM 2013).

The aquatic hydrophilid beetle *Laccobius billi* is a Pilbara endemic species that also is rarely collected. *L. billi* was only recorded from one site during the PBS; Cangan Pool on the Yule River (Pinder *et al.* 2010). WRM (2009) recorded *Laccobius billi* at Mungarathoona Creek and from a number of Red Hill Creek sites.

The haliplid beetles *Haliplus halsei* and *H. pilbaraensis* are both endemic to the Pilbara region, and are relatively new to science, having only been recently described (Watts and McRae 2010). Each species appears to occur widely throughout the Pilbara, and have been recorded at localities such as Glen Ross Creek, Coondiner Pool, the Fortescue Marsh, Moreton Pool, Paradise Pool, Munreemya Billabong, Wackilina Creek Pool, West Peawah Creek Pool, Harding River Pool, and an un-named creek in Millstream (Watts and McRae 2010). Closer to the Project area, *Haliplus halsei* has been recorded from Chalyarn Pool and Myannore Creek during the PBS (Pinder *et al*. 2010), while *Haliplus pilbaraensis* has been recorded from Red Hill Creek by WRM (2009).

The dytiscid beetle *Sternopriscus pilbaraensis* is endemic to the Pilbara, is relatively common and known from a range of systems, including Red Hill Creek, the Fortescue River (Gregory Gorge and Kalgan Pool), Ashburton River (Bobswim Pool, Yandabiddy Pool, Whiskey Pool, Ashburton at Gorge Junction, Innawally Pool and Rocky Island Pool), DeGrey River (Pool at Yarrie Homestead, Pelican pool on

Nullagine, Tanguin Rockhole, Paradise Pool, Munereemya Billabong, Carleecarleethong Pool, Minigarra Creek Pools, Bonnie Pool, Cookes Creek Pools, Running Waters and Pool on Tongolock), Rudall River (Watrara Creek Pool), Shaw River (Panorama Spring), Sherlock River (Kangan Pool) and the Harding River (Harding River Pool) (Pinder *et al.* 2010).

The diving beetles *Tiporus tambreyi* and *T. lachlani* are also relatively common and widespread across the region (Pinder *et al.* 2010, WRM unpub. data), though *T. lachlani* is less frequently encountered than its congener (Pinder *et al.* 2010, WRM unpub. data). In the vicinity of the Project area, *T. tambreyi* has been recorded from Robe River pools (Streamtec/UWA), Chalyarn Pool (Pinder *et al.* 2010) and Red Hill Creek (WRM 2009, Pinder *et al.* 2010), while *T. lachlani* has only been previously recorded from Red Hill Creek (Pinder *et al.* 2010).

3.4 Fish

The fish fauna of the Pilbara region is unique, with 13 freshwater species recorded from inland waters to date, including catadromous[5] species (Allen *et al.* 2002, Morgan and Gill 2004). Of the freshwater species, three (or possibly four) are considered endemic to the region. These include the golden gudgeon (*Hypseleotris aurea*), the Murchison River hardyhead (*Craterocephalus cuneiceps*), one undescribed eel-tailed catfish, the Pilbara tandan *Neosilurus* sp.[6], and the conservation listed Fortescue grunter (*Leiopotherapon aheneus*) (Morgan and Gill 2004). *L. aheneus* (Plate 2) is currently listed on the IUCN Red List of Threatened Species as Lower Risk/Near Threatened (IUCN 2016), and as a Priority 4 (P4)[7] species on the Parks and Wildlife Priority Fauna List (Parks and Wildlife 2016). The Fortescue grunter has a restricted distribution within the Pilbara, and is only known from the Fortescue, Robe and Ashburton River systems (Allen *et al*. 2002, Morgan and Gill 2004). This species is considered to be reasonably common within its range.

Plate 2. Fortescue grunter *Leiopotherapon aheneus.* Photo by Chris Hofmeester (WRM) ©.

Other known species from Pilbara inland waters include the spangled perch (*Leiopotherapon unicolor*), barred grunter (*Amniataba percoides*), western rainbowfish (*Melanotaenia australis*), bony bream (*Nematalosa erebi*), flathead goby (*Glossogobius giuris*), empire gudgeon (*Hypseleotris compressa*), Hyrtl's tandan (eel-tailed catfish; *Neosilurus hyrtlii*), blue catfish or lesser salmon catfish (*Arius graeffei*), and the Indian short-finned eel (*Anguilla bicolor*) (Allen *et al.* 2002, Morgan and Gill 2004, Beesley 2006). The most common and widespread species are spangled perch, western rainbowfish and bony bream (Plate 3). The western rainbowfish, for example, has a range extending from the Ashburton River in the Pilbara to the Adelaide River near Darwin, inhabiting rivers, creeks, swamps, lakes and reservoirs

[5] Catadromous fishes live in freshwater as juveniles or sub-adults, but migrate to marine habitats to spawn.

[6] Previously referred to as *Neosilurus hyrtlii*. Recent genetic evidence indicates the Pilbara species is distinct from elsewhere in Australia (Peter Unmack, National Evolutionary Synthesis Centre, North Carolina, pers. comm.).

[7] P4 species are those with limited distributions "in need of monitoring" (Parks and Wildlife 2016).

(Allen *et al.* 2002). Spangled perch and bony bream are considered to be two of Australia's most widespread freshwater fish species, found in drainages throughout the Pilbara, Kimberley, Northern Territory, Queensland, northern New South Wales, as well as in Lake Eyre and the Murray-Darling system (Allen *et al.* 2002).

In addition, the Pilbara Drainage Division contains two endemic cave fishes restricted to the North West Cape region; the blind gudgeon (*Milyeringa veritas*) and the blind cave eel (*Ophisternon candidum*) (Allen *et al.* 2002, Morgan and Gill 2004). Both *M. veritas* and *O. candidum* are listed as Vulnerable under the EPBC Act.

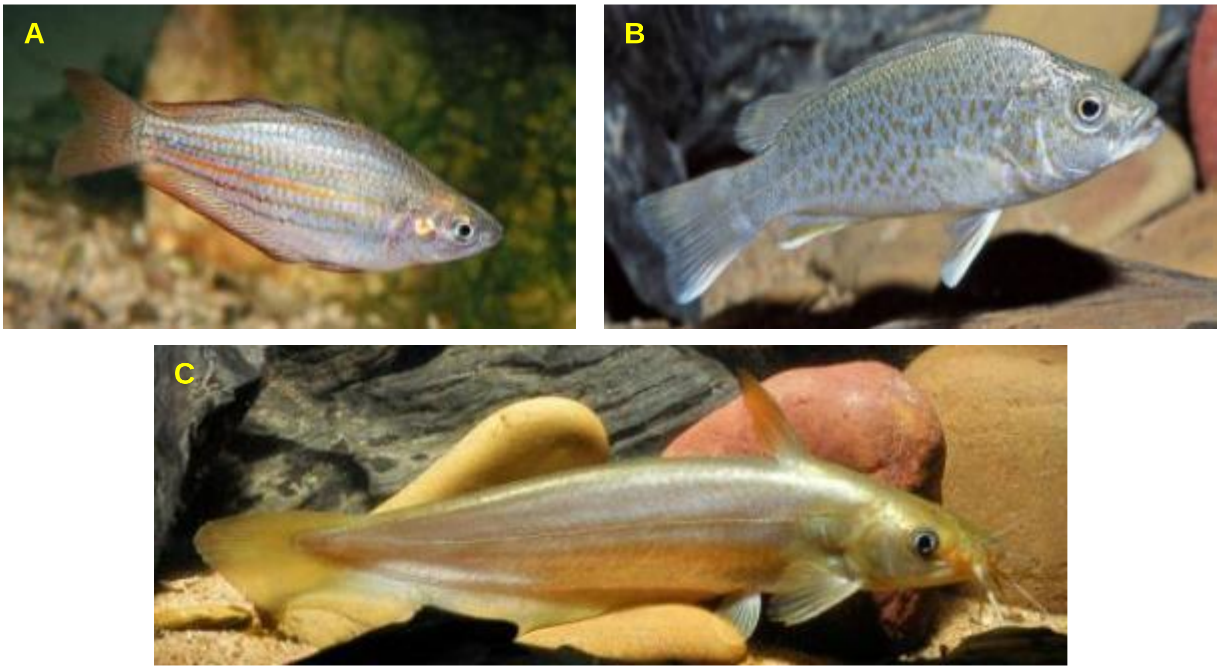


Plate 3. The three most commonly encountered freshwater fish species in the Pilbara; (A) western rainbowfish *Melanotaenia australis*, (B) spangled perch *Leiopotherapon unicolor* and (C) Pilbara tandan *Neosilurus* sp. (photos courtesy of Mark Allen ©).

Freshwater systems of the Pilbara also host a number of species that are considered to be of marine or estuarine origin, most of which have a non-obligatory freshwater juvenile phase. These commonly include barramundi (*Lates calcarifer*), mangrove jack (*Lutjanus argentimaculatus*), sea mullet (*Mugil cephalus*) and tarpon or ox-eye herring (*Megalops cyprinoides*) (Morgan and Gill 2004). The presence of marine/estuarine species in freshwater systems of the Pilbara is likely to be influenced by the frequency, timing and duration of flood events; the species listed above would only enter rivers if flooding coincided with their recruitment phase, while distance moved upstream is governed by the duration of the flood event (Morgan and Gill 2004). As floods recede, it is common for these species to become isolated in permanent upstream pools, forming small remnant populations that are cut-off from marine habitats (Morgan and Gill 2004).

Streamtec/UWA sampled the fish fauna of Robe River pools using seine nets, dip nets, and visual observation. Six freshwater fish species were recorded, including western rainbowfish, spangled perch, Pilbara tandan, barred grunter, bony bream and the conservation listed Fortescue grunter. Additionally, five marine vagrant/estuarine species were recorded, including tarpon, banded scat or striped butterfish (*Selenotoca multifasciata*), threadfin silver-biddy (*Gerres filamentosus*), sea mullet and mangrove jack.

Morgan and Gill (2004) surveyed four Robe River sites for fish using a combination of sampling methods (refer Table 1). Six freshwater species were again recorded (western rainbowfish, spangled perch, Pilbara tandan, barred grunter, bony bream and Fortescue grunter); however, no marine/estuarine species were reported. Morgan and Gill (2004) also included historic records from the Western Australian Museum (WAM) that list empire gudgeon as occurring in the Robe River in the vicinity of the Project area.

The Department of Water (DoW) conducted a review of the ecological values of the lower Robe River, west of the North West Coastal Highway crossing point and Mesa A/Warramboo deposits, which included a summary of the freshwater and estuarine fish fauna of that reach (Antao and Braimbridge 2010). The review did not document any species from the lower Robe River that were not recorded by Streamtec/UWA or Morgan and Gill (2004).

WRM (2016) has recorded seven species from Nyeetbury Spring on upper Bungaroo Creek; Pilbara tandan, western rainbowfish, flathead goby, spangled perch, Fortescue grunter, barred grunter, and a fish that appears to be a hybrid between two of the three co-occurring terapontids (grunters; spangled perch, barred grunter and Fortescue grunter). At Yalleen Pool on Bungaroo Creek, WRM (2013) recorded only western rainbowfish, spangled perch and Pilbara tandan. WRM (2009) also surveyed the fish fauna of upper-Mungarathoona Creek, recording five species; western rainbowfish, spangled perch, Pilbara tandan, barred grunter and Fortescue grunter.

3.5 Other Fauna

3.5.1 Turtles

Although not typically targeted in aquatic surveys, one species of native turtle is known from the Pilbara region; the flat-shelled *Chelodina steindachneri.* This species has a widespread distribution throughout the Pilbara, having been recorded from most major river systems in the region, from the DeGrey River in the north to the Murchison River in the south (Kuchling 1988, WRM unpub. data). These turtles are adapted to survive drought by burrowing into the dry river beds (Kuchling 1988). Only one clutch of seven to eight relatively small eggs is laid each year; a pattern that appears to be adapted to a relatively long period of aestivation of up to three years (Kuchling 1988).

EPA (1991) note *Chelodina steindachneri* as present at Gnieraoora and Martangkuna, but do not state the source of the records, which was possibly the 1991 survey by Streamtec/UWA. Neither Antao and Braimbridge (2010) nor Pinder *et al.* (2010) document turtles. Similarly, turtles were not recorded or observed at upper-Mungarathoona Creek or Red Hill Creek by WRM (2009); however, given its widespread distribution across the Pilbara region, it is possible that *Chelodina steindachneri* may reside in pools in the vicinity of the Project area.

3.5.2 Frogs

The Pilbara is host to 13 species of frogs, three of which are endemic to the region; *Pseudophryne douglasi* (Gorge toadlet), *Uperoleia glandulosa* (Glandular toadlet) and *U. saxatilis* (Pilbara toadlet) (Tyler and Doughty 2009, Doughty *et al*. 2011). None of these species are currently listed for conservation significance, though *U. saxatilis* has only recently been described (Catullo *et al.* 2011). *U. saxatilis* is broadly distributed throughout the Pilbara, occurring in or near rocky creeks, and appears to be adapted to rocky landscapes (Catullo *et al.* 2011, Doughty *et al*. 2011). *U. glandulosa* has a more restricted distribution in the northern coastal Pilbara but penetrates inland along the Yule River drainage (Catullo *et al.* 2011, Doughty *et al*. 2011). *Pseudophryne douglasi* is a rare species that has an ancient relictual arid distribution separate from other toadlets (Doughty *et al*. 2011, WA Museum).

The Pilbara, Gascoyne and Murchison populations of the desert tree frog, *Litoria rubella*, are separated from Kimberley and Northern Territory populations by the Great Sandy Desert. *L. rubella* is known to occur in a wide range of habitats across northern Australia, including northern Western Australia, Northern Territory, north-east of South Australia, Queensland, and northern New South Wales (Tyler and Knight 2011). The desert tree frog is commonly found sheltering under stones or bark around creeks and waterholes, and can breed at any time of year if water is present (Tyler and Knight 2011).

Frogs are difficult to survey in the Pilbara region, as captures are typically dependent on rainfall that is spatially and temporally variable (Doughty *et al*. 2011). Many frog species of the Pilbara aestivate over dry periods to avoid desiccation, emerging following rains to opportunistically breed and spawn (Tyler and Doughty 2009). No data were available on targeted frog surveys in the vicinity of the Project area, and although there have been a number of terrestrial vertebrate surveys (*e.g.* Biota 2005, 2006b, 2009, Strategen 2006), few have recorded frogs. Biota (2006a) recorded two species of Hylidae (tree frogs): *L. rubella* and *Cyclorana maini* - and one Myobatrachidae (southern frog) species *Uperoleia russelli* during baseline surveys for the Mesa A/Warramboo project area. In addition to *L. rubella* and *U. russelli*, Biota (2009) recorded the ornate burrowing frog *Platyplectrum ornatus* (formerly *Limnodynastes ornatus)* from the Red Hill Creek catchment.

3.6 Summary of Known Species of Conservation and/or Scientific Interest

Table 2 below provides a summary of known aquatic invertebrates (including hyporheos) and fish of conservation and/or scientific interest.

Table 2. Aquatic species (invertebrates and fish) of conservation and/or scientific value known to occur, or likely to occur, within the Project area.

Species	Common name	Scientific value	Conservation listing	Occurrence within 100 km of Project area	Likelihood of occurrence within the Project area	Occurrence elsewhere
Microinvertebrates						
Lecane noobjupi	Rotifer	WA endemic	N/A	Nyeetbury Spring, Red Hill Creek	High in surface waters	Weeli Wolli Ck, Marillana Ck, Coondiner Ck, Mindy Mindy Ck, Kalgan Ck and Un-named Ck, DeGrey R. Also in SW Western Australia
Paracyclops sp. 6	Copepod (micro-crustacean)	Pilbara endemic	N/A	Chalyarn Pool	High in surface waters	20+ locations Pilbara-wide
Vestalenula matildae	Ostracod (micro-crustacean)	Pilbara endemic	N/A	Chalyarn Pool	High in surface waters	Various systems of the Ashburton R., DeGrey R., Fortescue R. and Sherlock R.
Hyporheos						
Paramelitidae spp.	Stygal amphipods	Potential SRE	N/A	Yalleen Pool, Red Hill Ck, Mungarathoona Ck.	High in ground-waters and hyporheos	Unknown given family level identification.
Melitidae spp.	Stygal amphipods	Potential SRE	N/A	Bores across the Robe River catchment area	High in ground-waters; Low-moderate in hyporheos	Unknown given family level identification
Haptolana yarraloola	Stygal isopod	Potential SRE	N/A	Bores in the lower Robe River catchment area – Mesa A/Warramboo/Yarraloola	Low	Recently described species; known only from Mesa A/ Warramboo/Yarraloola bores
Kagalana tonde	Stygal isopod	Potential SRE	N/A	Bores in the lower Robe River catchment area – MesaA/Warramboo/Yarraloola	Low	Recently described genus and species; elsewhere known from Cane River and Hardey River catchments
Pilbarophreatoicus platyarthricus	Stygal isopod	Potential SRE	N/A	Chalyarn Pool, Nyeetbury Spring, Bores in the Robe River catchment area	High in ground-water and hyporheos	Weeli Wolli Ck, Coondiner Ck, Bobswim Pool (Ashburton R.)
Pygolabis sp.	Stygal isopod	Potential SRE	N/A	One undescribed species known from the Robe River catchment	High in ground-water and hyporheos	Uncertain. Members of this genus restricted to either Fortescue, Ashburton or Robe catchment groundwater and hyporheos
Tainisopus sp.	Stygal isopod	Potential SRE	N/A	Nyeetbury Spring	Low-moderate; only known from Nyeetbury Spring hyporheos	Unknown given genus level identification

Species	Common name	Scientific value	Conservation listing	Occurrence within 100 km of Project area	Likelihood of occurrence within the Project area	Occurrence elsewhere
Parabathynellidae spp.	Stygal syncarids	Potential SRE	N/A	Unknown given genus level identification	High in ground-waters; Low-moderate in hyporheos	Unknown given genus level identification
Macroinvertebrates						
Hemicordulia koomina	Pilbara emerald dragonfly	Pilbara endemic	IUCN, Near Threatened	Robe River pools, Red Hill Ck.	High in surface waters	Fortescue R., Coondiner Ck; now known to be widespread throughout the Pilbara, though infrequently collected
Eurysticta coolawanyah	Pilbara pin damselfly	Pilbara endemic	IUCN, Near Threatened	Chalyarn Pool, Robe River pools, Yalleen Pool	High in surface waters	Ashburton R. (Bobswim Pool); Kalgan Ck; Coondiner Ck; Fortescue R.
Ictinogomphus dobsoni	Pilbara tiger dragonfly	Pilbara endemic	N/A	Chalyarn Pool, Robe River pools, Red Hill Ck.	High in surface waters	Fortescue, Ashburton, Yule, DeGrey and Sherlock rivers
Nannophlebia injibandi	Pilbara archtail dragonfly	Pilbara endemic	N/A	Robe River pools, Red Hill Ck.	Low-Moderate in surface waters	Fortescue R. catchment, but uncommonly collected
Agriocnemis kunjina	Pilbara wisp damselfly	Pilbara endemic	N/A	Robe River Pools, Yalleen Pool	Low-Moderate in surface waters	Millstream, Harding River, Tanberry Ck; rarely collected
Haliplus halsei	Aquatic beetle	Pilbara endemic	N/A	Chalyarn Pool, Myannore Ck.	Low-Moderate in surface waters	Uncommonly collected from ephemeral systems and claypans, *e.g.* the Fortescue Marsh and Coondiner Pool
Haliplus pilbaraensis	Aquatic beetle	Pilbara endemic	N/A	Red Hill Ck.	Low-Moderate in surface waters	Uncommonly collected from ephemeral systems and claypans, *e.g.* the Fortescue Marsh and Coondiner Pool
Sternopriscus pilbaraensis	Diving beetle	Pilbara endemic	N/A	Red Hill Ck.	Moderate in surface waters	A range of systems across the Pilbara, fairly commonly collected
Tiporus tambreyi	Diving beetle	Pilbara endemic	N/A	Chalyarn Pool, Robe River pools, Red Hill Ck.	Moderate-High in surface waters	A range of systems across the Pilbara, very commonly collected
Tiporus lachlani	Diving beetle	Pilbara endemic	N/A	Red Hill Ck.	Low-Moderate in surface waters	A range of systems across the Pilbara, infrequently collected
Laccobius billi	Aquatic beetle	Pilbara endemic	N/A	Mungarathoona Ck, Red Hill Ck.	Low-Moderate in surface waters	Yule R. and Fortescue R.

Species	Common name	Scientific value	Conservation listing	Occurrence within 100 km of Project area	Likelihood of occurrence within the Project area	Occurrence elsewhere
Fish						
Leiopotherapon aheneus	Fortescue grunter	Pilbara endemic	IUCN Near Threatened; Parks and Wildlife P4	Robe River pools, Red Hill Ck., Mungarathoona Ck.	High in surface waters	Fortescue R (below Fortescue Marsh); Ashburton R.

4 METHODS FOR BASELINE SURVEYS

4.1 General

For the current baseline field sampling, WRM employed sampling design, methods and general approaches consistent with the following:

- Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC/ARMCANZ 2000);
- Environment Protection Authority (EPA) Guidance No. 20, Sampling of Short Range Endemic Invertebrate Fauna for Environmental Impact Assessment in Western Australia (EPA 2009);
- EPA Position Statement No. 3, Terrestrial Biological Surveys as an Element of Biodiversity Protection (EPA 2002);
- EPA Guidance No. 56, Terrestrial Fauna Surveys for Environmental Impact Assessment in Western Australia (EPA 2004).

Aquatic fauna sampling methods were also similar to the following:

- Streamtec/UWA surveys of benthic macroinvertebrates of the Robe River (see Dobbs and Davies 2009, Streamtec 2014);
- Parks and Wildlife surveys of benthic macroinvertebrates for the regional Pilbara Biological Survey (PBS) (see Pinder *et al.* 2010).

4.2 Licences

This study was conducted under Department of Fisheries (DoF) Exemption #2706 (Authority to Take Fish for Scientific Purposes), and Parks and Wildlife Licence SF010732 (Licence to Take Fauna for Scientific Purposes).

As a condition of these licences, taxa lists and reports are required to be submitted to the respective government departments, and have been done so.

4.3 Sampling Design and Sites

The sampling design is an mBACI (multiple Controls - Before/After - Control/Impact) type design (Keough and Mapstone 1995). Location and number of sites were selected to provide data for robust statistical analysis and to meet requirements of such a design. An mBACI design is considered ideal for impact assessment, as impacts may be placed in context with natural temporo-spatial catchment changes. An mBACI type design provides both benchmark information as well as a strong basis to detect future changes. Reference sites upstream of the Project area were selected to serve as the “control” for potentially impacted sites. Surveys conducted in April/May 2016 are part of the benchmark or “before” phase against which to assess any potential future changes.

Sampling was conducted during the late wet season, between 28th April and 7th May 2016.

A total of 12 pools were sampled along the main channel of the Robe River (Table 3 and Figure 1). Sites included six potentially exposed sites within the predicted surface extent of dewatering discharge, and six reference sites upstream of the Jimmawurrada Creek-Robe River confluence.

