# YANDI:
# MARILLANA CREEK AQUATIC FAUNA SURVEY

## Wet & Dry 2017 Sampling
## Final Report

Wetland Research & Management

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*Frontispiece (left to right):* Marillana Creek site MC2 upstream of Yandi discharge; Weeli Wolli Creek reference pool WMC, and MC9 downstream of discharge. All photos taken during the wet-17.

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# EXECUTIVE SUMMARY

BHP Iron Ore Pty Ltd (BHPIO) commissioned *Wetland Research and Management* (WRM) to undertake an aquatic fauna survey of Marillana Creek within the Marillana (Yandi) mining lease. Hereafter, this area is referred to as the Study Area.

The scope of work for the survey included:

- A literature and database review of prior aquatic surveys and aquatic fauna of significance within the Study Area, including the findings from the previous survey conducted by WRM in 2014;
- Field surveys in 2017, to supplement benchmark data from 2014 surveys on water quality and aquatic fauna of Marillana Creek;
- Determine the significance of the aquatic fauna of Marillana Creek;
- Provide a comprehensive dataset against which any future changes in water quality or aquatic fauna may be assessed, including potential effects of creek diversion as well as other potential mine-related impacts.

Field sampling in 2017 was conducted at the same time of year as in 2014, i.e. during the late wet (May) and late dry (September) season, however not all sites were sampled on each occasion. A number of sites were dry at the time of the 2014 field surveys, while three sites were dry at the time of the dry season survey 2017. In total, nine sites were successfully sampled during the late wet season 2017, and six sites successfully sampled in the late dry 2017. Of these, five sites were sampled on both occasions in 2017. Field surveys included habitat characterisation and sampling of water quality, microinvertebrates (zooplankton), hyporheic fauna, macroinvertebrates, fish and opportunistic observations for other aquatic vertebrates (frogs and turtles).

Sites within the Study Area were generally dominated by transmissive gravel and sand substrates and characterised by submerged macrophyte and algal habitats. Sites MC1 and MC2, both located within the Study Area, are considered to be of some importance as they are the only long-term pools within the Study Area. These pools were classified as semi-permanent to permanent based on visual extent of surface water during the dry seasons of both 2014 and 2017.

Surface water quality within the Study Area was generally good. Sites were characterised by fresh to slightly brackish waters, with moderate to high dissolved oxygen levels, circum-neutral to basic pH, generally low dissolved metal levels and high alkalinity (thus buffering capacity). At sites within the Study Area and at reference sites, a number of water quality parameters exceeded ANZECC/ARMCANZ (2000) default guidelines (trigger values) for the protection of aquatic systems in tropical northern Australia. ANZECC/ARMCANZ (2000) recommend that default trigger values only be applied to systems for which there are no baseline data. Local conditions are naturally variable between river systems and because of this, ANZECC/ARMCANZ (2000) recommend the development of 'system-specific' trigger values. The aim in developing site-specific guidelines would be to protect the current integrity and ecological value of the system (i.e. avoid any adverse changes), while acknowledging that surface water quality is already likely modified compared to pre-mine condition. This is particularly relevant to concentrations of inorganic nitrate downstream of the discharge outlet, which are at least an order of magnitude greater than at upstream sites on Marillana Creek and at regional reference sites.

A diverse invertebrate fauna (microinvertebrates, hyporheos fauna and macroinvertebrates) was recorded during both the 2014 and 2017 surveys. The sections of natural creekline upstream of the western diversion (MC1 - MC3), and between the western and eastern diversions (MC4 - MC6) supported the highest number of all faunal components, as well as the greatest number of significant species (short range endemics, conservation listed species, rare taxa and/or Pilbara endemics).

The majority of invertebrate species recorded are common and widespread throughout the Pilbara. None are specifically listed under state or national legislation (DBCA Priority Fauna or EPBC Act). However, a number of stygal species recorded in the hyporheos are of importance as they are locally restricted, short range endemics (SREs). Five acknowledged stygal SREs occur within, but are not restricted to, the Study Area. These include the amphipods Paramelitdae sp. B (MC1 to Weeli Wolli Creek confluence), Paramelitdae sp. D (MC1 to Weeli Wolli Creek confluence) and *Chydaekata* sp. (MC1 to Weeli Wolli Creek confluence), the isopod *Pygolabis weeliwolli* (MC7 to downstream of Rio Tinto Yandicoogina), and the ostracod *Gomphodella* n. sp. (BOS334) (MC1 & MC6). A sixth stygal SRE amphipod, *Maarrka Weelwolli*, is likely to occur within the Study Area, based on its occurrence in the Marillana catchment downstream, and from the Weeli Wolli catchment, both upstream and downstream of the Marillana Creek confluence. A table detailing all of the significant species recorded during the current study and/or previously known from the Marillana Creek system, along with their site locations and wider distributions, is provided in Section 6 of this report.

Three common, widespread freshwater fish species were recorded from within the Study Area and at reference sites. These were the western rainbowfish (*Melanotaenia australis*), spangled perch (*Leiopotherapon unicolor*) and Pilbara tandan (*Neosilurus* sp.). The IUCN and DBCA Priority Fauna listed Fortescue grunter *Leiopotherapon aheneus* occurs in the greater Fortescue catchment, but is not considered likely to occur in Marillana Creek.

Given that all recorded stygal SREs have distributions which extend outside the Study Area, and that the epigean species recorded are common throughout the Marillana, Weeli Wolli and Fortescue catchments, it is expected that any localised reduction or loss of epigean or stygal species, due to disturbance from channel re-alignment, will be short-term. This assumes suitable stable aquatic habitats are available within the diverted sections.

There are however, existing differences in aquatic invertebrate communities upstream and downstream of the discharge outlet, which together with water quality differences (e.g. nitrate levels), will need to be taken into consideration when interpreting results from any future impact assessments. The differences in invertebrate communities are considered largely flow-related and include lower species richness, abundance and differing species assemblage composition downstream of the discharge outlet, compared to upstream and in reference creeks.

This report presents data from four sampling events, covering the late wet and late dry seasons of 2014 and 2017. The data provide a benchmark against which any future changes in water quality and aquatic fauna assemblages (microinvertebrates, hyporheos fauna, macroinvertebrates and fish) within the Study Area may be assessed. It is recommended that any future monitoring include reference sites as sampled for the current study, in order to distinguish any potential mine-related impacts from natural year-to-year variability (e.g. climate change).

# 1. INTRODUCTION

## 1.1 Background

BHP Iron Ore Pty Ltd (BHPIO) currently operates the Marillana (Yandi) open pit iron ore mine, which is located approximately 100 km to the north-west of the town of Newman in the Pilbara region of Western Australia. BHPIO is in the advanced stages of planning, to undertake a series of diversions of the Marillana Creek at Yandi. To ensure the capturing of a robust aquatic fauna baseline prior to the commencement of future planned work associated with these diversions, BHPIO commissioned Wetland Research and Management (WRM) to undertake wet and dry season surveys in 2017, that would build upon the previous wet and dry season survey conducted by WRM in 2014 (WRM 2015).

As requested by BHPBIO at the time, the 2014 survey was not 'targeted' to any specific project *per se* but was intended to characterise the fauna and conditions within the broader project area. Now that the locations of the proposed diversions on Marillana Creek are known, the current survey was designed to address specific aspects of the overall project, including i) potential downstream impacts of the diversions on the fauna, habitat and water quality of Marillana Creek, and ii) provision of a robust baseline which may be used to assess the 'ecological performance' of the diversions relative to the natural creekline once the diversions are constructed and stable.

Together with the 2014 sampling, the 2017 sampling provides benchmark data on the aquatic ecosystem of Marillana Creek within the Yandi mining lease (the "Study Area"), as well as reference pools outside this area to provide regional context.

## 1.3 Scope of Work

The specific scope of work included:

- A literature/database review of all previous, publicly available aquatic fauna work carried out within the vicinity of the Study Area, including the findings from the previous survey conducted by WRM;
- Systematic sampling of aquatic fauna (fish, macro- and microinvertebrates, hyporheic fauna), water quality (general ions, conductivity, pH, nitrogen, phosphorus, dissolved metals, TDS, dissolved oxygen) and habitat assessments at all Marillana Creek and reference sites in late wet and late dry seasons 2017;
- Reporting of water quality data against ANZECC/ARMCANZ (2000) water quality guidelines for protection of aquatic ecosystems;
- Identification of all specimens collected to species level where possible;
- Assessment of the conservation status of aquatic fauna recorded;
- Analysis of all data using univariate and multivariate techniques to assess natural variability and detail seasonal changes in fauna, habitat and water quality (this will assist in discriminating between natural and potential mine-related impacts in the future);
- Preparation of a detailed technical report of all findings.

Aquatic sampling methods were consistent with those used in all previous WRM surveys for BHPIO, and are consistent with the methods detailed in the request for quote.

# 2. SURROUNDING AREA

## 2.1 Topography and Biogeographic Region

The regional topography, in which the Study Area is situated, is dominated by the Chichester Ranges in the north and the Hamersley Plateau to the south, with these features being divided by the Fortescue Valley. The main drainage system in the area is the Fortescue River, which flows north and then northwest into the Fortescue Marsh, before continuing northwest to the ocean.

The Study Area is located within the Hamersley subregion of the Pilbara region as defined in the Interim Biogeographic Regionalisation of Australia (IBRA) (Thackway and Cresswell 1995). This subregion is a mountainous area characterised by low mulga woodland over bunch grasses on fine soils within valley floors, and snappy gum (*Eucalyptus leucophloia*) over spinifex (*Triodia brizoides*) on skeletal soils of the ranges (Kendrick 2001a).

## 2.2 Hydrology

A number of creeklines traverse the Yandi tenement, including Marillana Creek, a major tributary of Weeli Wolli Creek. The Marillana Creek Catchment covers an area of approximately 2,050 km$^2$ and is part of the broader Upper Fortescue River Catchment (Johnson and Wright 2001). The headwaters rise in the Hamersley Range, and flow in an east and north-easterly direction into the Munjina Claypan (RTIO 2012). When the internal holding capacity of the claypan is exceeded, surface water flows south-east into the lower Marillana Creek catchment (RTIO 2012). The upper catchment is characterised by a broad alluvial plain with large areas of calcrete, while lower in the catchment, in the vicinity of the Yandi tenement, the drainage is well defined (Johnson and Wright 2001). While the creek is naturally ephemeral, there are a number of semi-permanent and permanent pools, including one named pool, Flat Rocks. This pool is located approximately 2 km east of Yandi, and is currently influenced by groundwater drawdown associated with Yandi operations. Surface flow in Marillana Creek is also currently influenced by dewatering discharge from both Yandi and the Rio Tinto Yandicoogina mine further downstream. Surplus dewater from Yandi has been discharged since 1994, while downstream, discharge from Rio Tinto Yandicoogina has been occurring since 1998. The cumulative discharge has led to an almost permanent flow downstream of the Rio Tinto discharge points, and isolated, intermittent pools below the BHPIO discharge point. As a result, the current aquatic fauna of Marillana Creek likely reflects this increase in flow, as well as pool permanence.

Marillana Creek flows into Weeli Wolli Creek. Weeli Wolli Creek is approximately 70 km in length, and has a catchment area of 4,100 km$^2$. A dense network of ephemeral tributary streamlines is associated with the system. Weeli Wolli Creek is fed in its mid-reaches by Weeli Wolli Spring, which prior to mining, arose as a result of groundwater flow being “dammed” by the Brockman Iron Formation (BIF), forcing groundwater to the surface and appearing as the perennial spring. Weeli Wolli Creek flows to the north, where it drains into the Fortescue River at the Fortescue Marsh. However, the two systems are only connected during flooding associated with intense cyclonic events (Kendrick 2001b). The Marsh is an extensive, episodically inundated samphire marsh, approximately 100 km long and 10 km wide (Kendrick 2001b, DEC 2009).

## 2.3 Climate

The climate of the Pilbara is semi-arid, with relatively dry winters and hot summers. Most rainfall occurs during the summer months and is predominantly associated with cyclonic events; when flooding frequently occurs along creeks and rivers (BOM 2018). 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. Average annual pan evaporation in the Pilbara is ten times greater than rainfall (BOM 2018). Most rainfall occurs during the summer months, between November and March.

Data from two DWER rainfall and streamflow gauging stations were accessed for analyses of recent trends; Waterloo Bore gauging station on Weeli Wolli Creek, downstream of the confluence with Marillana Creek, and Flat Rocks on Marillana Creek, upstream of Yandi. The Waterloo Bore GS lies downstream of the current wetting front and as such has been unaffected by mining operations to-date. Flows at this station, however, will likely become more heavily influenced by discharge operations in the future. Long-term median rainfall at Flat Rocks and Waterloo Bore was 358 mm (1974 - 2017) and 402 mm (1986 - 2017), respectively. Total annual rainfall varied greatly between years, with a maximum of 976 mm at Flat Rocks in 2000, and 950 mm at Waterloo Bore in 1999 (Figure 1). In only three of the last 10 years has rainfall below the long-term median at Flat Rocks (2009, 2010, 2011) and Waterloo Bore (2008, 2009, 2010).

Like rainfall, streamflow is also highly seasonal and variable. Natural flows occur as a direct response to rainfall, with peak flows tending to occur within 24 hours of a major rainfall event and continuing for several days. At Flat Rocks, the long-term median discharge was 3,498 ML/annum (1968 - 2017), with a maximum of 144,500 ML/annum in 1975 associated with high annual rainfall (717 mm). Since 2015, total annual discharge (1,086 - 2,070 ML) has been below the long-term median despite a trend toward increasing rainfall over the same period (Figure 1). At Waterloo Bore, the long-term median discharge was 6,118 ML/annum (1985 - 2017), with a maximum of 215,500 ML/annum in 2000.

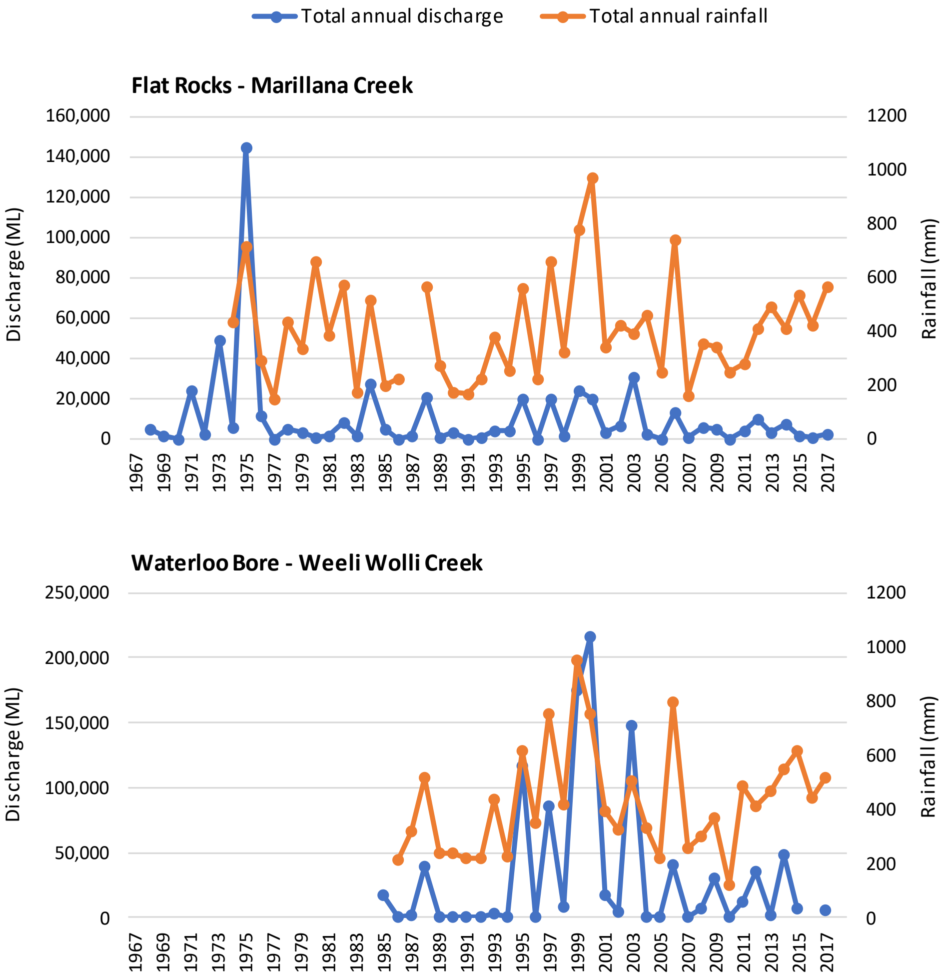

**Figure 1.** Total annual rainfall and streamflow at DWER gauging stations.

# 3. LITERATURE REVIEW

Many aquatic surveys have been conducted within the broader northwest region of Western Australia, including the Pilbara (Dames and Moore 1975, Miles and Burbidge 1975, Taylor 1985, Masini and Walker 1989, Kay *et al.* 1999, Smith *et al.* 1999), as well as a number which have included sample sites along Marillana Creek itself (i.e. Halse *et al.* 2001, Streamtec 2004, WRM 2011, WRM 2015 and unpub. data). Details of the studies which have included sites along Marillana Creek, and for which data are available within the public domain, are provided in Table 1. Locations of sample sites are shown in Figures 2 and 3.

The aquatic fauna of Marillana Creek is becoming reasonably well known. In 2014, WRM conducted wet and dry season aquatic fauna surveys of Marillana Creek on behalf of BHPIO, in order to provide benchmark data against which any potential changes caused by Yandi operations could be assessed (WRM 2015). Eight sites were successfully sampled on Marillana Creek within the Study Area, and two sites were sampled on Marillana Creek outside of the Study Area (reference sites). Surveys incorporated water quality, habitat characteristics, microinvertebrates, hyporheos fauna, aquatic macroinvertebrates and fish.

The authors have also sampled Marillana Creek for Rio Tinto bi-annually since 2008 (WRM 2011 and unpub. data). Twelve sites on Marillana Creek downstream of BHPIO's lease are sampled as part of Rio Tinto's Yandicoogina Aquatic Fauna Monitoring and two sites are sampled as part of Rio Tinto's Regional Sampling Program (WRM 2011). This work is ongoing. Limited data from these surveys is publicly available and is contained within the Yandi Aquatic Management Report (WRM 2011). Prior to the WRM sampling programme for Rio Tinto, few studies included sample sites along Marillana Creek (i.e. Halse *et al.* 2001, Streamtec 2004).

As part of a wider program throughout Western Australia, called the First National Assessment of River Health (FNARH), aquatic macroinvertebrates of the upper Fortescue River were sampled, including one site along Marillana Creek (Halse *et al.* 2001). This site was located downstream of both BHPIO and Rio Tinto's discharge and was sampled in March 1998 and November 1998 (site named Marillana Creek; Figure 1). A number of habitats were sampled, including channel, riffle, macrophytes, and pool rocks. FNARH was the second phase in the Australia-wide program, known as the Monitoring River Health Initiative (MRHI), to develop a biomonitoring system for assessing river condition based on aquatic macroinvertebrates (Halse *et al.* 2001). The biomonitoring system (AusRivAS) used predictive models to compare the occurrence of families of aquatic macroinvertebrate from a particular river, with those expected to occur if the site was in good biological condition (Halse *et al.* 2001). More than 550 sites in all of the major river systems of Western Australia were assessed in this manner. Invertebrate data available from this study is only to family-level rather than species-level.

In addition, Streamtec (2004) conducted an aquatic survey of a number of freshwater systems within the upper Fortescue River catchment, including Marillana Creek. This survey was commissioned by BHPIO to "assess the potential impacts, if any, of nearby iron-ore mining operations" (Streamtec 2004). The study was undertaken over two years, with field sampling being carried out during two seasons; the "wet" (March 2002 and 2003) and the "dry" (November 2001 and 2003). Surveys incorporated water quality, riparian vegetation, aquatic macroinvertebrates, fish, and other vertebrates.

**Table 1.** Details of aquatic studies which have included sites along Marillana Creek, including sample sites and methodology used. Fauna refers to the type of fauna targeted, i.e. macroinvertebrate (macro), microinvertebrate (micro), hyporheos (hypo) or fish.

| Program | Sampled by | Sites sampled | Fauna | Methods used | Identification | Sampling dates | Reference |
|---|---|---|---|---|---|---|---|
| First National Assessment of River Health as part of AusRivAS | DBCA | Many sites along the upper Fortescue River, including:<br>• One site on Marillana Creek (located downstream of both BHP Iron Ore's Yandi and Rio Tinto's Yandicoogina; referred to as MAR-DEC; see Figure 2). | Macro | Sweep netting using a 250 um dip net through all habitats. Identification to family level only. | Family-level only. | March-98 & Nov-98. | Halse *et al*. (2001) |
| Survey of the upper Fortescue River Catchment | Streamtec Consulting (commissioned by BHP Iron Ore) | A number of sites in the upper Fortescue River catchment, including:<br>• One permanent pool on Marillana Creek, upstream of all mining activity; Flat Rocks (see Figure 2). | Macro<br>Fish | Macro – sweep netting with a 250 um mesh pond net through all habitats.<br>Fish – seine netting | Various (some groups to order, some family, some genus and some to species). | Nov-01, March-02, March-03, Nov-03. | Streamtec (2004) |
| Rio Tinto Yandi Aquatic Fauna Monitoring | WRM | • 12 sites on Marillana Creek; 6 immediately downstream of BHPIO's Yandi and 6 downstream of Rio Tinto's Yandicoogina (see Figure 2);<br>• Flat Rocks (upstream of all mining activity on Marillana Creek);<br>• MAR-DEC. | Macro<br>Micro<br>Hypo<br>Fish | Macro - sweep netting with a 250 µm mesh pond net through all habitats.<br>Micro - sweep with a 53 µm mesh pond net over all habitats except benthos.<br>Hypo - Karaman-Chappuis method.<br>Fish – seine netting, electrofishing, gill nets. | Lowest taxon possible (species-level wherever possible). | Biannually (late wet and late dry) since 2008. Ongoing.<br>Only dry 2008- wet 2011 data available in the public domain. | WRM (2011) |
| BHPIO Yandi Aquatic Fauna Survey Wet & Dry Season 2014 | WRM | • Eight sites on Marillana Creek within the BHPIO Yandi lease;<br>• Two sites on Marillana Creek outside of the Study Area; upstream of all mining activity (Flat Rocks and FRDR);<br>• Three reference sites on Weeli Wolli Creek upstream of all mining activity (UWWCS, WM, WMU). | Macro<br>Micro<br>Hypo<br>Fish | Macro – sweep netting with a 250 µm mesh pond net through all habitats.<br>Micro - sweep with a 53 µm mesh pond net over all habitats except benthos.<br>Hypo - Karaman-Chappuis method.<br>Fish – seine netting, electrofishing, gill nets. | Lowest taxon possible (species-level wherever possible). | April/May-14 (wet season) & Sep-14 (dry season). | WRM (2015) |

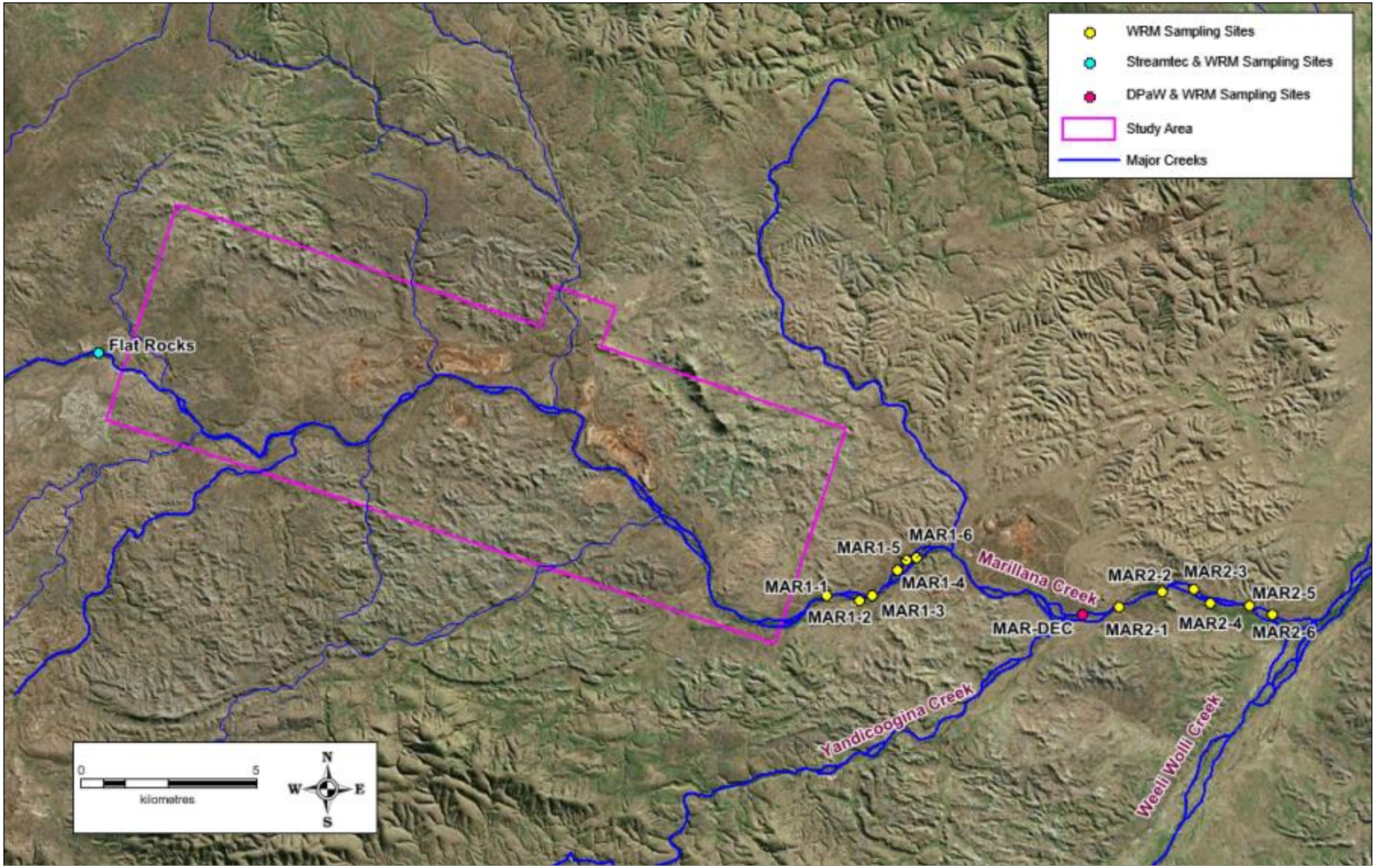

**Figure 2.** Location of sites previously sampled along Marillana Creek by WRM and others.

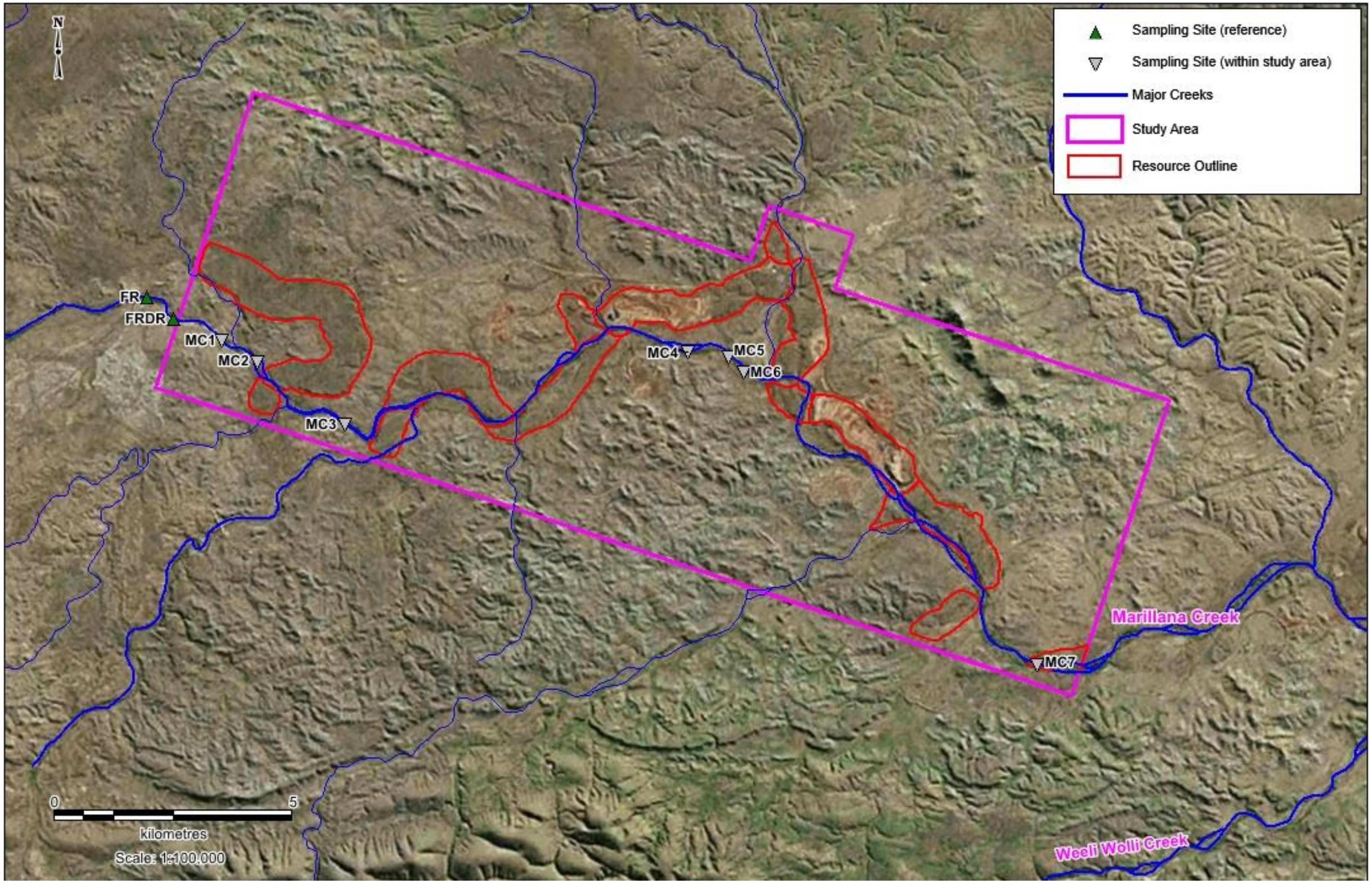

**Figure 3.** Location of Marillana Creek sites sampled by WRM (2015), in relation to the Yandi mine and Study Area.

Marillana Creek was sampled by Streamtec (2004) at Flat Rocks, a permanent pool located approximately 20 km upstream of all mining operations (Figure 2). Sampling involved *in situ* water quality measurements (temperature, dissolved oxygen and pH) and laboratory analyses (salinity, electrical conductivity, turbidity and nutrients). Aquatic macroinvertebrates were collected using both standard qualitative (composite sweep samples) and quantitative (Surber sampling) methods (Streamtec 2004). In addition, stable carbon and nitrogen isotope analysis was undertaken to "examine the structure of stream food webs" (Streamtec 2004).

Flat Rocks (FR), and a pool downstream of Flat Rocks (FRDR) was sampled by WRM as part of the BHPIO Yandi aquatic fauna survey in 2014 (WRM 2015) (Figure 3). Flat Rocks is also sampled bi-annually by WRM as part of Rio Tinto's Regional Program (WRM 2011).

## 3.1 Microinvertebrates

Neither the AusRivAS FNARH study nor the Streamtec (2004) work included aquatic microinvertebrates[1]. However, the microinvertebrate fauna has previously been sampled by WRM as part of Rio Tinto's routine monitoring (WRM 2011). Incorporating all data over the six sampling events reported in WRM (2011), a total of 143 taxa of microinvertebrates were known from the creek. The microinvertebrate fauna comprise Protista, Rotifera, Ostracoda (seed shrimps), and Copepoda. WRM also sampled microinvertebrates at Marillana Creek as part of aquatic fauna studies within the BHBPIO Yandi tenement in 2014. A total of 101 taxa were recorded in the study (88 recorded in the wet-14, and 49 in the dry-14), with the fauna comprised of Protista (Ciliophora and Rhizopoda), Rotifera (Bdelloidea and Monogononta), Copepoda (Cyclopoida), Cladocera (water fleas) and Ostracoda.

In each study, the microinvertebrate fauna was generally typical of tropical systems reported elsewhere (e.g. Koste and Shiel 1983, Tait *et al.* 1984, Smirnov and De Meester 1996, Segers *et al*. 2004). Brachionidae within the Rotifera were poorly represented. This family tends to dominate temperate rotifer plankton, but is overshadowed by Lecanidae in tropical waters, as was the case in Marillana Creek (WRM 2011, 2015).

Of interest within the microinvertebrate fauna of Marillana Creek was the collection of the cyclopoid copepod, *Australoeucyclops karaytugi*, which is restricted (endemic) to the Pilbara region. Within the region, it is known from Weeli Wolli Spring nearby, as well as other spring systems including Palm Springs (Caves Creek), Bamboo Springs (De Grey) and Skull Springs (De Grey), and the permanent pools Coppin Gap (De Grey), Glen Herring Pool (De Grey), Wannagunna Pool (Ashburton), Horrigan's Pool (Ashburton), and Pool on Billan Ballan (Yule). *Australoeucyclops karaytugi* was recorded from four sites within the Study Area and at Flat Rocks (WRM 2015). It was also recorded at a site downstream of Rio Tinto's Yandi, just upstream of the confluence with Weeli Wolli Creek (WRM 2011).

Another Pilbara endemic copepod recorded at Marillana Creek by WRM (2015) was *Mesocyclops holynskae*, which was recorded at one site within the Study Area. Elsewhere, it has been recorded from the nearby Weeli Wolli Creek, along with Mulga Downs Station and Pardoo (Karanovic 2006, Ecowise 2007, WRM unpub. data).

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[1] A microinvertebrate is an animal without a backbone which can only be seen under magnification such as a rotifer, and is retained by small mesh nets (< 50 µm).

## 3.2 Hyporheos Fauna

The hyporheos fauna of Marillana Creek has only been surveyed by WRM (2011, 2015). The hyporheic zone[2] is becomingly increasingly recognised as a critical component of many streams and rivers (Edwards 1998). The hyporheic zone is thought to provide a rearing habitat (Brunke and Gonser 1999) and important refuge for aquatic invertebrates, buffering them from floods (Palmer *et al.* 1992, Dole-Oliver and Marmonier 1992, Edwards 1998), disturbance in food supply (Edwards 1998), and drought (Cooling and Boulton 1993, Edwards 1998, Coe 2001, Hose *et al*. 2005). The hyporheic zone serves to enhance the resilience of the benthic community to disturbance and influence river recovery following perturbations.

Interstitial fauna exhibit unique traits and adaptations to survive life in sediment pores. They have long, slender and flexible bodies which facilitate movement through interstitial spaces, and their small, hard, blunt bodies allow them to force their way through (Williams 1984). Some organisms are simply very small. Stygobites are blind and lack pigmentation. Hyporheos fauna can be classified in the following manner:

- Stygobite - obligate inhabitants of hypogean habitats, including the hyporheic zone and deeper groundwater habitats (such as aquifers), with special adaptations to survive such conditions;
- Permanent hyporheos stygophiles - epigean[3] species which may be present in the hyporheic zone during all life stages, but may also be able to complete their life-cycle in benthic habitats;
- Occasional hyporheos stygophiles - typically early instars of organisms that usually predominate in benthic habitats at later stages of development; may use the hyporheic zone seasonally (seeking refuge during spates or drought) or during early life history stages;
- Stygoxene - species that have no affinity with groundwater habitats but occur accidentally due to passive infiltration (Boulton 2001).

Hyporheos sampling by WRM (2011, 2015) was undertaken using the Karaman-Chappuis method (Karaman 1935, Chappuis 1942, Delamare Deboutteville 1953) also used in similar studies by Danielopol (1980), Mary and Marmonier 2001, Boulton *et al.* (2004), and Sak *et al.* (2008). This involved digging a hole in alluvial gravels in the dry streambed adjacent to the water's edge, allowing the hole to infiltrate with water, and then sweeping through with a modified 53 µm mesh plankton net (WRM 2011, 2015).

A number of species recorded from the hyporheic zone of Marillana Creek are known to be endemic to the Pilbara. Such species include the stygobitic amphipods Paramelitidae sp. D, Paramelitidae sp. B, *Chydaekata* sp. and *Maarrka weeliwolli*, the stygobitic isopod *Pygolabis weeliwolli*, and the stygobitic ostracods *Areacandona* sp. and *Gomphodella* n. sp. (BOS334).

Paramelitidae sp. D (also referred to as Paramelitidae Genus 2 sp. B3 by a different environmental consultancy[4]) and Paramelitidae sp. B (also referred to as Paramelitidae Genus 2 sp. B2 by a different environmental consultancy[7]) are both currently undescribed species that appear to be restricted to Weeli Wolli Creek and Marillana Creek (WRM unpub. data) and the Coondewanna Flats Catchment (Stuart Halse, Bennelongia, pers comm.). This suggests they are both short range endemics as defined by Harvey (2002)[5], and therefore of high conservation significance. These species have been recorded from the hyporheic zone both within the BHPIO Yandi lease (WRM 2015), and along the length of creek sampled by WRM (2011), downstream of BHPIO's Yandi discharge point and the confluence with Weeli Wolli Creek.

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[2] Hyporheic zone = the mixing zone of streamwater and groundwater; an ecotone largely, or totally, dependent on groundwater.

**3** Epigean – living or occurring on or near the surface of the ground.

[4] Bennelongia morphotype name.

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

*Chydaekata* sp. is also an undescribed SRE amphipod. It is known from a small number of systems in close proximity; Weeli Wolli Creek, Marillana Creek, Coondiner Creek and Mindy Mindy Creek (WRM unpub. data). Within these systems it has been recorded from groundwater (Bennelongia 2011), the hyporheic zone (WRM 2011, 2015) and surface waters (Streamtec 2004, WRM unpub. data). Other species of *Chydaekata* are known from the Pilbara, however, the species from Marillana Creek is known to be genetically distinct from these (Dr Terrie Finston, UWA, pers. comm.). *Chydaekata* sp. was recorded from the hyporheic zone of Marillana Creek within the Study Area (WRM 2015) and has also been recorded along the reach of Marillana Creek between the BHPIO Yandi discharge point and the confluence with Weeli Wolli Creek (WRM 2011).

The stygobitic amphipod *Maarrka weeliwolli* is also an SRE and has previously been recorded from multiple bores along Weeli Wolli and Marillana creeks (Finston *et al.* 2011). It appears to be restricted to these two creeklines. *Maarrka weeliwolli* appears to be less commonly recorded than the other three species of stygobitic SRE amphipods (WRM unpub. data). *M. weeliwolli* was recorded downstream of Rio Tinto's Yandicoogina (WRM 2011).

The stygobitic isopod *Pygolabis weeliwolli* is known only from Marillana and Weeli Wolli Creeks in the Pilbara region. *Pygolabis weeliwolli* has also been recorded from groundwater bores within the Yandicoogina tenement (Biota 2010). It is an SRE of high conservation value. *P. weeliwolli* was recorded in the hyporheos assemblages downstream of Rio Tinto's Yandicoogina (WRM 2011).

The stygobitic ostracods recorded in the hyporheos of Marillana Creek by WRM (2015), *Areacandona* sp. and *Gomphodella* n. sp. (BOS334), are likely to be locally or regionally endemic. The genus *Areacandona* was erected by Karanovic (2005) for two species recorded from three bores and one well in the Fortescue River valley. Since then, another 26 species have been described, mostly from Pilbara bores. The specimens collected from Marillana Creek by WRM (2015) were from within the BHPIO Yandi lease but were immature and unable to be definitively identified to species. Whichever species they belong to, they are all endemic to the Pilbara. The authors have also recorded immature specimens of *Areacandona* from Weeli Wolli Creek.

