Mesa A / Warramboo Project

Baseline Aquatic Ecosystem Survey
Wet Season Sampling 2016

Wetland Research & Management

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Frontispiece (left to right): Warramboo Creek ephemeral site WARDS6 (May 2016); ostracods (seed shrimp) which emerged from the rehydrated sediment sample taken at WARDS6 (May 2016); Warramboo Creek site WARUS2 in flood (May 2016).

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Disclaimer

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Tables, Figures and Plates

EXECUTIVE SUMMARY

This report summarises the results of a baseline sampling program for aquatic ecosystems of Warramboo Creek. The creek is a naturally ephemeral system adjacent to the Robe River Mining Co. Pty Ltd Mesa A / Warramboo iron ore mine, in the Pilbara region of Western Australia. The Warramboo deposit has been mined above water table since 2012, however, in order to access the orebody that lies below water table, dewatering and discharge of excess water is considered necessary. The proposed surplus water discharge location is located on Warramboo Creek, approximately 3.5 km to the south-west of current operations. The aim of the current sampling program was to document the existing ecological condition of Warramboo Creek, and procure benchmark data against which any potential changes associated with dewatering discharge from the below water table development can be assessed. To provide regional context for the sampling program, the current report also includes a review of previous comparable aquatic fauna surveys conducted within 50 km of Warramboo Creek.

The intent was to sample six sites (WARDS1 to 6) likely to fall within the zone of dewatering discharge (i.e. 'potentially exposed' sites), and six sites (WARUS1 to 6) located upstream of the proposed discharge point (i.e. 'reference' sites). These sites were selected as those most likely to contain suitable surface water pools for sampling, based on aerial imagery[1] of the creekline. However, at the time of survey (2 - 6 May 2016), most sites were dry and no surface water pools were present within the modelled dewatering discharge zone downstream of the proposed discharge location. Only two of the 12 sites (WARUS5 and WARUS6) were successfully sampled for water quality, microinvertebrates (zooplankton), hyporheic fauna and macroinvertebrates. One reference site (WARUS2) could not be accessed/sampled due to flash flooding on the final day of the survey.

Rehydration trials were therefore conducted on sediment samples collected from 11 sites (WARUS1, 3 to 6, WARDS1 to 6), allowing the enumeration of dormant/resting fauna residing in the creek bed. Invertebrate assemblages that emerge from rehydration trials are not entirely representative of what may be present in surface water pools, and will not detect the presence of tempory resident taxa. Results of previous studies referred to in this report are not necessarily representative of Warramboo Creek.

The main findings of the baseline survey were:

- Surface waters at WARUS5 and WARUS6 were fresh (211 - 309 µS/cm EC), with alkaline pH values (7.56 - 8.22) and high dissolved oxygen concentrations (109.8 - 125.2% DO). Salinity (as EC) and concentration of associated ions was relatively low in surface waters, reflecting the influence of rainwater. Concentrations of dissolved metals were generally below ANZECC/ARMCANZ (2000) default trigger values (TV) for protection of 95% of aquatic species. The exception was dissolved aluminium at WARUS5 (0.083 mg/L Al), which exceeded the default 95% species protection TV (0.55 mg/L Al) and slightly exceeded the default 90% species protection TV (0.080 mg/L). Surface waters were also enriched in nitrogen, (N-total, $N\text{-}NO_X$ and $N\text{-}NH_3$), most likely due to current and historic unrestricted cattle access to the creekline and evapo-concentration effects under recessional flow conditions.

- A total 19 microinvertebrate (zooplankton) taxa were recorded from surface waters at WARUS5 and WARUS6. Microinvertebrate groups included Protista, Rotifera, Copepoda and Ostracoda (seed shrimp). The composition of microinvertebrate fauna was somewhat atypical of that commonly recorded from tropical/sub-tropical freshwater systems, with Lecanidae comprising less than half the Rotifera taxa of WARUS6, and completely absent from WARUS5. Microinvertebrate taxa richness was significantly lower than wet season taxa richness recorded during previous similar

[1] Google Earth imagery – acquisition dates: 1/3/2004, 4/7/2004, 9/1/2005, 12/21/2006, 4/10/2012, 9/3/2013, 5/7/2015, 11/3/2015.

surveys of nearby Mungarathoona Creek (45 km south east of the current survey area) and Red Hill Creek (50 km south east), but was similar to dry season taxa richness in these creeks (WRM 2009, Pinder *et al.* 2010). Possible explanations for the low taxa richness recorded during May 2016, include fewer sites sampled on Warramboo Creek (two sites) compared to Mungarathoona (eight sites) and Red Hill (eight sites), low antecedent rainfall, and apparent lack of perennial waterbodies within the Warramboo Creek system. One microinvertebrate species listed for conservation significance, the calanoid copepod *Eodiaptomus lumholtzi* (IUCN **Vulnerable**), was recorded in low numbers at both sites. The conservation listing of this species is, however, considered in need of revision, as it is now 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 (WRM unpub. data).

- A total 25 hyporheic invertebrate taxa were recorded from WARUS5 and WARUS6, none of which were considered to be stygobitic (obligate groundwater inhabitants). The majority were stygoxene species (i.e. not specially adapted to groundwater environments). Approximately 20% were considered occasional hyporheic stygophiles (i.e. species that use the hyporheic zone seasonally or during early life history stages), and 12% possible hyporheic taxa. None of the taxa recorded are likely to be short range endemic (SRE) species. Taxa richness was higher than recorded during similar previous studies of Mungarathoona and Red Hill creeks. The absence of stygobitic species and low number of possible hyporheic species, suggests limited ground-surface water connectivity along Warramboo Creek within the survey area.

- A total 76 macroinvertebrate taxa were recorded from surface waters at WARUS5 and WARUS6. Faunal composition was typical of freshwater systems throughout the world, being dominated by Insecta, in particular Coleoptera (aquatic beetles) and Diptera (two-winged flies). Macroinvertebrate taxa richness was comparable to that recorded during previous studies of Mungarathoona and Red Hill creeks by WRM (2009), though species composition was significantly different. The naturally high temporal variability in invertebrate assemblages of dry tropical Australian rivers in general, is likely to be the main contributing factor to the observed differences in macroinvertebrate species assemblages between the current and WRM (2009) study. No macroinvertebrate species listed for conservation significant were collected.

- A total 20 invertebrate taxa emerged from the 11 rehydrated sediment samples, following 57 days of inundation. Taxa included Protista (flagellates and ciliates), Rotifera, Cladocera, Ostracoda, Turbellaria (flat worms), Anostraca (fairy shrimp) and Conchostraca (clam shrimp). Ciliates and ostracods were present in all rehydrated samples. No conservation significant invertebrate fauna emerged from rehydrated Warramboo Creek sediments. Average taxa richness was similar between sites upstream and downstream of the proposed discharge outlet location. The number of new emergents plateaued after approximately 22 days for the upstream sites (WARUS1, 3 to 6) and after 31 days for the downstream sites (WARDS1 to 6). Richness was higher than recorded during similar rehydration trials for Coolibah woodlands in the Marandoo area, where 11 taxa were recorded over a 47-day incubation period (WRM 2012). The taxa assemblage in Warramboo Creek sediments was also markedly different to sediments in the Coolibah woodlands. These differences possibly reflect differences in hydroperiod. Insecta were absent from Warramboo Creek rehydrated sediments, which may indicate that the length of time between periods of inundation is too long for survival of species that may otherwise persist as larvae by aestivating or encysting (e.g. Baetidae, Simuliidae, Ceratopogonidae, Chironomidae).

- Fish were not observed in the small (width 2 - 3 m), shallow (depth ~20 cm) remnant pools of WARUS5 or WARUS6. It is unknown whether fish may have been present in the larger pool at WARUS2 prior to the flood event, therefore their presence in Warramboo Creek cannot be entirely discounted.

It must be emphasised that this study provides a snapshot of water quality and aquatic faunal communities at a single point in time, and is unlikely to fully capture the range in temporal / seasonal variability within the survey area.

1 INTRODUCTION

1.1 Background

Robe River Mining Co. Pty Ltd (Robe) is proposing to undertake below water table (BWT) mining at the Mesa A / Warramboo deposits, in the Robe Valley area of the Pilbara region of Western Australia. The deposits are located approximately 38 km northwest of the existing Mesa J operations, 43 km west of Pannawonica town and 245 km by rail from the Cape Lambert port facilities (Figure 1). The Warramboo deposit has been mined above water table since 2012, in accordance with environmental approvals under Ministerial Statement 756, as part of the Mesa A / Warramboo Iron Ore Project. However, as part of the proposed BWT development, dewatering and discharge of any excess water are considered likely to be necessary, introducing a new environmental factor which potentially requires a referral to the EPA under Section 38 of the *Environmental Protection Act 1986* (EP Act). The proposed surplus water discharge location is the Warramboo Creek, via a single discharge point located between the old and new North West Coastal Highway (Figure 1). Current hydrological monitoring predicts the discharge footprint will range from 2.2 km to 7.6 km downstream of the proposed discharge location, depending on the discharge rate (maximum continuous discharge of 20 ML/day), before completely infiltrating/evaporating (Figure 1). Dewatering is anticipated to continue for approximately five years.

The Warramboo Creek catchment drains an area of approximately 685 km^2 and 70 km in length, flowing in a northerly direction. Climate factors such as sporadic rainfall, high temperatures and high evaporation rate in the Pilbara region, and apparent lack of groundwater contribution to surface water flow (RTIO 2015a), contribute to the highly ephemeral nature of Warramboo Creek. The catchment experiences high-velocity flash flooding following infrequent but intense cyclonic and monsoonal rainfall events, which combined with impervious ground conditions and infiltration excess, have carved out a well-defined main channel. One pool upstream of the proposed dewatering discharge point appears to hold water for longer periods, and water quality at this site has been monitored periodically by Robe.

The surplus water discharge volume and velocities modelled were considered to be significantly smaller than the volume and velocities generated by the catchment during flood events (RTIO 2015a). As such, channel erosion and overtopping of the creek banks as an impact of dewatering discharge is considered unlikely to occur. However, the permanent presence of water or changed flow regimes resulting from dewatering discharge can alter the ecological composition of aquatic-dependent species, particularly invertebrates which are adapted to intermittent flows (Bunn and Arthington 2002). Temporary waters in Australia may support species richness not unlike that found in more permanent streams, and tend to have a high degree of endemism (Lake *et al*. 1985, Boulton and Suter 1986, Davis *et al*. 1993, Pontin and Shiel 1995, Williams 1998, Williams 2002, Shiel *et al.* 2002). Initial data on groundwater quality indicate the water is brackish, so discharge may have an adverse effect on the freshwater fauna of the receiving creek. Groundwater also has the potential to have high concentrations of dissolved ions, metals and nutrients, which can impact fauna through loss of habitat (calcification of substrate), toxicity, and eutrophication (Bunn and Arthington 2002, WRM unpub. data). Additionally, the creation of a water source through dewatering discharge has the potential to attract cattle and feral herbivores, which contribute to increased eutrophication, erosion and sedimentation in the creek and riparian zone (Carwardine *et al.* 2014). These impacts are likely to be limited to the discharge footprint, predicted to be around 2.2 km to 7.6 km downstream of the proposed discharge location.

Astron Environmental Service Pty Ltd (Astron), on behalf of Robe, commissioned *Wetland Research & Management* (WRM) to design and conduct a baseline sampling program for aquatic ecosystems downstream and upstream of the Mesa A / Warramboo BWT development. The aim of the sampling program is to document current ecological condition, including the presence of any fauna of conservation and/or regional significance, and provide a benchmark against which any future effects of the Mesa A / Warramboo mine may be assessed.

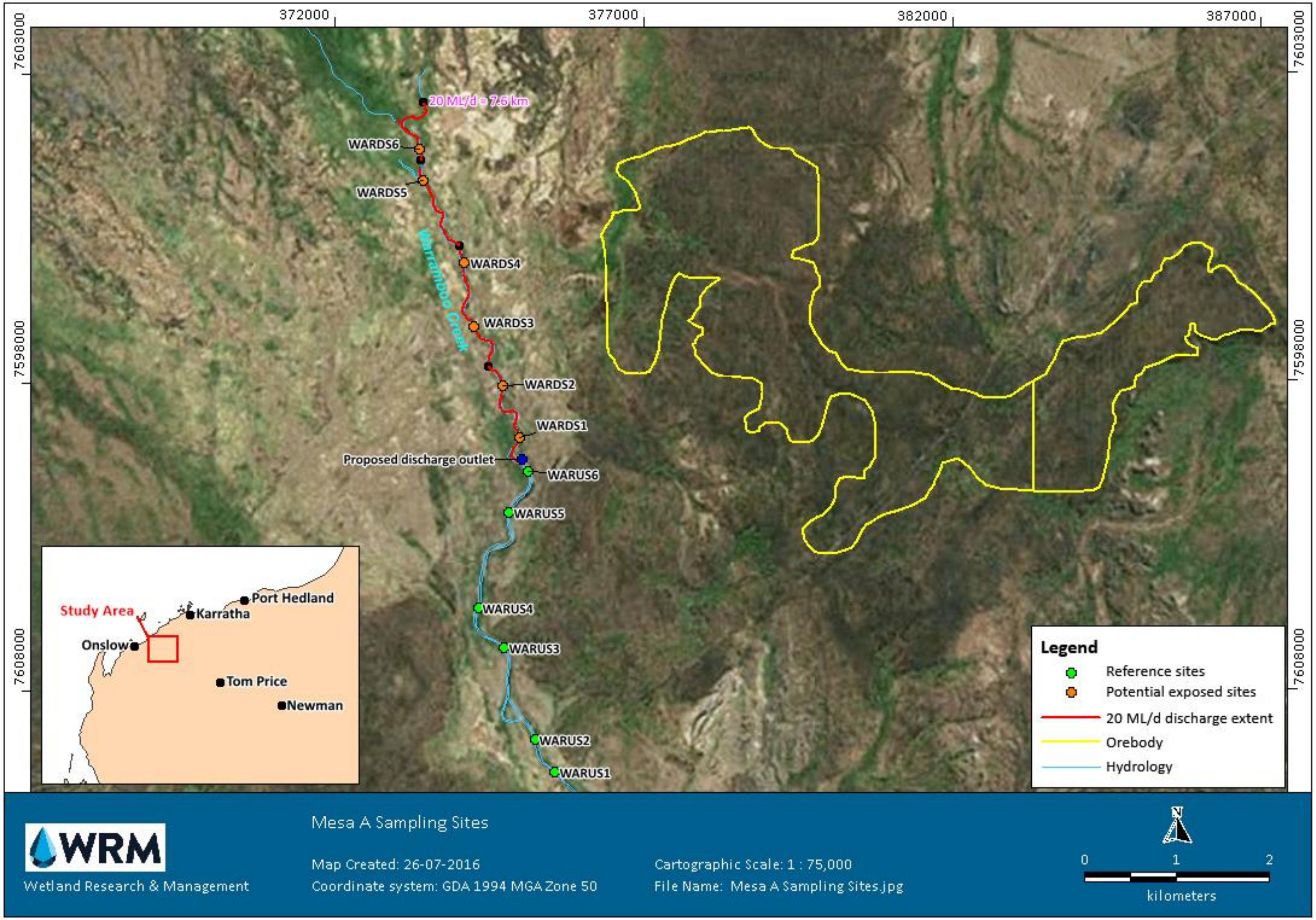

Figure 1. Baseline aquatic fauna and water quality sampling sites along Warramboo Creek in the Mesa A / Warramboo survey area, together with locations of the orebody, and the largest predicted discharge extent (20 ML/day scenario).

1.1.1 Rationale for sampling components of aquatic fauna

Microinvertebrates

Aquatic microinvertebrate fauna consists of microscopic fauna including micro-crustacea (ostracods, copepods and cladocera), protists and rotifers (nominally <53 µm in size). Microinvertebrate fauna are found in both permanent and ephemeral water bodies, and species representing all the groups listed above have strategies to survive periods of drought (Radzikowski 2013). 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).

Hyporheic fauna

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 and Boulton 1993, Coe 2001, Hose *et al.* 2005). The aquatic fauna of hyporheic zones is collectively referred to as hyporheos. Nearly all stygofauna are invertebrates (Gibert *et al.* 1994) and they are often classified into three broad categories according to their dependence on groundwater (Camacho 1992, Sket 2008). Stygobites spend their full life cycle in groundwater; stygophiles either have a life stage in epigean (surface) habitats or some of their populations occur in surface water; stygoxenes are facultative users of groundwater that are found mostly in epigean habitats (Halse *et al.* 2014).

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 short range endemic (SRE) as defined by Harvey (2002). 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 (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, Culicidae) (Horsfall 1956, Hinton 1960, Danks 1987), or produce desiccation-resistant propagules or eggs which hatch upon inundation (e.g. ciliates, rotifers, flatworms, nematodes, segmented worms and crustaceans) (Radzikowski 2013).

Sediment rehydration hatching trials

Watercourses in Australia, particularly ephemeral and seasonally-inundated creeks and wetlands, tend to support two broad groups of fauna; temporary residents and permanent residents. The former re-invade wetlands each time they fill, usually by aerial invasion directly as adult stages (i.e. beetles, water bugs) or by adults ovipositing in the wetland, and establishing a population following development of eggs (i.e. midges, dragonflies, damselflies, mosquitoes, beetles, mayflies) (Williams 1985, Boulton 1989). Permanent residents are always present in the wetland and survive dry periods through resistant life stages such as drought-resistant eggs (Towns 1985) or in extreme cases cryptobiosis where all life processes are halted until re-wetting (Hynes 1976, Beadle 1974). The eggs are dispersed across the wetland as it dries, and then survive in the dry sediments, to emerge as soon as the wetland refills (or water is added). Smith *et al.* (2004) suggested that the measurement of 'permanent' residents is an appropriate approach for assessing mine (and other impacts) in ephemeral systems. By re-hydrating samples of creek sediment in the laboratory it is possible to trigger the emergence of a proportion of these 'permanent' residents from their resistant stages, and thereby document this component of the aquatic invertebrate communities. Knowledge of the permanent residents provides an integrated measure of the creek over recent seasons/years.

Fish

Historically, fish diversity has been used worldwide as an indicator of ecosystem health (Oberdoff and Hughes 1992, Hugueny *et al.* 1996, An and Choi 2003). Because fish continually inhabit the receiving water, they integrate the chemical, physical and biological 'histories' of the river. 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.

1.1.2 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 EP Act. This includes freshwater turtles, frogs, fish and invertebrates (including hyporheic and stygal invertebrates). Hyporheic invertebrates (collectively referred to hyporheos) 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 referral and environmental impact assessment (EIA) of proposals and schemes likely, if implemented, to have a significant effect on the environment, are provided for under the EP Act. As part of the EIA process, the Act requires the Environmental Protection Authority of Western Australia (EPA) to provide what it considers to be the key environmental factors identified during the course of an assessment to the Minister for Environment (EPA 2013). Environmental factors and associated objectives are the EPA's basis for assessing whether a proposal or scheme's impact on the environment is acceptable (EPA 2013). In the most recent EPA Environmental Assessment Guideline (EAG) No. 12 (EPA 2013), two key environmental factors were detailed which relate to water resources:

i) Hydrological Processes - with the objective "to maintain the hydrological regimes of groundwater and surface water so that existing and potential uses, including ecosystem maintenance, are protected";

ii) Inland Waters Environmental Quality - with the objective "to maintain the quality of groundwater and surface water, sediment and biota so that the environmental values, both ecological and social, are protected".

Proponents are therefore required to provide baseline documentation relating to these two factors in order to determine whether they will be deemed key environmental factors for the project by the EPA (EPA 2013).

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). Many stygal invertebrates are also SREs. The EPA expects that environmental impact assessments will consider impacts on conservation of SRE species (EPA 2004).

The Department of Parks and Wildlife uses the International Union for Conservation of Nature (IUCN) Red List criteria for assigning species and communities to threat categories under the WC Act. Not all Western Australian species listed by the IUCN are also listed by the Department of Parks and Wildlife.

Objectives for the management of potential impacts on water-dependent ecosystems are also outlined in the Western Australian Department of Water 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. Aquatic invertebrates in particular, have historically been under-studied. 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 environmental impact assessment (EPA 2004).

The current baseline sampling constitutes a Level 1 survey for environmental impact assessment, as described under the State Environmental Protection Authority (EPA) 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.

1.1.3 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 on the federal Department of Agriculture website (www.agriculture.gov.au/water/quality/guidelines; last reviewed on 01 August 2016).

1.2 Scope of Works for Current Study

The scope of works for the current study was to establish baseline and future monitoring sites, and develop a robust dataset with which to determine future impacts, if any, of the Mesa A / Warramboo development. Specifically, the scope of work included:

- Identification of baseline and future riverine monitoring sites;
- Systematic sampling of aquatic fauna (fish, macroinvertebrates, hyporheic fauna), water quality (e.g. pH, EC, ions, nutrients, metals, TSS), and observations of turtle and frog species (if present);
- Collection of sediment samples from each site for rehydration in the laboratory to provide a species list of invertebrates which are prompted to emerge following seasonal inundation, as Warramboo Creek is a highly ephemeral system;
- Identification of all specimens to the lowest level possible;
- Determination of the conservation significance of all fauna, taking into account species listed as:
    - Threatened fauna under the IUCN Red List,
    - Threatened fauna under the EPBC Act (1999),
    - Scheduled fauna listed under the WA Wildlife Conservation (Rare Fauna) notice,
    - Priority fauna recognised by the Department of Parks and Wildlife (DPaW), and
    - Restricted or likely short-range endemic (SRE) species;
- Reporting water quality data against ANZECC/ARMCANZ (2000) guidelines.

