

Greater Paraburdoo Iron Ore Hub:

Aquatic Fauna Survey

Interim Report: Dry Season 2019

Biologic Environmental Survey

Report to Rio Tinto Iron Ore

March 2020

Greater Paraburdoo Iron Ore Hub: Aquatic Fauna Survey

Interim Report: Dry Season Sampling 2019

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GLOSSARY

ALA	Atlas of Living Australia
BOM	Bureau of Meteorology
DBCA	Department Biodiversity, Conservation and Attractions
DO	Dissolved oxygen
DoEE	Department of Environment and Energy
DPaW	Department of Parks and Wildlife
DPIRD	Department of Primary Industry and Regional Development
DRF	Declared Rare Flora
EC	Electrical conductivity
EPA	Western Australian Environmental Protection Authority
EPBC Act	*Environment Protection and Biodiversity Conservation Act 1999*
FFG	Functional feeding group
GV	Guideline value
IUCN	International Union for the Conservation of Nature
PBS	Pilbara Biological Survey
PEC	Priority Ecological Communities
SRE	Short-range endemic
SSGV	Site-specific guideline value
WAM	Western Australian Museum

EXECUTIVE SUMMARY

Biologic Environmental Survey (Biologic) was commissioned by Rio Tinto Iron Ore Pty Ltd (Rio Tinto) to undertake aquatic ecosystem surveys within, and adjacent to the Greater Paraburdoo Iron Ore Hub. Rio Tinto, on behalf of the joint venture participants, is evaluating the development of several iron ore deposits within this area, including the development of a new iron ore mine at Western Range and the extension of existing operations at Paraburdoo and Eastern Range. As part of the development, dewatering and discharge is required to access ore below the water table. There may be potential impacts to aquatic systems as a result of these operations, although the Proposal indicates that discharge to the environment will be minimal.

In September 2019, aquatic ecosystem surveys were undertaken at 15 sites; five along Seven Mile Creek, three on Pirraburdu Creek, one within Western Range, three within Eastern Range, and three long-term reference sites on Turee Creek. A total of 20 sites were proposed for sampling, but at the time of survey, five were dry (SM1, PC4, PC5, WR1 and WR3). At these sites, sediments were collected to conduct rehydration/emergence trials in the Biologic laboratory. Ecosystem surveys at all other sites included habitat assessments and sampling of water quality, submerged macrophytes, emergent macrophytes, hyporheos, macroinvertebrates and fish.

Pools within the Greater Paraburdoo Iron Ore Hub and surrounds (long-term reference sites on Turee Creek) were under stress at the time of sampling and showed the effects of successive dry years. Low rainfall and lack of flushing has led to creeks and waterholes receding and undergoing evapoconcentration of ions and nutrients. Cattle were concentrated around these pools, leading to elevated nutrient concentrations, trampling within the littoral zone and emergent macrophytes being eaten. The high nutrient levels coupled with the high light intensity, resulted in abundant algal and macrophyte growth. Extremes in DO were also recorded across the Study Area, likely associated with the high algal and macrophyte growth. Eight sites recorded relatively high salinity which would be considered brackish, and in excess of the known point of ecological stress for freshwater aquatic fauna. Dissolved metal concentrations were generally low across all sites, with some exceptions (noted below).

Water quality concentrations outside default ANZECC/ARMCANZ (2000) GVs were recorded for several analytes from most sites. Exceedances of default GVs included:

- EC – at all sites except ER1 and WR2.
- DO - SM2, SM6, PC1, PC3 and TC3 recorded insufficient DO, below the lower default GV.
- DO – SM3 recorded super-saturated DO, in excess of the default GV.
- pH – ER1 recorded acidic pH, below the lower default GV.
- pH - SM3 recorded basic pH which was greater than the default GV.
- Turbidity – exceeded the default GV at SM4 and PC2.
- N_NH_3 - concentrations from TC3 exceeded the default 95% toxicity GV.

- N_NO_3 – most sites exceeded the default 95 % toxicity GV, including SM2, SM4, SM5, SM6, PC1, PC2, PC3, ER1, ER3, TC1 and TC2.
- N_NOx - exceeded the default eutrophication GV at all sites.
- TN – all sites except WR2 exceeded the default eutrophication GV.
- TP – concentrations were higher than the default eutrophication GV at all sites except WR2.
- dAl – was greater than the default 99% GV at ER1.
- dAs - exceeded the 99% GV at a number of sites including SM2, SM3, S5, PC1, PC2, PC3, ER3, TC2 and TC3.
- dB - was greater than the 99% GV at all sites except WR2 and ER1. The 95% GV was also exceeded at SM2, SM3, SM4, SM5, SM6 and TC2.
- dCr – concentrations were above the 99% GV at TC1.
- dZn - exceeded the 95% GV at SM4. However, once hardness was considered, this site did not exceed the HMGV.

Elevated nitrogen nutrients were likely the result of direct cattle access to waters at some sites, and discharge of groundwater with high nutrient concentrations downstream of the current discharge point.

Water quality of the gorge pool at Western Range (WR2) was notably different to all other sites. Concentrations of ions were much lower, likely reflecting the lack of evaporation and therefore lack of evapoconcentration. Correspondingly, EC was also low and fresh at this site. Nutrient and dissolved metal levels were generally low at WR2, and considerably lower than other sites.

In-stream habitats of most sites comprised a diversity of complex, heterogenous structures with which to support aquatic fauna. Exceptions to this were the Eastern Range gorge pools ER1 and ER2, and Seven-Mile Creek site SM3 (Kelly's Pool). These sites were dominated by open cover of inorganic sediments, with some debris.

A total of 11 macrophyte taxa was collected; five emergent taxa and six submerged macrophyte taxa. Other riparian vegetation collected included Eucalypts, *Melaleuca*, ghost gum, shrubs, *Acacia* species, *Grevillea*, herbs and grasses. No macrophytes were recorded from the gorge pools WR3 and ER1, or the dry site on Pirraburdu Creek PC5. This is perhaps unsurprising given the ephemeral nature of these sites. No submerged macrophytes were recorded from the hydrocarbon contaminated SM4.

None of the emergent or submerged macrophytes collected were of significance. However, a declared rare flora (DRF), *Aluta quadrata*, was found along the dry creekbed at WR3 in Western Range. *Aluta quadrata* is restricted to a banded iron formation that runs east and west of Paraburdoo, in the southern edge of the Hamersley Range. There are three known disjunct populations; Western Range, Pirraburdu Creek, and Howie's Hole.

Despite the obvious stress these pools and creeklines were under at the time of sampling, they still supported a diverse range of aquatic fauna, including 263 invertebrate taxa[1], one species of turtle, and five freshwater fish species. Sites of high ecological value included SM2, PC1 and PC2. These sites generally recorded a high macroinvertebrate diversity, high richness of hyporheos fauna (SM2 and PC2), and high Pilbara endemic taxa richness. PC1 also recorded high richness of sensitive EPT taxa. The greatest diversity and abundance of fish was recorded from PC1 and PC2, and SM2 supported the flat-shelled turtle *Chelodina steindachneri*.

The aquatic fauna assemblage of SM4 was displaying effects of hydrocarbon contamination at the time of sampling, with low diversity of macroinvertebrates, high abundance of tolerant and nuisance taxa such as Nematoda, lack of sensitive and Pilbara endemic taxa, and no fish. Some of the invertebrates recorded from SM4 may have been dead on collection.

Despite the seemingly high diversity recorded in the current study, the number of macroinvertebrate taxa recorded was generally low in comparison to the PBS. In comparing sites sampled on both occasions, an additional 38 taxa were recorded during the PBS at Fork Spring and 22 taxa from Paperbark Spring. These previous surveys were undertaken following a much wetter period, and as such, nutrients and ions were likely considerably less concentrated than they were in the dry season of 2019, and aquatic habitats generally less stressed.

Two species recorded during the current study are listed and therefore of conservation significance (*Eurysticta coolawanyah* and *Leiopotherapon aheneus*). The Pilbara pin damselfly *Eurysticta coolawanyah* (Vulnerable IUCN Redlist) was recorded from SM2. The Fortescue grunter, *Leiopotherapon aheneus* (DBCA Priority 4 species and IUCN Near Threatened) was recorded from SM2, PC1, PC2 and PC3.

In addition to the Pilbara pin and Fortescue grunter, several taxa were considered to be of scientific interest. These include;

- The clam shrimp *Limnadopsis pilbarensis* which emerged from WR3 is a relatively uncommon Pilbara endemic. It is known from a small number of temporary pools across the region.
- The water mite *Wandesia* sp. `BAC004`recorded from the hyporheic zone of PC2.
- The water mite *Tillia* sp.`BAC003` from a hyporheic sample collected from Pirraburdu Creek (PC3) likely represents the first record of this genus from the Pilbara and this specimen may be a species new to science.
- The water mite *Unionicola* nr *minutissima* was recorded from SM5 and ER3. This species displays a highly disjunct distribution and appears to be rarely collected.

[1] The total invertebrate richness includes taxa recorded in both hyporheic and macroinvertebrate samples, as well as emergences during rehydration trials (noting that some IDs are still pending for Phase 2 of the rehydrate trials).

- The backswimmer *Anisops nabillus* from SM5, ER1 and ER2 is a relatively uncommon Pilbara endemic, with a relatively broad, disjunct distribution across the region, but few records.
- the Pilbara tandan *Neosilurus* sp. - Pilbara endemic recorded from CG1 and CG3.

This study represents the first aquatic ecosystem survey undertaken in the Greater Paraburdoo Iron Ore Hub. Results from this survey provide a snapshot of the ecological values and health of aquatic systems in the area. An additional field survey is planned for the wet season 2020 which will provide an indication of natural seasonal variability and will likely yield additional species.

1. INTRODUCTION

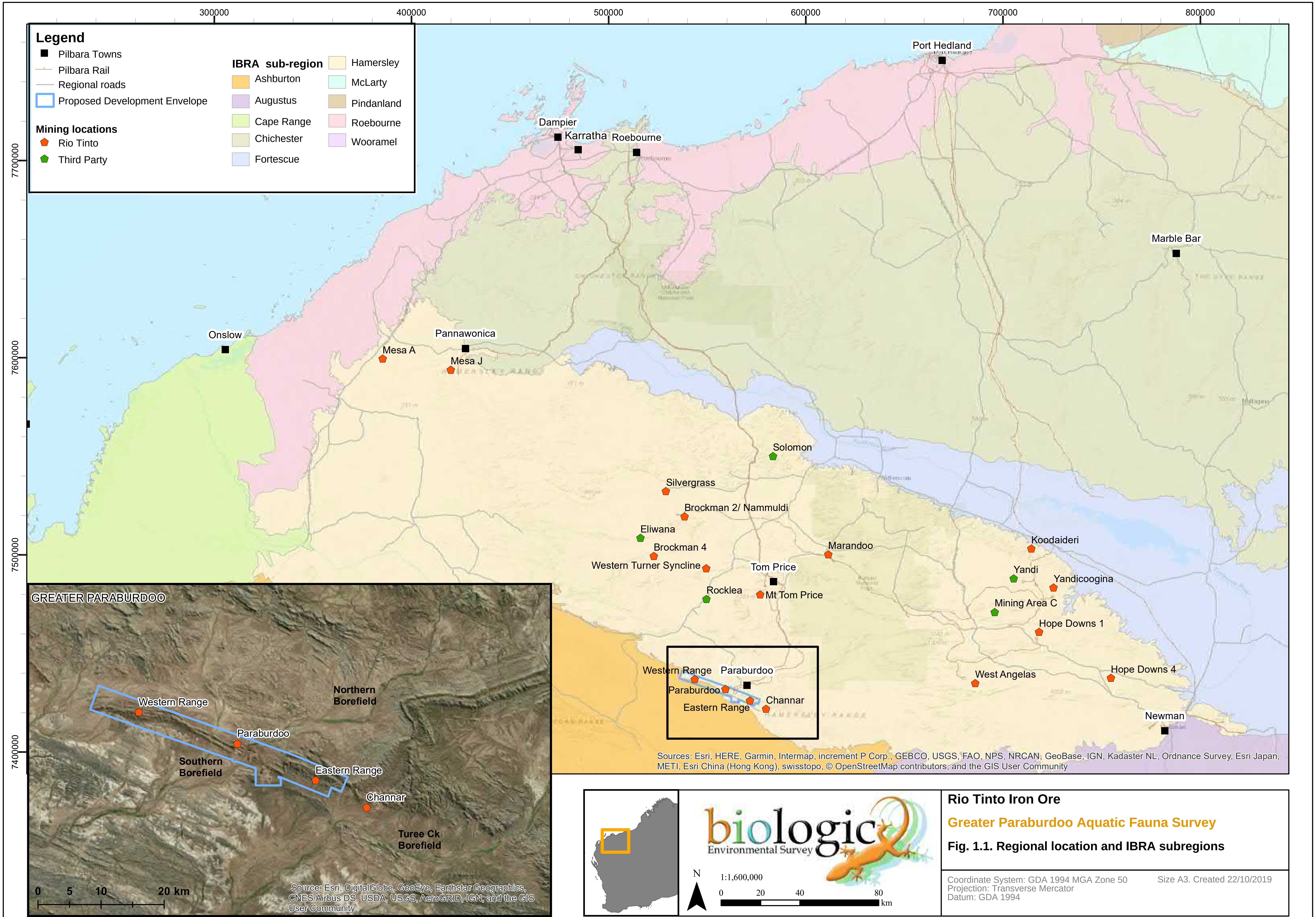
1.1 Background

Rio Tinto (Rio Tinto) owns and operates the Greater Paraburdoo mining operations in the Pilbara region of Western Australia, approximately six km to the south of the town of Paraburdoo (Figure 1.1). Rio Tinto, on behalf of the joint venture participants, is evaluating the development of several iron ore deposits within the Greater Paraburdoo Iron Ore Hub (the Proposal). This includes the development of a new iron ore mine at Western Range (mainly above water table - AWT), and the extension of existing operations at Paraburdoo (below water table - BWT) and Eastern Range (AWT). The development envelope covers a 17, 422 ha area.