Table 3. Aquatic ecosystem sampling sites on the Robe River. Equivalent sites monitored by Streamtec/UWA are also indicated.

Type	WRM Site	Description	GPS co-ordinates (zone 50 K)		Date sampled	Maximum wetted width, length and depth of pool (m)			Streamtec/ UWA site
			Easting	Northing		Width	Length	Depth	
Reference	RRU1	Approx. 3.7 km upstream of Pannawonica Hill.	435628	7603253	05-05-16	20	100	1.2	
	RRU2	Approx. 600 m downstream of Streamtec/UWA site at Pannawonica Hill Pool; upper end of Medawandy Waters area, adjacent Mesa N.	431811	7602046	28-04-16	9	55	3.0	Pannawonica Hill
	RRU3	Approx. 1.6 km downstream of Pannawonica Hill, near Mesa N; within the Medawandy Waters area.	430912	7601562	28-04-16	5	3	1.0	Medawandy
	RRU4	Approx. 1.5 km downstream of RRU3; within the Medawandy Waters area, in the vicinity of Mesa M.	429677	7601439	28-04-16	20	120	1.0	
	RRU5	Approx. 1 km downstream of RRU4; within the Medawandy waters area, adjacent Mesa L.	428769	7601342	29-04-16	10	40	1.2	
	RRU6	Approx. 1 km upstream of Jimmawurrada Creek confluence; lower end of the Medawandy waters area, at base of Mesa L.	424573	7597240	07-05-16	12	40	0.6	
Potentially Exposed	RRD1	Martangkuna; approx. 600 m downstream of existing Mesa J dewatering discharge point (*i.e.* western discharge point).	417110	7598094	30-04-16	3	7	0.8	Martangkuna
	RRD2	Approx. 0.9 km downstream of RRD2.	416245	7598031	30-04-16	6	12	0.7	
	RRD3	Approx. 1 km downstream of RRD3.	415309	7598013	30-04-16	5	25	1.0	
	RRD4	Approx. 1.1 km downstream of RRD3; 1 km upstream of Yeera Bluff.	414419	7597633	29-04-16	20	150	2.0	
	RRD5	Gnieraroora / Dthulurat* at Yeera Bluff; 8.6 km downstream of existing Mesa J western discharge point.	414426	7596622	29-04-16	25	45	4.0	Gnieraoora
	RRD6	Approx. 12.5 km downstream of existing Mesa J western discharge point; within projected discharge footprint (at 20 ML/day).	411415	7594924	30-04-16	30	20	1.2	

* Dthulurat = Western Guruma name.

The original intent was that the assessment would utilise, wherever possible, long-term data from sites sampled by Streamtec/UWA; however, only two of these sites are located within the predicted footprint of surface discharge extent; Martangkuna (RRD1) and Gnieraoora/Dthulurat (RRD5). Therefore, four new sites (RRD2, RRD3, RRD4 and RRD6) were added to allow a more robust characterisation of ecological condition within this reach (Table 3 and Figure 1). These sites may also be exposed to any runoff from the Project area.

Of the sites sampled by Streamtec/UWA upstream of the Jimmawurrada-Robe confluence, two were selected as reference sites for the Project area; Medawandy and Pannawonica Hill Pool; however, only Medawandy (RRU3) held surface water at the time of sampling in April-May 2016. Therefore, five new reference sites were established within the Medawandy Waters area; RRU1, RRU2, RRU4, RRU5 and RRU6 (Table 3 and Figure 1). Site photographs are provided in Appendix 1.

The 2016 sampling was timed to correspond with recessional flow conditions at the end of the wet (April-May) season. It was considered that the end of the wet season would be a more ecologically important time of year to sample, as biological diversity would be expected to be at its highest. By comparison, lower biological diversity may be expected at the start of the wet season, as many invertebrate fauna would not yet have emerged/colonised the seasonal creeks.

4.4 Water Quality

At each site, pH, dissolved oxygen and temperature were measured *in situ* using hand-held Wissenschaftlich-Technische-Werkstätten (WTW) field meters. Meters were calibrated immediately prior to field surveys. Water depth was measured using a graduated pole. Undisturbed water samples were collected for laboratory analyses of major ions, alkalinity, dissolved metals, nutrients and total suspended solids (TSS). Water samples for nitrogen and phosphorus nutrient and dissolved metal analyses were filtered in the field through 0.45 µm nitrocellulose filters. To avoid contamination, all sample bottles and filtering equipment used for dissolved metals were acid-washed (0.1% nitric acid) prior to use. Bottles and filters used for nutrients weren’t acid washed to avoid nitrogen contamination from nitric acid. Water samples for analysis of dissolved metals and nutrients were collected using nitrile gloves. All samples were double-wrapped in polyethylene zip-lock bags and kept cool on ice-packs in an esky while in the field and during transport. At the end of each field day, samples were either refrigerated (ions and metals) or frozen (nutrients). Samples were stored refrigerated or frozen for a maximum of 10 days prior to transport on ice to analytical laboratories at ChemCentre, Bentley, together with chain-of-custody forms. All water quality variables measured are summarised in Table 4.

4.4.1 Comparison against ANZECC/ARMCANZ Guidelines

Water quality data were compared against default ANZECC/ARMCANZ (2000) guidelines (trigger values) for the protection of freshwater ecosystems (provided in Appendix 2). Default trigger values (TVs) for 95% aquatic species protection were considered more appropriate than default TVs for 99% protection, given that the Robe River catchment in the vicinity of current mining operations is already slightly to moderately disturbed by historic mining and pastoral practices (Strategen 2006). In accordance with ANZECC/ARMCANZ (2000) however, the default 99% TVs were applied to bioaccumulating metals such as selenium. For metals and nutrients, dissolved concentrations (0.45 µm filtered samples) were compared to the default TVs. Filtered concentrations were considered a better reflection of the fraction that may be bioavailable. By contrast, comparison of the default TVs to the total metal or total nutrient concentration may overestimate the risk to the environment (ANZECC/ARMCANZ 2000).

Table 4. Measured and derived water quality and habitat parameters. Metals (Al, As, B, Ba, Cd, Co, Cr, Cu, Fe, Mn, Mo, Ni, Pb, S, Se, U, V, Zn) and nutrients (N-NH_3, N-NO_2, N-NO_3, N-NO_X, N-total, P-total) were measured as dissolved concentration. All units for water quality parameters are mg/L unless stated otherwise.

Water Quality Parameters	Code	Habitat Parameters	Code
Temperature (°C)	Temp	Maximum pool depth (m)	depth
pH (H^+)	pH	Maximum wetted length of pool (m)	length
Dissolved oxygen (%)	DO%	Mean wetted width of pool (m)	width
Dissolved oxygen (mg/L)	DO	Mineral substrates (total % cover within habitat)	min
Conductivity (µS/cm)	EC	Bedrock (% cover)	bedr
Redox (mV)	Redox	Boulders >256 mm (% cover)	boul
Alkalinity (as $CaCO_3$)	Alk	Cobbles 64-256 mm (% cover)	cobb
Ammonia	N-NH_3	Pebbles 16-64 mm (% cover)	pebb
Arsenic	As	Gravel 4-16 mm (% cover)	grav
Barium	Ba	Sand 1-4 mm (% cover)	sand
Boron	B	Silt <1 mm (% cover)	silt
Cadmium	Cd	Mean particle size (from substrate proportions)	phi
Calcium)	Ca	Emergent macrophyte (% cover)	emerg
Carbonate	CO_3	Submerged macrophyte (% cover)	submerg
Chloride (mg/L)	Cl	Floating macrophyte (% cover)	float
Chromium (µg/L)	Cr	Algae (% cover)	algae
Copper (µg/L)	Cu	Detritus (% cover)	detr
Hardness (as $CaCO_3$)	Hard	Riparian vegetation canopy (% canopy cover)	ripvegco
Hydrogen carbonate	HCO_3	Large woody debris (>10 cm diameter) (% cover)	LWD
Iron	Fe	Root mats (% cover)	rootm
Lead	Pb	Trailing riparian vegetation (% cover)	ripveg
Magnesium	Mg	Habitat diversity (total no. of habitat types)	habdiv
Manganese	Mn	Substrate compaction (1 = loose, to 5 = armoured)	compct
Nickel	Ni	Substrate diversity (total no. substrate types)	subdiv
Nitrate-nitrogen	N-NO_3		
Nitrite-nitrogen	N-NO_2		
Nitrogen oxides	N-NO_X		
Nitrogen-total	N-total		
Phosphorus-total	P-total		
Potassium	K		
Selenium	Se		
Sodium	Na		
Sulfate	S-SO_4		
Sulfur	S		
Total dissolved solids	TDS		
Total suspended solids	TSS		
Uranium	U		
Vanadium	V		
Zinc	Zn		

4.5 Habitat Characteristics

Details of habitat characteristics at each site were recorded (Table 4) to assist in explaining any patterns in faunal assemblages, particularly due to existing differences in benthic substrate composition. Habitat parameters were assessed for the approximately 10 m section of river over which each macroinvertebrate sample was collected. Water depth was measured with a graduated pole. Substrate type was visually assessed and recorded as estimated percent cover by bedrock, boulders, cobbles, pebbles, gravel, sand, silt and clay, from which mean particle size was determined using the phi scale. As an indication of habitat heterogeneity, the number of organic and inorganic substrate types represented at each site was totalled. Habitat characteristics recorded included estimated percent cover by inorganic sediment, submerged macrophyte, floating macrophyte, emergent macrophyte, algae, large woody debris, detritus, roots and trailing vegetation.

WRM has specific worksheets for this task to ensure qualitative habitat recordings between sites are as comparable as possible. To limit variation due to different observers, all estimations were made by the same sampler.

4.6 Microinvertebrates (zooplankton)

Microinvertebrate samples were collected from each site by gentle sweeping over an approximate 15 m distance with a 53 μm mesh plankton net (Plate 4). Care was taken not to disturb the benthos (bottom sediments) during sampling. Samples were preserved in 70% ethanol and sent to Dr Russell Shiel at the University of Adelaide, South Australia, for processing. Dr Shiel is a world authority on microfauna, with extensive experience in fauna survey and impact assessment across Australasia, including the Pilbara.

Plate 4. Microinvertebrate sampling at RRD4.

Microinvertebrate samples were processed by identifying the first 200-300 individuals encountered in an agitated sample decanted into a 125 mm^2 gridded plastic tray, with the tray then scanned for additional missed taxa also taken to species and recorded as 'present'. Specimens were identified to the lowest taxon possible, *i.e*. species or morphotypes. Abundance data were reported as $\log_{10}$ scale abundance classes (*i.e.* 1 = individual, 2 = 2-10 individuals, 3 = 11-100 individuals, 4 = 101-1000 individuals, 5 = >1000). Where specific names could not be assigned, vouchers were established. These vouchers are held by Dr Shiel at Adelaide University, Adelaide, Australia.

4.7 Hyporheos

At each site, hyporheic sampling was conducted using the Karaman-Chappuis method (Delamare Deboutteville 1960). This involved digging a hole approximately 20 cm deep and 40 cm diameter in alluvial gravels in dry streambed adjacent to the water's edge, allowing the hole to infiltrate with water, and sweeping the water column with a modified 110 µm mesh plankton net (Plate 5). The water column was swept immediately after the hole had filled, and again after approx. 30 minutes, once other sampling had been conducted.

Plate 5. Hyporheic sampling at RRU3.

Samples were preserved in 70% ethanol and returned to the laboratory for processing. Any aquatic fauna present was removed from samples by sorting under a low power dissecting microscope. In-house expertise was used to identify the majority of hyporheic taxa using available published keys and through reference to the established voucher collections held by WRM. External specialist taxonomic expertise was sub-contracted to assist with Chironomidae (Dr Don Edward, UWA) and micro-crustacea (Dr Russel Shiel, University of Adelaide).

All taxa recorded from hyporheic samples were classified using the categories of Boulton (2001):

- stygobite, *i.e.* obligate groundwater species, with special adaptations to survive such conditions,
- permanent hyporheos stygophile, *i.e.* epigean[8] species that may occur in both surface and groundwaters, but is a permanent inhabitant of the hyporheic zone,
- occasional hyporheos stygophile, *i.e.* species that use the hyporheic zone seasonally or during early life history stages, or
- stygoxene, *i.e.* species that appear rarely and apparently at random in groundwater habitats; there by accident or seeking refuge during spates or drought; not specialised for dwelling permanently underground.

4.8 Macroinvertebrates

Macroinvertebrate sampling was conducted with a 250 μm mesh FBA pond net (Plate 6). All meso-habitats were sampled, including trailing riparian vegetation, woody debris, open water column and benthic sediments with the aim of maximising the number of species recorded. Each sample was washed through a 250 μm sieve to remove fine sediment, while leaf litter and other debris were carefully washed in the sieve and removed by hand. Samples were then preserved in 70% ethanol. In the laboratory, macroinvertebrates were removed from samples by sorting under a low power dissecting microscope.

Plate 6. Macroinvertebrate sampling at RRU5.

Collected specimens were identified to the lowest practicable level (typically genus or species) and enumerated to $\log_{10}$ scale abundance classes (*i.e.* 1 = individual, 2 = 2-10 individuals, 3 = 11-100 individuals, 4 = 101-1000 individuals, 5 = >1000). In-house expertise was used to identify invertebrate taxa using available published keys and through reference to the established voucher collections held by WRM. External specialist taxonomic expertise was sub-contracted to assist with Chironomidae (Dr Don Edward, UWA).

4.9 Fish

A number of fish sampling methods were used at each site in order to collect as many species and individuals as possible. Methods included electrofishing, seine nets and gill nets. Electrofishing was conducted with a Smith-Root Model LR24 battery powered backpack electrofisher (Plate 7A). Electrofishing is an extremely useful and efficient sampling tool in rivers with clear, low salinity, slow flow water. All meso-habitats within a maximum 40 m reach were shocked with the intention of recovering as many species/individuals as possible. Shocking was not continuous, but targeted areas of optimum habitat, whereby the operator would shock, move to a new habitat before shocking again, and so prevent fish being driven along in front of the electrical field.

Duplicate 30 m multi-panel gill nets were set at each site where there was sufficient depth of water (Plate 7B). Each net consisted of 6 x 5 m panels, with panels increasing in size from 1” to 6” stretched mesh size. The nets were set perpendicular to the bank, with the smallest mesh set against the bank, and the large mesh positioned into the channel with a float and weight to keep the nets in place. At

[8] Epigean – living or occurring on or near the surface of the ground.

each sampling location, two nets were set for approximately 2.5 hours. Nets were checked frequently to avoid fish deaths. Catch from the duplicate nets were combined to form one replicate sample from each sampling location.

Smaller species and juveniles were sampled by beach seine (10 m net, with a 2 m drop and 6 mm mesh) deployed in shallow areas where there was little vegetation or large woody debris. Typically, two seine hauls were made at each location to maximise the number of individuals caught.

All fish were identified in the field, measured for standard length (SL)[9], and then released alive. Fish nomenclature followed that of Allen *et al.* (2002). Fish measurements provided information on the size structure, breeding and recruitment of fish populations.

Plate 7. Example of electrofishing (left), and setting gill nets at RRU1 (right).

4.10 Data Analysis

Samples were grouped *a priori* into categories according to exposure; potentially exposed sites downgradient of the Jimmawurrada-Robe confluence (RRD) or reference sites upgradient of the Jimmawurrada-Robe confluence (RRU). Water quality and species richness (number of taxa) data were plotted in order to illustrate spatial differences. For comparison of species richness against previous studies, invertebrate taxonomy was standardised across datasets to account for differences in taxonomic resolution and/or advancements in taxonomic knowledge between studies (*i.e.* some taxa were condensed to family or order level to enable comparison). As such, taxa richness may appear lower than was originally reported in each study. Where sufficient numbers of each fish species were measured, length-frequency histograms of current data were plotted.

Univariate analyses (one-way ANOVA) was used to test for statistically significant (p <0.05) differences in water quality variables and micro- and macroinvertebrate species richness between groups (RRD, RRU). The assumptions of normality and homogeneity of sample variances were checked using Shapiro-Wilk and Levene's tests, respectively. Data were $\log_{10}(x+1)$ transformed where appropriate. All univariate analyses were performed using IBM SPSS Statistics (v21) software package.

Multivariate patterns in micro- and macroinvertebrate species assemblages were analysed using procedures from the PRIMER (v7) software package (Clarke and Gorley 2006). Non-metric Multi-Dimensional Scaling (nMDS) ordination plots (Clarke and Warwick 2001) were constructed to visualise differences between sites. nMDS ordinations were based on Bray-Curtis similarity measures for species abundance ($\log_{10}$ class) data. Ordinations were depicted as two-dimensional plots. The Analysis of

[9] Standard length (SL) - measured from the tip of the snout to the posterior end of the last vertebra or to the posterior end of the mid-lateral portion of the hypural plate (*i.e*. this measurement excludes the length of the caudal fin).

Similarity (ANOSIM) routine within PRIMER was used to test for significant ($p < 0.05$) differences in species assemblages between groups (RRD, RRU), based on both abundance ($\log_{10}$ class) and presence/absence data. The SIMPER routine within PRIMER was used to determine those species contributing most to the similarity/dissimilarity between significant site groupings identified by ANOSIM.

Too few taxa were recorded from hyporheic samples to warrant ANOVA or PRIMER analyses of these data.

4.11 Survey Limitations

Inherent physical sampling deficiencies are acknowledged as a barrier to sampling aquatic fauna, and in particular fish. For example, fish catch rates may have been hindered by the abundance of aquatic vegetation (macrophytes and algae) which physically obstructed seine and gill nets at some sites. This was somewhat compensated for by the use of a back-pack electrofisher, which generates a pulsed direct electrical current to draw fish out from under such habitat.

This study provides a snapshot of water quality conditions and faunal communities at a single point in time, and is unlikely to fully capture the range of temporal/seasonal variability within the Project area. Prior to sampling, total monthly rainfall at Pannawonica Gauging Station was well below the 45-year average, particularly during February, March and April. As such, there was no surface flow connecting pools along the Robe River, with pools heavily receded and even some fish mortality evident, possibly due to low overnight dissolved oxygen concentrations. The relative lack of rainfall leading up to the survey may also have caused recordings of some other water quality parameters, such as salinity and nutrients, to be higher than would be expected under “average” wet season baseflow conditions, due to evapo-concentration effects and lack of flushing within the system. Dry conditions may also have affected aquatic faunal communities, particularly hyporheic fauna, which require saturation of the alluvium and strong connectivity between ground and surface waters, and fish, with many speces known to require higher baseflows and connectivity between pools to enable upstream migration and spawning.

5 RESULTS AND DISCUSSION

5.1 Water Quality

5.1.1 General

Raw data for spot measurements of water quality, made in conjunction with aquatic fauna sampling, are provided in Appendix 3. Water quality was highly variable amongst sites (Figures 4 and 5). Salinity levels ranged from fresh[10] (592 µS/cm, RRD5) to brackish (1,700 µS/cm, RRU6), pH from circum-neutral (6.9, RRU3) to slightly alkaline (7.9, RRU1), hardness from 230 mg/L (RRD2) to 520 mg/L (RRU6), total suspended solids from <1 mg/L (RRD4, RRU3, RRU4) to 34 mg/L (RRD5), and dissolved oxygen from hypoxic[11] (14.5%, RRU5) to supersaturated (134.9%, RRD6).

There were no obvious longitudinal gradients upstream or downstream of the Jimmawurrada-Robe confluence. Site RRU6 (located ~1 km upstream of the confluence), together with the downstream sites, tended to have higher salinity (as EC and TDS), alkalinity, hardness and concentrations of associated ions, than sites upstream (Figure 3). Maximum values for most of these parameters (*i.e.* EC, TDS, hardness, Na^+, Cl^+, Ca^{2+}, S-SO_4, Mg^{2+}) and for nitrogen (as N-total, N-NO_X, N-NH_3) were recorded at RRU6. Average concentration of K^+, S-SO_4 and total dissolved sulfur (S) was significantly higher downstream of the Jimmawurrada-Robe confluence (one-way ANOVA, Table 5).

Table 5. Summary results from one-way ANOVAs testing for significant (p <0.05) differences in mean concentrations of water quality parameters, upstream (RRU) and downstream (RRD) of the Jimmawurrada-Robe confluence. Only significant results are shown. Mean (±SE) vales for untransformed data are also provided.

Water quality parameter	ANOVA (df = 1, 11)			Mean (±SE)	
	MS	F	*p*	RRD (*n* = 6)	RRU (*n* = 6)
Fe	0.005	9.52	0.012	0.05 (0.01)	0.12 (0.005)
K	23.24	21.96	0.001	8.4 (0.52)	5.6 (0.29)
S	352.08	35.62	<0.001	25.3 (0.95)	14.5 (1.54)
S-SO_4	2104.10	15.52	0.003	70.2 (4.67)	43.7 (4.83)

The significantly higher concentrations of some ions, most notably S-SO_4, and to a lesser extent Mg (Figure 4), downstream of the Jimmawurrada-Robe confluence, may reflect the influence of dewatering discharge from current mining operations. Some inter-site variability could also be attributed to differences in volume of the remnant pools sampled, and evapoconcentration effects under recessional flows. For example RRU6, where maximum values for a number of parameters were recorded, was the shallowest of the pools sampled (maximum water depth of 0.6 m), and supported extensive organic deposits and abundant macrophyte growth (*Typha* and *Potamogeton*) (Appendix 4). The relative abundance of macrophytes, algae and accumulated organics would also be expected to have varying effect on DO levels, pH and rates of nutrient recycling within each of the pools. The higher level of TSS recorded at Gnieraoora (RRD5) compared to all other sites (Figure 5) was likely due to recent cattle activity, which caused the physical disturbance and suspension of benthic sediments.

At most sites, Na^+ was the dominant cation, with Ca^{2+} sub-dominant, and HCO_{3-} the dominant anion, with Cl^- sub-dominant. The exception was RRU6, where Cl^- was dominant and HCO_{3-} sub-dominant. This suggests groundwater ingress had less influence on the water chemistry of the remnant pool at RRU6

[10] Fresh defined as < 1,500 µS/cm; brackish = 1,500 – 4,500 µS/cm; saline = 4,500 - 50,000 µS/cm; hypersaline > 50,000 µS/cm (DoE 2003). Classifications were presented as TDS (mg/L) in DoE (2003) so a conversion factor of 0.68 was used to convert to conductivity µS/cm as recommended by ANZECC/ARMCANZ (2000).

[11] Dissolved oxygen (DO) levels of zero percent saturation = anoxic; < 20% = defined as hypoxic; 100% = saturated; >100% = super-saturated; more oxygen is dissolved than would be in a state of equilibrium.

than at other pools, which may help to also explain the relatively higher salinity at RRU6 (*i.e*. less groundwater inflow to offset effects of evapoconcentration).

5.1.2 Exceedance of ANZECC/ARMCANZ default TVs

Exceedance of ANZECC/ARMCANZ default 95% TVs was recorded for EC, DO, dissolved zinc, N-total, N-NO_x and N-NH_3 at a number of sites upstream and downstream of the Jimmawurrada-Robe confluence (refer Appendix 3). No exceedance of ANZECC/ARMCANZ (2000) default TVs was recorded for any other parameter. Exceedances are discussed in the following sub-sections.