2 SURVEY AREA

2.1 Climate

The proposed Mesa A / Warramboo survey area is located on the western edge of the Hamersley Ranges, approximately 150 km south-west of Karratha and 53 km south-west of Pannawonica. The 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; Figure 2) 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 (BOM 2016).

Prior to sampling in May 2016, total monthly rainfall was well below the 45-year average (Figure 2), particularly during February, March and April. As such, there was no surface water in Warramboo Creek at the time of sampling between 2nd and 6th May. However, on the final day of sampling, a major storm event on the 6th - 7th May lead to 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 (Figure 2).

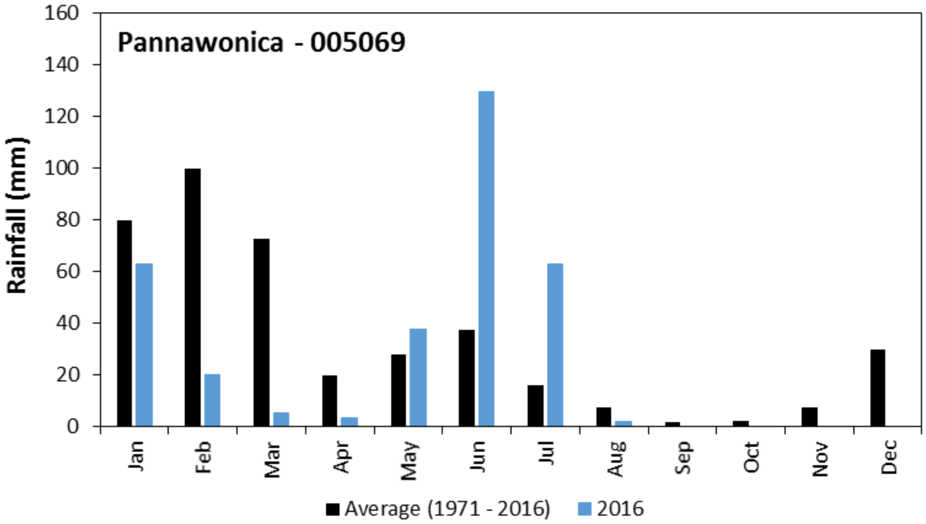

Figure 2. Average monthly rainfall (1971 – 2016) and total monthly rainfall (2016) for Bureau of Meteorology (BOM) Pannawonica Gauging Station (005069).

2.2 Hydrogeology

Warramboo Creek is located within the Onslow Coast River Region within the Pilbara-Gascoyne Topographic Drainage Division (RTIO 2015a). The catchment measures approximately 70 km in length with an equivalent uniform slope of 1.4 m/km, and drains approximately 685 km^2 in area. For the most part, the Warramboo Creek is well-defined before discharging into poorly defined scrubland in the coastal plain. Surface flow in Warramboo Creek is naturally ephemeral, typically only occurring in response to significant rainfall events and continuing for one to two months. It is likely that during large floods the poorly defined lower reaches of the Warramboo Creek in the coastal plain merge with the Robe River floodplain (Aquaterra 2005). There are no known permanent surface water pools in the immediate area of Warramboo (RTIO 2013a).

The nearest streamflow gauging station to Warramboo Creek is Yarraloola (707002), located on the Robe River adjacent to the North West Coastal Highway, approximately 15 km north-east of the proposed discharge location. However, the Robe River has a catchment area of 7,100 km^2, much greater than the Warramboo Creek catchment (685 km^2), and is thus unlikely to adequately represent the hydrologic regime of the survey area. The next closest streamflow gauging station is Toolunga (707005), located on Cane River, with a catchment area of 2,330 km^2, located 43 km south of the proposed discharge location. The Cane River catchment is believed to be more representative of the Warramboo Creek catchment, both physiographically and climatically (RTIO 2015a). The maximum total monthly river discharge for the period of record at Toolunga (1986 - 2014) was 194 GL (February 1995), and the maximum instantaneous discharge was 1,747 m^3/sec (February 1995) (DoW 2016). Mean annual runoff was 84 GL (RTIO 2015a). Although data from nearby Yarraloola and Toolunga stations could be used to infer frequency of flow in Warramboo Creek, the "patchy" occurrence of rainfall across the area means there is no certainty that rainfall events that trigger flow in the Robe or Cane rivers correspond to flow events in the Warramboo catchment, particularly for smaller events.

The Warramboo area of the Robe Valley is underlain by the Ashburton Formation, a very low permeability aquitard that serves as a basement for the palaeochannel aquifer (RTIO 2015b). The groundwater at Warramboo is stored within an unconfined aquifer comprised of the Robe Pisolite and the Yarraloola Conglomerate (RTIO 2013b, RTIO 2015b). Robe Pisolite is a pisolitic alluvial sedimentary rock that fills the broad valley between ridges of the Brockman Iron Formation and outcrops along the Robe palaeochannel (EPA 1991). The Yarraloola Conglomerate is comprised of angular to rounded pebble gravel, with minor beds of sand and clay (DoW 2010). The aquifer is particularly transmissive where the conglomerate underlies the pisolite within the Robe Valley palaeochannel. The water table in the area of Warramboo is between 12 and 30 metres below ground level. Recharge to the main aquifers is predominantly via direct infiltration from rainfall and indirectly during periods of high streamflow (RTIO 2015a).

3 REVIEW OF PREVIOUS AQUATIC FAUNA SURVEYS

Numerous aquatic surveys have been conducted in the Pilbara region (Dames & Moore 1975, Miles and Burbidge 1975, Taylor 1985, Masini and Walker 1989, Kay *et al.* 1999, Smith *et al.* 1999), however, the aquatic fauna of Warramboo Creek surface waters have not been surveyed previously. The most comprehensive surveys of aquatic fauna in the vicinity of the Mesa A / Warramboo development are those of Streamtec Pty Ltd (Streamtec) in association with The University of Western Australia (UWA) (Dobbs and Davies 2009, Streamtec/UWA 1996 - 2014). Since 1991, Streamtec / UWA have conducted annual sampling of Robe River pools, as part of long-term monitoring for the Mesa J Project area. Other recent aquatic fauna studies by WRM (2009) and Pinder *et al.* (2010) have featured a number of ephemeral, semi-permanent and permanent waterbodies within the vicinity of the Mesa A / Warramboo development, including pools along Mungarathoona Creek, Red Hill Creek (i.e. upper-Mungarathoona Creek, to the south-east) and Myannore Creek (to the north-west), and Yarraloola Station Claypan (to the north-west) (Figure 3). These studies, though generally conducted in more permanent waterbodies compared to the ephemeral Warramboo Creek, provide information on aquatic taxa present within 50 km of the Mesa A / Warramboo survey area, which also have the potential to reside in this previously unsampled system through various means of dispersal.

Additionally, stygofauna[2] have been sampled by Biota Environmental Sciences in the Mesa A / Warramboo survey area, including 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). Stygofauna were also surveyed by DPaW as part of the Pilbara Biological Survey (PBS), including five bores in the Yarraloola Station area, sampled between 2002 and 2005 (see Eberhard *et al*. 2009, Halse *et al.* 2014). These studies are included in this review, as groundwater dwelling fauna (stygofauna) can sometimes appear in surface waters, particularly during the wet season when connectivity between ground and surface waters is high.

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. Four sites were sampled along the Robe River; two upstream of the North-west Coastal Highway crossing point, near the Mesa H/J deposits, and two downstream of the Highway, just to the west of the Mesa A / Warramboo deposits (Morgan and Gill 2004).

Collectively, the above surveys have identified three taxa of conservation significance (i.e. IUCN Red List and/or DPaW Priority Fauna) which are known to occur within 50km of the Mesa A / Warramboo survey area, and therefore may reside within the potential discharge impact zone (Table 2). These are the Pilbara Emerald dragonfly (*Hemicordulia koomina*), Pilbara Pin damselfly (*Eurysticta coolawanyah*), and the Fortescue Grunter fish (*Leiopotherapon aheneus*). Additionally, there are a number of other regionally restricted invertebrate taxa, and/or invertebrate taxa of scientific interest, which have the potential to reside, either seasonally or permanently, within the potential impact zone.

A review of previous aquatic fauna surveys conducted within 50 km of the Mesa A / Warramboo survey area, including sites sampled, methods used, and notable fauna found, is presented in the following sections. A summary of the studies is provided in Table 1 and sampling locations shown in Figure 3.

[2] Fauna adapted to life in groundwater, often lacking eyes and pigmentation.

Table 1. Summary of previous recent aquatic fauna studies conducted within a 50 km radius of the Mesa A / Warramboo survey area. Stygofauna assessments appropriate to the survey area are also listed, together with methodologies. Codes for 'Fauna': 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)							
Robe River Mining Co. 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 & visual observation (mask & snorkel).	Species	Annually between Nov - Mar, 1991 - 2013.	Streamtec/UWA (1996, 1998, 2002, 2007-2009, 2011, 2014), Dobbs and Davies (2009)
Fish Fauna of Pilbara inland waters	Murdoch Uni	• Robe River near Mesas H & J, • Lower Robe River, west of Mesa A / Warramboo	Fish	• Fish – seine nets, gill nets, cast nets, rod & line, & visual observation (mask & snorkel).	Species	Once between Dec 2000 - Nov 2002.	Morgan and Gill (2004)
Pilbara Biological Study (PBS)	DPaW	Numerous sites throughout the Pilbara, but none within the Warramboo / Mesa A area. Sites sampled nearby (≤50 km) include: • Chalyarn Pool on Mungarathoona Creek (25 km east of the survey area) • Myanore Pool (30 km north) • Red Hill Creek (30 km east) • Yarraloola Claypan (32 km north-west) • House Pool on the Cane River (44 km south-west)	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)
Australian Premium Iron (API) West Pilbara Iron Ore Project (WPIOP) Baseline Aquatic Fauna Survey	WRM	• 2 sites on Mungarathoona Creek (45 km SE), • 6 sites on Red Hill Creek (50 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 & gill nets.	Species	Dec 2008, Apr 2009.	WRM (2009)
Stygofauna							
Pilbara Biological Study (PBS)	DPaW	• 36 bores across the Robe River catchment, including 5 bores in the Yarraloola Station area (30 km W)	Stygo	• Replicate hauls with weighted plankton nets (50 µm & 150 µm mesh).	Species	3 wet & 3 dry season occasions 2002 - 2005.	Eberhard *et al.* (2009), Halse *et al.* (2014)
Robe River Mining Co. Pty Ltd Mesa A / Warramboo Baseline Stygofauna Assessment	Biota	• 21 bores within the Warramboo area, Robe River catchment • 20 bores within the Yarraloola area, Robe River catchment	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 SE)	Stygo	• Hauls with weighted plankton nets (70 µm mesh).	Species	Jun 2008, Sep 2009.	Biota (2010)

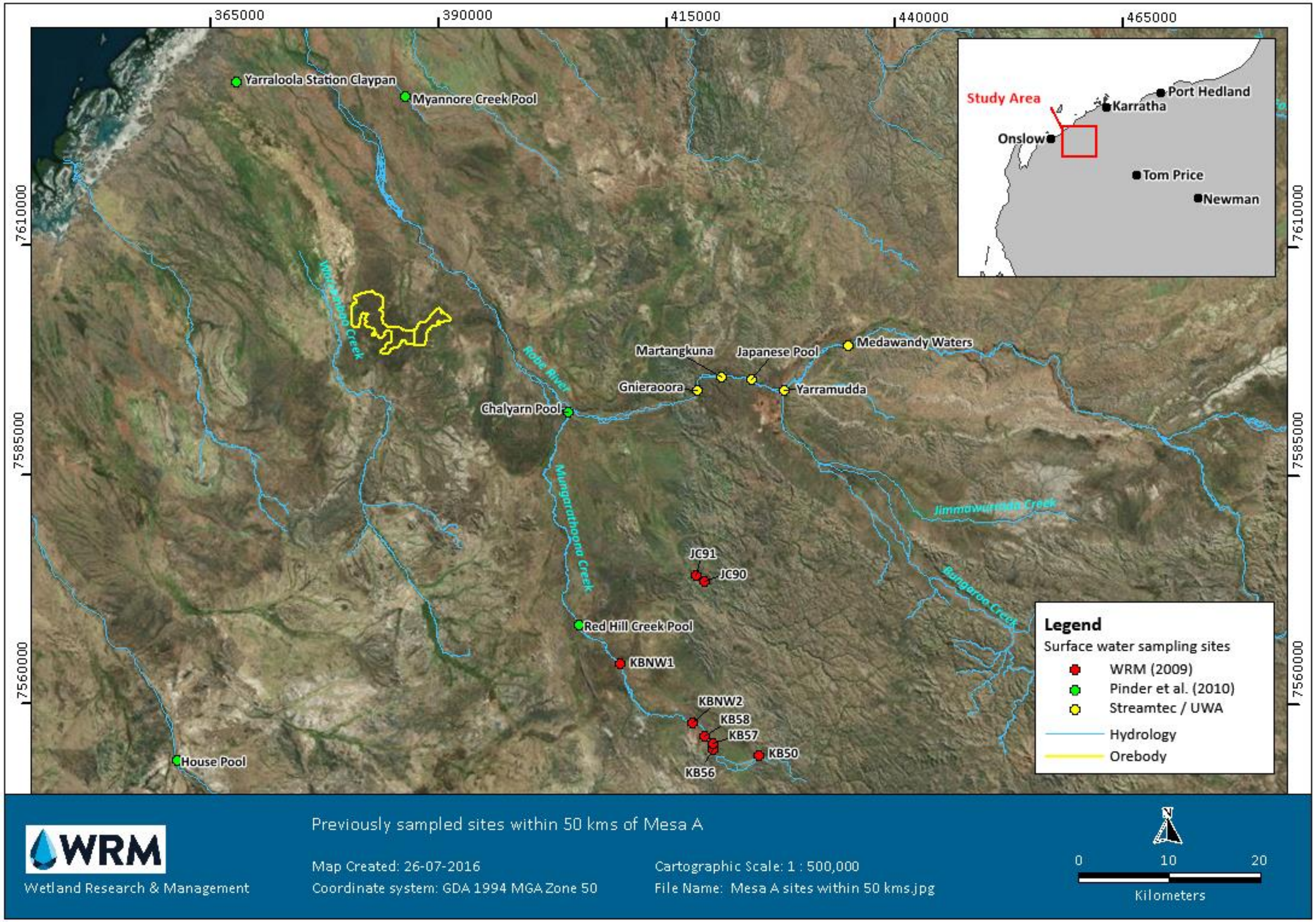

Figure 3. Summary of surface water sites surveyed previously for aquatic fauna within 50 km of the Mesa A / Warramboo survey area by Streamtec/UWA (1991 – 2014), WRM 2009 and Pinder *et al.* 2010. NB: Groundwater bores sampled for stygofauna by Biota (2006a, 2010) are not included. Morgan and Gill (2004) did not provide GPS co-ordinates for their study of Robe River fish fauna.

3.1 Microinvertebrates

The microinvertebrate fauna in the vicinity of the Mesa A / Warramboo survey area is poorly known. Microinvertebrates were sampled at five sites within 50 km of the survey area during the Pilbara Biological Survey (PBS); an extensive, Pilbara-wide aquatic fauna survey conducted by DPaW between 2003 and 2006 (Pinder *et al.* 2010). These included Chalyarn Pool on Mungarathoona Creek (25 km to the east of the survey area), along with pools along Red Hill Creek (30 km to the east) and Myanore Creek Pool (30 km to the north), Yarraloola Station Claypan (32 km to the north-west), and House Pool on the Cane River (44 km to the south-west). A total of 145 microinvertebrate taxa were recorded from these sites with higher taxa richness recorded at all sites during the wet season compared to the dry (Pinder *et al.* 2010). These sites were able to be sampled during the sry season and were classed as clear river pools (Chalyarn Pool, House Pool and Red Hill Creek), or turbid pools/claypans (Myanore Creek Pool and Yarraloola Station Claypan) and are thus likely to represent environmental conditions which differ from those producing the small, fresh ephemeral pools at Warramboo Creek.

Microinvertebrates from Mungarathoona Creek (two sites adjacent to the Jewel Cochrane development, approximately 45 km to the south-east of the survey area) and Red Hill Creek (six sites adjacent to the Ken's Bore development, approximately 50 km south-east of the survey area) were sampled by WRM as part of baseline aquatic surveys for Australian Premium Iron (API)'s West Pilbara Iron Ore Project (WPIOP) (WRM 2009). A total of 135 microinvertebrate taxa were recorded by WRM across two sampling events, conducted in December 2008 and April 2009 (WRM 2009).

In both the Pinder *et al*. (2010) and WRM (2009) studies, microinvertebrate fauna was found to be generally typical of tropical/sub-tropical systems (e.g. Koste and Shiel 1983, Tait *et al.* 1984, Smirnov and De Meester 1996, Segers *et al*. 2004). For example, in the four PBS sites in focus for the current study, Brachionidae within the Rotifera were relatively poorly represented (35 taxa). This family tends to dominate temperate rotifer plankton, but is sub-dominant to Lecanidae in tropical waters, as was the case at these PBS sites (63 taxa; Pinder *et al.* 2010).

Microinvertebrate fauna of note from these studies (i.e. of conservation or scientific value) included the stygal ostracod *Vestalenula matildae,* the rotifer *Lecane noobijupi* and the cyclopoid copepod *Paracyclops* sp. 6. Both *Vestalenula matildae* and *Paracyclops* sp. 6 were recorded at Chalyarn Pool during the PBS, and *Lecane noobijupi* was recorded from Red Hill Creek during the WRM (2009) study.

The Pilbara endemic ostracod *Vestalenula matildae* was recorded at Mungarathoona Creek (Chalyarn Pool) during the PBS (Pinder *et al*. 2010). *V. matildae* is a recently described stygal[3] species known from groundwater environments (bores and wells) of the Ashburton River catchment (Government Well, Divide Well), DeGrey River catchment (Kylena Well, Home Well), and Sherlock River (Muorena Well); the hyporheic zone of the Ashburton (Yindabiddy Pool) and Fortescue River catchments (Weeli Wolli Spring); and, surface waters of the Ashburton (Horrigans Pool), Fortescue (Gregory Gorge) and DeGrey (Martens and Rosetti 2002, Halse *et al*. 2002, Pinder *et al.* 2010, Schön *et al*. 2010).

Paracyclops sp. 6 is a cyclopoid copepod restricted to the Pilbara (Pilbara endemic), and was also collected from Chalyarn Pool during the PBS (Pinder *et al*. 2010). This species is known from at least 20 locations across the Pilbara region, including the Ashburton River (Bobswim Pool, Fork Spring, Whiskey Pool, Cheela Spring, Paperbark Spring, and Innawally Pool), Fortescue River (Palm Pool, Gregory Gorge, Palm Spring near Millstream and Joffre Creek), DeGrey River (Pelican Pool, Glen Herring Pool, Chinaman Spring, Minigarra Creek pools, Skull Springs and Bonnie Pool), Harding River (Springs Creek and Harding River Pool) and Sherlock River (Pinder *et al.* 2010, WRM unpub. data).

[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).

The rotifer *Lecane noobijupi* was collected from Red Hill Creek in December 2009 (WRM 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). However, the authors have since recorded *Lecane noobijupi* from a number of locations in the Pilbara region, including Weeli Wolli Creek, Marillana Creek, Coondiner Creek, Mindy Mindy Creek, Kalgan Creek and Un-named Creek (WRM unpub. data), as well as the DeGrey River during the PBS (Pinder *et al.* 2010). It would now appear that the Pilbara may be the normal locality of this species, with the Muir location in the south-west being an isolated occurrence.

Microinvertebrates are an important aspect of aquatic fauna sampling for Warramboo Creek, given the limited knowledge of microinvertebrate taxa in the region, and the ongoing potential for the discovery of new species.

3.2 Hyporheic Fauna

Hyporheic fauna was not sampled by Streamtec / UWA during their long-term study of Robe River pools upstream, nor during the PBS (Pinder *et al.* 2010). However, WRM (2009) sampled the hyporheic zones of Mungarathoona Creek and Red Hill Creek in 2008/2009 during baseline surveys for the Australian Premium Iron (API) West Pilbara Iron Ore Project (WPIOP). A total of 45 hyporheic fauna were recorded in the survey, including the stygal amphipod Paramelitidae sp. (WRM 2009). Specimens of Paramelitidae sp. were not able to be identified further than family due to immaturity and/or damage. However, they were likely to be SREs, given that stygal species of Paramelitidae have generally been found to be restricted to river systems in close proximity, with different species occurring in different areas.