The species of *Gomphodella* recorded from two sites on Marillana Creek within the Study Area by WRM (2015) could not be identified based on current taxonomic keys, as it had morphological features that did not match any currently described species. However, it did match an undescribed species new to science; *Gomphodella* n. sp. (BOS334). This species appears similar to described species such as *G. glomerosa* and *G. hirsuta*, but differs in that it has no ventral stria, is dorso-ventrally compressed and has a different shaped hemipenis (Dr Russ Shiel, University of Adelaide, pers. comm.). The collection of *Gomphodella* n. sp. (BOS334) from the hyporheos of Marillana Creek was not the first record of the new species. It has previously been recorded from bores in the Yandi area (Dr Stuart Halse, Bennelongia, pers. comm.), as well as from hyporheic zones on Weeli Wolli Creek (WRM unpub. data). *Gomphodella* n. sp. (BOS334) appears to be a SRE and of high conservation value. Several *Gomphodella* species are known only from one locality and are commonly found in springs (Karanovic 2006, Reeves *et al.* 2007).

Also of interest was the collection of the hyporheic water mite *Stygolimnochares* nr *australica*, recorded within the Study Area by WRM (2015). This collection represented only the second record of the species in the Pilbara, which either constitutes a range extension for the Queensland species *Stygolimnochares australica*, or is a new species to science. *Stygolimnochares* nr *australica* has previously been recorded from Koodaideri Spring (Bennelongia 2011), approximately 20 km north of Yandi. The specimen is currently with Dr Mark Harvey at the Western Australian Museum (WAM) for further taxonomic examination.

## 3.3 Macroinvertebrates

As part of the AusRivas FNARH study, a total of 23 macroinvertebrate[6] families from nine orders were recorded (see Appendix 1a). Using the AusRivas approach, Halse *et al.* (2001) found the Fortescue River to be a relatively undisturbed system. The other major rivers of the Pilbara, the Ashburton and the De Grey, were also considered relatively undisturbed. In a comparison with rivers of the Kimberley, Halse *et al.* (2001) suggested that these systems were in better biological "condition than the Ord and parts of the Fitzroy, but not as undisturbed as parts of the Kimberley".

Streamtec (2004) recorded a total of 63 macroinvertebrate taxa from Flat Rocks on Marillana Creek (see Appendix 1b). The composition of taxa was typical of lotic (flowing) freshwater systems throughout the world (Hynes 1970) and was dominated by Insecta (over 93% of taxa). The most common insects were Coleoptera (over 35% of the insects). However, chironomids (non-biting midge larvae) were not identified to species-level in this study (Streamtec 2004). Chironomidae typically comprise the most abundant insects in lotic systems.

WRM (2011) recorded a total of 173 taxa of macroinvertebrates from the 14 sites sampled between the dry season 2008 and the wet season 2011. The macroinvertebrate fauna included Cnidaria (freshwater hydra), Mollusca (freshwater snails), Oligochaeta (aquatic segmented worms), Crustacea (side swimmers), Acarina (water mites), Ephemeroptera (mayfly larvae), Odonata (dragonfly and damselfly larvae), Hemiptera (true aquatic bugs), Coleoptera (aquatic beetles), Diptera (two-winged fly larvae), Trichoptera (caddisfly larvae), and Lepidoptera (aquatic moth larvae). The majority of macroinvertebrate taxa were common, ubiquitous species, with distributions extending across Northern Australia, Australasia, and the world (WRM 2011).

WRM (2015) recorded 212 macroinvertebrate taxa from sites on Marillana and Weeli Wolli creeks within and just outside of the Study Area; 181 in the wet season 2014, and 145 in the dry season 2014. The macroinvertebrate fauna comprised Cnidaria (freshwater hydra), Turbellaria (flat worms), Nematoda (round worms), Oligochaeta (aquatic segmented worms), Mollusca (aquatic snails), Hydracarina (water mites), Coleoptera (aquatic beetles), Diptera (two-winged fly larvae), Ephemeroptera (mayfly larvae), Hemiptera (aquatic true bugs), Lepidoptera (aquatic moth larvae), Odonata (dragonfly and damselfly larvae), and Trichoptera (caddisfly larvae) (see Table 8). Overall, the macroinvertebrate fauna was dominated by Insecta with 74% of all species recorded belonging to this class (WRM 2015).

Two IUCN Red Listed species have previously been recorded from Marillana Creek; the Pilbara emerald dragonfly *Hemicordulia koomina* and the Pilbara pin damselfly *Eurysticta coolawanyah* (WRM 2015). Both species are listed as Near Threatened (NT)[7] A number of species were also recorded during previous surveys which are known to be locally or regionally (Pilbara) restricted (see Table 16, section 6). Such species included the dragonflies *Ictinogomphus dobsoni* and *Nannophlebia injibandi*, dytiscid beetles *Limbodessus occidentalis* and *Tiporus tambreyi*, the haliplid beetles *Haliplus halsei* and *Haliplus pinderi* and the hydrophilid beetle *Laccobius billi*.

The Pilbara emerald dragonfly *Hemicordulia koomina* was recorded at Flat Rocks by WRM (2015). This species was listed as Near Threatened by the IUCN based on its distribution being restricted to an area of less than 500 km$^2$ and it being thought to exist at no more than five locations; including Millstream station, Koomina Pools (Tanberry Creek), Palm Pool (50 km south of Karratha), Fortescue Crossing, and Millstream Spring (Hawking 2009a). However, revision of its listing is considered necessary given its more recent

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[6] A macroinvertebrate is an animal without a backbone which is visible to the naked eye, and is retained by a net with mesh aperture of 250 µm, such as insect larvae or amphipods.

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

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), Robe River system (Nyeetbury Spring, Red Hill Creek pools and Wackiline Creek Pool), the De Grey 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), Cane River (House Pool), Sherlock River (Pool Spring), and the Shaw River (Panorama Spring) (Pinder *et al.* 2010, WRM unpub. data). However, this species is still considered rare, as it is infrequently collected and rarely recorded (WRM, unpub. data). The major threat to this species is considered to be loss of habitat through groundwater abstraction (Hawking 2009a).

The Pilbara pin damselfly *Eurysticta coolawanyah* was recorded both within the BHPIO Yandi lease and upstream of the Yandi lease (Flat Rocks) by WRM (2015). Like *Hemicordulia koomina,* this species is also listed as Near Threatened by the IUCN based on its distribution being restricted to an area of less than 500 $km^2$ and it being thought to occur at less than five locations (Millstream Station, Nanuturra Pools, Palm Pool and the Millstream area). However, like the Pilbara emerald, the listing of the Pilbara pin is considered to require revision as it has since been recorded from over 40 locations throughout the Pilbara (Pinder *et al.* 2010). This increases its distribution above the 500 $km^2$ threshold defined by the IUCN. Hawking (2009b) lists no currently known threats, or likely in the near future, to this species.

The Pilbara tiger dragonfly, *Ictinogomphus dobsoni*, occurs in permanent still or sluggish waters of the Pilbara region of Western Australia (Watson 1991). As well as Marillana Creek, it is also known from a number of sites along the Fortescue River, Robe River, Ashburton River, Yule River, De Grey River, and Sherlock River (CSIRO 2014, DEC 2009, Pinder *et al*. 2010, WRM unpub. data). On Marillana Creek, *I. dobsoni* has been recorded from Flat Rocks by Streamtec (2004), a site downstream of BHPIO's Yandi but upstream of Rio Tinto's Yandicoogina by WRM (2011), and from three sites within the Study Area by WRM (2015).

The dragonfly *Nannophlebia injibandi* is also endemic to the Pilbara. While this species was recorded infrequently during the Pilbara Biological Survey (Millstream Delta and Gregory Gorge in the Fortescue River catchment; Pinder *et al.* 2010), it has been recorded by the authors from Coondiner Creek, Roy Hill on the Fortescue River, Weeli Wolli Creek and Marillana Creek (WRM unpub. data). *Nannophlebia injibandi* is known from Marillana Creek both within (WRM 2015) and downstream of BHPIO's Yandi lease (WRM 2011).

The hyporheic beetle *Limbodessus occidentalis*[8] was recorded from surface water samples taken from Marillana Creek by WRM (2011). This beetle is an occasional hyporheos stygophile, being known from epigean, hyporheic and stygal habitats. It has been recorded from calcrete aquifers while sampling bores at Killara North (approximately 300 km south of Marillana Creek) and Moorarie (around 125 km west of Killara), as well as surface water samples from Gregory Gorge (Fortescue River), Creek Pool near Mt Amy (Ashburton River), Red Hill Creek pools (Robe River), Pool on lower Fortescue River, Harding River Pool, and Joffre Creek (Fortescue River; Watts and Humphreys 2004, Pinder *et al.* 2010). Most of the *Limbodessus occidentalis* specimens have been collected from the edge of pools in sandy riverbeds (Watts and Humphreys 2004). In Marillana Creek, it has been recorded from a site located downstream of BHPIO's Yandi but upstream of Rio Tinto's Yandicoogina.

*Tiporus tambreyi* appears to be commonly recorded and widespread throughout the Pilbara region. It is previously known from the Upper Fortescue River, Weeli Wolli Creek, Coondiner Creek, Kalgan Creek, and Bobswim Pool in Karijini NP (WRM, unpub. data). On Marillana Creek, WRM (2015) recorded this species from Flat Rocks and three locations within the Study Area.

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[8] Previously known as *Boongurrus occidentalis* sp. nov. (Watts and Humphreys 2004). The genus *Boongurrus* has since been synomised with *Limbodessus* (Balke and Ribera 2004).

The hydrophilid beetle *Laccobius billi* recorded from Marillana Creek by WRM (2011) is a Pilbara endemic that appears to be rarely collected. It was only recorded from one site during DPaW's Pilbara Biological Survey; Cangan Pool on the Yule River (Pinder *et al.* 2010), approximately 100 km north-west of Marillana Creek. It has also been recorded by the authors from Weeli Wolli Creek, Coondiner Creek and Mindy Mindy Creek (WRM unpub. data). *Laccobius billi* is known from the lower end of Marillana Creek (WRM unpub. data).

The Pilbara endemic haliplid beetles *Haliplus halsei* and *Haliplus pinderi* have only recently been described (Watts and McRae 2010). *H. halsei* is widely distributed throughout the Pilbara, and is previously known from House Pool (Cane River), Myanore Creek Pool (Red Hill Creek), Glen Ross Creek, Coondiner Pool, Fortescue Marsh West (Moorjari Well), Kumina Creek (Robe), Chalyarn Pool (Onslow), Moreton Pool (Ashburton River), Creek Pool near Mt Amy Well (Onslow), Paradise Pool and Munreemya Billabong on the De Grey River, Wackilina Creek Pool, West Peawah Creek Pool, Harding River Pool and an un-named creek in Millstream National Park (Pinder *et al.* 2010, Watts and McRae 2010). WRM (2015) recorded this species from Marillana Creek at Flat Rocks. *H. pinderi* has been recorded across the southern and eastern Pilbara (Watts and McRae 2010). During the Pilbara Biological Survey it was recorded from Bobswim Pool, Nyeetbury Spring, Pelican Pool on Nullagine, House Pool (Cane River), Bonnie Pool (De Grey River), Kalgan Pool, Ashburton at Gorge Junction and Innawally Pool (Fortescue River) (Pinder *et al.* 2010). WRM (2015) recorded *H. pinderi* from one site on Marillana Creek within the Study Area.

## 3.4 Fish

A number of studies have examined the freshwater fish fauna of river systems in the Pilbara region of Western Australia (Dames and Moore 1975, Masini 1988, Allen *et al*. 2002, Morgan *et al.* 2002, 2003, Morgan and Gill 2004, Streamtec 2004). However, other than work undertaken by the authors, only one study included a sample site on Marillana Creek (at Flat Rocks; Streamtec 2004). The fish fauna of the Pilbara is characterised by low species diversity yet high levels of endemicity; over 42% of species recorded are restricted to the region (Unmack 2001, Allen *et al.* 2002). Masini (1988) found the relatively clear waters of permanent and semi-permanent waterbodies supported the best developed fish assemblages in the region. In a study of the biogeography of Australian fish fauna, Unmack (2001) recognised ten distinct freshwater fish biogeographic provinces, of which the Pilbara Province was one. This region was considered distinct because its fauna did not cluster with other drainages in multivariate (parsimony and UPGMA) analysis of fish distribution patterns (Unmack 2001).

Allen *et al.* (2002) suggested the sparse freshwater fish fauna of the Pilbara was due to its aridity. The fish which inhabit the region are adapted to the extreme conditions and many have strategies for surviving drought (Unmack 2001). For example, Australia's most widespread native fish, the spangled perch (*Leiopotherapon unicolor*), is thought to survive drought by aestivating in wet mud or under moist litter in ephemeral waterbodies (Allen *et al.* 2002). However, conclusive evidence is still required to validate this hypothesis. Spangled perch can migrate in very shallow waters, and can be found in any temporary water of the Pilbara following rainfall, including wheel ruts of vehicle tracks (Allen *et al.* 2002). They are known to tolerate extremes in the aquatic environment (Llewellyn 1973, Beumer 1979, Glover 1982) and occupy a wide range of habitats (Bishop *et al*. 2001, Allen *et al.* 2002). Spangled perch and western rainbowfish are the only species known from an area in the Pilbara with little or no surface run-off in the Great Sandy Desert (Morgan and Gill 2004).

Beesley (2006) found life history strategies of fish species in the Fortescue River was between 'opportunistic' and 'periodic', reflecting the seasonal yet unpredictable nature of rainfall in the region. Breeding in spangled perch of the Pilbara occurs during the summer wet season, between late November and March (Beesley 2006). During this time, multiple spawning events are known to occur (Beesley 2006). Breeding in the western rainbowfish occurs throughout the year, with multiple spawning bouts which take full advantage of the regions intermittent rainfall and streamflow (Beesley 2006).

According to Allen *et al.* (2002), 12 native freshwater fish species (including catadromous[9] species) are known from the Pilbara. However, Morgan and Gill (2004) proposed an additional undescribed species of eel-tailed catfish, *Neosilurus* sp., may exist in the Robe and Fortescue rivers, but this is yet to be formally recognised. This species was considered different to *N. hyrtlii* based on its proportionally larger head and longer snout. Other known species from the Pilbara include spangled perch (*Leiopotherapon unicolor*), Fortescue grunter (*Leiopotherapon aheneus*), barred grunter (*Amniataba percoides*), western rainbowfish (*Melanotaenia australis*), bony herring (*Nematalosa erebi*), flat head goby (*Glossogobius giuris*), empire gudgeon (*Hypseleotris compressa*), golden gudgeon (*Hypseleotris aurea*), Hyrtl's tandan (eel-tailed catfish; *Neosiluris hyrtlii*), blue catfish or lesser salmon catfish (*Neoarius graeffei*), Murchison River hardyhead (*Craterocephalus cuneiceps*), and Indian short-finned eel (*Anguilla bicolor*) (Masini 1988, Allen *et al.* 2002, Morgan and Gill 2004, Beesley 2006). In addition, two endemic cave fishes have also been recorded from the North West Cape in the Pilbara Drainage Division; the blind cave eel (*Ophisternon candidum*) and the blind gudgeon (*Milyeringa veritas*) (Humphreys and Adams 1991, Allen *et al.* 2002). Four introduced fish species are known from the Pilbara; mosquitofish (*Gambusia holbrooki*), guppy (*Poecilia reticulata*), swordtail (*Xiphophorus helleri*), and tilapia (*Oreochromis mossambicus*) (Morgan and Gill 2004).

At least two studies have examined the fish fauna of the Fortescue River (Morgan and Gill 2004, Beesley 2006). Morgan and Gill (2004) sampled 16 sites along the Fortescue River as part of a broader study describing the distribution of fishes in inland waters of the Pilbara. A total of 171 sites were sampled across the region between December 2000 and November 2002 using a combination of methods, including seine nets, gills nets, cast nets, mask and snorkel, and rods and lines (Morgan and Gill 2004). Exact locations of study sites were not provided by Morgan and Gill (2004). Therefore, it is not known whether any sites along Marillana Creek were sampled.

Beesley (2006) examined the role of environmental stability in structuring fish communities of the Fortescue River. Sampling was restricted to pools within the western catchment of the Fortescue. Between December 2000 and December 2002, pools were sampled on nine occasions over both 'wet' and 'dry' seasons. Fish recorded by Beesley (2006) included the Indian short-finned eel, bony herring, lesser salmon catfish, Hyrtl's tandan, western rainbowfish, barred grunter, Fortescue grunter, spangled perch, empire gudgeon, and the flathead goby. Morgan and Gill (2004) also reported the new catfish species *Neosilurus* sp., which may have been collected by Beesley (2006) but not recognised. No introduced species have been recorded from the Fortescue River. All known introduced fishes of the Pilbara are currently restricted to the region south of the Lyndon River (Morgan and Gill 2004).

The fish fauna of Marillana Creek were surveyed by Streamtec (2004) as part of the larger BHPIO aquatic fauna study previously described. A combination of sampling methods was used, including sweep netting, seine nets and direct observation (Streamtec 2004). Fish surveys were undertaken in conjunction with macroinvertebrate sampling at the same location (Flat Rocks). Only two of the eleven species known from the Fortescue River were recorded from Flat Rocks by Streamtec (2004). These were the spangled perch and western rainbowfish (Plate 1).

**Plate 1.** Western rainbowfish *Melanotaenia australis* (left) and spangled perch *Leiopotherapon unicolor* (right) (photos taken and provided by Mark Allen ©).

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[9] Catadromous fishes live in freshwaters as juveniles or sub-adults, but migrate to estuaries or the sea to spawn.

During more recent surveys of Marillana Creek, both within (WRM 2015) and downstream of the Study Area (WRM 2011), three species of fish have been recorded; spangled perch, western rainbowfish and Pilbara tandan (eel-tailed catfish; Plate 2). In these studies, western rainbowfish were the most abundant species and were collected from length of creek sampled (WRM 2011, 2015). Pilbara tandan were more abundant from the most downstream sites of Marillana Creek (i.e. closest to the confluence with Weeli Wolli Creek), and included juveniles (WRM 2011).

**Plate 2**. Pilbara tandan, *Neosilurus* sp. (photo taken and provided by Mark Allen ©).

These three fish species are the only species known from the upper Fortescue River catchment (i.e. upstream of the Fortescue Marsh and Karijini National Park) (Streamtec 2004, WRM 2011, WRM 2015, WRM unpub. data). Streamtec (2004) attributed the low species diversity in this region to physical barriers, such as waterfalls, impeding dispersal.

All three species are common and widespread. The spangled perch is the most widespread fish species in Australia, with a distribution in coastal drainages from the Greenough River in WA north across the Top End and southwards to the Hunter River and Murray-Darling system in NSW. It also occurs inland in the Lake Eyre/Bulloo-Bancannia Drainage System (Allen *et al*. 2002). Spangled perch occur in a variety of habitats across this range including, flowing streams, small billabongs, lakes, dams and bores (Allen *et al.* 2002). The western rainbowfish has a distribution from the Ashburton River in Western Australia to the Adelaide River near Darwin in the Northern Territory. It is common and abundant throughout the Pilbara and Kimberley regions of WA (Allen *et al*. 2002). The Pilbara tandan is likely a subspecies of the common and widespread Hyrtl's tandan (*Neosilurus hyrtlii*). While Hyrtl's tandan catfish have a broad distribution across Australia (Allen *et al.* 2002), recent genetic evidence indicates that there are a number of species within the Hyrtl's tandan group, and that the species from the Pilbara is endemic to the region (Dr Peter Unmack, National Evolutionary Synthesis Centre, North Carolina, pers. comm.).

## 3.5 Other Vertebrate Fauna

No other vertebrate fauna were recorded from Marillana Creek during any of the aforementioned studies. However, the native flat-shelled turtle, *Chelodina steindachneri*, is known from the nearby Weeli Wolli Spring and upper Weeli Wolli Creek (Wunna Munna reference site; Streamtec 2004, WRM 2011). It is considered likely that *Chelodina steindachneri* occurs in Marillana Creek. This species is endemic to Western Australia, where it occurs in coastal drainages from the De Grey River in the north to the Irwin River in the south, and west to the Wiluna salt lakes (Georges and Thomson 2010). *Chelodina steindachneri* is adapted to seasonal and ephemeral systems, aestivating over the dry season to avoid desiccation (Legler and Georges 1993). It may aestivate for up to three years. In the Pilbara region, the life history strategies of this species are not well understood, although mating has been observed to coincide with increased water flow after rainfall. The flat-shelled turtle is largely carnivorous and its diet includes invertebrates, fish, tadpoles and frogs.

In addition, one species of frog is known from the creek, and at least two more are considered likely to occur. The desert tree frog, *Litoria rubella*, has been observed by the authors throughout the creekline on a number of occasions (WRM unpub. data). *Litoria rubella* is a common species in the Pilbara and is known to occur in a wide range of habitats across wider northern Australia, including northern Western Australia, Northern Territory, north-east of South Australia, Queensland, and northern New South Wales (Tyler and Knight 2009). 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. Main's frog, *Cyclorana maini*, and the Pilbara toadlet, *Uperoleia saxatilis*, may occur in Marillana Creek. Main's frog is a species of burrowing frog which spends much of its time underground conserving water. As such, they are rarely encountered except following rains when they emerge to breed. The authors have recorded this species from a number of creeklines near Marillana Creek (WRM unpub. data). *Cyclorana maini* tadpoles develop rapidly, enabling them to breed in unpredictable water supplies that dry rapidly. Main's frog is found in the central arid zone of Western Australia and into the southern extent of the Northern Territory and north-west corner of South Australia. It is listed on the IUCN Redlist of Threatened Species as Least Concern due to its wide distribution and presumed large population (Hero *et al*. 2004). It is considered that its population decline is not occurring fast enough to qualify for listing in a more threatened category (Hero *et al.* 2004). *Uperoleia saxatilis* was only recently described, and specimens from the Pilbara were previously considered to be *U. russelli*. Genetic analyses, morphology and analyses of mating calls, have recently shown the two to be distinctly separate species, with *U. russelli* confined to the Carnarvon/Gascoyne region and *U. saxitilis* endemic to the Pilbara (Catullo *et al.* 2011). The Pilbara toadlet occurs in or near rocky creeks, and appears adapted to rocky landscapes. It has not been found to occur in any sandy regions (Catullo *et al.* 2011). As such, it may occur in the more upstream sites of Marillana Creek (FR &/or FRDR), where bedrock substrates predominate, but is not likely to occur within the Study Area. The authors have recorded *U. saxatilis* from a nearby spring (WRM unpub. data).

## 3.6 Database Search

A search of Federal and state databases and lists was completed in order to identify the presence of any threatened and priority aquatic fauna (EPBC Act, DBCA Priority Fauna, etc.) in the vicinity of the Yandi lease. Table 2 summarises the databases accessed and information used in the search.

A thorough search of the EPBC Protected Matters, DBCA NatureMap, and the Atlas of Living Australia databases returned no aquatic fauna species (invertebrates, fish, amphibians and turtles) listed for conservation significance in the vicinity (within 40 km) of BHPIO Yandi. This, in some respect, highlights the fact that 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).

**Table 2.** Summary of databases accessed and search information used.

| Database | Authority | Reference | Coordinates | Search radius | Date accessed |
|---|---|---|---|---|---|
| Protected Matters | Federal/Commonwealth (EPBC Act 1999) | Department of the Environment and Energy (2018) | -22.725904°<br>119.068644° | 40 km | 23/04/2018 |
| NatureMap | State (DBCA) | Department of Biodiversity, Conservation and Attractions (2018) | -22.725904°<br>119.068644° | 40 km | 23/04/2018 |
| Atlas of Living Australia | Joint contributors; receives support from the Australian Government / CSIRO; pools information from databases such as the Australian National Insect Collection (CSIRO) and the Western Australian Museum's "WAMinals". | Atlas of Living Australia 2018 | -22.725904°<br>119.068644° | 10 km | 23/04/2018 |

# 4. CURRENT SURVEY METHODS

## 4.1 Compliance

There are no specific guidance statements for undertaking aquatic fauna surveys. However, field surveys 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 by WRM is consistent with methodology used by government and Universities for similar surveys, including the Pilbara Biological Survey (i.e. Pinder *et al.* 2010) and National Monitoring River Health Initiative (Department of Environment Sport and Territories *et al*. 1994).

This study was conducted under Fisheries Licence EXEM 2760 (Instruments of Exemption to the Fish Resources Management Act 1994 for Scientific Research Purposes), and DBCA Licence 08-000316-2 (Reg 17; 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 authorities.

Surveys were undertaken in the late wet (16th to the 19th of May) and late dry seasons (30th September to the 1st of October) of 2017. Sampling during the wet and dry seasons allowed seasonal change in fauna composition to be characterised and provided a more comprehensive record of species present than sampling in a single season.

## 4.2 Sites and Sampling Design

This sampling program built on data obtained in the wet and dry seasons of 2014, aiming to establish the current condition of Marillana Creek for future assessment of effects, if any, of development and operation of the Yandi mine. As in 2014, sampling was conducted at sites within the Study Area (WSA), as well as reference sites outside the Study Area. Table 3 provides a summary of sites sampled in each sampling event in 2014 and 2017. Sampling site locations are shown in Figure 4 and site photographs provided in Appendix 3.

In the wet-17, nine sites were successfully sampled on Marillana Creek within the Study Area; MC1 - 9. Of these sites, six were ephemeral pools located upstream of the BHPIO Yandi dewatering discharge point, i.e. MC1 to MC3 upstream of the western diversion, and MC4 to MC6, between the western and eastern diversions (i.e. between pits W6 and E1). Three sites, MC7 to MC9, were located downstream of the Yandi discharge point and downstream of the eastern diversion. There was flow at MC7 to MC9 at the time of sampling. Three reference sites were sampled on Weeli Wolli Creek upstream of any mining activities; Wunna Munna Upstream (WMU), Wunna Munna (WM) and Wunna Munna Central (WMC). An additional reference site was sampled on the Fortescue River outside the influence of any mining activity (FU), approximately 100 km southeast of the Study Area.

In the dry-17, six sites were successfully sampled within the Study Area; MC1, MC1B, MC2, MC7, MC8 and MC9. All sites between MC2 and the Yandi discharge outlet (i.e. MC3, MC4, MC5 and MC6) were dry. However, an additional site, MC1B, was sampled between MC1 and MC2 as a substitute for one dry site.

Weeli Wolli Creek reference sites WM, WMU and WMC were also successfully sampled, however Fortescue River site FU was dry.

Flat Rocks, previously sampled in 2014, was not included in the 2017 sampling program, as it is likely impacted by dewatering drawdown from Yandi operations, and as such is not representative of a true reference site. UWWCS was also not sampled in 2017 as it is located on Rio Tinto tenement and access to this site has not been obtainable since the wet-14. In 2017, these sites were replaced by Weeli Wolli Creek reference site WMC, and Fortescue River site FU.

**Table 3.** Summary of 2014 and 2017 sampling locations. WSA = Within Study Area ; R = Reference site.

| Creekline | Site name | Code | Type | Permanency | Easting | Northing | Wet-14 | Dry-14 | Wet-17 | Dry-17 |
|---|---|---|---|---|---|---|---|---|---|---|
| Marillana Creek | Marillana Creek 1 | **MC1** | **WSA** | Permanent/semi-permanent pool | 703744 | 7485416 | ✓ | ✓ | ✓ | ✓ |
| | Marillana Creek 1-B | **MC1-B** | **WSA** | Permanent/semi-permanent pool | 703895 | 7485275 | | | | ✓^ |
| | Marillana Creek 2 | **MC2** | **WSA** | Permanent/semi-permanent pool | 704467 | 7484980 | ✓ | ✓ | ✓ | ✓ |
| | Marillana Creek 3 | **MC3** | **WSA** | Ephemeral pool | 706285 | 7483654 | **dry** | **dry** | ✓ | **dry** |
| | Marillana Creek 4 | **MC4** | **WSA** | Ephemeral pool | 713451 | 7485047 | ✓ | **dry** | ✓ | **dry** |
| | Marillana Creek 5 | **MC5** | **WSA** | Ephemeral pool | 714305 | 7484934 | ✓ | **dry** | ✓ | **dry** |
| | Marillana Creek 6 | **MC6** | **WSA** | Ephemeral pool | 714618 | 7484631 | ✓ | **dry** | ✓ | **dry** |
| | Marillana Creek 7 | **MC7** | **WSA** | Maintained by discharge | 720629 | 7478491 | | ✓^ | ✓ | ✓ |
| | Marillana Creek 8 | **MC8** | **WSA** | Maintained by discharge | 720979 | 7478386 | | | ✓ | ✓ |
| | Marillana Creek 9 | **MC9** | **WSA** | Maintained by discharge | 721435 | 7478307 | | | ✓ | ✓ |
| | Flat Rocks | **FR** | **R** | Permanent pool | 702190 | 7486341 | ✓ | ✓ | | |
| | Flat Rocks downstream | **FRDR** | **R** | Permanent pool | 702734 | 7485885 | | ✓ | | |
| Weeli Wolli Creek | Upstream Weeli Wolli Creek Spring* | **UWWCS** | **R** | Spring | 720427 | 7448986 | ✓ | | | |
| | Wunna Munna | **WM** | **R** | Semi-permanent pool | 717888 | 7442746 | ✓ | ✓ | ✓ | ✓ |
| | Wunna Munna Upstream | **WMU** | **R** | Semi-permanent pool | 709968 | 7440243 | ✓ | ✓ | ✓ | ✓ |
| | Wunna Munna Central | **WMC** | **R** | Semi-permanent pool | 718897 | 7444513 | | | ✓ | ✓ |
| Fortescue River | Fortescue River Upstream | **FU** | **R** | Ephemeral pool | 784860 | 7407316 | | | ✓ | **dry** |
| | **Total number of sites sampled in each season** | | | | | | **9** | **7** | **13** | **9** |

* This site has also been known as 'Ben's Oasis'. Due to being on Rio Tinto tenement, access for sampling has been unobtainable since wet '14.

^ These sites were not part of the original sampling program but were added in the field due to a number of sites being dry or not able to be accessed.

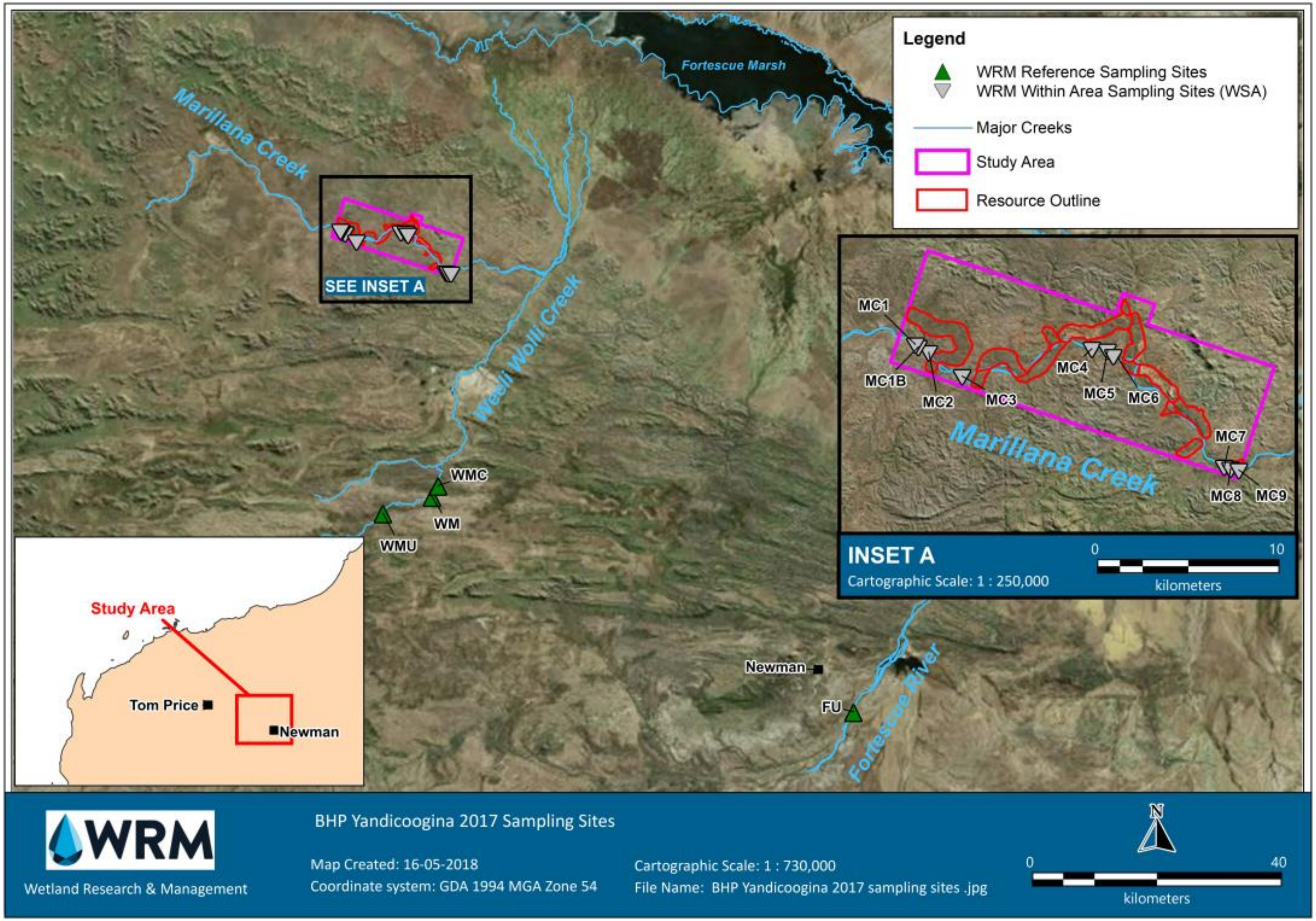

**Figure 4.** Location of 2017 survey sites on Marillana Creek in relation to the Yandi mine and Study Area.

## 4.3 Water Quality

At each site a number of water quality variables were recorded *in situ* using portable WTW field meters, including pH, electrical conductivity (µS/cm), dissolved oxygen (% and mg/L), and water temperature (°C). Water depth was estimated during sampling. Undisturbed water samples were taken for laboratory analyses of ionic composition, nutrients and dissolved metals. Samples collected for nutrients and metals were filtered through 0.45 µm Millipore nitrocellulose filters. To avoid any potential for incidental contamination, all water samples were collected using the rigorous methodologies described in Ahlers *et al.* (1990). These methodologies involved acid washing Nalgene sample bottles, filters and syringes, double-wrapping sample bottles and all filtering equipment in polyethylene bags, and samplers wearing polyethylene gloves. It is widely acknowledged that incidental zinc contamination of water samples is a common and widespread issue (Laxen and Harrison 1981, Ahlers *et al.* 1990, Batley 1990), with contamination often coming from the sample bottles and filters supplied for routine water quality analyses (Batley 1990). Ahlers *et al.* (1990) reported that when rigorous sampling methodologies were used, zinc concentrations were almost a factor of three lower.

All water samples were kept cool on ice in an esky while in the field, then samples refrigerated as soon as possible (or frozen in the case of nutrients) for subsequent transport to the laboratory. All laboratory analyses were conducted by the ChemCentre WA (a NATA accredited laboratory).

Water quality variables measured are summarised in Table 4.

Water quality data were compared against the ANZECC/ARMCANZ (2000) water quality guidelines. ANZECC/ARMCANZ (2000) provides default trigger values (TVs) for a range of water quality parameters for the protection of aquatic ecosystems. These TVs may be adopted in the absence of adequate site-specific data. ANZECC/ARMCANZ (2000) recommends different levels of species protection applied to different levels of ecosystem condition. The 99% value is applied to high conservation/ecological value ecosystems, the 95% value to slightly to moderately disturbed ecosystems and the 90% or 80% values to highly disturbed ecosystems. When applying TVs, ANZECC/ARMCANZ (2000) state the following:

> "*Trigger values are concentrations that, if exceeded, would indicate a potential environmental problem, and so 'trigger' a management response, e.g. further investigation and subsequent refinement of the guidelines according to local conditions*." (Section 2.1.4); and
>
> "*Exceedances of the trigger values are an 'early warning' mechanism to alert managers of a potential problem. They are not intended to be an instrument to assess 'compliance' and should not be used in this capacity*" (Section 7.4.4).

Hence, TVs should not be used in a 'pass-fail' approach to water quality management. Their main purpose is to inform managers and regulators that changes in water quality are occurring and may need to be investigated. In the case of baseline or benchmark data collection, the guidelines may be used to establish background levels relative to TVs, and show where certain elements may be naturally elevated (i.e. due to geological features). This allows future discrimination of mine effects from natural enrichment. Where background levels are elevated, then it is desirable to establish site-specific TVs.

The guidelines recommend, that where an appropriate default TV does not exist, or natural background concentrations are consistently higher than the default TV, natural background data should be used to derive system-specific TVs (SSTVs). In these instances, the 80th percentile (and 20th percentile in the case of variables that require a lower guideline, e.g. pH and dissolved oxygen) of a baseline/benchmark dataset should be used.

**Table 4.** All water quality parameters measured.

| Parameter | Units | Parameter | Units |
|---|---|---|---|
| pH | pH units | Total Phosphorus (total P) | mg/L |
| Electrical conductivity | µS/cm | Aluminium (Al) | mg/L |
| Dissolved oxygen | % saturation | Arsenic (As) | mg/L |
| Dissolved oxygen | mg/L | Boron (B) | mg/L |
| Water temp | °C | Barium (Ba) | mg/L |
| Average water depth | m | Cadmium (Cd) | mg/L |
| Maximum water depth | m | Cobalt (Co) | mg/L |
| Sodium (Na) | mg/L | Chromium (Cr) | mg/L |
| Potassium (K) | mg/L | Copper (Cu) | mg/L |
| Calcium (Ca) | mg/L | Iron (Fe) | mg/L |
| Magnesium (Mg) | mg/L | Manganese (Mn) | mg/L |
| Chloride (Cl) | mg/L | Molybdenum (Mo) | mg/L |
| $CO_3$ | mg/L | Nickel (Ni) | mg/L |
| $HCO_3$ | mg/L | Lead (Pb) | mg/L |
| $SO_4$ | mg/L | Selenium (Se) | mg/L |
| Alkalinity | mg/L | Uranium (U) | mg/L |
| Hardness | mg/L | Vanadium (V) | mg/L |
| Nitrate ($NO_3$) | mg/L | Zinc (Zn) | mg/L |
| Ammonium ($NH_3$) | mg/L | | |
| Total Nitrogen (total N) | mg/L | | |

## 4.4 Habitat Assessment

Details of habitat characteristics were recorded from each site. WRM have specific worksheets for this task so that recordings between sites remain as comparable as possible. Habitat characteristics recorded included percent cover by inorganic sediment, submerged macrophyte, floating macrophyte, emergent macrophyte, algae, large woody debris, detritus, roots and trailing vegetation. Details of substrate composition were also recorded and included percent cover by bedrock, boulders, cobbles, pebbles, gravel, sand, silt and clay.

## 4.5 Microinvertebrates

Microinvertebrate samples were collected from each site by gentle sweeping over an approximate 15 m distance with a 53 µm mesh pond net. Care was taken not to disturb the benthos (bottom sediments). Samples were preserved in 70% ethanol and sent to Dr Russ Shiel of 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 Region.

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 Shiel at the University of Adelaide.

## 4.6 Hyporheos Fauna

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

Samples were preserved in 70% ethanol and returned to the laboratory for processing. Any hyporheic fauna present was removed from samples by sorting under a low power dissecting microscope. Specimens were identified, and where necessary sent to appropriate taxonomic experts for confirmation of their identification and status as hyporheic fauna. Chironomidae (non-biting midges) were sent to Dr Don Edward (The University of Western Australia), and Copepoda and Ostracoda to Dr Russ Shiel (The University of Adelaide) for identification.

All taxa recorded from hyporheic samples were classified using Boulton's (2001) categories (see Section 3.2).

## 4.7 Macroinvertebrates

Macroinvertebrate sampling was conducted with a 250 µm mesh pond net to selectively collect the macroinvertebrate fauna. In order to allow comparisons to be made between sites, a standardised sampling approach was adopted, whereby all meso-habitats (e.g. macrophyte, detrital build up, open water column and flowing riffles) were sampled at each site. This standardises for habitat and avoids issues with greater diversity due to greater habitat diversity on any reach. Each sample was washed through a 250 µm sieve to remove fine sediment. Leaf litter and other coarse debris were removed by hand and then samples were preserved in 70% ethanol.

In the laboratory, macroinvertebrates were removed from samples by sorting under a low power dissecting microscope. Collected specimens were then identified to the lowest possible level (genus or species level) and enumerated to $\log_{10}$ scale abundance classes (i.e. 1 = individual, 2 = 2 - 10 individuals, 3 = 11 - 100 individuals, 4 = 101 - 1000 individuals, 5 = > 1000). In-house expertise was used to identify invertebrate taxa using available published keys and through reference to the established voucher collections held by WRM.