<u>**Electrical Conductivity (EC)**</u>

EC values were in exceedance of the ANZECC/ARMCANZ (2000) TV (250 μS/cm) at all sites sampled, although surface waters could still be classified as "fresh" (<1,500 μS/cm) at most sites (Figure 4). The relatively higher EC at RRU6 (1,700 μS/cm) constitutes "brackish" conditions, and was above EC levels reported during long-term monitoring of Robe River pools by Streamtec/UWA and the Proponent (*i.e.* 453 - 1,400 μS/cm). Elevated EC was again considered due to high levels of evapoconcentration in these isolated pools, a process common to surface waters in arid/semi-arid zones (Jolly *et al.* 2008). Although some dilution may occur following wet season rains, salinity can often remain high in arid-zone surface waters due to the variability of flows and flushing of stored salts (Jolly *et al.* 2008). ANZECC/ARMCANZ (2000) acknowledge that the default TV for EC may not be representative of local background levels in all areas of Australia. In such instances, ANZECC/ARMCANZ (2000) recommend developing site-specific trigger values (SSTVs) relevant to local conditions.

<u>**Dissolved Oxygen (DO)**</u>

Daytime DO saturation was below the ANZECC/ARMCANZ (2000) lower TV (80%) at the majority of sites, and above the upper TV (120%) at RRD6 (134.9%) (Figure 5 andAppendix 3). In aquatic ecosystems, low DO levels are typically considered of greater concern than high levels; however, super-saturated levels (>100%) during the day are often indicative of anoxic or hypoxic conditions at night. Low DO is commonly associated with standing pools (with little physical aeration) that support heavy organic loads (*e.g.* aquatic vegetation, algae, bacteria, *etc.*) (Caraco and Cole 2002). DO saturation is typically lowest in the early morning, following overnight consumption of oxygen through the respiratory processes of aquatic biota (Caraco and Cole 2002, Connolly *et al.* 2004, Flint *et al.* 2014). Sites which exhibited particularly low DO in the current study (*e.g.* RRU3 16.1%, RRU5 14.5%) were sampled early in the morning (*i.e.* between 0700 hrs and 0830 hrs), and also tended to support relatively high abundances of macrophytes and/or algae (Appendix 4). While the oxygen needs of aquatic biota differ between species and life history stages, values less than 50% saturation are associated with chronic responses in fish and macroinvertebrates (Connolly *et al.* 2004, Flint *et al.* 2014).

Super-saturation can occur when net photosynthesis exceeds total oxygen consumption in waterbodies, and is common in areas of high algal and macrophyte growth, particularly if spot measurements are taken later in the day (Caraco and Cole 2002). The organic habitat at RRD6, (134.9% DO) comprised emergent and submerged macrophyte (covering 50% of the site area; Appendix 4), and the spot measurement of DO was taken at 1230 hrs, when photosynthetic processes were likely near their peak. Waterbodies with super-saturated daytime DO are likely to experience overnight hypoxia or anoxia, as respiration by plants, algae, bacteria and other aquatic fauna deplete DO (Caraco and Cole 2002, Connolly *et al.* 2004, Flint *et al.* 2014).

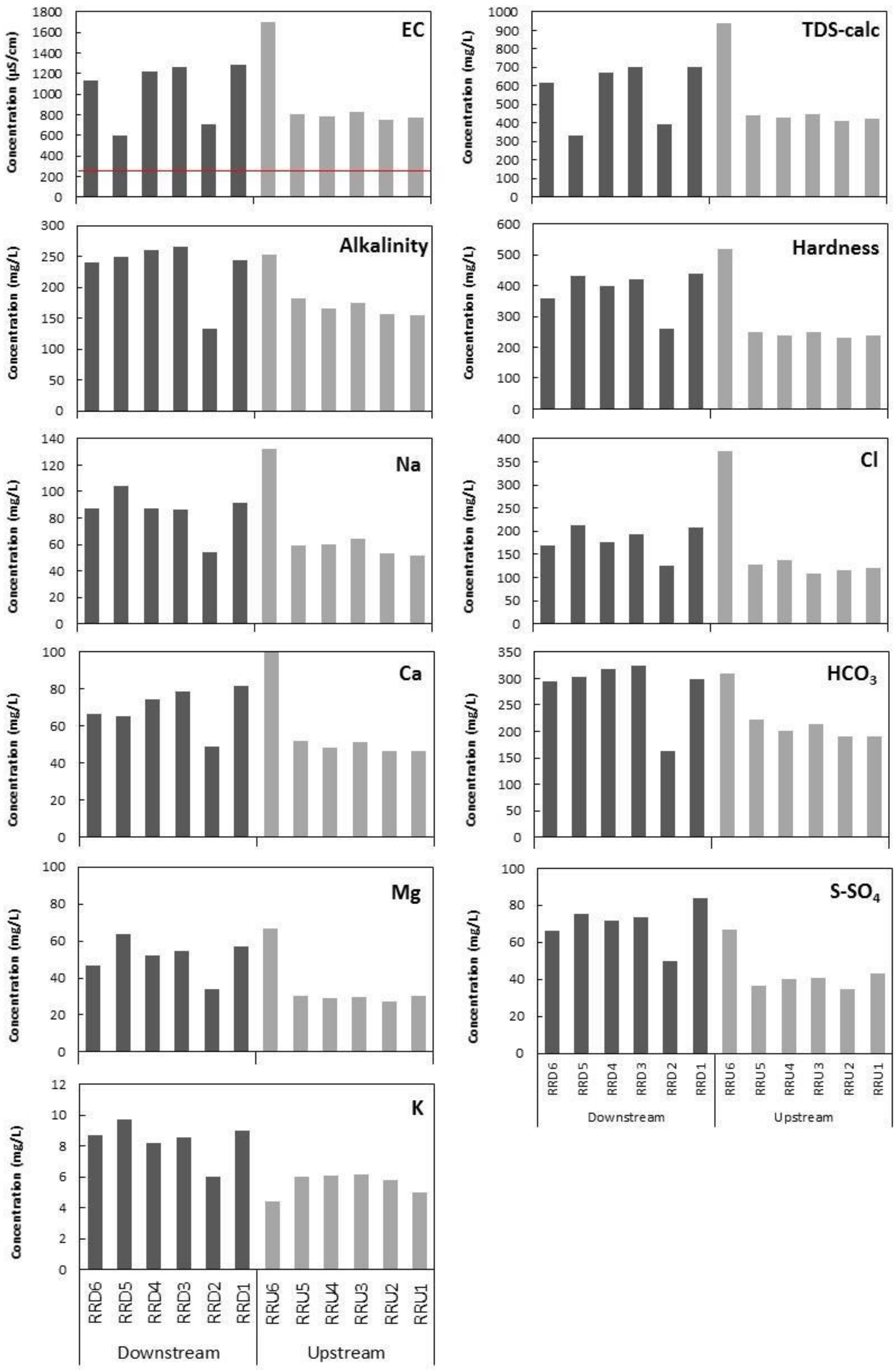


Figure 4. Comparison of EC, alkalinity, hardness and concentration of major ions amongst surface water sampling sites upstream (RRU1 to 6) and downstream (RRD1 to 6) of the Jimmawurrada-Robe confluence. Refer Table 1 for explanation of site codes and Figure 1 for location of sites. ANZECC/ARMCANZ (2000) default 95% species protection level TV (unbroken red line) is indicated for relevant parameters.

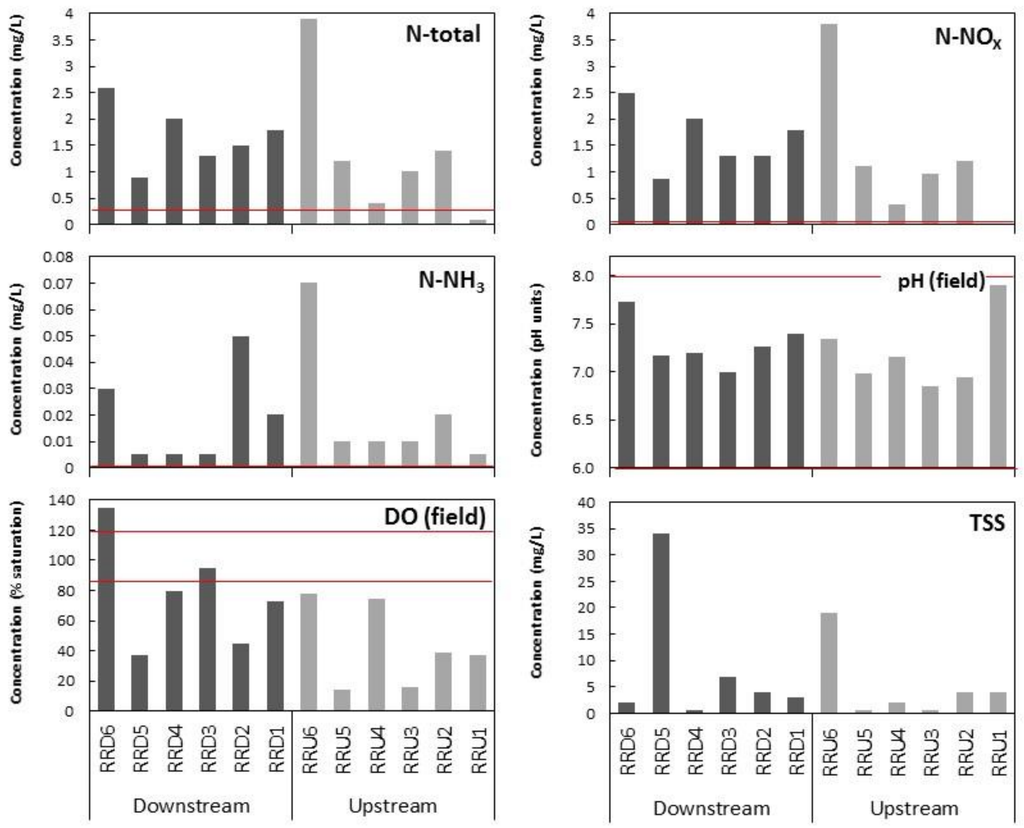


Figure 5. Comparison of N-total, N-NO$_X$, N-NH$_3$, pH, DO and TSS amongst surface water sampling sites upstream (RRU1 to 6) and downstream (RRD1 to 6) of the Jimmawurrada-Robe confluence. Refer Table 1 for explanation of site codes and Figure 1 for location of sites. ANZECC/ARMCANZ (2000) default 95% species protection level TV (unbroken red line) is indicated for relevant parameters; upper and lower TVs are shown for pH and DO.

Dissolved zinc

Dissolved zinc (dZn) concentration was in exceedance of ANZECC/ARMCANZ (2000) TVs (0.008 mg/L) at RRU5 (0.012 mg/L) and RRD3 (0.011 mg/L) (Appendix 3). ANZECC/ARMCANZ (2000) provide algorithms to calculate hardness modified TVs (HMTVs), as hardness has an ameliorating effect on the toxicity of a number of metals including cadmium, lead, nickel and zinc[12]. However, once the algorithm was applied, concentrations of dZn at RRU5 and RRD3 still excceded HMTVs. Although elevated, it is unknown what proportion of dZn was labile (bioavailable) or unavailable through processes such as complexing with dissolved organic carbon. Where dissolved levels are elevated, ANZECC/ARMCANZ (2000) recommends testing for labile concentrations/bioavailability to assess if levels are likely to be toxic to aquatic fauna. Given that exceedances of the ANZECC/ARMCANZ (2000) TV were recorded at sites both upstream (reference) and downstream of the Jimmawurrada-Robe confluence, it is unlikely that current Mesa J discharge operations are influencing dZn levels in the Project area.

Nitrogen (N-total, N-NO$_X$, N-NH$_3$)

At most sites (except RRU1), N-total, N-NO$_X$ and N-NH$_3$ exceeded ANZECC/ARMCANZ (2000) default 95% TVs for protection against eutrophication (0.3 mg/L N-total, 0.01 mg/L N-NO$_X$, 0.01 mg/L N-NH$_4$[13])

[12] HMTV algorithm for zinc = Default TV*(Hardness/30)^0.85.
[13] Ammonia was analysed as nitrogen-ammonia (N-NH$_3$), so a conversion factor of 1 was used to convert to nitrogen as ammonium (N-NH$_4$) for comparison against ANZECC/ARMCANZ (2000) default TV for protection against eutrophication.

(Figure 5 and Appendix 3). N-NO_X levels were greatly in exceedance, *i.e.,* 10 times the default TV at most sites. N-NO_3 constituted nearly all of the measured N-NO_X and N-total (Appendix 3).

In order to compare against the default 95% TV for nitrate as a toxicant (0.7 mg/L NO_3), N-NO_3 concentrations were converted to NO_3 concentration by multiplying by a factor of 4.4. NO_3 exceeded the default 95% TV for nitrate as a toxicant at most sites (except RRU1); however, the default toxicant TV is currently under review as being too conservative. The new ANZECC/ARMCANZ 95% TV for NO_3 as a toxicant is likely to be around 2 - 2.5 mg/L N-NO_3 (~11 mg/L NO_3) (R. van Dam, *eriss*, pers. comm.), and will incorporate most recent data from acute and chronic toxicity testing in New Zealand. Recently published guidelines for Canada also recommend a higher guideline of 2.9 mg/L N-NO_3 (~13 mg/L NO_3) for freshwaters (CCME 2014). In comparison to the proposed ANZECC/ARMCANZ TV of 2 - 2.5 mg/L N-NO_3, only the concentration at RRU6 (3.8 mg/L) was still in exceedance, though the concentration at RRD6 (2.5 mg/L) was close to exceedance. Similar elevated levels of N-NO_3 have been recorded at Medawandy Waters (3.1 mg/L N-NO_3, 3.45 mg/L N-total) during previous monitoring in the Project area (Rio Tinto unpub. data).

Elevated background levels of N-NO_3 and N-NH_3 within the Project area are unsurprising, given that the Robe River catchment is already effected by current and historic pastoral practices (Strategen 2006). Cattle, or evidence of high cattle use were observed at a number of pools during the survey. Elevated N-NO_3 and N-NH_3 in waterbodies caused by livestock disturbance can reduce acid-neutralising capacities of waterbodies, adversely affect the growth, survival and reproduction of aquatic fauna, and most notably stimulate eutrophication and algal blooms (Camargo and Alonso 2006). Another potential anthropogenic source is ammonium nitrate used in mine explosives, though groundwaters in arid zone areas across Australia are often naturally enriched in nitrate, as is the case in the current Project area (Magee 2009).

Significantly higher concentrations of some ions, most notably S-SO_4, and to a lesser extent Mg, as well as elevated N-total and N-NO_x downstream of the Jimmawurrada-Robe confluence (Figures 4 and 5), may also reflect the influence of current mining operations discharges on the water quality of the downstream reach. The elevated S-SO_4 and Mg may indicate presence of geochemical reactions, resulting in the release of these elements downstream of the existing discharge points. The elevated nitrogen levels may indicate discharge of groundwater elevated in nitrates, with groundwaters in the vicinity of current mining operations appearing to be enriched (*e.g.* up to 23.9 mg/L N-NO_3 in bore MB15MEH014) (Rio Tinto unpub. data). The relative contribution of anthropogenic and natural sources to nitrogen enrichment in surface and groundwater of the Project area is unknown, but discharge of nitrogen-enriched groundwater has resulted in elevated nitrate levels in surface waters downstream of other BWT mining operations in the Pilbara.

5.2 Microinvertebrates

5.2.1 Species richness and abundance

A total of 81 microinvertebrate taxa were recorded from the Project area in May 2016, of which 46 were present at potentially exposed sites downstream of the Jimmawurrada-Robe confluence, and 69 were recorded at upstream reference sites (Table 6 and Appendix 5). The list includes groups which could not be identified to species level due to unresolved taxonomy and/or immature specimens. Therefore, the total microinvertebrate species richness is likely to be greater than that reported. Microinvertebrate composition included Protista (protists), Rotifera (rotifers), Copepoda (copepods), Cladocera (water fleas) and Ostracoda (seed shrimp) (Table 6). Generally, Rotifera dominated microinvertebrate taxa at each site, with comparatively few Copepoda, Ostracoda and Cladocera. The microinvertebrate fauna was generally typical of that commonly recorded from tropical/sub-tropical freshwater systems (*e.g.* Koste and Shiel 1983, Tait *et al.* 1984, Smirnov and De Meester 1996, Segers *et al*. 2004), with Lecanidae dominating within the Rotifera, with Brachionidae and other families less prominent (Appendix 5).

Table 6. Summary of higher-order microinvertebrate taxa composition in the Robe River, upstream (RRU) and downstream (RRD) of the Jimmawurrada-Robe confluence. Refer Appendix 5 for full species list.

Microinvertebrates		Number of Taxa	
Scientific name	Common name	RRD (*n* = 6)	RRU (*n* = 6)
Protista	Protists	7	12
Rotifer	Rotifers	20	33
Micro-crustacea			
Cladocera	Water fleas	5	11
Copepoda	Copepods	9	6
Ostracoda	Seed shrimps	5	7
	Total taxa richness	**46**	**69**

Microinvertebrate taxa richness ranged from 33 taxa at RRD6 and RRU5, to just one taxa at RRD5 (Figure 6). There was no significant difference in mean total taxa richness between downstream potentially exposed sites and upstream reference sites (one-way ANOVA, Table 7). Nor were there any significant upstream-downstream differences in taxa richness of major groups of microinvertebrate (rotifers, protists, micro-crustacea) (Table 7).

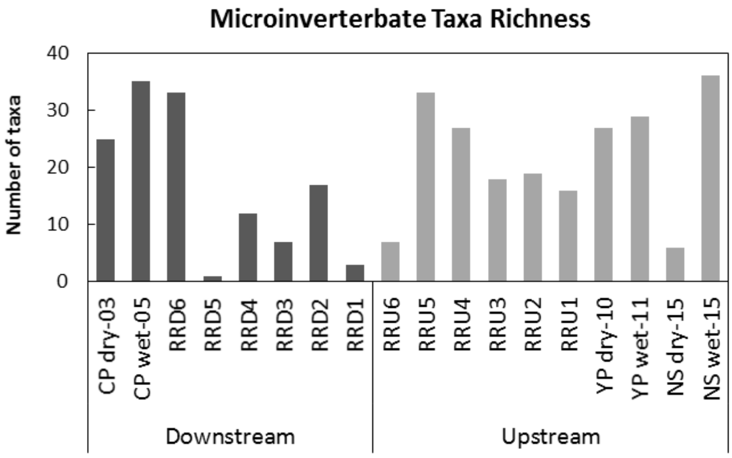


Figure 6. Microinvertebrate taxa richness recorded during the current study, upstream (RRU1 to 6) and downstream (RRD1 to 6) of the Jimmawurrada-Robe confluence, compared with most recent data for nearby Chalyarn Pool (CP; Pinder *et al.* 2010), Yalleen Pool (YP; WRM 2013) and Nyeetbury Spring (NS; WRM 2016). Refer Figure 1 for location of sites.

Table 7. Summary results from one-way ANOVAs testing for significant (p <0.05) differences in taxa richness of major microinvertebrate groups, upstream (RRU) and downstream (RRD) of the Jimmawurrada-Robe confluence. Mean (±SE) vales for untransformed data are also provided.

Microinvertebrate metric	ANOVA (df = 1, 11)			Mean (±SE)	
	MS	F	*p*	RRD (*n* = 6)	RRU (*n* = 6)
Total taxa richness	184.1	1.672	0.225	12.17 (4.81)	20.00 (3.69)
Protista richness	8.333	1.168	0.305	2.33 (0.92)	4.00 (1.24)
Rotifera richness	80.08	2.313	0.159	3.67 (2.46)	8.83 (2.34)
Micro-crustacea richness	3.000	0.183	0.183	6.17 (2.01)	7.17 (1.20)

5.2.2 Comparison against previous surveys

To provide spatial context for microinvertebrate fauna within the Project area, total taxa richness at each site within the Project area was compared against most recent data for nearby pools upstream and downstream of the Project area, *i.e.* Yalleen Pool and Nyeetbury Spring on upper Bungaroo Creek (WRM 2013, 2016), and Chalyarn Pool on Mungarathoona Creek (Pinder *et al.* 2010) (Figure 6). Each of these previous studies used similar microinvertebrate sampling techniques (sweep netting using 50 - 53 μm mesh FBA pond net) and taxonomic resolution to those approaches for the current study.

Some temporal variation was observed between wet and dry season sampling events, with the wet season favouring microinvertebrate taxa richness at Chalyarn Pool, Yalleen Pool and Nyeetbury Spring (Figure 6). At sites upstream of the Jimmawarruda-Robe confluence, taxa richness was spatially variable, with richness at RRU4 and RRU5 similar to that recorded at Yaleen Pool (both seasons) and Nyeetbury Spring in the wet-15 (Figure 6), and slightly higher than that recorded at RRU1, RRU2 and RRU3. Richness was lowest at Nyeetbury Spring in the dry-15, comparable to that recorded at RRU6 in the current study (Figure 6). Within the potentially exposed downstream reach, taxa richness at sites closest to the confluence (RRD1 to RRD5) was generally lower than that recorded at sites further downstream (RRD6 and Chalyarn Pool in both seasons) (Figure 6).

Large spatial (and temporal) variability in species richness and abundance are commonly reported for freshwater systems world-wide. Variation typically depends on factors such as flow regime (with lotic habitat generally favouring taxa richness), pool size, primary production rates and water quality parameters (Miquelis *et al.* 1998, Schiemer *et al*. 2001, Schöll *et al.* 2012). In Pilbara surface waters, microinvertebrate taxa richness is known to fluctuate markedly between sites and seasons (Pinder *et al.* 2010, WRM unpub. data). It is possible that below-average rainfall in the months prior to the current survey may have contributed to the somewhat lower microinvertebrate taxa richness recorded at sites such as RRD1, RRD3, RRD5 and RRU6. Pinder *et al.* (2010) found the wet season (higher rainfall) to generally favour taxa richness during the PBS, as was the case at Chalyarn, Yalleen and Nyteetbury (Figure 6); however, as these studies only provide a snapshot of the microinvertebrate fauna at pools within the Project area, the specific factors driving taxa richness and composition remain unknown.

5.2.3 Spatial variation in species assemblages

Multivariate analysis (ANOSIM) detected no significant difference in microinvertebrate species assemblage composition between upstream reference and downstream potentially exposed sites (Table 8), suggesting there was a high degree of natural variability and overlap amongst assemblages both upstream and downstream of the Jimmawarruda-Robe confluence. Although SIMPER analysis found only a 21% similarity of species assemblages between the upstream and downstream reaches, nMDS plotting displayed no discernible separation of upstream/downstream sites based on Bray-Curtis similarity (Figure 7). SIMPROF analysis did detect some clustering of sites, though with no clear patterns in relation to upstream/downstream location (Figure 7). For example, the upstream sites RRU1, RRU2 and RRU3 clustered with downstream site RRD2, and upstream sites RRU5 and RRU6 clustered with downstream site RRD6, based on similarity of microinvertebrate species assemblages (Figure 7). RRD1 and RRD3 also clustered with a high degree of similarity (Figure 7).