Biota (2006a) sampled stygofauna from 41 bores within the Mesa A / Warramboo survey 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 two new stygal amphipod species from the bores within the Mesa A / Warramboo survey area, Melitidae sp. A and Melitidae sp. F, which are known only from the survey area (Biota 2006a).

Halse *et al.* (2014) sampled a total of 507 wells and drill holes across the Pilbara between 2002 and 2005, including 36 within the Robe River catchment area (within 50km of Warramboo Creek). A total of 110 stygal invertebrate taxa were recorded from these bores, including taxa belonging to the groups Oligochaeta (segmented worms), Polychaeta (bristle worms), Nematoda (round worms), Turbellaria (flat worms), Gastropoda (snails), Acarina (mites), Rotifera, Copepoda, Isopoda, Ostracoda, Amphipoda, Syncarida and Themosbaenacea (*H. tulki*). 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).

Knott and Halse (1999) identified the SRE isopod *Pilbarophreatoicus platyarthricus* from the Robe River (including Chalyarn Pool), which was 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). Keable and Wilson (2003) also suggested that a species of undescribed SRE isopod (*Pygolabis* sp.) also occurs in the subsurface zone of the Robe River catchment, although the specific locality of this species was not disclosed. All species of *Pygolabis* appear to be restricted to groundwaters and / or hyporheic zones of one or several creek drainages of the Pilbara region; the Fortescue, Ashburton or Robe River catchments (Keable and Wilson 2003).

Although WRM (2009) did not encounter either *Pilbarophreatoicus platyarthricus* or *Pygolabis* sp. in the hyporheos of Red Hill Creek or Mungarathoona Creek, Biota (2010) recorded both isopod taxa from groundwater bores within API's WPIOP development area, southeast of the current survey area. Biota (2010) also captured a number of Melitidae amphipods (*Nedsia* spp. and nr *Norcapensis* sp.), as well as Paramelitidae amphipods, (*Pilbarus* nr *millsi*, Paramelitidae sp. 2 and sp. 6), other isopods (*Haptolana yarraloola*, *Kagalana tonde*) and syncarids (*Bathynella* spp., *Billibathynella* sp., *Hexabathynella* sp. and *Notobathynella sp.*).

It is possible that hyporheic sampling in Warramboo Creek may reveal the presence of a number of stygal/SRE taxa. However, the likelihood of this is considered to be low, given there appears to be little to no connectivity between the surface waters of Warramboo Creek and the underlying aquifer (the water table in the area of Warramboo is between 12 and 30 metres below ground level) (RTIO 2015a).

3.3 Macroinvertebrates

A number of permanent and ephemeral pools within a 50 km radius of Warramboo Creek have been previously sampled for macroinvertebrate taxa. The macroinvertebrate fauna of Mungarathoona Creek (Chalyarn Pool), Red Hill Creek, House Pool on the Cane River, Myannore Creek Pool and the Yarraloola Station claypan were sampled during the PBS (Pinder *et al.* 2010). A total of 279 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 sample was collected at House Pool, with 103 taxa collected in the wet and dry season of 2004 (Pinder *et al.* 2010).

Macroinvertebrates from Mungarathoona Creek and Red Hill Creek were also sampled by WRM 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; December 2008 (dry season) and April 2009 (wet season) (WRM 2009). The taxonomic list comprised Nematoda (round worms), Hydrozoa (freshwater hydra), Oligochaeta (aquatic segmented worms), Gastropoda (freshwater snails), Arachnida (water mites), Ephemeroptera (mayflies), Odonata (dragonflies and damselflies), Hemiptera (true bugs), Coleoptera (aquatic beetles), Diptera (aquatic fly larvae), Trichoptera (caddisflies) and Lepidoptera (aquatic caterpillars).

Since 1991, Streamtec / UWA have conducted annual sampling for macroinvertebrates at five pools along the Robe River approximately 45 km east of Mesa A / Warramboo; Medawandy Waters, Yarramudda, Japanese Pool, Martangkuna and Gnieraoora. 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 Trichoptera (caddisflies) 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 composition of macroinvertebrate taxa from each of these sites was typical of freshwater systems throughout the world (Hynes 1970), being dominated by Insecta, within which Diptera and Coleoptera were particularly well represented (Streamtec / UWA, WRM 2009, Pinder *et al.* 2010, WRM 2011).

Of the macroinvertebrate fauna recorded during studies in the vicinity (<50 km) of the Mesa A/ Warramboo survey area (Streamtec / UWA, WRM 2009, Pinder *et al.* 2010), two species are listed for conservation significance (IUCN Redlist), and nine are endemic to the Pilbara region, and/or are relatively new to science. These species, with their known dispersal capabilities (i.e. with winged-adult forms with strong capacity for flight), have the potential to occur within the modelled discharge zone in Warramboo Creek:

IUCN Redlist species:

- *Hemicordulia koomina* (dragonfly);
- *Eurysticta coolawanyah* (damselfly).

Pilbara endemic taxa with restricted distributions:

- *Ictinogomphus dobsoni* (dragonfly);
- *Nannophlebia injibandi* (dragonfly);
- *Agriocnemis kunjina* (damselfly);
- *Sternopriscus pilbaraensis* (dytiscid beetle);
- *Tiporus lachlani* (dytiscid beetle);
- *Tiporus tambreyi* (dytiscid beetle);
- *Laccobius billi* (hydrophilid beetle);
- *Haliplus pinderi* (haliplid beetle);
- *Haliplus pilbaraensis* (haliplid beetle);
- *Haliplus halsei* (haliplid beetle).

The Pilbara Emerald dragonfly, *Hemicordulia koomina* (Plate 1), has been recorded at multiple locations within a 50 km radius of Warramboo Creek; at Red Hill Creek and House Pool on the Cane River (Pinder *et al.* 2010). This species is listed as **Near Threatened** on the IUCN Redlist (IUCN 2016). However, revision of its listing is considered necessary given its more recent collection from a number of localities across a range greater than 500 km^2, including sites in the Fortescue River system (Hamersley Gorge and Fortescue Falls in Karijini National Park, and Kalgan Pool on Kalgan Creek), the DeGrey River (Bamboo Springs and Minigarra Creek pools at Woodie Woodie), Ashburton River system (Moreton Pool, Creek Pool near Mt Amy, Henry River pools, and Pool at Gorge Junction), Sherlock River (Pool Spring), and the Shaw River (Panorama Spring) (Pinder *et al.* 2010). Despite this, it is still considered rare, as it is infrequently collected and rarely recorded. The major threat to this species is considered to be loss of habitat (i.e. drying of pools/waterways) through groundwater abstraction (Hawking 2009b).

The Pilbara Pin damselfly, *Eurysticta coolawanyah* (Plate 1), is restricted to the Pilbara region, where it prefers riverine pools. Within 50 km of Warramboo Creek, this species has been recorded from Chalyarn Pool, and Red Hill Creek (Pinder *et al.* 2010). This species is listed as **Near Threatened** on the IUCN Redlist (IUCN 2016), based on its restricted distribution to an area of less than 500 km^2, and as it was 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. *E. coolawanyah* is known to inhabit riverine pools of the Pilbara region (Theischinger and Hawking 2006). WRM have 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 mine dewatering discharge operations.

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). Given their proficient dispersal capabilities, and the record of these species at multiple locations within close proximity to the survey area (including Mungarathoona Creek), it is considered likely that macroinvertebrate sampling could reveal the presence of one or both of *E. coolawanyah* or *H. koomina* within the survey area.

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 River, Robe River, Ashburton River, Yule River, DeGrey River, and Sherlock River (CSIRO 2015, DEC 2009, Pinder *et al*. 2010). Near Warramboo Creek, *I. dobsoni* has been recorded at Chalyarn Pool and Red Hill Creek (Pinder *et al.* 2010), and pools along the Robe River (Dobbs and Davies 2009).

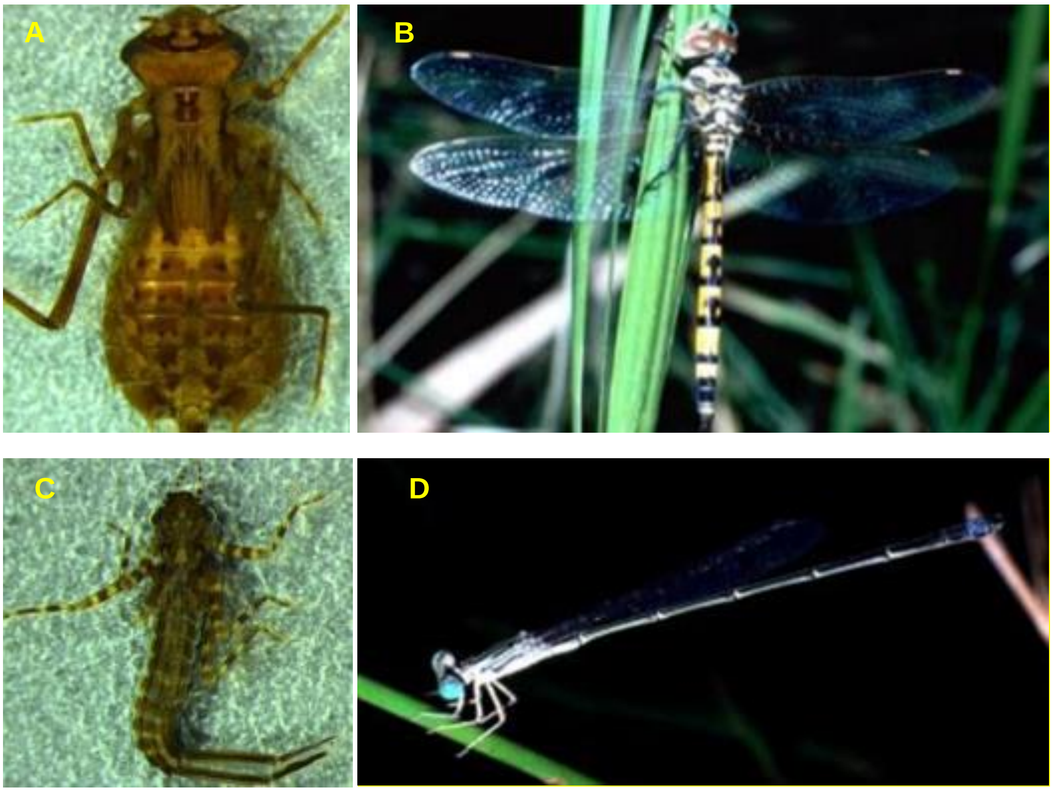

Plate 1. (A) Larval Pilbara emerald dragonly, *Hemicordulia koomina*, (B) adult *H. koomina*, (C) larval Pilbara pin damselfly, *Eurysticta coolawanyah*, and (D) adult *E. coolawanyah* (larval photos by WRM © and adult photos taken and provided by Jan Taylor ©). NB: larval stages of all dragonflies and damselflies are aquatic.

The Pilbara Archtail dragonfly *Nannophlebia injibandi*, is also restricted to the Pilbara region. This species was recorded infrequently during the PBS (Millstream Delta and Gregory Gorge in the Fortescue River catchment; Pinder *et al.* 2010). Within the vicinity of Warramboo Creek, *N. injibandi* was recorded from Robe River pools (Streamtec / UWA), and at one Red Hill Creek site during the WPIOP baseline surveys (WRM 2009).

The Pilbara Wisp damselfly, *Agriocnemis kunjina,* is a Pilbara endemic rarely encountered. It is known from Millstream, Harding River and Tanberry Creek (ANIC Database), however it was not recorded during the PBS (Pinder *et al.* 2010). *Agriocnemis kunjina* is known from both still and flowing waters (Theischinger and Hawking 2006), and has been recorded at Robe River pools by Streamtec / UWA).

While the dytiscid (diving) beetle *Sternopriscus pilbaraensis* is endemic to the Pilbara, it is fairly commonly collected and known from a range of systems, including 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). In previous macroinvertebrate surveys near the survey area, *S. pilbaraensis* has been recorded from Red Hill Creek (Pinder *et al*. 2010).

Of the two remaining Pilbara endemic dytiscid beetles, *Tiporus tambreyi* is commonly collected and widespread across the region (Pinder *et al.* 2010, WRM unpub. data). *T. lachlani* is also widespread across the region, though more infrequently collected than its congener (Pinder *et al.* 2010, WRM unpub. data). *T. tambreyi* has been recorded from a variety of locations within close proximity to the survey area, including Chalyarn Pool (Pinder *et al.* 2010), Robe River pools upstream (Streamtec / UWA) and Red Hill Creek (WRM 2009, Pinder *et al.* 2010). Comparatively, the more infrequently collected *T. lachlani* has only been previously recorded from Red Hill Creek (Pinder *et al.* 2010).

The aquatic hydrophilid beetle *Laccobius billi* is a Pilbara endemic species that 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 recorded *L. billi* at Mungarathoona Creek during their 2008/2009 WPIOP surveys (WRM 2009). *L. billi* was also recorded at a number of Red Hill Creek sites further upstream (WRM 2009).

The haliplid beetles *Haliplus halsei*, *Haliplus pinderi* and *Haliplus pilbaraensis* are all endemic to the Pilbara region, and are relatively new to science, having only been recently described. 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). During the PBS, *H. halsei* was recorded at Chalyarn Pool and Myannore Creek, and *H*. *pinderi* was recorded at House Pool (Pinder *et al*. 2010), while *Haliplus pilbaraensis* was recorded from Red Hill Creek by WRM in April 2009 (WRM 2009).

3.4 Drought Resistant Fauna and Previous Sediment Rehydration Studies

Sediment rehydration studies have previously been conducted by the authors in the Pilbara region, but not within the vicinity of Warramboo Creek. However, it is relevant to this study to investigate which fauna have previously emerged from rehydrated Pilbara sediments. The closest sediment rehydration study was conducted on the Coolibah Woodlands, near Mount Bruce and Rio Tinto's Marandoo Mine (260 km south-east of Mesa A / Warramboo), in February 2012 over 31 days (WRM 2012). The samples were depauperate in invertebrate fauna, with less diversity and numbers emerging than expected (Dr Russell Shiel, University of Adelaide, pers. comm.). A total of 10 taxa micro- and macroinvertebrate were recorded, comprising of protists, rotifers, cladocerans, the notostracan (shield shrimp) *Triops australiensis australiensis* (Plate 2), and conchostracans (clam shrimp). The conchostracans recorded during the study, *Limnadopsis sp.* and *Eulimnadia sp.*, may have represented Pilbara endemic species. Although *Eulimnadia* and *Limnadopsis* appear to be widely distributed throughout Australia in ephemeral wetlands and clay pans their taxonomy has been under debate for some time (Sayce 1903, Webb and Bell 1979, Hoeh *et al.* 2006, Schwentner *et al.* 2009, Vanschoenwinkel *et al.* 2012, Dr Brian Timms, Newcastle University/Australian Museum, Sydney, pers. comm.). *Limnadopsis* is the only conchostracan genus endemic to Australia (Schwentner *et al.* 2009).

Five macroinvertebrate crustaceans considered to be ephemeral wetland specialists were recorded in the vicinity of the Mesa A / Warramboo survey area during the PBS (Pinder *et al*. 2010). These include *T. australiensis australiensis,* the conchostracans *Eocyzicus* sp. and *Caenestheriella packardi*, and the anostracans (fairy shrimp) *Branchinella halsei* and *Branchinella* nr *pinnata*. Out of 98 sites sampled across the Pilbara, *B.* nr *pinnata* was only collected from the Myanore Creek Pool (30 km north west of the Project), and *B. halsei* was only recorded from Yarraloola Claypan and Cane River Claypan (70 km west of the project). *C. packardi* (40 records), *Eocyzicus* sp. (21 records), and *T. australiensis australiensis* (11 records) were widespread across the Pilbara Region, though appeared to be restricted to seasonally inundated claypans and turbid pools. It is thought that turbidity facilitates the occurrence of macroinvertebrate crustaceans such as *Branchinella* and *Triops* that would otherwise be prone to predation by waterbirds, although ephemerality frequently eliminates fish which would also predate on such invertebrates (Pinder *et al*. 2010).

T. australiensis australiensis is endemic to mainland Australia where it is only known from systems which periodically dry, as it requires a period of desiccation for eggs to undergo development and completion of its life cycle (Williams 1968, Williams 1980, Williams and Busby 1991, Tyler *et al*. 1996). *T. australiensis australiensis* has been known to disappear from systems that remain inundated for a longer period of time (Gooderham and Tsyrlin 2002). Eggs of *Triops* are highly resistant to desiccation and, being very small, they are easily transported by the wind and other dispersal agents. Notostraca are among the most primitive of all living Crustacea, as their external morphology has remained unchanged since the Triassic period, approximately 200 million years ago, and are often referred to as 'living fossils' (Fisher 1990, Suno-Uchi *et al.* 1997, King and Hanner 1998).

Plate 2. *Triops australiensis australiensis*. Photograph by WRM ©.

Although *T. australiensis australiensis* are widely distributed, they are not commonly collected/encountered due to their very specific habitat requirements. Of the 98 sites sampled by the Department of Environment and Conservation during the Pilbara Biological Survey, only ten supported *T. australiensis australiensis*, and all of these were ephemeral wetlands and claypans. The taxonomy of *Triops* is still under debate, principally because morphological taxonomy is complicated by high phenotypic variation within, and low variability among, nominal species (Vanschoenwinkel *et al.* 2012). A recent phylogenetic analysis of *Triops* collected worldwide found that the grouping of Australian *Triops* into a single species may be unjustified (Vanschoenwinkel *et al.* 2012). The *T. australiensis australiensis* clade was found to comprise a number of monophyletic groups and halotypes endemic to specific localities, with distinct lineages were recorded from rock pools on granite outcrops, in comparison to clay pans (Vanschoenwinkel *et al.* 2012).

Fairy shrimp of the genus *Branchinella* are known to occur in temporary freshwaters such as pools, ditches, rockholes, ponds and claypans (Williams 1980). At least eight species of *Branchinella* are known from ephemeral waterbodies in the Pilbara, including *Branchinella affinis*, *Branchinella australiensis*, *Branchinella lyrifera*, *Branchinella occidentalis*, *Branchinella proboscida*, *Branchinella halsei*, *Branchinella mcraeae* and *Branchinella pinderi* (Pinder *et al*. 2010). Williams (1980) suggests that individual species tend to be locally restricted.

3.5 Fish

The fish fauna of the Pilbara region is unique, with 13 freshwater species of fish being recorded to date, including catadromous[4] species (Allen *et al.* 2002, Morgan and Gill 2004). Of the freshwater species recorded to date, three (or possibly four) are considered endemic to the region. These include the Golden Gudgeon (*Hypseleotris aurea*), the Murchison River Hardyhead (*Craterocephalus cuneiceps*), an undescribed member of the Plotosidae (eel-tailed catfish), *Neosilurus* sp.[5], and the Fortescue Grunter (*Leiopotherapon aheneus*) (Morgan and Gill 2004). *L. aheneus* (Plate 3) is currently listed on the IUCN Red List of Threatened Species as **Lower Risk/Near Threatened** (IUCN 2016), and as a **Priority 4 (P4)**[6] Species on the Department of Parks and Wildlife (DPaW) Priority Fauna List (DPaW 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 reasonably common within its range, and has been recorded from sites within 50 km of the Mesa A / Warramboo survey area, including the Robe River (Allen *et al.* 2002,

[4] Catadromous fishes live in freshwater as juveniles or sub-adults, but migrate to marine habitats to spawn.
[5] 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.).
[6] P4 species are those with limited distributions "in need of monitoring" (DPaW 2016).

Morgan and Gill 2004, Antao and Braimbridge 2010, Streamtec / UWA) and associated tributaries Mungarathoona Creek (WRM 2009), and Red Hill Creek (WRM 2009).

Streamtec / UWA recorded six freshwater fish species from Robe River pools approximately 40 km east of the survey area, including the western rainbowfish *Melanotaenia australis*, the Spangled Perch *Leiopotherapon unicolor,* the Pilbara Tandan (eel-tailed catfish) *Neosilurus* sp*.,* the Barred Grunter *Amniataba percoides,* the Bony Bream *Nematolosa erebi*, and the conservation listed Fortescue Grunter *L. aheneus.*

Plate 3. Fortescue grunter *Leiopotherapon aheneus.* Photograph by Chris Hofmeester/ WRM ©.

Additionally, Streamtec / UWA recorded four fish species with marine vagrant/estuarine origins, including Ox-eye Herring *Megalops cyprinoides,* Striped Butterfish *Selenotoca multifasciata,* Threadfin Silver-biddy *Gerres filamentosus* and Mangrove Jack *Lutjanus argentimaculatus.* A fifth estuarine fish species is known from the lower Robe River system, the Banded Scat *Scatophagus multifacsicatus* (DoW 2010). Morgan and Gill (2004) also surveyed four Robe River sites for fish, recording six freshwater species (Western Rainbowfish, Spangled Perch, Pilbara Tandan, Barred Grunter, Bony Bream and Fortescue Grunter). Additionally, Morgan and Gill (2004) noted that the Western Australian Museum (WAM) had previously documented the Empire Gudgeon *Hypseleotris compressus* from a single Robe River location, just upstream of the Mesa B/C deposits. During WPIOP baseline surveys in 2008/2009, WRM encountered five freshwater fish species from two sites on Mungarathoona Creek, including Western Rainbowfish, Spangled Perch, Pilbara Tandan, Barred Grunter and Fortescue Grunter (WRM 2009).