## 4.8 Fish

Fish fauna was sampled using a variety of methods in order to effectively collect as many species and individuals as possible at each site in each reach. Fish sampling methods included electrofishing, seine nets, gill nets and dip nets.

Electrofishing was conducted with a Smith-Root Model LR24 battery powered backpack electrofisher (see Plate 3 and Box 1). All meso-habitats within a 40 m reach were shocked with the intention of recovering as many species/ individuals as possible. Shocking was not continuous, but targeted areas of optimum habitat, whereby the operator would shock, move to a new habitat before shocking again, and so prevent fish being driven along in front of the electrical field.

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

Gill netting involved setting 10 m long light-weight fine mesh gill nets with a 2 m drop (of stretched mesh size of 13 mm and 19 mm) at each site. Nets were left for the duration of sampling at that particular site.

All fish were identified in the field, measured and then released alive. Fish nomenclature followed that of Allen *et al.* (2002). Measuring the fish captured provided information on the size structure, breeding and recruitment of the fish population.

**Box 1. Principles of electrofishing:**

A DC voltage is passed from a negative electrode (cathode) to a positive electrode (anode) whilst the electrodes are immersed in the water. If a fish is caught in the electrical field generated, a process referred to as 'Galvanotaxis' occurs. This is the involuntary movement of the fish towards the anode, until it reaches an electrical field strong enough to stun it ('galvanoarcosis'). The Smith-Root electrofisher uses a pulsed DC current, which is more effective than a flat DC signal because the body of the fish flexes with each pulse, accentuating the involuntary swimming action towards the anode. Once the current is switched-off, or the fish removed from the electrical field, the fish quickly recovers. Some damage to fish may occur if they are caught in a high electrical field close to the anode for an extended period. The operator of the electrofisher carries the anode (in the form of a modified pond net) whilst trailing the cathode (a stainless steel cable approximately 3.5 m long, referred to as a 'rat tail'). The Smith-Root backpack electrofisher has an effective range of approximately 3 m. Galvanotaxis can be used to 'pull' fish and crayfish out from under debris, logs, boulders and bank undercuts.

**Plate 3.** Example of electrofishing (photo by WRM).

## 4.9 Data Analysis

Univariate analyses were performed using the IBM SPSS statistics package v22 to investigate temporal and spatial differences in water quality and aquatic fauna richness/abundance. Two-way ANOVA was used to test for significant differences ($p < 0.05$) in 2017 water quality and fauna richness/abundance data between site locations (i.e. within Study Area upstream of discharge (WSA-USD), within Study Area downstream of discharge (WSA-DSD), or reference site) and seasons (wet vs dry). Two-way ANOVA was also used to test for significant differences ($p < 0.05$) in water quality and fauna richness/abundance data between site locations (i.e. within Study Area or reference site) and years (2014 vs 2017). Given the low replication in the dry seasons of both 2014 and 2017, due to many sites being dry, two-way ANOVA was only undertaken on wet season data.

Multivariate analyses were performed using the PRIMER package v7 (Plymouth Routines in Multivariate Ecological Research; Clarke and Gorley 2006) to investigate differences in aquatic fauna assemblages (macroinvertebrates and microinvertebrates) between seasons (wet vs dry), years (2014 vs 2017) and site locations (i.e. within Study Area or reference site), and relationships with physico-chemical characteristics from each site. The PRIMER package, developed for multivariate analysis of marine fauna samples, has been applied extensively to analysis of freshwater invertebrate data. Analyses applied to the data included some or all of the following:

1. Describing patterns amongst the fauna assemblage data (macroinvertebrates and microinvertebrates) using ordination techniques based on Bray-Curtis similarity matrices (Bray and Curtis 1957). The clustering technique uses a hierarchical agglomerative method where samples of similar assemblages are grouped, and the groups themselves form clusters at lower levels of similarity. A group average linkage (SIMPROF) was used to derive clusters on the resultant dendrogram. Ordination of data was by non-metric Multi-Dimensional Scaling (nMDS) (Clarke and Warwick 2001). Ordinations were depicted as two-dimensional plots based on the site by site similarity matrices. For environmental data (i.e. water quality and habitat data), the Euclidean Distance Measure was used to create resemblances, and the data were first transformed (where necessary) and normalised.
2. Permutational multivariate analysis of variance (PERMANOVA) was undertaken (one-factor design) to determine whether there was any significant difference in environmental or biotic data (i.e. microinvertebrates, hyporheos fauna and macroinvertebrate assemblages) between site locations, years and seasons.
3. The relationship between the environmental and biotic data was assessed using the BVSTEP routine. This analysis calculates the minimum suite of parameters that explain the greatest percent of variation (i.e. the parameters which most strongly influence the species ordination).

# 5. RESULTS AND DISCUSSION

## 5.1 Water Quality

### 5.1.1 Water quality in 2017

**pH**

Within the Study Area (WSA), pH ranged from circum-neutral to basic, with pH values between 7.19 and 9.0 during the wet season, and 7.07 to 8.77 during the dry season (Figure 5 and Appendix 4). A similar range in pH values was recorded for the reference sites, with a wet season minimum of 7.62 (FRU) and maximum 8.09 (WM), and a dry season minimum of 8.03 (WM) and maximum 8.47 (WMC) (Figure 5). At the majority of sites in both seasons, pH was above the ANZECC/ARMCANZ (2000) upper guideline value (pH 8) for the protection of aquatic fauna in slightly-moderately disturbed ecosystems in tropical northern Australia (Figure 5). The main exceptions were the three WSA sites maintained by dewatering discharge (MC7 - MC9), where pH was lower and within ANZECC/ARMCANZ (2000) guidelines in both seasons.

The basic pH values recorded from Marillana Creek upstream of dewatering discharge, and at nearby Weeli Wolli Creek reference sites, are considered due to local geology (calcrete aquifer), and are similar to pH values recorded from surface waters in other un-impacted systems in the East Pilbara, including Coondiner Creek, Kalgan Creek and the Fortescue River (Johnson and Wright 2001, WRM unpub. data). Values recorded at WSA sites suggest pH of dewatering water tends to be slightly lower than that of surface waters upstream.

**Redox potential**

Redox (reduction-oxidation potential) is a measure of a systems capacity to oxidise material and can be used to assess stream health and the potential for water quality issues (Suslow 2004). Positive values indicate oxidative conditions prevail (e.g. biological conversion of ammonia to nitrites and nitrates), whilst negative values suggest reductive conditions (e.g. removal of nitrates). Redox values recorded during the current study were all negative (reductive) and ranged from -9.5 mV (MC7 in wet-17) to -112.2 mV (MC2 in wet-17) (Appendix 4). Low redox potential arises from biogeochemical reactions that transfer electrons from organic matter released from plants to various electron acceptors, and leads to increased ammonium concentrations through denitrification (Tabacci *et al*. 1998, Hauer and Lamberti 2007). Redox potential also reflects biological (BOD) and chemical (COD) oxygen demand (use). Typically, in well-aerated natural river systems, the water provides an oxidising environment and has a positive, or nearing positive, redox value. However, in any water body, redox potential can vary greatly throughout the day as relative rates of photosynthesis and respiration by aquatic biota vary.

**Dissolved oxygen (DO)**

DO concentrations were highly variable between sites and seasons. At WSA sites, wet season DO ranged from 71.1% (MC5) to 132.2% (MC3). At reference sites, wet season DO ranged from 60.1% (WM) to 92.2% (WMC) (Figure 5). Values for the dry season DO ranged from 30.8% (MC1) to 124.2% (MC2) within the Study Area, and from 55.5% (WM) to 103.2% (WMU) at reference sites (Figure 5). Values below the ANZECC/ARMCANZ (2000) lower TV (85% DO) were recorded at numerous sites, both within and outside of the Study Area, in both seasons (Figure 5). Low dissolved oxygen (DO) is generally associated with heavy growth of aquatic macrophyte (with high rates of night-time respiration consuming DO in the water column), sluggish flows (with lack of physical aeration) and/or the microbial decomposition of heavy loads of organic matter, often resulting in conditions of anoxia (zero DO). Low DO at sites such as MC1 and WM, particularly under baseflow during the dry season, was likely due decomposing organic matter (detritus) in the small receding pools. Concentrations exceeding the ANZECC/ARMCANZ (2000) upper TV

(120% DO) were recorded from two WSA sites; MC2 during the dry-17 and MC3 during the wet-17 (Figure 5). Super-saturated DO (i.e. > 100%) occurs when net photosynthesis exceeds total oxygen consumption and is common in areas of high macrophyte and algal growth, as was present at these sites (see Appendix 4). Sites with super-saturated (>120%) DO may experience oxygen stress overnight, as respiration by plants, algae, bacteria and other aquatic fauna deplete DO. A diurnal pattern of peak DO level during the late afternoon and minimum DO level just prior to dawn, is commonly observed in waterbodies, reflecting the natural flux in aquatic respiration versus photosynthesis.

## Electrical conductivity (EC)

EC varied from fresh to brackish, as classified by the Department of Environment (DoE 2003)[10], with a wide range in values, from 120 µs/cm (WMC) to 900 µs/cm (MC9) in the wet-17, and 208 µs/cm (WMC) to 2,520 µs/cm (WM) in the dry-17 (Figure 5). EC within the Study Area was generally fresh, with the exception of MC1 (1,870 µs/cm) and MC2 (2,420 µs/cm) in the dry season (Figure 5). Higher values during the dry reflected evapo-concentration effects on ion concentrations in receding pools. EC exceeded the ANZECC/ARMCANZ (2000) TV (250 µs/cm) at most sites, except WMC (wet and dry seasons) and WMU (wet season) (Figure 5). However, ANZECC/ARMCANZ (2000) acknowledge that EC may naturally exceed the TV, as the TV was developed from limited datasets for northern Australia, in particular Western Australia. Elevated nitrogen and phosphorus have previously been recorded by the authors at sites on Marillana Creek and other waterbodies throughout the Pilbara region (WRM unpub. data). There is a general acceptance that when conductivity is less than 1,500 µS/cm, freshwater ecosystems experience little ecological stress (Hart *et al.* 1991, Horrigan *et al.* 2005). EC at Study Area sites MC1 and MC2, and at reference site WM, was elevated above this level in the dry season, qualifying as brackish (Figure 5).

Notably, there was less between-site variability in EC downstream of the discharge outlet (MC7 - MC9) than for upstream sites and reference sites. This suggests dewatering discharge has reduced the seasonal variation in EC in Marillana Creek, by maintaining pool water levels throughout the dry season and thereby reducing the effects of evapo-concentration.

## Turbidity

Turbidity was only measured during the wet-17 due to an oversight in sample collection. During the wet-17, turbidity at all sites was below the ANZECC/ARMCANZ (2000) upper TV (i.e. < 15 NTU) (Figure 5). In natural systems, turbidity increases during runoff events as a result of increased overland flow, stream flow and erosion. Turbidity can also increase due to anthropogenic disturbances, such as agricultural activities (e.g. cattle/livestock, which trample through pools and stir up substrates when given unrestricted access to creeklines).

## Alkalinity

Alkalinity refers to the capacity of water to neutralise acid and is an expression of buffering capacity. Alkalinity of less than 20 mg/L is considered low; waters would be poorly buffered and the removal of carbon dioxide during photosynthesis may result in rapidly rising pH and relatively large range in diel values (Sawyer and McCarty 1978, Romaire 1985, Lawson 2002). Alkalinity recorded from all sites was above 20 mg/L, ranging from 33 mg/L at WMC in the wet-17 to 616 mg/L at WM in the dry-17, suggesting the buffering capacity of Marillana Creek and reference waters is good.

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[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).

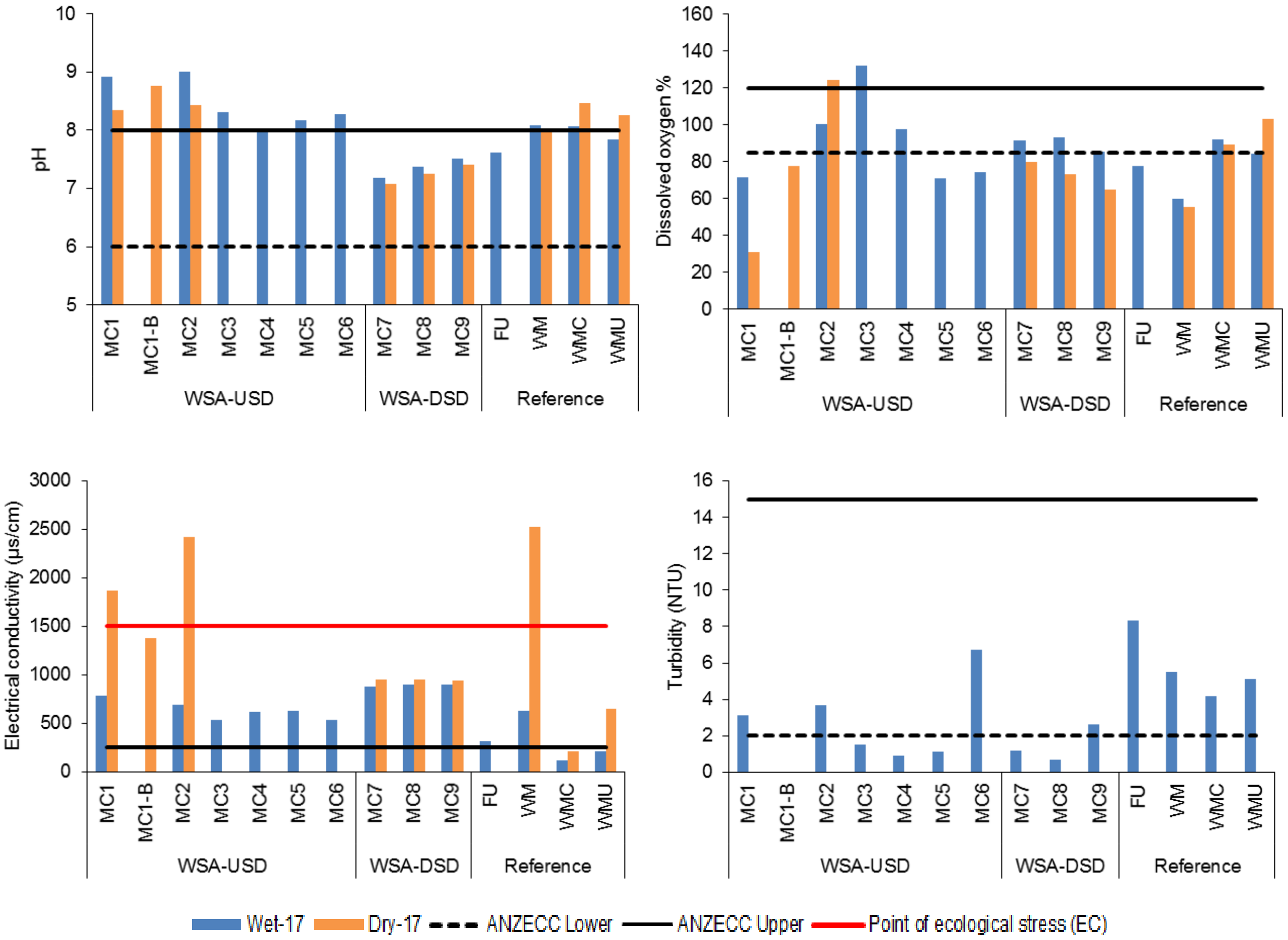

**Figure 5.** pH, dissolved oxygen (%), electrical conductivity (µm/cm) and turbidity (NTU) recorded from sites within the Study Area upstream of dewatering discharge (WSA-UDS), downstream of dewatering discharge (WSA-DSD), and reference sites, during the wet-17 and dry-17. The ANZECC/ARMCANZ (2000) upper and lower TVs, and point of ecological stress (EC) are indicated. NB. Turbidity was only recorded in the wet season.

## Ions

The composition of major ions was typically dominated by bicarbonate and chloride anions, and sodium and sulphate cations. Ionic composition at both Marillana Creek Study Area sites (both upstream and downstream of discharge) and Weeli Wolli Creek reference sites was generally similar, with ionic sodium the dominant cation and magnesium sub-dominant: $Na^+ > Mg^{2+} > Ca^{2+} > K^+$: $HCO_3^- > Cl^- > SO_4^{2-} > CO_3^-$. Concentrations of the majority of ions were greater in the dry-17, compared to the wet-17, particularly WSA sites MC1 and MC2, and reference site WM (Figure 6). Each of these pools had receded considerably between wet-17 and dry-17 (see site photographs, Appendix 4). Evaporation of pools during the dry season likely resulted in concentration of ions. There appeared to be less seasonal variation in ionic concentrations at sites maintained by dewatering discharge (MC7 - MC9) (Figure 6), likely due to the maintenance of water levels and reduced effects of evapo-concentration during the dry season.

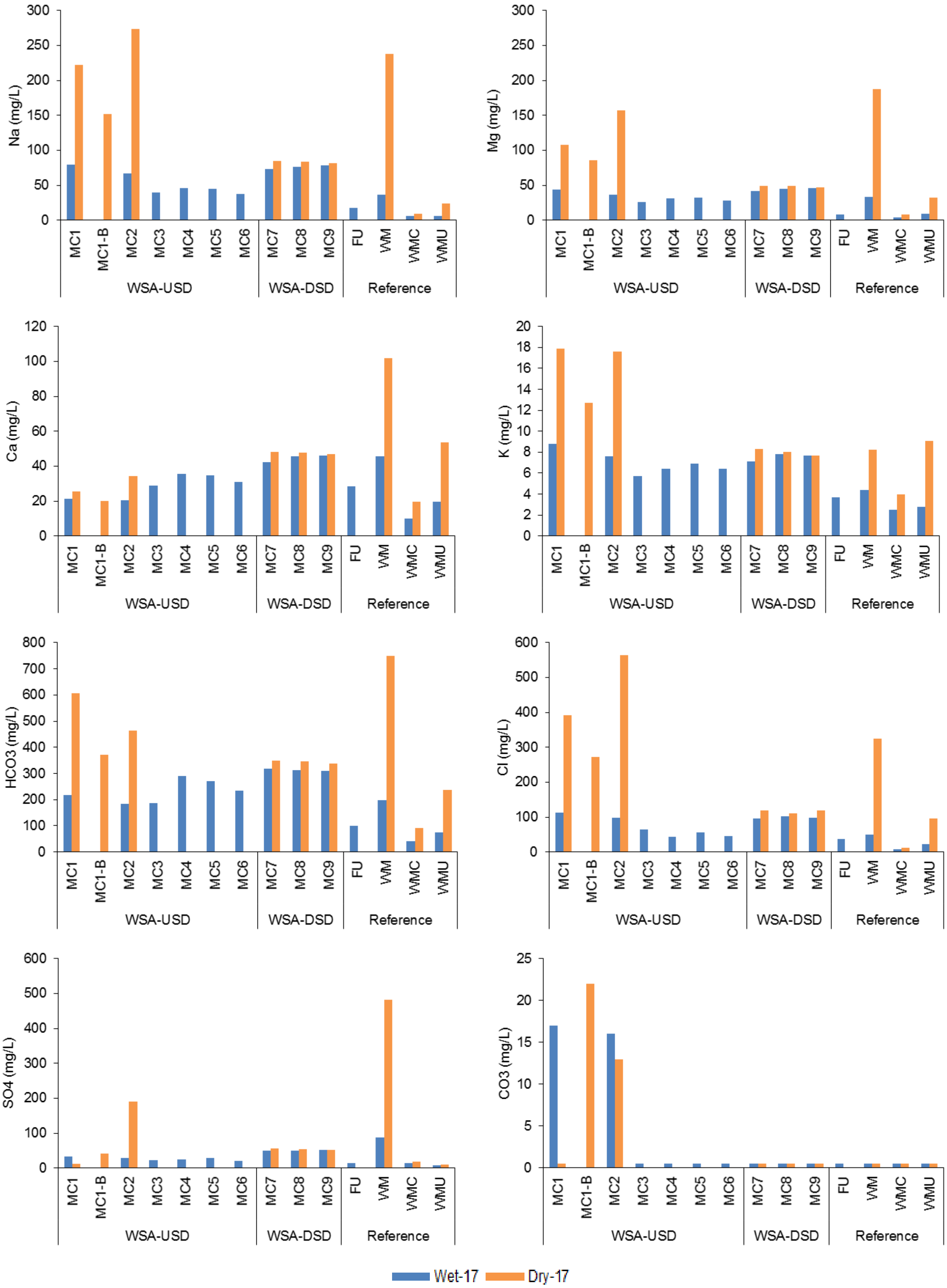

**Figure 6.** Concentrations of major ions (mg/L) recorded from sites within the Study Area upstream of dewatering discharge (WSA-UDS), downstream of dewatering discharge (WSA-DSD), and reference sites, during the wet-17 and dry-17.

## Nitrogen and Phosphorus

Total nitrogen levels were mostly below the ANZECC/ARMCANZ (2000) guideline value (0.3 mg/L) during the wet-17, with the exception of the three WSA sites downstream of the dewatering discharge outlet, all of which had elevated concentrations (3.6 - 3.8 mg/L) (Figure 7). Comparatively, most sites (except WMC) recorded total nitrogen concentrations in exceedance of the ANZECC/ARMCANZ (2000) TV in the dry-17, though highest total nitrogen values were again recorded at Study Area sites downstream of the discharge outlet (3.1 - 3.4 mg/L) (Figure 7). The total nitrogen was predominantly inorganic nitrogen oxides ($N\_NO_X$), with nitrate ($N\_NO_3$) constituting the major portion. $N\_NO_X$ concentrations at these ranged from 3.3 mg/L (MC7) to 3.8 mg/L (MC8) in the wet-17, and from 1.8 mg/L (MC9) to 3.0 mg/L (MC7) in the dry-17. These values were well above the ANZECC/ARMCANZ (2000) TV (0.01 mg/L $N\_NO_X$). During the dry-17, ammonia ($N\_NH_3$), as opposed to nitrogen oxides, appeared to contribute more to elevated total nitrogen levels at reference sites (WM, WMC) and sites upstream of any dewatering discharge (MC1, MC1-B and MC2) (Figure 7). Ammonia levels at WM in the dry season (0.49 mg/L $N\_NH_3$) exceeded the ANZECC/ARMCANZ (2000) toxicity TV for protection of 95% of aquatic species (0.32 mg/L $N\_NH_3$).

Total phosphorous levels were below the ANZECC/ARMCANZ (2000) TV (0.01 mg/L) at most sites in the wet-17, with the exception of MC4 (0.014 mg/L), MC8 (0.035 mg/L) and MC9 (0.032 mg/L) (Figure 7). In the dry-17, MC8 (0.011 mg/L) and MC9 (0.011 mg/L) also recorded total phosphorus levels above the ANZECC/ARMCANZ (2000) TV, as did reference sites WM (0.026 mg/L) and WMU (0.016 mg/L) (Figure 7).

Nitrogen and phosphorus enrichment in aquatic systems can eventually lead to eutrophication problems such as excessive algal and cyanobacterial growth, particularly during the dry season as water levels recede and water temperatures increase. Such nuisance blooms can result in adverse impacts to the aquatic ecosystem through reduced DO and toxic effects as blooms decay, and associated changes in biodiversity (ANZECC/ARMCANZ 2000). Highly eutrophic waters tend to support high abundances of pollution-tolerant species, but few rare taxa, and overall, less complexity in community structure. Also, both nitrate and ammonia can be toxic to aquatic fauna, with toxicity increasing at low DO concentrations and high pH (ANZECC/ARMCANZ 2000). Fish are more susceptible to ammonia toxicity than invertebrates, where it may cause loss of equilibrium, increased breathing and heart rate, reduction in hatching success and growth rate, and in extreme cases, death (ANZECC/ARMCANZ 2000).

Although nitrogen and phosphorus levels often exceeded ANZECC/ARMCANZ (2000) TVs, these guidelines were developed primarily for water bodies other than those in the arid and semi-arid tropics. The acceptable or 'normal' range common to water bodies of the Pilbara remains poorly understood and consequently, the guidelines should be applied with caution. Elevated nitrogen and phosphorus have previously been recorded by the authors at sites on Marillana Creek and other waterbodies throughout the Pilbara region, notably downstream of dewatering discharge operations, where nutrient-enriched groundwaters are released into the surface environment (WRM unpub. data).

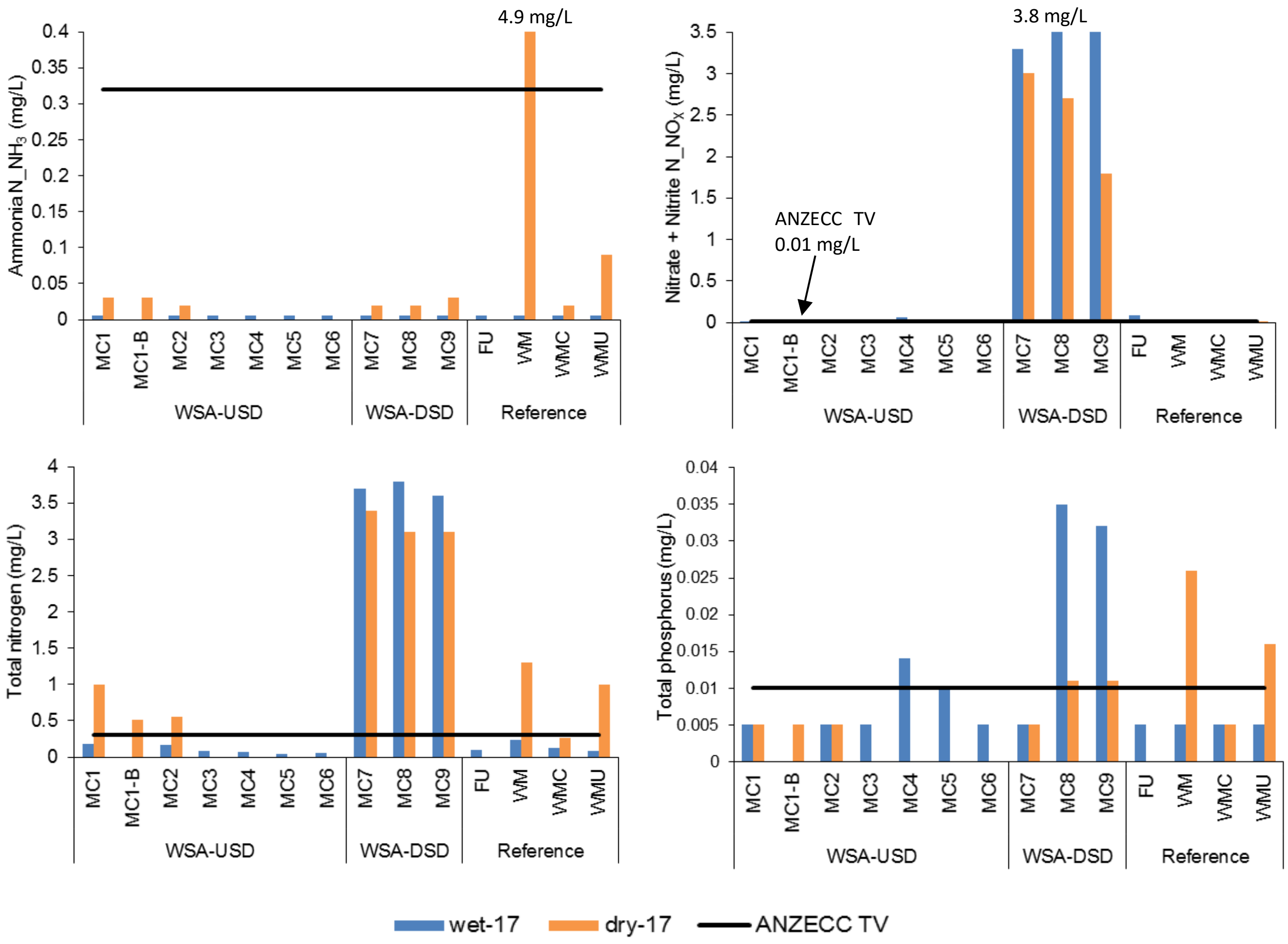

**Figure 7.** Nutrient levels recorded from sites within the Study Area upstream of dewatering discharge (WSA-UDS), downstream of dewatering discharge (WSA-DSD), and reference sites, during the wet-17 and dry-17. The ANZECC/ARMCANZ (2000) toxicity TVs are indicated.

## Dissolved metals

Metal levels were generally low, with the exception of dissolved boron (dB), copper (dCu) and zinc (dZn) at some sites (Figure 7).

In the wet-17, concentrations of dB exceeded the 99% ANZECC/ARMCANZ (2000) default TV (0.09 mg/L) at all WSA sites (both upstream and downstream of discharge), though not at any reference site (Figure 8). MC9 also recorded dB above the 95% ANZECC/ARMCANZ (2000) TV (0.37 mg/L) in the wet season (Figure 8). In the dry-17, all sites except reference sites WMC and WMU recorded dB concentrations above the 99% ANZECC/ARMCANZ (2000) TV, and MC1, MC2, MC7 and MC8 recorded dB levels exceeding the 95% TV (Figure 8). Elevated dB appears to be natural in the region, and similarly elevated concentrations of dB have been reported previously from Marillana Creek and other systems in the Pilbara, including the Fortescue River, Kalgan Creek, Mindy Mindy Creek, and Coondiner Creek (WRM, unpub. data). It is likely the aquatic fauna of this region are adapted to these levels of dB.

Dissolved copper levels exceeded the ANZECC/ARMCANZ (2000) 99% species protection TV (0.001 mg/L) at three reference sites; WM (wet-17), WMC (wet and dry-17) and WMU (dry-17) (Figure 8). However, water hardness is known to affect the toxicity of some dissolved metals, including cadmium, chromium, copper, lead, nickel and zinc, such that greater 'softness' places biota at increased risk, whilst greater water hardness may ameliorate toxicity (Markich *et al.* 2001, Charles *et al.* 2002). As such, ANZECC/ARMCANZ (2000) provide algorithms to modify trigger values for these metals based on hardness (as $CaCO_3$) at the time of sampling. Once water hardness at each site was taken into account, dCu concentrations only exceeded the hardness modified TV (HMTV) at WMC in the wet-17 (Figure 8). According to recent reviews, the HMTV for dCu may not be appropriate for protecting sensitive species (see Markich *et al.* 2005, USEPA 2014) and should be applied with caution.

Dissolved zinc was elevated at all sites, except MC3, in the wet-17, in comparison to the 99% species protection TV (0.0024 mg/L) (Figure 8). However, once water hardness was taken into account, only WMC recorded dZn concentrations in excess of HMTVs in the wet season. dZn was low at all site during thedry-17, and below the ChemCentre limit of reporting.

It is important to understand that the proportion of the measured dissolved metals that is bioavailable is not known. The bioavailability of trace metals is affected by a number of factors including, water hardness (Stephenson and Mackie 1989), alkalinity, salinity (Jackson *et al.* 2000), pH (Jackson *et al.* 2000) as well as the chemical form of the metal (Sander *et al.* 2007). Although total dissolved levels may exceed the trigger value, a proportion of this is likely complexed or bound with organics and so is not bioavailable, and therefore not toxic. When total dissolved levels exceed the trigger value, determination of bioavailable fraction is recommended as the next step by ANZECC/ARMCANZ (2000) to determine potential toxicity.

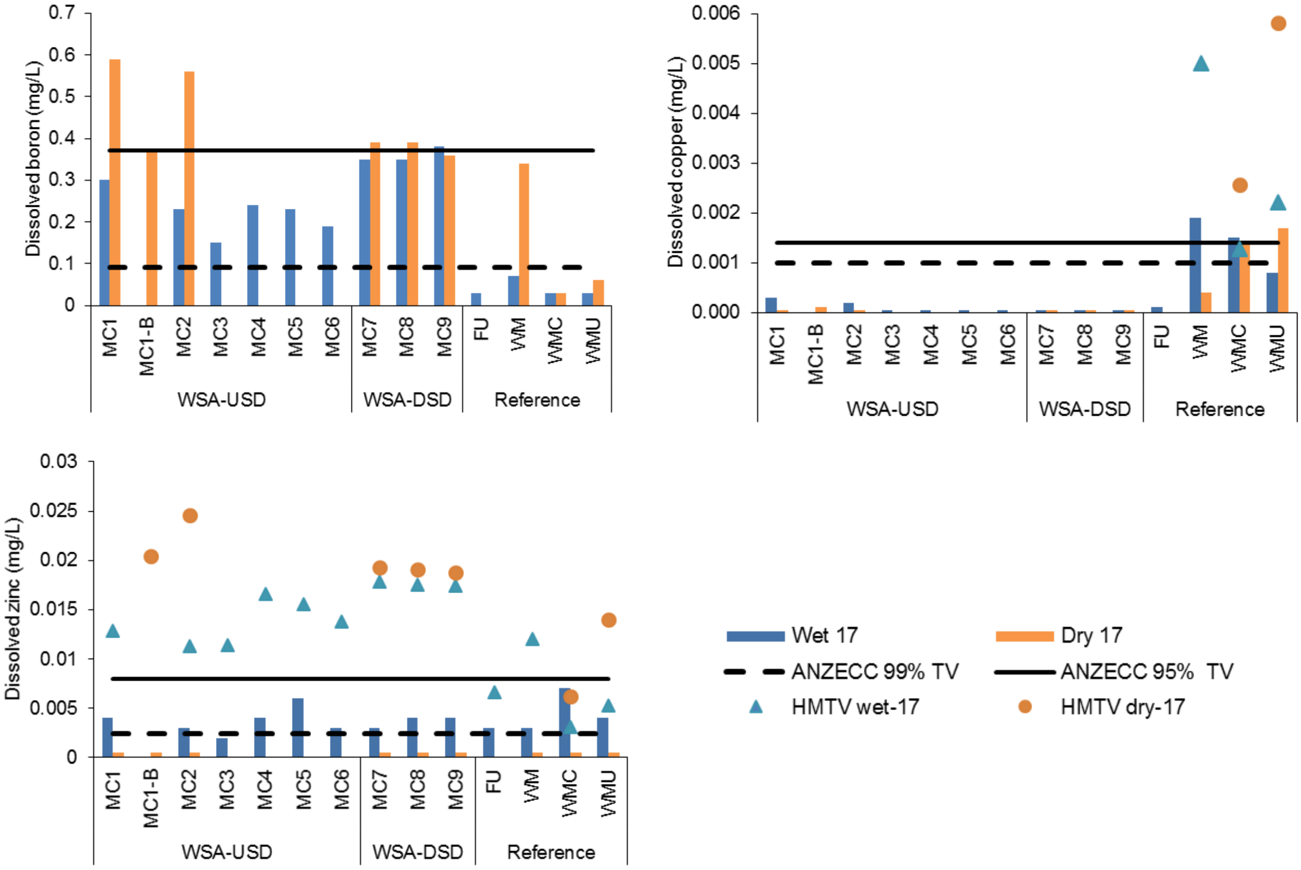

**Figure 8.** Dissolved metals levels recorded from sites within the Study Area upstream of dewatering discharge (WSA-UDS), downstream of dewatering discharge (WSA-DSD), and reference sites, during the wet-17 and dry-17. The ANZECC/ARMCANZ (2000) 99% and 95% species protection TVs, and calculated HMTVs, are indicated where applicable.

### 5.1.2 Temporal trends in water quality variables

Two-way ANOVA was used to test for significant differences in water quality parameters between sampling years (2014 vs 2017) and between locations (WSA vs reference sites). Analyses were performed on wet season data only, as only half of the sampling sites were holding surface water in the dry seasons of both 2014 and 2017, limiting replication for robust statistical testing (i.e. n = 3 reference, and n = 3 WSA replicate locations in each year). Sites sampled within the Study Area but downstream of dewatering discharge (WSA-DSD sites MC7, MC8, MC9) were excluded from these analyses, as they were not sampled in the wet-14. Dewatering appeared to be having some influence on water quality within the Study Area in 2017, which would also influence statistical comparisons between Study Area and regional reference sites.

Significant results are summarised below.

#### EC and turbidity

There was a significant difference in mean EC between years (*p* <0.001), but not between Study Area and reference sites (*p* = 0.62), and the non-significant interaction term (Year*Location, *p* = 0.243) indicated EC followed the same temporal pattern at both WSA and reference sites. For WSA and reference sites, mean EC was generally higher in 2017 than in 2014 (Table 5).

There was also a significant difference in mean turbidity levels between years (*p* = 0.004), and between WSA and reference sites (*p* = 0.009), with the non-significant interaction term (*p* = 0.246) indicating the difference between WSA and reference sites was consistent in both years. Overall, mean turbidity was higher at reference sites than at WSA sites, and higher in 2017 than in 2014 (Table 5).

**Table 5.** Summary of two-way ANOVA testing for significant year and site location effects for *in situ* water quality parameters. Mean values for untransformed data are provided for each level within the two factors, as well as the overall mean.

| **EC (µS/cm)** | **Two-way ANOVA (*df* = 1, 18)** | | | **Mean values** | | |
|---|---|---|---|---|---|---|
| | **Mean Square** | **F** | ***p*** | **Year** | **Ref.** | **WSA** |
| Year (2014 vs. 2017) | 1.441 | 23.06 | <0.001 | **2014** | 144.2 | 125.8 |
| Reference vs. WSA | 0.254 | 4.071 | 0.062 | **2017** | 316.0 | 632.2 |
| Year*Location | 0.092 | 1.475 | 0.243 | **Total** | 230.1 | 402.0 |
| **Turbidity (NTU)** | **Two-way ANOVA (*df* = 1, 18)** | | | **Mean values** | | |
| | **Mean Square** | **F** | ***p*** | **Year** | **Ref.** | **WSA** |
| Year (2014 vs. 2017) | 2.830 | 11.714 | 0.004 | **2014** | 2.13 | 0.47 |
| Reference vs. WSA | 2.140 | 8.856 | 0.009 | **2017** | 5.78 | 2.83 |
| Year*Location | 0.352 | 1.457 | 0.246 | **Total** | 3.95 | 1.76 |

#### Major ions

As expected from analysis of EC, mean Cl concentrations were significantly different between 2014 and 2017 (*p* = 0.006), but not between WSA and reference sites (*p* = 0.053), with no significant interaction term (*p* = 0.609). At both WSA and reference sites, mean Cl concentration was lower in 2017 than 2014 (Table 6).

There was a significant difference in mean $HCO_3$ concentrations between years (*p* = 0.003) and sites (*p* = 0.029) and again, the interaction term was not significant (*p* = 0.07). In 2014, mean $HCO_3$ concentrations were relatively similar between reference and WSA sites. For both reference and WSA sites, mean $HCO_3$

was lower in 2017 than in 204, however, the difference between years was far greater for reference sites than WSA sites (Table 6).

Similar patterns were observed in mean concentrations of K, Mg and Na; significant differences between both years and site locations were detected ($p < 0.05$), though with no interaction ($p > 0.05$). Mean concentrations of each of these ions decreased at both WSA and reference sites between 2014 and 2017, with the decrease at reference sites far greater than at WSA sites (Table 6).

Mean concentrations of S and $SO_4$_S were higher at reference sites in both years, and decreased significantly at both WSA and reference sites between 2014 and 2017 ($p < 0.05$), with no interaction between year and site location ($p > 0.05$) (Table 6).