Biologic Environmental Survey (Biologic) was commissioned by Rio Tinto to undertake a two-phase aquatic ecosystem survey within the Proposal Area (the Study Area). Three significant creeks traverse the development envelope; Seven Mile Creek, Pirraburdu Creek and a tributary of Six Mile Creek. Semi-permanent waterholes occur within Seven Mile Creek (augmented by discharge from the Paraburdoo Plant), and Pirraburdu Creek (Ratty Spring, Pirraburdu Spring), some of which are groundwater dependent. Within Western Range and Eastern Range, numerous rainwater fed pools are also known to exist. Whilst most are short-lived, some do persist for several months depending on aspect (located within deeply incised shaded gorges) and evaporation.

As part of the development, dewatering and discharge is required to access ore below the water table. Although the Proposal indicates that discharge to the environment will be minimal as a result of on-site use and potential discharge into old mine pit voids, there may be some discharge to creeklines in the vicinity of the operations. Potential discharge creeklines include Seven Mile Creek and/or Pirraburdu Creek. In dry conditions, Rio Tinto (2019a) estimated that the discharge extent would remain on Rio Tinto tenements for a 1.7 GL/yr rate of discharge into Pirraburdu Creek, and a 0.8 GL/yr rate of discharge into Seven Mile Creek. There may also be potential impacts to aquatic systems through drawdown.

The Proposal was referred to the EPA in November 2008. Rio Tinto noted that requirements identified in the EPA approved Environmental Scoping relating to aquatic fauna had not yet been addressed. Specifically, the following requirements were included under the Inland Waters Environmental Quality key environmental factor:



Rio Tinto Iron Ore

Greater Paraburdoo Aquatic Fauna Survey

Fig. 1.1. Regional location and IBRA subregions

Coordinate System: GDA 1994 MGA Zone 50
Projection: Transverse Mercator
Datum: GDA 1994

Size A3. Created 22/10/2019

- Characterise the baseline ecological values and water quality, both in a local and regional context, including, but not limited to aquatic fauna assemblages and water quality.
- Analyse, discuss and assess potential groundwater and surface water impacts (direct and indirect). The analysis should include, but not be limited to:
  - Assessment and description of direct and indirect impacts to aquatic fauna through drawdown, discharge or changes to hydrological regimes.

Therefore, Rio Tinto commissioned Biologic to undertake a two-phase aquatic fauna survey to address this gap in biological knowledge. This survey will support the development of the Environmental Review Document for the Project. The current interim report presents the findings from the first round of sampling in the dry season of 2019 (dry-19).

1.2 Project summary

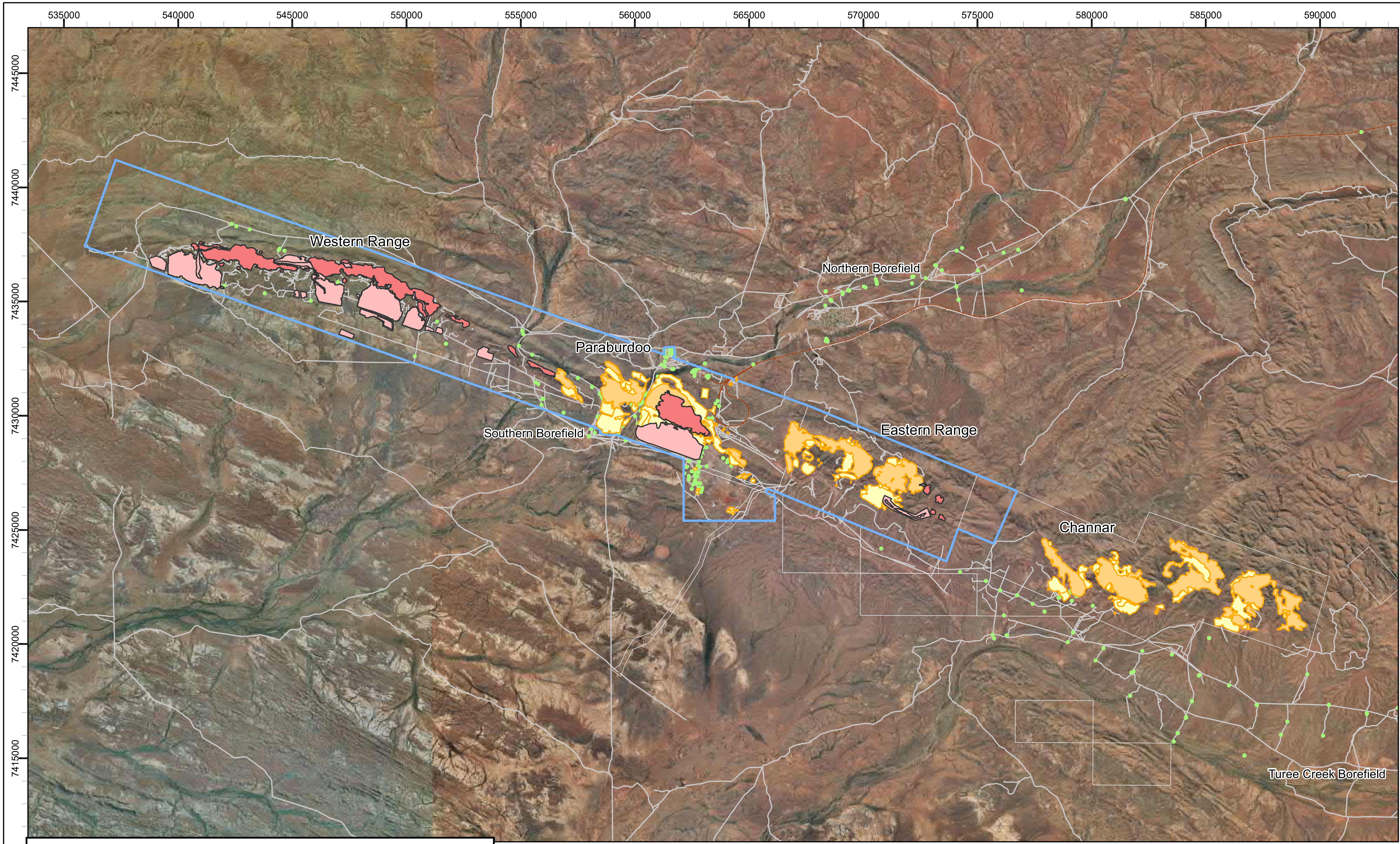
The Greater Paraburdoo mining operations commenced production in 1972 and active iron ore mining is currently underway at a number of deposits at Paraburdoo and Eastern Range. The Greater Paraburdoo Iron Ore Hub Proposal includes the development of a new iron ore mine at Western Range, and extension of existing mining operations (and associated infrastructure) at Paraburdoo and Eastern Range (Figure 1.2). The Proposal aims to sustain the current level of iron ore production at 25Mt/a from the Greater Paraburdoo locality.

The key components of the Proposal are:

- development of new pits at Western Range (deposits 36 West to 66 West);
- development of the 4 East Extension (4EE) at Paraburdoo as an extension of the existing 4 East BWT pit, including new dewatering of the Wittenoom Formation;
- development of new AWT pits at Paraburdoo (deposits 14W-16W and 27 West); and
- development of new AWT pits at Eastern Range (deposits 42EE and 47 East).

Groundwater has been abstracted in the 4 East and 4 West area since 2001, resulting in the development of a cone of depression in the Brockman Iron Formation aquifer (RTIO 2018). Further groundwater drawdown associated with the proposed mining activities is expected to occur in the area, with groundwater abstraction not expected to exceed 14 GL/annum.

Discharge currently occurs into Seven-Mile Creek from the Paraburdoo Plant. This maintains pools in the creek, downstream of the discharge point for approximately 2.5 km, depending on volumes discharged and climatic conditions (wet season rainfall/natural flows). Additional discharge may be required as part of the Proposal, with discharge options including Seven Mile Creek and Pirraburdu Creek.



Legend

- RTIO Tenure
- Proposed Development Envelope
- Track
- Pilbara Rail
- Waterbores

Existing and Approved Disturbance

- Existing Approved Disturbance
- Existing Approved Mining Pits

Conceptual Footprint

- Proposed Conceptual Disturbance
- Proposed Conceptual Mining Pits

biologic Environmental Survey

N

1:150,000

0 2 4 8 km

Rio Tinto Iron Ore

Greater Paraburdoo Aquatic Fauna Survey

Fig. 1.2: Current and proposed development within the Greater Paraburdoo Study Area

Coordinate System: GDA 1994 MGA Zone 50
Projection: Transverse Mercator
Datum: GDA 1994
Size A3. Created 13/03/2020

1.3 Legislation and guidance

There is currently (December 2019) no technical guidance applicable to the Inland Waters Environmental Factor; however, this survey was carried out in a manner consistent with the following:

- Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC/ARMCANZ 2000, ANZG 2019);
- Environmental Factor Guideline, Inland Waters (EPA 2018);
- Technical Guidance, Terrestrial Fauna Surveys (EPA 2016a);
- Technical Guidance, Sampling of Short-Range Endemic Invertebrate Fauna (EPA 2016b), and
- Similar surveys, including the Pilbara Biological Survey (Pinder *et al.* 2010) and National Monitoring River Health Initiative (MRHI; Choy 1995).

1.4 Scope of works

The scope of works includes:

- Undertake a two-phase aquatic fauna survey of pools within Seven Mile Creek, Pirraburdu Creek, Western Range, Eastern Range and Turee Creek, including
    - systematic sampling of macroinvertebrates, hyporheos fauna, fish, and water quality (pH, DO, water temperature, electrical conductivity, general ions, nutrients, dissolved metals, TSS),
    - qualitative habitat assessments; and
    - observations of other vertebrate fauna, including frogs, turtles and Pilbara Olive Python.
- Identification of all specimens to the lowest level possible (generally genus or species level).
- An assessment of the conservation status of all aquatic fauna recorded.
- Comparison of water quality against default ANZECC/ARMCANZ (2000) guidelines.
- Analysis of all data, including an assessment of the seasonal variability in water quality and aquatic fauna assemblages.
- Preparation of an interim report (after Phase I – dry season sampling).
- Preparation of a detailed report of all findings (Phase I and 2 – dry 2019 and wet 2020 sampling).
- Separate letter-style recommendations/strategic advice report.

This Interim Report covers the first round of sampling undertaken in the dry season of 2019.

2 ENVIRONMENT

2.1 Biogeography

The Study Area falls within the Pilbara biogeographical region as defined by the Interim Biogeographic Regionalisation of Australia (IBRA) (Thackway and Cresswell 1995). The Pilbara bioregion is characterised by vast coastal plains and inland mountain ranges with cliffs and deep gorges (Thackway and Cresswell 1995). Vegetation is predominantly mulga low woodlands or snappy gum over bunch and hummock grasses (Bastin 2008). Within the Pilbara bioregion there are four subregions: Hamersley, Chichester, Roebourne and Fortescue Plains.

The Study area lies predominately within the Hamersley subregion, with the southern portion crossing into the Ashburton subregion of the Gascoyne IBRA region (see Figure 1.1). The Hamersley subregion contains the southern section of the Pilbara Craton and comprises a mountainous area of Proterozoic sedimentary ranges and plateaux, dissected by basalt, shale and dolerite gorges (Kendrick 2001). Vegetation in the valley floors is predominately characterised by low mulga woodland over bunch grasses, with *Eucalyptus leucophloia* over *Triodia brizoides* dominating the skeletal soils on the ranges. Drainage is into the Fortescue River to the north, the Ashburton River to the south, or the Robe River to the west (Kendrick 2001).