The fish fauna of the Pilbara is characterised by low species diversity and high levels of endemicity; over 42% of species recorded are restricted to the region (Unmack 2001, Allen *et al.* 2002). Some fish species are adapted to the extreme conditions of the Pilbara region, and many have strategies for surviving drought (Unmack 2001). For example, Australia's most widespread native fish, the Spangled Perch, is thought to aestivate in wet mud or under moist leaf litter in ephemeral waterbodies during periods of drought (Allen *et al.* 2002). The reproductive strategies of 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).

The Fortescue Grunter, and other species of fish, are unlikely to currently reside within Warramboo Creek, as no permanent pools are known to exist in the Warramboo catchment. It is also highly unlikely fish could migrate to Warramboo Creek from permanent pools in the nearby Robe River catchment during flooding, as Warramboo Creek and the Robe River do not appear to share any drainage lines on the coastal plains. A large pool upstream of the proposed discharge point (Rio Tinto water quality monitoring site WBOO15001, aquatic fauna survey site WARUS2) may persist for longer during the dry season and support fish, but it has not yet been surveyed for their presence. Given the ephemeral nature of Warramboo Creek and the isolation from nearby systems with permanent pools, it is highly unlikely fish are present in this pool, unless they have been artificially introduced.

3.6 Other Fauna

3.6.1 Turtles

Warramboo Creek has not been previously surveyed for turtles, though they have been recorded from several systems within a 50 km radius of the survey area. The native Flat-shelled Turtle, *Chelodina steindachneri,* has a widespread distribution throughout the Pilbara and Gascoyne regions of Western Australia (Kuchling 1988), and is not listed for conservation significance. These turtles are adapted to survive drought by burrowing into the dried-up 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 for the Mesa J Project area. 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, including highly ephemeral creeks (WRM 2013), it is possible that *Chelodina steindachneri* may reside in the current survey area.

3.6.2 Frogs

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 Mesa A / Warramboo survey 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 (2006b) recorded two species of Hylidae (tree frogs) – *Litoria rubella* and *Cyclorana maini* - and one Myobatrachidae (Southern Frog) species *Uperoleia russelli* during baseline surveys for the survey 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.

The Pilbara region is host to 13 species of frogs, three of which are endemic to the Pilbara 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 of conservation significance (IUCN Redlist, DPaW Threatened and Priority Fauna), 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). In addition, the Pilbara, Gascoyne and Murchison populations of *L. 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, 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).

3.7 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. Summary of aquatic species (including hyporheic species) of conservation and/or scientific value know to occur, or likely to occur within the Mesa A / Warramboo survey area.

Species	Common name	Conservation / Scientific value	Occurrence within 50 km of suvey area	Likelihood of occurrence within survey area	Occurrence elsewhere
Microinvertebrates					
Lecane noobjupi	Rotifer	WA endemic	Red Hill Creek, Nyeetbury Spring	Moderate	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	Chalyarn Pool	Moderate	20+ locations Pilbara-wide.
Vestalenula matildae	Ostracod (micro-crustacean)	Pilbara endemic	Chalyarn Pool	Moderate	Various systems of the Ashburton R., DeGrey R., Fortescue R. and Sherlock R..
Hyporheos					
Paramelitidae sp.	Stygal amphipods	Stygal SRE	Red Hill Ck, Mungarathoona Ck, Yalleen Pool	Low-Moderate	Unknown given family level identification.
Melitidae spp.	Stygal amphipod	Stygal SRE	Bores in the Robe River catchment area	Low-Moderate	Unknown given family level identification.
Pygolabis sp.	Stygal isopod	Stygal SRE	One undescribed species known from the Robe River.	Low-Moderate	Uncertain. Members of this genus restricted to either Fortescue, Ashburton or Robe catchments.
Pilbarophreatoicus platyarthricus	Stygal isopod	Stygal SRE	Chalyarn Pool	Moderate	Nyeetbury Spring; Robe River catchment.
Haptolana yarraloola	Stygal isopod	Stygal SRE	Bores in API's WPIOP area, Bores in Yarraloola area	Moderate	Recently described species; known only from bores in the Robe River catchment.
Kagalana tonde	Stygal isopod	Stygal SRE	Bores in API's WPIOP area	Low	Recently described genus and species; elsewhere known from Cane River and Hardey River catchments.
Bathynellidae/ Parabathynellidae spp.	Stygal syncarids	Stygal SREs	Bores in API's WPIOP area	High in ground-waters; Low-moderate in hyporheos	Unknown given genus level identification.
Macroinvertebrates					
Hemicordulia koomina	Pilbara emerald dragonfly	IUCN, **Near Threatened**	Robe River pools, Red Hill Ck.	High; known from Robe River pools near Mesa J	Fortescue R., Coondiner Ck; now known to be widespread throughout the Pilbara, though infrequently collected.
Eurysticta coolawanyah	Pilbara pin damselfly	IUCN, **Near Threatened**	Chalyarn Pool	High; known from Chalyarn Pool.	Ashburton R. (Bobswim Pool); Kalgan Ck; Coondiner Ck; Fortescue R; now known to be widespread throughout the Pilbara, though infrequently collected.
Ictinogomphus dobsoni	Pilbara tiger dragonfly	Pilbara endemic; restricted distribution	Chalyarn Pool, Robe River pools, Red Hill Ck.	High	Fortescue R.; Ashburton R.; Yule R.; DeGrey R.;Sherlock R.
Nannophlebia injibandi	Pilbara archtail dragonfly	Pilbara endemic; restricted distribution	Red Hill Ck	Low-Moderate	Fortescue R. catchment, but uncommonly collected.
Agriocnemis kunjina	Pilbara wisp damselfly	Pilbara endemic; restricted distribution	Robe River Pools.	Low-Moderate	Fortescue R.; Ashburton R.; Yule R.; DeGrey R.;Sherlock R., but uncommonly collected.

Species	Common name	Conservation / Scientific value	Occurrence within 50 km of suvey area	Likelihood of occurrence within survey area	Occurrence elsewhere
Haliplus halsei	Aquatic haliplid beetle	Pilbara endemic; relatively new to science	Chalyarn Pool, Myannore Ck.	High; known from Myannore Ck. and Chalyarn Pool.	Uncommonly collected from ephemeral systems and claypans, e.g. the Fortescue Marsh & Coondiner Pool.
Haliplus pilbaraensis	Aquatic haliplid beetle	Pilbara endemic; relatively new to science	Red Hill Ck.	Moderate	Uncommonly collected from ephemeral systems and claypans, e.g. the Fortescue Marsh & Coondiner Pool.
Haliplus pinderi	Aquatic haliplid beetle	Pilbara endemic; relatively new to science	House Pool on Cane River	Moderate	Uncommonly collected from ephemeral systems and claypans, e.g. the Fortescue Marsh & Coondiner Pool.
Stenopriscus pilbaraensis	Aquatic dytiscid beetle	Pilbara endemic; restricted distribution	Red Hill Ck.	Moderate	A range of systems across the Pilbara, fairly commonly collected.
Tiporus tambreyi	Aquatic dytiscid beetle	Pilbara endemic; restricted distribution	Chalyarn Pool, Robe River pools, Red Hill Ck.	Known from Chalyarn Pool on Mungarathoona Ck.	A range of systems across the Pilbara, very commonly collected.
Tiporus lachlani	Aquatic dytiscid beetle	Pilbara endemic; restricted distribution	Red Hill Ck.	Low-Moderate	A range of systems across the Pilbara, infrequently collected.
Laccobius billi	Aquatic hydrophilid beetle	Pilbara endemic; restricted distribution	Mungarathoona Ck., Red Hill Ck.	Moderate	Yule R.; Fortescue R.
Fish					
Leiopotherapon aheneus	Fortescue grunter	IUCN, **Near Threatened**; DPaW **Priority 4**	Mungarathoona Ck., Red Hill Ck., Robe River pools	Very low (likely dependent on permanent pool habitat).	Fortescue R. (below Fortescue Marsh); Ashburton R.

4 METHODS

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 Pty Ltd (Streamtec) and The University of Western Australia (UWA) surveys of fish and benthic macroinvertebrates of the Robe River, as part of long-term (1991-2016) monitoring for the Mesa J Project (see Dobbs and Davies 2009, Streamtec 2014);
- Department of 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 Department of 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.

4.3 Sampling Design and Sites

The sampling design is a mBACI (multiple Controls - Before/After - Control/Impact) type design (Keough and Mapstone 1995). Sites were selected to provide data for robust statistical analysis and to meet requirements of such a design. A mBACI design is considered ideal for impact assessment, as impacts may be placed in context with natural temporo-spatial catchment changes. A mBACI type design provides both benchmark information as well as a strong basis to detect future changes. Reference sites upstream of the proposed discharge location on Warramboo Creek were selected to serve as the "control" for potentially impacted sites. Surveys conducted in May 2016 are part of the benchmark or "before" phase against which to assess any future changes following mine development.

Sampling was conducted during the late wet season, between 2nd and 6th of May 2016. A total of 12 sites were visited along the main channel of Warramboo Creek, including six 'potential exposed' sites on Waramboo Creek downstream of the proposed discharge location, and six 'reference' sites located on Waramboo Creek upstream of the potential discharge, and likely outside any mining impact zones (Table 3 and Figure 1). These sites were selected as those most likely to contain suitable surface water pools for sampling, based on aerial imagery[7] of the creekline.

[7] Google Earth imagery – acquisition dates: 1/3/2004, 4/7/2004, 9/1/2005, 12/21/2006, 4/10/2012, 9/3/2013, 5/7/2015, 11/3/2015.

Table 3. Summary of aquatic ecosystem sampling sites on Warramboo Creek, including: site codes, descriptions, GPS co-ordinates, dates sampled, and checklist of samples collected (WQ = water quality, MACRO = macroinvertebrate, MICRO = microinvertebrate, HYPO = hyporheic invertebrate, and SEDIMENT = sediment rehydration sample), ✓ = collected, x = not collected.

Type	WRM Site	Description	GPS co-ordinates (zone 50)		Date sampled	Samples collected				
			Easting	Northing		WQ	MACRO	MICRO	HYPO	SEDIMENT
Reference	WARUS1	Warramboo upstream site 1, ~ 5.8 km upstream of the discharge point. Dry at time of sampling.	375798	7596721	02/05/2016	x	x	x	x	✓
	WARUS2	Warramboo upstream site 2, ~ 5 km upstream of the discharge location. Pool also referred to as WBOO15001 by Rio Tinto. In flood following a significant rainfall event 05/05/2016 – 06/05/2016 (38 mm) – therefore samples were unable to be collected.	375470	7597247	06/05/2016	x	x	x	x	x
	WARUS3	Warramboo upstream site 3, ~ 3.5 km upstream of the discharge location. Dry at time of sampling.	374957	7598720	02/05/2016	x	x	x	x	✓
	WARUS4	Warramboo upstream site 4, ~ 2.7 km upstream of the discharge location. Dry at time of sampling.	374534	7599364	02/05/2016	x	x	x	x	✓
	WARUS5	Warramboo upstream site 5, ~ 1 km upstream of the discharge location. Small pools ~300 m downstream of the GPS co-ordinates held water at the time of sampling. Frogs and tadpoles were present, fish were absent. Sediment sample taken at GPS co-ordinates.	375029	7600887	04/05/2016	✓	✓	✓	✓	✓
	WARUS6	Warramboo upstream site 6, ~ 400 m upstream of the discharge location. Small pool present at the time of sampling. Frogs and tadpoles were present, fish were absent.	375323	7601566	02/05/2016	✓	✓	✓	✓	✓
Potentially exposed	WARDS1	Warramboo downstream site 1, ~ 200 m downstream of the discharge location. Dry at time of sampling.	375196	7602100	02/05/2016	x	x	x	x	✓
	WARDS2	Warramboo downstream site 2, ~ 1 km downstream of the discharge location. Dry at time of sampling.	374906	7602939	02/05/2016	x	x	x	x	✓
	WARDS3	Warramboo downstream site 3, ~ 2 km downstream of the discharge location. Dry at time of sampling.	374437	7603891	02/05/2016	x	x	x	x	✓
	WARDS4	Warramboo downstream site 4, ~ 3 km downstream of the discharge location. Dry at time of sampling.	374261	7604906	02/05/2016	x	x	x	x	✓
	WARDS5	Warramboo downstream site 5, ~ 4.5 km downstream of the discharge location. Dry at time of sampling.	373588	7606225	02/05/2016	x	x	x	x	✓
	WARDS6	Warramboo downstream site 6, ~ 5.5 km downstream of the proposed discharge location, and therefore likely within the zone of dewatering discharge extent. Dry at time of sampling.	373529	7606742	02/05/2016	x	x	x	x	✓

The sites chosen were located within a 12 km stretch; 6 km upstream and 6 km downstream of the proposed discharge location (Figure 1). The intent was to sample six replicate sites in each 'zone' (reference and potential exposed) to characterise the fauna and current conditions along that stretch of river, and most importantly, to allow adequate statistical power to test for spatial and temporal change in water quality and aquatic fauna in the future.

As Warramboo Creek is a highly ephemeral creekline, surveys were timed to coincide with the wet season. At the time of survey however, surface water was present at only three sites, WARUS2, WARUS5 and WARUS6. Of these, WARUS2 was not sampled due to an unexpected flood event which occurred overnight on the $5^{th}/6^{th}$ May 2016, as a result of 38 mm of rainfall received within a period of a couple of hours (Plate 4). Sampling was not possible due to the strong current. Even if sampling had been possible, data would likely not have been comparable to that from the small ephemeral pools sampled on prior days.

Plate 4. Warramboo Creek at WARUS2, in flood following a 38 mm overnight rainfall event.

At all other sites (n = 11), most of which were dry, sediment samples were collected for rehydration trials in the laboratory. All aquatic faunal components (except fish which were not present) and water quality were able to be sampled from the remnant pools present at WARUS5 and WARUS6 (Table 3).

Site photographs are provided in Appendix 1.

4.4 Water quality

At each site which held water (prior to the flooding), 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 and dissolved metal analyses were filtered in the field through 0.45 µm nitrocellulose filters. To avoid contamination, all sample bottles and filtering equipment were acid-washed (0.1% nitric acid) prior to use. Water samples for analysis of dissolved metals 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 (Appendix 2). Warramboo Creek is considered a slightly to moderately disturbed ecosystem, due to impacts associated with historic pastoral use (Yarraloola Station), clearing of transport corridors (Great Northern Highway construction and realignment) and mine development. Therefore, ANZECC/ARMCANZ (2000) trigger values (TVs) TVs for the protection of 95% of species were considered more appropriate than default TVs for 99% protection. 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.

In the absence of ANZECC/ARMCANZ (2000) TVs, benchmark levels for protection against toxicity were sourced from the *United States Environmental Protection Agency Aquatic Life Ambient Water Quality Criteria* (USEPA 2015), the *Canadian Council of Ministers of the Environment Water Quality Guidelines for the Protection of Aquatic Life* (CCME 2015) and/or the *British Columbia Approved Water Quality Guidelines* (BCME 2015).

4.4.2 Comparison against groundwater quality

Water quality data were compared against the known range of concentrations measured from groundwater bores (monitoring and production) in the Warramboo region (RTIO 2015b). Data were collected by Rio Tinto from 13 monitoring bores (depth varying from 36 m to 106 m) during a single sampling event in September 2013 (06/06/2013 - 09/09/2013). Additionally, 73 samples were collected from eight production bores (depth varying from 43 m to 78 m) located along the perimeter of the Warramboo pit, between 31/01/2009 and 21/08/2014. Water abstraction from bores commenced in 2008 (RTIO 2015b). The majority of the monitoring and production bores are located within the Yarraloola Conglomerate.

4.5 Habitat Characteristics

Details of habitat characteristics at each site which held water 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 creek/river over which each macroinvertebrate sample was collected. Water depth was visually estimated. 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 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, and to limit variation due to different observers, all estimations were made by the same sampler.

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 ($N\text{-}NH_3$, $N\text{-}NO_2$, $N\text{-}NO_3$, $N\text{-}NO_X$, 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
Aluminium	Al	Cobbles 64-256 mm (% cover)	cobb
Alkalinity (as $CaCO_3$)	Alk	Pebbles 16-64 mm (% cover)	pebb
Ammonia	$N\text{-}NH_3$	Gravel 4-16 mm (% cover)	grav
Arsenic	As	Sand 1-4 mm (% cover)	sand

Water Quality Parameters	Code	Habitat Parameters	Code
Barium	Ba	Silt <1 mm (% cover)	silt
Boron	B	Mean particle size (from substrate proportions)	phi
Cadmium	Cd	Emergent macrophyte (% cover)	emerg
Calcium)	Ca	Submerged macrophyte (% cover)	submerg
Carbonate	CO_3	Floating macrophyte (% cover)	float
Chloride	Cl	Algae (% cover)	algae
Chromium	Cr	Detritus (% cover)	detr
Cobalt	Co	Riparian vegetation canopy (% canopy cover)	ripvegco
Copper	Cu	Large woody debris (>10 cm diameter) (% cover)	LWD
Hardness (as $CaCO_3$)	Hard	Root mats (% cover)	rootm
Hydrogen carbonate	HCO_3	Trailing riparian vegetation (% cover)	ripveg
Iron	Fe	Habitat diversity (total no. of habitat types)	habdiv
Lead	Pb	Substrate compaction (1 = loose, to 5 = armoured)	compct
Magnesium	Mg	Substrate diversity (total no. substrate types)	subdiv
Manganese	Mn		
Nickel	Ni		
Nitrate-nitrogen	$N\text{-}NO_3$		
Nitrite-nitrogen	$N\text{-}NO_2$		
Nitrogen oxides	$N\text{-}NO_X$		
Nitrogen-total	N-total		
Phosphorus-total	P-total		
Potassium	K		
Selenium	Se		
Sodium	Na		
Sulphate	$S\text{-}SO_4$		
Sulphur	S		
Total dissolved solids	TDS		
Total suspended solids	TSS		
Uranium	U		
Vanadium	V		
Zinc	Zn		

4.6 Sediment Collection and Rehydration of Invertebrate Resting Stages

Plate 5. Sediment sample collection at WARDS3.

One sediment sample was taken at each site for rehydration and identification of emergent fauna (Plate 5). Where possible, samples were collected from areas with low elevation in relation to surrounding topography, i.e. spots that were likely to hold water after a rainfall event; fine, silty sediment with minimal rocky debris. Drought resistant eggs of permanent resident fauna tend to settle in the surficial sediments of ephemeral creeks and wetlands (i.e. top ~ 5 mm – 10 mm), and tend to collect around the waterline where they may be blown by prevailing winds. Each sample consisted of approximately five scrapings taken from the top 2-5 mm of sediment with a hand trowel, generally from near the waterline where propagules tend to be blown by prevailing winds. The total weight of each sample was approximately 500 g. Each sample was placed in a 1 L plastic container with the lid lightly screwed on to allow aeration of sediments. Samples were kept cool in the field, out of direct sunlight and were express freighted to Dr Russell Shiel (University of Adelaide) for rehydration under controlled conditions.

In the laboratory, 100 g of each sediment sample were rehydrated in a plastic container flooded with 300 ml of deionised water (Plate 6). Rehydration was undertaken in a controlled temperature room maintained at 25°C with a 12 hour light/12 hour dark cycle. Samples were examined every 48 hours when possible for emergent fauna for up to 57 days after rehydration (Plate 6). Emergent fauna were identified to species (where possible) under high-powered magnification, and abundance recorded in a $\log_{10}$ scale (0 = absent, 1 = 1, 2 = 2 - 10 individuals, 3 = 11 - 100, 4 = 101 - 1000, 5 = 1001 - 10000). Samples were kept hydrated and animals fed on a yeast culture until no new taxa were recorded.

Electrical conductivity (EC) was measured during rehydration trials, seven days after the rehydration of sediments. The EC of surficial waters in rehydration trays will reflect the dissolution of salts stored in the creek bed sediments, and these stored salts will reflect the salinity of the creeks when flowing/holding water. It is probable that some species will also be sensitive to dissolved oxygen (DO), and have a particular cue to emergence. DO however, was not artificially maintained or measured during the current trials, as DO saturation was assumed to be 100% (at 25°C), given the small volumes of the samples and relatively large surface area.

It also probable that under the 'general' ambient conditions provided in the trials (constant temperature, 12 hr cycles of light-dark etc.), not all species present in a sediment egg bank will hatch (Radzikowski 2013). To study the effect of varying single parameters on local species was beyond the scope of the current study, and would involve a more complex experimental design for the hatching trials, and greater replication.

The conservation status of those taxa that did emerge was determined.