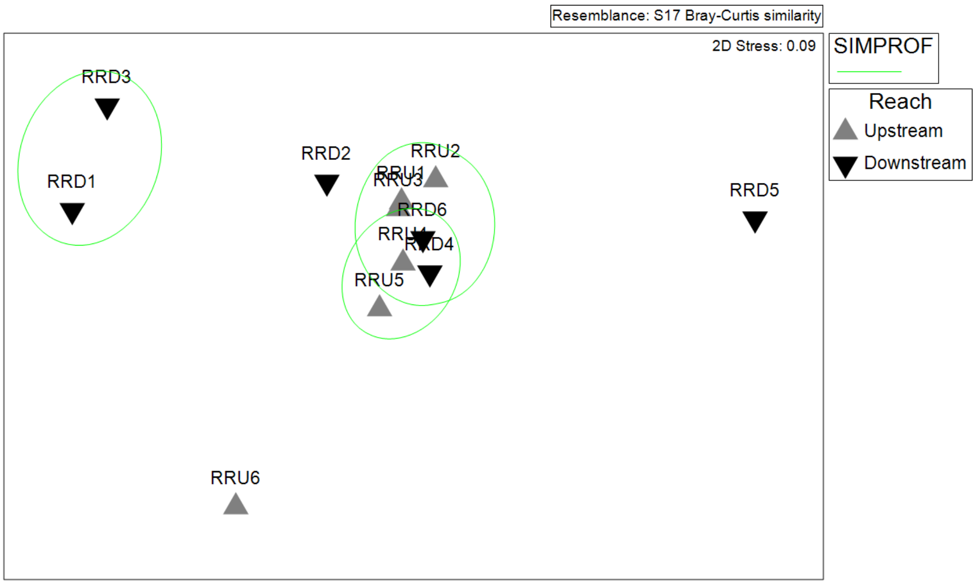


Figure 7. Plot of nMDS ordination on microinvertebrate species assemblages (log_{10} abundance class) upstream (RRU) and downstream (RRD) of the Jimmawurrada-Robe confluence. Ordination based on Bray-Curtis similarity, with SIMPROF analysis as green circles overlain demonstrating significant clustering of sites. Refer Table 1 for explanation of site codes and Figure 1 for location of sites.

Table 8. Summary results from ANOSIM testing for significant (*p* <0.05) differences in microinvertebrate assemblages (Bray-Curtis similarity) upstream (RRU) and downstream (RRD) of the Jimmawurrada-Robe confluence.

Microinvertebrate assemblage similarity (Bray-Curtis)	ANOSIM	
	R-statistic	*p*
Abundance (log_{10} class)	0.115	0.108
Presence/absence	0.137	0.097

The sampling design allows comparison of change in the similarity (Bray-Curtis) of microinvertebrate assemblages over time between reference and potential exposed sites. The premise being that if the degree of similarity between exposed and reference sites differs significantly over time (compared with pre-mine similarity), this would indicate mine-related response rather than stochastic variability due to factors such as climatic change.

5.2.4 Conservation significance of microinvertebrate fauna of the Project area

The majority of microinvertebrate taxa recorded from the Project area were common, ubiquitous species with Australasian or cosmopolitan distributions; however, the calanoid copepod *Eodiaptomus lumholtzi*, currently listed on the IUCN Red List of Threatened Species as Vulnerable (Reid 1996), was recorded at potentially exposed site RRD6. *E. lumholtzi* was assessed as Vulnerable in 1996 (IUCN ver. 2.3), as it was then known only from a few localities; Lake Woods in Northern Territory, Collinson's Lagoon at Ayr and Saltern Lagoon in the Valley of Lagoons, west of Ingham, Queensland. IUCN (2016) states this assessment requires updating because *E. lumholtzi* has since been recorded from many localities across the Australasian region. *E. lumholtzi* has been recorded previously by the authors at locations across the Pilbara region, including sites along Fortescue River, Coondiner Creek, Kalgan Creek, Weeli Wolli Creek, Koodaideri Springs, Caves Creek, Duck Creek and Cane River (WRM unpub. data). *E. lumholtzi* has also been found in Papua New Guinea, and is considered to have a pan-tropical distribution (Vlaardingerbroek 1989, WRM unpub. data).

Of scientific interest was the collection of an undescribed species of Lecanidae rotifer, *Lecane* n. sp., recorded both upstream and downstream of the Jimmawarruda-Robe confluence (RRU5 and RRD6). Morphologically, this species is similar to the described *Lecane quadridentata*, with the two variants synonymized by Segers (1995); however, the smaller Australian variant recorded in the current study is now recognised as a separate species, and forms part of a wider *L. quadridentata* species complex (Dr Russel Shiel, University of Adelaide, pers. comm.).

5.3 Hyporheic Fauna

5.3.1 Species richness and abundance

A total of 59 taxa were recorded from the hyporheic zone of pools in the Project area (Appendix 6). The majority of these taxa were classified as stygoxene (54%), *i.e.* species that appear in groundwater habitats by accident or seeking refuge during drought, and not specially adapted to subterranean inhabitation. Of these, 8% were classified as stygobitic, *i.e.*, obligate groundwater inhabitants with specialised morphological adaptations to survive in such environments (stygofauna). Of the remaining taxa, 31% were considered occasional hyporheic stygophiles (species that use the hyporheic zone seasonally or during early life history stages), 2% were possible hyporheic taxa, and 5% were unable to be classified (Appendix 6). Although classifications followed those of Boulton (2001), this type of analysis should be treated with some caution, as results are likely affected by available information on life history, taxonomic resolution, and interpretation of classification categories.

Hyporheic taxa richness (combined richness of stygobites, occasional hyporheic stygophiles and possible hyporheic fauna) ranged from two taxa at upstream reference site RRU2, to 12 taxa at potentially exposed downstream site RRD1 (Figure 8). Relatively high hyporheic taxa richness was also recorded at RRU6 (nine taxa), RRU4 and RRD2 (eight taxa), and RRU3 and RRD5 (seven taxa) (Figure 8). The high taxa richness encountered in the hyporheos of these sites, and because surface water was present at these sites despite below average rainfall in the months prior, suggests at least some connectivity between ground- and surface waters (*i.e.* they may be groundwater-supported pools).

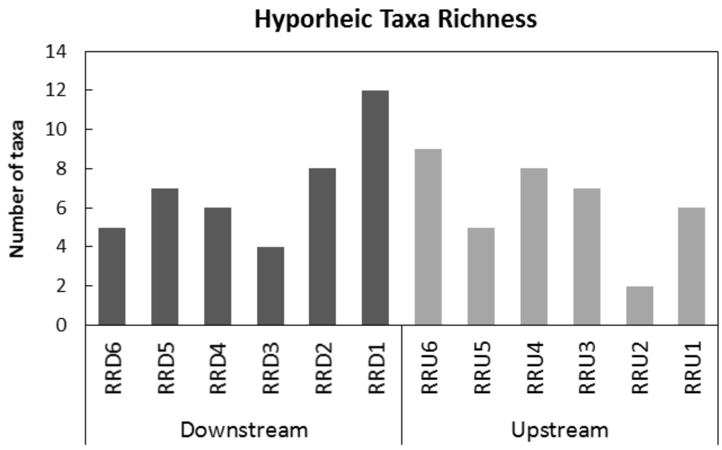


Figure 8. Hyporheic taxa richness (combined richness of stygobites, occasional hyporheic stygophiles and possible hyporheic fauna) of sites upstream (RRU) and downstream (RRD) of the Jimmawurrada-Robe confluence.

5.3.2 Conservation significance of hyporheic fauna of the Project area

Of the fauna collected in hyporheic samples of the Project area, only the amphipod, *Nedsia* sp. is considered likely to be a potential SRE species.

Nedsia sp. (family Melitidae) was recorded from the hyporheic zones of RRU3, RRU4 and RRU6 upstream of the Jimmawurrada-Robe confluence, and RRD1, RRD2, RRD3 and RRD4 downstream of the confluence (Appendix 6). *Nedsia* amphipods were also recorded in the surface water macroinvertebrate samples of RRD3 and RRD4 (Appendix 7). These amphipods could not be confidently identified to species level due to a current lack of taxonomic resolution within the Melitidae amphipods and would require DNA sequencing.

Biota (2006a) recorded four genetically-distinct amphipods of the family Melitidae from bores in the Yarraloola area, downstream (west) of the Project area. A fifth distinct Melitidae lineage was recorded from the Bungaroo Creek area to the southeast (Biota 2006a). Interestingly, based on genetic evidence, each of the four Melitidae lineages from the Yarraloola area have been isolated from one-another for between 2.4 and 6.65 million years, highlighting the extreme degree of amphipod short-range endemism that can occur amongst aquifers in the region despite close geographical proximity (Biota 2006a). Biota (2010) and Bennelongia (2013) also recorded a high abundance of Melitidae amphipods from bores to the south of the current Project area. The majority of these specimens belonged to the genus *Nedsia* (*Nedsia* nr. *hulberti* and *Nedsia* spp.). It is currently unknown whether the *Nedsia* recorded in the current study represent one or more of the *Nedsia* species or Melitidae halotypes recorded by Biota (2006a, 2010) and Bennelongia (2013) or a separate species previously unrecorded.

Although not conservation listed or considered SRE species, the following are stygal species, with their presence indicating some connectivity between ground- and surface-waters. As such, they are of some interest.

The Thermosbaenacean *Halosbaena tulki* was recorded both upstream (RRU3) and downstream (RRD2, RRD3 and RRD4) of the Jimmawurrada-Robe confluence. *Halosbaena tulki* is the single species of Thermosbaenacean known from the Southern Hemisphere, where it appears to be restricted to the Pilbara region (Poore and Humphreys 1992). Thermosbaenacea are a rare order of crustacean, with approximately 16 species known worldwide, all of which are restricted to groundwater environments (Poore and Humphreys 1992). In the vicinity of the Project area, this species was previously collected from seven bores in the Yarraloola area by Biota (2006a).

The ostracod *Candonopsis* cf. *tenuis* is known to occur widely across Australia (DeDeckker 1982, Karanovic and Marmonier 2002), including groundwaters of the Pilbara (Halse *et al.* 2002). WRM has recorded *C.* cf. *tenuis* from the hyporheic zone of a number of sites in the Weeli Wolli Creek catchment, Coondiner Creek, Kalgan Creek, Hamersley Gorge and the Ashburton River (WRM unpub. data). During the current study, *C.* cf. *tenuis* was collected from the hyporheic zone of upstream reference site RRU6 (Appendix 6).

Vestalenula marmonieri is a stygal ostracod species known only from Western Australia and New Caledonia (Schön *et al.* 2010). This species is relatively widespread across the Pilbara region (being collected from over 50 locations by Pinder *et al.* (2010) during the PBS), though due to its preference for phreatic[14] environments, is most commonly associated with groundwater-fed systems such as Weeli Wolli Creek (WRM unpub. data). In the current study, *V. marmonieri* was recorded from potentially exposed downstream sites RRD1 and RRD5, and upstream reference site RRU1 (Appendix 6). *V.*

[14] Groundwater environments.

marmonieri was also collected in microinvertebrate samples of RRU1, RRU2, RRU3, RRU6, RRD2, RRD4 and RRD5 (Appendix 5).

5.4 Macroinvertebrates

5.4.1 Species richness and abundance

A total of 148 macroinvertebrate taxa were recorded from the Project area, of which 116 were present at sites downstream of the Jimmawurrada-Robe confluence, and 117 at upstream reference sites (Table 9, Appendix 7). In this context, "taxa" includes groups which could not be identified to species level, due to unresolved taxonomy and/or immaturity of specimens. Therefore, the total macroinvertebrate taxa richness at each site is likely greater than reported herein. The macroinvertebrate fauna comprised Cnidaria (freshwater hydra), Mollusca (freshwater snails and bivalves), Oligochaeta (aquatic segmented worms), Crustacea (amphipods and freshwater shrimp), Acarina (water mites), Collembolla (springtails), Odonata (dragonflies and damselflies), Ephemeroptera (mayflies), Hemiptera (true bugs), Coleoptera (aquatic beetles), Diptera (two-winged or "true" fly larvae), Trichoptera (caddisflies) and Lepidoptera (aquatic moth larvae; Table 9). Macroinvertebrate composition was typical of freshwater systems throughout the world (Hynes 1970), being dominated by Insecta (comprising 89% of all taxa), with Diptera (29%) and Coleoptera (32%) most prominent within this class. There were 46 singleton taxa recorded (*i.e.* those recorded from only one site), and 12 taxa were considered common taxa, *i.e.* they were present at over 80% of sites. These included the snail *Melanoides* spp., segmented worms (Oligochaeata spp.), the freshwater shrimp *Caridina indistincta*, the mayflies Baetidae spp. and *Cloeon* sp. Red Stripe, the pygmy backswimmer *Paraplea* spp., and the midge larvae/pupae Ceratopogonidae spp., Dasyheleinae spp., Chironomidae spp., *Polypedilum* sp. 1, *Larsia albiceps* and *Paramerina* sp. (Appendix 7).

Table 9. Summary of higher-order microinvertebrate taxa composition in the Robe River, upstream (RRU) and downstream (RRD) of the Jimmawurrada-Robe confluence. Refer Appendix 7 for full species list.

Macroinvertebrates		Number of Taxa	
Scientific name	Common name	RRD (*n* = 6)	RRU (*n* = 6)
Cnidaria	Freshwater hydra	1	0
Oligochaeta	Aquatic worms	1+	1+
Gastropoda	Freshwater snails	4	5+
Bivalvia	Freshwater bivalves	0	1
Amphipoda	Stygal amphipods	2	0
Decapoda	Freshwater shrimps	1+	1+
Acarina	Water mites	1+	1+
Ephemeroptera	Mayflies	6	5
Odonata	Dragonflies and damselflies	14	14
Hemiptera	True bugs	18	16
Coleoptera	Aquatic beetles	30	35
Diptera	Two-winged flies	30	31
Trichoptera	Caddisflies	7	4
Lepidoptera	Aquatic moth larvae	2	2
	Total taxa richness	**116**	**117**

+ indicates a taxa could only be identified to genus/family/order level (not species level), and as such more than one species is likely to be present within this taxonomic group.

Macroinvertebrate taxa richness at upstream sites ranged from 34 taxa at RRU3 and RRU5, to 72 taxa at RRU1 (Figure 9). Richness at sites downstream of the Jimmawarruda-Robe confluence ranged from 38 taxa at RRD3 and RRD5, to 56 taxa at RRD2 (Figure 9). There was no significant difference in total taxa richness between downstream potentially exposed sites and upstream reference sites (one-way ANOVA, Table 10). Nor were there any significant upstream-downstream differences in taxa richness of most major macroinvertebrate groups (Table 10). The exception was Ephemeroptera (mayflies), where mean richness was significantly higher at sites downstream of the confluence (4.3) compared to those upstream (2.5) (Table 10). This was largely due to the lower richness/absence of *Tasmanocoenis* sp. P/*arcuata* (Caenidae) and *Cloeon fluviatile* (Baetidae) at upstream sites, particularly RRU4 to 6 closest to the confluence.

Table 10. Summary results from ANOVAs testing for significant (p <0.05) differences in taxa richness of major macroinvertebrate groups (indicated by *), upstream (RRU) and downstream (RRD) of the Jimmawurrada-Robe confluence. Mean (±SE) vales for untransformed data are also provided.

Macroinvertebrate metric	ANOVA			Mean (±SE)	
	MS	F	*p*	RRD (*n* = 6)	RRU (*n* = 6)
Total taxa richness	0.083	0.001	0.982	46.2 (3.5)	46.3 (6.1)
Diptera richness	0.000	0.000	1.000	14.0 (1.8)	14.0 (4.6)
Coleoptera richness	18.75	0.587	0.461	8.5 (2.4)	11.0 (2.2)
Hemiptera richness	0.333	0.035	0.855	6.3 (1.1)	6.0 (1.4)
Odonata richness	1.333	0.377	0.553	5.33 (0.6)	6.0 (0.9)
Trichoptera richness	1.333	1.429	0.260	1.7 (0.4)	1.0 (0.4)
Ephemeroptera richness	10.08	6.798	0.026*	4.3 (0.5)	2.5 (0.5)
Mollusca richness	0.083	0.068	0.799	2.7 (0.4)	2.8 (0.5)
Crustacea richness	0.750	-0.738	0.411	2.7 (0.5)	2.2 (0.3)

5.4.2 Comparison against previous studies

To provide spatial context for macroinvertebrate fauna within the Project area, total taxa richness at each site was compared against most recent data for nearby pools upstream and downstream, *i.e.* Yalleen Pool and Nyeetbury Pool on upper Bungaroo Creek (WRM 2013, 2016), and Chalyarn Pool on Mungarathoona Creek (Pinder *et al.* 2010) (Figure 9). Each of these previous studies used similar macroinvertebrate sampling techniques (kick-sweep netting using 250 µm mesh FBA pond net) and taxonomic resolution to those of the current study.

Taxa richness within the Project area (34 – 72 taxa) was generally comparable to that previously recorded for Yalleen Pool (39 – 45), Nyeetbury Spring (51 – 52) and Chalyarn Pool (49 – 77) (Figure 9). The lack of spatial variability in macroinvertebrate taxa richness between studies probably reflects the similar hydrological nature and size of these pools (*i.e.* all are either permanent/semi-permanent riverine pools, flowing only after heavy rainfall) because they are all within relatively close geographical proximity to one-another (*i.e.* within 20 – 30 km, and all part of the Robe River catchment). Pinder *et al.* (2010) noted riverine pools of the Pilbara (particularly those of the same catchment) generally display a high degree of homogeneity, in terms of macroinvertebrate species richness and composition, in comparison to similarly sized turbid wetlands and claypans.

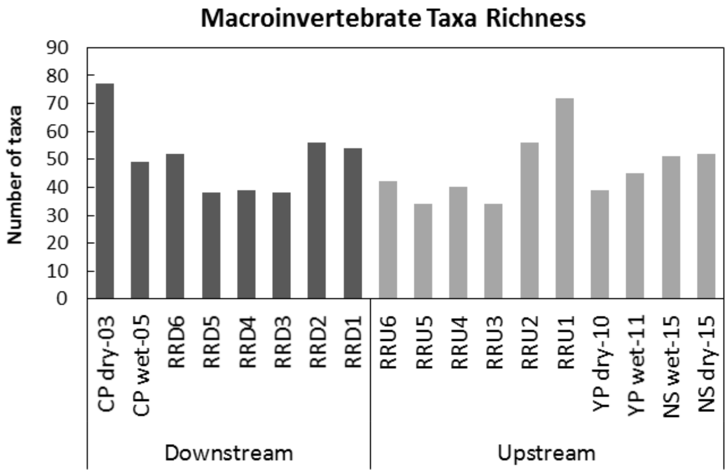


Figure 9. Macroinvertebrate taxa richness recorded during the current study, upstream (RRU1 to 6) and downstream (RRD1 to 6) of the Jimmawurrada-Robe confluence, together with most recent data for nearby Chalyarn Pool (CP; Pinder *et al.* 2010), Yalleen Pool (YP; WRM 2013) and Nyeetbury Spring (NS; WRM 2016). Refer Figure 1 for location of sites.

To provide temporal/seasonal context for macroinvertebrate taxa richness in the current Project area, April/May (wet season) 2016 figures were compared against historic mean dry season taxa richness recorded at Robe River pools by Streamtec/UWA between 2002 and 2011[15]. Again, both studies utilised the same macroinvertebrate sampling technique (sweep netting using a 250 µm mesh FBA pond net), and taxonomy was standardised across datasets to account for inherent variation/advancements in taxonomic knowledge between studies (*i.e.* some taxa were condensed to family or order level to enable comparison). As such, taxa richness may appear lower than was originally reported in each study.

At the reach upstream of the Jimmawarruda-Robe confluence, mean dry season richness at Medawandy Waters (22) and Pannawonica Hill (23) were generally comparable to wet season taxa richness recorded at RRU3 (22), RRU4 (30), RRU5 (20) and RRU6 (26), but slightly lower than taxa richness recorded at RRU1 (54) and RRU2 (38) (Figure 10). Downstream of the confluence, mean dry season richness recorded at Gnieroora, Martangkuna, Pulari, Japanese Pool and Yarramudda (20 – 27 taxa) was also similar to wet season richness recorded at RRD1, RRD3, RRD4 and RRD5 (21 – 33 taxa), and only slightly lower than that recorded at RRD6 (41 taxa) and RRD2 (38 taxa). The apparent lack of seasonal variability in taxa richness likely reflects the capacity for pools of the Project area to hold water year-round (*i.e.* they are either permanent/semi-permanent), acting as refuge pools for migratory macroinvertebrates during the dry season, and generally favouring both temporary and permanent resident macroinvertebrate species over more ephemeral waterbodies (Sponseller *et al.* 2001, Pinder *et al.* 2010). Furthermore, Pinder *et al.* (2010) found there to be little seasonal variation in macroinvertebrate assemblages at permanent/semi-permanent riverine pools of the Pilbara region in comparison to more ephemeral waterbodies, particularly when flooding had not occurred prior to wet season sampling (as was the case in the current study). It must be noted that the current study provides only a snapshot of the macroinvertebrate fauna of the Project area and taxa richness could still vary considerably between time periods.

[15] The most recent round of macroinvertebrate data (2013) was not included in analysis, as Streamtec (2014) did not feature a raw species list. Earlier species lists (1996 & 1998) were not included in the analysis due to the vast improvements in taxonomic knowledge and microscope technology since those studies.

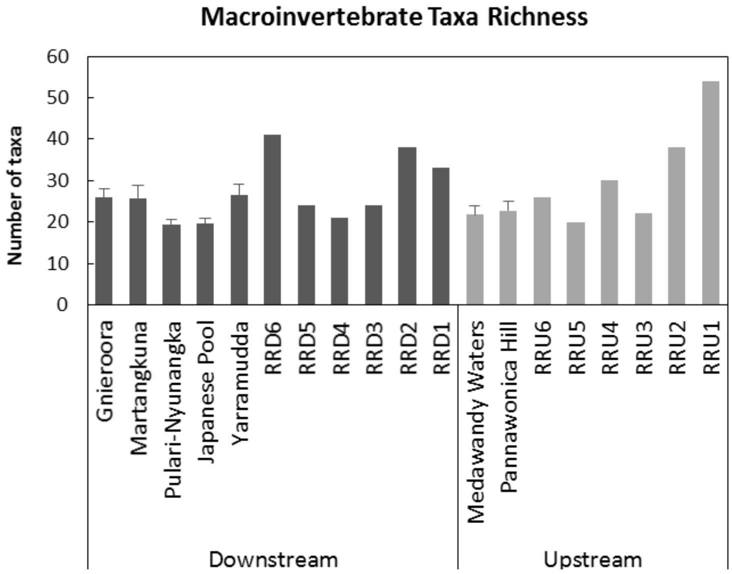


Figure 10. Comparison of standardised macroinvertebrate taxa richness recorded during the current study, with that recorded by Streamtec/UWA during long-term monitoring of Robe River pools. Refer Figure 1 for location of sites.