2.2 Hydrology

The Study Area is located within a series of ephemeral tributaries of the Ashburton River Basin, including Turee Creek, Six-Mile Creek, Seven-Mile Creek, and Pirraburdu Creek. Together, Six Mile Creek (1,345 km^2), Seven Mile Creek (2,575 km^2) and Turee Creek (6,910 km^2) sub-catchments account for around 15% of the Ashburton River Basin (Rio Tinto 2019a). Flow directions are generally from north east to south west, intersecting the north west- south east trending Paraburdoo Ranges at roughly perpendicular angles (Figure 2.1).

Pirraburdu Creek flows through the western portion of the Paraburdoo mining area, separating the 11W and 4W deposits before joining Seven-Mile Creek south west of the Paraburdoo Ranges (Figure 2.1). The Pirraburdu catchment is located to the north of the Paraburdoo Ranges and spans roughly 482 km^2. The catchment has a geology dominated by largely impermeable volcanic rocks, therefore only modest rainfall is needed to generate substantial surface water flows (RTIO 2016*a*).

Seven-Mile Creek passes through the Paraburdoo Ranges at ~340 mRL within a 200 m wide valley that separates Paraburdoo's 4W and 4E deposits (RTIO 2018). Seven-Mile Creek discharges into the Ashburton River at Deolan Pool, approximately 58 km downstream of the Study Area. Seven-Mile Creek periodically floods following heavy rainfall, with flows up to 2 m recorded. Ephemeral pools occur upstream and downstream of the mine as surface flows recede. The Seven-Mile Creek catchment is located to the north of the ranges, spanning roughly 1200 km^2, with Bellary Creek as a major tributary (Figure 2.1) (RTIO 2016*a*).

The Western Range deposits are located west of the Paraburdoo mining area and straddle the catchment divide between Six-Mile Creek and Pirraburdu Creek. A tributary of Six-Mile Creek cuts through the deposit at the western end of Western Range (Figure 2.1). The surface water regime in Western Range is influenced by the steeply incised gullies (Rio Tinto 2019b). These gullies form headwaters to both major creeks, which flow in a southerly direction. Pools in the area are fed by upper catchment runoff following rainfall, with their persistence dependent on substrate type, and aspect (i.e. gorge pools located against cliff faces which are shaded for most of the day can be maintained by reduced evaporation). Isotope analysis indicated surface waters in Western Range pools reflect locally derived rainfall, rather than aged groundwater inflows (Rio Tinto 2019b). Due to the steep topography, flow velocities can be high following rainfall events (Rio Tinto 2019b).

Turee Creek is located south of the Channar Mining Operations and hosts the Turee Creek Borefield (Figure 2.1). The headwaters of Turee Creek arise within Karijini National Park, from two main branches; Turee Creek main branch within 6 km of Marandoo and Turee Creek East Branch less than 1 km from West Angelas. Turee Creek flows roughly from east to west along the southern edge of a valley bounded by the Brockman Iron Formation ridges to the north and the Wyloo Group to the south (Rio Tinto 2017). Turee Creek is ephemeral, but large pools persist within the creek following surface flows, and several semi-permanent and permanent pools are located along its length. After turning southwards and then further westwards below the Channar Borefield, Turee Creek is sequentially joined by its tributaries from the north, including Seven-Mile Creek, Pirraburdu Creek and Six-Mile Creek, before eventually merging with the Ashburton River.

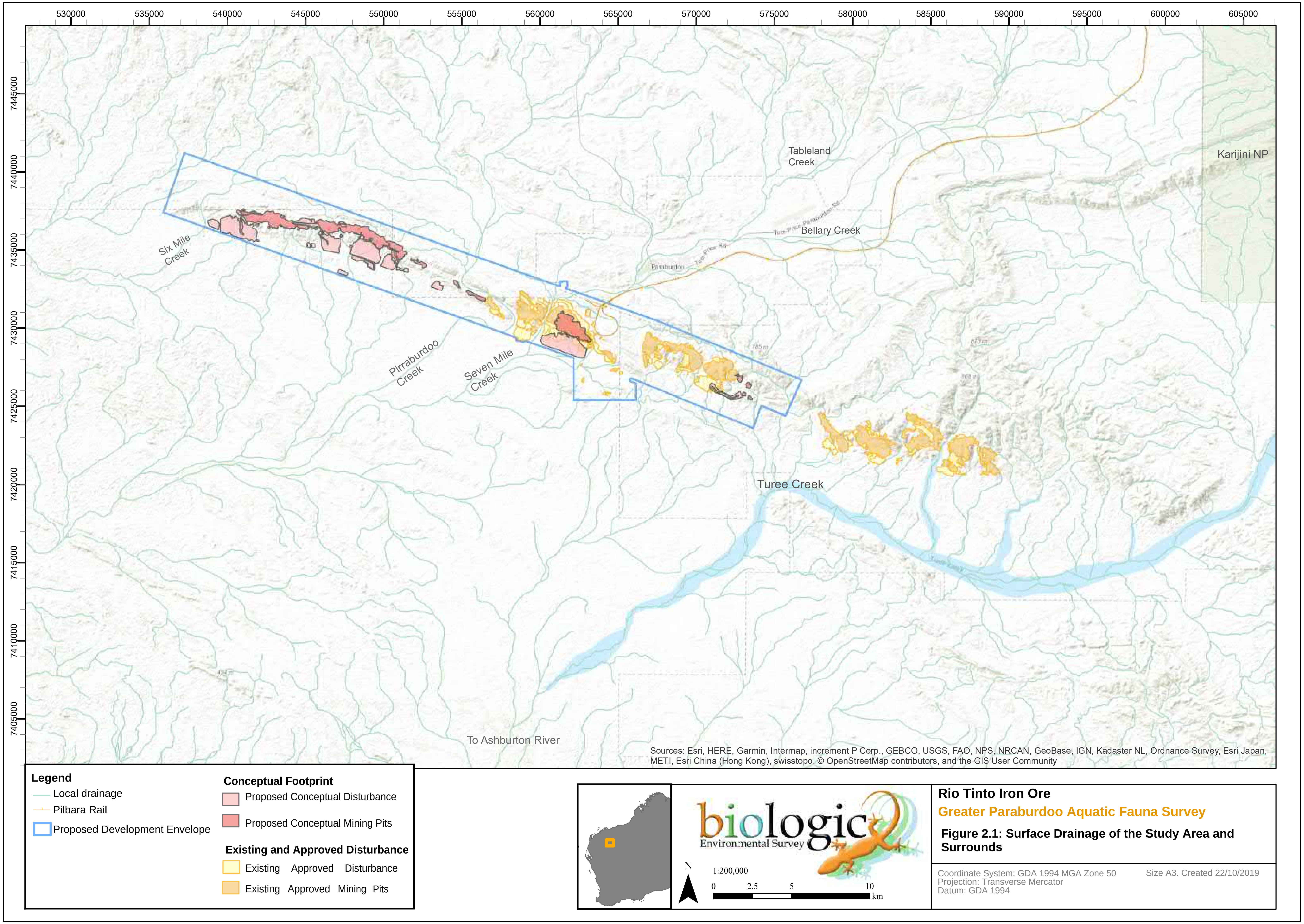


Figure 2.1: Surface Drainage of the Study Area and Surrounds

2.3 Climate

The Pilbara region has a semi-desert to tropical climate, with relatively dry winters and hot summers. Rainfall is highly variable, mostly occurs during the summer, and is associated with convective thunderstorms, low pressure systems and tropical cyclones that generate ephemeral flows and occasional flooding in creeks and rivers. Due to the nature of cyclonic events and thunderstorms, total annual rainfall in the region is highly unpredictable and individual storms can contribute several hundred millimetres of rain at one time. The average annual rainfall over the broader Pilbara area ranges from around 200 – 350 millimetres (mm) (predominantly in January, February and March), although rainfall may vary widely from year to year (van Etten 2009). Temperatures vary considerably throughout the year with average maximum summer temperatures reaching 35 °C to 40 °C and winter temperatures generally fluctuating between 22 °C and 30 °C.

Nearby rainfall gauging stations for the Study Area include; the Bureau of Meteorology (BoM) Paraburdoo Aero Station (#7185; length of record 1974 to current), located approximately 10 km north east of the Study Area, and the Department of Water and Environmental Regulation (DWER) Ashburton River Capricorn Range Station (#507002; length of record 1972-current), located approximately 65 km south west of the Study Area. Average annual rainfall recorded from Paraburdoo Aero is 310.2 mm (BoM 2019), in comparison to 285.90 mm recorded from Ashburton River Capricorn Range (DWER 2019). The range in annual rainfall at Ashburton River Capricorn Range was 104.3 mm (recorded in 1983) to 601.2 mm (in 2006). This illustrates the high inter-annual variability in rainfall in the region.

Generally, average annual rainfall has decreased over the last few decades (Figure 2.2). At the Ashburton River Gauging Station, average annual rainfall was 332.78 mm between 1990 and 1999, 299.74 mm between 2000 and 2009, and 256.18 mm between 2010 and 2019 (bearing in mind that 2019 is an incomplete year, with three months of data yet to be collected) (Figure 2.2).

No streamflow stations exist within the Study Area. The closest nearby DWER streamflow gauging station is located at Turee Creek (Broken Springs; station number 706004), approximately 45 km to the north east of the Study Area (25 km north of TC1). However, this station has been closed since 1980, with no streamflow data available online. Unfortunately, using streamflow data from other catchments would not be indicative of flows within Seven-Mile Creek, Pirraburdu Creek or Turee Creek, in the vicinity of the Study Area. It is assumed that like elsewhere in the Pilbara, streamflow is directly dependent on rainfall.

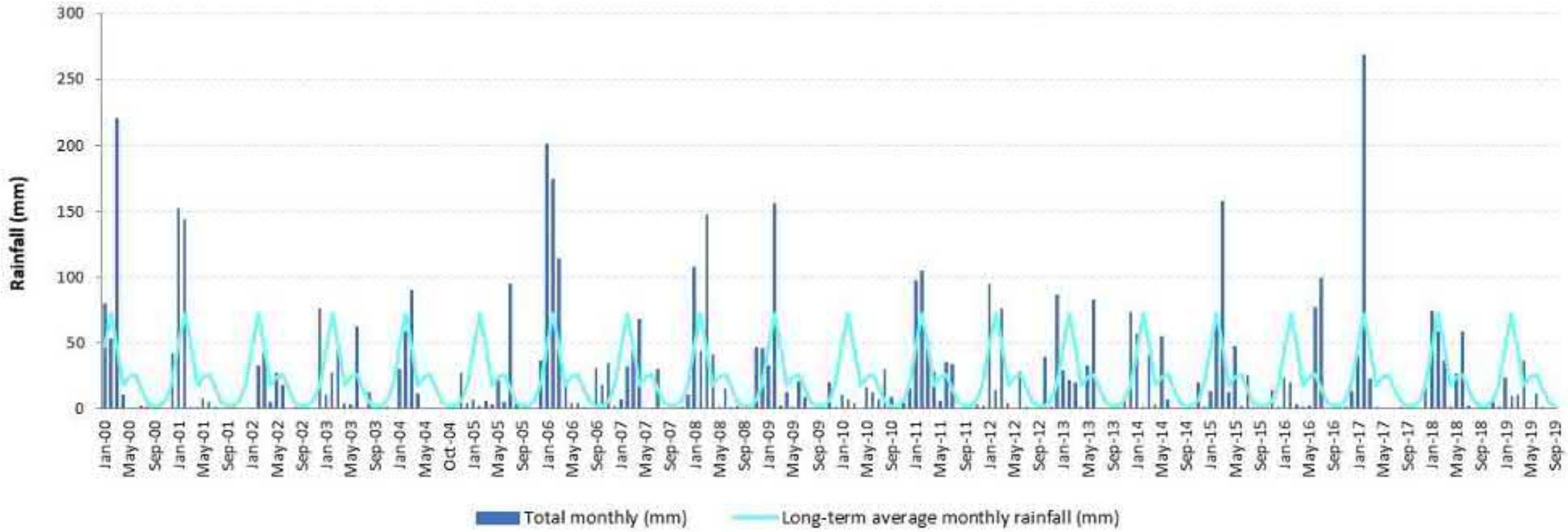


Figure 2.2: Monthly rainfall data for the DWER Ashburton River Capricorn Range Gauging Station (507002) recorded between January 2000 and September 2019 (from DWER 2019).

2.4 Current discharge regime

As mentioned above, discharge currently occurs into Seven-Mile Creek from the Paraburdoo Plant. This discharge maintains pools in the creek, downstream of the discharge point for approximately 2.5 km, depending on volumes discharged and climatic conditions (wet season rainfall/natural flows). Average monthly discharge has been in the order of 84.76 ML between November 2017 and September 2019. Greatest discharge over this period occurred in January 2018 (155.92 ML), closely followed by January 2019 (154.97 ML; Figure 2.3). Lowest discharge was 0.92 ML and occurred during the month of the dry season survey in September 2019 (Figure 2.3). Total annual discharge for 2018 was 1019.53 ML. This total excludes four months (May, June, July and September) when data quality was questionable, due to a blockage in the v-notch weir and/or lack of flows through the v-notch.