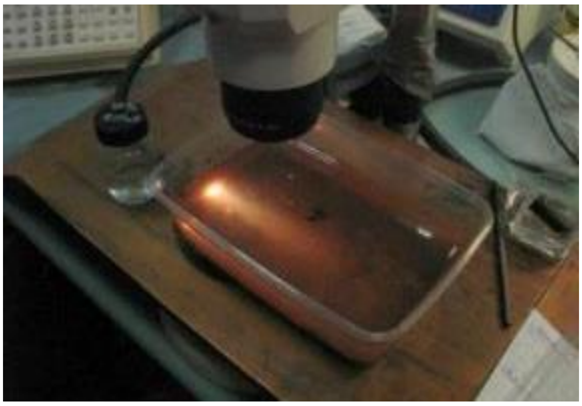

Plate 6. Example of set-up and rehydration of dry sediments (left), and scanning under microscope to detect emergent fauna (right). Photograph by Dr Russell Shiel, University of Adelaide.

4.7 Microinvertebrates

Microinvertebrate samples were collected from each site where water was present by gentle sweeping over an approximate 15 m distance with a 53 µm mesh plankton net. 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.

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. Where specific names could not be assigned, vouchers were established. These vouchers are held by Dr Russell Shiel at Adelaide University.

4.8 Hyporheos

At each site where water was present, 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. The water column was swept immediately after the hole had filled, and again after approximately 30 minutes. The Karaman-Chappuis method has been found to be more effective than using the Bou-Rouch pump[8] (Bou 1974), with many more taxa collected (Strayer 1988, Strayer and Bannon-O'Donnell 1988, Canton and Chadwick 2000).

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, The University of Western Australia) and micro-crustacea (Dr Russell 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[9] 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.

4.9 Macroinvertebrates

Macroinvertebrate sampling was conducted at each site where water was present with a 250 µm mesh FBA pond net. 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 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. 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

[8] In the Bou-Rouch pump method, water is pumped from specific depths in the streambed using either temporarily or permanently installed standpipe wells (Bou 1974). The method has a tendancy to underestimate larger animals that can resist suction.

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

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).

4.10 Fish

Fish were not observed in the small (width 2 - 3 m), shallow (depth ~20 cm) remnant pools of WARUS5 and WARUS6. It is unknown whether fish may have been present in the larger pool at WARUS2 prior to the flood event, therefore their presence in Warramboo Creek cannot be entirely discounted. Fish sampling methodology is not covered in this report.

4.11 Data Analysis

The invertebrate assemblages of Warramboo Creek (macroinvertebrate, microinvertebrate and hyporheic zone invertebrates) were compared against previous studies conducted nearby by Pinder *et al.* (2010) and WRM (2009), using data from sites within 50 km of the Mesa A / Warramboo survey area. Data were amalgamated in Microsoft Excel and taxonomy was standardised across datasets to account for inherent variation / advancements in taxonomic knowledge between studies (i.e. some species level taxa were amalgamated at genus, family or order level to enable comparison). Univariate statistics were performed using IBM SPSS Statistics software (Version 22.0 for Windows). Independent samples were used as replicates within a study and one-way analysis of variance (ANOVA) applied to test for significant ($p < 0.05$) differences in taxa richness between studies or sampling events. A Levene's test was used in the first instance to test for equality of variances (Levene 1960). Tukey's post-hoc tests were used to identify significant differences between location and/or sampling event.

Permutational multivariate analysis of variance (PERMANOVA) was undertaken (one-factor design) using the PRIMER package v 7 (**P**lymouth **R**outines in **M**ultivariate **E**cological **R**esearch; Clarke and Gorley 2015) to determine whether there was any significant difference in hyporheic and macroinvertebrate fauna assemblages between studies and sampling events (Anderson 2001). The SIMPER routine within PRIMER was used to determine those taxa contributing most to the similarity/dissimilarity between significant groups identified by PERMANOVA.

4.12 Survey Limitations

The sampling program was designed to allow for robust statistical comparison of aquatic fauna and water quality between reference and potentially exposed sites. A common rule-of-thumb is that a minimum six samples from each treatment group, i.e. $n = 6$ reference sites, and $n = 6$ potentially exposed sites (total $n = 12$) are required to provide sufficient statistical power to detect a meaningful difference. However, for the current study, only two sites (both reference sites) were successfully sampled for surface water parameters. As such, univariate statistical analyses (e.g. ANOVA, t-test), which would allow for testing of significant differences between treatment groups within the survey area, could not be performed on the dataset with any confidence. Similarly, results of analyses using historic data where $n < 6$ must be treated with caution. Differences in sampling times and conditions between current and previous studies may also confound interpretations. While the collection and rehydration of sediment samples at dry sites provided some insight into the faunal composition of ephemeral waterbodies of the survey area, these data could not be statistically compared to data from pools, due to inherent differences in sampling techniques.

As will be outlined throughout the remainder of the document, this study provides a snapshot of water quality conditions and faunal communities at a single point in time and at a limited number of sites (two small pools), and is unlikely to fully capture the range in temporal / seasonal variability within the survey area. For example, on what was to be the final day of sampling, a major rainfall event caused widespread flooding across the Warramboo Creek catchment, prior to which the creek comprised only a few isolated pools. If sampling had taken place following this flood event, the water quality and aquatic fauna may have been notably different to what is reported herein.

Additionally, it is generally acknowledged that when undertaking laboratory rehydration of dry stream bed sediments not all taxa present as resting stages in the sediment will emerge. This is because different taxa require different cues (light, temperature and salinity regimes, for example) to initiate emergence. Not all fauna will emerge from resting stages at the same time and under the same conditions (this is a selection strategy used by aquatic fauna to minimise the risk from predation and therefore maximise survival). The diversity and composition of aquatic fauna, especially in highly ephemeral creeks, will depend on the timing of sampling relative to time from wetting, as the fauna develops and progresses through a successional change in composition. Repeated sampling over the wetting and drying cycle would likely collect additional taxa over time. ANZECC/ARMCANZ (2000) recommend bi-annual monitoring of aquatic fauna over a period of at least three years, which would allow a more robust and accurate characterisation of the ecological values of waterbodies in the Mesa A / Warramboo survey area.

5 RESULTS AND DISCUSSION

5.1 Water Quality

5.1.1 General

Although Warramboo Creek was mostly dry during the May 2016 survey, water quality samples were able to be collected from two small remnant pools (WARUS5, WARUS6) in the upstream reference reach. A larger pool was present at WARUS2 when visited during the late afternoon of 2/05/2016, though insufficient time remained in the day to sample. The field team planned to return on 6/05/2016, however, 38 mm of rainfall occurred overnight between 5/05/2016 and 6/05/2016, resulting in flash flooding along the upstream reference reach (BOM 2016). Conditions at WARUS2 on 6/05/2016 were not conducive to sampling, as the strong current and chemistry of the floodwaters were not likely to be comparable to the small pools sampled at WARUS5 and WARUS6.

Water quality at WARUS5 and WARUS6 was characterised by circum-neutral to slightly basic pH (7.56 - 8.22), super-saturated dissolved oxygen levels (109.8 - 125.2% DO), high temperatures (29.2 - 30.5°C), generally low electrical conductivity (211 - 309 µs/cm EC), elevated ammonia (0.02 - 0.14 mg/L N-NH_3) and total nitrogen (0.79 - 1.80 mg/L TN), and generally low dissolved metal concentrations (Table 5). Calcium and potassium were the co-dominant cations, and hydrogen bicarbonate the dominant anion (Table 5). Alkalinity was greater than 20 mg/L (79 - 94 mg/L $CaCO_3$), suggesting Warramboo Creek waters are well buffered against rapid changes in pH. There were only minor differences in water quality between WARUS5 and WARUS6, reflecting differences in the size of the remnant pools and likely varying rate of evapo-concentration (Table 5). WARUS5 was a small pool (length 8 m, width 2 m, depth 0.2 m), with a substrate of sand and gravel, whereas WARU6 was a slioghtly larger (length 15 m, width 3 m, depth 0.2 m), with a substrate of bedrock.

5.1.2 Comparison against ANZECC/ARMCANZ (2000) default guidelines

Exceedance of ANZECC/ARMCANZ (2000) default 95% species protection TVs were recorded for pH, DO, EC, N-total, N-NO_3, dissolved aluminium and copper:

- The pH at WARUS6 (8.22), slightly exceeded the upper default TV of 8 (Table 5). The slightly elevated pH is unlikely to threaten biota and is similar to background values previously recorded from the region (i.e. Johnson and Wright 2003, Streamtec 2004). The pH of a waterbody is influenced by a number of factors including local geology, hydrology and biotic processes. pH values outside the default TV range are frequently reported for other systems in the Pilbara Region, including Marillana, Mindy Mindy, Kalgan and Weeli Wolli creeks in the Fortescue River catchment (WRM unpub. dat.).
- DO saturation at WARUS6 (125.2%) slightly exceeded the upper default TV of 120% (Table 5), however, this level of exceedance is not likely to cause biological stress.
- EC at WARUS6 (309 µs/cm) exceeded the default TV for rivers in north-west Western Australia (250 µs/cm), but was well below the default TV for wetlands in north-west Western Australia (900 µs/cm) (Table 5). The default TV for wetlands may arguably be more appropriate for recessional flow conditions and small pools with high evaporation rates, such as WARUS5 and WARUS6 during current sampling. Although some dilution may occur following wet season rains, salinity in Pilbara surface waters can often remain higher than default guidelines 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. Remnant waters at both WARUS5 and WARUS6 were still also

considered "fresh" as defined by the Department of Environment (DoE 2003)[10], and EC was well below the limit of ecological stress, generally accepted to be around 1,500 µS/cm (Hart *et al.* 1991, Horrigan *et al.* 2005).

- Dissolved aluminium at WARUS5 (0.083 mg/L Al) exceeded both the default 95% TV (0.055 mg/L Al) and 90% TV (0.080 mg/L Al) (Table 5).
- Dissolved copper at WARUS5 (0.0018 mg/L Cu) and WARUS6 (0.003 mg/L) exceeded the default 95% TV (0.0014 mg/L Cu) (Table 5).
- Total nitrogen and ammonia concentrations at WARUS5 (1.80 mg/L N-total, 0.14 mg/L N-NH_3) and WARUS6 (0.79 mg/L N-total, 0.02 mg/L N-NH_3) exceeded the default TVs for protection against eutrophication (0.03 mg/L N-total, 0.01 mg/L as N-NH_4[11]) (Table 5). Concentration of nitrogen oxides at WARUS5 (0.02 mg/L N-NO_X) was also elevated above the default TV for eutrophication (0.01 mg/L N-NO_X). Nitrate[11] level however (0.044 mg/L NO_3), was below the default TV for protection of 95% of aquatic species against direct toxic effects (0.70 mg/L NO_3). Elevated nitrogen concentrations are likely due to current and historic pastoral activities, with evidence of cattle presence (tracks, manure, etc.) observed at WARUS2, WARUS5 and WARUS6. Evapo-concentration effects will exacerabate elevated nutrient concentrations in small, remnant pools. Nitrogen enrichment in aquatic systems can lead to increased algal growth and cyanobacterial blooms (ANZECC/ARMCANZ 2000). Such nuisance blooms can have adverse effects on the aquatic ecosystem through direct toxicity, reductions in dissolved oxygen and changes in biodiversity.

5.1.3 Comparison against groundwater quality

Water quality data for Warramboo Creek sites WARUS5 and WARUS6 were compared against known concentration ranges for analytes in groundwater bores throughout the Warramboo area (Table 5). The surface water data represents a single sampling event, so variation in water quality over time is currently unknown. Concentrations of most measured surface water analytes were within or below the known concentration ranges in groundwater monitoring and production bores, which were highly variable across the survey area (Table 5). Of note were elevated background concentrations of Al and N-total in surface waters at WARUS5 relative to the known range in the production bores. A number of analytes were also elevated in production bores relative to surface waters, i.e. EC and associated ions (Ca, Cl, HCO_3, Na, Mg, SO_4), TDS, alkalinity, hardness, NO_3, N-NO_3, B, Cd, Cr, Mn, Pb, Ni, U and Zn. Average concentrations of EC, B, Cd, N-total, NO_3 and N-NO_3 in production bores also exceeded ANZECC/ARMCANZ (2000) default 95% species protection TVs for surface waters (Table 5):

- EC levels exceeded the default TV for surface waters (250 µs/cm) on all monitoring occasions in production bores (n = 29) and monitoring bores (n = 13) (Table 5). All water samples from production bores qualify as brackinsh, with EC levels exceeding 1,500 µS/cm. Elevated EC in freshwater systems can directly impact fauna through affects to osmoregulatory physiology as the maintenance of constant solute body concentration is impaired (Bayly 1972, Kefford *et al.* 2003, 2011), and affects the rates of many ecological processes such as organic matter decomposition and nutrient cycling (Schäfer *et al.* 2012).
- Boron concentrations in all monitoring and production bores exceeded the 95% toxicity TV (0.37 mg/L B), on all sampling occasions (Table 5). Boron is known to be toxic to aquatic biota and can affect the growth, survival and reproduction of aquatic invertebrates (i.e. Cladocera) and fish

[10] Fresh defined as < 1500 µS/cm; Brackish = 1500 - 4500 µS/cm, Saline = 4500 - 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] For comparison against default eutrophication TV for ammonium nitrogen (N-NH_4), a 1:1 conversion factor was assumed for measured ammonia nitrogen N-NH_3. For comparison against the default toxicity TV for nitrate (NO_3), a conversion factor of 4.42 was used for measured nitrate nitrogen (N-NO_3).

(Eisler 1990). Naturally high boron levels frequently recorded in both surface waters and groundwaters in the Pilbara region (*e.g.* Fortescue River, Kalgan Creek, Marillana Creek, Mindy Mindy Creek, Coondiner Creek, Caves Creek and Duck Creek; WRM unpub. data). Girgin *et al.* (2010) suggest that boron enters aquatic systems primarily through the weathering of sedimentary rocks.

- Cadmium concentrations in 17 samples across six production bores met or exceeded the 95% toxicity TV (0.002 mg/L), even when the default TV was modified to allow for water hardness at the time of sampling (Table 5). ANZECC/ARMCANZ (2000) provide algorithms to allow for water hardness which has an ameliorating effect on toxicity of a number of metals (refer footnotes to Appendix 2 Table A2-3). Cadmium is a toxic accumulative poison that can kill aquatic biota in low concentrations, however, toxicity is dependent on water hardness (Ray and Coffin 1977, Jarvinen and Ankley 1999, ANZEEC/ARMCANZ 2000). Chronic exposure leads to adverse effects on growth, reproduction, immune and endocrine systems, development, and behavior in aquatic organisms (USEPA 2016). Amphipods are known to be particularly susceptible to cadmium poisoning (Borgmann *et al*. 2005).
- Concentrations of NO_3 in seven monitoring bores, and in all but one sample from production bores (total of 48 samples) exceeded the 95% toxicity TV (0.7 mg/L) (Table 5). Concentrations of N-total were also elevated above the eutrophication TV (0.3 mg/L) in the three production bores sampled for this analyte (Table 5). Elevated nitrate can reduce acid-neutralising capacities of waterbodies, adversely affect the growth, survival and reproduction of aquatic fauna, and stimulate eutrophication in still or slow flowing waterbodies by fuelling nuisance algal and macrophyte growth (e.g. *Typha*) (Camargo and Alonso 2006). The relationship between nutrient enrichment and enhanced algal growth in freshwaters is well documented, often resulting in very high density/abundance but low species richness (Gorden *et al.* 1982, Townsend *et al*. 2011, Muhid *et al.* 2013). Groundwaters in arid zone areas across Australia are often naturally enriched in nitrate (Magee 2009), however, the relative contribution of anthropogenic and natural sources to nitrogen enrichment in surface and groundwater of the Warramboo area is unknown.

High levels of EC and potential toxicants such as metals and nitrate in dewatering discharge may be of issue, particularly if discharge water constitutes most of the surface water in remnant creek pools over the dry season.

Table 5. Water quality in Warramboo Creek during the May 2016 survey, compared against known ranges and means (se = standard error) for groundwater quality data from monitoring and production bores recorded between 2009 and 2014 (RTIO 2015b). Values which exceeded ANZECC/ARMCANZ (2000) default trigger values (TVs) for protection of 95% of aquatic species are highlighted, and magnitude of the exceedance is indicated as: ■ ≥default TV, ■ ≥2x TV and ■ ≥10x TV. Units in mg/L unless stated otherwise. Values preceded by "<" were below the limit of reporting.

Water Quality Parameters	Warramboo Creek Upstream Reference		Known groundwater ranges, averages (se) and medians							
			Monitoring bores				Production bores			
	WARUS5	WARUS6	Range	Average (se)	Median	Count	Range	Average (se)	Median	Count
Temperature (°C)	29.2	30.5	-	-	-	0	-	-	-	0
pH [H^+]	7.56	8.22[a]	7.40 - 8.00	7.64 (0.05)	7.6	13	7.00 - 8.30	7.70 (0.04)	7.70	64
Dissolved oxygen (%)	109.8	1252[b]	-	-	-	0	-	-	-	0
Dissolved oxygen	8.58	9.67	-	-	-	0	-	-	-	0
Conductivity (µS/cm)	211	309[c]	500 - 7000	2652 (479)	2100	13	1700 - 2800	2131 (63)	2000	29
Redox (mV)	-34.4	-76.0	-	-	-	0	-	-	-	0
Aluminium	0.083	0.02	0.005 - 0.21	0.033 (0.016)	0.007	13	0.003 - 0.014	0.007 (0.0004)	0.005	62
Alkalinity (as $CaCO_3$)	73.0	94.0	210.0 - 510.0	311.5 (26.0)	260.0	13	200.0 - 320.0	254.8 (3.9)	-	0
Ammonia (N-NH_3)	0.140	0.020	-	ID	-	0	<0.005	<0.005	<0.005	13
Arsenic (total)	<0.001	0.001	0.001 - 0.008	0.002 (0.001)	<0.001	13	<0.001	<0.001	<0.001	66
Barium	0.062	0.06	0.012 - 0.88	0.163 (0.065)	0.048	13	0.005 - 0.043	0.022 (0.005)	0.02	8
Boron	0.11	0.26	0.47 - 1.50	0.77 (0.08)	0.62	13	0.40 - 0.83	0.61 (0.02)	0.59	36
Cadmium	<0.0001	<0.0001	0.0001 - 0.0005	0.0001 (0.00004)	<0.0001	13	0.002 - 0.005[d]	0.004[d] (0.0004)	<0.0001	40
Calcium	15.8	21.2	32.0 - 230.0	86.23 (14.58)	68.0	13	57.0 - 110.0	73.5 (1.3)	72.0	63
Carbonate	<1	<1	<1	<1	<1	13	<1 - 16	4 (1)	3	48
Chloride	13	26	31 - 2000	632 (144)	470	13	350 - 730	505 (12)	480	61
Chromium (total)	<0.0005	<0.0005	0.001 - 0.003	0.001 (0.0002)	<0.0005	13	0.001 - 0.007	0.003 (0.0004)	<0.0005	32
Cobalt	0.0004	0.0003	0.001 - 1.70	0.274 (0.165)	0.002	13	0.001 - 0.013	0.003 (0.002)	<0.001	7
Copper	0.0018	0.003	0.001 - 0.065	0.012 (0.005)	0.005	13	0.001 - 0.007	0.002 (0.0002)	0.0025	66
Hardness (as $CaCO_3$)	61.0	83.0	-	-	-	0	340.0 - 720.0	447.9 (13.2)	420.0	39
Hydrogen carbonate	89.0	114.0	250 - 620	378.5 (32.9)	320.0	13	190.0 - 330.0	257.4 (5.1)	250.0	50
Iron	0.093	0.036	0.006 - 19.0[h]	2.29 (1.444)	0.11	13	0.003 - 0.45	0.036 (0.011)	0.01	66
Lead	<0.0001	<0.0001	0.001 - 0.089[d]	0.011[d] (0.007)	0.0005	13	0.001 - 0.01	0.001 (0.0004)	0.0005	64
Magnesium	5.3	7.4	24.0 - 240.0	73.4 (15.3)	61.0	13	49.0 - 110.0	62.1 (1.4)	60.0	63
Manganese	0.140	0.015	0.008 - 7.50	1.475 (0.720)	0.045	13	<0.001 - 0.22	0.019 (0.006)	<0.001	36
Nickel	0.001	0.002	0.001 - 0.220[d]	0.036[d] (0.018)	0.005	13	0.001 - 0.018	0.004 (0.001)	0.0025	50

Water Quality Parameters	Warramboo Creek Upstream Reference		Known groundwater ranges, averages (se) and medians							
			Monitoring bores				Production bores			
	WARUS5	WARUS6	Range	Average (se)	Median	Count	Range	Average (se)	Median	Count
Nitrate	0.044	<0.044	<0.05 - 27.0[g]	6.886[g] (2.498)	2.80[g]	13	0.05 - 20.0[g]	9.60[g] (0.900)	9.10[g]	48
Nitrate-nitrogen	0.01[e]	<0.01	<0.011 - 6.1[e]	1.55[e] (0.564)	0.623[e]	13	0.011 - 4.51[e]	2.17[e] (0.203)	2.05[e]	48
Nitrite-nitrogen	<0.01	<0.01	<0.05 - 0.10	0.03 (0.01)	<0.05	13	<0.01	<0.01	0.025	30
Nitrogen oxides	0.02[e]	<0.01	-	-	-	0	-	-	-	0
Nitrogen-total	1.8[f]	0.79[f]	-	-	-	0	0.88 - 1.20[f]	1.06[f] (0.08)	1.10[f]	3
Phosphorus-total	<0.01	0.014	-	-	-	0	<0.01	<0.01	<0.01	3
Potassium	17.2	20.8	7.6 - 25.0	13.4 (1.3)	13.0	13	7.6 - 20.0	11.4 (0.3)	12.0	63
Selenium	<0.001	<0.001	-	-	-	0	<0.001	<0.001	<0.001	28
Sodium	5	12	35 - 890	338 (67)	270	13	180 - 430	269 (6)	260	63
Sulphate	5.5	12.8	8.0 - 500.0	139.2 (36.5)	93.0	13	59.0 - 150.0	101.2 (3.2)	98.0	50
Sulphur	1.8	4.3	-	-	-	0	-	-	-	0
Total dissolved solids	120	170	280 - 4000	1569 (282)	1200	13	880 - 1700	1200 (27)	1200	41
Total suspended solids	26.0	7.0	-	-	-	0	0.5 - 8.0	3.2 (0.5)	2.5	16
Uranium	0.0001	0.0003	-	-	-	0	0.002 - 0.006	0.004 (0.001)	0.004	3
Vanadium	0.0007	0.0007	0.001 - 0.03	0.005 (0.0020)	0.002	13	<0.001	<0.001	<0.001	4
Zinc	0.005	0.005	0.012 - 0.54[d]	0.105[d] (0.040)	0.041	13	<0.001 - 0.18[d]	0.017 (0.004)	0.006	66

[a] Exceeded upper default TV for DO for north west lowland rivers (range 85 - 120%).