5.4.3 Spatial variation in species assemblages

Multivariate analysis (ANOSIM) detected no significant difference in macroinvertebrate species assemblage composition between upstream reference and downstream potentially exposed sites (Table 11), suggesting there was a high degree of natural variability and overlap amongst upstream/downstream sites. Although SIMPER analysis found only a 45% similarity of species assemblages between upstream and downstream sites, nMDS plotting displayed no distinguishable separation of upstream/downstream sites based on Bray-Curtis similarity (Figure 11), with SIMPROF analysis (not shown) detecting no clustering of these groups. One site (RRU3) was separate from all other sites, which is attributed to the low overall taxa richness (34) recorded at this site compared to others. As with taxa richness, the lack of variability in upstream/downstream macroinvertebrate assemblages likely reflects the relatively similar hydrological nature (permanent/semi-permanent) of pools in the Project area.

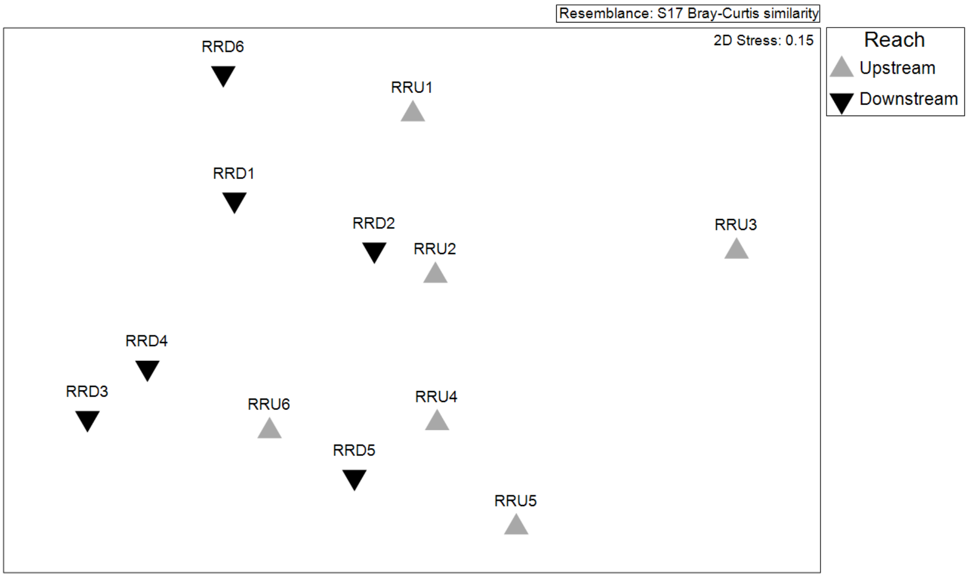


Figure 11. Plot of nMDS ordination on macroinvertebrate species assemblages (log_{10} abundance class) upstream (RRU) and downstream (RRD) of the Jimmawurrada-Robe confluence. Ordination based on Bray-Curtis similarity. Refer Table 1 for explanation of site codes and Figure 1 for location of sites.

Table 11. Summary results from ANOSIM testing for significant (*p* <0.05) differences in macroinvertebrate assemblages (Bray-Curtis similarity) upstream (RRU) and downstream (RRD) of the Jimmawurrada-Robe confluence.

Macroinvertebrate assemblage similarity (Bray-Curtis)	ANOSIM	
	R-statistic	*p*
Abundance (log_{10} class)	0.154	0.106
Presence/absence	0.111	0.186

5.4.4 Conservation significance of macroinvertebrate fauna of the Project area

The Pilbara pin damselfly, *Eurysticta coolawanyah* (family Isostictidae), is endemic to the Pilbara region, and is currently listed as Near Threatened on the IUCN Red List of Threatened Species (IUCN 2016). *Eurysticta coolawnyah* was recorded from two sites in the current study; RRD3 and RRD4, both downstream of the Jimmawarruda-Robe confluence (Appendix 7). *E. coolawanyah* is known from over 40 locations across the Pilbara (Pinder *et al.* 2010), and has been recorded by WRM from a number of riverine pools and springs along the Fortescue River, DeGrey River, Coondiner Creek, Kalgan Creek and Weeli Wolli Creek (WRM unpub. data). Along the Robe River, this species has been recorded consistently by Streamtec/UWA, as well as from Bungaroo Creek (WRM 2013) and Mugarathoona Creek (Pinder *et al.* 2010).

It is likely that both RRD3 and RRD4 are important refuge pools for *E. coolawanyah* in the area, as both are persistent waterbodies which support relatively high densities of emergent macrophyte (see Appendix 4). Damselflies (such as *E. coolawanyah*) are known to actively select sites with greater concentrations of emergent macrophyte, which are used for perching, mating and oviposition (egg-laying) (D'Amico *et al.* 2004, Rouquette and Thomson 2004, Ward and Mill 2005, Remsburg and Turner 2009).

Although the following species are not listed for conservation significance, they are endemic to the Pilbara region and therefore of some scientific interest. The Pilbara tiger dragonfly, *Ictinogomphus dobsoni* (family Lindeniidae), was collected at reference site RRU3, and potentially exposed sites RRD1, RRD4 and RRD6 (Appendix 7). This species appears to be relatively common across the Robe River catchment, having been recorded from Chalyarn Pool, Red Hill Creek (Pinder *et al*. 2010) and a number of permanent/semi-permanent Robe River pools (Streamtec/UWA). Elsewhere, *I. dobsoni* has been recorded from many of the other major river systems of the Pilbara, including the Fortescue, Ashburton, Yule, DeGrey and Sherlock rivers (DEC 2009, Pinder *et al*. 2010, CSIRO 2015). Large pools within the Project area epitomise ideal refuge habitats for *I. dobsoni*, which is known to prefer still or sluggish permanent riverine waterbodies (Watson 1991).

The Pilbara endemic dytiscid beetle *Tiporus tambreyi* was recorded at reference sites RRU3, RRU4 and RRU6, and potentially exposed site RRD1 (Appendix 7). This species is common and ubiquitous across the region, and in the vicinity of the Project area, has been recorded from Robe River pools (Streamtec/UWA), Chalyarn Pool (Pinder *et al.* 2010) and Red Hill Creek (WRM 2009, Pinder *et al.* 2010).

The haliplid beetle *Haliplus pilbaraensis,* recorded from reference site RRU1 (Appendix 7), is endemic to the Pilbara region and relatively new to science (Watts and McRae 2010). This species appears to occur fairly widely throughout the Pilbara, and has been recorded at localities such as Glen Ross Creek, Coondiner Pool, the Fortescue Marsh, Moreton Pool, Paradise Pool, Munreemya Billabong, Wackilina Creek Pool, West Peawah Creek Pool, Harding River Pool, and an un-named creek in Millstream (Watts and McRae 2010). Closer to the Project area, *H. pilbaraensis* was previously recorded from Red Hill Creek (WRM 2009).

5.5 Fish

5.5.1 Species composition and abundance

A total of 3,515 individual fish were caught, measured and released in the Project area; 1,578 from upstream reference sites (RRU1 - 6), and 1,937 from sites downstream of the Jimmawarruda-Robe confluence (RRD1 - 6). Seven true freshwater taxa were recorded, including the western rainbowfish, spangled perch, Pilbara tandan (eel-tailed catfish), Fortescue grunter, barred grunter, bony bream, and a hybridised form of Terapontidae (grunter) (Table 12). Four species captured were of estuarine/marine origin, including milkfish, tarpon (ox-eye herring) (Plate 8), mullet and banded scat (striped butterfish) (Plate 8) (Table 12). Each of the freshwater species, with the exception of bony bream, was recorded both upstream and downstream of the Jimmawarruda-Robe confluence (bony bream were only recorded upstream of the confluence) (Table 12). The marine vagrant tarpon and mullet were also recorded both upstream and downstream of the confluence; however, milkfish and banded scat were only recorded from the downstream reach (Table 12). Each of these species, except milkfish, was previously recorded from the Robe River by Morgan and Gill (2004) and Streamtec/UWA.

Table 12. Summary of freshwater and estuarine/marine vagrant fish species recorded in the Project area, including scientific and common names. ✓ = fish species was present.

Origin	Species	Common name	Downstream						Upstream					
			RRD6	RRD5	RRD4	RRD3	RRD2	RRD1	RRU6	RRU5	RRU4	RRU3	RRU2	RRU1
Freshwater	*Melanotaenia australis*	Western rainbowfish	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Neosilurus sp.	Pilbara tandan			✓	✓	✓			✓		✓	✓	✓
	Leipotherapon unicolor	Spangled perch	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Leipotherapon aheneus	Fortescue grunter	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Amniataba percoides	Barred grunter	✓		✓	✓		✓	✓	✓				
	Terapontidae sp.	Grunter hybrid		✓			✓		✓	✓		✓		✓
	Nematalosa erebi	Bony bream											✓	
Estuarine/ marine	*Chanos chanos*	Milkfish	✓		✓									
	Megalops cyprinoides	Tarpon/ox-eye herring	✓	✓		✓	✓	✓		✓	✓		✓	
	Mugil sp.	Mullet		✓				✓			✓		✓	
	Selenotoca multifasciata	Banded scat/striped butterfish	✓	✓	✓	✓	✓	✓						

There was no significant difference in mean abundance of fish upstream and downstream of the Jimmawarruda-Robe confluence (one-way ANVOA, $p = 0.433$), nor was there any significant difference in mean abundance of any of the individual species between the upstream and downstream reaches (one-way ANOVA, $p < 0.05$). There was a significant difference in mean species richness between upstream and downstream sites, with mean richness significantly higher downstream of the Jimmawarruda-Robe confluence (one-way ANVOA, $p = 0.008$). This was mainly due to the greater presence of estuarine species such as banded scat, milkfish and tarpon at the downstream reach (Table 12).

Western rainbowfish were the most abundant fish of the Project area, with a total of 2,401 individuals captured. Western rainbowfish were present at all sites, with 1,019 recorded from upstream reference sites (42%), and 1,382 recorded from downstream sites (48%) (Figure 12). Fortescue grunter (685 individuals) and spangled perch (203 individuals) were the second and third most abundant species of the Project area, respectively. Fortescue grunter were collected from all sites, with similar numbers captured both upstream (320 individuals; 47%) and downstream (365 individuals; 53%) of the Jimmawarruda-Robe confluence (Figure 12). Spangled perch were also present at all sites, with the majority recorded at upstream sites (145 individuals; 71%) (Figure 12). Of the remaining freshwater species, Pilbara tandan (34 individuals) were recorded at upstream sites RRU1, RRU2, RRU3, RRU5, and downstream sites RRD2, RRD3 and RRD4; barred grunter (47 individuals) were recorded at upstream sites RRU5 and RRU6, and at downstream sites RRD3, RRD4 and RRD5. Terapontidae hybrids (12 individuals) were recorded at upstream sites RRU1, RRU3, RRU5 and RRU6, and downstream sites RRD2 and RRD5 (Figure 12). Bony bream (5 individuals) were only recorded at upstream site RRU2.

Of the estuarine/marine fish species, tarpon (39 individuals) (Plate 8) were recorded at upstream sites RRU2, RRU4 and RRU5, and all sites downstream of the Jimmawarruda-Robe confluence (Figure 12). Mullet (33 individuals) were recorded at upstream sites RRU2 and RRU4, and downstream sites RRD1 and RRD5 (Figure 12). Banded scat (53 individuals) (Plate 8) were only recorded downstream of the confluence, but were present at all sites within that reach (Figure 12). Milkfish (7 individuals) were only recorded from downstream sites RRD4 and RRD6 (Figure 12).

Plate 8. The banded scat *Selenotoca multifaciata* (left) and the tarpon *Megalops cyprinoides* (right), captured downstream of the Jimmawarruda-Robe confluence.

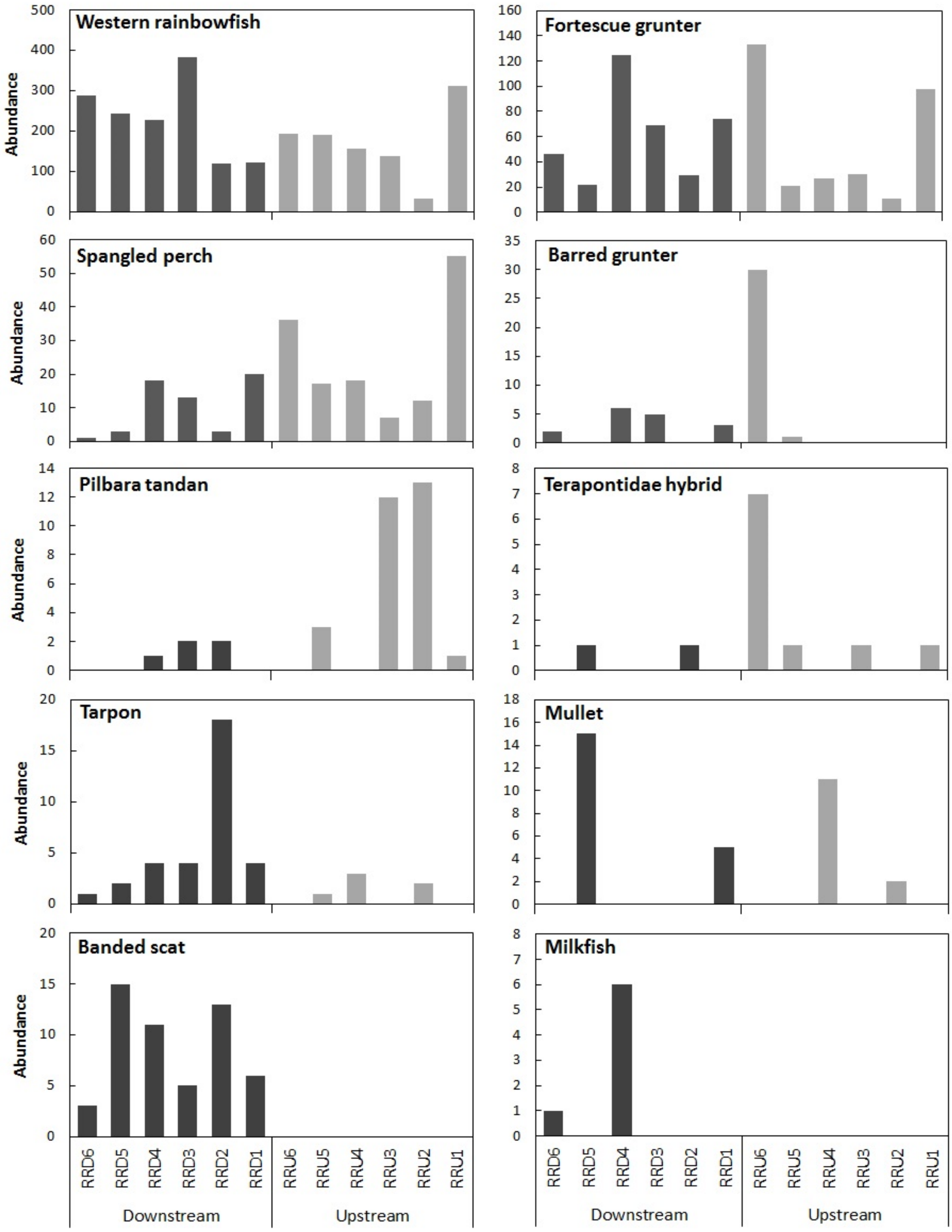


Figure 12. Abundance of each fish species recorded from upstream (RRU1 to 6) and downstream (RRD1 to 6) of the Jimmawurrada-Robe confluence. Note: bony bream (*Nematalosa erebi*) were also recorded from the Project area, but were not plotted due to low overall abundance of this species.

5.5.2 Conservation significance of fish species

One conservation listed freshwater fish species was recorded from the Project area; the Pilbara endemic Fortescue grunter (*Leipotherapon aheneus*). Currently, the Fortescue grunter is listed on the IUCN Red List of Threatened Species as Lower Risk/Near Threatened (IUCN 2016), and as a Priority 4 (P4) species on the Department of Parks and Wildlife (Parks and Wildlife) Priority Fauna List (Parks and Wildlife 2016). This species is only known from the Fortescue, Robe and Ashburton River systems (Allen *et al*. 2002, Morgan and Gill 2004); however, it is considered to be common within this range, as is evidenced by the ubiquitousness of this species across the current Project area, being the second most abundant fish collected (685 individuals) and occurring at all sites both upstream and downstream of the Jimmawarruda-Robe confluence (Table 12 and Figure 12).

The following species are not listed for conservation significance, but are of some scientific interest:

Individuals which appeared to be hybridised forms of two of the three co-occurring Robe River Terapontidae species (spangled perch, barred grunter and/or Fortescue grunter; Plate 9) were recorded from RRU1, RRU3, RRU5, RRU6, RRD2 and RRD5 (Table 12 and Figure 12). Hybridised grunters have been recorded from other Pilbara systems by the authors and others, including the Fortescue, Murchison and Ashburton rivers (Morgan and Gill 2006, Morgan *et al.* 2009, WRM 2016, WRM unpub. data). Morgan and Gill (2006) propose hybridisation between closely related fish species is not uncommon; however, the hybridisation of grunters in Pilbara river systems is not fully understood, and is of some interest, particularly if hybridisation results in the loss of species through replacement with reproductively unviable individuals, or if there is evidence of incipient speciation (the formation of a new species). Loss or replacement of a species is especially important in the case of the Fortescue grunter, as it is a nationally and internationally listed species of conservation significance.

A. B.

C. D.

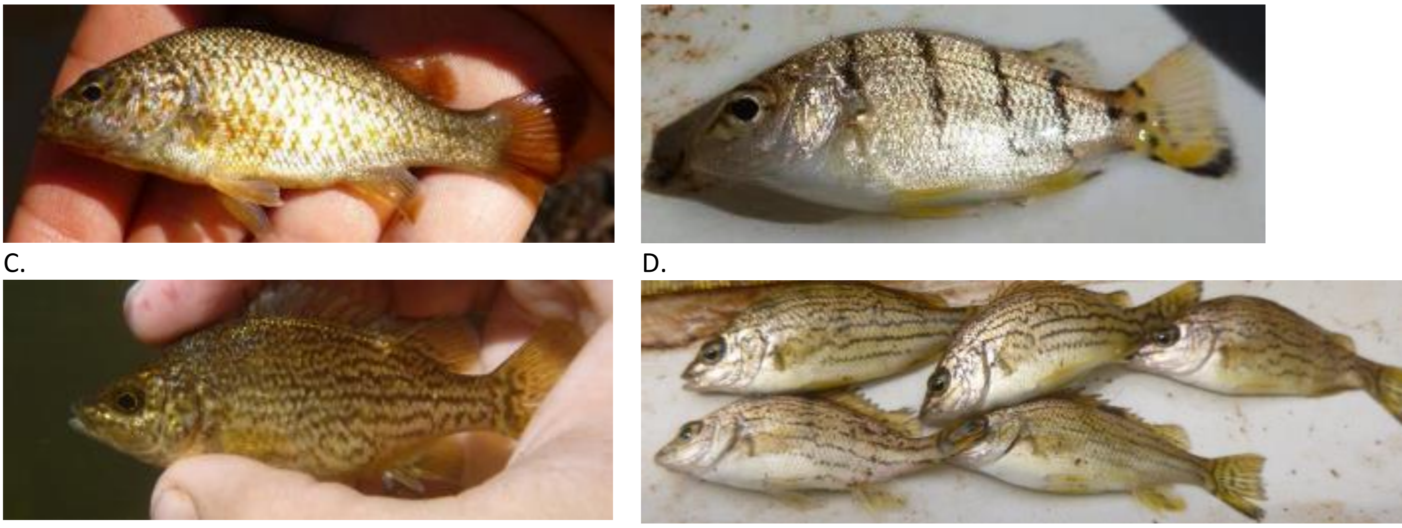


Plate 9. Terapontid hybridisation, illustrating (A) Spangled perch *Leiopotherapon unicolor*, (B) barred grunter *Amniataba percoides*, (C) Fortescue grunter *Leiopotherapon aheneus*, and (D) Terapontidae hybrids from RRU6, possibly sharing the features of barred and Fortescue grunter. Photographs by Chris Hofmeester (A, B and C)/WRM (D) ©.

None of the estuarine/marine fish species recorded in the Project area are endemic to the Pilbara region or currently listed for conservation significance. Milkfish (*Chanos chanos*) were not reported from the freshwater reaches of the Robe River by either Streamtec/UWA, Morgan and Gill (2004) or Antao and Braimbridge (2010). As such, collection of this species during the current study (along with its collection from further downstream) likely establishes a new record for the system. *Chanos chanos* is widely distributed across tropical and sub-tropical climes of the Indo-West Pacific region (Bagarinao 1994, Swanson 1998, Allen *et al.* 2002). This species is known to utilise fresh, brackish, oceanic and hypersaline lagoon environments (*i.e.* are euryhaline), being extremely efficient at osmoregulation during all life-history stages (Swanson 1998, Lin *et al.* 2003). In Australian waters, adult milkfish are pelagic schooling fish, inhabiting shallow, off-shore marine habitats. Spawning typically takes place offshore, following which juveniles migrate to sheltered estuaries. Sub-adult milkfish occasionally penetrate further upstream into freshwater reaches, before returning to the ocean to undergo sexual maturation and spawning (Bagarinao 1994, Allen *et al.* 2002).

5.5.3 Fish population structure

The reproductive strategies of freshwater fish species in the Pilbara are 'opportunistic' and 'periodic', reflecting the seasonal yet unpredictable nature of rainfall and streamflow in the region (Beesley 2006). Breeding of many species occurs during the wet season and during this time, multiple spawning events are known to occur (Beesley 2006). Further, the volume, hydrological regime and habitat complexity of Pilbara waterbodies can have a marked influence on fish population structure, with larger pools and more complex habitat considered generally advantageous for fish communities (Allen *et al.* 2002, Morgan *et al.* 2002, Morgan *et al.* 2009). Therefore, anthropogenically-induced alterations to streamflow patterns, water levels and water quality can have a discernible impact on life-history strategies and assemblage composition of local fish populations (Allen *et al.* 2002). Analysing population structure provides one means of characterising the health of fish assemblages at each site, and by extension the ecological processes driving aquatic communities within the waterbody. The presence of newly recruited and juvenile fish, for example, indicates recent spawning activity (and conditions conducive to such). Conversely, the presence of only sub-adult and adult (larger) fish may indicate a higher amount of predatory pressure on juvenile fish, and/or that conditions in pools are not conducive to spawning.

In order to examine population structures of the most ubiquitous freshwater fish of the Pilbara region (western rainbowfish, spangled perch and Pilbara tandan), length-frequency data for age-classes were estimated from published literature (*i.e.* Lake 1971, Bishop *et al.* 2001, Allen *et al.* 2002, Morgan *et al*. 2002, Beesley 2006; Table 13).

Table 13. Age-classes used in length-frequency analysis of Western rainbowfish, spangled perch and Pilbara tandan from the Project area. Age-classes are adapted from Lake (1971), Bishop *et al.* (2001), Allen *et al.* (2002), Morgan *et al*. (2002) and Beesley (2006).