**Table 6.** Summary of two-way ANOVA testing for significant year and site location effects for ionic parameters. Mean values for each level within the two factors, and total means, are also provided.

| **Cl** | **Two-way ANOVA (*df* = 1, 18)** | | | **Mean values** | | |
|---|---|---|---|---|---|---|
| | **Mean Square** | **F** | ***p*** | **Year** | **Ref.** | **WSA** |
| Year (2014 vs. 2017) | 1.302 | 10.125 | 0.006 | **2014** | 198.0 | 189.4 |
| Reference vs. WSA | 0.565 | 4.395 | 0.053 | **2017** | 29.25 | 70.0 |
| Year*Location | 0.035 | 0.272 | 0.609 | **Total** | 113.6 | 124.3 |
| **HCO$_3$** | **Two-way ANOVA (*df* = 1, 18)** | | | **Mean values** | | |
| | **Mean Square** | **F** | ***p*** | **Year** | **Ref.** | **WSA** |
| Year (2014 vs. 2017) | 0.536 | 13.053 | 0.003 | **2014** | 345.0 | 336.4 |
| Reference vs. WSA | 0.241 | 5.871 | 0.029 | **2017** | 103.5 | 230.8 |
| Year*Location | 0.157 | 3.813 | 0.07 | **Total** | 224.3 | 278.8 |
| **K** | **Two-way ANOVA (*df* = 1, 18)** | | | **Mean values** | | |
| | **Mean Square** | **F** | ***p*** | **Year** | **Ref.** | **WSA** |
| Year (2014 vs. 2017) | 0.287 | 13.416 | 0.002 | **2014** | 7.76 | 10.84 |
| Reference vs. WSA | 0.335 | 15.673 | 0.001 | **2017** | 3.35 | 6.97 |
| Year*Location | 0.014 | 0.653 | 0.432 | **Total** | 5.56 | 8.73 |
| **Mg** | **Two-way ANOVA (*df* = 1, 18)** | | | **Mean values** | | |
| | **Mean Square** | **F** | ***p*** | **Year** | **Ref.** | **WSA** |
| Year (2014 vs. 2017) | 1.172 | 15.523 | 0.001 | **2014** | 77.63 | 61.62 |
| Reference vs. WSA | 0.351 | 4.650 | 0.048 | **2017** | 13.75 | 32.73 |
| Year*Location | 0.234 | 3.094 | 0.099 | **Total** | 45.70 | 45.86 |
| **Na** | **Two-way ANOVA (*df* = 1, 18)** | | | **Mean values** | | |
| | **Mean Square** | **F** | ***p*** | **Year** | **Ref.** | **WSA** |
| Year (2014 vs. 2017) | 0.992 | 6.807 | 0.020 | **2014** | 115.2 | 102.9 |
| Reference vs. WSA | 0.987 | 6.848 | 0.019 | **2017** | 16.38 | 52.4 |
| Year*Location | 0.111 | 0.770 | 0.394 | **Total** | 65.8 | 75.4 |
| **S** | **Two-way ANOVA (*df* = 1, 18)** | | | **Mean values** | | |
| | **Mean Square** | **F** | ***p*** | **Year** | **Ref.** | **WSA** |
| Year (2014 vs. 2017) | 1.130 | 5.854 | 0.029 | **2014** | 74.85 | 25.80 |
| Reference vs. WSA | 0.059 | 0.303 | 0.590 | **2017** | 10.17 | 8.73 |
| Year*Location | 0.005 | 0.023 | 0.880 | **Total** | 42.51 | 16.49 |
| **SO$_4$_S** | **Two-way ANOVA (*df* = 1, 18)** | | | **Mean values** | | |
| | **Mean Square** | **F** | ***p*** | **Year** | **Ref.** | **WSA** |
| Year (2014 vs. 2017) | 1.065 | 5.544 | 0.033 | **2014** | 220.4 | 75.54 |
| Reference vs. WSA | 0.062 | 0.324 | 0.578 | **2017** | 30.45 | 26.33 |
| Year*Location | 0.004 | 0.021 | 0.886 | **Total** | 125.44 | 48.70 |

## Nitrogen

There was a significant difference in both mean total nitrogen and mean N_NO$_x$ levels between 2014 and 2017 ($p < 0.05$), but not between WSA and reference sites ($p > 0.05$), and non-significant interaction term. Mean concentrations of total N and N_NO$_x$ were similar at both reference and WSA sites, and followed a similar temporal trend, with notably lower values in 2017 than 2014 (Table 7).

**Table 7.** Summary of two-way ANOVA testing for significant year and site location effects for nutrient parameters. Mean values for each level within the two factors, and total means, are also provided.

| N total | Two-way ANOVA (*df* = 1, 18) | | | Mean values | | |
|---|---|---|---|---|---|---|
| | Mean Square | F | *p* | Year | Ref. | WSA |
| Year (2014 vs. 2017) | 2.049 | 14.072 | 0.002 | **2014** | 0.76 | 1.10 |
| Reference vs. WSA | 0.008 | 0.057 | 0.815 | **2017** | 0.14 | 0.10 |
| Year*Location | 0.058 | 0.400 | 0.537 | **Total** | 0.45 | 0.60 |
| **N_NO$_x$** | **Two-way ANOVA (*df* = 1, 18)** | | | **Mean values** | | |
| | **Mean Square** | **F** | ***p*** | **Year** | **Ref.** | **WSA** |
| Year (2014 vs. 2017) | 9.197 | 27.363 | <0.001 | **2014** | 0.47 | 0.86 |
| Reference vs. WSA | 0.015 | 0.046 | 0.833 | **2017** | 0.02 | 0.01 |
| Year*Location | 0.018 | 0.055 | 0.818 | **Total** | 0.24 | 0.40 |

## Metals

There was a significant difference in mean concentration of dB between years ($p < 0.001$), and between WSA and reference sites ($p < 0.001$), though there was no significant interaction between the factors ($p = 0.056$). Overall, mean dB was higher at WSA sites than at reference sites, with concentrations decreasing at both locations between 2014 and 2017 (though the decrease was far greater at reference sites) (Table 8).

Mean concentrations of dCu were significantly different between WSA and reference sites ($p = 0.009$), but not between years ($p = 0.956$). There was no interaction between the factors ($p = 0.428$). Mean dCu concentrations were higher at reference sites in both years, with concentrations increasing slightly at reference sites between 2014 and 2017, and decreasing slightly at WSA sites over the same period (Table 8).

Mean dMn concentrations were significantly different between 2014 and 2017 ($p = 0.006$), but not between WSA and reference sites ($p = 0.251$), with no interaction ($p = 0.364$). Mean Cl concentrations decreased at both WSA and reference sites between 2014 and 2017, with the decline at reference sites far greater relative to the decrease at WSA sites (Table 8).

There was a significant difference in mean concentrations of dZn between years ($p < 0.001$), and between WSA and reference sites ($p = 0.032$), though there was no significant interaction between the factors ($p = 0.155$). Overall, mean dZn was higher at reference sites than at WSA sites, with concentrations increasing at both locations between 2014 and 2017 (Table 8).

**Table 8.** Summary of two-way ANOVA testing for significant year and site location effects for dissolved metal parameters. Mean values for each level within the two factors, and total means, are also provided.

| **Cu** | **Two-way ANOVA (*df* = 1, 18)** | | | **Mean values** | | |
|---|---|---|---|---|---|---|
| | **Mean Square** | **F** | ***p*** | **Year** | **Ref.** | **WSA** |
| Year (2014 vs. 2017) | 0.001 | 0.003 | 0.956 | **2014** | 0.0008 | 0.0002 |
| Reference vs. WSA | 2.374 | 9.135 | 0.009 | **2017** | 0.0011 | 0.0001 |
| Year*Location | 0.172 | 0.663 | 0.428 | **Total** | 0.0009 | 0.0002 |
| **B** | **Two-way ANOVA (*df* = 1, 18)** | | | **Mean values** | | |
| | **Mean Square** | **F** | ***p*** | **Year** | **Ref.** | **WSA** |
| Year (2014 vs. 2017) | 1.002 | 26.081 | <0.001 | **2014** | 0.22 | 0.41 |
| Reference vs. WSA | 1.557 | 40.540 | <0.001 | **2017** | 0.04 | 0.22 |
| Year*Location | 0.165 | 4.308 | 0.056 | **Total** | 0.13 | 0.31 |
| **Mn** | **Two-way ANOVA (*df* = 1, 18)** | | | **Mean values** | | |
| | **Mean Square** | **F** | ***p*** | **Year** | **Ref.** | **WSA** |
| Year (2014 vs. 2017) | 2.698 | 10.052 | 0.006 | **2014** | 0.110 | 0.015 |
| Reference vs. WSA | 0.382 | 1.424 | 0.251 | **2017** | 0.005 | 0.003 |
| Year*Location | 0.235 | 0.876 | 0.364 | **Total** | 0.058 | 0.009 |
| **Zn** | **Two-way ANOVA (*df* = 1, 18)** | | | **Mean values** | | |
| | **Mean Square** | **F** | ***p*** | **Year** | **Ref.** | **WSA** |
| Year (2014 vs. 2017) | 0.874 | 38.836 | <0.001 | **2014** | 0.002 | 0.001 |
| Reference vs. WSA | 0.126 | 5.605 | 0.032 | **2017** | 0.004 | 0.004 |
| Year*Location | 0.050 | 2.241 | 0.155 | **Total** | 0.003 | 0.002 |

### 5.1.3 Multivariate analysis of water quality data

Multivariate analysis revealed the following patterns for the suite of water quality variables sampled at each site:

PERMANOVA revealed that overall, there was a significant difference in water quality between 2014 and 2017 (df = 1, pseudo-F = 4.27, *p* = 0.003). The nMDS plot (Figure 9A) shows that there is some separation of sites based on sampling year, however there is a relatively high amount of overlap among samples, particularly among Marillana Creek reference and Study Area (WSA) sites. There appeared to be less overlap of Weeli Wolli Creek reference sites (e.g. WM, WMU, WMC) among years.

There was also a significant difference in water quality between wet and dry seasons (PERMANOVA df = 1, pseudo-F = 3.39, *p* = 0.005), however overlap among groups relatively high (Figure 9B). In general, dry season sites were spread more widely on the nMDS plot, whereas sites sampled in the wet season grouped relatively closely (Figure 9B). This suggests water quality is slightly more variable within and between systems in the dry season, likely driven by receding water levels, evapo-concentration effects and lack of connectivity between pools.

Water quality was also significantly different between site locations (i.e. between Marillana, Weeli Wolli and Fortescue River reference sites, and WSA sites upstream and downstream of discharge) (PERMANOVA df = 1, pseudo-F = 2.89, *p* = 0.001). Cluster analysis (SIMPROF) was able to define a number of separate groups based on water quality characteristics (Figure 9C). Of note was the distinct separation of WSA-DSD sites from WSA-USD sites (PERMANOVA pairwise testing t = 2.785, *p* = 0.001), Weeli Wolli Creek reference sites (t= 2.070, *p* = 0.006) and Marillana Creek reference sites (t = 3.800, *p* = 0.011). WSA-USD sites were also significantly different to Weeli Wolli Creek reference sites (t = 1.746, *p* = 0.011), but not Marillana Creek reference sites (t = 1.094, *p* = 0.274) (Figure 9C).

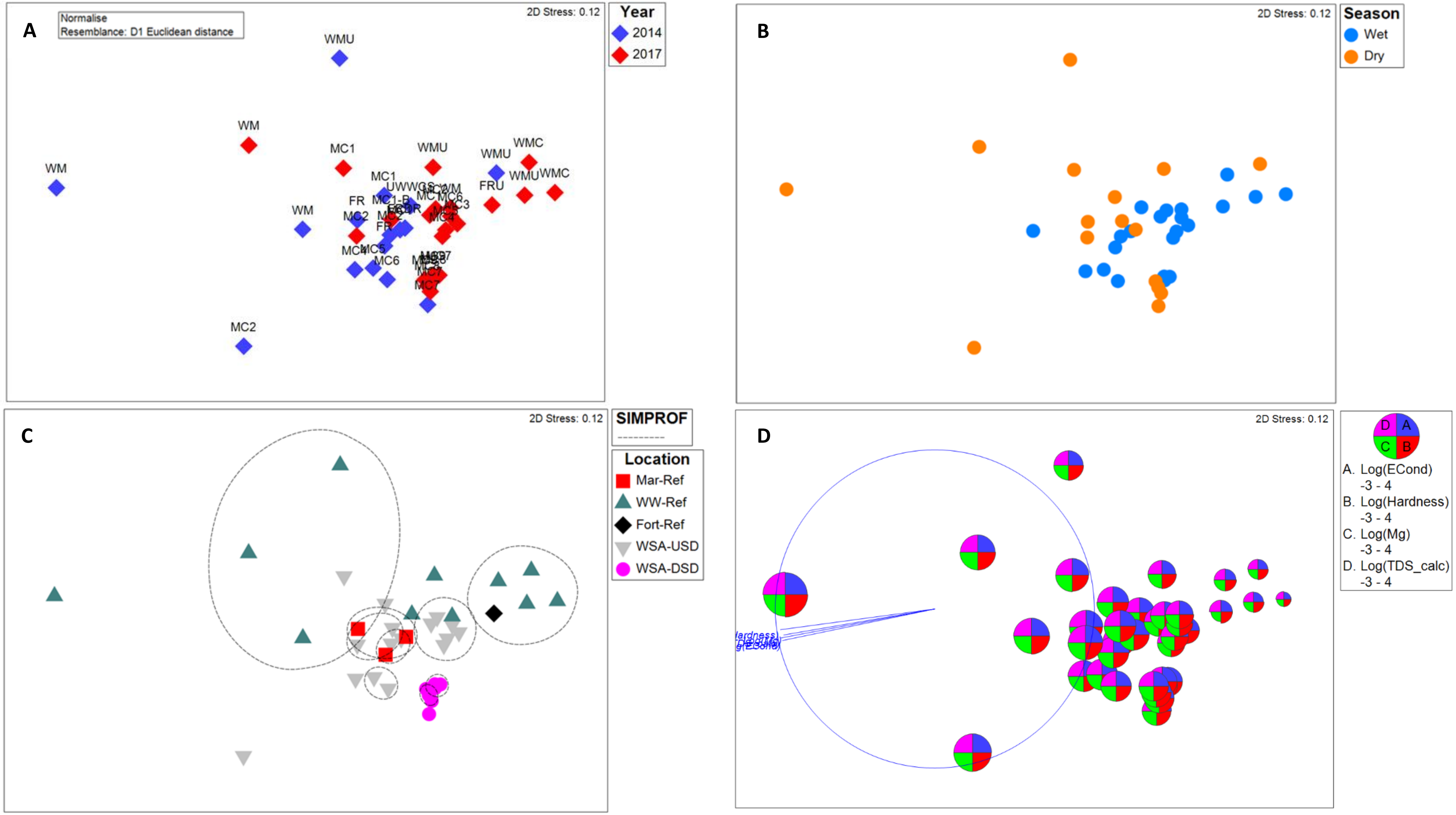

**Figure 9.** nMDS plots of water quality data, showing samples identified by year (A), season (B) and location (C). SIMPROF clustering of groups is shown as a black dotted line. Bubble plots (D) show the relative influence of EC, Hardness, Mg and TDS on the distribution of sites on the nMDS plots.

Pearson correlations showed that EC, Hardness, Mg and total dissolved solids (TDS) had the most influence site distribution (correlation of > 0.95), with overlain bubble plots displaying the relative influence of these four parameters on the spread of sites on the nMDS plot (Figure 9D). The bubble plots show a generally increasing trend in these parameters from right-to-left on the nMDS plot (Figure 9D). Sites sampled in the dry season, particularly in 2014, tended to be most heavily influenced by higher concentrations of EC, Hardness, Mg and TDS, likely an artefact of evapo-concentration of ions as pools receded. Sites sampled in 2017, and particularly in the wet season, were subject to lower concentrations of these parameters, with wet season rains likely diluting the influence of ions.

## 5.2 Habitat Characteristics

In general, the substrate of the of Marillana Creek (WSA) sites was dominated by transmissive gravel, sand and pebbles, with the substrate of Weeli Wolli reference sites comprising a higher bedrock component (Appendix 5). Habitat at a number of sites, such as WSA sites MC1 and MC2, appeared to change slightly between the wet and dry seasons, with an increase in the dominance of bedrock, and therefore an increase in mean substrate size and bed compaction. This was primarily a reflection of receding waters revealing more bedrock than was initially observed at these sites, with remnant surface waters perched atop areas of bedrock rather than transmissive gravels and sands. Habitat diversity at sites MC1 and MC2 was also lower in the dry-17, as fewer habitats, such as trailing fringing vegetation and emergent macrophyte, were inundated at this time. However overall, there was no significant difference in habitat characteristics between the wet and dry seasons (PERMANOVA df = 1, pseudo-F = 1.02, *p* = 0.401), with a high degree of overlap among wet and dry season groups on the nMDS plot (Figure 10A).

There was a highly significant difference in habitat characteristics between site locations (i.e. WSA-USD, WSA-USD, and reference sites) (PERMANOVA df = 1, pseudo-F = 5.37, *p* = 0.001). Pairwise testing showed that habitat was most different between WSA-DSD and Weeli Wolli reference sites (t = 3.486, *p* = 0.003), and between WSA-DSD and WSA-USD sites (t = 2.868, *p* = 0.001). The separation of these groups can be clearly seen on the nMDS plot of Figure 10B. Vectors overlain (Pearson correlation > 0.7) show that the higher proportion of bedrock was the main factor influencing the separation of Weeli Wolli Creek reference sites, reflecting the fact that these are semi-permanent pools with surface water perched atop a bedrock layer (Figure 10B; see also site photographs in Appendix 2). Higher proportions of trailing vegetation, canopy cover, large woody debris (LWD) such as fallen logs and branches, and habitat diversity were all factors contributing to the separation of WSA-DSD sites, an artefact of these sites being located within forested sections of Marillana Creek, with greater surface water extent (due to discharge) leading to increased habitat diversity (Figure 10B). WSA-USD sites are slightly more exposed (i.e. located in less vegetated areas), with larger mean particle size, and to a lesser extent emergent macrophyte and silt, influencing the separation of these sites (Figure 10B).

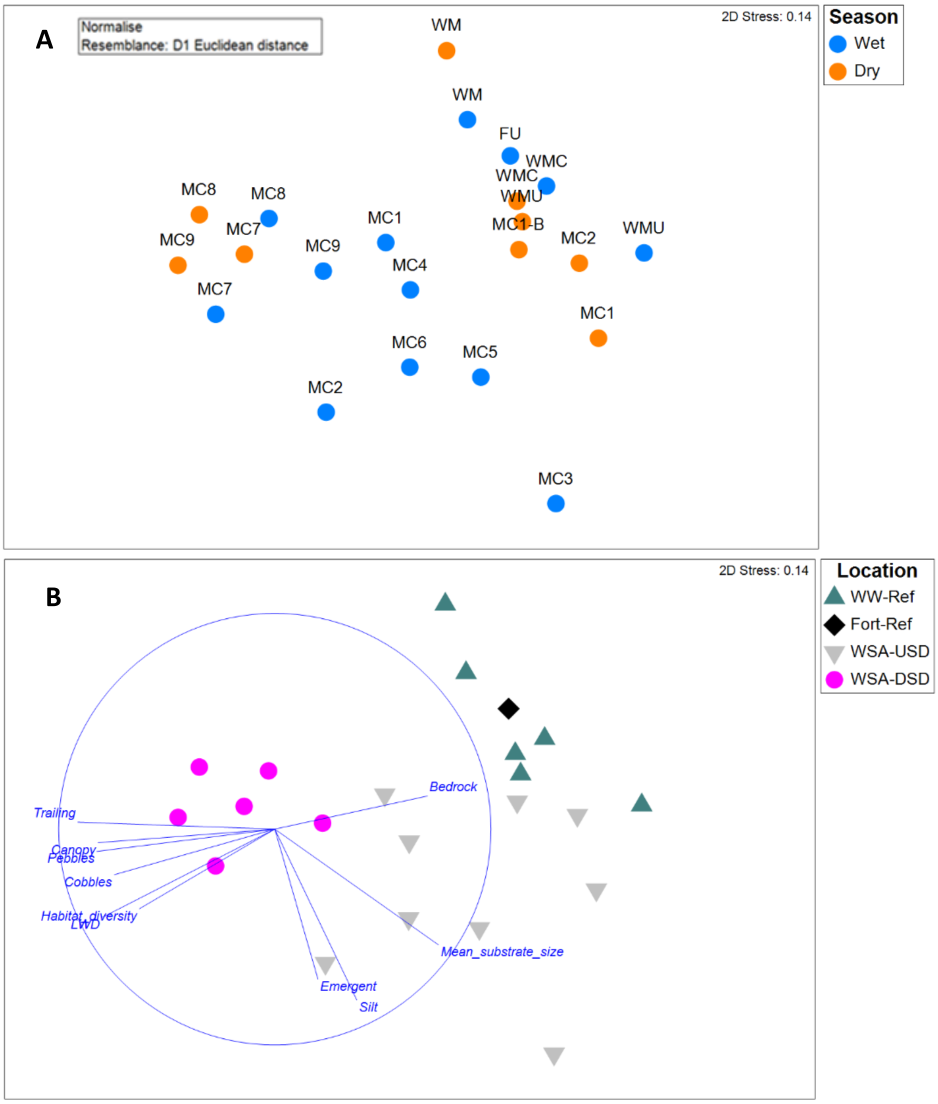

**Figure 10.** nMDS plot of 2017 habitat data, showing samples identified by season (A) and location (B). Vectors overlain on Figure 11B show the relative influence of habitat characteristics (Pearson correlation >0.7) on the distribution of sites on the nMDS plots**.**

## 5.3 Microinvertebrates

### 5.3.1 Taxonomic composition and species richness

A total of 92 taxa[11] of microinvertebrates were recorded during the current study, with 72 being recorded in wet-17 and 32 in dry-17 (Table 9 and Appendix 6). The list includes groups which could not be identified to species level due to unresolved taxonomy and/or specimens being damaged or immature. Therefore, the total microinvertebrate species richness is likely greater than that reported here. The microinvertebrate fauna comprised Protista, Rotifera, Copepoda, Cladocera (water fleas), and Ostracoda (seed shrimp) (see Table 9). The microinvertebrate fauna was typical of tropical systems reported elsewhere, with lecanids dominating the Rotifera and chydorids dominating the Cladocera (e.g. Koste and Shiel 1983, Tait *et al.* 1984, Smirnov and De Meester 1996, Segers *et al*. 2004).

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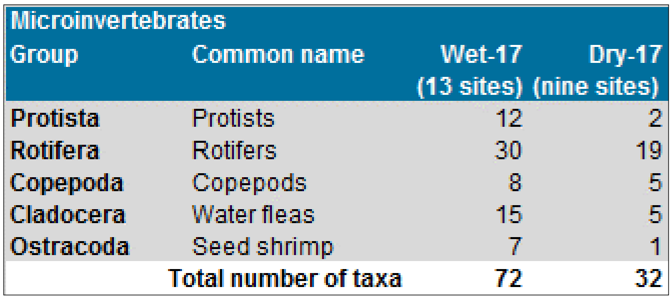
[11] Not all specimens could be identified to species, so taxa refers to the lowest levels of identification, whether that be species, genus, family or order.

**Table 9**. Summary of higher-order microinvertebrate taxa composition by season.



| Microinvertebrates<br>Group | Common name | Wet-17<br>(13 sites) | Dry-17<br>(nine sites) |
|---|---|---|---|
| **Protista** | Protists | 12 | 2 |
| **Rotifera** | Rotifers | 30 | 19 |
| **Copepoda** | Copepods | 8 | 5 |
| **Cladocera** | Water fleas | 15 | 5 |
| **Ostracoda** | Seed shrimp | 7 | 1 |
| | **Total number of taxa** | **72** | **32** |

Microinvertebrate taxa richness varied between site and season (Figure 11). Taxa richness ranged from 1 (at MC8) to 34 (at reference site WM) during the wet-17, and zero (at MC7 and MC8) to 13 (at MC2 and reference site WMU) during dry-17. At sites which were successfully sampled in both seasons, a greater number of microinvertebrate taxa was recorded in the dry season (Figure 11). Average microinvertebrate taxa richness was significantly lower from Study Area sites downstream of the Yandi discharge point (i.e. WSA-DSD sites; Two-way ANOVA; df = 2, F = 5.23, *p* = 0.018), than either reference sites or Study Area sites upstream of the discharge (i.e. WSA-USD sites; Figure 12). There was no significant difference in average microinvertebrate taxa richness between WSA-USD sites and reference sites, nor was there a significant difference in taxa richness between season (Two-way ANOVA; df = 1, F = 2.32, *p* = 0.147; Figure 12).

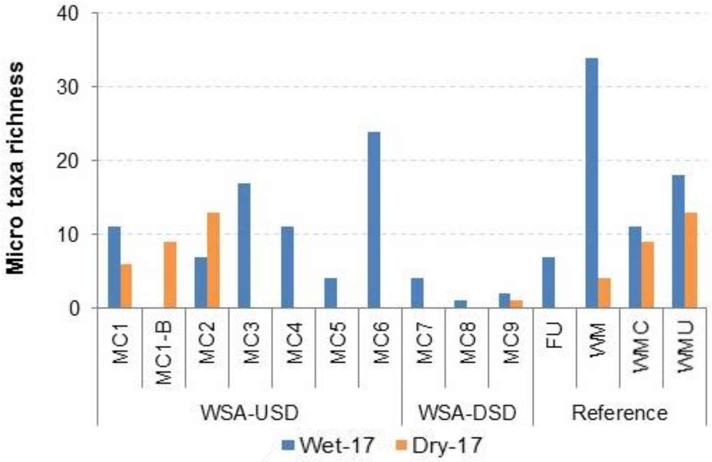


**Figure 11.** Microinvertebrate taxa richness recorded from the Study Area (WSA-USD, WSA-DSD) and reference sites during the wet-17 and dry-17.

The cause of the significantly lower microinvertebrate taxa richness recorded from sites downstream of the Yandi discharge point remains unknown, but is likely due to a combination of possible explanations including a) wash out of microinvertebrates due to greater shear velocity/flow associated with the dewatering-discharge, b) discharge of groundwater which is essentially devoid of plankton with little time for recolonisation, and c) differences in water quality downstream of the discharge point due to the discharge of dewatered groundwater.

Instantaneous abundances of microinvertebrates in a river reach are dependent on a number of factors, including the ability of the individuals to maintain position, effects of water movement on feeding and reproduction, and the length of time that favourable conditions for population growth have been maintained (Richardson 1992). Higher velocity flows, such as experienced downstream of the discharge point, in comparison to upstream, are known to 'sweep-out' existing microinvertebrate populations, impact feeding and/or limit reproduction (Miquelis *et al.* 1998, Schöll *et al.* 2012). Slow-flowing or still water habitats are necessary for the survival of zooplankton assemblages (Schiemer *et al*. 2001), and reductions in this habitat have been associated with reductions in microinvertebrate diversity and changes in community structure elsewhere (Schöll *et al.* 2012). In natural systems, where flood-pulse regimes and seasonal changes in flow are common, there is a lagged response in the re-development of assemblages as early colonisers are swept away during floods (Schöll *et al.* 2012). In an experimental study examining the effect of flow on various species of micro-crustacea, Richardson (1992) found Cladocera had the poorest ability to maintain position of all groups tested, and were unable to maintain position at velocities greater than 0.025 m/s. Washout of *Daphnia* (Cladocera) and *Eucyclops* (Copepoda: Cyclopoida) was complete at velocities greater than 0.025 m/s and 0.077 m/s, respectively (Richardson 1992). Immature copepods were reported to be particularly susceptible to downstream washout (Richardson 1992), and have been found to dominate invertebrate densities in drift (i.e. Saunders and Lewis 1989). In Richardson's (1992) study, experimental results were compared with field observations. The highest densities of micro-crustacea, including Cladocera, Rotifera and immature copepods, were recorded from the non-flowing or downstream zones of pools (Richardson 1992).

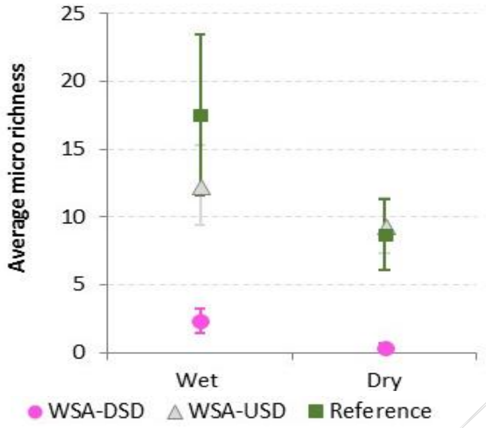


**Figure 12.** Average microinvertebrate taxa richness (±se) from each location (WSA-DSD, WSA-USD, or reference) in 2017.

The low richness downstream of the Yandi discharge point may also have been due to the discharge of 'pure' groundwater, which is essentially devoid of microinvertebrates, with the fauna taking time (distance downstream) to establish.

Alternatively, the reduction in microinvertebrate recorded from Marillana Creek DSD may be due, at least in part, to the water quality changes experienced due to the continuous discharge of excess groundwater (see Section 5.1.1), most notably the elevated nitrogen nutrients. Effects to microinvertebrates from increased nitrogen nutrients include changes in species composition favouring pollution tolerant species (Camargo and Alonso 2006), changes in food web structures due to the proliferation of primary producers (eutrophication; Turner 2002), and direct toxic effects. The main toxic effect, in particular of nitrate, appears to be the conversion of oxygen-carrying pigments into forms that are incapable of carrying oxygen (Cheng *et al*. 2002). No microinvertebrates of any description were recorded from WSA-DSD sites MC7 and MC8 in the dry-17, and very few cladocerans or ostracods were recorded from any WSA-DSD site in either the wet-17 or dry-17 (see Appendix 6). In ecotoxicity experiments, Maceda-Veiga *et al.* (2015) found that increased temperature and nitrate concentrations led to increased mortality of the cladoceran *Daphnia magna*, with chronic effects including reduced body size filtering rates and fecundity reported at lower concentrations. Maceda-Veiga *et al.* (2015) also reported decreased density of protists in elevated nitrate treatments.

It is likely the lower microinvertebrate richness on Marillana Creek downstream of the discharge point are a result of a combination of the aforementioned factors, rather than any single driver. Low microinvertebrate richness recorded from sites below dewatering-discharge outlets is a common finding in aquatic ecosystem surveys by WRM across the Pilbara (WRM unpub. data).

### 5.3.2 Significance of microinvertebrate fauna

The majority of microinvertebrate taxa recorded during the current study were common ubiquitous species, with distributions extending throughout Australasia or the world (cosmopolitan species). Of interest within the microinvertebrate fauna was the collection of species endemic to the Pilbara, Western Australia, and an undescribed species. Such taxa included the rotifer *Lecane* 'bulloid' n. sp., and the copepod *Australoeucyclops karaytugi*.

*Lecane* ‘bulloid’ n. sp was recorded from MC6, WM and WMC in the wet-17, and MC1-B in the dry-17. It was not recorded in 2014. This species is currently undescribed and has been recorded from nearby Weeli Wolli Creek, Kalgan Creek and Mindy Mindy Creek previously. It is one of a species complex of lecanids of similar morphology to *noobijupi*, but of considerable size, being larger than *bulla* (Dr Hendrik Segers, Royal Belgian Institute of Natural Sciences, pers. comm.). Genetics is required to elucidate species within this complex. On present evidence, the ‘bulloid’ morphotype is known only from the Pilbara region of Western Australia.

The copepod *Australoeucyclops karaytugi* is also endemic to the Pilbara. Within the region, it is known from Weeli Wolli Spring nearby, as well as other spring systems including Palm Springs (Caves Creek), Bamboo Springs (De Grey) and Skull Springs (De Grey), and the permanent pools Coppin Gap (D eGrey), Glen Herring Pool (De Grey), Wannagunna Pool (Ashburton), Horrigan's Pool (Ashburton), and Pool on Billan Ballan (Yule). It was recorded from MC1 in the wet-17. *A. karaytugi* is also previously known from MC2, MC4, MC6 and MC7, as well as the reference site FR on Marillana Creek (2014 records). It was not recorded from any Weeli Wolli Creek reference sites during the current study but it is known from Weeli Wolli Spring.

### 5.3.3 Temporal and spatial differences in microinvertebrate fauna

**Taxa richness**

Given the low replication in the dry seasons of both 2014 and 2017, due to many sites being dry, two-way ANOVA was only undertaken on wet season data, with a comparison being made between years (2014 vs 2017) and location (WSA vs reference sites). In addition, only one site downstream of the Yandi discharge point (i.e. WSA-DSD sites) was sampled in 2014 (MC7 in the dry-14).

Overall, there was no significant difference in wet season microinvertebrate taxa richness between year (Two-way ANOVA; df = 1, $p$ = 0.223) or between site location (df = 1, $p$ = 0.620; Table 10 and Figure 13). There was also no significant interaction term (df = 18, $p$ = 0.104; Table 10). This is despite the fact that average taxa richness was slightly higher from WSA sites in the 2014, but slightly higher from reference sites in 2017 (Figure 13).

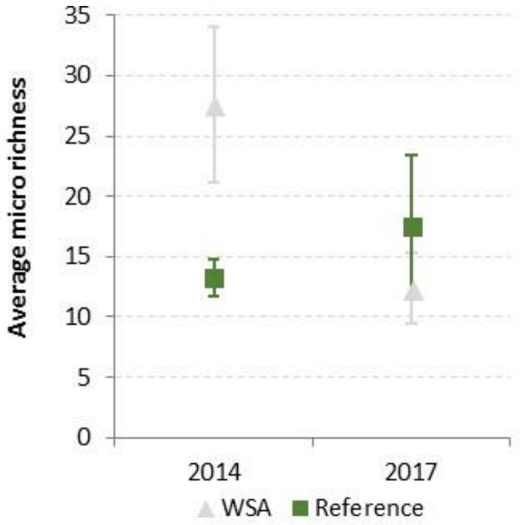


**Figure 13**. Average microinvertebrate taxa richness (±se) recorded from WSA and reference sites in the wet seasons of 2014 and 2017.

**Table 10.** Summary of two-way ANOVA results testing for significant differences in microinvertebrate taxa richness between year (2014 vs 2017) and site location (WSA vs reference). Wet season data only.

| Source | Two-way ANOVA (*df* = 1, 18) | | |
|---|---|---|---|
| | Mean Square | F | *p* |
| Year (2014 vs. 2017) | 0.11 | 1.61 | 0.223 |
| Reference vs. WSA | 0.02 | 0.26 | 0.620 |
| Year*Location | 0.19 | 2.99 | 0.104 |

## Patterns in microinvertebrate fauna assemblage structure

Any patterns in the nMDS ordination of all microinvertebrate assemblage data (total abundance, dispersion weighted and square root transformed) collected in 2014 and 2017, were masked by the large difference in microinvertebrate assemblages of the sites located downstream of the Yandi discharge point (namely the MC7, MC8 and MC9 samples from the dry-17, and MC8 sample from the wet-17; Figure 14). This was despite the fact that the fix collapse function was used in PRIMER which incorporates some metric MDS (5% mMDS) into the non-metric ordination. Therefore, these sites were removed from further multivariate analyses. These sites sat apart in the ordination due to the low microinvertebrate richness and abundance recorded in comparison to all other samples.

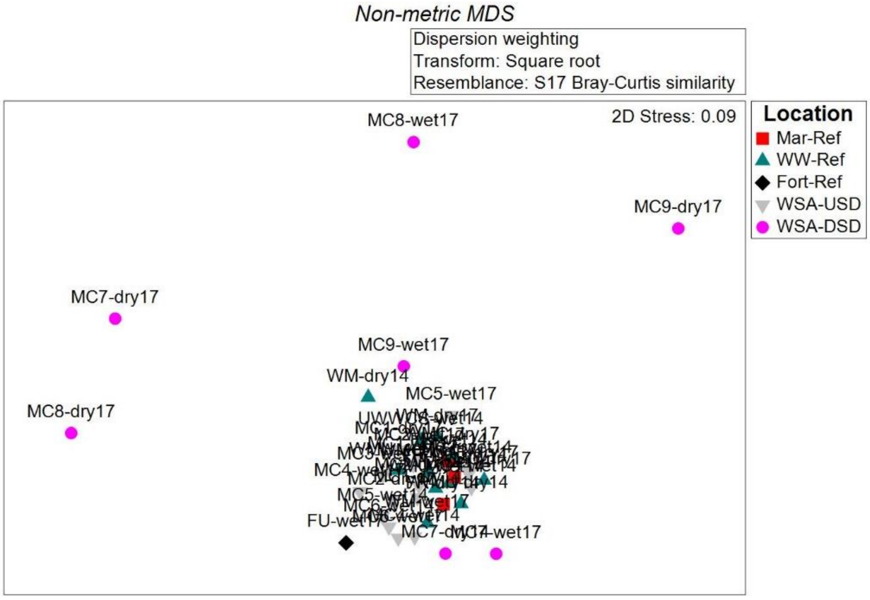


**Figure 14.** nMDS plot of all microinvertebrate assemblage data (total abundance, dispersion weighted and square root transformed). Ordination was a combined MDS to fix collapse (95% nMDS & 5% mMDS). Samples are identified by location and labelled by site and sampling event.

Patterns were evident in the microinvertebrate assemblage nMDS of all sites sampled in 2014 and 2017 (except those outliers which were removed from the analysis), with samples generally separating by location (Figure 15). Generally, reference sites from Weeli Wolli Creek and Marillana Creek had similar assemblages, but these reference samples separated in ordination space from Marillana Creek WSA sites (Figure 15). Within the Marillana Creek WSA sites, there was further separation of sites upstream and downstream of the Yandi discharge point (Figure 15). There was a high degree of variability within each location type though, with groupings not being particularly tight. A total of six significant SIMPROF cluster groups were detected (Figure 15).

Overall, there was a significant difference in microinvertebrate assemblages between site location (PERMANOVA; df = 1, pseudo-F = 1.40, p = 0.0011; Figure 15), and year (df = 1, pseudo-F = 1.45, *p* = 0.0312; Figure 16). However, there was no significant difference between season (PERMANOVA; df = 1, pseudo-F = 1.09, *p* = 0.3002; Figure 16). In the case of location and year, the low pseudo-F values indicate that despite the significant result there was still some overlap of samples within each factor.

Water quality variables best correlated with the microinvertebrate assemblage ordination included pH, TSS and concentrations of total N, dCu, dCo, dFe and dV (BVSTEP; correlation = 0.48, *p* = 0.001).

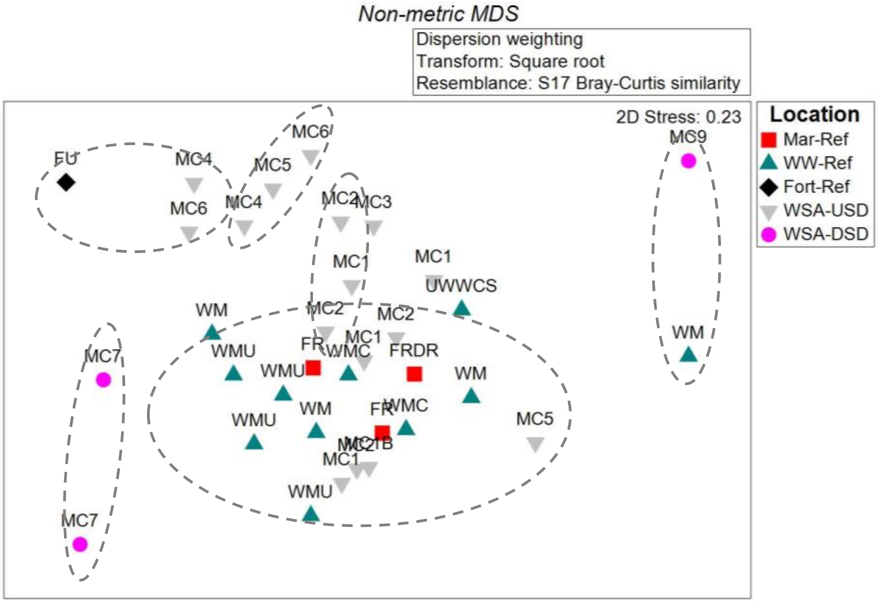


**Figure 15.** nMDS plot of microinvertebrate assemblage data (total abundance, dispersion weighted and square root transformed), with outlier sites from Figure 3 removed (MC7, MC8 and MC9 from the dry-17 and MC8 from the wet-17). Samples are identified by location and labelled by site. Samples are grouped within grey circles based on significantly separate cluster groups as determined by SIMPROF.