[b] Exceeded upper default TV for pH north west lowland rivers (range 6.5 - 8).

[c] Exceeded default TV for EC for north west rivers (range 20 - 250 µs/cm).

[d] Exceeded the hardness modified default TV (HMTV), as recommended by ANZECC/ARMCANZ (2000) for assessing risk of toxicity to aquatic biota.

[e] Exceeded default eutrophication TV for north west lowland rivers = 0.01 mg/L NO_x.

[f] Exceeded default eutrophication TV for north west lowland rivers = 0.03 mg/L N-total.

[g] Exceeded default toxicity TV for nitrate = 0.7 mg/L NO_3. Note that this default TV is currently under revision and is likely to be revised to approximately 11 mg/L NO_3 (equivalent to 2 - 2.5 mg/L N-NO_3).

[h] It is probable that elevated iron levels in some of the monitoring bores are a result of improper sample filtering and are not an indicator of a degraded groundwater system (RTIO 2015b).

5.2 Microinvertebrate Fauna

5.2.1 Taxonomic composition

A total of 19 microinvertebrate taxa[12] were recorded from the two surface water pools present along Warramboo Creek (WARUS5 and WARUS6) during May 2016 (full taxa list provided in Appendix 3). Due to the limited number of sampling sites, the diveristy of microinvertebrate taxa in the suvey area is likely to be higher than is currently reported. 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 greater than that reported here. Microinvertebrate composition included one species of Protista, 11 Rotifera taxa, five Copepoda taxa and two species of Ostracoda (seed shrimp). Typically, the microinvertebrate fauna of tropical systems is dominated by lecanid rotifers (e.g. Koste and Shiel 1983, Tait *et al.* 1984, Smirnov and De Meester 1996, Segers *et al*. 2004). However, the assemblages at WARUS5 and WARUS6 did not appear to follow this trend, with only five of 11 Rotifera taxa belonging to the family Lecanidae.

Microinvertebrate taxa richness was higher at WARUS6 (15 taxa) than at WARUS5 (8 taxa). This difference was largely due to the absence of Rotifera from WARUS5, compared with 11 species present at WARUS6. However, one species of Protista and two species of Ostracoda were present at WARUS5, but no taxa belonging to these groups were recorded at WARUS6 (Appendix 3).

5.2.2 Comparison against previous studies

Mean microinvertebrate taxa richness at Warramboo Creek was compared to sites sampled previously within 50 km of the Mesa A / Warramboo survey area by WRM (2009) and Pinder et al. (2010) (see Figure 3 for site locations). As WRM (2009) and Pinder *et al.* (2010) sampled twice, once during a wet season and once during a dry season, mean number of taxa for each study were separated by season. One-way ANOVA indicated there was a significant difference in taxa richness between each sampling event (one-way ANOVA; df = 4, F = 19.013, p = < 0.001). Tukey's *post-hoc* test indicated mean richness at Warramboo Creek was significantly lower than mean richness recorded by WRM (2009) and Pinder *et al.* (2010) from wet season sampling events, but similar to mean richness recorded from dry season sampling events (Figure 4, indicated by "b"). The relatively low mean taxa richness in Warramboo Creek during the wet 2016, may reflect the ephemerality of flow in the creek and differences in the composition of in-stream habitat. This would be expected to limit colonisation by surface water species, in comparison to the pools sampled by WRM (2009) and Pinder *et al.* (2010), which hold surface water for long periods of time (years to decades). Low richness could also be related to below-average wet season rainfall, leading to smaller surface areas of inundation along the creekbed from which invertebrates might emerge. Taxa richness at Warramboo Creek was comparable to dry season richness recorded under recessional flows by WRM (2009) and Pinder *et al.* (2010). The relatively low wet season richness may also be a result of smaller sample size for Warramboo Creek (two small pools), compared to the eight pools sampled by WRM (2009) and the five pools sampled by Pinder *et al.* (2010).

[12] Not all specimens could be identified to species, so the term 'taxa' refers here to the lowest levels of identification, whether that be species, genus, family or order.

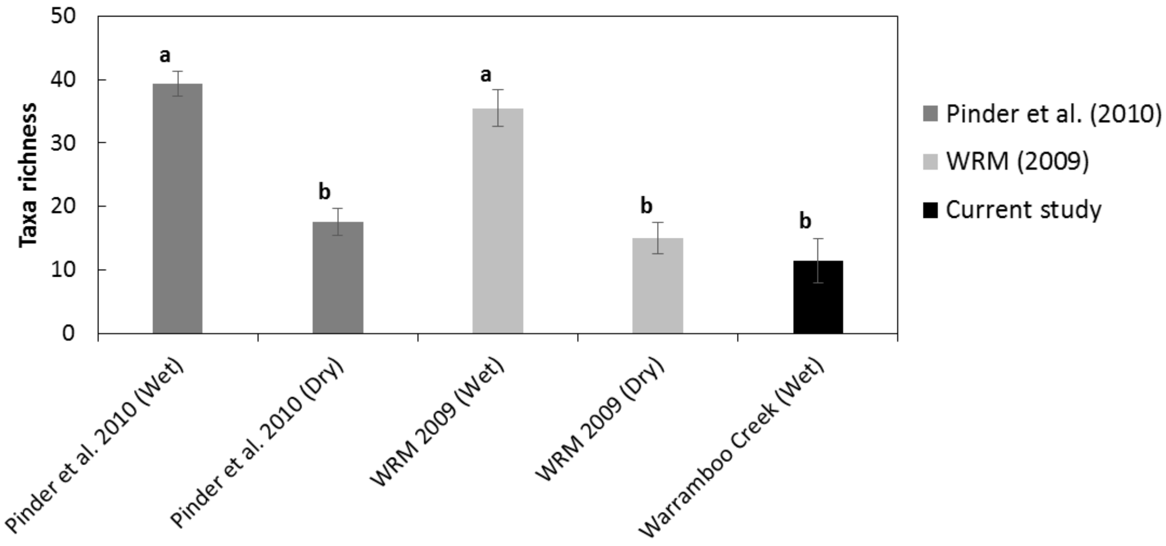

Figure 4. Comparison of mean microinvertebrate taxa richness (± standard error) from Warramboo Creek against mean taxa richness recorded at pools sampled by Pinder *et al.* (2010) and WRM (2009), during the wet and dry seasons. Statistically similar groups (a, b) identified by Tukey's post-hoc tests (following one-way ANOVA) are indicated above each sampling event.

5.2.3 Conservation/scientific significance of microinvertebrates

The majority of microinvertebrate taxa recorded from Warramboo Creek 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 both WARUS5 and WARUS6. *E. lumholtzi* was assessed as **Vulnerable** in 1996 (IUCN ver. 2.3), as it was 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. However, IUCN (2016) states this assessment requires updating, likely 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 the rotifer *Lecane nitida* from WARUS6. This species is thought to represent a new record for Western Australia (Dr Russell Shiel, University of Adelaide, pers. comm.). Until recently, this rotifer was considered a sup-species of *Lecane curvicornis* (Segers and Sanoamuang 2007) (Dr Russell Shiel, University of Adelaide, pers. comm.). Pinder *et al*. (2010) identified a rotifer as *Lecane* cf *nitida* from Jofre Creek in the Karijini National Park, however it is not known if this species represents a variant of *L. nitida* or a new species. *L. nitida* is considered to have a cosmopolitan distribution, and has been recorded from Laos (Segers and Sanoamuang 2007), India (Dhuru 2002) and Brazil (Yoshio Joko *et al.* 2008).

5.3 Hyporheic Fauna

5.3.1 Taxonomic composition

A total of 25 taxa were recorded from the two hyporheic samples collected from Warramboo Creek in May 2016; 18 of which were collected from WARUS5, and 18 from WARUS6 (full taxa list provided in Appendix 4). The majority of taxa were classified as stygoxene (60%) and do not have specialised adaptations for groundwater habitats. Approximately 20% of the taxa were classified as occasional hyporheos stygophiles, and 12% were classified as possible hyporheic taxa. No taxa were classified as stygobites (obligate groundwater species). The absence of stygobitic fauna in the hyporheic zone of Warramboo Creek pools was not unexpected, given the apparent lack of connectivity between groundwater and surface water in this area (RTIO 2015a). Classifications followed those by Boulton (2001). This type of analysis should be treated with some caution as the results are likely affected by the available information on life history, taxonomic resolution and interpretation of classification categories.

One possible hyporheic species, the cladoceran *Ilyocryptus raridentatus*, was collected from WARUS5. All species of *Ilyocryptus* are slow moving mud dwellers (Smirnov and Timms 1983), with the holotype of *I. raridentatus* described from Derby, Western Australia (Dr Russell Shiel, University of Adelaide, pers. comm). *I. raridentatus* was widely collected from Pilbara surface waters during the PBS (Pinder *et al.* 2010).

The copepod *Microcyclops varicans* was classified as an occasional hyporheic stygophile as it is known from groundwater environments, but is also widespread in surface waters. This species has been recorded from groundwaters in the Gascoyne (Box Well on House Station and Two-Mile Bore on Killara Station; Karanovic 2004), and Pilbara (bores at Newman and Mulga Downs; Karanovic 2006). During the current study this species was recorded from the hyporheic zone of both WARUS5 and WARUS6. Previously, this species has been recorded by the authors from nearby Mungarathoona Creek and Red Hill Creek (WRM 2009), and Weeli Wolli Creek (WRM unpub. data). *M. varicans* was widely collected from Pilbara surface waters during the PBS (Pinder *et al.* 2010).

The oligochaete *P. longiseta* collected during the current study was also classified as an occasional hyporheic stygophile as it is known to occur in both hyporheic and groundwater environments. It has previously been collected from other systems in the Pilbara Region including Weeli Wolli Creek, Marillana Creek, and Coondiner Creek (WRM unpub. data). *P. longiseta* was widely collected from Pilbara surface waters during the PBS (Pinder *et al.* 2010). It is considered to have a cosmopolitan distribution, as it frequently recorded from aquatic systems around the world (Rodriguez 1985).

5.3.2 Comparison against previous studies

Mean taxa richness in Warramboo Creek hyporheic samples was compared to sites sampled previously within 50 km of the Mesa A / Warramboo survey area by WRM (2009) (see Figure 3 for site locations). 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.

Standardised taxa richness in Warramboo Creek hyporheic samples during May 2016 (16 - 17 taxa) was higher than that recorded at nearby Mungarathoona Creek and Red Hill Creek by WRM (2009) (average 9.4 taxa per sample; Figure 5). Little variation in richness was observed between wet and dry season sampling events (WRM 2009). Despite the higher average taxa richness recorded at Warramboo Creek, one-way ANOVA indicated no significant difference in taxa richness between the current study and either of the WRM (2009) sampling events (one-way ANOVA; df = 2, F = 3.095, p = 0.080).

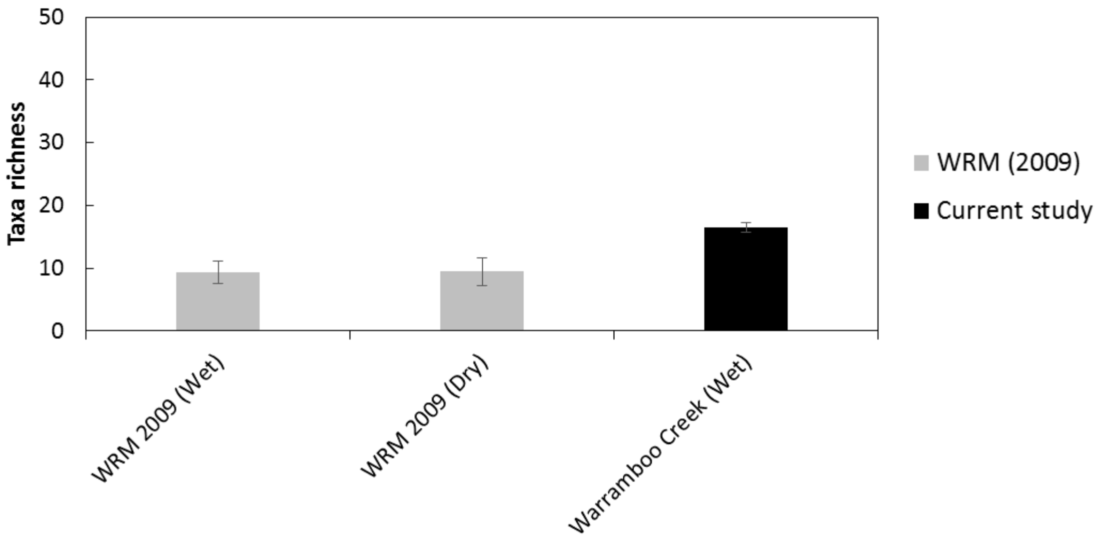

Figure 5. Comparison of mean hyporheic taxa richness (± standard error) between Warramboo Creek (May 2016) and pools on Mungarathoona and Red Hill creeks sampled by WRM (2009) during the wet and dry seasons.

The composition of hyporheic invertebrate assemblages at Warramboo Creek was however, significantly different to both the wet and dry season assemblages of Mungarathoona and Red Hill creeks recorded by WRM (2009) (one-way PERMANOVA; df = 2, pseudo-F = 2.123, p = 0.005). Only 25% of taxa were common to both the current and WRM (2009) study. The Warramboo Creek hyporheic zone was dominated by the occasional hyporheic stygophile copepod *M. varicans*. Nematodes, oligochaetes and larval and pupal diptera of the family Ceratopogonidae (biting midges) were also common. The hyporheic zones of Mungarathoona and Red Hill creeks were also dominated by oligochaetes and ceratopogonids in both seasons, however, other common taxa included the beetle *Hydraena* sp., the copepod *Mesocyclops papuensis*, and the chironomid (non-biting midges) *Paramerina* sp.

While differences in species assemblages between the current and WRM (2009) study may be explained by differences in habitat and permanence of water within each creek system, large shifts in invertebrate assemblage composition often occur naturally over time in dry tropical Australian river systems (Marshall *et al.* 2006, Leigh and Sheldon 2009, Blanchette and Pearson 2013). Seasonal flooding and recession of pools provide contrasting physical stresses, with the intervening periods also subject to substantial events such contraction of habitats and changes in biophysical variables. The harsh biophysical variables associated with the late dry season may have significant effects on invertebrate assemblages, coupled with the different resistance and resilience traits of invertebrates (such as colonisation and establishment abilities), the fragmented and the varying ephemeral or permanent nature of pools along dry-tropical rivers, and a 'boom-and-bust' ecology with 'bust' disturbances by flash flooding and 'boom' periods of still water or gentle flows. It is likely that different taxa show differential success across seasons according to their particular resilience or resistance traits, which would be reflected by different responses to disturbances of different magnitudes (Blanchette and Pearson 2013). This high temporal variability is likely the most influential factor contributing to significant differences in assemblages between Warramboo Creek sampled in 2016, and Mungarathoona and Red Hill creeks sampled in 2008/2009.

5.4 Macroinvertebrate Fauna

5.4.1 Taxonomic composition

A total of 76 macroinvertebrate taxa were recorded from the two surface water pools present along Warramboo Creek (WARUS5 and WARUS6) during May 2016 (full taxa list provided in Appendix 5). It should be noted that these results represent a single point in time and at a limited number of sites (two samples), and are unlikely to fully capture the range in temporal / seasonal variability within the survey area. Taxa richness was similar between the two sites, with 53 taxa recorded at WARUS5 and 57 taxa recorded at WARUS6. The totals include groups that could not be identified to species level due to a lack of suitable taxonomic keys (i.e. Diptera families, some families of Coleoptera, etc.), unresolved taxonomy, damage, or life history stage (i.e. immature specimens). Therefore, the total macroinvertebrate species richness at these sites is likely greater than that reported here.

The fauna consisted of Nematoda (round worms), Mollusca (aquatic snails), Oligochaeta (aquatic segmented worms), Crustacea, Acarina (water mites), Odonata (dragonfly and damselfly larvae), Ephemeroptera (may fly larvae), Hemiptera (aquatic true bugs), Coleoptera (aquatic beetles), Diptera (two-winged fly larvae) and Trichoptera (caddis-fly larvae) (Table 6). Insecta were the dominant group, with 69 of the 76 taxa (91%) recorded belonging to this class (Table 6). Typically, insects constitute around 80% of all aquatic fauna in freshwater systems of the Pilbara (Pinder *et al*. 2010). Of the insects, the best represented taxa were Coleoptera (22 taxa, 32% of Insecta), followed by Diptera (18 taxa, 26%) and Hemiptera (14 taxa, 20%). Diptera are typically the most diverse order of insects in freshwater systems (Hutchinson 1993), but in Warramboo Creek, coleopterans were more diverse, predominantly due to the high abundance of dysticids (diving beetles). Mollusca (freshwater snails and bivalves) comprised less than 3% (3 species) of total macroinvertebrate fauna collected. Only one species of macro-crustacean was collected, the conchostracan *Caenestheriella packardi*, which was collected from both WARUS5 and WARUS6. *C. packardi* is widespread throughout much of mainland Australia.

Table 6. Summary of macroinvertebrate composition recorded from Warramboo Creek surface water pools during the May 2016 survey.

Taxon	Common name	Total	WARUS5	WARUS6
Nematoda	Round worms	1	0	1
Mollusca	Snails & bivalves	2	1	2
Oligochaeta	Segmented worms	1	1	1
Crustacea (Conchostraca)	(clam shrimp)	1	1	1
Acarina	Water mites	1	1	1
Collembola	Spring tails	1	0	1
Insecta		69	49	50
Odonata	Dragonflies & damselflies	7	5	7
Ephemeroptera	Mayflies	5	4	2
Hemiptera	True bugs	14	9	12
Coleoptera	Beetles	22	15	18
Diptera	Two-winged flies	18	14	10
Trichoptera	Caddisflies	3	2	1
	Total taxa richness	**76**	**53**	**57**

The composition of the macroinvertebrate assemblages differed between WARUS5 and WARUS6, with only 34 taxa common to both sites. The most noticeable differences were slightly greater diversity within the orders Odonata, Hemiptera and Coleoptera at WARUS6, but slightly greater diversity within orders Ephemeroptera, Diptera and Trichoptera at WARUS5. Typically, these differences were due to differences of only four taxa or less within each order.

The majority of macroinvertebrate fauna recorded from the two Warramboo Creek surface water pools were “temporary” resident taxa, consisting of adult stage insects which colonise pools by aerial migration (i.e. Coleoptera, Hemiptera), and larval stage insects that would have hatched from eggs deposited by winged adults (i.e. Diptera, Odonata, Trichoptera and Ephemeroptera) (Williams 1985, Boulton 1989). Some insects may be "semi-permanent" residents, persisting as larvae during periods of drought by aestivating or encysting in sediments (e.g. Baetidae, Simuliidae, Ceratopogonidae, Chironomidae) (Hinton 1960, Danks 1987, Radzikowski 2013). In the minority were the "permanent" resident taxa that do not have well-developed dispersal abilities, which typically produce desiccation-resistant propagules or eggs which hatch upon inundation (e.g. nematodes, oligochaetes and conchostracans) (Radzikowski 2013). However, passive or assisted migration is possible for some of these fauna, either via wind dispersal or surface water drainage (e.g. eggs of rotifers, branchiopods, copepods and turbellarians), or through synchronization of the life cycle with that of an actively migrating vector species (Dudley 1997). For example, the eggs of anostracans (fairy shrimp), notostracans (tadpole shrimp), conchostracans, cladocerans and ostracods are known to pass through the guts of waterfowl, unharmed, whereas adult amphipods and leeches have been observed clinging to the feathers and feet of waterfowl that were some distance from water (Rosine 1957, Proctor 1964). The larvae of aquatic mites have been found to disperse through the parasitising mosquitoes, attaching to hosts either when the mosquito emerges from the aquatic pupal stage or during oviposition (Smith 1983, 1988, 1999). It is unknown if collembola (spring tails) are dependent on seasonal water presence for their life-cycles, though they lack wings for aerial migration. Collembola are basically terrestrial animals, lacking adaptions to aquatic life, though many species have developed successful mechanisms to exploit water surfaces (e.g. water-repelling body cuticle, claws modified to walk on water), and are often found in the hyporheic zone (Noble-Nesbitt 1963, Deharveng *et al.* 2008).