Species	Age-class	Size mm SL
Western rainbowfish	New recruit	< 30
(*Melanotaenia australis*)	Juvenile	31-40
	Sub-adult	41-50
	Adult	> 51
Spangled perch	New recruit	< 30
(*Leiopotherapon unicolor*)	Juvenile	31-50
	Sub-adult	51-70
	Adult	> 71
Pilbara tandan	New recruit	< 30
(*Neosilurus* sp.)	Juvenile	31-70
	Sub-adult	71-90
	Adult	> 91

Western rainbowfish

Western rainbowfish breed throughout the year, with multiple spawning bouts that take full advantage of the region's intermittent rainfall and streamflow (Beesley 2006). Rainbowfish of the family Melanotaeniidae are usually sexually mature by the end of their first year (Allen *et al.* 2002). The size at sexual maturity can vary between river systems (typically around 50 mm SL), though western rainbowfish generally attain a maximum size of 110 mm total length (TL) (Allen *et al.* 2002).

The population structure of western rainbowfish at most upstream and downstream sites appeared to be healthy, with a variety of age-classes (new recruits, juveniles, sub-adults and adults) represented at RRU1, RRU4, RRU5, and RRD2 – RRD6 (Figure 13). New recruits and juveniles were particularly abundant at upstream site RRU4, and downstream sites RRD2, RRD4 and RRD6 (Figure 13), indicating spawning activity and good recruitment at these waterbodies. No western rainbowfish new recruits were recorded at RRD1, where sub-adults and adults (50 – 90 mm SL) dominated the population (Figure 13). Relatively low numbers of new recruits and juveniles (and low western rainbowfish numbers in general) were also recorded at RRU2 (Figure 13). Low recruitment of rainbowfish at RRD1 was possibly due to the small size of this pool, which also contained piscivorous species such as spangled perch, Fortescue grunter and barred grunter. Reduced depth and volume of small pools such as RRD1 inherently increases the risk of juvenile fishes to teleost (fish) and avian predation (Morgan *et al.* 2009). Conversely, low western rainbowfish abundance (and concurrent low abundance of new recruits and juveniles) recorded at RRU2 may have been related to the large size and volume of this pool, which would enable fish to avoid capture in seine and gill nets. Relatively low abundances of all fish species were recorded at RRU2, with the exception of Pilbara tandan, which are more commonly caught while electrofishing, rather than in seine and gill nets.

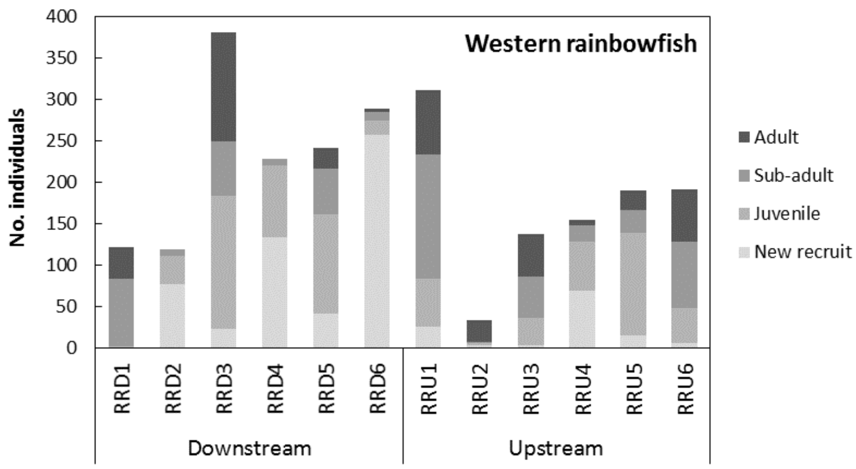


Figure 13. Abundance of western rainbowfish (*Melanotaenia australis*) age-classes recorded from each pool in the Project area.

Spangled Perch

Spangled perch are known to take advantage of wet season flooding to migrate upstream and breed (Bishop *et al.* 1995, Bishop *et al.* 2001, Pusey *et al.* 2004, Marsden and Power 2007). During this time, multiple spawning events are known to occur (Beesley 2006). In the Fitzroy River, Morgan *et al.* (2002) collected mature specimens at the beginning of the wet season, and larvae at the end of the wet season, indicating that spawning coincided with the flooding of the river. Spangled perch mature in their first year, at approximately 58 mm TL for males and 78 mm TL for females, and can reach a maximum size of 300 mm TL (Allen *et al.* 2002, Beesley 2006).

Spangled perch recruitment in the Project area appeared to be low, with new recruits (< 30 mm SL) only recorded at RRU1 and RRU2 upstream of the Jimmawarruda-Robe confluence, and RRD3 and RRD4 downstream of the confluence (Figure 14). Juveniles (31 - 60 mm SL) were also absent or recorded in low numbers at most sites (Figure 14). This reflects the high degree of variability in streamflow in the Project area, with low rainfall and streamflow leading up to the survey likely restricting spangled perch spawning activity. The exception was downstream site RRD3, where the spangled perch population comprised mainly juveniles (227 juveniles) (Figure 14). This suggests spangled perch may have spawned in or upstream of this pool recently following a flood event, with juveniles becoming isolated as waters receded. RRD3 supported the highest abundance of spangled perch in the Project area (382 individuals), constituting 67% of all spangled perch caught during the survey; however, given the ubiquitousness of this species across the Pilbara, it is likely that larger populations reside at larger pools within the Project area. Catch per unit effort is likely reduced in these pools, such as RRU2, RRU4, RRU5, RRD4, RRD5 and RRD6, due to their size and depth, and presence of submerged debris (*e.g.* logs, branches, snags), which hinders seine and gill netting.

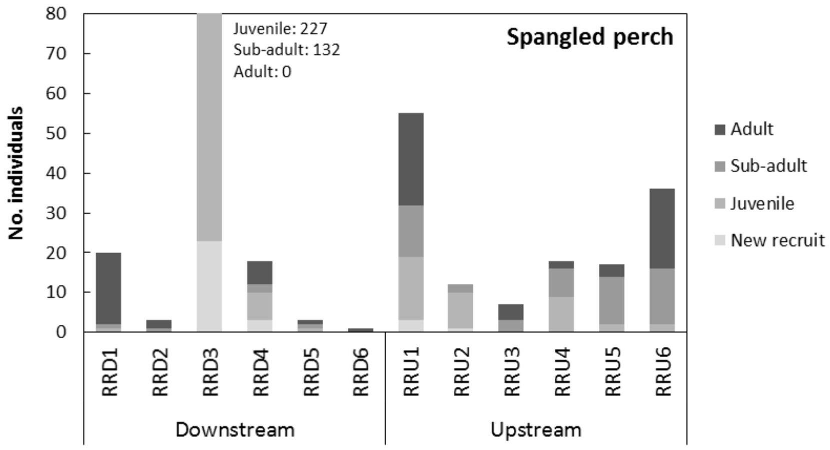


Figure 14. Abundance of spangled perch (*Leipotherapon unicolor*) age-classes recorded from each pool in the Project area. Note: column representing RRD3 is only partially displayed; the remainder of age-classes are given as text (new recruits are still displayed).

Pilbara tandan

Very little is known of the breeding ecology of the Pilbara tandan. Species of *Neosilurus* catfish usually attain a maximum size of only 200 mm SL, whereas similar species, such as *N. hyrtlii* and *N. ater*, can reach up to 400 mm TL (Lake 1971, Bishop *et al.* 2001). Breeding is thought to occur in the early wet season, where adults (> 91 mm SL) build their nests under large cobbles in flowing riffle zones (Bishop *et al*. 2001, Morgan *et al.* 2002). It is at this time when flooding increases the area and diversity of aquatic habitat available, while also initiating increases in plankton and other food sources (Bishop *et al.* 2001).

Pilbara tandan were collected in relatively low abundance throughout the Project area, with no new recruits (< 30 mm SL) recorded (Figure 15). Juvenile Pilbara tandan (31 – 70 mm SL) were only recorded at RRD2, RRU1 and RRU2 (Figure 15). Similar to spangled perch, low Pilbara tandan recruitment likely reflects the lack of streamflow in the Project area prior to the survey. Further, low overall catch rates of Pilbara tandan was likely due to the inherent difficulties in sampling this species. Like most other catfish, the Pilbara tandan is a benthic feeder, with techniques such as gill and seine netting generally limited in their ability to collect specimens due to the bottom-dwelling nature of these fish.

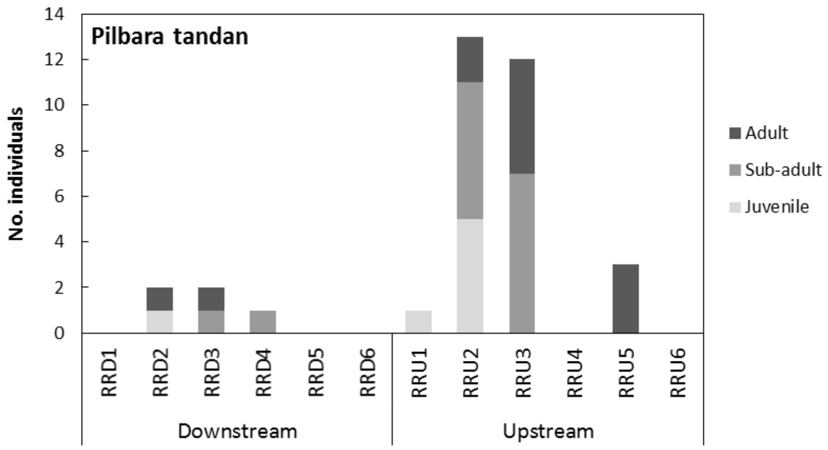


Figure 15. Abundance of Pilbara tandan (*Neosilurus* sp.) age-classes recorded from each pool in the Project area.

5.6 Other Fauna

No frogs or tadpoles were observed at any site in the current study. Although it is expected that some frogs do utilise pools within the Project area, the presence of large predatory fish, waterbirds and other predators (*e.g.* snakes) at these waterbodies would likely reduce survival rates of tadpoles in remnant pools.

No turtles were captured or observed in the Project area. EPA (1991) noted the native flat-shelled turtle, *Chelodina steindachneri,* was present at Gnieraoora and Martangkuna, but do not state the source of the records, which was possibly the 1991 survey by Streamtec/UWA for the Mesa J Project area.

6 SUMMARY AND CONCLUSIONS

This report summarises the results of wet season baseline sampling of aquatic ecosystems of the Robe River, both upstream and downstream of the proposed Mesa H development. The aim of the sampling program was to document the current ecological condition of the Robe River prior to the Mesa H development, which will require mine dewatering and surplus water discharge and may result in a surface discharge footprint along the Robe River. The current sampling program documents “current” ecological condition, moreso than “natural” condition due to the existing mine operations. In general, both water quality and aquatic fauna (microinvertebrate, hyporheic invertebrate, macroinvertebrate and fish) data indicated little ecological difference between “reference” sites upstream of the proposed development, and downstream sites that may be potentially exposed to dewatering discharge.

Water quality was highly variable amongst sites, with salinity levels ranging from fresh (592 μS/cm) to brackish (1,700 μS/cm), pH from circum-neutral (6.9) to slightly alkaline (7.9) and dissolved oxygen from hypoxic (14.5%) to supersaturated (134.9%). There were no obvious longitudinal gradients upstream or downstream of the Jimmawurrada-Robe confluence. Site RRU6, (~1 km upstream of the confluence) and the downstream sites, tended to have higher salinity (as EC and TDS), alkalinity, hardness and concentrations of associated ions, than sites upstream. This inter-site variability was attributed to differences in volume of the remnant pools sampled and evapoconcentration effects under recessional flows.

Exceedances of ANZECC/ARMCANZ default 95% TVs were recorded for nitrogen nutrients (N-total, N-NO_x and N-NH_3) at most sites upstream and downstream of the Jimmawurrada-Robe confluence. Elevated background levels of N-NO_3 and N-NH_3 within the Project area are unsurprising, given that the Robe River catchment is already effected by current and historic pastoral practices, with groundwaters also appearing to be enriched. Cattle, or evidence of high cattle use, were observed at a number of pools. Elevated N-total and N-NO_x downstream of the Jimmawurrada-Robe confluence may also reflect discharge of nitrogen-enriched groundwater from existing mine operations, though the relative contribution of anthropogenic and natural sources to nitrogen enrichment in surface waters of the Project area is unknown. With the exception of dissolved zinc at RRU5 and RRD3, no heavy metal analyte exceeded ANZECC/ARMCANZ default 95% TVs in the Project area.

A total of 81 microinvertebrate taxa were recorded from the Project area, of which 46 were present at potentially exposed sites downstream of the Jimmawurrada-Robe confluence, and 69 were recorded at upstream reference sites. The microinvertebrate fauna was generally typical of that commonly recorded from tropical/sub-tropical freshwater systems, comprising protists, rotifers, copepods, cladocerans (water fleas) and ostracods (seed shrimp), with Lecanidae dominating within the Rotifera. There were no significant differences in total mean microinvertebrate taxa richness between reference and potentially exposed sites, nor was there any significant difference in richness of any of the major microinvertebrate groups (protists, rotifers, micro-crustaceans) between these reaches.

Hyporheic sampling collected 59 taxa in total, the majority of which were species not specially adapted to groundwater environments (stygoxene); however, 8% were considered stygobitic (obligate groundwater inhabitants), 31% occasional hyporheic stygophiles (species that use the hyporheic zone seasonally or during early life history stages), and 2% possible hyporheic taxa. There were no obvious longitudinal gradients or patterns in hyporheic taxa richness between reference and potentially exposed sites, though hyporheic taxa richness was relatively high at RRD1, RRU6, RRD2 and RRU4, suggesting strong connectivity between ground- and surface- waters at these sites.

A total of 148 macroinvertebrate taxa were recorded from surface waters, with composition typical of freshwater systems throughout the world, being dominated by Insecta, in particular Diptera (true flies) and Coleoptera (aquatic beetles). There were no clear upstream/downstream gradients in macroinvertebrate richness within the Project area, with no significant difference in mean total taxa richness, and mean richness of most major macroinvertebrate groups, between reference and potentially exposed sites. Similarly, multivariate analysis detected no distinguishable separation of reference or potentially exposed sites based on macroinvertebrate species assemblage structure.

3,515 individual fish, representing 11 species, were captured, measured and released in the Project area. True freshwater species included western rainbowfish, spangled perch, Pilbara tandan (eel-tailed catfish), Fortescue grunter, barred grunter, Terapontidae (grunter) hybrids and bony bream. Estuarine/marine vagrant fish species included milkfish, tarpon/ox-eye herring, mullet and banded scat/striped butterfish, the majority of which were recorded at downstream sites. The conservation listed Fortescue grunter (*Leipotherapon aheneus*; IUCN Lower Risk/Near Threatened; Parks and Wildlife Priority 4) was the second most abundant fish species of the Project area, recorded at all upstream and downstream sites. Similar to other fauna indices, there was no significant difference in mean total abundance of fish between upstream and downstream sites, nor was there any significant difference in mean abundance of each individual species between the reaches. Healthy (breeding) populations of western rainbowfish, the most abundant fish species of the Project area, were recorded from both the upstream and downstream reaches; however, spangled perch and Pilbara tandan recruitment appeared to be low throughout the Project area.

Including the Fortescue grunter, four species of conservation significance were recorded in the Project area, all of which were present at sites potentially exposed to dewatering discharge. These are summarised in Table 14 below:

Table 14. Summary of aquatic species of conservation significance (conservation listed or short range endemic) recorded from the Project area.

Species	Common name	Conservation significance	Occurrence within the Project area	Occurrence elsewhere
Microinvertebrates				
Eodiaptomus lumholtzi	Calanoid copepod	IUCN Vulnerable	RRD6	Koodaderi Spring, Homestead Trib., Mindy Mindy Ck., Cane R., NT & QLD.
Stygal / SRE invertebrates				
Nedsia spp.	Stygal amphipod	Potential short range endemic (data deficient)	RRD1 – 4, RRU3, RRU4 and RRU5	Uncertain, possibly bores within the Yarraloola Area
Macroinvertebrates				
Eurysticta coolawanyah	Pilbara pin damselfly	IUCN Near Threatened, Pilbara endemic	RRD3 and RRD4	Widespread throughout the Pilbara, though infrequently collected
Fish				
Leipotherapon aheneus	Fortescue grunter	IUCN Near Threatened, Parks and Wildlife Priority 4, Pilbara endemic	All sites	Robe R. catchment, Fortescue R. (below Fortescue Marsh); Ashburton R.

Current results indicate little ecological difference between “reference” sites upstream of the proposed Mesa H development, and downstream sites that may be potentially exposed to dewatering discharge operations. As such, these results provide a good starting point to enable the detection of potential ecological changes downstream of the Mesa H development caused by an altered abstraction and dewatering discharge regime. Data collected from reference sites upstream of Mesa H serve as the “control” for potentially exposed sites, while April/May 2016 data provide a snapshot of the “before” condition, against which any future changes following mine development can be assessed. The premise being that if the degree of similarity between exposed and reference sites differs significantly over time (compared with pre-mine similarity), this would indicate mine-related response rather than stochastic variability due to factors such as climatic change.

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8 APPENDICES

Appendix 1. Photographs of sampled sites

Potential impact sites downstream of the Jimmawurrada-Robe confluence in April-May 2016.

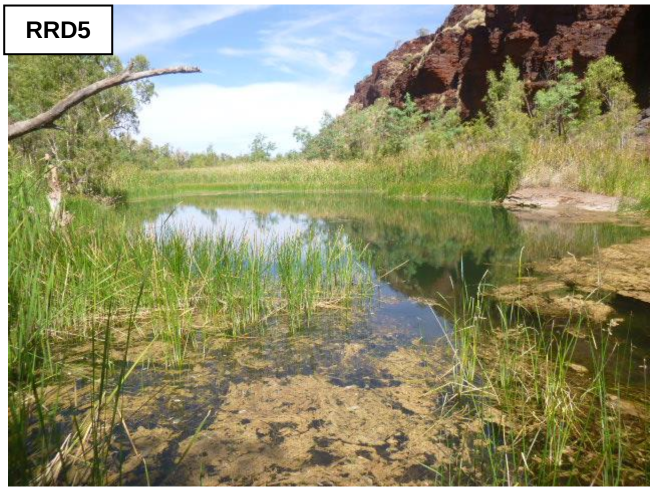
RRD1

RRD2

RRD3

RRD4

RRD5



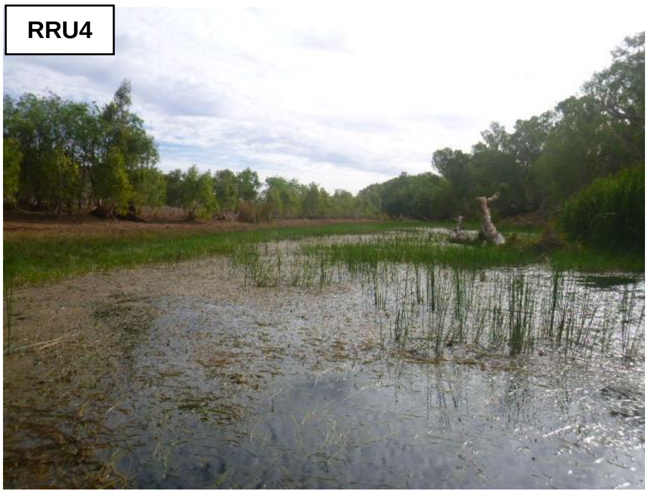
RRD6

Reference sites upstream of the Jimmawurrada-Robe confluence in April-May 2016


RRU1


RRU2


RRU3


RRU4


RRU5


RRU6

Appendix 2. ANZECC/ARMCANZ (2000) trigger values

Table A2-1. ANZECC/ARMCANZ (2000) default trigger values for some physical and chemical stressors for tropical Australia for slightly disturbed ecosystems (TP = total phosphorus; FRP = filterable reactive phosphorus; TN = total nitrogen; NOx = total nitrates/nitrites; NH4+ = ammonium). Data derived from trigger values supplied by Australian states and territories, for the Northern Territory and regions north of Carnarvon in the west and Rockhampton in the east.

	TP ($\mu g\ L^{-1}$)	FRP ($\mu g\ L^{-1}$)	TN ($\mu g\ L^{-1}$)	NOx ($\mu g\ L^{-1}$)	NH_4^+ ($\mu g\ L^{-1}$)	DO % saturation[f]	pH
Aquatic Ecosystem							
Upland River[e]	10	5	150	30	6	90-120	6.0-7.5
Lowland River[e]	10	4	200-300[h]	10[b]	10	85-120	6.0-8.0
Lakes & Reservoirs	10	5	350[c]	10[b]	10	90-120	6.0-8.0
Wetlands[3]	10-50[g]	5-25[g]	350-1200[g]	10	10	90[b]-120[b]	6.0-8.0

b = Northern Territory values are 5µgL-1 for NOx, and <80 (lower limit) and >110% saturation (upper limit) for DO;
c = this value represents turbid lakes only. Clear lakes have much lower values;
e = no data available for tropical WA estuaries or rivers. A precautionary approach should be adopted when applying default trigger values to these systems;
f = dissolved oxygen values were derived from daytime measurements. Dissolved oxygen concentrations may vary diurnally and with depth. Monitoring programs should assess this potential variability;
g = higher values are indicative of tropical WA river pools;
h = lower values from rivers draining rainforest catchments.

Table A2-2. ANZECC/ARMCANZ (2000) Default trigger values for salinity and turbidity for the protection of aquatic ecosystems, applicable to tropical systems in Australia.

Aquatic Ecosystem		*Comments*
Salinity	***(µs/cm)***	
Upland & lowland rivers	20-250	Conductivity in upland streams will vary depending on catchment geology. The fist flush may result in temporarily high values
Lakes, reservoirs & wetlands	90-900	Higher conductivities will occur during summer when water levels are reduced due to evaporation
Turbidity	***(NTU)***	
Upland & lowland rivers	2-15	Can depend on degree of catchment modification and seasonal rainfall runoff
Lakes, reservoirs & wetlands	2-200	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.

Table A2-3. ANZECC/ARMCANZ (2000) default trigger values for toxicants at alternative levels of protection (µg/L).

Compound	*Trigger values for freshwater Level of protection (% species)*			
	99%	*95%*	*90%*	*80%*
METALS & METALLOIDS				
Aluminium pH > 6.5	27	55	80	150
Aluminium pH < 6.5	ID	ID	ID	ID
Arsenic (As III)	1	24	94	360
Arsenic (As IV)	0.9	13	42	140
Boron	90	370	680	1300
Cadmium	0.06	0.2	0.4	0.8
Cobalt	ID	ID	ID	ID
Chromium (Cr III)	ID	ID	ID	ID
Chromium (Cr VI)	0.01	1	6	40
Copper	1	1.4	1.8	2.5
Iron	ID	ID	ID	ID
Manganese	1200	1900	2500	3600
Molybdenum	ID	ID	ID	ID
Nickel	8	11	13	17
Lead	1	3.4	5.6	9.4
Selenium (Se total)	5	11	18	34
Selenium (Se IV)	ID	ID	ID	ID
Uranium	ID	ID	ID	ID
Vanadium	ID	ID	ID	ID
Zinc	2.4	8	15	31
NON-METALLIC INORGANICS				
Ammonia	320	900	1430	2300
Chlorine	0.4	3	6	13
Nitrate	17	700	3400	17000

Appendix 3. Water quality data

Results from spot measurement of surface water quality taken in conjunction with aquatic fauna sampling. ANZECC/ARMCANZ (2000) default TV for protection of 95% of freshwater species is also provided for comparison; ☐ ≥ default TV, ☐ ≥ 2x default TV, ☐ ≥ 10x default TV; note, for DO, values highlighted are less than the lower default TV.