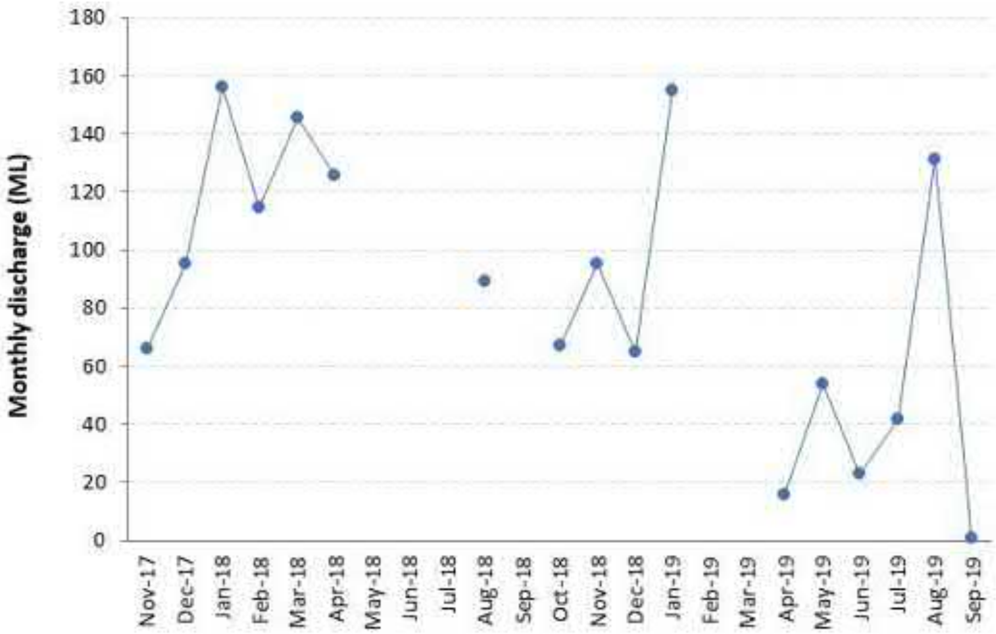


Figure 2.3. Monthly discharge volumes (ML) from the Paraburdoo Plant into Seven-Mile Creek. NB – months with no data indicate data quality was questionable (i.e. blockage in the v-notch weir).

3 METHODS

3.1 Desktop assessment

A desktop assessment was undertaken comprising database searches and a literature review. The purpose of the desktop assessment was to determine the extent of any previous aquatic survey work in and around the Study Area, and the presence of aquatic fauna species known or likely to occur in the area, including conservation significant species.

3.1.1 Database searches

Table 3.1 shows the search area for the relevant databases included in the database search for aquatic fauna records:

- DBCA (2019a) NatureMap database;
- Atlas of Living Australia (ALA); and
- DoEE (2019) Protected Matters.

Table 3.1. Databases used for the review.

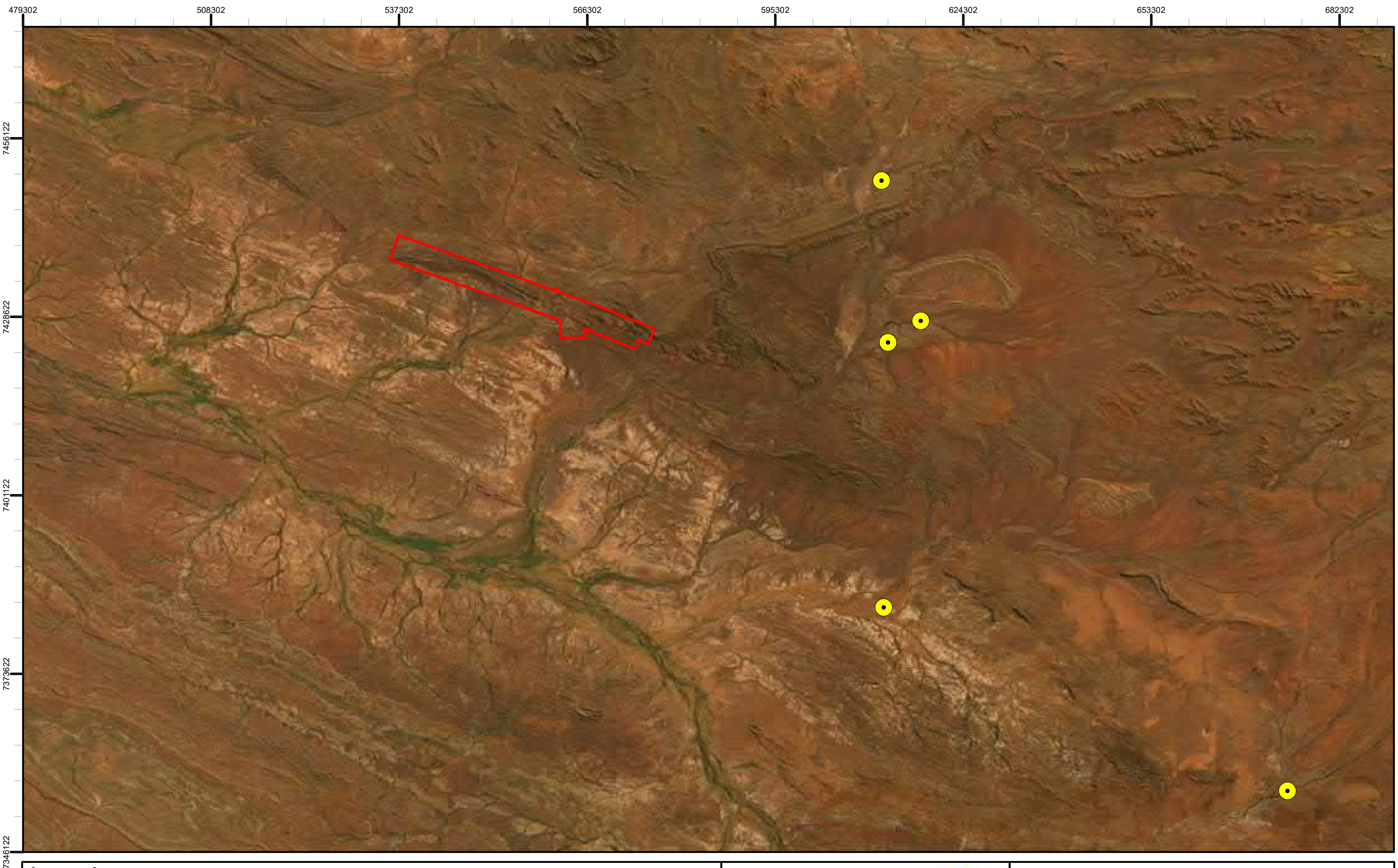
Database	Source	Parameters
NatureMap	DBCA (2019a)	100 km radius around 23°15'55.21"S and 117°49'52.91"E
ALA Taxon Occurrence Search	ALA (2019)	
ALA Field Guide Database Search	ALA (2019)	
Protected Matters Database Search Tool	DoEE (2019)	

Other data sources referenced for this desktop assessment included:

- The Australian Faunal Directory,
- The Australian National Insect Collection Database; and
- MRHI database.

3.1.2 Literature review

A review of available literature relevant to the Study Area was undertaken to compile a list of aquatic fauna species previously known to occur nearby, and therefore have the potential to occur within the Study Area. A number of surveys have included aquatic ecosystem sampling to varying degrees, with sites located as close as 36 km to the Greater Paraburdoo Study Area (Fork Spring) (Table 3.2, Figure 3.1). None of these surveys included sites within the Greater Paraburdoo Iron Ore Hub area itself.



Legend

Study Area

Previous Surveys

Pinder et al. (2010)

biologic Environmental Survey

N

1:750,000

0 5 10 20 km

Rio Tinto Iron Ore

Greater Paraburdoo Aquatic Fauna Survey

Figure 3.1: Previous aquatic surveys conducted in the area

Coordinate System: GDA 1994 MGA Zone 50
Projection: Transverse Mercator
Datum: GDA 1994

Size A4. Created 4/11/2019

Table 3.2: Literature sources used for the review.

Survey Title	Reference	Survey Type	Closest Site to Study Area (km)
Pilbara Biological Survey	Pinder *et al.* (2010)	Aquatic flora Zooplankton & Macroinvertebrates	36 km (Fork Spring, one of the long-term reference sites sampled in the current study)

3.2 Field survey

3.2.1 Survey team

Fauna sampling for this survey was conducted under DBCA Fauna Taking (Biological Assessment) Licence BA27000093 issued to Kim Nguyen and DPIRD Instrument of Exemption to the *Fish Resources Management Act 1994 Section 7 (2)* number: 3266 issued to Jessica Delaney. Flora was collected under DBCA Flora Taking (Biological Assessment) Licence FB62000095, also issued to Jessica Delaney.

The dry season survey was undertaken by Biologic zoologists Jessica Delaney, Kim Nguyen and Morgan Lythe; all with extensive experience undertaking aquatic ecosystem surveys in the Pilbara. Macroinvertebrate specimens were identified in-house by Alex Riemer, Kim Nguyen and Syngeon Rodman, with assistance from Jane McRae for specific groups, such as Cladocera, Copepoda and Ostracoda specimens from hyporheic samples. Flora samples (submerged and emergent macrophytes) were identified by Biologic's Flora Team, including Clinton van den Bergh, Samuel Coultas and Emily Eakin-Busher, in conjunction with Syngeon Rodman and Alex Riemer.

3.2.2 Survey timing and weather

Sampling was undertaken in the dry season of 2019 (11th to 18th September). The survey was undertaken at a time of above average ambient temperature. Maximum daytime temperatures over the survey averaged 36.0 °C, in comparison to the long-term average for September of 31.4°C. While there was no rainfall during or immediately preceding the survey, rainfall recorded from the Ashburton River GS in April 2019 was above the long-term average (Figure 3.2). Despite this late wet season rainfall, the wet season of 2018/19 was considerably drier than normal, with less than half the long-term average wet season rainfall (long-term wet season average = 211.6 mm) being recorded (2018/19 wet season = 85.8 mm; Figure 3.2). The low rainfall preceding the survey affected streamflow in the creeks sampled, with most pools having receded considerably by the time of the survey.

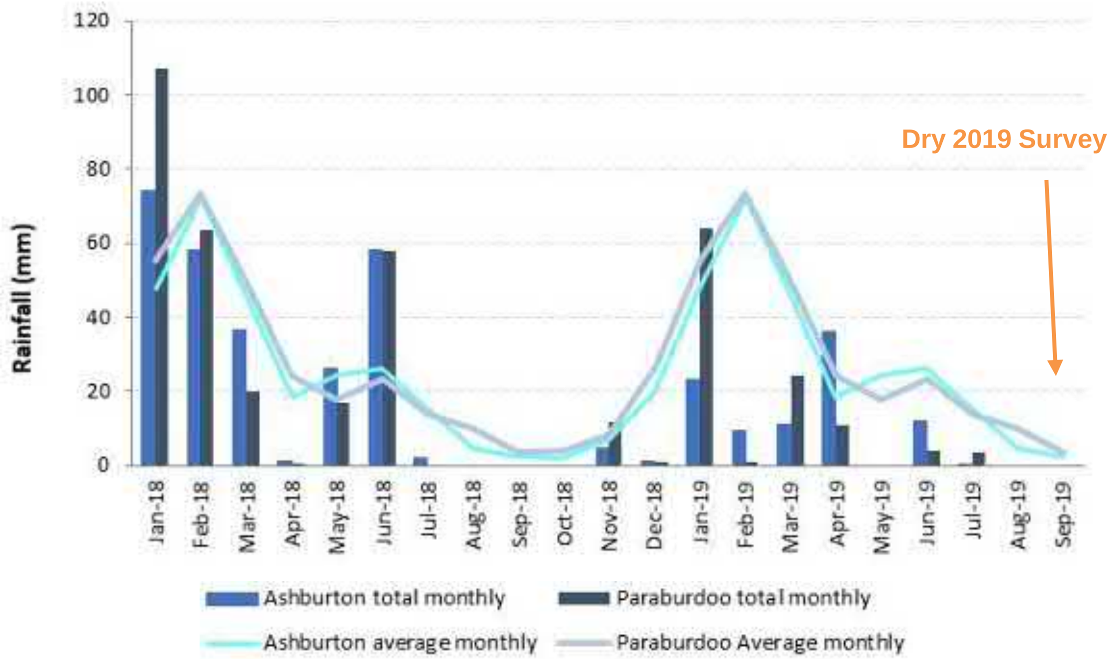


Figure 3.2. Total monthly rainfall and long-term average monthly rainfall (mm) recorded from nearby gauging stations in the two years preceding the dry season 2019 aquatic survey.

3.2.3 Sampling sites

A total of 20 sites were sampled in the dry season of 2019, across a range of aquatic habitat types. In order to allow statistical analysis, this included 11 potential impact sites and nine reference sites.