5.4.2 Comparison against previous studies

Mean macroinvertebrate taxa richness at Warramboo Creek was compared to sites sampled previously within 50 km of the Mesa A / Warramboo survey area by WRM (2009) and Pinder *et al.* (2010) (see Figure 3 for site locations). Each of these 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.

Standardised macroinvertebrate taxa richness Warramboo Creek in May 2016 (52 - 54 taxa) was generally comparable to, or higher than that recorded at nearby Mungarathoona Creek and Red Hill Creek by WRM (2009), and at PBS sites by Pinder *et al.* (2010) (Figure 6). Little variation in richness was observed between wet and dry season sampling events (WRM 2009, Pinder *et al.* (2010). One-way ANOVA indicated no significant difference in taxa richness between each sampling event (one-way ANOVA; df = 4, F = 2.303, p = 0.092). This was somewhat unexpected, given that the small, shallow ephemeral pools at Warramboo Creek differed in morphology and hydrological character to the mostly permanent/semi-permanent pools sampled by WRM (2009) and Pinder *et al.* (2010), and there were significant differences in microinvertebrate taxa richness between these studies (see section 6.3.2). This may reflect the different dispersal capabilities of macroinvertebrates versus microinvertebrates, and the potential limiting factors of ephemerality and poor wet season rainfall on microinvertebrate taxa richness. In all three studies, most of the macroinvertebrate taxa recorded were considered "temporary" residents capable of aerial migration (i.e. Coleoptera, Hemiptera), or larval stages hatched from eggs deposited by winged adults. Microinvertebrate assemblages consist of taxa that do not have a winged adult stage capable of aerial migration, thus the colonisation of ephemeral pools is often limited to taxa that emerge from desiccation-resistant propagules or eggs that hatch upon inundation, or from eggs which are carried in via wind, downstream drift during surface water flooding, or with another species more capable of migration (e.g. waterfowl) (Rosine 1957, Proctor 1964, Radzikowski 2013).

The composition of macroinvertebrate assemblages at Warramboo Creek in 2016 was however, significantly different to both the wet and dry season assemblages of Mungarathoona and Red Hill creeks sampled by WRM (2009) (one-way PERMANOVA; df = 2, pseudo-F = 3.576, p = 0.001). Only 36% of taxa were common to both studies. Warramboo Creek macroinvertebrate assemblages were dominated by the aquatic beetles *Dineutus australis* and *Berosus pulchellus*, the freshwater snail *Bayardella* spp., juvenile dragonflies (Anisoptera)., the non-biting midge *Polypedilum* sp. 1, the clam shrimp *Caenestheriella packardi*, *Agraptocorixa parvipunctata* (water boatman) and *Anisops* spp *(backswimmers).* Common taxa in macroinvertebrate assemblages of Mungarathoona and Red Hill creeks that were absent or in low in abundance at Warramboo Creek included, the aquatic beetle *Tiporus tambreyi*, the mayfly *Tasmanocoenis* sp. P/*arcuata*, the non-biting midge *Tanytarsus* sp. and freshwater hydra (*Hydra* sp.). As discussed in section 5.3.2 above, the naturally high temporal variability in invertebrate assemblages of dry tropical Australian rivers is likely to be the main contributing factor to the observed differences in macroinvertebrate species assemblages between the current and WRM (2009) study.

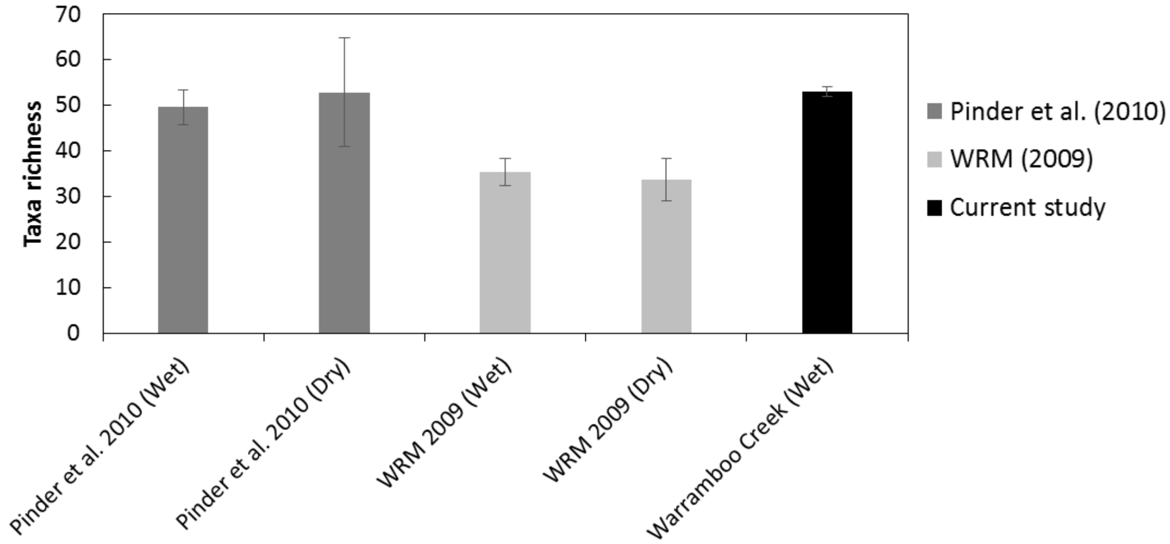

Figure 6. Comparison of mean macroinvertebrate taxa richness (± standard error) from Warramboo Creek (WARUS5, WARUS6) against mean taxa richness recorded at pools sampled by Pinder *et al.* (2010) and WRM (2009), separated into wet and dry season sampling events.

5.4.3 Conservation/scientific significance of macroinvertebrates

The majority of macroinvertebrate species recorded were common, ubiquitous species, with distributions extending across Northern Australia, Australasia, and the world (cosmopolitan species). No species listed for conservation significance were recorded. However, two species of aquatic beetle, the haliplid *Haliplus halsei* (WARUS5 and WARUS6), and the hydrophilid *Laccobius billi* (WARUS5), are endemic to the Pilbara region.

H. halsei (Plate 7) is also relatively new to science, having only been recently described (Watts and McRae 2010). *H. halsei* appears to occur widely throughout the Pilbara but is infrequently collected. It is known from House Pool on the Cane River, Glen Ross Creek, Kumina 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). During the PBS, *H. halsei* was recorded at Chalyarn Pool and Myannore Creek, within 50 km of Warramboo Creek (Pinder *et al*. 2010).

L. billi (Plate 7) is rarely collected, and was recorded from only one site during the PBS; Cangan Pool on the Yule River (Pinder *et al.* 2010). WRM recorded *L. billi* at Mungarathoona Creek and a number of Red Hill Creek sites during their 2008/2009 WPIOP surveys (WRM 2009).

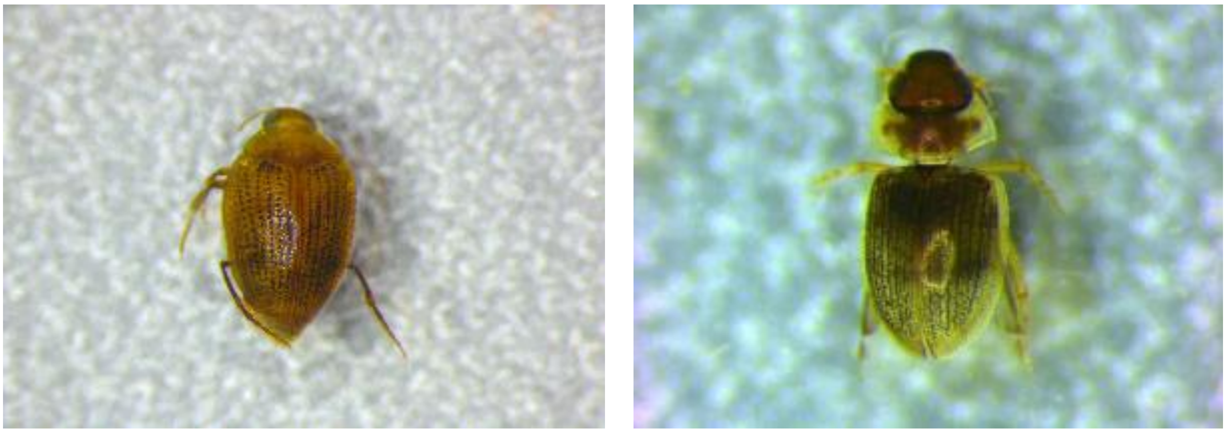

Plate 7. Pilbara endemic aquatic beetles *Haliplus halsei* (left) and *Laccobius billi* (right). Photographs by WRM ©.

5.5 Sediment Rehydration

5.5.1 Taxonomic composition

A total of 20 micro- and macro-invertebrate taxa were recorded from rehydrated sediments collected from Warramboo Creek, after the 57 day inundation period. Macroinvertebrate fauna recorded in the current study included Turbellaria (flat worms), Anostraca (fairy shrimp) and Conchostraca (clam shrimps), while microinvertebrate fauna included flagellates, ciliates, rotifers, cladocerans and ostracods. Ciliates and ostracods were present in all rehydrated samples. A complete list of taxa recorded at each site is provided in Appendix 6. This list includes specimens which could not be identified to species level due to unresolved taxonomy or immaturity of life stages present.

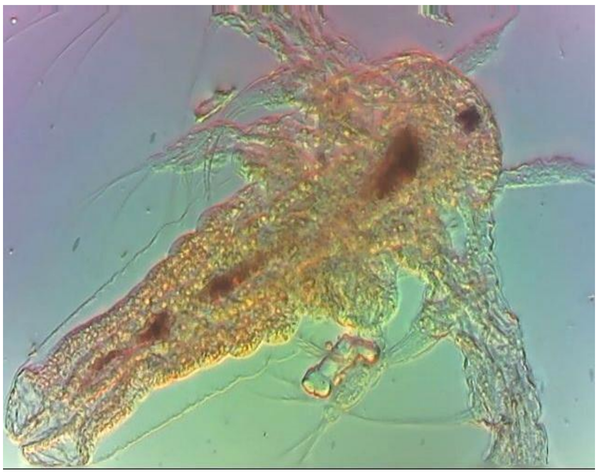

Plate 8. Anostraca nauplius (larva). Photograph by Dr Russell Shiel, University of Adelaide.

Flagellate and ciliate protists, the rotifers *Epiphanes spinosa* and *Brachionus* sp., the cladoceran *Moina* sp., and the anostracan nauplius (Plate 8) were the earliest to emerge after day five of inundation. Next to emerge, at day seven, was the turbellarian cf. *Mesostoma* sp. (WARDS2). At day ten, conchostracans and the cypridid ostracods *Bennelongia* spp. and *Cypretta* sp. emerged. Last to emerge were the rotifers *Trichocerca* cf. *pusilla* and *Filinia longiseta*, on day 26.

Numerous emergent fauna respond quickly to favourable conditions in order to mature and breed before conditions deteriorate (Brendonck 1996). For example, dormant bdelloid rotifers typically emerge within hours of rehydration (Ricci 2001), while most studies of dormancy in Branchipoda (cladocerans and conchostracans), report emergence within the first 1 - 3 days (Belk 1972, Stern and Stern 1971, Bishop 1967, Brendonck *et al.* 1993).

Ostracods were the dominate emergents in the current hatching trials, with at least three taxa recorded from each sample. *Bennelongia* species were present in all 11 samples, and *Cypretta* sp. present in 10 samples. First emergence of ostracods was between day 10 and day 22, though day of first emergence varied between samples within some species. For example, the cypridid cf. *Ilyocypris* sp., first emerged from WARUS6, WARDS2 and WARDS3 samples after day 15, but only emerged from WARUS5 samples on day 57.

The majority of taxa that emerged from the rehydrated sediments were not recorded in microinvertebrate, hypoheic or macroinvertebrate samples from WARUS5 or WARUS6. Of the macro- and microinvertebrate taxa recorded from Warramboo Creek surface waters, only *Bennelongia* and conchostracans also emerged from rehydrated sediments. *Bennelongia* species were present in surface water, hyporheic zone and sediments at WARUS5, while conchostracans were recorded in surface waters at both WARUS5 and WARUS6, and in sediments at WARUS5.

In total, nine taxa emerged from the WARUS5 sediment sample (seven exclusive to rehydrate samples), and eleven emerged from the WARUS6 sample (ten exclusive to rehydrate samples). These results indicate the sediment rehydration technique was successful in detecting taxa additional to those collected from surface waters and hyporheic zones.

Amongst sites, taxa richness in rehydrated sediments ranged from six (WARUS3, WARUS4, WARDS5, WARDS6) to 11 (WARUS6, WARDS3). There was no significant difference in richness between upstream reference sites (mean 8.0 taxa) and potentially exposed sites downstream of the proposed discharge outlet location (mean 8.5 taxa) (one-way ANOVA; df = 1, F = 0.195, p = 0.669). Average rates of emergence were similar for samples collected upstream and downstream of the proposed discharge outlet location, with total taxa richness appearing to plateaux (i.e. few new taxa emerging) by around day 22 at WARUS and day 31 at WARDS (**Error! Reference source not found.**).

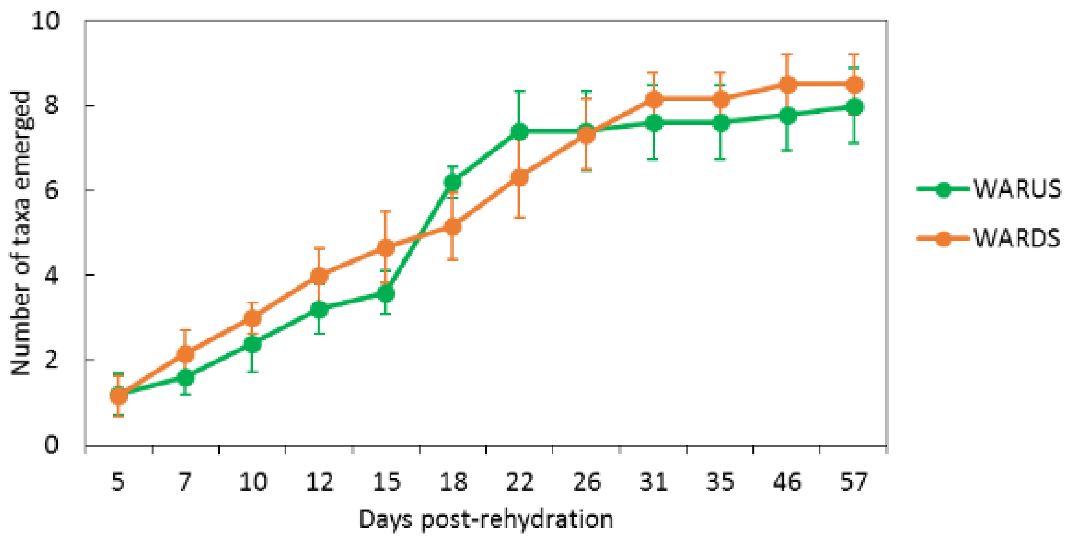

Figure 7. Cumulative number (mean ± standard error) of invertebrate taxa observed in rehydrated sediment samples over a 57 day period after inundation. Samples were collected from Warramboo Creek, upstream (WARUS) and downstream (WARDS) of the proposed discharge outlet location.

Overall, taxa richness in rehydrated Warramboo Creek sediments (20 taxa) was similar to, or higher than, richness recorded in other sediment rehydration studies of the Pilbara conducted by WRM (WRM 2012, WRM unpub. data). For example, rehydration of sediment samples from Coolibah woodlands in the Marandoo area, revealed a total of 11 taxa over a 47-day trial period. The number of emergents was considered low and with less diversity than expected (Dr Russell Shiel, University of Adelaide, pers. comm.). The composition of emergent taxa at Warramboo Creek was quite different to that of the Marandoo Coolibah woodlands, due to the absence of ostracods, but presence of notostracans (*Triops australiensis australiensis*) in the latter. The Coolibah woodlands were characterised by abundant vegetation and had been dry for six years prior to the 2012 sampling, whereas Warramboo Creek is sparsely vegetated and is likely inundated more frequently. While adaptation to resist desiccation promotes survival during drought, complete resistance to drying cannot be assured (Fryer 1996), and recovery rate of some dormant fauna has been shown to decrease as period between rainfall/wetting increases (Ricci 2001). Dormant propagules in an egg bank may also require several wetting/drying cycles to trigger emergence (Brandonck 1996). Insecta were absent from Warramboo Creek rehydrated sediment samples, which may indicate that the length of time between periods of inundation in this system is too long for taxa that can persist as larvae by aestivating or encysting in sediments (e.g. Baetidae, Simuliidae, Ceratopogonidae, Chironomidae) (Horsfall 1956, Hinton 1960, Danks 1987).

5.5.2 Conservation/scientific significance of emergent taxa

The majority of aquatic fauna recorded during the sediment rehydration study were common ubiquitous species, with distributions extending across Northern Australia. No species recorded are listed on international conservation lists or known to be priority species, threatened, and/or scheduled fauna. However, the presence of Epiphanidae rotifer *Epiphanes spinosa* (Plate 9) in the sample from WARDS3 represents a new record for Western Australia. There are only three other records of this species for the Australian continent, all from the Murray-Darling River system in South Australia/New South Wales (Dr Russell Shiel, University of Adelaide, pers. comm.). This species is considered cosmopolitan in distribution, and has been found on the continents of North American and Africa.

Plate 9. Rotifer *Epiphanes spinosa*. Photograph by Dr Russell Shiel, University of Adelaide.

The immature anostracans recorded from WARUS1, WARUS6 and WARDS6 may belong to either the genus *Branchinella*, or *Streptocephalus*. As the specimens could not be identified to species, it was not possible to accurately assess their conservation status, but Williams (1980) suggests that individual species of *Branchinella* tend to be locally restricted. *Branchinella* are known to occur in temporary freshwaters such as pools, ditches, rockholes, ponds and claypans (Williams 1980). At least eight species of *Branchinella* are known from ephemeral waterbodies in the Pilbara, including *Branchinella affinis*, *Branchinella australiensis*, *Branchinella lyrifera*, *Branchinella occidentalis*, *Branchinella proboscida*, *Branchinella halsei*, *Branchinella mcraeae* and *Branchinella pinderi* (Pinder *et al*. 2010). It is possible that the anostracans from Warramboo Creek belong to one of these Pilbara endemics. However, they may belong to the species *Streptocephalus archeri*, which is known to occur throughout the Pilbara and beyond (Pinder *et al*. 2010, Timms 2015).

5.6 Other Fauna

Tadpoles were observed at both WARUS5 and WARUS6, with visual estimates of over 1,000 individuals per site. Though species-level identification of tadpoles was not undertaken, small adult Desert Tree Frogs, *Litoria rubella*, were also common around the edges of the pools at both sites (Plate 10). *L. rubella* is a common species in the Pilbara and is known to occur in a wide range of habitats across wider northern Australia (Tyler and Knight 2011). The Desert Tree frog is commonly found sheltering under stones or bark around creeks and waterholes. In the north they can breed at any time of year if water is present.

Plate 10. Desert Tree frog, *Litoria rubella*, at WARUS5. Photograph by WRM ©.

6 SUMMARY AND CONCLUSION

Baseline water quality and aquatic fauna sampling was conducted at two ephemeral surface water pools in Warramboo Creek (WARUS5 and WARUS6) within the Mesa A / Warramboo survey area in May 2016, upstream of the proposed dewatering discharge location. Due to the highly ephemeral nature of Warramboo Creek, sediment samples were collected from 11 sites (six downstream and five upstream of the proposed discharge location) for rehydration in the laboratory to provide a species list of invertebrates which are prompted to emerge following seasonal inundation. One site upstream of the proposed discharge location, WARUS2, was unable to be sampled due to strong currents caused by flooding, which occurred as a result of a large overnight rainfall event prior to the last scheduled sampling day.

The water in the two small surface water pools was fresh with generally low electrical conductivity (211 - 309 µS/cm), super-saturated dissolved oxygen levels (109.8 - 125.2%) and pH of 7.56 - 8.22. Background concentrations of most metals were below ANZECC/ARMCANZ (2000) default TVs for the protection of 95% of freshwater species. The exception was aluminium at WARUS5 (0.083 mg/L), which exceeded both the default 95% TV (0.055 mg/L) and 90% TV (0.080 mg/L). Background levels of nitrogen were enriched in both pools, with ammonia ($N\text{-}NH_3$) and total nitrogen (TN) exceeding the default TVs for protection against eutrophication at both WARUS5 (0.14 mg/L N-NH3, 1.8 mg/L N-total) and WARUS6 (0.02 mg/L N-NH3, 0.79 mg/L N-total). Nitrogen oxides also exceeded the default eutrophication TV at WARUS5 (0.02 mg/L $N\text{-}NO_x$). Nitrogen enrichment was likely due to the presence of cattle and evapo-concentration effects in the small ephemeral pools. In general, there were only minor differences in water quality between WARUS5 and WARUS6, reflecting differences in the size of the remnant pools and likely varying rate of evapoconcentration.