Water Quality Parameter	Method Code	*LOR*	Units	ANZECC TV	RRD1 30-04-16 0815hr	RRD2 30-04-16 1345hr	RRD3 30-04-16 1530hr	RRD4 29-04-16 1415hr	RRD5 29-04-16 1200hr	RRD6 30-04-16 1230hr	RRU1 05-05-16 0845hr	RRU2 28-04-16 1130hr	RRU3 28-04-16 0830hr	RRU4 28-04-16 1500hr	RRU5 29-04-16 0715hr	RRU6 07-05-16 1015hr
Al	iMET1WCICP	*0.005*	mg/L	0.055	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Alkalinity	iALK1WATI	*1*	mg/L	NP	245	133	266	260	249	241	155	156	175	166	183	253
As	iMET1WCMS	*0.001*	mg/L	0.013[A]	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
B	iMET1WCICP	*0.02*	mg/L	0.37	0.29	0.18	0.2	0.28	0.36	0.28	0.19	0.19	0.22	0.2	0.21	0.33
Ba	iMET1WCICP	*0.002*	mg/L	NP	0.051	0.035	0.039	0.04	0.058	0.046	0.043	0.044	0.055	0.039	0.044	0.05
CO_3	iALK1WATI	*1*	mg/L	NP	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Ca	iMET1WCICP	*0.1*	mg/L	NP	81.5	48.9	78.5	74.2	65.6	66.8	46.5	46.3	51.1	48.4	51.8	100
Cd	iMET1WCMS	*0.0001*	mg/L	0.0002	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Cl	iCO1WCDA	*1*	mg/L	NP	209	126	193	176	213	169	120	115	109	138	128	372
Co	iMET1WCMS	*0.0001*	mg/L	ID	0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0002	<0.0001	<0.0001	<0.0001
Cr	iMET1WCMS	*0.0005*	mg/L	0.001	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Cu	iMET1WCMS	*0.0001*	mg/L	0.0014	0.0002	0.0002	0.0002	0.0002	0.0002	0.0007	0.0003	0.0002	0.0002	0.0002	0.0002	0.0003
DO (field)	TPS WP-82Y logger	*0.01*	% sat.	90 - 120	72.7	44.6	94.6	79.2	37.4	134.9	37.2	38.5	16.1	74.1	14.5	77.8
DO (field)	TPS WP-82Y logger	*0.01*	mg/L	NP	5.8	3.6	8.0	5.8	2.7	8.4	2.4	2.9	1.2	5.8	0.9	5.3
EC	iEC1WZSE	*2*	µS/cm	250	1280	711	1260	1220	592	1130	772	748	824	782	802	1700
Fe	iMET1WCICP	*0.005*	mg/L	0.3*	0.007	0.013	<0.005	<0.005	0.012	0.036	0.058	0.022	0.099	0.059	0.061	0.018
HCO_3	iALK1WATI	*1*	mg/L	NP	299	162	324	317	303	294	190	191	214	202	223	309
Hardness	iHTOT2WACA	*1*	mg/L	NP	440	260	420	400	430	360	240	230	250	240	250	520
K	iMET1WCICP	*0.1*	mg/L	NP	9	6	8.6	8.2	9.7	8.7	5	5.8	6.2	6.1	6	4.4
Mg	iMET1WCICP	*0.1*	mg/L	NP	57.2	33.7	54.3	52.4	63.6	46.7	30.3	27	29.7	29.3	30.3	66.5
Mn	iMET1WCICP	*0.001*	mg/L	1.9	<0.001	0.002	<0.001	<0.001	0.003	0.004	0.002	0.009	0.099	0.002	0.004	0.004
Mo	iMET1WCMS	*0.001*	mg/L	ID	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001
$N\text{-}NH_3$	iAMMN1WFIA	*0.01*	mg/L	0.01[N]	0.02	0.05	<0.01	<0.01	<0.01	0.03	<0.01	0.02	0.01	0.01	0.01	0.07
$N\text{-}NO_2$	iNTRN1WFIA	*0.01*	mg/L	NP	<0.01	0.02	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.04
$N\text{-}NO_3$	iNTAN1WCALC	*0.01*	mg/L	NP	1.8	1.3	1.3	2	0.86	2.5	<0.01	1.2	0.95	0.38	1.1	3.7

Water Quality Parameter	Method Code	*LOR*	Units	ANZECC TV	RRD1 30-04-16 0815hr	RRD2 30-04-16 1345hr	RRD3 30-04-16 1530hr	RRD4 29-04-16 1415hr	RRD5 29-04-16 1200hr	RRD6 30-04-16 1230hr	RRU1 05-05-16 0845hr	RRU2 28-04-16 1130hr	RRU3 28-04-16 0830hr	RRU4 28-04-16 1500hr	RRU5 29-04-16 0715hr	RRU6 07-05-16 1015hr
N-NO_x	iNTAN1WFIA	*0.01*	mg/L	0.01	1.8	1.3	1.3	2	0.87	2.5	<0.01	1.2	0.96	0.38	1.1	3.8
N-total	iNP1WTFIA	*0.01*	mg/L	0.3	1.8	1.5	1.3	2	0.88	2.6	0.09	1.4	1	0.41	1.2	3.9
Na	iMET1WCICP	*0.1*	mg/L	NP	91.4	53.9	86.4	87.1	104	87.2	51.6	53.3	64.7	60.1	58.9	132
Ni	iMET1WCMS	*0.001*	mg/L	0.011	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
OH	iALK1WATI	*1*	mg/L	-	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
P-total	iPP1WTFIA	*0.005*	mg/L	0.01	0.011	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	0.011
Pb	iMET1WCMS	*0.0001*	mg/L	0.034	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
pH (field)	WTW pH330i field meter	*0.1*	[H+]	6.0 - 8.0	7.4	7.3	7.0	7.2	7.2	7.7	7.9	7.0	6.9	7.2	7.0	7.4
pH (lab)	iPH1WASE	*0.1*	[H+]	6.0 - 8.0	7.9	7.8	7.7	7.9	7.8	8	8	7.7	7.6	7.9	7.7	7.8
Redox (field)	WTW pH330i field meter	*-1999*	mV	NP	-27.2	-19.3	-3.8	-15.6	-13.5	-46.1	-56.8	-1.1	2.6	-19.4	-3.3	-22.9
S	iMET1WCICP	*0.1*	mg/L	NP	28	28	25	24	25	22	14	12	14	13	12	22
S-SO_4	iMET1WCICP	*0.1*	mg/L	NP	84	50	73.6	72	75.3	66.3	43.3	34.8	40.5	40	36.6	67.1
Se	iMET1WCMS	*0.001*	mg/L	0.011	0.002	<0.001	<0.001	0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.003
TDS-calc	iSOL1WDCA	*5*	mg/L	NP	700	390	700	670	330	620	420	410	450	430	440	940
Temp (field)	TPS WP-82Y logger	*-5*	°C	NP	27.4	25.0	30.1	30.7	27.4	28.2	24.8	29.6	26.6	28.6	28.2	27.7
TSS	iSOL1WPGR	*1*	mg/L	NP	3	4	7	<1	34	2	4	4	<1	2	<1	19
U	iMET1WCMS	*0.0001*	mg/L	ID	0.0009	0.0004	0.0004	0.0004	0.001	0.0008	0.0002	0.0002	0.0001	0.0004	0.0003	0.0016
V	iMET1WCMS	*0.0001*	mg/L	ID	0.0017	0.0012	0.0008	0.0016	0.0015	0.0031	0.0019	0.0011	0.0003	0.0013	0.001	0.0027
Zn	iMET1WCMS	*0.001*	mg/L	0.008[H]	0.004	0.002	0.011	0.003	0.003	0.007	0.004	0.004	0.001	0.003	0.012	0.004

* ANZECC/ARMCANZ (2000) provide only a low reliability TV for iron (Fe);

[A] Default TV shown is for AsV, as no default TV is provided for total arsenic;

[B] For bioaccumulating chemicals, ANZECC/ARMCANZ (2000) recommend using the default 99% species protection level TV;

[H] Default TV should be modified for water hardness using algorithms provided in Table 3.4.3 of ANZECC/ARMCANZ (2000);

[N] Default TV shown is for ammonium nitrogen, as N-NH_4^+, for protection against eutrophication. Default TV for protection against toxic effects of ammonia, as N-NH_3, is 0.9 mg/L.

Appendix 4. Habitat data

Site	RRD1	RRD2	RRD3	RRD4	RRD5	RRD6	RRU1	RRU2	RRU3	RRU4	RRU5	RRU6
Date	30-04-16	30-04-16	30-04-16	29-04-16	29-04-16	30-04-16	05-05-16	28-04-16	28-04-16	28-04-16	29-04-16	07-05-16
Canopy cover (%)	0	25	5	15	35	5	2	20	2	5	50	5
Bedrock %	0	5	2	0	0	5	5	0	0	0	0	2
Boulders %	0	2	5	0	2	2	2	2	1	5	0	2
Cobbles %	10	3	5	5	10	3	10	10	19	15	5	35
Pebbles %	30	15	35	35	23	25	36	50	60	40	65	25
Gravel %	30	55	35	55	45	35	40	32	15	38	23	15
Sand %	5	20	13	5	15	5	5	3	3	2	5	0
Silt %	15	0	5	0	5	10	0	1	2	0	0	21
Clay %	10	0	0	0	0	15	2	2	0	0	2	0
Mineral %	45	41	41	36	49	5	5	49	53	12	10	20
Emergent veg %	10	10	20	35	20	20	5	25	0	60	43	40
Submergent veg %	0	30	15	5	15	30	25	15	0	10	20	5
Floating veg %	0	0	0	0	0	0	55	3	0	10	0	0
Algae %	5	2	10	5	10	3	5	2	15	5	10	3
Detritus %	40	10	10	15	2	38	0	2	5	2	5	30
Trailing veg %	0	5	2	2	2	2	0	3	0	0	5	0
LWD %	0	2	2	2	2	2	3	1	2	1	5	2
Other %	0	0	0	0	0	0	2	0	25	0	2	0
Max Pool Depth (m)	0.8	0.7	1	2	4	1.2	1.20	3	1	1	1.2	0.6
Pool Length (m)	7	12	25	150	45	20	100	60	3	120	40	40
Ave Pool Width (m)	3	6	5	20	25	30	20	10	5	20	10	12
Bed compaction*	2	3	3	2	3	1	3	2	2	2	3	3
Habitat diversity	4	7	7	7	7	7	7	8	5	7	8	6
Mean substrate size (phi)	-0.575	-1.750	-2.465	-2.900	-2.140	-0.025	-2.960	-3.405	-4.135	-3.945	-3.420	-2.515
Substrate diversity**	6	6	7	4	6	8	7	6	5	5	5	6

* Bed compaction categories range from 1 = loose, to 5 = armoured.

** Total number of substrate types present.

Appendix 5. Microinvertebrate data

Values are total abundance.

Phylum/Class/Order	Family	Lowest Taxon	RRU1	RRU2	RRU3	RRU4	RRU5	RRU6	RRD1	RRD2	RRD3	RRD4	RRD5	RRD6
PROTISTA														
CILIOPHORA	**Stentoridae**	*Stentor* sp.	0	0	0	4	*	0	0	0	0	0	0	0
RHIZOPODA	**Arcellidae**	*Arcella discoides* Ehrenberg, 1843	*	0	13	3	0	0	0	1	0	1	0	1
		Arcella hemisphaerica Perty 1852	0	0	25	0	0	0	0	2	0	0	0	0
		Arcella megastoma Penard, 1902	0	0	0	2	0	0	0	0	0	0	0	0
		Arcella [sm]	*	0	0	0	0	0	0	0	0	0	0	0
	Centropyxidae	*Centropyxis aculeata* (Ehrenberg, 1838)	0	0	0	0	1	0	0	0	0	0	0	0
		Centropyxis cf. *aculeata* (Ehrenberg, 1838) [v. sm]	0	0	0	1	1	0	0	0	0	0	0	0
		Centropyxis ecornis (Ehrenberg, 1841)	0	*	0	5	11	0	0	1	0	1	2	2
	Difflugiidae	*Difflugia globulosa* Dujardin, 1837	*	1	1	6	2	0	0	3	0	0	0	3
		Difflugia gramen Penard, 1902	0	0	0	0	0	0	0	0	0	0	0	2
		Difflugia sp. [sm, pyriform]	0	0	0	1	4	0	0	0	0	0	0	*
	Lesquereusiidae	*Lesquereusia spiralis* (Ehrenberg, 1840)	0	0	1	0	3	0	0	0	1	0	0	2
	Trigonopyxidae	*Cyclopyxis* sp.	0	0	0	1	0	0	0	0	0	0	0	0
ANIMALIA														
ROTIFERA														
Bdelloidea		indet. bdell. [lg, bidentate]	0	0	0	0	20	4	0	0	0	0	0	4
		indet. bdell. [sm, likely more than one sp.]	0	1	8	4	14	2	0	0	0	0	0	4
		indet. bdell. [tiny]	0	0	0	0	*	0	0	0	0	1	0	0
Monogononta	**Asplanchnidae**	*Asplanchnopus hyalinus* (Harring, 1913)	0	0	0	0	0	0	0	0	0	0	0	*
	Brachionidae	*Brachionus angularis* Gosse, 1851	*	0	0	0	0	0	0	0	0	0	0	0
		Keratella procurva (Thorpe, 1912)	0	0	0	0	0	0	0	0	0	*	0	0
		Plationus patulus (Müller, 1786)	0	1	0	0	0	0	0	0	0	0	0	2
		Platyias quadricornis (Ehrenberg, 1832)	0	*	0	0	0	0	0	0	0	0	0	0
	Dicranophoridae	*Dicranophoroides caudatus* (Ehrenberg, 1834)	0	0	0	0	1	0	0	1	0	0	0	0
	Euchlanidae	*Euchlanis dilatata* Ehrenberg, 1832	0	*	0	0	0	0	0	0	0	0	0	1
		Tripleuchlanis plicata (Levander, 1894)	0	0	0	2	1	0	0	0	0	0	0	*
	Flosculariidae	*Sinantherina* sp. [solitary]	*	*	0	0	0	0	0	0	0	0	0	0
	Gastropodidae	*Ascomorpha* sp.	0	0	1	0	0	0	0	0	0	1	0	3
	Lecanidae	*Lecane bulla* (Gosse, 1851)	0	0	1	7	2	0	0	0	0	0	0	4
		Lecane curvicornis (Murray, 1913)	0	0	0	0	9	0	0	0	0	0	0	0
		Lecane hamata (Stokes, 1896)	0	0	1	0	0	0	0	0	0	0	0	1

Phylum/Class/Order	Family	Lowest Taxon	RRU1	RRU2	RRU3	RRU4	RRU5	RRU6	RRD1	RRD2	RRD3	RRD4	RRD5	RRD6
		Lecane ludwigii (Eckstein, 1883)	0	0	0	0	0	0	0	0	0	1	0	0
		Lecane **n. sp.**	0	0	0	0	1	0	0	0	0	0	0	2
		Lecane stenroosi (Meissner, 1908)	2	0	0	0	0	1	0	0	0	1	0	0
		Lecane thalera(Harring & Myers, 1926)	0	0	0	11	9	0	0	0	0	1	0	1
		Lecane (s. str.) a	0	0	0	0	12	0	0	0	0	0	0	0
		Lecane (s. str.) b [v. sm]	0	0	0	0	1	0	0	0	0	0	0	0
		Lecane (*M.*) sp. a	0	0	0	1	4	0	0	0	0	0	0	0
		Lecane (*M.*) sp. b	0	0	0	0	3	0	0	0	0	0	0	0
		Lecane (*M.*) sp. c	0	0	0	0	1	1	0	0	0	0	0	0
	Lepadellidae	*Colurella* sp. [tiny]	0	0	0	0	2	0	0	0	0	0	0	0
		Lepadella cf. *rhomboides* (Gosse, 1886)	0	0	0	0	1	0	0	0	0	0	0	0
		Lepadella sp.	0	0	1	1	2	0	0	0	0	0	0	0
		Squatinella rostrum (Schmarda, 1846)	0	0	0	0	1	0	0	0	0	0	0	1
	Lindiidae	*Lindia* sp.	0	0	0	0	3	0	0	0	0	0	0	0
	Notommatidae	*Cephalodella gibba* (Ehrenberg, 1830)	0	0	1	0	0	0	0	0	0	0	0	0
		Cephalodella sp.	*	0	0	0	0	0	0	0	0	0	0	0
		notommatid, indet.	0	0	0	0	0	0	0	0	0	0	0	1
	Proalidae	*Proales* sp.	0	0	0	1	0	0	0	0	0	0	0	3
	Scaridiidae	*Scaridium* sp.	0	0	0	0	1	0	0	0	0	0	0	0
	Synchaetidae	*Polyarthra* sp.	5	145	6	0	0	0	0	0	0	0	0	39
		indet. contr. blob	*	0	3	2	0	0	0	0	0	0	0	0
		maybe rotifer	0	0	0	1	0	0	0	0	0	0	0	0
ARTHROPODA														
CLADOCERA	**Bosminidae**	*Bosmina meriodionalis* Sars, 1904	0	0	0	2	0	0	0	0	0	0	0	0
	Chydoridae	*Anthalona harti* Van Damme, Sinev & Dumont, 2011	0	0	0	0	0	0	0	1	0	0	0	0
		Chydorus sp.	0	0	0	1	0	0	0	0	0	0	0	0
		Dunhevedia crassa King, 1853	0	*	0	0	0	0	0	0	0	0	0	0
		Ephemeroporus barroisi (Richard, 1894)	0	0	0	2	0	0	0	1	2	0	0	0
		Karualona karua (King, 1853)	0	0	0	1	0	0	0	4	0	0	0	0
		indet. alonine	*	0	*	0	0	0	0	1	1	0	0	0
	Daphnidae	*Ceriodaphnia cornuta* Sars, 1885	*	0	0	0	0	0	0	0	0	0	0	0
		Ceriodaphnia sp.	0	*	0	0	0	0	0	0	0	0	0	0
	Ilyocryptidae	*Ilyocryptus* sp. [juv.]	0	0	0	0	0	1	0	0	0	0	0	0
	Moinidae	*Moina micrura*	0	*	0	0	0	0	0	0	0	0	0	0
	Sididae	*Diaphanosoma excisum* Sars, 1885	0	*	0	0	0	0	0	0	0	0	0	*
COPEPODA	**Calanoida**	*Eodiaptomus lumholtzi* (Sars, 1889)	0	0	0	0	0	0	0	0	0	0	0	1
		calanoid copepodite	0	0	0	0	0	0	0	0	0	0	0	1

Phylum/Class/Order	Family	Lowest Taxon	RRU1	RRU2	RRU3	RRU4	RRU5	RRU6	RRD1	RRD2	RRD3	RRD4	RRD5	RRD6
		calanoid nauplii	0	0	0	0	0	0	0	0	0	0	0	3
	Cyclopoida	*Mesocyclops darwini* Dussart & Fernando, 1988	0	0	0	1	0	0	0	0	1	0	0	*
		Mesocyclops sp. [other]	0	0	0	0	*		0	0	0	0	0	0
		Tropocyclops cf. *prasinus* (Fischer, 1860)	0	0	0	0	0	0	0	0	0	9	0	3
		indet. cyclopoid sp. [3-seg. P1-4]	0	0	0	0	0	0	0	2	0	0	0	0
		indet. cyclopoid lg	*	*	0	0	0	0	0	0	0	0	0	0
		indet. cyclopoid sm	*	2	1	0	0	0	0	8	0	0	0	0
		cyclopoid copepodites	11	2	35	14	5	1	2	76	0	21	0	26
		cyclopoid nauplii	184	56	106	93	97	2	0	13	0	168	0	85
OSTRACODA	**Cyprididae**	*Cypretta* sp.	*	*	0	1	0	0	0	3	0	0	0	*
		cf. *Cypridopsis* sp.	0	0	*	1	0	valves	0	0	0	*	0	0
		Heterocypris sp.	0	*	0	0	0	0	0	0	0	0	0	0
		Sarscypridopsis sp.	0	0	0	0	0	0	0	0	0	0	0	0
	Darwinulidae	*Vestalenula marmonieri*	0	*	0	1	3	valves	2	70	13	0	0	*
	Limnocytheridae	*Limnocythere* sp.	0	0	0	0	*	0	valves	2	2	0	0	*
	Notodromadidae	indet. juv.	0	0	0	0	2	0	1	3	1	0	0	3
		Taxa Richness	**16**	**19**	**18**	**27**	**33**	**7**	**3**	**17**	**7**	**12**	**1**	**33**

*found after initial count of ~200 cells

Appendix 6. Hyporheic invertebrate data

Values are $\log_{10}$ abundance categories, where 1= 1 individual, 2 = 2-10 individuals, 3 = 11-100, 4 = 101-1000, and so on. Hyporheic fauna classifications (Class) followed those of Boulton (2001), where: X = stygoxene, O = occasional hyporheic stygophile, P = possible hyporheic taxa, S = stygobite and U = Unclassified.