Potential Impact Sites

- Seven Mile Creek: Three sites within the modelled dewatering drawdown extent (SM4, SM5 and SM6).
- Pirraburdu Creek: Two sites downstream, to cover any potential downstream impacts from discharge (PC4 and PC5).
- Western Range: three of the more persistent pools (WR1, WR2 and WR3).
- Eastern Range: three of the more persistent pools (ER1, ER2 and ER3).

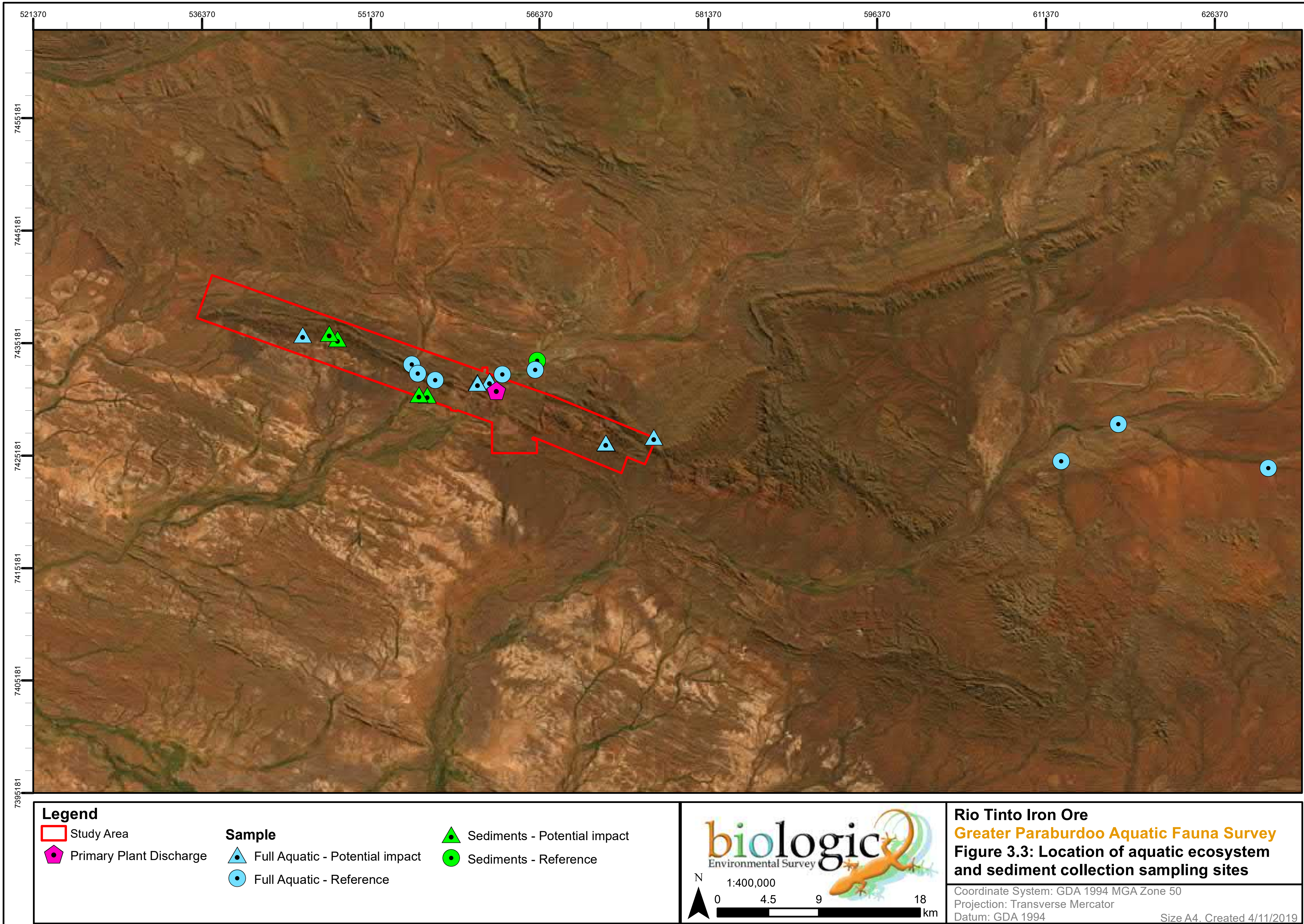
Reference Sites

- Seven Mile Creek: Three sites upstream of dewatering drawdown impacts, including Rio Tinto's surface water monitoring locations (SM1, SM2 and SM3 – Kelly's Pool).
- Pirraburdu Creek: PC1 (Ratty Spring), PC2, and PC3 (Pirraburdu Springs).
- Turee Creek: three long-term reference sites located outside the zone of all potential mining impacts (TC1 – Fork Spring, TC2 – Paperbark Spring, and TC3).

At the time of sampling, five sites were dry and did not hold water to allow aquatic survey (SM1, PC4, PC5, WR1 and WR3). At these sites, sediment samples were collected and re-wetting/emergence trials undertaken in the Biologic laboratory (Table 3.3; Figure 3.3).

Table 3.3: Site locations, indicating site type and sampling effort.

Area	Site	Zone	Easting	Northing	Type	Sampling undertaken							
						WQ	Aquatic habitat	Flora	Zoop	Macro	Hypo	Fish	Seds
Seven Mile Creek	SM1	50	566154	7433609	Reference	×	×	×	×	×	✓	×	✓
	SM2	50	565985	7432800		✓	✓	✓	✓	✓	✓	✓	×
	SM3 (Kelly's Pool)	50	563046	7432399		✓	✓	✓	✓	✓	×	✓	×
	SM4	50	561918	7431803	Currently impacted (augmented)/potential impact from dewatering	✓	✓	✓	✓	✓	×	✓	×
	SM5	50	560817	7431694		✓	✓	✓	✓	✓	×	✓	×
	SM6	50	560838	7431609		✓	✓	✓	✓	✓	✓	✓	×
Pirraburdu Creek	PC1 (Ratty Spring)	50	555014	7433289	Reference	✓	✓	✓	✓	✓	×	✓	×
	PC2	50	555546	7432489		✓	✓	✓	✓	✓	✓	✓	×
	PC3 (Pirraburdu Spring)	50	557084	7431884		✓	✓	✓	✓	✓	✓	✓	×
	PC4	50	556373	7430536	Potential impact (downstream discharge)	×	×	×	×	×	×	×	✓
	PC5	50	555649	7430602		×	×	×	×	×	×	×	✓
Western Range	WR1	50	548421	7435556	Potential impact	×	×	×	×	×	×	×	✓
	WR2	50	545321	7435894		✓	✓	✓	✓	✓	✓	✓	×
	WR3	50	547673	7436040		×	×	×	×	×	×	×	✓
Eastern Range	ER1	50	572310	7426253	Potential impact	✓	✓	✓	✓	✓	✓	✓	×
	ER2	50	572245	7426317		✓	✓	✓	✓	✓	×	✓	×
	ER3	50	576506	7426818		✓	✓	✓	✓	✓	✓	✓	×
Turee Creek	TC1 (Fork Spring)	50	612732	7424690	Long-term reference	✓	✓	✓	✓	✓	×	✓	×
	TC2 (Paperbark Spring)	50	617788	7427974		✓	✓	✓	✓	✓	×	✓	×
	TC3	50	631133	7424085		✓	✓	✓	✓	✓	✓	✓	×



biologic Environmental Survey

Rio Tinto Iron Ore

Greater Paraburdoo Aquatic Fauna Survey

Figure 3.3: Location of aquatic ecosystem and sediment collection sampling sites

Coordinate System: GDA 1994 MGA Zone 50
Projection: Transverse Mercator
Datum: GDA 1994
Size A4. Created 4/11/2019

3.2.4 Water quality

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

All water quality variables measured included:

In situ – pH, DO (% and mg/L), EC (µS/cm), water temperature (°C) and redox (mV);

Ionic composition - Ca, K, Mg, Na, HCO_3, Cl, SO_4, CO_3, alkalinity and hardness (all mg/L);

Water clarity – turbidity (NTU) and total suspended solids (TSS);

Nutrients – N_NO2, N_NO3, N_NOx, N_NH_3, total N and total P (all mg/L); and

Dissolved metals – Al, As, B, Ba, Cd, Co, Cr, Cu, Fe, Mn, Mo, Ni, Pb, S, Se, U, V and Zn (all mg/L).

Samples collected for dissolved metals were filtered through 0.45 µm Millipore nitrocellulose filters in the field (Plate 3.1). As ALS filter all nutrient samples in the laboratory as part of their analytical methods, it was not necessary to field filter for nutrients. To avoid any potential for contamination, all water samples were collected using clean Nalgene sample bottles, and clean/new filters and syringes. All water quality sampling equipment was stored in polyethylene bags, and samplers wore polyethylene gloves whilst sampling water quality.

Plate 3.1. Filtering dissolved metal samples at ER1 (photo by Biologic ©).

All water samples were kept cool in an esky whilst in the field, and either refrigerated (ions, dissolved metals, nutrients, general water), or frozen (total nutrients) as soon as possible for subsequent transport to the ALS laboratory.

3.2.5 Habitat

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

3.2.6 Submerged and emergent vegetation

Macrophytes are important structural and biological components of lowland streams, providing aquatic fauna with habitat, breeding sites, food and cover from predators. Therefore, submerged macrophytes and emergent riparian vegetation from the families Cyperaceae (sedges) and Restionaceae (rushes) were collected from each site, where present. Submerged macrophytes were hand collected and placed in sample containers and assigned a unique number. Sufficient water from the waterbody was included in the sample container to ensure the collected material did not dry out or degrade. Roots, stem and flowering/fruiting bodies from emergent and riparian sedges and rushes were hand collected, ensuring sufficient material to allow confident identifications. The emergent samples were assigned a unique number and pressed in the field. All specimens collected were processed as per WA Herbarium guidelines and identified in the Biologic laboratory.

3.2.7 Hyporheos fauna

The hyporheic zone is an ecotone between the surface and groundwater, and provides a number of ecosystem services to both habitats, including mediating exchange processes, regulating water flows and transfer of nutrients, carbon, oxygen and nitrates, as well as the maintenance of biodiversity (Dole-Oliver and Marmonier 1992, Edwards 1998, Boulton 2001). Fauna utilising this habitat are also an ecotone between surface and groundwater, with representatives of both benthic epigean species and stygofauna. Benthic macroinvertebrates migrate vertically to exploit hyporheic habitats as a nursery to protect juveniles from predation (Jacobi *et al.* 1996, Bruno *et al.* 2012), and during times of floods (Palmer *et al.* 1992, Dole-Oliver and Marmonier 1992, Edwards 1998), drought (Cooling and Boulton 1993, Edwards 1998, Coe 2001, Hose *et al*. 2005), and disturbance in food supplies (Edwards 1998). The hyporheic zone serves to enhance the resilience of the benthic community to disturbance and influence river recovery following perturbations. Hyporheos[2] fauna have been used worldwide as an indicator of ecosystem health, especially in ephemeral creeks, with reported responses

[2] Fauna residing in the hyporheic zone with intent. Surface water species utilising the zone for protection against perturbations in the river environment and obligate groundwater species, are collectively known as hyporheos fauna (Brunke and Gonser 1997).

to disturbances such as metal pollution and eutrophication (Leigh *et al*. 2013, Boulton 2014, Moldovan *et al.* 2013, Pacioglu *et al*. 2016).

At each site, the hyporheic zone was sampled using the Karaman-Chappuis (karaman) method (Karaman 1935, Chappuis 1942). This involved digging a hole (approximately 20 cm deep, 40 cm diameter) in alluvial sediments adjacent to the water's edge (Plate 3.2). The hole was swept with a modified 110 µm mesh plankton net immediately once it had filled with water, after approximately 30 minutes, and then again at the completion of sampling at that site. Although Bou-Rouch (Bou 1974) sampling has widely been used to sample the hyporheic zone, the karaman method has been found to be more effective with many more taxa collected (Strayer and Bannon-O'Donnell 1988, Canton and Chadwick 2000).

Plate 3.2: Using the Karaman-Chappuis method to sample the hyporheos at WR2.

Hyporheic samples were preserved in 100% ethanol in the field (equivalent to 70% ethanol including the hyporheic sample) and returned to the Biologic laboratory for processing. Hyporheos fauna present were removed by sorting under a low power dissecting microscope. Specimens were identified in-house, or sent to appropriate taxonomic experts for identification, where necessary (i.e. Jane McRae for Cladocera, Copepoda and Ostracoda).

3.2.8 Macroinvertebrates

Aquatic macroinvertebrates are invertebrates (animals without a backbone) that can be seen with the naked eye. They are used worldwide as indicators of ecosystem health for a number of reasons: they are ubiquitous; relatively easy to collect; have high species diversity and varying sensitivity to environmental disturbances; have relatively long life cycles; and are continuously exposed to environmental conditions and constituents of the surface water they inhabit (Cain *et al.* 1992, Sonnemann *et al.* 2001, Hodkinson *et al.* 2005, Bressler *et al.* 2006, Carew *et al.* 2007). In Australia, the inherent value in using aquatic macroinvertebrates as key biological indicators is evidenced by their inclusion in river health initiatives across the country, including the Monitoring River Health Initiative, the Australian River Assessment System (AusRivAS), and the Framework for the Assessment of River and Wetland Health, to name a few.