A number of analytes were also found to be elevated in Mesa A / Warramboo production bores relative to surface waters, i.e. EC and associated ions (Ca, Cl, HCO_3, Na, Mg, SO_4), TDS, alkalinity, hardness, NO_3, $N\text{-}NO_3$, B, Cd, Cr, Mn, Pb, Ni, U and Zn. Average concentrations of EC, B, Cd, N-total, NO_3 and $N\text{-}NO_3$ in production bores also exceeded ANZECC/ARMCANZ (2000) default 95% species protection TVs for surface waters. High levels of EC and potential toxicants such as metals and nitrate in dewatering discharge may be of issue for aquatic biota, particularly if discharge water constitutes most of the surface water in remnant creek pools over the dry season.

A total of 19 microinvertebrate (zooplankton) taxa were recorded, of which 8 were present at WARUS5 and 15 at WARUS6. Microinvertebrate groups included Protista, Rotifera, Copepoda and Ostracoda (seed shrimp). The composition of microinvertebrate fauna was somewhat atypical of that commonly recorded from tropical / sub-tropical freshwater systems, with Lecanidae (which usually dominate the assemblages of tropical assemblages) comprising less than 50% of rotifer taxa. Microinvertebrate taxa richness was significantly lower than wet season taxa richness recorded during previous similar surveys of nearby Mungarathoona Creek (45 km south east of the current survey area) and Red Hill Creek (50 km south east), but was similar to dry season taxa richness in these creeks (WRM 2009, Pinder *et al.* 2010). Possible explanations for the low diversity recorded during May 2016, include limited sampling at Warramboo Creek (2 sites) compared to Mungarathoona (8 sites) and Red Hill (8 sites), low antecedent rainfall, and apparent lack of perennial waterbodies within the Warramboo Creek system. One microinvertebrate species listed for conservation significance, the calanoid copepod *Eodiaptomus lumholtzi* (IUCN **Vulnerable**), was recorded in low numbers at both sites. The conservation listing of this species is, however, considered in need of revision, as it is now known to occur at numerous locations across the Pilbara region.

A total of 25 hyporheic invertebrate taxa were recorded from WARUS5 and WARUS6, the majority of which were species not specially adapted to groundwater environments (stygoxene). Approximately 20% were considered occasional hyporheic stygophiles (species that use the hyporheic zone seasonally or during early life history stages) and 14% were classified as possible hyporheic taxa. No taxa recorded were considered to be stygobites (obligate groundwater species) or likely short-range endemics (SREs). Hyporheic taxa richness was higher than recorded during similar previous studies of hyporheos of Mungarathoona and Red Hill creeks (WRM 2009). The absence of stygobitic fauna in the hyporheic zone of Warramboo Creek pools suggests there is limited connectivity between the creek bed and the underlying aquifer. RTIO (2015a) documents the water table at between 12 and 30 metres below ground level in the Warramboo area.

A total of 76 macroinvertebrate taxa were recorded from surface waters at WARUS5 and WARUS6. Species composition was typical of freshwater systems throughout the world, being dominated by Insecta, and in particular Coleoptera (aquatic beetles) and Diptera (true flies). No macroinvertebrate species listed for conservation significance were recorded. The majority of macroinvertebrate fauna recorded from WARUS5 and WARUS6 were considered “temporary” resident taxa, i.e. mostly adult stage insects which colonise pools by aerial migration (i.e. Coleoptera, Hemiptera), and larval stage insects that would have hatched from eggs deposited by winged adults (i.e. Diptera, Odonata, Trichoptera and Ephemeroptera) (Williams 1985, Boulton 1989). However, some “permanent” resident taxa (nematodes, oligochaetes and conchostracans) were also present. Macroinvertebrate taxa richness was generally comparable to, or higher than, that recorded at nearby Mungarathoona and Red Hill creeks by WRM (2009), and at PBS sites by Pinder *et al.* (2010). Assemblage composition was significantly different between the current and WRM (2009) study, though the high temporal variability in invertebrate assemblages (widely observed for dry tropical Australian rivers) is likely to be the main factor contributing to these differences, given the time difference of seven years between sampling events.

The rehydration of benthic sediments from 11 sites on Warramboo Creek, revealed 20 micro- and macro-invertebrate taxa. Emergent macroinvertebrate fauna included Turbellaria (flat worms), Anostraca (fairy shrimp) and Conchostraca, while microinvertebrate fauna included Protista (flagellates and ciliates), Rotifera, Cladocera and Ostracoda. Only two taxa recorded from sediment rehydrates were also recorded from surface water and hyporheic zone samples, namely the ostracods *Bennelongia* spp. and immature conchostracans. In total, 14 taxa (seven from WARUS5 and nine from WARUS6) were recorded from sediment rehydrates that were not recorded from either surface waters or hyporheic zones.

This study provides a snapshot of water quality conditions and faunal communities at a single point in time and at a limited number of sites, therefore the values reported above are unlikely to represent the full range of conditions present along Warramboo Creek, and do not provide information on temporal / seasonal variability within the survey area. A summary of all the conservation/scientifically significant aquatic fauna recorded from Warramboo Creek during the 2016 survey is provided in Table 7.

Table 7. Summary of aquatic species of conservation and/or scientific value recorded during the current survey**.**

Species	Type	Conservation / Scientific value	Current survey	Occurrence within 50 km of survey area	Occurrence elsewhere
Microinvertebrates					
Lecane nitida	Rotifer	Not previously known from Western Australia	WARUS6	No records	Cosmopolitan distribution, previously recorded from Laos, India and Brazil.
Epiphanes spinosa	Rotifer	Not previously known from Western Australia	WARDS3	No records	Cosmopolitan distribution, previously recorded from Laos, India and Brazil.
Eodiaptomus lumholtzi	Copepod (micro-crustacean)	**IUCN, Vulnerable** (needs updating)	WARUS5, WARUS6	No records	Fortescue River, Coondiner Creek, Kalgan Creek, Weeli Wolli Creek, Koodaideri Springs, Caves Creek, Duck Creek, Cane River. Known also from Papua New Guinea.
Macroinvertebrates					
Haliplus halsei	Aquatic haliplid beetle	Pilbara endemic; relatively new to science	WARUS5, WARUS6	House Pool (Cane River), Chalyarn Pool and Myannore Creek Pool	Glen Ross Ck, Coondiner Pool, the Fortescue Marsh, Moreton Pool, Paradise Pool, Munreemya Billabong, Wackilina Ck Pool, West Peawah Creek Pool, Harding River Pool, and an un-named creek in Millstream.
Laccobius billi	Aquatic hydrophilid beetle	Pilbara endemic; rarely collected	WARUS5	Mungarathoona Creek and Red Hill Creek	Cangan Pool on Yule River, Weeli Wolli Creek, Coondiner Creek, Mindy Mindy Creek and the Ashburton River.

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APPENDICES

Appendix 1. Photographs of Warramboo Creek aquatic ecosystem sampling sites.

WARUS1

WARUS2

WARUS3

WARUS4

WARUS5

WARUS6


WARDS1


WARDS2


WARDS3


WARDS4


WARDS5


WARDS6

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 species protection (mg/L).

Compound		*Trigger values for freshwater Level of protection (% species)*			
		99%	*95%*	*90%*	*80%*
METALS & METALLOIDS					
Aluminium pH > 6.5		0.027	0.055	0.08	0.15
Aluminium pH < 6.5		ID	ID	ID	ID
Arsenic (As III)		0.001	0.024	0.094	0.36
Arsenic (As IV)		0.0008	0.013	0.042	0.14
Boron		0.09	0.37	0.68	1.3
Cadmium	H	0.00006	0.0002	0.0004	0.0008
Cobalt		ID	ID	ID	ID
Chromium (Cr III)	H	ID	ID	ID	ID
Chromium (Cr VI)		0.00001	0.001	0.006	0.04
Copper	H	0.001	0.0014	0.0018	0.0025
Iron		ID	ID	ID	ID
Manganese		1.2	1.9	2.5	3.6
Molybdenum		ID	ID	ID	ID
Nickel	H	0.008	0.011	0.013	0.017
Lead	H	0.001	0.0034	0.0056	0.0094
Selenium (Se total)		0.005	0.011	0.018	0.034
Selenium (Se IV)		ID	ID	ID	ID
Uranium		ID	ID	ID	ID
Vanadium		ID	ID	ID	ID
Zinc	H	0.0024	0.008	0.015	0.031
NON-METALLIC INORGANICS					
Ammonia (N-NH_3)		0.32	0.9	1.43	2.3
Chlorine		0.0004	0.003	0.006	0.013
Nitrate (NO_3)		0.017	0.7	3.4	17

H = default TV for these metals should be adjusted to allow for the ameliorating influnce of water hardness of metal toxicity. ANZECC/ARMCANZ (2000) provides algorithms for this in Tables 3.4.3 and 3.4.4 of Section 3.4.3. ANZECC/ARMCANZ (2000) note that a hardness modified default TV for copper may not protect sensitive species.

Appendix 3. Microinvertebrates collected from Warramboo Creek surface waters in May 2016

Table 3-1. Microinvertebrate taxa recorded from the surface water pools present along Warramboo Creek during May 2016. 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	WARUS5	WARUS6
PROTISTA				
Rhizopoda	**Arcellidae**	*Arcella discoides*	1	0
ROTIFERA				
Monogononta	**Brachionidae**	*Keratella procurva*	0	2
		Plationus patulus	0	2
	Euchlanidae	*Euchlanis dilatata*	0	1
	Gastropodidae	*Ascomorpha* sp.	0	3
	Lecanidae	*Lecane bulla*	0	2
		Lecane lunaris	0	2
		Lecane nitida **(New record for WA)**	0	2
		Lecane (M.) sp. a	0	1
		Lecane (M.) sp. b	0	1
	Notommatidae	*Cephalodella* sp.	0	1
	Synchaetidae	*Polyarthra* sp.	0	1
ARTHROPODA				
CRUSTACEA				
MAXILLIPODA				
Calanoida		Calanoid copepodite	2	0
		Calanoid nauplii	1	4
	Diaptomidae	*Eodiaptomus lumholtzi* **(Vulnerable D2 IUCN ver 2.3)**	3	1
Cyclopoida		Cyclopoid copepodites	2	1
		Cyclopoid nauplii	1	2
OSTRACODA				
Podocopida	**Cyprididae**	*Bennelongia* sp.	2	0
	Notodromadidae	*Newnhamia fenestrata*	3	0
		Taxa richness	**8**	**15**

Appendix 4. Hyporheic invertebrates collected from Warramboo Creek in May 2016

Table 4-1. Hyporheic invertebrate taxa recorded from Warramboo Creek during May 2016. 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	WARUS5	WARUS6
NEMATODA		Nematoda spp.	2	2
ANNELIDA				
OLIGOCHAETA				
Tubificida	**Naididae**	Naidinae spp. (imm./dam.)	3	2
		Pristina longiseta	4	3
ARTHROPODA				
CRUSTACEA				
MAXILLIPODA				
Cyclopoida		Cyclopoid copepodites	3	2
	Cyclopidae	*Microcyclops varicans*	3	2
BRANCHIOPODA				
DIPLOSTRACA				
Cladocera	**Ilyocryptidae**	*Ilyocryptus raridentatus*	2	0
OSTRACODA				
Podocopida		indet. juvenile ostracod	0	1
	Cyprididae	*Bennelongia* sp.	1	0
ARACHNIDA		Acarina sp.	0	1
HEXAPODA				
ENTOGNATHA				
Entomobryomorpha		Entomobryoidea sp.	0	1
Symphypleona		Symphypleona spp.	1	1
INSECTA				
Odonata				
Anisoptera		Anisoptera sp. (imm./dam.)	0	1
Ephemeroptera	**Caenidae**	Caenidae spp. (imm./dam.)	0	2
Diptera	**Ceratopogonidae**	Ceratopogonidae spp. (P)	2	2
		Ceratopogoninae spp.	4	3
	Chironomidae			
	Chironominae			
	Chironomini	*Dicrotendipes* sp. 2	2	0
		Polypedilum sp. 1	3	0
		Parachironomus sp. K2	1	0
	Tanytarsini	*Tanytarsus* sp. (WWTS1)	2	0
		Cladotanytarsus sp. (WWTS4)	3	1
	Tanypodinae	*Larsia albiceps*	2	0
		Procladius sp. (WWT5)	2	1
		Dolichopodidae spp.	0	2
		Tipulidae spp.	2	1
Trichoptera		Trichoptera sp. (imm./dam.)	0	1
		Taxa richness	18	18

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 5. Macroinvertebrates collected from Warramboo Creek surface waters in May 2016

Table 5-1. Macroinvertebrate taxa recorded from the surface water pools present along Warramboo Creek during May 2016. 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	WARUS5	WARUS6
NEMATODA		Nematoda sp.	0	1
MOLLUSCA				
GASTROPODA				
Cerithimorpha	**Thiaridae**	*Melanoides* spp.	0	2
	Planorbidae	*Bayardella* spp.	2	3
ANNELIDA				
OLIGOCHAETA		Oligochaeta spp.	3	2
ARTHROPODA				
CRUSTACEA				
Branchiopoda				
Diplostraca	**Cyzicidae**	*Caenestheriella packardi*	3	2
CHELICERATA				
ARACHNIDA		Acarina spp.	2	3
HEXAPODA				
ENTOGNATHA				
Symphypleona		Symphypleona spp.	0	2
INSECTA				
Odonata				
Anisoptera		Anisoptera spp. (imm./dam.)	2	3
	Aeshnidae	*Hemianax papuensis*	2	2
	Corduliidae	*Hemicordulia tau*	2	2
	Libellulidae	*Diplacodes haematodes*	3	1
		Neurothemis sp.	0	1
		Orthetrum caledonicum	3	2
Zygoptera	**Coenagrionidae**	*Ischnura aurora*	0	1
Ephemeroptera	**Baetidae**	Baetidae spp. (imm./dam.)	2	2
		Cloeon fluviatile	2	0
	Caenidae	Caenidae sp. (imm./dam.)	0	1
		Tasmanocoenis sp. M	1	0
		Tasmanocoenis sp. P/*arcuata*	1	0
Hemiptera	**Corixidae/Micronectidae**	Corixidae/Micronectidae spp. (imm./dam.)	2	3
	Corixidae	*Agraptocorixa* spp.	2	1
		Agraptocorixa parvipunctata	3	2
	Micronectidae	*Micronecta* spp.	0	2
		Micronecta annae	0	2
		Micronecta gracilis	2	2
		Micronecta lansburyi	2	2
	Hebridae	Hebridae sp.	0	1
		Hebrus axillaris	2	0
	Notonectidae	Notonectidae spp. (imm./dam.)	0	3
		Anisops spp.	3	3
		Anisops nasutus	2	2
		Anisops stali	2	0
	Pleidae	*Paraplea* sp.	0	1
Coleoptera	**Dytiscidae**	*Allodessus bistrigatus*	1	2
		Eretes australis	3	1
		Hydroglyphus grammopterus	2	3
		Hydroglyphus orthogrammus	2	0

Phylum/Class/Order	Family	Lowest Taxon	WARUS5	WARUS6
		Hyphydrus lyratus	0	2
		Laccophilus sharpi	2	2
		Limbodessus compactus	0	2
		Tiporus lachlani	2	1
	Gyrinidae	*Dineutus* sp. (L)	0	1
		Dineutus australis	3	3
	Haliplidae	*Haliplus halsei*	2	1
	Hydraenidae	*Hydraena* spp.	3	3
		Limnebius spp.	3	3
		Ochthebius spp.	0	2
	Hydrochidae	*Hydrochus* spp.	3	3
	Hydrophilidae	*Agraphydrus coomani*	1	0
		Berosus dallasae	2	0
		Berosus pulchellus	3	2
		Enochrus deserticola	0	2
		Helochares tatei	0	1
		Laccobius billi	2	0
		Regimbartia attenuata	0	1
Diptera	**Ceratopogonidae**	Ceratopogonidae spp. (P)	2	0
		Ceratopogoninae spp.	3	3
		Dasyheleinae sp.	1	0
		Forcipomyiinae sp.	1	0
	Chironomidae	Chironomidae spp. (P)	2	2
	Chironominae			
	Chironomini	*Cryptochironomus griseidorsum*	2	0
		Polypedilum (Pentapedilum) leei	0	3
		Dicrotendipes sp. 2	2	0
		Polypedilum sp. 1	2	3
		Parachironomus sp. K2	2	2
		Dicrotendipes sp. 5 (WWC38)	2	0
	Tanytarsini	*Cladotanytarsus* sp. (WWTS4)	3	2
	Tanypodinae	*Paramerina* sp. (WWT1)	0	2
		Larsia albiceps	3	0
		Procladius sp. (WWT5)	3	2
		Ablabesmyia hilli	2	0
	Culicidae	*Culex* sp.	0	1
	Tanyderidae	Tanyderidae sp.	0	1
Trichoptera	**Ecnomidae**	*Ecnomus* sp.	1	0
	Leptoceridae	Leptoceridae sp. (imm./dam.)	0	1
		Oecetis spp.	3	0
		Taxa richness	**53**	**57**

(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 6. Invertebrates emerged from rehydrated Warramboo Creek sediment samples collected in May 2016

Table 6-1. Invertebrate taxa emerged from rehydrated sediments collected from Warramboo Creek during May 2016. The earliest day taxa emerged in each sample is provided, along with the median day of first emergence is given for each taxa (across all samples), and for each sample (across all taxa). 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	Earliest emergence (day)	Median first day of emergence	WARU S1	WARU S3	WARU S4	WARU S5	WARU S6	WARD S1	WARD S2	WARD S3	WARD S4	WARD S5	WARD S6
PROTISTA															
Flagellates		Flagellates	*5*	*7*	0	2	0	2	3	3	2	0	3	4	0
Ciliophora		Ciliates	*5*	*5*	4	3	3	3	3	3	3	3	3	3	2
PLATYHELMINTHES															
Turbellaria	**Typhloplanidae**	cf. *Mesostoma* sp.	*7*	*15*	2	1	2	0	2	2	2	0	0	0	0
ROTIFERA		Indet. rotifer	*22*	*27*	0	0	0	0	1	0	1	0	0	0	0
Monogononta	**Brachionidae**	*Brachionus* sp.	*5*	*6*	0	0	0	0	0	0	0	1	0	2	0
	Epiphanidae	*Epiphanes spinosa*	*5*	*5*	0	0	0	0	0	0	0	2	0	0	0
	Trichocercidae	*Trichocerca* cf. *pusilla*	*26*	*26*	0	0	0	0	0	0	0	1	0	0	0
	Trochosphaeridae	*Filinia longiseta*	*26*	*26*	0	0	0	0	0	0	0	1	0	0	0
ARTHROPODA															
CRUSTACEA															
ANOSTRACA		Indet. anostracan	*5*	*10*	1	0	0	0	2	0	0	0	0	0	2
DIPLOSTRACA															
Conchostraca		Conchostraca sp.	*10*	*10*	0	0	0	1	0	0	0	0	0	0	0
Cladocera	**Chydoridae**	Aloninae sp.	*18*	*18*	0	0	0	0	1	0	0	0	0	0	0
	Macrotrichidae	*Macrothrix* sp.	*22*	*22*	0	0	0	0	3	0	0	0	0	0	0
	Moinidae	*Moina* sp.	*5*	*7*	3	0	0	1	0	0	1	0	0	0	0
OSTRACODA															
Podocopida		Indet. ostracod	*10*	*18*	0	1	0	2	0	0	0	1	2	3	0
	Cyprididae	cf. Cypridopsid	*12*	*22*	0	0	0	3	1	1	1	3	2	3	2
		Bennelongia spp.*	*10*	*18*	3	3	4	3	3	2	3	3	3	3	4
		Cypretta sp.	*10*	*18*	3	3	3	3	2	2	3	3	3	0	3
		cf. *Ilyocypris* sp.	*15*	*18*	0	0	3	2	0	2	3	3	2	0	2
		Stenocypris major	*18*	*22*	2	2	3	0	3	0	3	2	2	2	2
	Limnocytheridae	cf. *Limnocythere* sp.	*22*	*22*	0	0	0	0	0	0	0	0	2	0	0
			Taxa richness		**7**	**7**	**6**	**9**	**11**	**7**	**10**	**11**	**8**	**7**	**7**
			Earliest emergence (day)		***5***	***5***	***5***	***7***	***5***	***5***	***5***	***5***	***7***	***5***	***10***
			Median day of first emergence		***10***	***15***	***17***	***12***	***18***	***26***	***12***	***15***	***18***	***18***	***12***

*two morphotypes observed.