Phylum/Class/Order	Family	Lowest Taxon	Class	RRD1	RRD2	RRD3	RRD4	RRD5	RRD6	RRU1	RRU2	RRU3	RRU4	RRU5	RRU6
PLATYHELMINTHES															
TURBELLARIA		Turbellaria spp.	X	0	0	0	0	1	1	0	0	0	0	0	2
NEMATODA		Nematoda spp.	O	0	0	0	0	3	2	2	0	0	1	0	0
MOLLUSCA															
GASTROPODA															
Cerithimorpha	**Thiaridae**	*Melanoides* spp.	X	2	0	0	3	2	0	0	0	0	0	0	0
Hygrophila	**Planorbidae**	*Gyraulus* spp.	X	0	0	0	2	0	0	0	0	0	0	0	0
ANNELIDA															
OLIGOCHAETA		Oligochaeta spp. (imm./dam.)	U	0	0	2	0	2	0	0	0	2	2	0	0
Tubificida	**Naididae**	Naididae spp. (imm./dam.)	O	1	3	0	0	3	0	0	0	0	2	2	0
		Allonais pectinata	O	0	0	0	0	0	0	0	0	0	1	0	0
		Branchiura sowerbyi	O	0	2	0	0	0	0	0	0	0	3	0	0
		Pristina aequiseta	O	0	3	0	0	0	0	0	0	0	0	0	0
		Pristina leidyi	O	0	0	0	0	0	0	0	0	0	0	2	0
		Pristina longiseta	O	1	0	2	0	1	3	0	0	0	1	0	1
	Phreodrilidae	Phreodrilidae spp.	O	0	0	0	2	0	0	0	0	1	0	0	0
ARTHROPODA															
CRUSTACEA															
MALACOSTRACA															
Amphipoda		Amphipoda spp. (stygofauna)	S	3	2	3	0	0	0	1	0	2	0	2	3
	Eriopisidae	*Nedsia* spp.	S	3	2	1	1	0	0	0	0	2	1	0	3

Phylum/Class/Order	Family	Lowest Taxon	Class	RRD1	RRD2	RRD3	RRD4	RRD5	RRD6	RRU1	RRU2	RRU3	RRU4	RRU5	RRU6
Thermosbaenacea	**Halosbaenidae**	*Halosbaena tulki*	S	0	2	2	1	0	0	0	0	2	0	0	0
MAXILLIPODA															
Cyclopoida		cyclopoid copepodites	U	2	3	1	0	1	3	2	0	3	0	2	3
	Cyclopidae	*Halicyclops calm*	O	0	0	0	0	0	0	1	1	0	0	0	0
		Mesocyclops darwini	O	0	0	0	0	0	0	0	0	2	0	0	0
		Microcyclops varicans	O	1	0	0	0	0	2	0	0	0	0	0	2
OSTRACODA															
	Candonidae	*Candonopsis* cf. *tenuis*	S	0	0	0	0	0	0	0	0	0	0	0	1
	Cyprididae	*Cypridopsis* sp.	O	2	0	0	1	0	0	0	0	0	0	0	0
		Cyprinotus cingalensis	O	1	0	0	0	0	0	0	0	0	0	0	0
		Stenocypris major	X	0	0	0	1	0	0	0	0	0	0	0	0
	Darwinulidae	*Vestalenula marmonieri*	S	3	0	0	0	1	0	2	0	0	0	0	0
ARACHNIDA		Acarina spp.	P	2	3	0	2	2	3	2	0	2	2	1	2
HEXAPODA															
ENTOGNATHA															
Entomobryomorpha		Entomobryoidea spp.	O	2	1	0	0	3	1	0	1	2	2	2	3
Poduromorpha		Poduroidea spp.	O	1	0	0	2	0	0	0	0	0	0	0	0
Symphypleona		Symphypleona spp.	O	0	0	0	0	0	0	2	0	0	0	0	1
INSECTA															
Ephemeroptera	**Caenidae**	*Tasmanocoenis* sp. P/*arcuata*	X	0	0	0	0	0	0	0	0	1	0	0	0
Coleoptera		Coleoptera spp. (L)	U	0	2	0	0	0	0	0	0	0	2	0	2
	Carabidae	Carabidae sp.	X	0	0	0	0	0	0	0	0	0	1	0	0
	Dytiscidae	Bidessini sp. (L)	X	0	0	0	0	0	0	0	0	0	1	0	0
	Elmidae	*Austrolimnius* spp. (L)	X	2	0	2	0	0	0	0	0	0	0	0	0
	Hydraenidae	Hydraenidae sp. (L)	O	0	0	0	0	1	0	0	0	0	0	0	1
		Hydraena spp.	O	2	0	0	0	0	0	0	0	0	0	0	0
	Hydrophilidae	Hydrophilidae spp. (L)	X	0	0	1	0	0	0	0	0	0	0	1	0

Phylum/Class/Order	Family	Lowest Taxon	Class	RRD1	RRD2	RRD3	RRD4	RRD5	RRD6	RRU1	RRU2	RRU3	RRU4	RRU5	RRU6
		Chaetarthria nigerrima (L)	X	0	0	0	0	2	0	0	0	0	0	0	0
		Enochrus sp. (L)	X	0	0	0	0	1	0	0	0	0	0	0	0
		Helochares sp. (L)	X	0	0	0	0	0	0	1	0	0	0	0	0
	Ptiliidae	Ptiliidae sp.	X	0	0	1	0	0	0	0	0	0	0	0	0
	Scirtidae	Scirtidae spp. (L)	X	2	1	0	0	0	1	0	0	0	1	2	2
	Staphylinidae	Staphylinidae sp.	X	0	1	0	0	0	0	0	0	0	0	0	0
Diptera	**Ceratopogonidae**	Ceratopogonidae spp. (P)	X	1	2	0	0	2	0	3	0	0	2	1	2
		Ceratopogoninae spp.	X	3	3	3	2	4	3	0	3	3	4	2	4
		Dasyheleinae spp.	X	0	3	3	2	3	1	3	2	1	2	0	0
		Forcipomyiinae spp.	X	0	0	0	0	2	0	0	0	0	0	0	0
	Chironomidae	Chironomidae sp. (P)	X	0	1	0	0	0	0	0	0	0	0	0	0
	Chironominae														
	Chironomini	*Paratendipes* sp. K1	X	0	1	0	0	3	0	0	0	0	0	0	0
		Polypedilum sp. 1	X	0	0	0	0	0	0	0	0	0	2	0	0
	Tanytarsini	*Cladotanytarsus* sp. (WWTS4)	X	0	0	0	0	1	0	0	0	0	0	0	0
		Tanytarsus sp. (WWTS1)	X	1	1	0	0	1	0	2	0	1	1	0	0
		Paratanytarsus sp. (WWTS2)	X	1	2	0	0	2	0	2	0	0	0	0	0
	Orthocladiinae	Orthocladiinae sp. (WWO7)	X	0	2	0	0	0	0	0	0	0	0	0	0
		Orthocladiinae sp. (WWO8)	X	0	0	2	0	0	2	0	0	2	0	0	2
	Tanypodinae	*Paramerina* sp. (WWT1)	X	2	0	0	0	0	0	0	0	1	0	0	0
	Dolichopodidae	Dolichopodidae spp.	X	0	2	2	0	0	0	0	1	0	0	0	0
	Empididae	Empididae spp.	X	0	0	2	0	0	0	0	0	0	0	0	0
	Tabanidae	Tabanidae sp.	X	0	0	0	0	0	0	1	0	0	0	0	0
	Tipulidae	Tipulidae spp.	X	0	1	0	0	3	0	2	1	0	0	0	0
		Taxa richness		**21**	**22**	**14**	**11**	**22**	**11**	**14**	**6**	**15**	**18**	**10**	**16**

(imm./dam) = taxa were too immature / damaged to be accurately identified to a lower taxonomic level.

(P) = taxa were in pupal form.

(L) = taxa were in larval form.

NB: some chironomid taxa are followed by their unique morphotype code (in parentheses).

Appendix 7. Macroinvertebrate data

Values are log_{10} abundance categories, where 1= 1 individual, 2 = 2-10 individuals, 3 = 11-100, 4 = 101-1000, and so on.

Phylum/Class/Order	Family	Lowest Taxon	RRD1	RRD2	RRD3	RRD4	RRD5	RRD6	RRU1	RRU2	RRU3	RRU4	RRU5	RRU6
CNIDARIA														
HYDROZOA														
Anthoathecata	**Hydridae**	*Hydra* sp.	1	0	0	0	0	0	0	0	0	0	0	0
MOLLUSCA														
GASTROPODA		Gastropoda spp. (imm./dam.)	0	0	0	0	0	0	0	0	0	0	2	0
Cerithimorpha	**Thiaridae**	*Melanoides* spp.	3	0	3	3	2	3	4	4	2	2	3	4
Hygrophila	**Lymnaeidae**	*Bullastra vinosa*	2	2	0	0	3	3	2	2	1	0	0	0
	Planorbidae	*Amerianna* spp.	0	0	0	0	0	0	0	2	0	0	0	0
		Ferrissia petterdi	2	2	0	0	0	0	0	0	0	0	2	0
		Gyraulus spp.	3	3	0	3	2	3	4	3	0	0	2	2
BIVALVIA														
Unionoida	**Hyriidae**	*Velesunio* spp.	0	0	0	0	0	0	0	0	0	0	0	2
ANNELIDA														
OLIGOCHAETA		Oligochaeta spp.	3	3	3	3	3	0	3	3	3	3	4	2
ARTHROPODA														
CRUSTACEA														
MALACOSTRACA														
Amphipoda		Amphipoda spp. (stygofauna)	0	0	3	2	0	0	0	0	0	0	0	0
	Eriopisidae	*Nedsia* spp.	0	0	2	3	0	0	0	0	0	0	0	0
Decapoda	**Atyidae**	Atyidae spp. (imm./dam.)	2	0	2	0	0	0	0	0	0	0	2	2
		Caridina indistincta	3	3	3	2	3	3	3	4	3	2	3	1
CHELICERATA														
ARACHNIDA		Acarina spp.	3	3	0	2	2	0	4	3	3	0	3	2
HEXAPODA														
ENTOGNATHA														
Entomobryomorpha		Entomobryoidea spp.	2	2	0	0	0	0	2	0	0	0	0	0
Symphypleona		Symphypleona sp.	0	0	0	0	0	0	1	0	0	0	0	0
INSECTA														
Odonata														
Anisoptera		Anisoptera spp. (imm./dam.)	2	2	2	0	1	2	2	3	2	2	0	0
	Aeshnidae	*Hemianax papuensis*	0	0	0	0	0	1	0	0	0	0	0	0
	Libellulidae	*Crocothemis nigrifrons*	0	2	0	0	0	0	1	0	0	0	1	0

Phylum/Class/Order	Family	Lowest Taxon	RRD1	RRD2	RRD3	RRD4	RRD5	RRD6	RRU1	RRU2	RRU3	RRU4	RRU5	RRU6
		Diplacodes bipunctata	0	0	0	0	0	1	0	0	2	2	0	1
		Diplacodes haematodes	0	0	0	0	0	0	1	0	0	1	0	0
		Orthetrum caledonicum	2	0	0	1	0	1	1	0	0	0	0	0
		Rhodothemis lieftincki	0	0	0	0	1	0	0	2	2	3	2	0
		Rhyothemis graphiptera	0	0	1	2	1	0	0	0	0	0	0	0
		Zyxomma elgneri	0	0	1	0	0	0	0	1	2	0	1	0
	Lindeniidae	*Ictinogomphus dobsoni*	1	0	0	1	0	2	0	0	1	0	0	0
Zygoptera		Zygoptera spp. (imm./dam.)	1	2	1	2	0	2	2	2	0	3	0	3
	Coenagrionidae	*Argiocnemis rubescens*	2	2	0	0	0	0	2	0	2	0	1	0
		Ischnura aurora	0	2	0	0	2	2	3	2	0	2	0	2
		Ischnura heterosticta	0	0	0	0	0	0	0	0	0	2	0	0
		Pseudagrion aureofrons	0	0	0	0	0	0	2	1	0	1	0	0
		Pseudagrion microcephalum	0	0	0	0	0	1	0	0	0	2	0	0
	Isostictidae	*Eurysticta coolawanyah*	0	0	1	2	0	0	0	0	0	0	0	0
Ephemeroptera	**Baetidae**	Baetidae spp. (imm./dam.)	2	3	3	3	2	3	1	3	0	2	0	2
		Cloeon fluviatile	0	3	2	2	2	0	3	0	0	0	0	0
		Cloeon sp. Red Stripe	2	4	3	3	2	2	3	3	1	3	2	3
	Caenidae	Caenidae spp. (imm./dam.)	0	3	3	2	0	2	1	0	2	0	0	0
		Tasmanocoenis sp. M	0	0	2	0	0	0	0	0	0	0	0	0
		Tasmanocoenis sp. P/*arcuata*	2	3	2	2	0	2	1	0	0	0	1	0
Hemiptera	**Belostomatidae**	Belostomatidae spp. (imm./dam.)	0	2	0	0	0	2	3	2	0	2	2	2
		Diplonychus spp.	0	2	1	0	1	0	0	2	0	0	2	1
		Lethocerus distinctifemur	0	0	0	0	0	0	0	0	1	0	0	0
	Corixidae/Micronectidae	Corixidae/Micronectidae spp. (imm./dam.)	0	2	0	2	0	2	2	3	0	0	0	0
	Gelastocoridae	*Nerthra* spp. (imm./dam.)	0	0	0	1	0	0	1	0	0	0	0	0
	Gerridae	Gerridae spp. (imm./dam.)	0	2	0	0	0	0	2	2	0	0	1	0
		Limnogonus fossarum gilguy	0	2	0	0	2	0	2	1	0	2	0	0
	Hebridae	Hebridae spp. (imm./dam.)	1	1	0	0	2	2	0	2	0	0	1	2
		Hebrus axillaris	0	0	0	0	0	2	0	0	0	0	0	0

Phylum/Class/Order	Family	Lowest Taxon	RRD1	RRD2	RRD3	RRD4	RRD5	RRD6	RRU1	RRU2	RRU3	RRU4	RRU5	RRU6
		Merragata hackeri	0	0	0	0	0	0	0	2	0	0	2	0
	Hydrometridae	*Hydrometra papuana*	0	0	0	0	0	0	0	0	0	0	1	0
	Mesoveliidae	Mesoveliidae spp. (imm./dam.)	2	3	0	0	1	2	3	0	0	2	0	2
		Mesovelia spp. (imm./dam.)	0	0	0	2	0	0	0	0	0	0	0	0
		Mesovelia hackeri	0	1	0	0	0	2	0	0	0	0	0	0
		Mesovelia hungerfordi	0	0	0	2	0	0	0	0	0	0	0	0
		Mesovelia vittigera	0	2	0	2	0	0	2	0	0	0	1	0
	Micronectidae	*Micronecta* spp. (imm./dam.)	0	0	0	0	0	0	0	2	0	0	0	0
		Micronecta paragoga	0	0	0	0	0	2	0	0	0	0	0	0
	Nepidae	Nepidae spp. (imm./dam.)	1	0	0	0	0	0	0	0	0	0	0	0
		Laccotrephes tristis	0	0	1	0	0	0	0	1	0	0	0	0
		Ranatra diminuta	1	2	0	0	0	0	1	0	0	0	0	0
	Pleidae	*Paraplea* spp.	3	2	1	2	2	3	4	3	0	3	0	3
Coleoptera		Coleoptera spp. (L)	2	0	0	0	0	0	0	0	0	0	0	0
		Unknown spp. (L)	0	0	0	0	0	0	2	0	0	0	0	0
	Dytiscidae	*Allodessus bistrigatus*	0	0	0	0	0	2	0	0	0	0	0	0
		Bidessini spp. (L)	0	0	0	0	0	0	1	0	0	2	1	0
		Copelatus nigrolineatus	0	0	0	0	0	0	1	0	0	0	0	1
		Cybister tripunctatus	0	0	0	0	0	1	0	0	1	0	0	0
		Hydaticus consanguineus	0	2	0	0	0	0	0	0	0	0	0	0
		Hydaticus daemeli	0	0	0	0	0	0	0	1	0	0	0	0
		Hydroglyphus godeffroyi	0	0	0	0	0	2	0	1	0	0	0	0
		Hydroglyphus grammopterus	0	0	0	0	0	2	0	0	0	0	0	0
		Hydroglyphus leai	0	0	0	0	0	0	2	0	0	0	0	0
		Hydroglyphus orthogrammus	0	0	0	0	0	2	2	2	0	0	0	0
		Hydrovatus spp. (L)	2	0	0	0	0	0	4	0	2	0	1	0
		Hydrovatus opacus	2	0	0	0	0	0	2	0	2	0	0	0
		Hyphydrus lyratus	0	1	0	0	0	2	0	2	0	0	0	1
		Laccophilus sharpi	0	0	0	0	0	0	0	2	0	0	0	0
		Limbodessus compactus	2	1	0	0	0	2	2	0	0	1	0	0

Phylum/Class/Order	Family	Lowest Taxon	RRD1	RRD2	RRD3	RRD4	RRD5	RRD6	RRU1	RRU2	RRU3	RRU4	RRU5	RRU6
		Necterosoma darwini	0	0	0	0	0	0	0	0	0	0	0	1
		Necterosoma regulare	0	0	0	0	0	0	0	0	0	0	0	2
		Onychohydrus atratus	1	0	0	0	0	0	0	0	2	0	0	0
		Platynectes decempunctatus var. *decempunc.*	0	0	0	0	0	2	0	1	2	0	0	1
		Rhantaticus congestus	0	1	0	0	0	0	1	0	0	0	0	0
		Tiporus tambreyi	2	0	0	0	0	0	0	0	2	2	0	3
	Elmidae	*Austrolimnius* spp. (L)	2	0	2	0	0	0	0	0	0	0	0	0
	Haliplidae	*Haliplus pilbaraensis*	0	0	0	0	0	0	2	0	0	0	0	0
	Hydraenidae	*Hydraena* spp.	2	0	0	0	0	2	4	3	0	0	0	0
		Limnebius spp.	0	0	0	0	0	2	0	2	0	0	0	0
	Hydrochidae	*Hydrochus* spp.	3	2	0	2	0	3	3	1	2	1	0	3
	Hydrophilidae	Hydrophilidae spp. (L)	0	0	0	0	0	0	3	0	0	0	0	0
		Anacaena horni	2	2	0	0	0	0	0	0	0	0	0	0
		Berosus dallasae	0	0	0	0	0	2	0	1	0	0	0	2
		Enochrus deserticola	0	1	0	0	0	1	3	2	2	0	0	0
		Helochares spp. (L)	0	2	0	2	2	2	3	0	0	3	0	2
		Helochares tatei	0	0	0	0	1	1	1	0	0	0	0	0
		Laccobius sp.	0	0	0	0	0	0	0	0	0	1	0	0
		Paracymus spenceri	0	2	0	0	0	0	3	2	0	2	0	0
		Regimbartia attenuata	1	0	0	0	0	2	2	0	0	0	0	0
		Regimbartia attenuata (L)	0	0	0	0	0	0	0	1	0	0	0	0
		Sternolophus marginicollis	2	3	1	0	0	0	0	3	3	0	1	0
	Noteridae	*Neohydrocoptus subfasciatus* (L)	2	1	0	0	0	0	0	0	0	0	0	0
	Scirtidae	Scirtidae spp. (L)	0	0	0	0	2	0	1	0	1	0	1	0
Diptera	**Ceratopogonidae**	Ceratopogonidae spp. (P)	0	2	2	2	2	0	2	0	0	3	0	2
		Ceratopogoninae spp.	2	0	3	2	1	2	3	2	1	2	3	3
		Dasyheleinae spp.	2	3	3	2	3	1	4	3	0	3	3	2
		Forcipomyiinae spp.	0	1	0	0	0	0	3	0	0	0	0	0
	Chironomidae	Chironomidae spp. (P)	2	2	2	2	2	2	3	2	0	1	2	0
	Chironominae													

Phylum/Class/Order	Family	Lowest Taxon	RRD1	RRD2	RRD3	RRD4	RRD5	RRD6	RRU1	RRU2	RRU3	RRU4	RRU5	RRU6
	Chironomini	*Chironomus* sp. (WWC3)	0	2	0	0	3	0	0	2	3	3	2	0
		Cladopelma curtivalva	3	2	3	2	0	3	2	0	0	0	0	0
		Cryptochironomus griseidorsum	2	0	0	0	0	0	0	0	0	0	0	0
		Dicrotendipes sp. (WWC17)	0	0	0	2	0	0	0	0	0	0	0	0
		Dicrotendipes sp. 1	0	0	2	2	0	0	0	0	0	0	0	0
		Dicrotendipes sp. 2	3	0	3	0	0	1	3	3	2	0	0	0
		Kiefferulus intertinctus	0	0	0	2	2	0	0	2	3	0	0	0
		Parachironomus sp. K2	0	0	0	0	0	0	2	0	0	0	0	0
		Paratendipes sp. K1	3	2	0	0	0	0	0	0	0	0	0	0
		Polypedilum (Pentapedilum) leei	2	0	0	0	0	3	2	0	0	0	0	2
		Polypedilum sp. 1	3	3	0	2	2	2	0	3	2	3	3	3
		Polypedilum sp. 2	0	0	0	0	2	0	0	0	0	0	0	2
		Skusella subvittata	2	0	0	0	0	0	0	0	0	0	0	0
	Tanytarsini	*Cladotanytarsus* sp. (WWTS4)	3	2	3	3	0	1	2	3	0	0	0	3
		Paratanytarsus sp. (WWTS2)	0	0	2	0	0	0	0	0	0	2	3	2
		Tanytarsus sp. (WWTS1)	0	3	2	0	3	0	3	3	3	3	3	2
	Orthocladiinae	*Nanocladius* sp. (WWO6)	0	0	0	0	0	0	3	0	0	0	0	0
	Tanypodinae	*Ablabesmyia hilli*	0	0	0	2	2	0	0	2	0	2	0	0
		Fittkauimyia disparipes	0	0	0	0	0	0	0	0	2	0	0	0
		Larsia albiceps	4	3	3	3	3	3	3	4	2	3	3	3
		Paramerina sp. (WWT1)	3	3	2	2	2	0	3	3	3	2	0	3
		Procladius sp. (WWT5)	3	0	3	3	3	0	0	0	0	2	0	3
	Culicidae	Culicidae spp. (P)	0	0	0	0	0	0	3	1	0	0	0	0
		Anopheles spp.	0	2	0	0	2	0	3	3	0	2	2	2
		Culex spp.	0	2	0	0	0	0	4	2	0	0	0	2
	Dolichopodidae	Dolichopodidae sp.	1	0	0	0	0	0	0	0	0	0	0	0
	Ephydridae	Ephydridae spp.	0	0	0	0	0	0	0	0	0	0	0	2
	Sciomyzidae	Sciomyzidae spp.	0	0	0	0	0	0	2	0	0	0	0	0
	Stratiomyidae	Stratiomyidae spp.	2	0	0	0	0	2	3	0	0	1	0	0
		Stratiomyidae sp. (P)	0	0	0	0	1	0	0	0	0	0	0	0

Phylum/Class/Order	Family	Lowest Taxon	RRD1	RRD2	RRD3	RRD4	RRD5	RRD6	RRU1	RRU2	RRU3	RRU4	RRU5	RRU6
	Tabanidae	Tabanidae spp.	0	2	0	0	0	1	3	0	0	0	0	0
	Thaumaleidae	Thaumaleidae spp.	0	0	0	0	0	0	0	0	0	0	0	2
	Tipulidae	Tipulidae sp. (P)	0	0	0	0	0	0	1	0	0	0	0	0
Trichoptera	**Ecnomidae**	*Ecnomus* spp.	1	0	2	0	1	0	0	0	0	0	0	0
	Hydroptilidae	*Hellyethira* spp.	0	0	2	0	0	0	0	0	0	0	0	0
	Leptoceridae	Leptoceridae spp. (imm./dam.)	0	0	0	0	2	0	0	0	1	0	0	0
		Leptocerus souta	0	0	0	0	0	0	2	0	0	0	0	0
		Oecetis sp.	1	0	0	0	0	0	0	0	0	0	0	0
		Triplectides ciuskus seductus	0	0	2	0	0	0	0	0	0	0	0	0
Lepidoptera	**Crambidae**	*Acentropinae* spp.	0	2	0	0	0	0	0	1	0	0	0	0
		Parapoynx spp.	0	1	0	0	0	2	2	2	0	2	0	0
		Taxa richness	**54**	**56**	**38**	**39**	**38**	**52**	**72**	**56**	**34**	**40**	**34**	**42**

(imm./dam) = taxa were too immature / damaged to be accurately identified to a lower taxonomic level.

(P) = taxa were in pupal form.

(L) = taxa were in larval form.

NB: some chironomid taxa are followed by their unique morphotype code (in parentheses)