Macroinvertebrate sampling was conducted with a 250 μm mesh D-net to selectively collect the macroinvertebrate fauna. At each site the objective was to maximise species richness by sampling across as many habitats as possible, including open water, macrophyte beds, large woody debris (LWD), leaf litter and edge habitat. Each sample was washed through a 250 μm sieve to remove fine sediment, with leaf litter and other coarse debris being removed by hand (Plate 3.3). Samples were preserved in 100% ethanol in the field (equivalent to 70% ethanol including the macroinvertebrate sample) and transported to the Biologic laboratory for processing. Sorting was conducted under a low power dissecting microscope. Specimens were identified to the lowest possible level (genus or species level) and enumerated to $\log_{10}$ scale abundance classes (*i.e.* 1 = 1 individual, 2 = 2 - 10 individuals, 3 = 11 - 100 individuals, 4 = 101-1000 individuals, 5 = >1000). All macroinvertebrate groups were identified using in-house expertise, however, external taxonomists were used when required (Jane McRae, Bennelongia).

Plate 3.3: Aquatic macroinvertebrate sampling using a 250 μm mesh D-net at ER3 (left), and sieving a macroinvertebrate sampling at PC2 to remove fine sediment and leaf litter prior to sample preservation (right).

3.2.9 Fish

Fish sampling included a variety of methods to collect as many species and individuals as possible. Methods included light-weight fine mesh gill nets (10 m net, with a 2 m drop, using 10 mm, 13 mm, 19 mm and 25 mm stretched mesh) set across the creek/pool (Plate 3.4), seine netting (10 m net, with a 2 m drop and 6 mm mesh) and direct observation. The seine was deployed in shallow areas with little vegetation or large woody debris, and up to three seine hauls were undertaken per site.

Plate 3.4: Light-weight fine mesh gill nets set across a pool at TC3

Fish were identified in the field and standard length (SL)[3] measured. All fish were released alive to the site where they were collected.

It was anticipated that electrofishing would also be conducted, but site conditions including high EC, high cover of submerged macrophytes/algae, and difficult bank access at some sites, precluded its use. For a number of sites, access was via hiking relatively long distances up creeklines and over gorges. Carrying the electrofisher to these sites was not deemed safe given the amount and weight of other sampling gear required.

3.2.10 Other vertebrate fauna

Any other vertebrate fauna observed or caught during aquatic surveys were also recorded for each site.

3.2.11 Sediments for re-wetting trials

Sediment samples were collected from five dry sites to enable rehydration/emergence trials in the laboratory; two sites along lower Pirraburdu Creek (PC4 and PC5), one site on Seven Mile Creek (SM1) and two sites in Western Range (WR1 and WR3) (see Figure 3.3). The aim of the rehydration trials was to obtain information on the types of resident fauna these sites support by identifying species which emerge from desiccation-resistant resting stages following inundation and rehydration.

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

Surficial sediments (top 3-5 cm) were collected from low elevation areas which appeared to have held water recently, i.e. after the March rainfall event. Approximately 600 g of sediment was collected and placed in labelled, breathable calico bags (Plate 3.5). In the Biologic laboratory, 400 g of sediment from each sample was rehydrated in an aquarium flooded with dechlorinated filtered water (Plate 3.5). Each aquarium was aerated, and diluted liquid fertiliser added to enhance productivity. The rehydration trials were heated to simulate conditions in the field, with a 12 hour light / 12 hour dark cycle. Samples were examined every 24 to 48 hours for emergent fauna. The trials were conducted for a total period of 40 days. As cues for emergence and colonisation rates are different for different species, additional water was added after 24 days, effectively simulating a second flooding event.

Plate 3.5: Collecting sediment samples for rehydration/emergence trials (top left), PC4 tank set up (top right), and all tanks set up in the laboratory once sediments were inundated (below).

Emergent fauna and macrophytes were identified to species level (where possible) under high-powered magnification, and abundance recorded. The conservation status of emergent taxa was also determined.

In situ water quality was measured every three days for the duration of the trial, providing an indication of the potential conditions experienced within these creeks when inundated. The EC of surficial waters in rehydration trays will reflect the dissolution of salts stored in creek bed sediments, and these stored salts will reflect the salinity of the creeks when inundated.

3.3 Data analysis

3.3.1 Water quality

Water quality data were compared against the default ANZECC/ARMCANZ (2000) water quality guideline values (GVs) for the protection of aquatic ecosystems in the tropical north-west of Western Australia (see Appendix B for default values). For this purpose, sites sampled in the current study were classified as lowland rivers.

The primary objective of the guidelines is to "provide authoritative guidance on the management of water quality in Australia and New Zealand …. and includes setting water quality and sediment quality objectives designed to sustain current, or likely future, community values for natural and semi-natural water resources" (ANZG 2019). 'Default' GVs are provided for a range of parameters designed to protect aquatic systems at a low level of risk, but are not designed as pass or fail compliance criteria. Rather, exceedances of default GVs are triggers to inform managers and regulators that changes in water quality are occurring and may need to be investigated.

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

- High conservation/ecological value systems - where the goal is to maintain biodiversity with no (or little) change to ambient condition. 99% species protection GVs for toxicants apply[4].
- Slightly to moderately disturbed systems - where aquatic biodiversity has already been adversely impacted to a small but measurable degree by human activity. The aquatic ecosystem remains in a healthy condition and ecological integrity is largely retained. The aim is to maintain current biodiversity and ecological function. 95% species protection GVs for toxicants apply.
- Highly disturbed systems - are measurably degraded and of lower ecological value. Guideline aims for these systems may be varied and more flexible, ranging from maintenance of the current yet modified ecosystem that supports management goals, to continual improvement in ecosystem condition. For toxicant, the 90% or 80% species protection GVs may be applied.

Given mining activity and pastoral use, the sites sampled in the current study were classified as slightly to moderately disturbed systems and the 95% GVs applied.

Two GVs relating to nutrient concentrations are provided for within the default ANZECC/ARMCANZ (2000) guidelines;

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

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

The guidelines have recently been updated to reflect a better understanding of physical and chemical stressors, the availability of additional monitoring data, the addition of recent toxicity data in GVs for a number of toxicants, a weight of evidence approach, and the fact that water quality varies greatly across ecosystem types and regions (ANZG 2019). The guidelines are now presented via an interactive online platform to improve usability and facilitate updates as new information becomes available. While information relating to management frameworks, background to derivation of GVs, and approaches for sampling design and monitoring programs are available online, GVs are not currently presented for all ecoregions. The Study Area falls within the Indian Ocean Inland Waters region, data for which is not currently available online. As such, data from the current study were compared against the default ANZECC/ARMCANZ (2000) GVs for systems within the tropical north-west of Western Australia.

3.3.2 Invertebrates

All taxa recorded from hyporheic samples were classified based on categories of Boulton (2001):

- stygobite – obligate groundwater species, with special adaptations to survive such conditions;
- permanent hyporheos stygophiles - epigean species (living on or near the surface of the ground) which can occur in both surface- and groundwaters, but is a permanent inhabitant of the hyporheos;
- occasional hyporheos stygophiles – use the hyporheic zone seasonally or during early life history stages; and
- stygoxene (species that appear rarely and apparently at random in groundwater habitats, there by accident or seeking refuge during spates or drought; not specialised for groundwater habitat).

Additionally, Biologic have one further hyporheic classification:

- possible hyporheos stygophile – likely to be hyporheos fauna, but due to taxonomic resolution or a lack of ecological information we are unable to say this with certainty.

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

- Cosmopolitan – species is found widely across the world;

- Australasian – species is found across Australia, New Guinea and neighbouring islands, including those of Indonesia;
- Australian endemic – species is only found in Australia;
- Northern Australia – species with distributions across the northern, tropical regions of the Australian continent;
- North Western Australia – found across northern W.A., including the Pilbara and Kimberley regions;
- Western Australian endemic – only known from W.A. (is restricted to, but is widely distributed across the state);
- Pilbara endemic - restricted to the Pilbara region of Western Australia;
- Short range endemic (SRE) – as defined by Harvey (2002), an SRE is a species occupying an area of less than 10, 000 km^2. Such species have traits which make them vulnerable to disturbance and changes in habitat, and affords them high conservation value; and
- Unknown distribution – taxa could not be assigned to one of the above, as there is currently insufficient knowledge on either its distribution or taxonomy to assess its level of endemism.

Uni-variate analysis was undertaken in SPSS to compare overall macroinvertebrate richness between site types (reference vs currently impacted by dewatering discharge vs potential impact in the future). This was undertaken using ANOVA. Data was assessed prior to analysis to ensure it met the assumptions of the test (i.e. Levene's test to check for equality of variances). Additional macroinvertebrate metrics were also tested in this way, including the richness of Pilbara endemics and the EPT Index. The EPT Index relates to the number of taxa recorded from the sensitive Ephemeroptera, Trichoptera and Plecoptera groups. These taxa are intolerant of environmental disturbance and change, and as such can provide an indication of good water quality and habitat. Plecoptera do not occur in the Pilbara, and as such, the EPT Index in the current study includes Ephemeroptera and Trichoptera only.

Macroinvertebrate data were also compared against the Pilbara Biological Survey PBS (Pinder *et al.* 2010) datasets for sites in the vicinity of the Study Area. Richness (total number of taxa) recorded from each site was compared using histogram plots. Assemblage structure was analysed using multivariate techniques in PRIMER v7 (Clarke and Gorley 2015), including cluster analysis and ordination. Ordination was by non-metric Multi-Dimensional Scaling (nMDS), which, unlike other ordination techniques uses rank orders, and therefore can accommodate a variety of different types of data. Ordination was based on the Bray-Curtis similarity matrix (Bray and Curtis 1957). Similarity Profile Analysis (SIMPROF) was undertaken within the cluster analysis to test for significant groups. Data were transformed to presence/absence prior to analysis to conform with PBS data.

3.3.3 Fish

Length-frequency analysis was undertaken for each fish species recorded, whereby each species was classified into four age classes based on body size (SL mm). Age classes were determined from the literature (i.e. Puckridge and Walker 1990, Allen *et al.* 2002), and was based on knowledge of size of maturity for each species (Table 3.4).

Table 3.4: Standard lengths used for each age class for each species recorded.

Age class	Western rainbowfish	Spangled perch	Pilbara tandan	Bony bream
New recruit	< 30	< 30	< 30	< 30
Juvenile	31-40	31-50	31-70	31-80
Sub-adult	41-50	51-70	71-90	81-110
Adult	>50	>70	>90	>110

4 RESULTS AND DISCUSSION

4.1 Database searches

The database searches identified 384 records of aquatic fauna taxa and waterbirds (Table 4.1). The total included 302 species of invertebrate and 82 species of vertebrate. Insects and Crustaceans account for over 55% of the total taxa previously recorded. These records provide context for the aquatic ecosystems of the Greater Paraburdoo Iron Ore Hub.

Table 4.1: Aquatic fauna recorded within 100 km of the Study Area.

Type	Taxonomic Group	Common Name	Number of Taxa
Invertebrate	Annelida	Segmented Worms	15
Invertebrate	Nematoda	Roundworms	5
Invertebrate	Platyhelminthes	Flatworms	1
Invertebrate	Arachnida	Mites	30
Invertebrate	Insecta	Insects	159
Invertebrate	Crustacea	Crustaceans	56
Invertebrate	Mollusca	Molluscs	5
Invertebrate	Cnidaria	Hydras	1
Invertebrate	Porifera	Freshwater Sponges	1
Invertebrate	Rotifera	Rotifers	29
Vertebrate	Actinopterygii	Fish	7
Vertebrate	Reptilia	Turtles	1
Vertebrate	Amphibia	Frogs	13
Vertebrate	Aves	Waterbirds	61
		Total	**384**

Of the taxa recorded within 100 km of the Study Area, eight species of waterbird, one fish and one species of insect are considered to be of conservation significance (Table 4.2). The waterbirds *Calidris ferruginea* (Curlew Sandpiper) and *Rostratula australis* (Australian Painted Snipe), are listed as Critically Endangered (CR) and Endangered (EN) on the IUCN Redlist of Threatened Species, respectively and are known to occur in temporary freshwater wetlands. The Fortescue grunter *Leiopotherapon aheneus* is endemic to the Pilbara and known only from three river systems, including the Ashburton. It is listed as a Priority 4 (P4) species on the DBCA Threatened and Priority Fauna Species List (DBCA 2019b) and Near Threatened on the IUCN Redlist (IUCN 2019).