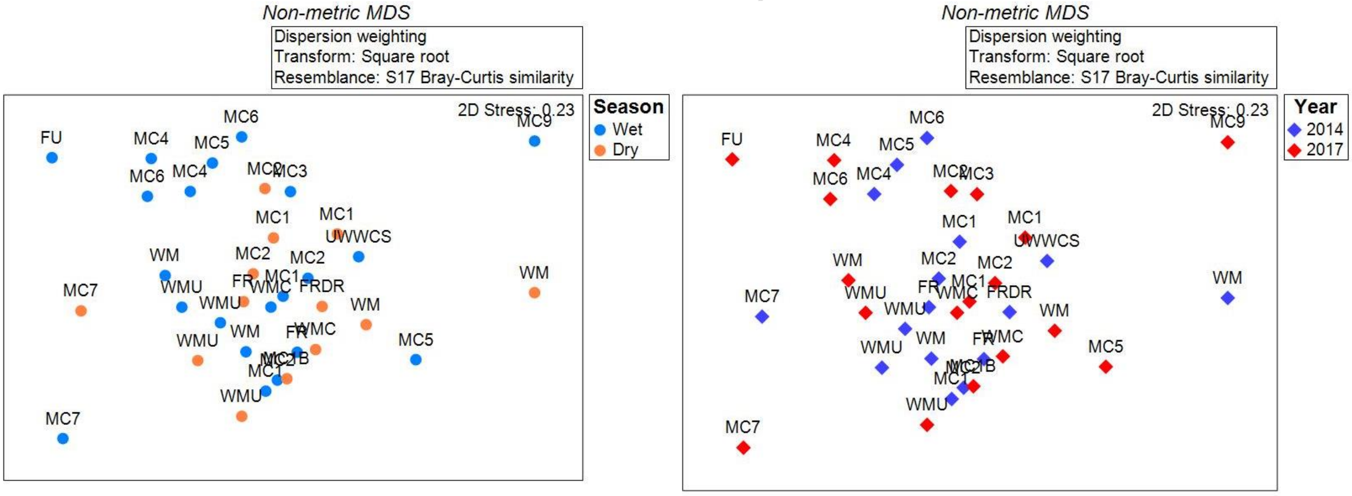


**Figure 16.** nMDS plot of microinvertebrate assemblage data (total abundance, dispersion weighted and square root transformed), with outlier sites removed, showing samples identified by season (left) and year (right).

## 5.4 Hyporheos

### 5.4.1 Taxonomic composition and species richness

A total of 96 taxa were recorded from hyporheic samples collected during the current study, with 79 recorded in the wet-17 and 62 in the dry-17 (Appendix 7). The majority of these taxa were classified as stygoxene (58%), *i.e.* species that appear in groundwater habitats by accident or seeking refuge during drought, and not specially adapted to subterranean inhabitation. Of the remaining taxa, 9% were classified as stygobitic, *i.e.*, obligate groundwater inhabitants with specialised morphological adaptations to survive in such environments (stygofauna), 16% were considered occasional hyporheic stygophiles (species that use the hyporheic zone seasonally or during early life history stages), 14% were possible hyporheic taxa, and 1% were unknown due to insufficient taxonomy or information in the literature. Although classifications followed those of Boulton (2001), this type of analysis should be treated with some caution, as results are likely affected by available information on life history, taxonomic resolution, and interpretation of classification categories. Stygobites were recorded from all sites except WMC.

Possible troglobitic taxa[12] were also recorded; Myriapoda spp. from MC7 (wet-17) and MC9 (wet and dry-17), and Pauropoda spp. from MC1 in the wet-17.

The number of taxa considered hyporheic (including occasional hyporheos stygophiles, stygobites and possible hyporheic species) varied greatly amongst sites and between seasons (Figure 17). Taxa richness ranged from two (at WMU in the wet-17 and MC9 in the dry-17) to 13 (at MC2 and MC7 in the wet, and WMC in the dry; Figure 17). In both seasons there appeared to be a longitudinal gradient in taxa richness downstream of the Yandi discharge point, with greatest richness closest to the discharge and decreasing progressively downstream to MC9 (Figure 17).

**Figure 17.** Hyporheic taxa richness recorded from the Study Area (WSA-USD, WSA-DSD) and reference sites during the wet-17 and dry-17.

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[12] Troglofauna are terrestrial animals which live entirely in the dark within cave systems or underground within fissures in bedrock. Similar to stygobites (stygofauna) they have adaptations to survive such conditions, including long antennas, no eyes, and a lack of pigmentation. The word 'troglo' means hole.

Overall, there was no significant difference in taxa richness between site location (WSA-USD, WSA-DSD or reference site; Two-way ANOVA; df = 1, F = 0.67, *p* = 0.527), nor was there any significant difference between seasons (df = 1, F = 0.00, *p* = 0.987; Figure 18). In both seasons, greatest average taxa richness was recorded from WSA-USD (Figure 18).

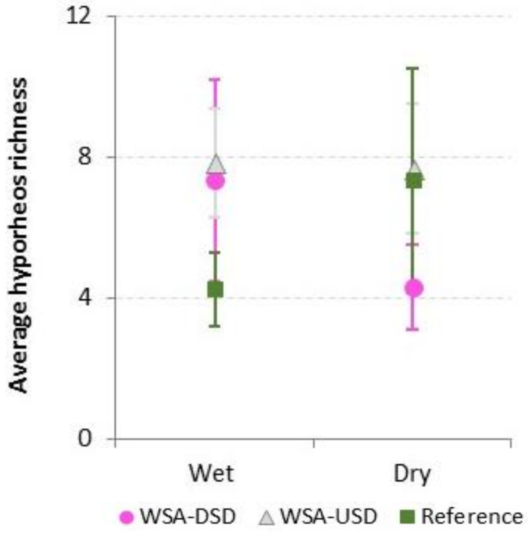

**Figure 18.** Average hyporheos fauna taxa richness (±se) from each location (WSA-DSD, WSA-USD, or reference) in 2017.

### 5.4.2 Significance of hyporheic fauna

Taxa recorded in 2017 which classified as obligate groundwater fauna (stygobites) or occasional stygophiles were:

Stygobites

- copepod *Parastenocaris jane*,
- ostracod *Candonopsis tenuis*,
- amphipods Paramelitidae sp. B, Paramelitidae sp. D, *Chydaekata* sp. and immature or damaged Paramelitidae specimens,
- bathynellid *Atopobathynella* species,
- isopod *Pygolabis weeliwolli*, and
- water mite *Stygolimnochares* nr *australica.*

Occasional stygophiles

- oligochaetes *Allonais pectinata*, *Pristina* aequiseta, *Pristina longiseta* and *Pristina nr. Sima*,
- copepods *Australoeucyclops karaytugi* and *Microcyclops varicans*,
- collembolla (spring-tails) Entomobryoidea and Poduroidea
- beetle of the genera *Austrolimnius*, *Hydraena*, *Limnebius* and *Ochthebius*, and families Limnichidae and Scirtidae.

A number of possible hyporheic species were also recorded, including the chironomid ?*Pentaneura* sp.

The stygal amphipods Paramelitidae sp. B, Paramelitidae sp. D and *Chydaekata* sp., and the isopod *Pygolabis weeliwolli* are of conservation interest as they are short range endemics (SREs) as defined by Harvey (2002) are species known to occupy an area of less than 10, 000 km$^2$. Such species have been found to possess a number of common ecological and life-history traits, including:

- poor powers of dispersal,
- confinement to discontinuous habitats,
- usually highly seasonal, only active during cooler, wetter periods, and
- low levels of fecundity.

Such traits make SRE species vulnerable to disturbance and changes in habitat and affords them high conservation value. As it can be difficult to determine whether a species actually occupies an area less than 10, 000 km$^2$, and therefore undoubtedly classifies as an SRE, the Western Australian Museum (WAM) have developed a three-tier classification system for SREs. Based on this system, the stygal amphipod species recorded during the current study meet the criteria for ‘Confirmed SREs’. That is, they belong to a species “with a known distribution range < 10, 000 km$^2$, the taxonomy is well known and the group is well represented in collections and/or via comprehensive sampling” (EPA 2009). This is based on the fact that genetic studies have been undertaken on the stygal amphipod species recorded in Marillana and Weeli Wolli creeks, along with specimens collected elsewhere to confirm they are in fact distinct from other species (Finston *et al.* 2010, Helix on behalf of WRM unpub. data). In addition, WRM sample the hyporheic fauna of many rivers and creek systems across the Pilbara, and have not recorded these species from anywhere other than the creeks outlined above. WRMs stygal amphipod collections have also been compared with others by Biota and Bennelongia to ensure distributions as detailed by the authors are correct.

Paramelitidae sp. D[13] and Paramelitidae sp. B[14]) are restricted to the Marillana Creek, Weeli Wolli Creek and Coondewanna Flats catchments. Within the Study Area, Paramelitidae sp. B was recorded during the wet-14 (MC5, MC6), the wet-17 (MC1, MC5, MC7) and the dry-17 (MC1-B), while Paramelitidae sp. D was recorded during the wet-14 (MC5, MC6), wet-17 (MC7, MC9) and dry-17 (MC8).

*Chydaekata* sp. is restricted to Weeli Wolli Creek, Marillana Creek, Coondiner Creek, Kalgan Creek and Mindy Mindy Creek catchments. Within the Study Area, *Chydaekata* sp. was recorded during the wet-14 (MC5, MC6), wet-17 (MC7) and dry-17 (MC1-B, MC7).

The stygobitic isopod *Pygolabis weeliwolli* is also a confirmed SRE, known only from Weeli Wolli Creek and the nearby Marillana Creek, in the Pilbara region of Western Australia. *Pygolabis weeliwolli* was recorded from the hyporheic zone of MC7 in the wet-17.

The stygal water mite *Stygolimnochares* nr *australica* appears to have a highly limited distribution. Other than the previous record on Marillana Creek (from the hyporheic zone of MC6 in the wet-14), to the best of the authors knowledge it has only been recorded from one other location in the Pilbara; Koodaideri Spring, approximately 20 km to the north (Bennelongia 2011, WRM unpub. data). During the current study, it was recorded from the hyporheic zone of MC2, MC7 and reference site FU in the wet-17. *Stygolimnochares* nr *australica* was considered a potential SRE, being a species that “belong to a group where there are gaps in our knowledge of the taxon, either because the group is not well represented in collections, taxonomic knowledge is incomplete, or the distribution is imperfectly understood because sampling has been patchy”. They were further classified within this system as Data Deficient; there is “insufficient data available to determine SRE status, either because there is a

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[13] Also referred to as Paramelitidae Genus 2 sp. B3 (Bennelongia morphotype).

[14] Also referred to as Paramelitidae Genus 2 sp. B2 by a different environmental consultancy (Bennelongia morphotype).

lack of geographic and taxonomic information, or because the individuals sampled cannot be identified to species level (e.g. wrong sex, juvenile, damaged)".

*Gomphodella* n. sp. (BOS334) recorded from the hyporheic zone within the Study Area during the wet-14 (MC1, MC6) is also considered an SRE. It was not recorded from any of the reference sites in 2014, nor was it recorded in 2017. *Gomphodella* n. sp. (BOS334) has previously been collected from bores in the Yandi area (Dr Stuart Halse, Bennelongia, pers. comm.), as well as from hyporheic zones on Weeli Wolli Creek (WRM unpub. data). *Gomphodella* species are often restricted to one locality and are commonly found in springs (Karanovic 2006, Reeves *et al.* 2007).

One of the chironomid species recorded from the hyporheic zone of the Fortescue River reference site (FU) in the wet-17 is also of note; the tanypod ?*Pentaneura* sp. This was considered a possible hyporheic species due to its small size (they are at least half the size of other tanyponids) and characteristic reduced eye (Dr Don Edward, The University of Western Australia, pers. comm.). ?*Pentaneura* sp. is currently undescribed and appears to have a highly disjunct distribution in the Pilbara, being known from Marillana Creek, Weeli Wolli Creek, upper Fortescue River, Fortescue River South, Caves Creek (Palm Spring), as well as within the Robe River and De Grey River catchments (WRM unpub. data).

### 5.4.3 Temporal and spatial differences in hyporheos fauna

**Taxa richness**

As discussed above for microinvertebrates, two-way ANOVA was only undertaken on wet season data because there was insufficient replication in the dry seasons of both 2014 and 2017. In addition, only one site downstream of the Yandi discharge point (i.e. WSA-DSD sites) was sampled in 2014 (MC7 in the dry-14). Although average hyporheic taxa richness was greater from WSA sites in comparison to reference sites (Figure 19), overall, there was no significant difference in richness between site locations (Two-way ANOVA; df = 1, $p$ = 0.054; Table 11). There was no significant difference in hyporheic taxa richness between years (df = 1, $p$ = 0.457, Figure 19 and Table 11).

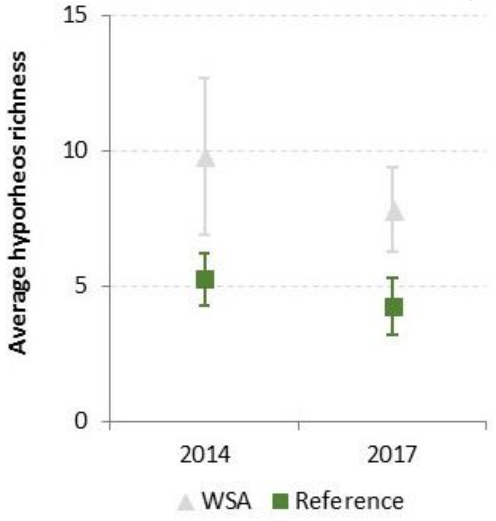

**Figure 19.** Average hyporheos fauna taxa richness (±se) recorded from WSA and reference sites in the wet seasons of 2014 and 2017.

**Table 11.** Summary of two-way ANOVA results testing for significant differences in hyporheos taxa richness between year (2014 vs 2017) and site location (WSA vs reference). Wet season data only.

| Source | Two-way ANOVA (*df* = 1, 18) | | |
|---|---|---|---|
| | Mean Square | F | *p* |
| Year (2014 vs. 2017) | 1 | 0.58 | 0.457 |
| Reference vs. WSA | 1 | 4.38 | 0.054 |
| Year*Location | 1 | 0.06 | 0.807 |

## Patterns in hyporheos fauna assemblage structure

Hyporheic taxa assemblages were highly variable (Figure 20). However, some patterns were evident in the nMDS ordination, with samples generally grouping by site location (Figure 20). Upstream sites within the Study Area (WSA-USD) clustered with reference sites from all systems (Weeli Wolli Creek, Marillana Creek and Fortescue River), while the downstream sites generally separated from other samples (Figure 20). SIMPROF detected four significant cluster groups, with WSA-USD sites, WW-Refs, Mar-Refs and Fort-Ref samples being part of the main cluster, the majority of WSA-DSD sites forming a group, the wet-17 WMU sample grouping with MC1 and MC8 from the dry-17, and MC7 from the wet-17 sitting alone in terms of SIMPROF clusters.

There was also some separation between years, with 2014 samples generally clustering at the top of the ordination (Figure 21).

Overall, there was a significant difference in taxa assemblages between site location (PERMANOVA; df = 1, pseudo-F = 2.02, *p* = 0.0000; Figure 21), and year (df = 1, pseudo-F = 3.85, *p* = 0.000; Figure 21). However, there was no significant difference between season (PERMANOVA; df = 1, pseudo-F = 0.66, *p* = 0.7930; Figure 21). In the case of location, the low pseudo-F value indicates that despite the significant result there was still some overlap of samples across location types.

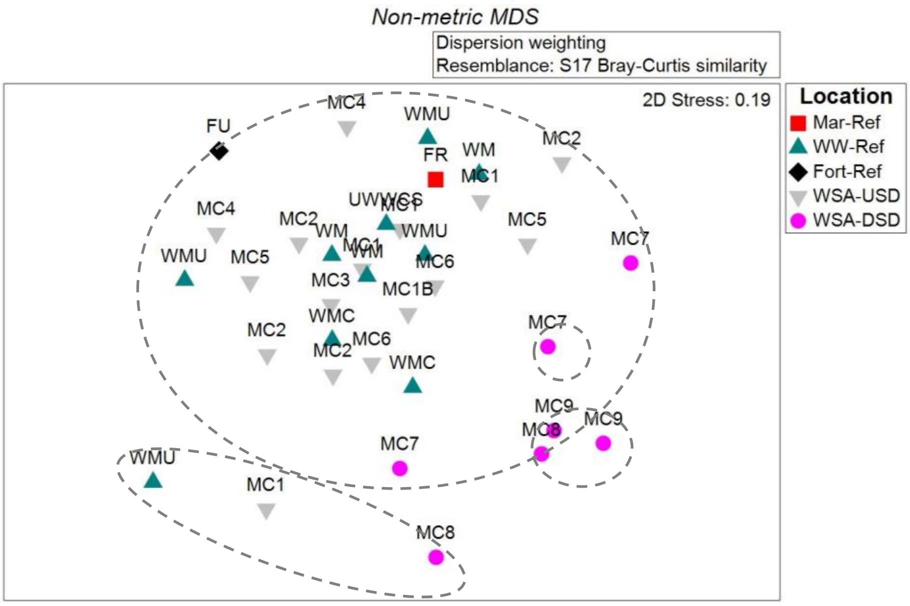

**Figure 20.** nMDS plot of hyporheos taxa assemblage data (log abundance categories, dispersion weighted) from all sites in both years. Samples are identified by location and labelled by site. Samples are grouped within grey circles based on significantly separate cluster groups as determined by SIMPROF.

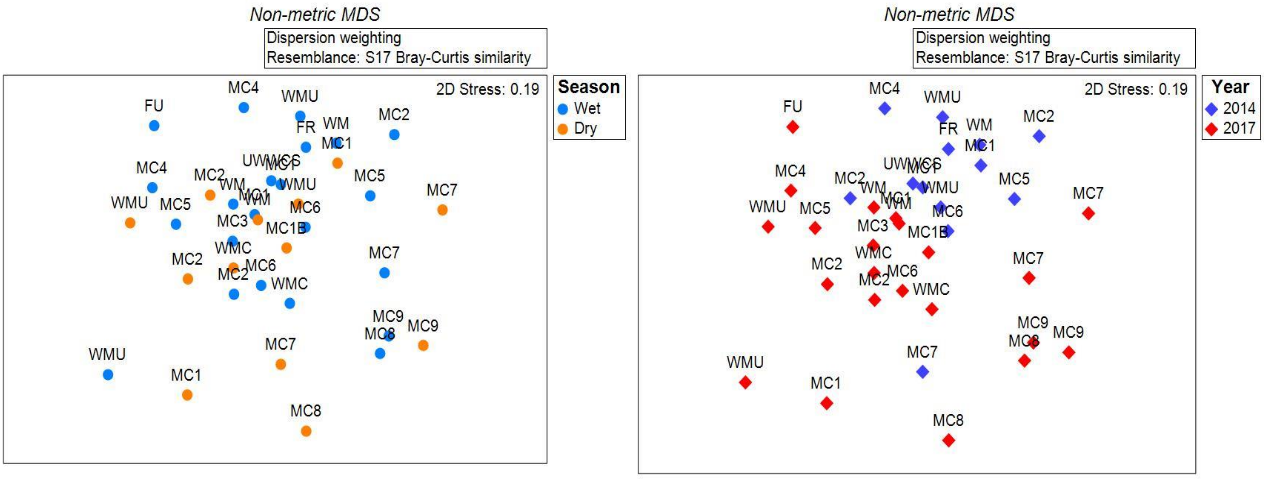

**Figure 21.** nMDS plot of hyporheos taxa assemblage data (log abundance categories, dispersion weighted) from all sites in both years, showing samples identified by season (left) and year (right).

## 5.5 Macroinvertebrates

### 5.5.1 Taxonomic composition and species richness

A total of 222 macroinvertebrate taxa were recorded in 2017, with 185 being recorded in wet-17 and 162 in dry-17 (Table 12 and Appendix 8). The list includes groups which 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 each site is likely greater than that reported here.

The macroinvertebrate fauna was composed of Cnidaria (freshwater hydra), Turbellaria (flat worms), Nematoda (round worms), Oligochaeta (aquatic segmented worms), Polychaeta (freshwater bristle worms), Mollusca (aquatic snails), Hydracarina (water mites), Amphipoda (side swimmers), Myriopoda (aquatic centipedes and millipedes), Collembola (springtails), Thysanoptera (thrips), Coleoptera (aquatic beetles), Diptera (two-winged fly or “true” fly larvae), Ephemeroptera (mayfly larvae), Hemiptera (aquatic “true” bugs), Lepidoptera (aquatic moth larvae), Odonata (dragonfly and damselfly larvae) and Trichoptera (caddisfly larvae) (see Table 12). Overall, the macroinvertebrate fauna was dominated by Insecta, with 84% and 80% of all species recorded belonging to this class in the wet and dry seasons, respectively. Typically, insects constitute around 80% of all aquatic fauna in freshwater systems of the Pilbara (Pinder *et al*. 2010).

Macroinvertebrate taxa richness ranged from 31 (at WMC) to 70 (at MC6) during the wet-17, and from 37 (at MC1) to 69 (at MC1-B) during dry-17 (Figure 23). Overall, there was a significant difference in average macroinvertebrate taxa richness between WSA-USD, WSA-DSD and reference sites (two-way ANOVA; df = 1, F = 4.229, $p = 0.034$), but not between wet and dry seasons (df = 1, F = 0.438, $p = 0.518$). During the wet-17, average macroinvertebrate taxa richness was lowest at WSA-DSD sites (36.6 taxa), followed by reference sites (43.25 taxa), and highest at WSA-USD sites (58.3 taxa) (Figure 23). During the dry-17, mean macroinvertebrate taxa richness was less variable between locations, being lowest at reference sites (44.3 taxa), followed by WSA-DSD (49.3 taxa), with WSA-USD sites again recording the highest mean taxa richness in the Study Area (52.7 taxa) (Figure 23).

**Table 12.** Summary of higher-order macroinvertebrate taxa composition by season.

| Macroinvertebrates | | Wet-17 | Dry-17 |
|---|---|---|---|
| **Group** | **Common name** | **13 Sites** | **Nine sites** |
| **Cnidaria** | Freshwater hydra | 1 | 1 |
| **Turbellaria** | Flat worms | 0 | 1 |
| **Nematoda** | Round worms | 1 | 0 |
| **Oligochaeta** | Aquatic segmented worms | 9 | 11 |
| **Polychaeta** | Bristle worms | 0 | 1 |
| **Mollusca** | Freshwater snails & bivalves | 3 | 3 |
| **Hydracarina** | Water mites | 13 | 14 |
| **Amphipoda** | Side-swimmers | 1 | 0 |
| **Myriopoda** | Aquatic centipedes & millipedes | 1 | 0 |
| **Collembolla** | Spring tails | 0 | 1 |
| **Thysanoptera** | Thrips | 0 | 1 |
| **Coleoptera** | Aquatic beetles | 54 | 41 |
| **Diptera** | Two-winged flies | 34 | 31 |
| **Ephemeroptera** | Mayflies | 8 | 8 |
| **Hemiptera** | True bugs | 27 | 22 |
| **Lepidoptera** | Moths | 6 | 3 |
| **Odonata** | Dragonflies & damselflies | 15 | 14 |
| **Trichoptera** | Caddisflies | 12 | 10 |
| | **Total number of taxa** | **185** | **162** |

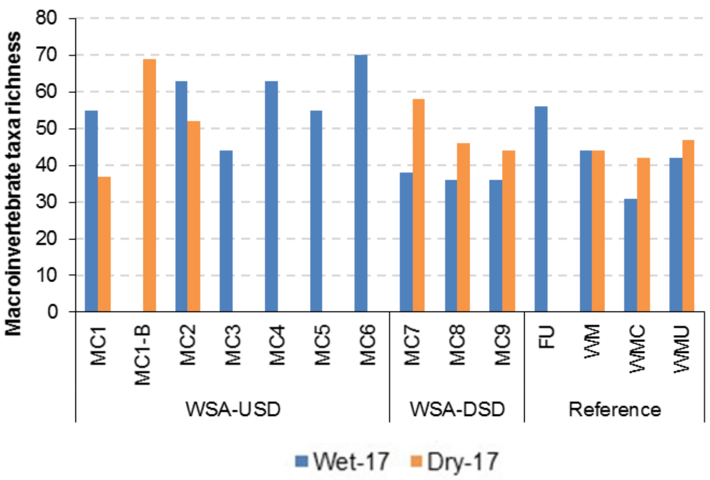

**Figure 22.** Macroinvertebrate taxa richness recorded from Study Area (WSA-USD, WSA-DSD) and reference sites during the wet-17 and dry-17.

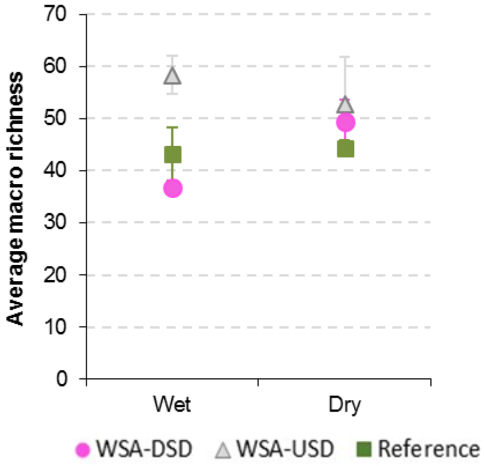

**Figure 23**. Average macroinvertebrate taxa richness (±se) from each location (WSA-DSD, WSA-USD or reference) in 2017.

### 5.5.2 Significance of macroinvertebrate fauna

The majority of macroinvertebrate taxa recorded during 2017 were common ubiquitous species, with distributions extending throughout Australasia or the world (cosmopolitan species). However, eight species were endemic to the Pilbara region, including the damselfly *Eurysticta coolawanyah,* the dragonflies *Nannophlebia injibandi* and *Ictinogomphus dobsoni*, the stygal/SRE amphipod Paramelitidae sp. D (discussed in Section 4), and the aquatic beetles *Laccobius billi, Haliplus pilbaraensis, Sternopriscus pilbaraensis* and *Tiporus lachlani*. *Eurysticta coolawanyah* is also listed for conservation significance by the IUCN.

*Eurysticta coolawanyah*, listed as Near Threatened by the IUCN, was recorded at sites WSA-DSD sites MC7 and MC8 in the wet-17. As mentioned in the literature review (Section 3.3), *E. coolawanyah* was listed as Near Threatened by the IUCN based on its distribution being restricted to an area of less than 500 km$^2$, and it being thought to occur at less than five locations (Millstream Station, Nanuturra Pools, Palm Pool and the Millstream area) Hawking (2009b). However, the listing of this species is considered to require revision, as it has since been recorded from over 40 locations throughout the Pilbara (Pinder *et al.* 2010), increasing its known distribution to above the 500 km$^2$ threshold for Near Threatened species as defined by the IUCN. Hawking (2009b) lists no currently known threats, or likely in the near future, to this species.

The endemic dragonfly *Nannophlebia injibandi* (Pilbara archtail) was recorded infrequently during the Pilbara Biological Survey (Millstream Delta and Gregory Gorge in the Fortescue River catchment; Pinder *et al*. 2010), but has since been recorded from Coondiner Creek, Roy Hill on the Fortescue River, Weeli Wolli Creek and Marillana Creek (WRM unpub. data). In the current study, *N. injibandi* was recorded from WSA-DSD sites MC7, MC8 and MC9 in wet-17, and MC8 and MC9 in the dry-17, clearly preferring sites with surface water maintained by dewatering discharge. The dragonfly *Ictinogomphus dobsoni* (Pilbara tiger) has been recorded widely across the Pilbara, and in the current study was recorded from Study Area sites MC1-B, MC2 and MC9.

The aquatic hydrophilid beetle *Laccobius billi* was recorded from WSA-USD site MC2 in the wet-17. *L. billi* is a Pilbara endemic species that is rarely collected; it was only recorded from one site during DPaW's extensive Pilbara Biological Survey, at Cangan Pool on the Yule River, approximately 100 km north-west of Marillana Creek (Pinder *et al.* 2010). It has also been recorded by the authors from Weeli Wolli Creek, Coondiner Creek, Mindy Mindy Creek and the Ashburton River (WRM unpub. data).

While the dytiscid beetle *Sternopriscus pilbaraensis* is endemic to the Pilbara, it is fairly commonly collected and known from a range of systems across the Pilbara, including the Fortescue River system (Gregory Gorge and Kalgan Pool), Ashburton system (Bobswim Pool, Yandabiddy Pool, Whiskey Pool, Ashburton at Gorge Junction, Innawally Pool and Rocky Island Pool), De Grey 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). *S. pilbaraensis* was collected from WSA-USD sites MC2 and MC5 in the wet-17.

The haliplid beetle *Haliplus pilbaraensis* is relatively new to science, having only been described in 2010 (Watts and McRae 2010). This species is thought to occur widely throughout the Pilbara, and has been recorded at localities such as Myanore Creek, 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). In the current study, *H. pilbaraensis* was collected from MC1-B in the dry-17.

*T. lachlani* is widespread across the Pilbara region, though infrequently collected (Pinder *et al.* 2010, WRM unpub. data). In the current study, it was collected from reference site WMU in the dry-17.

Pilbara endemic taxa were collected at all Study Area sites downstream of discharge (MC7 - MC9), and at MC1-B, MC2, MC4 and MC6 upstream of discharge (Figure 24). Of the reference sites, Pilbara endemic taxa were only collected at Weeli Wolli Creek site WMU. WSA-DSD site MC9 recorded the most Pilbara endemic taxa in the current study (four taxa), followed by WSA-USD site MC2 and WSA-DSD site MC8 (three taxa each) (Figure 24). WSA-DSD sites likely favour predatory and long-lived larval forms of the Pilbara endemic dragonfly and damselfly taxa such as *E. coolawanyah, I. dobsoni* and *N. injibandi*, as discharge creates greater persistence of surface waters and flows (leading to increased variability in in-stream habitat and higher abundance of prey) (WRM 2016). As mentioned, these sites are also located in a more enclosed, forested section of Marillana Creek, with habitat structure such as branches, overhanging vegetation and large woody debris providing perching mediums for the adult forms of these odonates (WRM 2016).

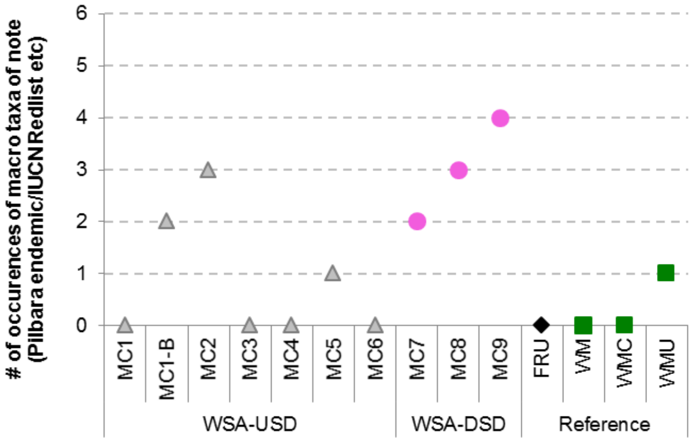

**Figure 24.** Number of occurrences of macroinvertebrate taxa of note (Pilbara endemics/IUCN Redlist, etc.) from each site across both seasons.

### 5.5.3 Temporal and spatial differences in macroinvertebrate fauna

**Taxa richness**

Again, given the low replication in the dry seasons of both 2014 and 2017, due to many sites being dry, two-way ANOVA was only undertaken on wet season data, with a comparison being made between years (2014 vs 2017) and location (WSA vs reference sites).

Overall, there was no significant difference in wet season macroinvertebrate taxa richness between year (two-way ANOVA; df = 1, F = 0.149, *p* = 0.704). There was, however, a significant difference in average taxa richness between site location (df = 1, F = 5.30, *p* = 0.036; Table 13 and Figure 25). There was no significant interaction term (df = 1, F = 0.772, *p* = 0.0.393; Table 13). In 2014, mean macroinvertebrate taxa richness was relatively similar at WSA and reference sites, with richness slightly lower at reference sites (56.0 and 49.25 taxa at WSA and reference sites, respectively). In 2017, mean macroinvertebrate taxa richness was significantly lower at reference sites (43.3) in comparison to WSA sites (58.3 taxa) (Figure 25).

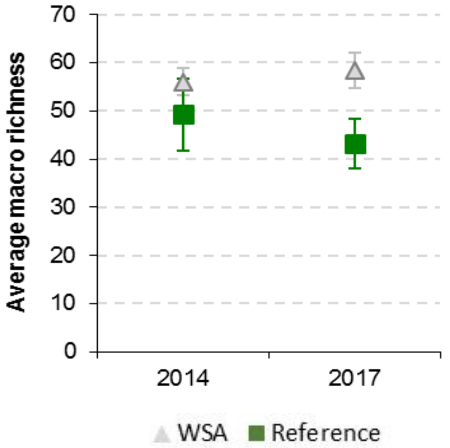

**Figure 25.** Average macroinvertebrate taxa richness (±se) recorded from WSA and reference sites in the wet seasons of 2014 and 2017.

**Table 13.** Summary of two-way ANOVA results testing for significant differences in mean macroinvertebrate taxa richness between year (2014 vs 2017) and site location (WSA vs reference). Wet season data only.

| Source | Two-way ANOVA (*df* = 1, 18) | | |
|---|---|---|---|
| | Mean Square | F | *p* |
| Year (2014 vs. 2017) | 15.5 | 0.149 | 0.704 |
| Reference vs. WSA | 550.0 | 5.300 | 0.036 |
| Year*Location | 80.1 | 0.772 | 0.393 |

## Patterns in macroinvertebrate fauna assemblage structure

Overall, there was a significant difference in macroinvertebrate assemblages between site location (PERMANOVA; df = 4, pseudo-F = 3.34, p = 0.001; Figure 26), and year (df = 1, pseudo-F = 2.96, *p* = 0.001; Figure 27). However, there was no significant difference between season (PERMANOVA; df = 1, pseudo-F = 1.60, *p* = 0.051; Figure 27). These patterns were evident in the macroinvertebrate assemblage nMDS of all sites sampled in 2014 and 2017, with some separation of samples by location (Figure 26). Generally, reference sites from Weeli Wolli Creek and Marillana Creek had similar assemblages, and there was relatively little separation of the majority of reference samples from Marillana Creek WSA sites located upstream of Yandi dewatering discharge (WSA-USD sites; Figure 26). There was, however, a distinct separation of sites downstream of the Yandi discharge point (WSA-DSD sites) from all other WSA and reference sites (Figure 26).

A total of eight significant SIMPROF cluster groups were detected (Figure 26), with assemblages at all WSA-DSD sites (regardless of season) significantly different from all other site locations (Figure 26). SIMPER analysis revealed that between-group average similarity in macroinvertebrate assemblages (Bray-Curtis similarity) was highest between WSA-USD sites and references sites from Marillana Creek (42.36%) and Weeli Wolli Creek (36.65%), with assemblage similarly lowest between WSA-DSD sites and WSA-USD sites (31.2%), WSA-DSD sites and Marillana reference sites (29.51%), and WSA-DSD sites and Weeli Wolli reference sites (26.46%). Dissimilarity between WSA-DSD sites and other sites was driven by higher abundances of species which favour permanent flows and greater persistence of surface water, such as the caddisflies *Cheumatopsyche wellsae* and *Triplectides ciuskus seductus*, the chironomids (non-biting midges) *Rheocriptocopus* sp. and *Thienemannimyia* sp., and the Pilbara endemic dragonfly *Nannophlebia injibandi* (SIMPER). Conversely, species which prefer lentic (still or standing) waterbodies, such as the snails *Bullustra vinosa* and *Gyraulus* sp., water mites from the family Limnesiidae and Unionicolidae, and the chironomid *Procladius* sp., were all recorded in higher (average) abundance at WSA-USD, Marillana reference and Weeli Wolli reference sites (SIMPER).

The suite of water quality variables best correlated with the macroinvertebrate assemblage ordination included pH, TDS, redox potential, and concentrations of N_NO$_x$, total N, total P, dB, dCu, dCr, dFe and dMn (BVSTEP; correlation = 0.668, $p$ = 0.001). Higher redox potential, and higher concentrations of N_NO$_x$, total N, dB and total P, most influenced the grouping of WSA-DSD sites on the left of the nMDS plot (Figure 26), whereas higher pH, and higher concentrations of dMn, dCu, and dFe influenced the separation of WSA-USD and reference sites (Figure 26).

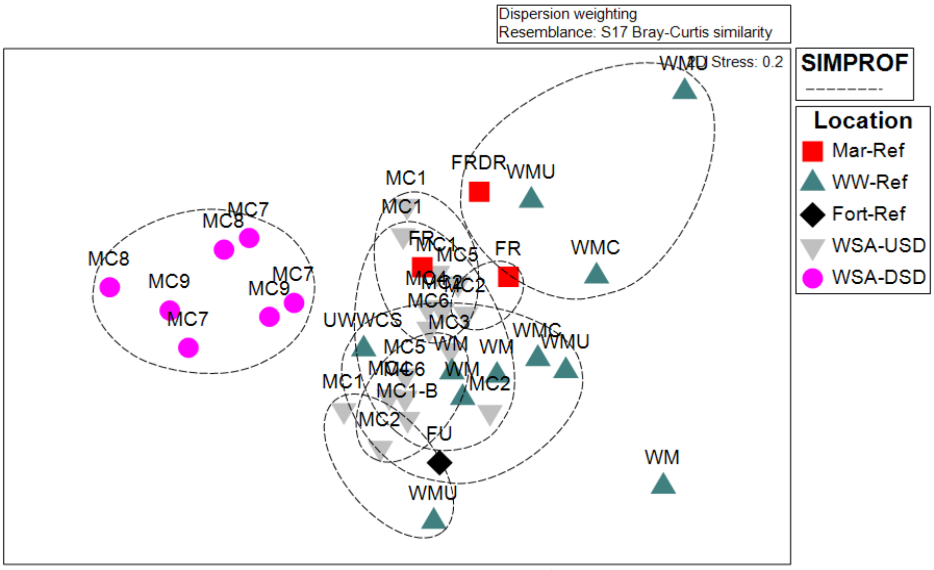

**Figure 26.** nMDS plot of macroinvertebrate assemblage data (log abundance categories, dispersion weighted) from all sites in both years. Samples are identified by location and labelled by site. Samples are grouped within grey circles based on significantly separate cluster groups as determined by SIMPROF.

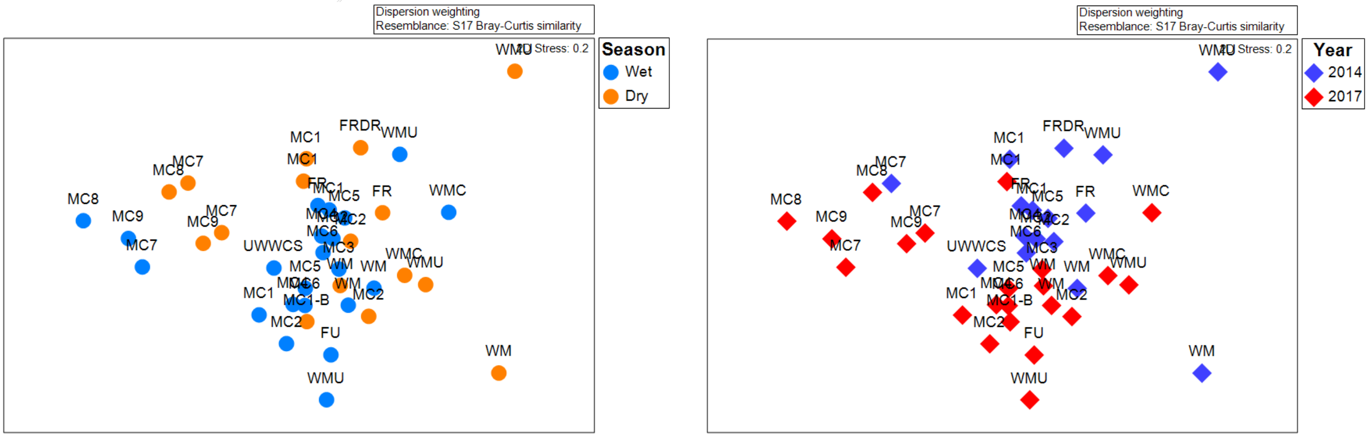

**Figure 27.** nMDS plot of macroinvertebrate assemblage data (log abundance categories, dispersion weighted) from all sites in both years, showing samples identified by season (left) and year (right).

## 5.6 Fish

### 5.6.1 Species richness and abundance

Three of the twelve freshwater fish species known from the Pilbara region were recorded during the current study. These were the western rainbowfish *Melanotaenia australis*, spangled perch *Leiopotherapon unicolor*, and the Pilbara tandan (eel-tailed catfish) *Neosilurus* sp. (see Plates 1 and 2, Section 3.4). These are also the only fish that were recorded from Marillana Creek during previous studies (Streamtec 2004, WRM 2011, WRM 2015).

A total of 2,604 fish were caught, measured and released during the current study; 1,598 in the wet-17 and 1,006 in the dry-17 (Appendix 9). Western rainbowfish were the most abundant species (1,459 individuals), followed by spangled perch (1,065) and the Pilbara tandan (80). Spangled perch were the most widespread species, recorded at all successfully sampled sites[15] during both seasons (Figure 28). Western rainbowfish were present at most sites in both seasons, except WSA site MC2 in the wet-17, and reference site WMC in the dry-17 (Figure 28). Pilbara tandan were recorded from a limited number of sites, including MC4, MC5, MC7, MC8 and MC9 in the wet-17, and MC1-B, MC7, MC8 and MC9 in the dry season (Figure 28).