The database search also identified 19 invertebrates that were endemic to the search area, with one insect listed on the IUCN Redlist (Table 4.2). The Pilbara pin damselfly, *Eurysticta coolawanyah* is currently listed as Vulnerable (IUCN 2019; see Appendix A for IUCN classification definitions). This listing was based on its collection from less than five locations. Although the listing was revised recently (2016), the revision did not consider grey literature records (baseline surveys and impact assessments associated with mining and development in the region). Its extent of occurrence, based on a polygon around the known occupied areas (four locations listed in the IUCN listing), is 7,937 km² (Dow 2019); however, Bush *et al.* (2014,

Table S2) provide an estimate of the current extent of suitable habitat as 298,177 km² . Including the PBS and grey literature records (sampling programs undertaken by the authors and others), the species has now been recorded from numerous locations in the Pilbara, albeit in low numbers and with a disjunct distribution (Pinder *et al.* 2010, Jess Delaney, unpub. data).

Table 4.2: Endemic and conservation significant aquatic fauna recorded within 100 km.

Taxonomic Group	Family	Taxa	Conservation Status			Endemic
			WA	EPBC	IUCN	
Nematoda		Nematoda sp. 10 (PSS)				Y
Arachnida	Arrenuridae	*Arrenurus* sp. S4 (PSS)				Y
Arachnida	Halacaridae	Halacaridae sp. S3 (PSS)				Y
Arachnida	Hydryphantidae	*Diplodontus* sp. B (PSW)				Y
Arachnida	Limnesiidae	*Limnesia* sp. P1 (PSW)				Y
Insecta	Ceratopogonidae	*Forcypomyia* sp. P3 (PSW)				Y
Insecta	Isostictidae	*Eurysticta coolawanyah*			VU	Y*
Crustacea	Candonidae	*Areacandona* '*atomus*' (PSS)				Y
Crustacea	Candonidae	*Areacandona* sp. 5' (PSS)				Y
Crustacea	Candonidae	Candonid Genus 2 sp. 1 (PSS)				Y
Crustacea	Candonidae	Candonid Genus 5 sp. 1				Y
Crustacea	Candonidae	*Deminutiocandona* '*aporia*' (PSS)				Y
Crustacea	Candonidae	*Deminutiocandona* cf. '*mica*' (PSS)				Y
Crustacea	Candonidae	*Pilbaracandona* 'sp. 4' (PSS)				Y
Crustacea	Chydoridae	*Chydorus kalypygos*				Y
Crustacea	Cyprididae	*Sarscypridopsis* sp 3 (nr 165)				Y
Crustacea	Limnocytheridae	*Gomphodella* cf. sp. 5 (PSS)				Y
Crustacea	Limnocytheridae	*Gomphodella* sp. 5 (PSS)				Y
Rotifera	Lecanidae	*Lecane opias*				Y
Actinopterygii	Terapontidae	*Leiopotherapon aheneus*	P4		NT	
Aves	Charadriidae	*Charadrius veredus* (Oriental Plover)		MI		
Aves	Rostratulidae	*Rostratula australis* (Australian Painted Snipe)			EN	
Aves	Scolopacidae	*Actitis hypoleucos* (Common Sandpiper)		MI		
Aves	Scolopacidae	*Calidris acuminata* (Sharp-tailed Sandpiper)		MI		
Aves	Scolopacidae	*Calidris ferruginea* (Curlew Sandpiper)		CR MI	NT	
Aves	Scolopacidae	*Calidris melanotos* (Pectoral Sandpiper)		MI		
Aves	Scolopacidae	*Calidris subminuta* (Long-toed Stint)		MI		
Aves	Scolopacidae	*Tringa glareola* (Wood Sandpiper)		MI		

P4 = Priority 4 species, NT= Near Threatened, VU = Vulnerable, CR = Critically Endangered; MI = Migratory species.

4.2 Previous surveys

No previous aquatic sampling has been conducted within the Greater Paraburdoo Iron Ore Hub; however, the Pilbara Biological Survey (PBS) did sample a number of sites nearby (Pinder *et al.* 2010), including two sites on Turee Creek sampled as part of the current study (i.e. long-term reference sites Fork Spring and Paperbark Spring; Table 4.3: Results of previous aquatic surveys conducted in the vicinity of the Study Area.Table 4.3). None of the broader Pilbara wide aquatic surveys, such as Masini (1988) or Pinder and Leung (2009), included any sites near the Study Area.

As part of the PBS (Pinder *et al.* 2010), water quality and aquatic fauna (zooplankton and macroinvertebrates) of 100 sites across the Pilbara were sampled between 2003 and 2006. Aquatic macrophytes and riparian flora were also sampled (Gibson *et al.* 2015). The survey included most wetland types from the region, such as wetlands, river pools, claypans, rock pools and springs. Sites within the vicinity of the Study Area included; Fork Spring, Paperbark Spring, Bobswim Pool, Kennedy Well Claypan and Yandabiddy Pool (Pinder *et al.* 2010).

The PBS recorded a combined total of 91 zooplankton, 163 macroinvertebrates, and ten macrophyte (submerged and emergent) taxa known from the five nearby sites, over two seasons. Of these taxa, only one is listed; the Pilbara Pin damselfly *E. coolawanyah* (Table 4.3). As mentioned above, this species is currently listed on the IUCN (2019) Redlist of Threatened Species as Vulnerable; however, its listing may need some revision given it has been now recorded from numerous locations across the Pilbara, and from a much wider area than the listing indicates (i.e. see Pinder *et al.* 2010). Records of *E. coolawanyah* from nearby surface water pools are shown in Figure 4.9 (see section 4.8).

The database search indicated that an additional 17 invertebrates were endemic to the search area. These include the following:

Zooplankton;

- rotifer *Lecane opias*;
- ostracods *Areacandona* '*atomus*', *Areacandona* sp. 5, Candonid Genus 2 sp. 1, Candonid Genus 5 sp. 1, *Deminutiocandona* '*aporia*', *Deminutiocandona* cf. '*mica*', *Pilbaracandona* 'sp. 4', *Sarscypridopsis* sp 3 (nr 165), *Gomphodella* cf. sp. 5 and *Gomphodella* sp. 5
- Cladocera *Chydorus kallipygos*

Macroinvertebrates;

- round worm Nematoda sp. 10
- the water mites *Arrenurus* sp. S4, Halacaridae sp. S3, *Diplodontus* sp. B and *Limnesia* sp. P1 (Table 4.3).

A number of these species were recorded during the stygofauna component of the PBS, the Pilbara Stygofauna Survey (PSS). These include *Arrenurus* sp. S4 (PSS050), Halacaridae sp. S3 (PSS110), *Areacandona* sp. 5' (PSS046), *Deminutiocandona* '*aporia*' (PSS052, PSS055 and PSS058), *Deminutiocandona* cf. '*mica*' (PSS065 and PSS177), *Pilbaracandona* 'sp. 4' (PSS050), *Gomphodella* sp. 5 (PSS046 and PSS050) and *Gomphodella* cf. sp. 5 (PSS179). All were recorded from bores within close proximity to the Study Area, with many being located along Seven Mile Creek, Pirraburdu Creek or Turee Creek. For many of these species the taxonomy is unresolved, and specimens were assigned to morphotypes during the PSS.

The rotifer *Lecane opias* was recorded from Bobswim Pool in May 2005 (Pinder *et al.* 2010). It is unclear why the database search classified this species as endemic to the search area, given it is also known from the Gascoyne, Murchison and Geraldton Sandplains regions of Western Australia, as well as Tasmania.

Table 4.3: Results of previous aquatic surveys conducted in the vicinity of the Study Area.

Report Reference	Sites Sampled	Conservation Significant Aquatic Fauna Recorded
Pilbara Biological Survey (Pinder *et al.* 2010)	Fork Spring	*Diplodontus* sp. B *Limnesia* sp. P1 *Sarscypridopsis* sp 3 (nr 165)
	Paperbark Spring	*Diplodontus* sp. B *Limnesia* sp. P1
	Bobswim Pool	*Lecane opias* *Chydorus kallipygos*
	Kennedy Well Claypan	
	Yandabiddy Pool	*Eurysticta coolawanyah*

The roundworm, Nematoda sp. 10 was recorded from Whiskey Pool on the Ashburton River, 255 km downstream of the Study Area during the PBS (Pinder *et al.* 2010). This was the only record of the species during the Pilbara wide survey. Although it doesn't appear to have been recorded elsewhere since, surface water Nematoda are an often-neglected group with respect to taxonomic identification. This species may be more widely distributed but has simply been reported as Nematoda sp. The DBCA and majority of consultancies no longer attempt to identify surface water Nematoda to species.

The Cladocera *Chydorus kallipygos* was only recorded from Bobswim Pool during the PBS (Pinder *et al.* 2010). There do not appear to be any other records of this species from the Pilbara, but records of this species elsewhere have used several different spellings (i.e. *Chydorus kallipigos* and *Chydorus kalypygos*).

No aquatic flora of conservation significance is known from the area (PBS data; Rio Tinto 2004, 2012, 2014).

4.3 Habitat Assessment

All raw habitat data is provided in Appendix C and a summary of the overall habitat assessment in (Table 4.4). While most sites were dominated by transmissive sediments such as gravel, pebbles and sand, clay dominated the substrate at SM3, SM5, SM6, and TC3. Composition by bedrock was greatest at Eastern Range sites and TC2 (Paperbark Spring).

In-stream habitat was generally high throughout the Study Area and included complex heterogenous substrates, such as submerged macrophyte, emergent macrophyte, large woody debris (LWD), root mats and trailing vegetation. Exceptions to this included the two Eastern Range gorge pools which comprised low in-stream habitat diversity, generally lacked complex habitat types and instead were dominated by detritus and open sediment.

Algal cover was notably high across the Study Area and was most apparent at sites with cattle access. At sites where algal cover was present, percentage cover ranged from 6% at ER3 to 66% at PC3. Average algal cover was 24% at Seven Mile, 49% at Pirraburdu Creek, 2% at Eastern Range and 17% at Turee Creek. The one Western Range site recorded 15% algal cover. SM3, ER1 and ER2 had no obvious algal growth.

Table 4.4.Summary of aquatic habitats sampled, including site photos.

Site	Habitat	Description	Site photo
SM1	**Ephemeral creekline pool**	Dry pool with rushes (*Typha domingensis*) and sedges (*Schenoplectus subulatus*) along the banks, some introduced weeds present. Riparian vegetation including open cover by *Eucalyptus camaldulensis*. The site had recently dried. A hyporheic sample was collected as water was present below the creekbed.	
SM2	**Semi-permanent/Permanent creek pool**	Emergent vegetation along the banks dominated by*Typha* domingensis, with some *Cyperus vaginatus*. Open canopy of *Eucalyptus camaldulensis*. Eutrophication apparent – heavy algal cover, cattle access. Maximum water depth of 1.2 m.	

Site	Habitat	Description	Site photo
SM3 (Kelly's Pool)	**Semi-permanent pool (historically was permanent and deep)**	Little to no fringing riparian vegetation, some *Schenoplectus subulatus* sedges and *Dysphania ?kalpari* herbs. Low abundance of submerged macrophytes. Anoxic sludge sediment layer, over predominately clay sediment. Maximum water depth of 0.2 m.	
SM4	**Artificially maintained permanent creekline**	Narrow, shallow channel downstream of the Paraburdoo Plant Discharge point. *Cyperus vaginatus* dominanted the emergent macrophyte along the creek's edge. Riparian vegetation comprised *Melaleuca glomerata*, Eucalypts, *Acacia* (*Acacia ampliceps*, *Acacia ?citrinoviridis*, *Acacia coriaceae* subsp. *pendens*) and shrubs (i.e. *Petalostylis labicheoides* and the introduced *Vachellia farnesiana*). Introduced couch grass also present. Maximum water depth of 0.25 m. ** Contaminated with hydrocarbons at the time of sampling **	
SM5	**Permanent pool – artificially maintained**	Large permanent pool including large backwater areas. Emergent macrophyte comprised *Cyperus vaginatus* and *Typha domingensis*. Riparian vegetation including *Eucalyptus camaldulensis* and *Sesbania cannibina*. Maximum water depth of 1.6 m.	

Site	Habitat	Description	Site photo
SM6	**Ephemeral pools artificially maintained**	Two small pools maintained by underground flows from upstream (SM5 and ultimately Paraburdoo Plant discharge). Dense riparian vegetation comprising Eucalypts, *Typha domingensis*, *Cyperus vaginatus*, fringing grasses and introduced species. High in-stream algal cover. Cattle impacts apparent. Maximum water depth of 0.3 m.	
PC1 (Ratty Spring)	**Semi-permanent (groundwater fed)**	Series of pools and interconnecting riffles. Good, dense riparian vegetation cover, consisting of Eucalypts, *Acacia ampliceps*, shrubs (i.e. *Petalostylis labicheoides*, *Adriana tomentosa* var. *tomentosa*), *Melaleuca bracteata*, sedges (*Cyperus vaginatus* and *Schoenoplectus subulatus*), and *Typha domingensis*. High in-stream algal cover. Cattle impacts apparent. Maximum water depth of 2.0 m.	
PC2	**Semi-permanent (groundwater fed)**	Series of long pools. Riparian vegetation comprising *Melaleuca*, Eucalypts, *Typha domingensis*, and sedges (*Cyperus vaginatus*, *Schenoplectus subulatus*, and ?*Schoenoplectus* sp. (juv.)). Cattle impacts apparent. Maximum water depth of 0.9 m.	
PC3 (Pirraburdu Spring)	**Semi-permanent (groundwater fed)**	Narrow groundwater-fed semi-permanent pool. Riparian vegetation comprising *Melaleuca*, Eucalypts, shrubs (*Petalostylis labicheoides*), sedges (*Cyperus* ?*vaginatus*, *Cyperus vaginatus* and *Schoenoplectus subulatus*), *Typha domingensis* and introduced buffel grass (*Cenchrus ciliaris*). Introduced passion vine present. High in-stream algal cover. Current disturbances include cattle impacts and introduced vegetation. Maximum water depth of 1.6 m.	