Pilbara tandan were not recorded at any reference site in either season (Figure 28). Increased surface water persistence and higher surface flows created by Yandi dewatering discharge clearly favoured Pilbara tandan abundance in the Study Area, with 96% of Pilbara tandan individuals (wet and dry seasons combined) being recorded from WSA-DSD sites MC7, MC8 and MC9 (Figure 28). Although very little is known about the biology and ecology of this species, breeding of *Neosilurus* catfish is thought to occur in the early wet season, where adults (> 91 mm SL) build their nests under large cobbles in flowing riffle zones (Bishop *et al*. 2001, Morgan *et al.* 2002). It is at this time when flooding increases the area and diversity of aquatic habitat available, while also initiating increases in plankton and other food sources (Bishop *et al.* 2001). This likely explains the relatively high abundance of Pilbara tandan at sites receiving perennial discharge.

There was no significant difference in mean western rainbowfish abundance between site locations (two-way ANOVA df = 2, F = 0.932, $p = 0.461$) or seasons (df = 1, F = 1.054, $p = 0.321$). Though not significant, in both seasons mean rainbowfish abundance was highest at WSA-DSD sites, followed by WSA-USD sites and then reference sites (Figure 29). There was also no significant difference in mean spangled perch abundance between site locations (df = 2, F = 1.506, $p = 0.253$) or seasons (df = 1, F = 0.003, $p = 0.954$). In the wet-17, mean spangled perch abundance was highest at reference sites, followed by WSA-DSD and WSA-USD sites (Figure 29). In the dry season, mean spangled perch abundance was highest at WSA-USD sites, followed by reference sites and sites downstream of Yandi discharge (WSA-DSD) (Figure 29).

Two-way ANOVA did find a significant difference in average Pilbara tandan abundance between site locations (df = 1, F = 24.697, $p < 0.001$), but not seasons (df = 1, F = 1.252, $p = 0.281$), with abundance significantly higher at WSA-DSD sites in both the wet-17 and dry-17 (Pilbara tandan were not recorded at reference sites) (Figure 29).

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[15] Despite holding enough water for water quality and invertebrate sampling, the pool at Weeli Wolli Creek site WM in the dry-17 was too small to allow fishing to be conducted.

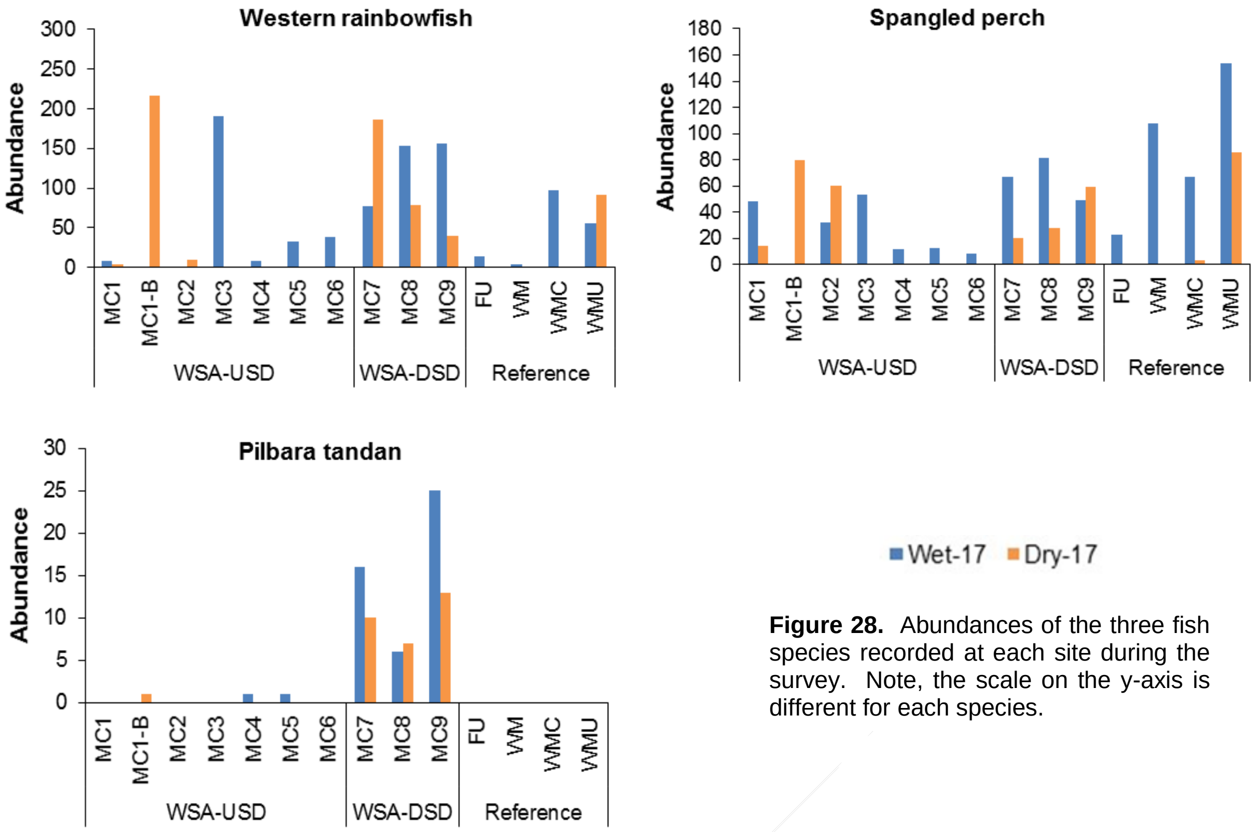

**Figure 28.** Abundances of the three fish species recorded at each site during the survey. Note, the scale on the y-axis is different for each species.

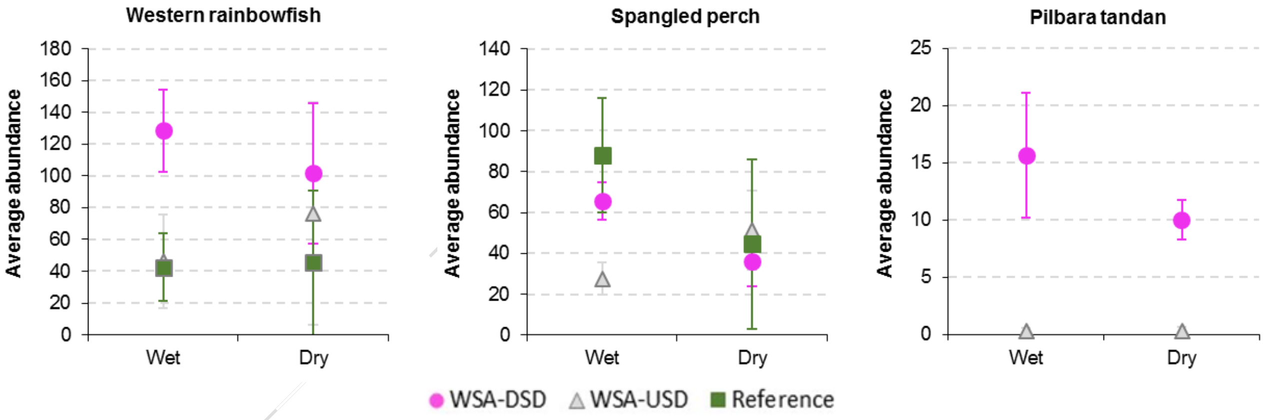

**Figure 29.** Average fish abundance (±se) from each location (WSA-DSD, WSA-USD, or reference) in 2017.

### 5.6.2 Significance of fish fauna

The Pilbara tandan *Neosilurus* sp. is endemic to the Pilbara region, however it is not listed for conservation significance, and appears to be widespread across the region (WRM unpub. data). The remaining two freshwater fish species recorded (western rainbowfish and spangled perch) are also widespread across the Pilbara region, and wider-northern Australia. The western rainbowfish, for example, has a range extending from the Ashburton River in the Pilbara to the Adelaide River near Darwin, inhabiting rivers, creeks, swamps, lakes and reservoirs (Allen *et al.* 2002). Spangled perch is considered to be Australia's most widespread freshwater fish species, found in drainages throughout the Pilbara, Kimberley, Northern Territory, Queensland, northern New South Wales, as well as in Lake Eyre and the Murray-Darling system (Allen *et al.* 2002).

### 5.6.3 Temporal and spatial differences in fish fauna

**Species abundance**

Two-way ANOVA did not detect any significance difference in mean wet season western rainbowfish, spangled perch or Pilbara tandan abundance between years, or between site locations (Table 14). In general, average abundances of western rainbowfish and spangled perch were lower at both WSA and reference sites in 2017, compared to 2014 (Figure 30). Average Pilbara tandan abundance was much higher at WSA sites in 2014, compared to reference sites in both years (and WSA sites in 2017), due to the extremely high number of individuals (98) captured at MC4 in the wet-14.

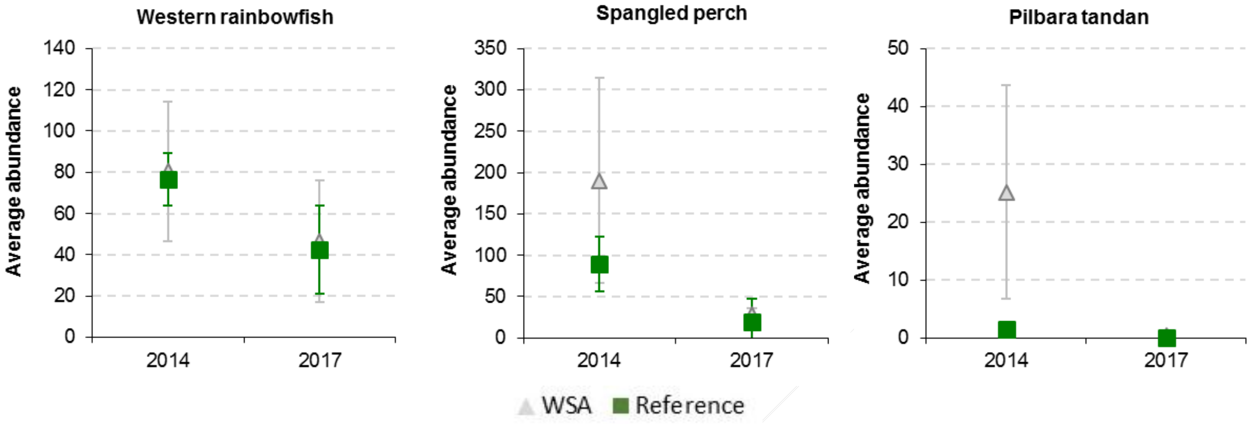

**Figure 30.** Average abundance of each fish species (±se) recorded from WSA and reference sites in the wet seasons of 2014 and 2017.

**Table 14.** Summary of two-way ANOVA results testing for significant differences in mean fish abundance between year (2014 vs 2017) and site location (WSA vs reference). Wet season data only.

| **Western rainbowfish** | **Two-way ANOVA (*df* = 1, 18)** | | |
|---|---|---|---|
| | **Mean Square** | **F** | ***p*** |
| Year (2014 vs. 2017) | 5345.8 | 1.413 | 0.253 |
| Reference vs. WSA | 69.005 | 0.018 | 0.894 |
| Year*Location | 0.005 | 0.001 | 0.999 |
| **Spangled perch** | **Two-way ANOVA (*df* = 1, 18)** | | |
| | **Mean Square** | **F** | ***p*** |
| Year (2014 vs. 2017) | 30933 | 1.392 | 0.256 |
| Reference vs. WSA | 1945.92 | 0.088 | 0.771 |
| Year*Location | 30181 | 1.358 | 0.262 |
| **Pilbara tandan** | **Two-way ANOVA (*df* = 1, 18)** | | |
| | **Mean Square** | **F** | ***p*** |
| Year (2014 vs. 2017) | 802.15 | 1.764 | 0.204 |
| Reference vs. WSA | 666.46 | 1.466 | 0.245 |
| Year*Location | 630.00 | 1.385 | 0.258 |

### 5.6.3 Population structure

The reproductive strategies of freshwater fish species in the Pilbara are 'opportunistic' and 'periodic', reflecting the seasonal yet unpredictable nature of rainfall and streamflow in the region (Beesley 2006). Breeding of many species occurs during the wet season and during this time, multiple spawning events are known to occur (Beesley 2006). Further, the volume, hydrological regime and habitat complexity of Pilbara waterbodies can have a marked influence on fish population structure, with larger pools and more complex habitat considered generally advantageous for fish communities (Allen *et al.* 2002, Morgan *et al.* 2002, Morgan *et al.* 2009). Therefore, anthropogenically-induced alterations to streamflow patterns, water levels and water quality can have a discernible impact on life-history strategies and assemblage composition of local fish populations (Allen *et al.* 2002).

Analysing population structure provides one means of characterising the health of fish assemblages at each site, and by extension the ecological processes driving aquatic communities within the waterbody. The presence of newly recruited and juvenile fish, for example, indicates recent spawning activity (and conditions conducive to such). Conversely, the presence of only sub-adult and adult (larger) fish may indicate a higher amount of predatory pressure on juvenile fish, and/or that conditions in pools are not conducive to spawning.

In order to examine population structures of the species recorded in the current study (western rainbowfish, spangled perch and Pilbara tandan), length-frequency data for age-classes were estimated from published literature (i.e. Lake 1971, Bishop *et al.* 2001, Allen *et al.* 2002, Morgan *et al.* 2002, Beesley 2006; Table 15).

**Table 15.** Sizes (standard length mm) used in length-frequency analysis of fish populations.

| Species | Age-class | Size mm SL |
|---|---|---|
| **Western rainbowfish** | New recruit | < 30 |
| | Juvenile | 31-40 |
| | Sub-adult | 41-50 |
| | Adult | >51 |
| **Spangled perch** | New recruit | < 30 |
| | Juvenile | 31-50 |
| | Sub-adult | 51-70 |
| | Adult | >71 |
| **Pilbara tandan** | New recruit | < 30 |
| | Juvenile | 31-70 |
| | Sub-adult | 71-90 |
| | Adult | >91 |

**Western rainbowfish**

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

There was a wide variation in western rainbowfish population structure across sites in the wet-17. New recruits and/or juveniles were recorded in low - moderate abundance at Study Area sites MC3, MC4, MC5, MC6, MC8 and MC9, and at reference site WMC, suggesting rainbowfish had recently (within the last year) spawned at these sites (Figure 31). Relatively high abundances of western rainbowfish adults were recorded at all three Study Area sites downstream of Yandi discharge, with increased persistence of surface water and habitat availability favouring larger individuals (Figure 31). In the dry-17, new recruits were only recorded at MC1-B, with juveniles being recorded at MC1-B, MC2, MC7, MC8, MC9 and WMU (Figure 31). Again, sites receiving discharge tended to favour higher abundances of adult fish (Figure 31). These sites likely provide refuge for rainbowfish (and other fish species) over the dry season, as pools upstream (e.g. MC3 – 6) recede or dry out completely.

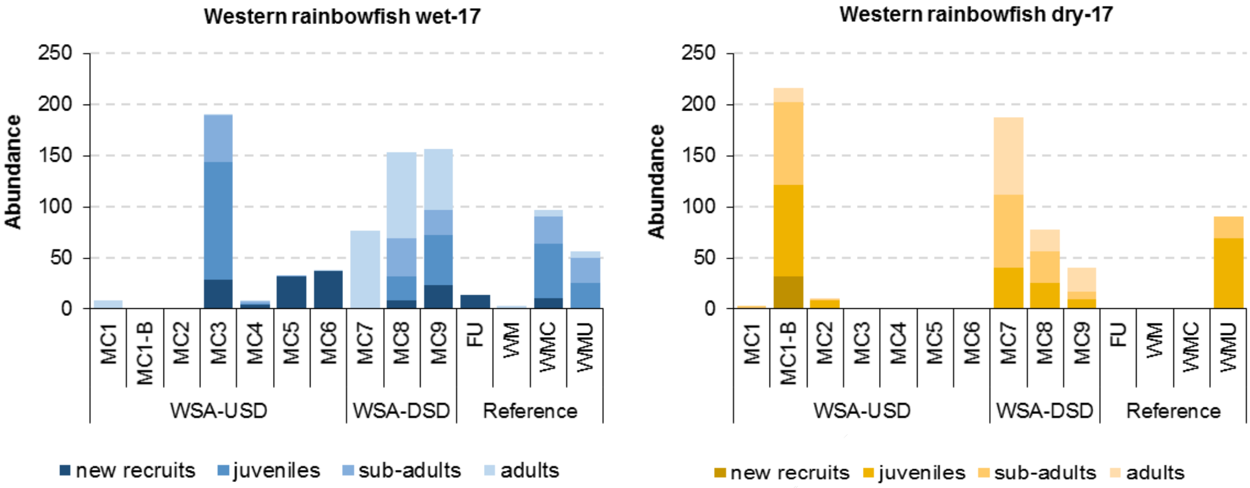

**Figure 31.** Abundances of western rainbowfish age-classes recorded in the wet (left) and dry (right) seasons in 2017.

## Spangled perch

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

Spangled perch recruitment at Marillana Creek appeared to be relatively low in the wet season, with low numbers of new recruits recorded at MC3 (3 individuals), MC7, MC8 and MC9 (one individual each) (Figure 32). Slightly higher abundances of new recruits were recorded at reference sites; four new recruits were recorded at Fortescue River Upstream (FU), 11 recorded at WM, seven recorded at WMC, and 32 recorded at WMU) (Figure 32). Relatively high abundances of adult fish were also recorded at WM, WMC and WMU, as well as at WSA-DSD sites MC7, MC8 and MC9 (Figure 32). In the dry-17, no spangled perch new recruits, and relatively low abundances of juveniles, were recorded across the Study Area (including reference sites) (Figure 32). Conversely, relatively high abundances of adult and/or sub-adult spangled perch were recorded at the majority of sites in the dry season (Figure 32). Spangled perch are highly predaceous and cannibalistic (Allen *et al.* 2002), with high numbers of adult fish likely restricting the abundance of new recruit and juvenile fish during the dry season, particularly as pools recede and submerged habitat, such as macrophyte, woody debris and overhanging vegetation, which juvenile fish can use to avoid predators, becomes limited.

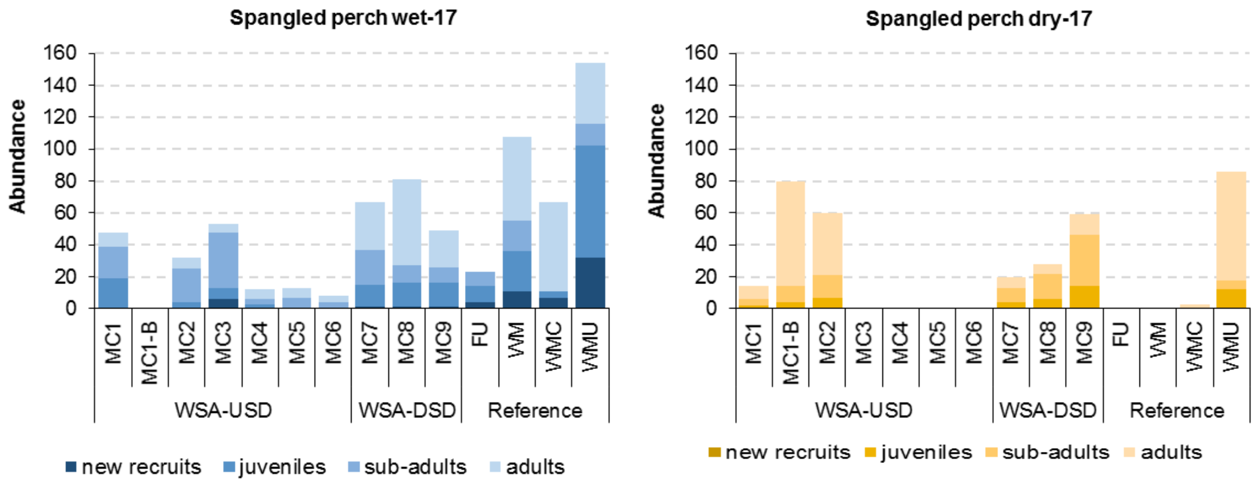

**Figure 32.** Abundances of spangled perch age-classes recorded in the wet (left) and dry (right) seasons in 2017.

## Pilbara tandan

As mentioned previously, little is known of the breeding ecology of the Pilbara tandan. Species of *Neosilurus* catfish usually attain a maximum size of only 200 mm SL, whereas similar species, such as *N. hyrtlii* and *N. ater*, can reach up to 400 mm TL (Lake 1971, Bishop *et al.* 2001). Breeding is thought to occur in the early wet season, where adults (> 91 mm SL) build their nests under large cobbles in flowing riffle zones (Bishop *et al*. 2001, Morgan *et al.* 2002).

Pilbara tandan were collected in relatively low abundance throughout the Study Area, with no new recruits (< 30 mm SL) recorded in either season (Figure 33). However, sites downstream of dewatering discharge appeared to favour relatively healthy populations of Pilbara tandan, with juveniles, sub-adults and adults recorded at MC7, MC8 and MC9 in both seasons (Figure 33). Low overall catch rates of Pilbara tandan was likely due to the inherent difficulties in sampling this species. Like most other catfish, the Pilbara tandan is a benthic feeder, with techniques such as gill and seine netting generally limited in their ability to collect specimens due to the bottom-dwelling nature of these fish.

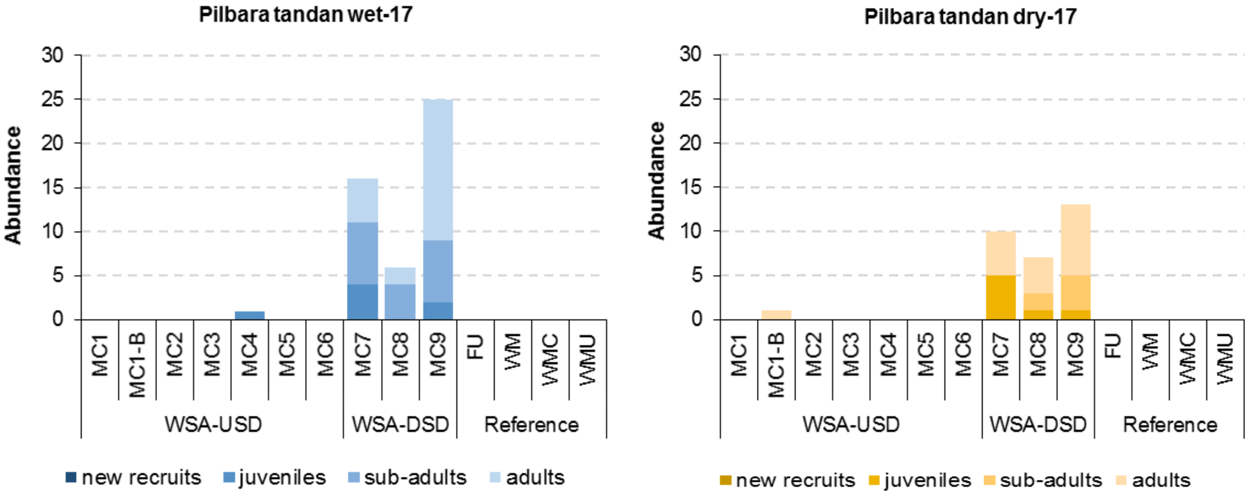

**Figure 33.** Abundances of Pilbara tandan age-classes recorded in the wet (left) and dry (right) seasons in 2017.

## 5.7 Other Vertebrate Fauna

No other vertebrate fauna were recorded from within, or outside, the Study Area in the wet or dry seasons of 2014 or 2017. However, the native flat-shelled turtle *Chelodina steindachneri* is considered likely to occur, the desert tree frog *Litoria rubella* is known, and at least two more species of frog may occur in Marillana Creek (Main's frog *Cyclorana maini* & the Pilbara toadlet *Uperoleia saxatilis*) (refer section 3.5). Of these, only the Pilbara toadlet is endemic to the Pilbara. This species is considered unlikely to occur within the Study Area due to its apparent requirement for rocky substrates. Within the Study Area, gravel and sand substrates predominate, whilst the more favourable bedrock characterises the streambed further upstream at the reference sites FR and FRDR.

# 6. SUMMARY TABLE OF SIGNIFICANT AQUATIC FAUNA

A summary of the significant aquatic fauna known from the Study Area is provided in Table 16.

**Table 16.** Summary of significant fauna recorded during this or previous surveys along Marillana Creek (i.e. Halse *et al*. 2001, Streamtec 2004, WRM 2011, WRM 2015).

| Species | Recorded from | Study | Distribution | Listed |
|---|---|---|---|---|
| **Rotifers** | | | | |
| *Lecane batillifer* | Study Area site MC5 | WRM 2015 | Rare rotifer known from northern Australia, China and Thailand. Within Australia, only known from the Pilbara and rarely encountered | No |
| *Lecane* 'bulloid' n. sp. | Study Area site MC1-B, MC5; reference sites WM, WMC | Current study | Undescribed species known only from Weeli Wolli, Kalgan and Mindy Mindy creeks | No |
| *Lecane noobijupi* | Study Area sites MC1, MC2, MC4, MC5, MC6 MC7; reference sites FR, WM, WMU | WRM 2015 | Known only from Western Australia; disjunct distribution, extreme southwest & the Pilbara | No |
| *Heterolepadella heterostyla* | Study Area sites MC5, MC6 | WRM 2015 | Thought to have cosmopolitan distribution, but is uncommon/ rarely collected; also known from Weeli Wolli Ck and Mindy Mindy Ck in the Pilbara | No |
| *Australoeucyclops karaytugi* | Marillana Ck d/s of Rio Tinto Yandicoogina mine | WRM 2011 | Pilbara endemic described from Weeli Wolli Spring. Also known from Caves Creek, De Grey, Ashburton, and Yule systems | No |
| | Study Area sites MC1, MC2, MC4, MC6 and MC7 & reference site FR | WRM 2015; Current study | | |
| **Cyclopoid Copepods** | | | | |
| *Mesocyclops holynskae* | Marillana Ck d/s of BHPBIO Yandi but u/s of Rio Tinto Yandicoogina mine | WRM 2011 | Pilbara endemic with disjunct distribution. Known from Marillana and Weeli Wolli creeks, Mulga Downs Station and Pardoo | No |
| | Study Area site MC6 | WRM 2015 | | |
| *Gomphodella* n. sp. (BOS334) | Study Area sites MC1, MC6 | WRM 2015 | Undescribed stygal species; known only from Marillana Ck, bores in the Yandi area, and Weeli Wolli Ck. | **SRE** |
| **Stygal Amphipods** | | | | |
| *Chydaekata* sp. | Length of Marillana Ck from just d/s of BHPBIO discharge to just u/s of the confluence with Weeli Wolli Ck | WRM 2011 | Stygal; restricted to Marillana Creek, Weeli Wolli Ck; Coondiner Ck and Mindy Mindy Ck; currently undescribed | **SRE** |
| | Study Area sites MC1-B, MC5, MC6, MC7 | WRM 2015; Current study | | |
| Paramelitidae sp. B (= Paramelitidae Genus 2 sp. B2[16]) | Length of Marillana Ck from just d/s of BHPBIO discharge to just u/s of the confluence with Weeli Wolli Ck | WRM 2011 | Stygal; restricted to Marillana Creek, Weeli Wolli Creek and Coondewanna Flats catchments; currently undescribed | |
| | Study Area sites MC1-B, MC5, MC6, MC7 | WRM 2015; Current study | | |

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[16] Bennelongia name.

| Species | Recorded from | Study | Distribution | Listed |
|---|---|---|---|---|
| Paramelitidae sp. D (= Paramelitidae Genus 2 sp. B3[21]) | Length of Marillana Ck from just d/s of BHPBIO discharge to just u/s of the confluence with Weeli Wolli Ck | WRM 2011 | Restricted to Marillana Ck, Weeli Wolli Ck and Coondewanna Flats catchments; currently undescribed; | **SRE** |
| | Study Area sites MC1, MC1-B, MC5, MC6, MC7 | WRM 2015; Current study | | |
| *Maarrka weeliwolli* | A site d/s of Rio Tinto's Yandicoogina mine | WRM 2011 | Restricted to Marillana Ck and Weeli Wolli Ck | **SRE** |
| **Stygal Isopod** | | | | |
| *Pygolabis weeliwolli* | A site d/s of Rio Tinto Yandicoogina mine | WRM 2011 | Known only from Marillana and Weeli Wolli creeks | **SRE** |
| | Study Area site MC7 | Current study | | |
| **Stygal Water Mite** | | | | |
| *Stygolimnochares* nr *australica* | Hyporheos and surface waters at Study Area site MC2, MC6, MC7 | WRM 2015; Current study | Constitutes either a range extension for QLD species *Stygolimnochares australica* or a species new to science. *Stygolimnochares* nr *australica* also recorded from Koodaideri Spring. Specimens from Yandi are currently with Dr Mark Harvey (WAM) still awaiting taxonomic assessment. | No |
| **Hyporheic Non-biting Midge** | | | | |
| *?Pentaneura* sp. | Hyporheic zone of reference site UWWCS on Weeli Wolli Ck, and FU on Fortescue River | WRM 2015; Current study | Pilbara endemic; known from Marillana Ck, Weeli Wolli Ck, upper Fortescue River, Fortescue River South, Caves Ck, Robe River and De Grey River; highly disjunct distribution; currently undescribed. | No |
| **Dragonflies** | | | | |
| *Eurysticta coolawanyah* | Study Area sites MC5, MC7, MC8; reference site FR on Marillana Ck | Pinder *et al*. 2010; WRM 2015; Current study | Pilbara endemic; also known from over 40 locations across the Pilbara. Its listing on IUCN Redlist is considered to require revision. | **IUCN - NT** |
| *Hemicordulia koomina* | Reference site FR on Marillana Ck u/s of all mining activity | WRM 2015 | Pilbara endemic; also known from pools in the Fortescue, Robe, De Grey, Ashburton, Cane, Sherlock and Shaw river systems. Considered rare, as is infrequently collected and rarely recorded. | **IUCN - NT** |
| **Aquatic Beetles** | | | | |
| *Limbodessus occidentalis* | Surface waters of a site just d/s of BHPBIO Yandi and u/s of Rio Tinto Yandicoogina | WRM 2011 | Pilbara endemic known from calcrete aquifers Weeli Wolli Spring, Killara North (~300 km south of Marillana Ck) and Moorarie (~125 km west of Killara), as well as surface water samples from Gregory Gorge (Fortescue), Creek Pool (Ashburton), Red Hill Creek (Robe), lower Fortescue, Harding River Pool and Joffre Creek (Fortescue). | No |
| | Study Area sites MC5, MC6 | WRM 2015 | | |
| *Laccobius billi* | Lower end of Marillana Creek near confluence with Weeli Wolli Creek | WRM 2011 | Rarely collected Pilbara endemic. Known from Cangan Pool (Yule River), Weeli Wolli and Mindy Mindy creeks | No |
| | Study Area site MC2 | Current study | | |

# 7. CONCLUSIONS

Surface water quality of Marillana Creek within Study Area was generally good and characterised by fresh to slightly brackish waters, with moderate to high dissolved oxygen levels, circum-neutral to basic pH, high alkalinity (thus buffering capacity), and low turbidity and dissolved metal levels. Background levels of nitrogen, phosphorus and dissolved boron appear naturally elevated, as evidenced by the relatively high concentrations in the reference creeks outside of the influence of mine activities.

Within the Study Area, Marillana Creek has a relatively diverse aquatic invertebrate fauna, with the sections of natural creekline upstream of the western diversion (MC1 - MC3) and between the western and eastern diversions (MC4 - MC6) supporting higher species richness of macroinvertebrate and hyporheic fauna than the regional reference creeks. Healthy fish communities, with good abundance of juvenile and sub-adult rainbowfish, spangled perch and tandan catfish, were also recorded for these reaches, suggesting strong recruitment is occurring over the wet season.

Five acknowledged stygal SREs occur within, but are not restricted to, the Study Area. These include the amphipods Paramelitdae sp. B (MC1 to Weeli Wolli Creek confluence), Paramelitdae sp. D (MC1 to Weeli Wolli Creek confluence) and *Chydaekata* sp. (MC1 to Weeli Wolli Creek confluence), the isopod *Pygolabis weeliwolli* (MC7 to downstream of Rio Tinto Yandicoogina), and the ostracod *Gomphodella* n. sp. (BOS334) (MC1 & MC6). A sixth stygal SRE amphipod, *Maarrka Weelwolli*, is also likely to occur within the Study Area, based on its occurrence in the Marillana catchment downstream, and from the Weeli Wolli catchment, both upstream and downstream of the Marillana Creek confluence.

Given that all recorded stygal SREs have distributions which extend outside the Study Area, and that the epigean species recorded are common and widespread throughout the Marillana, Weeli Wolli and Fortescue catchments, it is expected that any localised reduction or loss of epigean or stygal species, due to disturbance from channel re-alignment, will be short-term. Assuming suitable stable aquatic habitats are available within the diverted sections, invertebrates would be expected to rapidly recolonise as a result of natural dispersal following rain events (*e.g.* downstream drift, aerial invasion by winged adult stages *etc*.). Aquifers of the Marillana catchment, both upstream and downstream of the Study Area, probably provide considerable habitat connectivity for stygal SREs beyond the Study Area. Fishes recorded are all highly mobile species and could readily recolonise from the numerous permanent pools in downstream Weeli Wolli Creek and the Fortescue River.

There are however, existing differences in water quality and aquatic invertebrate communities upstream and downstream of the eastern diversion, which will need to be taken into consideration when interpreting results from any future impact assessments. These differences are associated with dewatering discharge from the mine and include changes in water quality and species richness, abundance and assemblage composition.

Levels of inorganic nitrate downstream of the discharge outlet were at least an order of magnitude greater than at upstream sites on Marillana Creek and at regional reference sites. Reduced seasonal variability in water quality parameters (e.g. nitrogen, phosphorus, EC, major ions, some dissolved metals) was also observed downstream of the discharge outlet. This is largely because the discharge maintains higher water levels over the dry season than would otherwise occur, thereby reducing evapo-concentration effects. It may therefore be prudent to develop 'system-specific' operational guidelines for Marillana Creek, rather than relying on ANZECC/ARMCANZ (2000) default TVs which may be overly conservative given the existing surface water quality. The aim in developing site-specific guidelines would be to protect the current integrity and ecological value of the system (i.e. avoid any adverse changes), while acknowledging that surface water quality is already likely modified compared to pre-mine condition.

Microinvertebrate and macroinvertebrate communities downstream of the discharge point, had lower species richness, abundance and differing species assemblage composition to those upstream of the discharge point and in reference creeks. These differences were considerably more pronounced for microinvertebrate compared to macroinvertebrate communities, and relatively more pronounced for wet season macroinvertebrate compared to dry season macroinvertebrate communities.

The differences are considered largely flow-related, with decreased abundance of taxa that prefer slow flowing or still water environments (e.g. most microinvertebrates, freshwater snails, water mites, some non-biting midge species), and increased abundance of a few taxa that prefer faster flows and/or increased permanency of flow (e.g. caddis-flies, biting midges, the dragonfly *Nannophlebia injibandi*). Such changes in communities below dewatering-discharge outlets is a common finding in aquatic ecosystem surveys by WRM across the Pilbara (WRM unpub. data).

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# 9. APPENDICES

## Appendix 1a. AusRivAS FNARH macroinvertebrate data

Macroinvertebrate families recorded from the Marillana Creek site sampled during the AusRivAS FNARH surveys (data provided by Adrian Pinder DPaW).

**Wet season, March 1998.**

| *Phylum/Class/Order* | *Family* |
|---|---|
| Oligochaeta | indeterminate |
| Acarina | indeterminate |
| Mollusca | |
| Gastropoda | Planorbidae |
| Crustacea | |
| Amphipoda | Paramelitidae |
| Insecta | |
| Ephemeroptera | Baetidae |
| | Caenidae |
| Odonata | Aeshnidae |
| | Coenagrionidae |
| | Corduliidae |
| | Isostictidae |
| | Libellulidae |
| Hemiptera | Belostomatidae |
| | Corixidae |
| | Gerridae |
| | Notonectidae |
| | Pleidae |
| Coleoptera | Dytiscidae |
| | Gyrinidae |
| | Hydrophilidae |
| Diptera | Chironominae* |
| | Tanypodinae* |
| | Ceratopogonidae |
| | Culicidae |
| No. of Families | 23 |

* = subfamily of Chironomidae

## Appendix 1b. Streamtec (2004) macroinvertebrate data

Macroinvertebrate taxa recorded by Streamtec (2004) from Flat Rocks between 2001 and 2003. Values are presence/absence data, where 1 = present and 0 = absent.

| *Class/Order* | *Family* | *Species/taxa* | *Dry-01* | *Wet-02* | *Wet-03* | *Dry-03* |
|---|---|---|---|---|---|---|
| **MOLLUSCA** | | | | | | |
| **GASTROPODA** | | | | | | |
| | **Planorbidae** | *Gyraulus* sp. | 1 | 1 | 0 | 1 |
| | **Lymnaeidae** | *Austropeplea lessoni* | 1 | 1 | 1 | 1 |
| | **Ancylidae** | *Ferrissia petterdi* | 0 | 0 | 0 | 1 |
| **ANNELIDA** | | | | | | |
| **Oligochaeta** | | Oligochaeta spp. | 0 | 1 | 0 | 1 |
| **ARACHNIDA** | | | | | | |
| **ACARINA** | | Acarina spp. | 1 | 1 | 1 | 1 |
| **INSECTA** | | | | | | |
| **EPHEMEROPTERA** | **Baetidae** | Genus 1 WA sp. 1 | 1 | 0 | 1 | 0 |
| | | *Cloeon* sp. | 1 | 1 | 1 | 1 |
| | **Caenidae** | *Tasmanocoenis arcuata* | 1 | 1 | 1 | 1 |
| **ODONATA** | | | | | | |
| **Anisoptera** | **Hemicorduliidae** | *Hemicordulia tau* | 1 | 0 | 0 | 0 |
| | **Gomphidae** | *Austrogomphus gordoni* | 1 | 0 | 0 | 1 |
| | **Lindeniidae** | *Ictinogomphus dobsoni* | 0 | 0 | 0 | 1 |
| | **Libellulidae** | *Orthetrum caledonicum* | 0 | 0 | 1 | 0 |
| | | *Diplacodes haematodes* | 1 | 1 | 1 | 1 |
| | **Aeshnidae** | *Hemianax papuensis* | 0 | 1 | 0 | 0 |
| **Zygoptera** | **Coenogrionidae** | *Coenagrionidae spp.* | 1 | 1 | 0 | 1 |
| | | *Ischnura pruinescens* | 0 | 0 | 0 | 1 |
| **HEMIPTERA** | **Veliidae** | *Microvelia* sp. | 0 | 0 | 0 | 1 |
| | **Mesoveliidae** | *Mesovelia* sp. | 0 | 1 | 0 | 0 |
| | **Pleidae** | *Plea brunni* | 1 | 1 | 0 | 1 |
| | **Corixidae** | *Micronecta* sp. UK1 | 1 | 0 | 1 | 1 |
| | **Notonectidae** | *Anisops* sp. | 1 | 0 | 1 | 0 |
| | **Naucoridae** | Naucoridae spp. | 0 | 1 | 0 | 1 |
| | **Gerridae** | *Limnogonus (L) fossarum* | 1 | 1 | 1 | 1 |
| | **Hebridae** | *Merragata hackeri* | 1 | 1 | 0 | 0 |
| **DIPTERA** | | Diptera sp. UD2 | 1 | 0 | 0 | 0 |
| | **Dolichopidae** | Dolichopodidae sp. | 0 | 0 | 1 | 0 |
| | **Simuliidae** | *Simulium ornatipes* | 1 | 1 | 1 | 1 |
| | **Chironomidae** | Chironomidae spp. | 1 | 1 | 1 | 1 |
| | **Ceratopogonidae** | Ceratopogonidae spp. | 1 | 1 | 1 | 1 |
| | **Culicidae** | *Anopheles* sp. | 1 | 0 | 1 | 1 |
| | | *Aedomyia catastica* | 0 | 1 | 0 | 1 |
| | | *Culex* sp. | 1 | 1 | 1 | 1 |
| | **Stratiomyidae** | Stratiomyidae sp. | 1 | 1 | 0 | 1 |
| | **Tabanidae** | *Tabanus* sp. | 1 | 0 | 0 | 1 |
| **LEPIDOPTERA** | **Pyralidae** | Pyralidae sp. | 1 | 1 | 1 | 1 |
| **TRICHOPTERA** | **Ecnomidae** | *Ecnomus* sp. | 1 | 0 | 1 | 1 |
| | **Leptoceridae** | *Leptocerus atsou* | 1 | 0 | 0 | 0 |
| | | *Oecetis* sp. 1 | 1 | 1 | 0 | 1 |
| | | *Triplectides ?australicus* | 1 | 0 | 0 | 1 |
| | | *Triplectides ciuskus seductus* | 1 | 1 | 0 | 1 |
| | **Hydroptilidae** | *Orthotrichia* sp. | 1 | 1 | 0 | 0 |
| | | *Hellyethera ?vernoni* | 0 | 1 | 0 | 1 |
| | **Hydropsychidae** | *Cheumatopsyche* sp. | 1 | 0 | 1 | 1 |
| **COLEOPTERA** | **Dytiscidae** | *Cybister tripunctatus* | 0 | 0 | 1 | 0 |
| | | *Hydroglyphus fuscolineatus* | 0 | 0 | 1 | 0 |
| | | *Hydroglyphus leai* | 0 | 1 | 1 | 1 |

| *Class/Order* | *Family* | *Species/taxa* | *Dry-01* | *Wet-02* | *Wet-03* | *Dry-03* |
|---|---|---|---|---|---|---|
| | | *Hydroglyphus orthogrammus* | 0 | 0 | 1 | 1 |
| | | *Hydroglyphus trilineatus* | 0 | 0 | 0 | 1 |
| | | *Hydrovatus* sp. (L) | 1 | 1 | 0 | 1 |
| | | *Necterosoma regulare* | 1 | 0 | 1 | 0 |
| | | *Sternopriscus* sp. | 1 | 0 | 0 | 1 |
| | | *Sternopriscus sp. (L)* | 0 | 0 | 0 | 1 |
| | | *Tiporus tambreyi* | 1 | 1 | 0 | 0 |
| | **Hydrophilidae** | *Berosus australiae* | 1 | 0 | 0 | 0 |
| | | *Helochares* sp. | 0 | 1 | 0 | 0 |
| | | *Regimbartia attenuata* | 0 | 0 | 0 | 1 |
| | | *Paracymus* sp. | 0 | 0 | 0 | 1 |
| | | Hydrophilidae sp. (L) | 0 | 1 | 0 | 1 |
| | | *Laccobius matthewsi* | 0 | 0 | 0 | 1 |
| | **Hydrochidae** | *Hydrochus* sp. | 1 | 0 | 0 | 1 |
| | **Hydraenidae** | *Hydreana* sp. | 0 | 0 | 0 | 1 |
| | | *Octhebius sp.* | 0 | 0 | 0 | 1 |
| | **Carabidae** | Carabidae sp. PB1 | 0 | 1 | 0 | 0 |
| | | **Taxa richness** | **37** | **31** | **24** | **45** |

# Appendix 2. Site photographs

## SITES ON MARILLANA CREEK WITHIN THE STUDY AREA

**Wet-17** **Dry-17**

**MC1**

**MC2**

**MC3**

**MC1-B (MC3 was dry)**

| Wet-17 | Dry-17 |
|---|---|
| **MC4**  | **Dry, not photographed** |
| **MC5**  | **Dry, not photographed** |
| **MC6**  | **Dry, not photographed** |

**Wet-17** **Dry-17**

**MC7**

**MC8**

**MC9**

# FORTESCUE RIVER REFERENCE SITE

| Wet-17 | Dry-17 |
|---|---|
| **FU**<br> | **Dry, not photographed** |

## WEELI WOLLI CREEK REFERENCE SITES

**Wet-17** **Dry-17**

**WM**

**WMU**

**WMC**

# Appendix 3. ANZECC/ARMCANZ (2000) trigger values

**Table A3-1.** Default trigger values for some physical and chemical stressors for tropical northern 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 (ANZECC/ARMCANZ 2000).

| | *TP*<br>*(mg $L^{-1}$)* | *FRP*<br>*(mg P $L^{-1}$)* | *TN*<br>*(mg $L^{-1}$)* | *NOx*<br>*(mg N $L^{-1}$)* | *$NH_4^+$*<br>*(mg N $L^{-1}$)* | *DO*<br>*% saturation[f]* | *pH* |
|---|---|---|---|---|---|---|---|
| **Aquatic Ecosystem** | | | | | | | |
| Upland River[e] | 0.01 | 0.005 | 0.15 | 0.03 | 0.006 | 90-120 | 6.0-7.5 |
| Lowland River[e] | 0.01 | 0.004 | 0.2-0.3[h] | 0.01[b] | 0.01 | 85-120 | 6.0-8.0 |
| Lakes & Reservoirs | 0.01 | 0.005 | 0.35[c] | 0.01[b] | 0.01 | 90-120 | 6.0-8.0 |
| Wetlands[3] | 0.01-0.05[g] | 0.005-0.025[g] | 0.35-1.2[g] | 0.01 | 0.01 | 90[b]-120[b] | 6.0-8.0 |

b = Northern Territory values are 0.005 $mgL^{-1}$ for $NO_x$, 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 A3-2.** Default trigger values for salinity and turbidity for the protection of aquatic ecosystems, applicable to tropical systems in Australia (ANZECC/ARMCANZ 2000).

| *Aquatic Ecosystem* | | *Comments* |
|---|---|---|
| ***Salinity*** | ***(µs/cm)*** | |
| **Aquatic Ecosystem** | | |
| 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)*** | |
| **Aquatic Ecosystem** | | |
| 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 A3-3.** Trigger values for toxicants at alternative levels of protection (mg/L).

| | Trigger values for freshwater Level of protection (% species) | | | |
|---|---|---|---|---|
| **Compound** | **99%** | **95%** | **90%** | **80%** |
| **METALS & METALLOIDS** | | | | |
| Aluminium pH > 6.5 | 0.027 | 0.055 | 0.080 | 0.15 |
| Aluminium pH < 6.5 | ID | ID | ID | ID |
| Arsenic (As III) | 0.001 | 0.024 | 0.094 | 0.36 |
| Arsenic (As IV) | 0.0009 | 0.013 | 0.042 | 0.14 |
| Boron | 0.09 | 0.37 | 0.68 | 1.30 |
| Cadmium | 0.00006 | 0.0002 | 0.0004 | 0.0008 |
| Cobalt | ID | ID | ID | ID |
| Chromium (Cr III) | ID | ID | ID | ID |
| Chromium (Cr VI) | 0.00001 | 0.001 | 0.006 | 0.040 |
| Copper | 0.001 | 0.0014 | 0.0018 | 0.0025 |
| Iron | ID | ID | ID | ID |
| Manganese | 1.20 | 1.90 | 2.50 | 3.60 |
| Molybdenum | ID | ID | ID | ID |
| Nickel | 0.008 | 0.011 | 0.013 | 0.017 |
| Lead | 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 | 0.0024 | 0.008 | 0.015 | 0.031 |
| **NON-METALLIC INORGANICS** | | | | |
| Ammonia ($N-NH_3$) | 0.32 | 0.90 | 1.43 | 2.30 |
| Chlorine | 0.004 | 0.003 | 0.006 | 0.013 |
| Nitrate ($NO_3$) | 0.017 | 0.70 | 3.40 | 17.00 |

# Appendix 4. Water quality data.

**Table A4-1.** Wet season 2017 *In situ* and laboratory derived water quality data, showing parameter units and limit of reporting (LOR). WSA-USD = sites within the Study Area upstream of dewatering discharge, WSA-USD = sites within the Study Area downstream of dewatering discharge.

| Parameter | LOR | Units | WSA-USD | | | | | | WSA-DSD | | | Reference | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | MC1 | MC2 | MC3 | MC4 | MC5 | MC6 | MC7 | MC8 | MC9 | FU | WM | WMU | WMC |
| Al | *0.005* | mg/L | 0.007 | 0.014 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | 0.006 | 0.007 | 0.011 |
| Alkalin | *1* | mg/L | 205 | 179 | 154 | 239 | 222 | 192 | 260 | 256 | 255 | 81 | 163 | 62 | 33 |
| As | *0.001* | mg/L | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 |
| B | *0.02* | mg/L | 0.3 | 0.23 | 0.15 | 0.24 | 0.23 | 0.19 | 0.35 | 0.35 | 0.38 | 0.03 | 0.07 | 0.03 | 0.03 |
| Ba | *0.002* | mg/L | 0.031 | 0.029 | 0.05 | 0.045 | 0.039 | 0.039 | 0.038 | 0.042 | 0.042 | 0.066 | 0.036 | 0.02 | 0.01 |
| CO3 | *1* | mg/L | 17 | 16 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 |
| Ca | *0.1* | mg/L | 21.4 | 20.5 | 28.8 | 35.7 | 34.8 | 31 | 42.4 | 45.8 | 46.2 | 28.4 | 45.8 | 19.6 | 10 |
| Cd | *0.0001* | mg/L | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 |
| Cl | *1* | mg/L | 112 | 99 | 64 | 44 | 56 | 45 | 97 | 102 | 98 | 38 | 49 | 22 | 8 |
| Co | *0.0001* | mg/L | <0.0001 | 0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | 0.0001 | <0.0001 | 0.0001 | 0.0001 | <0.0001 | <0.0001 |
| Cr | *0.0005* | mg/L | <0.0005 | <0.0005 | <0.0005 | <0.0005 | <0.0005 | <0.0005 | <0.0005 | <0.0005 | <0.0005 | <0.0005 | <0.0005 | <0.0005 | <0.0005 |
| Cu | *0.0001* | mg/L | 0.0003 | 0.0002 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | 0.0001 | 0.0019 | 0.0008 | 0.0015 |
| DO | *0.1* | % | 71.7 | 100.7 | 132.2 | 97.9 | 71.1 | 74.2 | 91.8 | 93.4 | 85.7 | 77.8 | 60.1 | 84.6 | 92.2 |
| DO | *0.01* | mg/L | 6.39 | 9.33 | 10.81 | 8.60 | 6.72 | 7.04 | 7.03 | 7.41 | 6.99 | 7.07 | 7.37 | 7.87 | 8.21 |
| Econd_Lab | *0.2* | mS/m | 78.5 | 68.8 | 53.6 | 61.7 | 63.1 | 53.6 | 87.5 | 89.7 | 90 | 31.1 | 62.7 | 20.6 | 12 |
| Fe | *0.005* | mg/L | 0.021 | 0.036 | 0.056 | 0.011 | 0.016 | 0.033 | <0.005 | <0.005 | <0.005 | 0.14 | 0.01 | 0.019 | 0.018 |
| HCO3 | *1* | mg/L | 217 | 185 | 188 | 291 | 270 | 234 | 317 | 312 | 310 | 99 | 199 | 76 | 40 |
| Hardness | *1* | mg/L | 230 | 200 | 180 | 220 | 220 | 190 | 280 | 300 | 310 | 110 | 250 | 85 | 43 |
| K | *0.1* | mg/L | 8.8 | 7.6 | 5.7 | 6.4 | 6.9 | 6.4 | 7.1 | 7.8 | 7.7 | 3.7 | 4.4 | 2.8 | 2.5 |
| Mg | *0.1* | mg/L | 43.4 | 36.6 | 26.1 | 30.9 | 31.8 | 27.6 | 42.2 | 44.7 | 46.4 | 8.5 | 33.4 | 8.8 | 4.3 |
| Mn | *0.001* | mg/L | 0.002 | 0.002 | 0.003 | 0.005 | 0.005 | 0.002 | <0.001 | <0.001 | <0.001 | 0.014 | 0.003 | 0.003 | 0.001 |
| Mo | *0.001* | mg/L | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 |
| N_NH3 | *0.01* | mg/L | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| N_NO2 | *0.01* | mg/L | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| N_NO3 | *0.01* | mg/L | <0.01 | <0.01 | <0.01 | 0.06 | <0.01 | <0.01 | 3.3 | 3.7 | 3.5 | 0.07 | <0.01 | <0.01 | <0.01 |
| N_NOx | *0.01* | mg/L | <0.01 | <0.01 | <0.01 | 0.06 | <0.01 | <0.01 | 3.3 | 3.8 | 3.5 | 0.08 | <0.01 | <0.01 | <0.01 |
| N_total | *0.01* | mg/L | 0.18 | 0.17 | 0.09 | 0.07 | 0.04 | 0.06 | 3.7 | 3.8 | 3.6 | 0.1 | 0.23 | 0.09 | 0.12 |
| Na | *0.1* | mg/L | 79.9 | 66.6 | 39.1 | 46.4 | 45 | 37.3 | 73.5 | 75.9 | 78.2 | 17.9 | 36 | 5.7 | 5.9 |
| Ni | *0.001* | mg/L | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 |
| OH | *1* | mg/L | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 |
| P_total | *0.005* | mg/L | <0.010 | <0.010 | <0.010 | 0.014 | 0.01 | <0.010 | <0.010 | 0.035 | 0.032 | <0.010 | <0.010 | <0.010 | <0.010 |
| Pb | *0.0001* | mg/L | <0.0001 | <0.0001 | <0.0001 | <0.0001 | 0.0007 | <0.0001 | <0.0001 | <0.0001 | 0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 |
| S | *0.1* | mg/L | 11 | 9.6 | 7.3 | 7.9 | 9.4 | 7.2 | 17 | 17 | 17 | 4.9 | 29 | 2.3 | 4.5 |
| SO4_S | *0.1* | mg/L | 34 | 28.8 | 21.9 | 23.7 | 28.2 | 21.4 | 50.6 | 50.3 | 51.6 | 14.8 | 86.7 | 6.9 | 13.4 |
| Se | *0.001* | mg/L | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | 0.001 | 0.001 | 0.001 | <0.001 | <0.001 | <0.001 | <0.001 |
| Si | *0.05* | mg/L | 8.6 | 6 | 10 | 21 | 18 | 16 | 28 | 30 | 29 | 5.8 | 3.8 | 3 | 1.7 |
| Sr | *0.002* | mg/L | 0.13 | 0.11 | 0.12 | 0.15 | 0.15 | 0.13 | 0.19 | 0.21 | 0.21 | 0.086 | 0.12 | 0.054 | 0.025 |
| Temperature | *0.1* | °C | 18.7 | 19.0 | 25.7 | 21.5 | 17.9 | 17.4 | 28.8 | 26.2 | 25.5 | 20.7 | 18.9 | 18.9 | 19.9 |
| TDS_calc | *5* | mg/L | 430 | 380 | 290 | 340 | 350 | 290 | 480 | 490 | 490 | 170 | 350 | 110 | 66 |
| TSS | *1* | mg/L | 3 | 4 | 1 | <1 | <1 | 13 | <1 | <1 | <1 | 9 | 5 | 3 | 3 |
| Turbidit | *0.5* | NTU | 3.1 | 3.7 | 1.5 | 0.9 | 1.1 | 6.7 | 1.2 | 0.7 | 2.6 | 8.3 | 5.5 | 5.1 | 4.2 |
| U | *0.0001* | mg/L | 0.0007 | 0.0005 | 0.0003 | 0.0006 | 0.0008 | 0.0004 | 0.0007 | 0.0007 | 0.0008 | 0.0002 | 0.0003 | <0.0001 | <0.0001 |
| V | *0.0001* | mg/L | 0.0038 | 0.0024 | 0.0016 | 0.0034 | 0.0049 | 0.0039 | 0.0009 | 0.0011 | 0.0012 | 0.001 | 0.0016 | 0.0007 | 0.0013 |
| Zn | *0.001* | mg/L | 0.004 | 0.003 | 0.002 | 0.004 | 0.006 | 0.003 | 0.003 | 0.004 | 0.004 | 0.003 | 0.003 | 0.004 | 0.007 |
| pH_Lab | *0.1* | H+ | 8.6 | 8.6 | 8.1 | 7.9 | 7.9 | 8 | 7.6 | 7.7 | 7.8 | 7.7 | 8 | 7.8 | 7.5 |
| pH_Field | *0.1* | H+ | 8.91 | 9.00 | 8.31 | 8.00 | 8.17 | 8.27 | 7.19 | 7.37 | 7.51 | 7.62 | 8.09 | 7.84 | 8.06 |

**Table A4-2.** Dry season 2017 *In situ* and laboratory derived water quality data, showing parameter units and limit of reporting (LOR). WSA-USD = sites within the Study Area upstream of dewatering discharge, WSA-USD = sites within the Study Area downstream of dewatering discharge.

| Parameter | LOR | Units | WSA-USD | | | WSA-DSD | | | Reference | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | MC1 | MC1-B | MC2 | MC7 | MC8 | MC9 | WM | WMU | WMC |
| Al | *0.005* | mg/L | 0.015 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | 0.017 | 0.008 |
| Alkalin | *1* | mg/L | 498 | 342 | 403 | 286 | 283 | 278 | 616 | 195 | 74 |
| As | *0.001* | mg/L | 0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | 0.002 | <0.001 | <0.001 |
| B | *0.02* | mg/L | 0.59 | 0.37 | 0.56 | 0.39 | 0.39 | 0.36 | 0.34 | 0.06 | 0.03 |
| Ba | *0.002* | mg/L | 0.073 | 0.03 | 0.041 | 0.045 | 0.044 | 0.042 | 0.092 | 0.073 | 0.021 |
| CO3 | *1* | mg/L | <1 | 22 | 13 | <1 | <1 | <1 | <1 | <1 | <1 |
| Ca | *0.1* | mg/L | 25.6 | 20 | 34.5 | 48.2 | 47.9 | 46.8 | 102 | 53.8 | 19.6 |
| Cd | *0.0001* | mg/L | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 |
| Cl | *1* | mg/L | 392 | 272 | 564 | 120 | 111 | 120 | 325 | 96 | 13 |
| Co | *0.0001* | mg/L | 0.0003 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0013 | 0.0005 | 0.0002 |
| Cr | *0.0005* | mg/L | <0.0005 | <0.0005 | <0.0005 | <0.0005 | <0.0005 | <0.0005 | <0.0005 | <0.0005 | <0.0005 |
| Cu | *0.0001* | mg/L | <0.0001 | 0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | 0.0004 | 0.0017 | 0.0014 |
| DO | *0.1* | % | 30.8 | 77.7 | 124.2 | 80 | 73.1 | 65.2 | 55.5 | 103.2 | 89.5 |
| DO | *0.01* | mg/L | 3.01 | 6.87 | 10.18 | 5.96 | 5.72 | 5.38 | 4.84 | 8.3 | 8.59 |
| Econd_Lab | *0.2* | mS/m | 187 | 138 | 242 | 94.7 | 94.7 | 93.5 | 252 | 64.5 | 20.8 |
| Fe | *0.005* | mg/L | 0.29 | 0.031 | 0.086 | <0.005 | <0.005 | <0.005 | 0.06 | 0.077 | 0.011 |
| HCO3 | *1* | mg/L | 607 | 372 | 464 | 349 | 345 | 338 | 750 | 238 | 91 |
| Hardness | *1* | mg/L | 510 | 400 | 730 | 320 | 320 | 310 | 1000 | 270 | 83 |
| K | *0.1* | mg/L | 17.9 | 12.7 | 17.6 | 8.3 | 8 | 7.7 | 8.2 | 9.1 | 4 |
| Mg | *0.1* | mg/L | 108 | 85.5 | 157 | 49.5 | 48.6 | 46.6 | 187 | 32.5 | 8.2 |
| Mn | *0.001* | mg/L | 0.33 | 0.009 | 0.009 | <0.001 | <0.001 | <0.001 | 0.86 | 0.074 | 0.001 |
| Mo | *0.001* | mg/L | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | 0.002 | <0.001 | 0.002 |
| N_NH3 | *0.01* | mg/L | 0.03 | 0.03 | 0.02 | 0.02 | 0.02 | 0.03 | 0.49 | 0.09 | 0.02 |
| N_NO2 | *0.01* | mg/L | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| N_NO3 | *0.01* | mg/L | <0.01 | <0.01 | <0.01 | 3 | 2.7 | 1.8 | <0.01 | <0.01 | <0.01 |
| N_NOx | *0.01* | mg/L | <0.01 | <0.01 | <0.01 | 3 | 2.7 | 1.8 | <0.01 | <0.01 | <0.01 |
| N_total | *0.01* | mg/L | 1 | 0.51 | 0.56 | 3.4 | 3.1 | 3.1 | 1.3 | 1 | 0.27 |
| Na | *0.1* | mg/L | 222 | 152 | 274 | 84.8 | 84 | 81.1 | 238 | 24 | 9.4 |
| Ni | *0.001* | mg/L | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | 0.002 | 0.001 | <0.001 |
| OH | *1* | mg/L | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 |
| P_total | *0.005* | mg/L | <0.010 | <0.010 | <0.010 | <0.010 | 0.011 | 0.011 | 0.026 | 0.016 | <0.010 |
| Pb | *0.0001* | mg/L | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 |
| S | *0.1* | mg/L | 4.3 | 14 | 64 | 19 | 18 | 17 | 160 | 3.3 | 6.1 |
| SO4_S | *0.1* | mg/L | 12.7 | 41.6 | 191 | 55.5 | 54.3 | 52.3 | 483 | 9.9 | 18.2 |
| Se | *0.001* | mg/L | <0.001 | <0.001 | <0.001 | 0.002 | 0.002 | 0.002 | <0.001 | <0.001 | <0.001 |
| Si | *0.05* | mg/L | 0.9 | 0.39 | 11 | 29 | 28 | 27 | 21 | 0.47 | 0.54 |
| Sr | *0.002* | mg/L | 0.14 | 0.074 | 0.13 | 0.22 | 0.22 | 0.21 | 0.27 | 0.18 | 0.051 |
| Temperature | *0.1* | °C | 16.3 | 20.6 | 26 | 31 | 28.3 | 25.5 | 20.6 | 26.9 | 16.2 |
| TDS_calc | *5* | mg/L | 1000 | 760 | 1300 | 520 | 520 | 510 | 1400 | 350 | 110 |
| TSS | *1* | mg/L | 39 | 4 | 4 | <1 | <1 | 2 | 17 | 23 | 10 |
| U | *0.0001* | mg/L | 0.0008 | 0.001 | 0.0018 | 0.0008 | 0.0008 | 0.0008 | 0.0009 | 0.0004 | <0.0001 |
| V | *0.0001* | mg/L | 0.0018 | 0.0013 | 0.0016 | 0.0011 | 0.0013 | 0.0013 | 0.0032 | 0.001 | 0.0007 |
| Zn | *0.001* | mg/L | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 |
| pH_Lab | *0.1* | H+ | 8.1 | 8.5 | 8.4 | 7.8 | 7.9 | 7.9 | 7.9 | 8.1 | 8.1 |
| pH_Field | *0.1* | H+ | 8.34 | 8.77 | 8.43 | 7.07 | 7.25 | 7.4 | 8.03 | 8.26 | 8.47 |

# Appendix 5. Habitat characteristic data.

WSA-USD = sites within the Study Area upstream of dewatering discharge, WSA-USD = sites within the Study Area downstream of dewatering discharge

**Table A5-1.** Wet Season 2017 habitat characteristic data. WSA-USD = sites within the Study Area upstream of dewatering discharge, WSA-USD = sites within the Study Area downstream of dewatering discharge

| Parameter | WSA-USD | | | | | | WSA-DSD | | | Reference | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | MC1 | MC2 | MC3 | MC4 | MC5 | MC6 | MC7 | MC8 | MC9 | FU | WM | WMU | WMC |
| Substrate composition | | | | | | | | | | | | | |
| Bedrock % | 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 20 | 50 | 30 |
| Boulders % | 0 | 0 | 20 | 5 | 0 | 0 | 0 | 5 | 0 | 0 | 40 | 0 | 10 |
| Cobbles % | 0 | 40 | 10 | 15 | 5 | 5 | 15 | 10 | 10 | 0 | 10 | 0 | 0 |
| Pebbles % | 30 | 10 | 5 | 15 | 30 | 30 | 35 | 30 | 40 | 20 | 5 | 0 | 10 |
| Gravel % | 30 | 10 | 3 | 25 | 20 | 30 | 40 | 50 | 40 | 30 | 10 | 5 | 20 |
| Sand % | 30 | 20 | 2 | 25 | 5 | 5 | 10 | 5 | 0 | 50 | 15 | 30 | 30 |
| Silt % | 0 | 20 | 60 | 15 | 40 | 30 | 0 | 0 | 10 | 0 | 0 | 15 | 0 |
| Clay % | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Total %** | **100** | **100** | **100** | **100** | **100** | **100** | **100** | **100** | **100** | **100** | **100** | **100** | **100** |
| In-stream habitat | | | | | | | | | | | | | |
| Mineral % | 18 | 10 | 15 | 25 | 25 | 20 | 25 | 40 | 50 | 83 | 60 | 65 | 95 |
| Emergent veg % | 15 | 10 | 5 | 10 | 10 | 5 | 5 | 13 | 10 | 0 | 15 | 0 | 0 |
| Submergent veg % | 10 | 10 | 60 | 30 | 40 | 50 | 5 | 15 | 5 | 0 | 10 | 0 | 0 |
| Floating Veg % | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 0 | 0 | 0 | 0 |
| algal cover % | 40 | 50 | 10 | 10 | 10 | 5 | 25 | 2 | 5 | 5 | 10 | 5 | 0 |
| Detritus % | 5 | 5 | 5 | 10 | 10 | 10 | 10 | 5 | 10 | 5 | 5 | 30 | 5 |
| Trailing veg % | 2 | 5 | 0 | 5 | 0 | 5 | 10 | 10 | 5 | 2 | 0 | 0 | 0 |
| LWD % | 5 | 10 | 5 | 5 | 5 | 5 | 15 | 5 | 5 | 0 | 0 | 0 | 0 |
| Roots | 0 | 0 | 0 | 5 | 0 | 0 | 5 | 10 | 5 | 5 | 0 | 0 | 0 |
| **Total %** | **100** | **100** | **100** | **100** | **100** | **100** | **100** | **100** | **100** | **100** | **100** | **100** | **100** |

**Table A5-2.** Dry Season 2017 habitat characteristic data. WSA-USD = sites within the Study Area upstream of dewatering discharge, WSA-USD = sites within the Study Area downstream of dewatering discharge

| Parameter | WSA-USD | | | WSA-DSD | | | Reference | | |
|---|---|---|---|---|---|---|---|---|---|
| | MC1 | MC1-B | MC2 | MC7 | MC8 | MC9 | WM | WMU | WMC |
| Substrate composition | | | | | | | | | |
| Bedrock % | 50 | 35 | 65 | 0 | 0 | 0 | 5 | 30 | 40 |
| Boulders % | 0 | 25 | 0 | 0 | 10 | 0 | 50 | 5 | 10 |
| Cobbles % | 0 | 5 | 5 | 20 | 40 | 35 | 5 | 0 | 5 |
| Pebbles % | 0 | 5 | 5 | 40 | 30 | 40 | 5 | 5 | 5 |
| Gravel % | 10 | 10 | 5 | 40 | 15 | 20 | 15 | 30 | 20 |
| Sand % | 15 | 10 | 10 | 0 | 5 | 5 | 15 | 20 | 20 |
| Silt % | 25 | 10 | 10 | 0 | 0 | 0 | 5 | 10 | 0 |
| Clay % | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Total %** | **100** | **100** | **100** | **100** | **100** | **100** | **100** | **100** | **100** |
| In-stream habitat | | | | | | | | | |
| Mineral % | 15 | 50 | 25 | 50 | 50 | 60 | 65 | 88 | 90 |
| Emergent veg % | 0 | 5 | 15 | 5 | 10 | 5 | 10 | 0 | 0 |
| Submergent veg % | 50 | 20 | 10 | 20 | 10 | 0 | 5 | 0 | 0 |
| Floating Veg % | 15 | 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| algal cover % | 5 | 5 | 40 | 5 | 5 | 10 | 5 | 5 | 0 |
| Detritus % | 15 | 10 | 10 | 10 | 5 | 5 | 10 | 5 | 5 |
| Trailing veg % | 0 | 0 | 0 | 5 | 10 | 10 | 5 | 0 | 0 |
| LWD % | 0 | 0 | 0 | 5 | 10 | 10 | 0 | 2 | 5 |
| Roots | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Total %** | **100** | **100** | **100** | **100** | **100** | **100** | **100** | **100** | **100** |

## Appendix 6. Microinvertebrate taxa list.

Values are total abundance. WSA-USD = sites within the Study Area upstream of dewatering discharge, WSA-USD = sites within the Study Area downstream of dewatering discharge.

**Wet-17**

| Phylum/Class/Order | Family | Lowest taxon | WSA-USD | | | | | | WSA-DSD | | | Reference | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | MC1 | MC2 | MC3 | MC4 | MC5 | MC6 | MC7 | MC8 | MC9 | FU | WM | WMU | WMC |
| **PROTISTA** | | | | | | | | | | | | | | | |
| **Ciliophora** | | | | | | | | | | | | | | | |
| | | *Stentor* sp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| **Rhizopoda** | **Arcellidae** | *Arcella discoides* | 1 | 83 | 0 | 2 | 15 | 16 | 2 | 0 | 0 | 0 | 1 | 0 | 1 |
| | | *Arcella* sp. [sm] | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | **Centropyxidae** | *Centropyxis ecornis* | 0 | 0 | 7 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Centropyxis* sp. [med, dk br] | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 |
| | **Difflugiidae** | *Difflugia 'fallax'* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 421 | 0 |
| | | *Difflugia gramen* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 105 | 0 |
| | | *Difflugia* sp. a [sm, ovoid] | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| | | *Difflugia* sp. b [sm, pyrif] | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 53 | 0 |
| | **Euglyphidae** | *Euglypha* sp. a [robust] | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | **Lesquereusiidae** | *Lesquereusia spiralis* | 0 | 0 | 63 | 1 | 0 | 3 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| | | *Netzelia tuberculata* | 0 | 0 | 0 | 0 | 0 | 11 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **ROTIFERA** | | | | | | | | | | | | | | | |
| **Bdelloidea** | **Philodinidae** | *Rotaria* sp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| | | indet. bdelloid [med.] | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| **Monogononta** | **Atrochidae** | *Cupelopagis vorax* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| | **Brachionidae** | *Anuraeopsis fissa* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 474 | 0 |
| | | *Brachionus angularis* | 0 | 0 | 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 286 | 1158 | 500 |
| | | *Keratella procurva* | 0 | 0 | 14 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 10643 | 2263 | 21750 |
| | | *Keratella tropica* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 53 | 0 |
| | | *Platyias quadricornis* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| | **Euchlanidae** | *Euchlanis dilatata* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 1 | 0 | 0 |
| | **Flosculariidae** | *Sinantherina* sp. [colony] | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| | **Gastropodidae** | *Ascomorpha* cf. *saltans indica* | 500 | 0 | 28 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 53 | 750 |
| | **Lecanidae** | *Lecane bulla* | 0 | 0 | 21 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 250 |
| | | *Lecane* 'bulloid' n. sp. | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 1 |
| | | *Lecane lunaris* | 0 | 0 | 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Lecane papuana* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 71 | 0 | 0 |
| | | *Lecane rhenana* | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | **Lepadellidae** | *Colurella uncinata bicuspidata* | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 71 | 0 | 0 |
| | **Mytilinidae** | *Mytilina ventralis* | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |

**Wet-17**

| Phylum/Class/Order | Family | Lowest taxon | WSA-USD | | | | | | WSA-DSD | | | Reference | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | MC1 | MC2 | MC3 | MC4 | MC5 | MC6 | MC7 | MC8 | MC9 | FU | WM | WMU | WMC |
| | **Notommatidae** | *Cephalodella* cf. *catellina* | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Cephalodella forficula* | 0 | 0 | 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Monommata* sp. | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| | **Scaridiidae** | *Scaridium* sp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| | **Synchaetidae** | *Polyarthra* sp. | 0 | 333 | 176 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 429 | 842 | 6750 |
| | | *Synchaeta* sp. | 0 | 83 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | **Testudinellidae** | *Testudinella amphora* | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Testudinella patina* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| | **Trichocercidae** | *Trichocerca pusilla* | 0 | 0 | 28 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Trichocerca similis* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 750 |
| | | *Trichocerca* sp. A | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 500 |
| | **Trichotriidae** | *Macrochaetus* sp. | 0 | 0 | 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **ARTHROPODA** | | | | | | | | | | | | | | | |
| **CRUSTACEA** | | | | | | | | | | | | | | | |
| **MAXILLIPODA** | | | | | | | | | | | | | | | |
| **Cyclopoida** | **Cyclopidae** | cyclopoid copepodites | 3500 | 833 | 127 | 33 | 74 | 23 | 0 | 0 | 3 | 0 | 786 | 1474 | 3500 |
| | | cyclopoid nauplii | 47000 | 15667 | 859 | 12 | 1 | 18 | 0 | 0 | 0 | 0 | 2071 | 3842 | 16250 |
| | | *Australoeucyclops karaytugi* | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Mesocyclops notius* | 1 | 0 | 1 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Mesocyclops* sp. | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| | | *Microcyclops varicans* | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 |
| | | *Thermocyclops decipiens* | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Tropocyclops* cf. *prasinus* | 0 | 1 | 42 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 |
| **DIPLOSTRACA** | | | | | | | | | | | | | | | |
| **CLADOCERA** | **Chydoridae** | *Alona rigidicaudis* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| | | *Alonella clathratula* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| | | *Anthalona harti occidentalis* | 0 | 0 | 7 | 0 | 0 | 3 | 0 | 0 | 0 | 2 | 0 | 0 | 0 |
| | | *Armatalona macrocopa* | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 |
| | | *Chydorus* cf. *sphaericus* | 1 | 1 | 0 | 13 | 0 | 6 | 0 | 0 | 0 | 1 | 1 | 1 | 0 |
| | | *Coronatella* sp. | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Ephemeroporus barroisi* | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Karualona karua* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| | | indet. juvenile chydorid | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| | **Daphnidae** | *Ceriodaphnia cornuta* | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| | | *Simocephalus* sp. | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

**Wet-17**

| Phylum/Class/Order | Family | Lowest taxon | WSA-USD | | | | | | WSA-DSD | | | Reference | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | MC1 | MC2 | MC3 | MC4 | MC5 | MC6 | MC7 | MC8 | MC9 | FU | WM | WMU | WMC |
| | **Macrotrichidae** | *Macrothrix* cf. *spinosa* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| | | *Macrothrix* sp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| | **Sididae** | *Diaphanosoma* sp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| | | *Latonopsis australis* | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **PODOCOPIDA** | | | | | | | | | | | | | | | |
| **OSTRACODA** | | juv. ostracods, indet. | 0 | 0 | 0 | 2 | 0 | 26 | 0 | 0 | 0 | 2 | 0 | 0 | 0 |
| | **Candonidae** | *Candonopsis tenuis* | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | **Cyprididae** | *Cypretta* sp. | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 |
| | | cf. *Sarscypridopsis* sp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 1 | 0 | 0 |
| | | *Stenocypris* sp. | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | **Darwinulidae** | *Vestalenula marmonieri* | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| | **Limnocytheridae** | *Limnocythere* sp. | 0 | 0 | 0 | 4 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | **Taxa richness** | **11** | **7** | **17** | **11** | **4** | **24** | **4** | **1** | **2** | **7** | **34** | **18** | **11** |

***Continued below.***

**Dry-17**

| Phylum/Class/Order | Family | Lowest taxon | WSA-USD | | | WSA-DSD | | | Reference | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | MC1 | MC1B | MC2 | MC7 | MC8 | MC9 | WM | WMU | WMC |
| **PROTISTA** | | | | | | | | | | | |
| **Ciliophora** | | | | | | | | | | | |
| | | *Stentor* sp. | 0 | 3333 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Rhizopoda** | **Arcellidae** | *Arcella discoides* | 0 | 1 | 53 | 0 | 0 | 0 | 0 | 1 | 1 |
| | | *Arcella* sp. [sm] | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | **Centropyxidae** | *Centropyxis ecornis* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Centropyxis* sp. [med, dk br] | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | **Difflugiidae** | *Difflugia 'fallax'* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Difflugia gramen* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Difflugia* sp. a [sm, ovoid] | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Difflugia* sp. b [sm, pyrif] | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | **Euglyphidae** | *Euglypha* sp. a [robust] | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | **Lesquereusiidae** | *Lesquereusia spiralis* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Netzelia tuberculata* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **ROTIFERA** | | | | | | | | | | | |
| **Bdelloidea** | **Philodinidae** | *Rotaria* sp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | indet. bdelloid [sm.] | 0 | 0 | 0 | 0 | 0 | 0 | 100 | 0 | 0 |
| | | indet. bdelloid [med.] | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | indet. bdelloid [lg.] | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 500 |
| **Monogononta** | **Atrochidae** | *Cupelopagis vorax* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | **Brachionidae** | *Anuraeopsis fissa* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 30000 | 0 |
| | | *Brachionus angularis* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 440000 | 0 |
| | | *Keratella procurva* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 510000 | 1 |
| | | *Keratella tropica* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 10000 | 23500 |
| | | *Platyias quadricornis* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | **Euchlanidae** | *Euchlanis dilatata* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | **Flosculariidae** | *Sinantherina* sp. [colony] | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | **Gastropodidae** | *Ascomorpha* cf. *saltans indica* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | **Lecanidae** | *Lecane bulla* | 48 | 1 | 632 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Lecane* 'bulloid' n. sp. | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Lecane closterocerca* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 10000 | 0 |
| | | *Lecane lunaris* | 0 | 0 | 53 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Lecane papuana* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Lecane rhenana* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Lecane signifera* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| | | *Lecane* (M.) b | 0 | 0 | 211 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Lecane* (M.) c [tiny] | 0 | 0 | 158 | 0 | 0 | 0 | 0 | 0 | 0 |

**Dry-17**

| Phylum/Class/Order | Family | Lowest taxon | WSA-USD |  |  | WSA-DSD |  |  | Reference |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  | MC1 | MC1B | MC2 | MC7 | MC8 | MC9 | WM | WMU | WMC |
|  | **Lepadellidae** | *Colurella uncinata bicuspidata* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
|  |  | *Lepadella* sp. a [cf. patella] | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 10000 | 0 |
|  |  | *Lepadella* sp. b [cf. *rhomboides*] | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
|  | **Mytilinidae** | *Mytilina ventralis* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
|  | **Notommatidae** | *Cephalodella* cf. *catellina* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
|  |  | *Cephalodella forficula* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
|  |  | *Monommata* sp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
|  | **Scaridiidae** | *Scaridium* sp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
|  | **Synchaetidae** | *Polyarthra* sp. | 48 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
|  |  | *Synchaeta* sp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
|  | **Testudinellidae** | *Testudinella amphora* | 0 | 0 | 105 | 0 | 0 | 0 | 0 | 0 | 0 |
|  |  | *Testudinella patina* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
|  | **Trichocercidae** | *Trichocerca pusilla* | 0 | 0 | 2947 | 0 | 0 | 0 | 0 | 0 | 0 |
|  |  | *Trichocerca similis* | 24 | 0 | 0 | 0 | 0 | 0 | 0 | 730000 | 42000 |
|  |  | *Trichocerca* sp. A | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
|  | **Trichotriidae** | *Macrochaetus* sp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **ARTHROPODA** |  |  |  |  |  |  |  |  |  |  |  |
| **CRUSTACEA** |  |  |  |  |  |  |  |  |  |  |  |
| **MAXILLIPODA** |  |  |  |  |  |  |  |  |  |  |  |
| **Cyclopoida** | **Cyclopidae** | cyclopoid copepodites | 1167 | 50000 | 211 | 0 | 0 | 0 | 600 | 10000 | 3500 |
|  |  | cyclopoid nauplii | 3857 | 623333 | 6211 | 0 | 0 | 0 | 19600 | 290000 | 32000 |
|  |  | *Australoeucyclops karaytugi* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
|  |  | *Mesocyclops notius* | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
|  |  | *Mesocyclops* sp. | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
|  |  | *Microcyclops varicans* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
|  |  | *Thermocyclops decipiens* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
|  |  | *Tropocyclops* cf. *prasinus* | 0 | 3333 | 0 | 0 | 0 | 0 | 1 | 1 | 500 |
| **DIPLOSTRACA** |  |  |  |  |  |  |  |  |  |  |  |
| **CLADOCERA** | **Chydoridae** | *Alona rigidicaudis* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
|  |  | *Alonella clathratula* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
|  |  | *Anthalona harti occidentalis* | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
|  |  | *Armatalona macrocopa* | 0 | 0 | 105 | 0 | 0 | 0 | 0 | 0 | 0 |
|  |  | *Chydorus* cf. *sphaericus* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
|  |  | *Coronatella* sp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
|  |  | *Dunhevedia crassa* | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |

**Dry-17**

| Phylum/Class/Order | Family | Lowest taxon | WSA-USD | | | WSA-DSD | | | Reference | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | MC1 | MC1B | MC2 | MC7 | MC8 | MC9 | WM | WMU | WMC |
| | | *Ephemeroporus barroisi* | 0 | 0 | 105 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Karualona karua* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | indet. juvenile chydorid | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | **Daphnidae** | *Ceriodaphnia cornuta* | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Simocephalus* sp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | **Macrotrichidae** | *Macrothrix* cf. *spinosa* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Macrothrix* sp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | **Sididae** | *Diaphanosoma* sp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Latonopsis australis* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **PODOCOPIDA** | | | | | | | | | | | |
| **OSTRACODA** | | juv. ostracods, indet. | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| | **Candonidae** | *Candonopsis tenuis* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | **Cyprididae** | *Cypretta* sp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | cf. *Sarscypridopsis* sp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Stenocypris* sp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | **Darwinulidae** | *Vestalenula marmonieri* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | **Limnocytheridae** | *Limnocythere* sp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | **Taxa richness** | **6** | **9** | **13** | **0** | **0** | **1** | **4** | **13** | **9** |

## Appendix 7. Invertebrate taxa recorded from the hyporheic zone.

Values are $log_{10}$ abundance categories, where 1 = 1 individual, 2 = 2-10 individuals, 3 = 11-100, 4 = 101-1000, and so on. WSA-USD = sites within the Study Area upstream of dewatering discharge, WSA-USD = sites within the Study Area downstream of dewatering discharge

**Wet-17**

| Phylum/Class/Order | Family | Lowest taxon | WSA-USD | | | | | | WSA-DSD | | | Reference | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | MC1 | MC2 | MC3 | MC4 | MC5 | MC6 | MC7 | MC8 | MC9 | WM | WMC | WMU | FU |
| **CNIDARIA** | | | | | | | | | | | | | | | |
| **HYDROZOA** | | | | | | | | | | | | | | | |
| **Anthoathecata** | **Hydridae** | *Hydra* spp. | 2 | 0 | 2 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **TURBELLARIA** | | Turbellaria spp. | 0 | 1 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| **NEMATODA** | | Nematoda spp. | 1 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| **MOLLUSCA** | | | | | | | | | | | | | | | |
| **GASTROPODA** | | | | | | | | | | | | | | | |
| **Hygrophila** | **Lymnaeidae** | *Bullastra vinosa* | 0 | 0 | 0 | 2 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **ANNELIDA** | | | | | | | | | | | | | | | |
| **OLIGOCHAETA** | | Oligochaeta spp. (imm./dam.) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 0 | 3 | 0 | 0 |
| **Tubificida** | **Naididae** | Naididae spp. (imm./dam.) | 0 | 3 | 0 | 0 | 2 | 2 | 0 | 2 | 0 | 0 | 0 | 0 | 0 |
| | | Naidinae spp. (imm./dam.) | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Allonais pectinata* | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Pristina leidyi* | 2 | 0 | 0 | 3 | 3 | 2 | 2 | 1 | 0 | 0 | 0 | 0 | 0 |
| | | *Pristina longiseta* | 3 | 2 | 4 | 0 | 0 | 2 | 0 | 0 | 0 | 3 | 0 | 0 | 0 |
| | | *Pristina nr. sima* | 0 | 3 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 |
| | **Phreodrilidae** | Phreodrilidae spp. | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 2 | 2 | 0 | 2 | 0 | 0 |
| **ARTHROPODA** | | | | | | | | | | | | | | | |
| **CRUSTACEA** | | | | | | | | | | | | | | | |
| **DIPLOSTRACA** | | | | | | | | | | | | | | | |
| **CLADOCERA** | **Chydoridae** | *Alona rigidicaudis* | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **MAXILLIPODA** | | | | | | | | | | | | | | | |
| **Cyclopoida** | | indet. cyclopoid | 0 | 0 | 0 | 0 | 0 | 1 | | 0 | 0 | 0 | 0 | 0 | 0 |
| | | cyclopoid copepodites | 2 | 0 | 3 | 1 | 2 | 2 | 2 | 0 | 0 | 0 | 3 | 0 | 2 |
| | **Cyclopidae** | *Microcyclops varicans* | 2 | 2 | 2 | 2 | 2 | 1 | 0 | 0 | 0 | 2 | 1 | 0 | 1 |
| **Harpacticoida** | **Parastenocarididae** | *Parastenocaris jane** | 0 | 3 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **PODOCOPIDA** | | | | | | | | | | | | | | | |

**Wet-17**

| Phylum/Class/Order | Family | Lowest taxon | WSA-USD | | | | | | WSA-DSD | | | Reference | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | MC1 | MC2 | MC3 | MC4 | MC5 | MC6 | MC7 | MC8 | MC9 | WM | WMC | WMU | FU |
| **OSTRACODA** | **Candoninae** | *Candonopsis tenuis** | 3 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 3 | 0 | 0 |
| | | juv candonids | 0 | 0 | 2 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **MALACOSTRACA** | | | | | | | | | | | | | | | |
| **Amphipoda** | **Paramelitidae** | Paramelitidae spp. (imm./dam.)* | 1 | 0 | 0 | 0 | 0 | 2 | 3 | 0 | 2 | 0 | 0 | 0 | 0 |
| | | Paramelitidae sp. B* | 1 | 0 | 0 | 0 | 2 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Paramelitidae sp. D* | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 2 | 0 | 0 | 0 | 0 |
| | | *Chydaekata* sp.* | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Bathynellacea** | **Parabathynellidae** | *Atopobathynella* spp.* | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Isopoda** | **Tainisopidae** | *Pygolabis weeliwolli** | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| **CHELICERATA** | | | | | | | | | | | | | | | |
| **ARACHNIDA** | | Hydracarina spp. | 0 | 3 | 2 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 2 | 1 | 0 |
| | | Trombidioidea spp. | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Sarcoptiformes** | | Oribatida spp. | 0 | 3 | 0 | 1 | 2 | 1 | 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| | **Mesostigmata** | Mesostigmata spp. | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| **Trombidiformes** | **Mideopsidae** | Mideopsidae spp. | 0 | 1 | 0 | 0 | 2 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| | **Piersigiidae** | *Stygolimnochares* nr *australica** | 0 | 2 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 2 |
| **MYRIAPODA** | | Myriapoda spp. | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 2 | 0 | 0 | 0 | 0 |
| | **Pauropoda** | Pauropoda spp. | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **ENTOGNATHA** | **Entomobryomorpha** | Entomobryoidea spp. | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 |
| | **Poduromorpha** | Poduroidea sp. | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **INSECTA** | | | | | | | | | | | | | | | |
| **Odonata** | | | | | | | | | | | | | | | |
| Anisoptera | | Anisoptera spp. (imm./dam.) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| **Ephemeroptera** | **Baetidae** | Baetidae spp. (imm./dam.) | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | **Caenidae** | Caenidae spp. (imm./dam.) | 0 | 0 | 3 | 2 | 1 | 0 | 0 | 0 | 0 | 2 | 0 | 2 | 0 |
| | | *Tasmanocoenis sp. P/arcuata* | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Coleoptera** | | Coleoptera sp. (L) (imm./dam.) | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | **Carabidae** | Carabidae sp. | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | **Dytiscidae** | Bidessini sp. | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Bidessini sp. (L) | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | **Elmidae** | *Austrolimnius* sp. (L) | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| | **Gyrinidae** | *Macrogyrus paradoxus* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| | **Hydraenidae** | Hydraenidae sp. (L) | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

**Wet-17**

| Phylum/Class/Order | Family | Lowest taxon | WSA-USD |  |  |  |  |  | WSA-DSD |  |  | Reference |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  | MC1 | MC2 | MC3 | MC4 | MC5 | MC6 | MC7 | MC8 | MC9 | WM | WMC | WMU | FU |
|  | **Hydrochidae** | Hydrochidae sp. | 0 | 0 | 1 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
|  |  | *Hydrochus* sp. | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
|  | **Hydrophilidae** | *Agraphydrus coomani* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
|  |  | *Enochrus* spp. (L) | 0 | 0 | 0 | 3 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 3 |
|  |  | *Helochares* sp. (L) | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
|  |  | Hydrophilidae spp. (L) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 |
|  |  | *Paracymus* spp. (L) | 2 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
|  |  | *Paracymus spenceri* | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
|  | **Limnichidae** | Limnichidae sp. | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
|  | **Scirtidae** | Scirtidae spp. (L) | 3 | 3 | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 0 | 0 | 0 | 0 |
|  | **Staphylinidae** | Staphylinidae sp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| **Diptera** | **Ceratopogonidae** | Ceratopogonidae spp. (P) | 1 | 0 | 0 | 2 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
|  |  | Ceratopogoninae spp. | 3 | 2 | 3 | 3 | 3 | 3 | 3 | 2 | 3 | 3 | 3 | 3 | 3 |
|  |  | Dasyheleinae spp. | 1 | 2 | 2 | 2 | 2 | 0 | 2 | 0 | 2 | 0 | 0 | 0 | 0 |
|  |  | Forcipomyiinae spp. | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
|  | **Chironomidae** | Chironomidae sp. (P) | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 |
|  | Chironominae | Chironominae spp. | 2 | 2 | 3 | 3 | 3 | 3 | 2 | 0 | 2 | 3 | 3 | 3 | 2 |
|  | Orthocladiinae | *Rheocricotopus* sp. (WWO1) | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 |
|  |  | *Parametriocnemus* sp. (WWO2) | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
|  |  | *Nanocladius* sp. (WWO6) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
|  | Tanypodinae | *Paramerina* sp. (WWT1) | 0 | 0 | 0 | 2 | 2 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
|  |  | *Paramerina* sp. 2 | 0 | 0 | 2 | 3 | 0 | 0 | 2 | 0 | 1 | 1 | 3 | 0 | 3 |
|  |  | *Larsia albiceps* | 0 | 1 | 2 | 2 | 3 | 0 | 1 | 0 | 2 | 0 | 3 | 0 | 2 |
|  |  | *Procladius* sp. (WWT5) | 0 | 0 | 0 | 0 | 2 | 1 | 0 | 0 | 0 | 3 | 2 | 2 | 0 |
|  |  | ?*Pentanuera* sp. (WWT9) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 |
|  | **Cecidomyiidae** | Cecidomyiidae spp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 |
|  | **Dolichopodidae** | Dolichopodidae spp. | 2 | 2 | 0 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 0 |
|  | **Ephydridae** | Ephydridae spp. | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 2 | 0 | 0 | 0 | 0 |
|  | **Muscidae** | Muscidae sp. | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
|  | **Thaumaleidae** | Thaumaleidae spp. | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
|  | **Tipulidae** | Tipulidae spp. | 0 | 0 | 0 | 3 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Lepidoptera** |  | Lepidoptera spp. (imm./dam.) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 |
| **Trichoptera** | **Hydroptilidae** | Hydroptilidae spp. (imm./dam.) | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 |
|  |  | **Taxa richness** | **20** | **23** | **22** | **24** | **19** | **20** | **29** | **6** | **17** | **10** | **15** | **7** | **14** |

***Continued below.***

## Dry-17

| Phylum/Class/Order | Family | Lowest Taxon | WSA-USD | | | WSA-DSD | | | Reference | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | MC1 | MC1-B | MC2 | MC7 | MC8 | MC9 | WM | WMC | WMU |
| **NEMATODA** | | Nematoda spp. | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| **MOLLUSCA** | | | | | | | | | | | |
| **GASTROPODA** | | | | | | | | | | | |
| **Hygrophila** | **Lymnaeidae** | *Bullastra vinosa* | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **ANNELIDA** | | | | | | | | | | | |
| **OLIGOCHAETA** | | Oligochaeta spp. (imm./dam.) | 0 | 3 | 2 | 0 | 0 | 0 | 0 | 2 | 0 |
| **Tubificida** | **Naididae** | Naididae spp. (imm./dam.) | 3 | 0 | 2 | 0 | 0 | 0 | 2 | 0 | 0 |
| | | Naidinae spp. (imm./dam.) | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 |
| | | *Allonais pectinata* | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Pristina aequiseta* | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 |
| | | *Pristina leidyi* | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 |
| | | *Pristina longiseta* | 0 | 3 | 0 | 0 | 0 | 0 | 3 | 2 | 0 |
| | | *Pristina nr. sima* | 2 | 3 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| | **Phreodrilidae** | Phreodrilidae spp. | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 2 | 0 |
| **ARTHROPODA** | | | | | | | | | | | |
| **CRUSTACEA** | | | | | | | | | | | |
| **DIPLOSTRACA** | | | | | | | | | | | |
| **CLADOCERA** | **Chydoridae** | *Alona rigidicaudis* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 |
| **MAXILLIPODA** | | | | | | | | | | | |
| **Cyclopoida** | | cyclopoid copepodites | 0 | 2 | 1 | 0 | 0 | 0 | 2 | 2 | 0 |
| | **Cyclopidae** | *Australoeucyclops karaytugi* | 0 | 1 | 2 | 0 | 0 | 0 | 0 | 2 | 0 |
| | | *Microcyclops varicans* | 0 | 3 | 3 | 0 | 0 | 0 | 1 | 2 | 2 |
| **PODOCOPIDA** | | | | | | | | | | | |
| **OSTRACODA** | | indet. ostracod | 0 | 0 | 0 | 0 | 1 | 0 | 2 | 0 | 0 |
| | **Candoninae** | *Candonopsis tenuis** | 0 | 0 | 1 | 0 | 0 | 0 | 3 | 0 | 0 |
| **MALACOSTRACA** | | | | | | | | | | | |
| **Amphipoda** | **Paramelitidae** | Paramelitidae spp. (imm./dam.)* | 0 | 2 | 0 | 1 | 1 | 0 | 0 | 0 | 0 |
| | | Paramelitidae sp. B* | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Paramelitidae sp. D* | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| | | *Chydaekata* sp.* | 0 | 2 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |

**Dry-17**

| Phylum/Class/Order | Family | Lowest Taxon | WSA-USD | | | WSA-DSD | | | Reference | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | MC1 | MC1-B | MC2 | MC7 | MC8 | MC9 | WM | WMC | WMU |
| **CHELICERATA** | | | | | | | | | | | |
| **ARACHNIDA** | | | | | | | | | | | |
| **Sarcoptiformes** | | Oribatida spp. | 0 | 1 | 1 | 2 | 1 | 2 | 0 | 2 | 1 |
| **Trombidiformes** | | Hydracarina spp. | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 2 | 0 |
| | | Trombidioidea spp. | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 |
| | **Hydrodromidae** | *Hydrodroma* spp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 |
| | **Unionicolidae** | Unionicolidae sp. | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **MYRIAPODA** | | Myriapoda sp. | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| **ENTOGNATHA** | **Entomobryomorpha** | Entomobryoidea sp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| **INSECTA** | | | | | | | | | | | |
| **Odonata** | | | | | | | | | | | |
| Anisoptera | | Anisoptera spp. (imm./dam.) | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| **Ephemeroptera** | **Baetidae** | Baetidae sp. (imm./dam.) | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| | **Caenidae** | *Tasmanocoenis* sp. M | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| **Hemiptera** | **Hebridae** | Hebridae spp. (imm./dam.) | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Coleoptera** | **Carabidae** | Carabidae spp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 |
| | **Dytiscidae** | Bidessini spp. (L) | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Hydroglyphus grammopterus* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 |
| | **Elmidae** | *Austrolimnius* spp. (L) | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 |
| | **Hydraenidae** | *Hydraena* spp. | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 2 | 0 |
| | | Hydraenidae sp. (L) (imm./dam.) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| | | *Limnebius* sp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| | | *Ochthebius* spp. | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| | **Hydrochidae** | *Hydrochus* spp. | 0 | 2 | 2 | 0 | 0 | 0 | 0 | 1 | 0 |
| | **Hydrophilidae** | *Coelostoma fabricii* | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Helochares* spp. (L) | 0 | 0 | 2 | 0 | 1 | 0 | 0 | 0 | 0 |
| | | *Paracymus* spp. (L) | 1 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| | **Limnichidae** | Limnichidae spp. | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 1 | 0 |
| | **Noteridae** | *Neohydrocoptus subfasciatus* | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| | **Scirtidae** | Scirtidae spp. (L) | 0 | 2 | 0 | 0 | 0 | 1 | 1 | 0 | 0 |
| | **Staphylinidae** | Staphylinidae spp. | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 2 | 0 |

**Dry-17**

| Phylum/Class/Order | Family | Lowest Taxon | WSA-USD | | | WSA-DSD | | | Reference | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | **MC1** | **MC1-B** | **MC2** | **MC7** | **MC8** | **MC9** | **WM** | **WMC** | **WMU** |
| **Diptera** | **Ceratopogonidae** | Ceratopogonidae spp. (P) | 0 | 2 | 3 | 0 | 0 | 0 | 3 | 3 | 3 |
| | | Ceratopogoninae spp. | 2 | 3 | 4 | 3 | 2 | 2 | 4 | 3 | 3 |
| | | Dasyheleinae spp. | 2 | 1 | 2 | 2 | 0 | 0 | 0 | 1 | 0 |
| | **Chironomidae** | Chironomidae spp. (P) | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 1 |
| | Chironominae | Chironominae spp. | 2 | 2 | 3 | 3 | 1 | 2 | 2 | 2 | 1 |
| | Tanypodinae | *Larsia albiceps* | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Paramerina* sp. 2 | 0 | 0 | 0 | 2 | 0 | 2 | 0 | 3 | 0 |
| | | *Procladius* sp. (WWT5) | 0 | 0 | 3 | 0 | 0 | 0 | 1 | 2 | 0 |
| | | *Thienemannimyia* sp. (WWT2) | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| | **Dolichopodidae** | Dolichopodidae spp. | 1 | 2 | 2 | 2 | 2 | 0 | 2 | 1 | 2 |
| | **Empididae** | Empididae spp. | 0 | 1 | 0 | 0 | 2 | 0 | 0 | 0 | 0 |
| | **Syrphidae** | Syrphidae spp. | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 |
| | **Tabanidae** | Tabanidae sp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| | **Tipulidae** | Tipulidae spp. | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 2 |
| | | **Taxa richness** | **11** | **19** | **25** | **15** | **11** | **10** | **15** | **30** | **9** |

## Appendix 8. Macroinvertebrate taxa list.

**Table A8-1.** Macroinvertebrate taxa list from wet season 2017. Values are $\log_{10}$ abundance categories, where 1 = 1 individual, 2 = 2-10 individuals, 3 = 11-100, 4 = 101-1000, and so on. WSA = sites within the Study Area and R = reference site.

| | | | WSA-USD | | | | | | WSA-DSD | | | Reference | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Phylum/Class/Order | Family | Lowest taxon | MC1 | MC2 | MC3 | MC4 | MC5 | MC6 | MC7 | MC8 | MC9 | FU | WM | WMC | WMU |
| **CNIDARIA** | | | | | | | | | | | | | | | |
| **HYDROZOA** | | | | | | | | | | | | | | | |
| **Anthoathecata** | **Hydridae** | *Hydra* spp. | 0 | 0 | 0 | 0 | 2 | 2 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| **NEMATODA** | | Nematoda sp. | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **ANNELIDA** | | | | | | | | | | | | | | | |
| **OLIGOCHAETA** | | | | | | | | | | | | | | | |
| **Tubificida** | **Enchytraeidae** | Enchytraeidae spp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 2 | 0 | 0 | 0 |
| | **Naididae** | *Allonais paraguayensis* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 |
| | | *Allonais pectinata* | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Allonais ranauana* | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 1 | 3 | 0 | 0 | 0 | 0 |
| | | *Pristina aequiseta* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| | | *Pristina leidyi* | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 1 | 0 |
| | | *Pristina longiseta* | 0 | 0 | 2 | 0 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | **Phreodrilidae** | Phreodrilidae spp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 |
| | | Oligochaeta spp. (imm./dam.) | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 3 | 2 | 2 | 0 | 0 | 0 |
| **MOLLUSCA** | | | | | | | | | | | | | | | |
| **GASTROPODA** | | | | | | | | | | | | | | | |
| **Hygrophila** | **Lymnaeidae** | *Bullastra vinosa* | 3 | 3 | 4 | 3 | 4 | 3 | 0 | 0 | 2 | 0 | 1 | 0 | 0 |
| | | Lymnaeidae spp. (imm./dam.) | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | **Planorbidae** | *Gyraulus* sp. | 3 | 4 | 3 | 3 | 3 | 3 | 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| **ARTHROPODA** | | | | | | | | | | | | | | | |
| **CHELICERATA** | | | | | | | | | | | | | | | |
| **ARACHNIDA** | **Mesostigmata** | Mesostigmata sp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| **Sarcoptiformes** | | Oribatida spp. | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 2 | 0 | 0 | 0 | 0 | 0 |
| **Trombidiformes** | | Hydracarina sp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 |
| | **Arrenuridae** | Arrenuridae sp. | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | **Aturidae** | Aturidae spp. | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| | **Hydrachnidae** | Hydrachnidae spp. | 0 | 2 | 0 | 0 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | **Hydrodromidae** | Hydrodromidae spp. | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 3 | 1 |
| | **Hydryphantidae** | Hydryphantidae spp. | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 2 | 2 | 0 | 1 |
| | **Hygrobatidae** | Hygrobatidae spp. | 2 | 2 | 2 | 0 | 0 | 2 | 0 | 0 | 1 | 2 | 0 | 1 | 1 |

| | | | WSA-USD | | | | | | WSA-DSD | | | Reference | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Phylum/Class/Order** | **Family** | **Lowest taxon** | **MC1** | **MC2** | **MC3** | **MC4** | **MC5** | **MC6** | **MC7** | **MC8** | **MC9** | **FU** | **WM** | **WMC** | **WMU** |
| | **Limnesiidae** | Limnesiidae spp. | 2 | 1 | 2 | 1 | 2 | 0 | 1 | 0 | 0 | 0 | 2 | 0 | 0 |
| | **Limnocharidae** | Limnocharidae spp. | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | **Pionidae** | Pionidae sp. | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | **Unionicolidae** | Unionicolidae spp. | 2 | 0 | 2 | 1 | 2 | 2 | 0 | 0 | 0 | 2 | 0 | 2 | 0 |
| **MYRIAPODA** | | Myriapoda spp. | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| **CRUSTACEA** | | | | | | | | | | | | | | | |
| **MALACOSTRACA** | | | | | | | | | | | | | | | |
| **Amphipoda** | **Paramelitidae** | Paramelitidae sp. D | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 |
| **HEXAPODA** | | | | | | | | | | | | | | | |
| **INSECTA** | | | | | | | | | | | | | | | |
| **Odonata** | | | | | | | | | | | | | | | |
| Anisoptera | | Anisoptera spp. (imm./dam.) | 0 | 3 | 2 | 3 | 2 | 2 | 2 | 2 | 1 | 2 | 2 | 1 | 2 |
| | **Aeshnidae** | *Hemianax papuensis* | 0 | 1 | 1 | 2 | 0 | 2 | 0 | 0 | 0 | 2 | 0 | 0 | 0 |
| | **Gomphidae** | *Austrogomphus gordoni* | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 2 | 2 | 1 | 0 | 2 | 0 |
| | **Libellulidae** | *Diplacodes bipunctata* | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Diplacodes haematodes* | 1 | 1 | 2 | 1 | 3 | 2 | 0 | 0 | 0 | 3 | 1 | 0 | 0 |
| | | *Nannophlebia injibandi* | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 3 | 2 | 0 | 0 | 0 | 0 |
| | | *Orthetrum caledonicum* | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Orthetrum migratum* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 |
| | **Lindeniidae** | *Ictinogomphus dobsoni* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 |
| Zygoptera | | Zygoptera spp. (imm./dam.) | 0 | 2 | 2 | 2 | 2 | 2 | 3 | 2 | 2 | 2 | 2 | 0 | 0 |
| | **Coenagrionidae** | *Agriocnemis* sp. | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Argiocnemis rubescens* | 0 | 2 | 0 | 1 | 0 | 2 | 3 | 0 | 2 | 0 | 0 | 0 | 0 |
| | | *Ischnura aurora* | 1 | 2 | 0 | 2 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Pseudagrion aureofrons* | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | **Isostictidae** | *Eurysticta coolawanyah* | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 0 | 0 | 0 | 0 | 0 |
| **Ephemeroptera** | **Baetidae** | Baetidae spp. (imm./dam.) | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 0 | 0 | 2 | 2 | 2 | 2 |
| | | *Cloeon fluviatile* | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Cloeon* sp. Red Stripe | 1 | 2 | 1 | 3 | 2 | 2 | 0 | 0 | 1 | 4 | 2 | 0 | 0 |
| | | *Offadens* sp. G1WA2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 |
| | | *Pseudocloeon hypodelum* | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 0 | 2 | 0 | 0 | 0 |
| | **Caenidae** | Caenidae spp. (imm./dam.) | 3 | 2 | 3 | 3 | 3 | 3 | 2 | 2 | 2 | 0 | 2 | 3 | 3 |
| | | *Tasmanocoenis sp. M* | 0 | 2 | 0 | 2 | 2 | 2 | 0 | 0 | 0 | 4 | 2 | 2 | 3 |
| | | *Tasmanocoenis sp. P/arcuata* | 3 | 2 | 3 | 3 | 3 | 3 | 2 | 2 | 2 | 3 | 2 | 0 | 3 |

| | | | WSA-USD | | | | | | WSA-DSD | | | Reference | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Phylum/Class/Order** | **Family** | **Lowest taxon** | **MC1** | **MC2** | **MC3** | **MC4** | **MC5** | **MC6** | **MC7** | **MC8** | **MC9** | **FU** | **WM** | **WMC** | **WMU** |
| **Hemiptera** | **Belostomatidae** | Belostomatidae spp. (imm./dam.) | 0 | 2 | 0 | 1 | 1 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Diplonychus spp. (imm./dam.) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 |
| | **Corixoidea** | Corixoidea spp. (imm./dam.) | 0 | 1 | 2 | 2 | 3 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 |
| | **Gerridae** | Gerridae spp. (imm./dam.) | 2 | 2 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 2 | 2 | 0 | 0 |
| | | *Limnogonus fossarum gilguy* | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 1 |
| | | *Rhagadotarsus anomalus* | 2 | 3 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | **Hebridae** | Hebridae spp. (imm./dam.) | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| | | *Hebrus nourlangiei* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| | **Mesoveliidae** | Mesovelia spp. (imm./dam.) | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| | | Mesoveliidae spp. (imm./dam.) | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| | | *Mesovelia hackeri* | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | **Micronectidae** | *Austronecta bartzarum* | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Austronecta micra* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| | | *Micronecta adelaidae* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| | | *Micronecta annae* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| | | *Micronecta paragoga* | 0 | 0 | 2 | 2 | 3 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Micronecta spp. (imm./dam.) | 0 | 2 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| | | *Micronecta virgata* | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | **Nepidae** | *Ranatra diminuta* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| | **Notonectidae** | *Anisops hackeri* | 3 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 2 |
| | | *Anisops nasutus* | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| | | Anisops spp. (imm./dam.) | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 |
| | | Notonectidae spp. (imm./dam.) | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | **Pleidae** | Paraplea spp. (imm./dam.) | 2 | 2 | 1 | 2 | 2 | 2 | 0 | 0 | 0 | 2 | 1 | 0 | 2 |
| | **Veliidae** | *Microvelia peramoena* | 0 | 0 | 0 | 2 | 0 | 2 | 0 | 0 | 0 | 2 | 2 | 1 | 0 |
| | | Microvelia spp. (imm./dam.) | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 2 | 0 | 1 |
| | | Veliidae spp. (imm./dam.) | 2 | 1 | 0 | 1 | 1 | 2 | 0 | 0 | 0 | 2 | 2 | 1 | 0 |
| **Coleoptera** | **Carabidae** | Carabidae spp. (imm./dam.) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 |
| | **Dytiscidae** | *Allodessus bistrigatus* | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 |
| | | Bidessini spp. (L) | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| | | *Copelatus irregularis* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| | | *Cybister* spp. (L) | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Cybister tripunctatus* | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Eretes australis* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 |
| | | *Hydaticus consanguineus* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 |
| | | *Hydroglyphus grammopterus* | 2 | 2 | 1 | 2 | 0 | 1 | 0 | 0 | 0 | 2 | 2 | 0 | 2 |
| | | *Hydroglyphus leai* | 1 | 3 | 0 | 2 | 3 | 1 | 0 | 0 | 0 | 2 | 0 | 0 | 0 |

| | | | WSA-USD | | | | | | WSA-DSD | | | Reference | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Phylum/Class/Order** | **Family** | **Lowest taxon** | **MC1** | **MC2** | **MC3** | **MC4** | **MC5** | **MC6** | **MC7** | **MC8** | **MC9** | **FU** | **WM** | **WMC** | **WMU** |
| | | *Hydroglyphus orthogrammus* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 |
| | | *Hydrovatus* spp. (L) | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Hydrovatus weiri* | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Hyphydrus elegans* | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 |
| | | *Hyphydrus lyratus* | 2 | 0 | 2 | 1 | 3 | 0 | 0 | 0 | 0 | 3 | 2 | 0 | 1 |
| | | *Hyphydrus* spp. (L) | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Laccophilus clarki* | 0 | 2 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Laccophilus sharpi* | 0 | 2 | 0 | 2 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| | | *Limbodessus compactus* | 0 | 2 | 2 | 2 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| | | *Necterosoma regulare* | 0 | 1 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 |
| | | *Necterosoma* spp. (L) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| | | *Neobidessodes denticulatus* | 2 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| | | *Onychohydrus* spp. (L) | 0 | 1 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Platynectes* spp. (L) | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| | | *Sternopriscus pilbarensis* | 0 | 1 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Sternopriscus* spp. (L) | 0 | 0 | 2 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | **Elmidae** | *Austrolimnius* spp. (L) | 2 | 0 | 0 | 0 | 0 | 0 | 3 | 3 | 0 | 0 | 0 | 0 | 0 |
| | **Gyrinidae** | *Dineutus australis* | 2 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 3 |
| | | *Macrogyrus paradoxus* | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 3 | 0 | 0 | 0 | 0 |
| | | *Macrogyrus* spp. (L) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 |
| | **Haliplidae** | *Haliplus* sp. | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | **Heteroceridae** | *Heterocerus* sp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| | **Hydraenidae** | *Hydraena* spp. | 0 | 2 | 0 | 3 | 0 | 1 | 1 | 0 | 0 | 3 | 2 | 3 | 0 |
| | | *Hydraenidae* spp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 3 |
| | **Hydrochidae** | *Hydrochus* spp. | 2 | 0 | 1 | 1 | 0 | 2 | 0 | 0 | 0 | 2 | 2 | 1 | 0 |
| | **Hydrophilidae** | *Agraphydrus coomani* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| | | *Anacaena horni* | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| | | *Berosus dallasae* | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Berosus pulchellus* | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 2 |
| | | *Berosus* spp. (L) | 0 | 0 | 2 | 0 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| | | *Coelostoma fabricii* | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Enochrus deserticola* | 2 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 2 | 0 | 2 |
| | | *Helochares* spp. (L) | 2 | 0 | 0 | 2 | 1 | 2 | 0 | 1 | 0 | 2 | 0 | 1 | 2 |
| | | *Helochares tatei* | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| | | *Laccobius billi* | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Paracymus pygmaeus* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| | | *Paracymus* spp. (L) | 0 | 0 | 0 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Paracymus spenceri* | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| | | *Regimbartia attenuata* | 0 | 0 | 0 | 1 | 0 | 2 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |

| | | | WSA-USD | | | | | | WSA-DSD | | | Reference | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Phylum/Class/Order** | **Family** | **Lowest taxon** | **MC1** | **MC2** | **MC3** | **MC4** | **MC5** | **MC6** | **MC7** | **MC8** | **MC9** | **FU** | **WM** | **WMC** | **WMU** |
| | | *Sternolophus australis* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| | | *Sternolophus marginicollis* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| | | *Sternolophus* spp. (L) | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | **Limnichidae** | Limnichidae sp. | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | **Noteridae** | *Neohydrocoptus subfasciatus* | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Diptera** | **Ceratopogonidae** | Ceratopogonidae spp. (P) | 1 | 2 | 0 | 2 | 1 | 1 | 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Ceratopogoninae spp. | 3 | 1 | 3 | 3 | 0 | 3 | 3 | 1 | 2 | 2 | 3 | 3 | 2 |
| | | Dasyheleinae spp. | 1 | 2 | 0 | 3 | 1 | 2 | 3 | 0 | 1 | 0 | 1 | 0 | 0 |
| | | Forcipomyiinae spp. | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 0 |
| | **Chironomidae** | *Ablabesmyia hilli* | 0 | 2 | 2 | 2 | 2 | 3 | 0 | 0 | 2 | 3 | 0 | 0 | 3 |
| | | Chironomidae spp. (P) | 2 | 2 | 2 | 2 | 0 | 1 | 2 | 0 | 0 | 2 | 2 | 2 | 2 |
| | | *Coelopymia pruinosa* | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 |
| | | *Corynoneura sp. (WWO5)* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 |
| | | *Cricotopus albitarsis* | 3 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Larsia albiceps* | 3 | 3 | 2 | 3 | 3 | 4 | 2 | 2 | 3 | 3 | 3 | 1 | 3 |
| | | *Nanocladius sp. (WWO6)* | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Nilotanypus sp. (WWT3)* | 0 | 0 | 0 | 2 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Parakiefferiella sp. (WWO9)* | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Paramerina sp. (WWT1)* | 2 | 2 | 0 | 2 | 2 | 2 | 2 | 0 | 2 | 3 | 3 | 1 | 3 |
| | | *Paramerina sp. 2* | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| | | *Procladius sp. (WWT5)* | 2 | 2 | 3 | 3 | 3 | 2 | 0 | 2 | 2 | 3 | 3 | 2 | 2 |
| | | *Rheocricotopus sp. (WWO1)* | 3 | 0 | 0 | 3 | 0 | 0 | 3 | 3 | 0 | 0 | 0 | 0 | 0 |
| | | *Tanytarsus sp. (WWTS1)* | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | *Thienemanniella sp. (WWO4)* | 2 | 0 | 0 | 2 | 0 | 0 | 0 | 2 | 2 | 0 | 0 | 0 | 0 |
| | | *Thienemannimyia sp. (WWT2)* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 3 | 0 | 0 | 0 | 0 |
| | | Chironominae spp. | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| | **Culicidae** | Aedes spp. | 0 | 2 | 0 | 0 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Anopheles spp. | 0 | 1 | 1 | 1 | 2 | 2 | 0 | 0 | 0 | 2 | 0 | 0 | 0 |
| | | Culex spp. | 0 | 2 | 0 | 3 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Culicidae spp. (P) | 0 | 2 | 1 | 2 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | **Dolichopodidae** | Dolichopodidae spp. | 2 | 0 | 0 | 2 | 0 | 0 | 2 | 2 | 0 | 0 | 0 | 2 | 0 |
| | **Ephydridae** | Ephydridae spp. | 0 | 2 | 1 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | **Sciomyzidae** | Sciomyzidae spp. | 0 | 0 | 0 | 0 | 2 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | **Simuliidae** | Simuliidae spp. | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 |
| | | Simuliidae spp. (P) | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | **Stratiomyidae** | Stratiomyidae spp. | 0 | 0 | 0 | 0 | 0 | 2 | 1 | 0 | 0 | 0 | 3 | 0 | 0 |
| | **Tabanidae** | Tabanidae spp. | 2 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 1 |
| | **Thaumaleidae** | Thaumaleidae sp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |

|  |  |  | WSA-USD |  |  |  |  |  | WSA-DSD |  |  | Reference |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Phylum/Class/Order** | **Family** | **Lowest taxon** | **MC1** | **MC2** | **MC3** | **MC4** | **MC5** | **MC6** | **MC7** | **MC8** | **MC9** | **FU** | **WM** | **WMC** | **WMU** |
|  | **Tipulidae** | Tipulidae spp. | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| **Lepidoptera** | **Crambidae** | Acentropinae spp. | 1 | 0 | 0 | 0 | 0 | 0 | 3 | 3 | 0 | 0 | 0 | 0 | 0 |
|  |  | *Eoophyla triplaga* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 |
|  |  | *Margarosticha* sp. 3 | 2 | 0 | 0 | 0 | 0 | 0 | 2 | 3 | 0 | 0 | 0 | 0 | 0 |
|  |  | *Margarosticha* sp. WRM01 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 |
|  |  | *Parapoynx* spp. | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
|  |  | *Tetrernia* sp. 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 1 | 0 | 0 | 0 | 0 |
| **Trichoptera** | **Ecnomidae** | *Ecnomus* spp. | 0 | 0 | 2 | 2 | 1 | 2 | 0 | 0 | 0 | 2 | 0 | 2 | 0 |
|  | **Hydropsychidae** | *Cheumatopsyche wellsae* | 2 | 0 | 0 | 0 | 0 | 0 | 4 | 4 | 4 | 0 | 0 | 0 | 0 |
|  | **Hydroptilidae** | *Hellyethira* spp. | 0 | 0 | 0 | 0 | 2 | 2 | 0 | 0 | 0 | 0 | 2 | 0 | 0 |
|  |  | *Orthotrichia* spp. | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 |
|  | **Leptoceridae** | Leptoceridae spp. (imm./dam.) | 0 | 0 | 1 | 0 | 0 | 2 | 3 | 0 | 2 | 2 | 0 | 0 | 0 |
|  |  | *Leptocerus atsou* | 0 | 0 | 2 | 0 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
|  |  | *Oecetis* spp. | 0 | 0 | 0 | 1 | 2 | 2 | 0 | 1 | 0 | 2 | 2 | 0 | 0 |
|  |  | *Triaenodes spp.* | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 2 | 2 | 0 | 0 | 0 |
|  |  | *Triplectides ciuskus seductus* | 1 | 1 | 0 | 0 | 0 | 0 | 4 | 3 | 4 | 0 | 0 | 0 | 2 |
|  | **Philopotamidae** | *Chimarra* spp. | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
|  |  | *Chimarra sp. AV17* | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
|  |  | Trichoptera sp. (imm./dam.) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |

# Appendix 9. Freshwater fish taxa list.

**Table A9-1.** Freshwater fish taxa list showing total counts for each species at each site in wet-17 and dry-17. Site codes: WSA = sites within the Study Area; R = reference site.

| | | **Wet 17** | | | | **Dry 17** | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Type** | **Site** | ***M. australis*** | ***L. unicolor*** | ***Neosilurus* sp.** | **Total** | ***M. australis*** | ***L. unicolor*** | ***Neosilurus* sp.** | **Total** |
| **WSA-USD** | **MC1** | 8 | 48 | 0 | **56** | 3 | 14 | 0 | **17** |
| | **MC1-B** | - | - | - | **0** | 216 | 80 | 1 | **297** |
| | **MC2** | 0 | 32 | 0 | **32** | 10 | 60 | 0 | **70** |
| | **MC3** | 191 | 53 | 0 | **244** | - | - | - | **0** |
| | **MC4** | 8 | 12 | 1 | **21** | - | - | - | **0** |
| | **MC5** | 33 | 13 | 1 | **47** | - | - | - | **0** |
| | **MC6** | 38 | 8 | 0 | **46** | - | - | - | **0** |
| **WSA-DSD** | **MC7** | 77 | 67 | 16 | **160** | 187 | 20 | 10 | **217** |
| | **MC8** | 153 | 81 | 6 | **240** | 78 | 28 | 7 | **113** |
| | **MC9** | 156 | 49 | 25 | **230** | 40 | 59 | 13 | **112** |
| **Reference** | **FU** | 14 | 23 | 0 | **37** | - | - | - | **0** |
| | **WM** | 3 | 108 | 0 | **111** | - | - | - | **0** |
| | **WMC** | 97 | 67 | 0 | **164** | 0 | 3 | 0 | **3** |
| | **WMU** | 56 | 154 | 0 | **210** | 91 | 86 | 0 | **177** |
| | **Total** | **834** | **715** | **49** | **1598** | **625** | **350** | **31** | **1006** |
| | | | | | | **Total number of fish caught** | | | **2604** |