Site	Habitat	Description	Site photo
PC4	**Ephemeral creek**	Dry creekbed, Riparian vegetation including *Melaleuca glomerata*, *Acacia* (i.e. *Acacia citrinoviridis* and *Acacia coriaceae* subsp. *pendens)*, shrubs (i.e. *Tephrosia rosea* var. Fortescue creeks and *Petalostylis labicheoides*) and sedges (*Cyperus vaginatus*).	
PC5	**Ephemeral creek**	Dry creekbed. Riparian flora including Acacia *citrinoviridis* and *Acacia coriaceae* subsp. *pendens*.	
WR1	**Ephemeral gorge pool**	Dry ephemeral gorge pool. When inundated the water would sit against the cliff face. Riparian vegetation including *Corymbia ferriticola*, *Acacia* (*Acacia citrinoviridis* and *Acacia tetragonophylla*), shrubs (*Pluchea rubelliflora*, *Psydrax latifolia*, and *Eremophila* sp.), herbs (*Stemodia grossa Stemodia viscosa*, *Nicotiana benthamiana*, and *Eriachne ?mucronata*), and sedges (*Cyperus vaginatus*).	

Site	Habitat	Description	Site photo
WR2	**Semi-permanent gorge pool**	Semi-permanent gorge pool against cliff face maintained by aspect and low evaporation. Riparian vegetation including iron plant (*Astrotricha hamptonii*), *Capparis spinosa* subsp. *nummularia* *Grevillea berryana*, *Eriachne ?mucronata* and *Ficus brachypoda*. Algal bloom present. Maximum water depth of 2.5 m.	
WR3	**Ephemeral creek**	Dry creekbed, characterised by *Triodia* few individual Eucalypts and the shrub *Senna glutinosa* ?subsp. *glutinosa*. A declared rare flora *Aluta quadrata* was also present.	
ER1	**Likely permanent gorge pool**	Small likely permanent rock/gorge pool. No trailing vegetation, but riparian vegetation includes *Eucalyptus* and fig *Ficus brachypoda*. No in-stream submerged macrophyte. No current disturbance. Maximum water depth of 1.3 m.	

Site	Habitat	Description	Site photo
ER2	**Semi-permanent gorge pool**	Small semi-permanent rock/gorge pool. No trailing vegetation, but riparian vegetation includes open *Eucalyptus* sp. Some *Cyperus ?vaginatus* sedges present. No algae or submerged macrophyte present. No current disturbance. Maximum water depth of 0.4 m.	
ER3	**Permanent creek pool**	Series of permanent creek pools (likely some connection to groundwater). Good fringing vegetation including *Cyperus vaginatus* and *Schenoplectus subulatus* and riparian vegetation including *Eucalyptus camaldulensis*, *Melaleuca glomerata* and date palm. Cattle access. Maximum water depth of 1.2 m.	
TC1	**Spring**	Permanent spring (Fork Spring). Open riparian vegetation of *Eucalytus camaldulensis* and *Melaleuca bracteata*. Emergent *Cyperus vaginatus* sedge along the banks. Cattle impacts apparent. Maximum water depth of 0.5 m.	

Site	Habitat	Description	Site photo
TC2	Spring	Permanent spring (Paperbark Spring) with high proportion of bedrock substrate along the creekbed. Open riparian vegetation including Eucalypts, *Melaleuca glomerata* and *Acacia sclerosperma* subsp. *sclerosperma.* Sedges along the water's edge (*Cyperus vaginatus*). Cattle impacts apparent. Maximum water depth of 0.3 m.	
TC3	Semi-permanent creek pool	Series of large semi-permanent/permanent creek pools (at Jezzas). Open *Eucalyptus camaldulensis* overstorey, with *Acacia* (*Acacia ampliceps*, *Acacia citrinoviridis*, and *Acacia sclerosperma* subsp. *sclerosperma*), and shrubs (*Eremophila fraseri* subsp. *fraseri*), and *Cyperus vaginatus* along the banks. Clay substrates with some bedrock and sand. Cattle impacts apparent. Maximum water depth of 0.4 m.	

4.4 Water quality

All raw water quality data are provided in Appendix D.

4.4.1 In situ

In situ water quality generally indicated that these sites were under stress from drying, with low rainfall and lack of flushing leading to the creeks and waterholes receding and undergoing evapoconcentration of ions and nutrients. The general lack of water in the area also meant that cattle were concentrated around these remaining pools, leading to increased nutrient loads. This, coupled with the high light intensity, resulted in abundant algal and macrophyte growth. As such, most sites recorded *in situ* water quality values outside default ANZECC/ARMCANZ (2000) GVs for the protection of aquatic systems in the tropical north-west for most analytes (see Appendix B).

Electrical conductivity (EC) ranged from 110 µS/cm (at ER1) to 4,332 µS/cm (at SM3). Most sites were classified as brackish, with the exception of PC1 (1473 µS/cm), ER1, ER2 (1119 µS/cm), WR2 (194 µS/cm), and all Turee Creek sites. All but ER1 and WR2 exceeded the default ANZECC/ARMCANZ (2000) GV. Most Pilbara waters have wide ranging EC, with large temporal and seasonal variability recorded as waters recede in the drier months and ionic concentrations evapoconcentrate. Generally, sites with EC less than 1,500 µS/cm experience little ecological stress, but a considerable shift in aquatic fauna assemblages is known to occur above this threshold. Many sites in the Study Area were likely under stress from the elevated EC.

The range in DO across the Greater Paraburdoo Iron Ore Hub and long-term reference sites was extreme, with 15.7% being the lowest DO recorded (at TC3) and 225.7% the highest (SM3). Five sites recorded low DO, below the lower default GV; SM2, SM6, PC1, PC3 and TC3. DO recorded from TC3 and SM6 (22.2%) were notably low, and likely to result in oxygen stress. The super saturated DO recorded from SM3 was likely due to the high submerged macrophyte growth at this site. It is likely that this site experienced oxygen stress overnight when respiration by the many plants and bacteria would exceed photosynthesis.

pH was also highly variable, ranging from acidic through circum-neutral to basic. Lowest pH was recorded from ER1 (5.97) and highest from SM3 (9.28). These two sites were the only sites which recorded pH outside the default ANZECC GVs.

Turbidity was generally low across all sites, indicating high water clarity and light penetration. Exceptions to this were SM4 (16.5 NTU) and PC2 (21.9 NTU), both of which recorded turbidity in excess of the default ANZECC GV.

4.4.2 Ionic composition

Cation composition at most sites was of the order sodium (Na) > magnesium (Mg) > calcium (Ca) > potassium (K). Exceptions to this were WR2, ER1 and TC1, all of which recorded cation concentrations in the order Ca > Na > Mg > K. Although, anion composition at ER2 was dominated by Na, sub-dominance was by Ca rather than Mg.

Anions were generally dominated by hydrogen carbonate (HCO_3); however, SM3, SM5 and SM6 were all chloride (Cl) dominated sites. Differences in ionic composition can reflect differing sources of water, with greater hydrogen carbonate dominance indicating greater contributions by groundwater, and Cl waters likely reflecting recent rainfall and/or catchment runoff.

Gorge pools (i.e. WR2, ER1 and ER2) had considerably lower ionic concentrations than creek pools.

Alkalinity measures the capacity of the water to resist sudden changes in pH, i.e. it is the buffering capacity of the water. Alkalinity of less than 20 mg/L is considered low and the system would have little ability to buffer against rapid changes in pH which may affect aquatic life. Alkalinity recorded in the current study was high, with most sites recording values greater than 200 mg/L. Only two sites recorded alkalinity below 200 mg/L (WR2 and ER1), however, even these sites were above the threshold of 20 mg/L.

4.4.3 Nutrients

Nitrogen ammonia (N_NH_3) concentrations were generally low, with the exception of two long-term monitoring sites (TC2 and TC3; Figure 4.1). Concentrations from TC3 were considerably higher than all other sites and exceeded the default 95% toxicity GV (Figure 4.1).

Nitrogen nitrate (N_NO_3) ranged from 0.03 mg/L (at WR2) to 9.77 mg/L (at SM4). Most sites recorded high concentrations, in excess of the default 95% GV (Figure 4.1). Exceptions to this were SM3, WR2, ER2 and TC3. Considerably high nitrate concentrations were recorded from SM4, SM6, PC1, PC3 and TC1 (Figure 4.1).

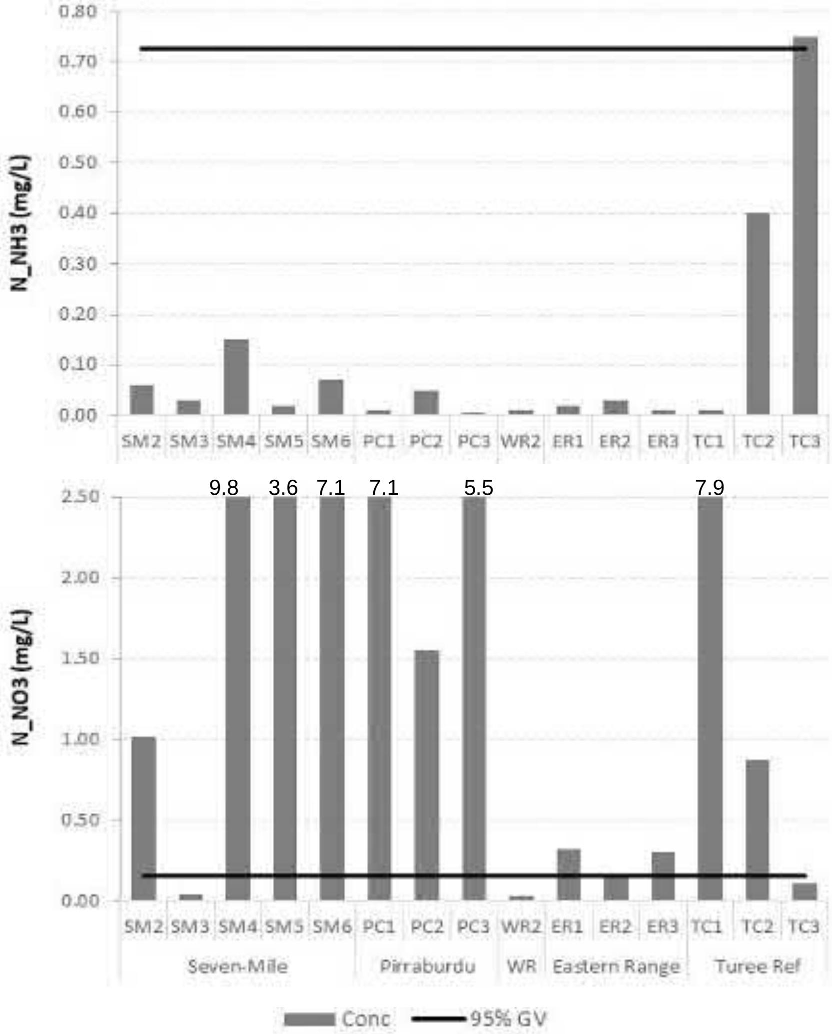


Figure 4.1. Ammonia (N_NH_3) and nitrate (N_NO_3) concentrations recorded from each site (mg/L), in comparison to default ANZECC/ARMCANZ (2000) 99% and 95% toxicity GVs. NB: Some N_NO_3 concentrations are above the limit of the y-axis.

Nitrogen oxides (N_NOx) exceeded the default eutrophication GV at all sites (Figure 4.2). Concentrations ranged from 0.03 mg/L (at WR2) to 10.30 mg/L (at SM4). Lowest N_NOx concentrations were recorded from SM3, WR2, ER1, ER2, ER3 and TC3 (Figure 4.2). Generally, N_NOx concentrations were highest from sites with high cattle activity and access, or those downstream of the current discharge point (i.e. SM4, SM5 and SM6).

Concentrations of total nitrogen (TN) were variable but generally high (Figure 4.2). All but WR2 exceeded the default eutrophication GV. Again, highest concentrations were generally recorded from sites with high cattle activity and access, or those downstream of the current discharge point.

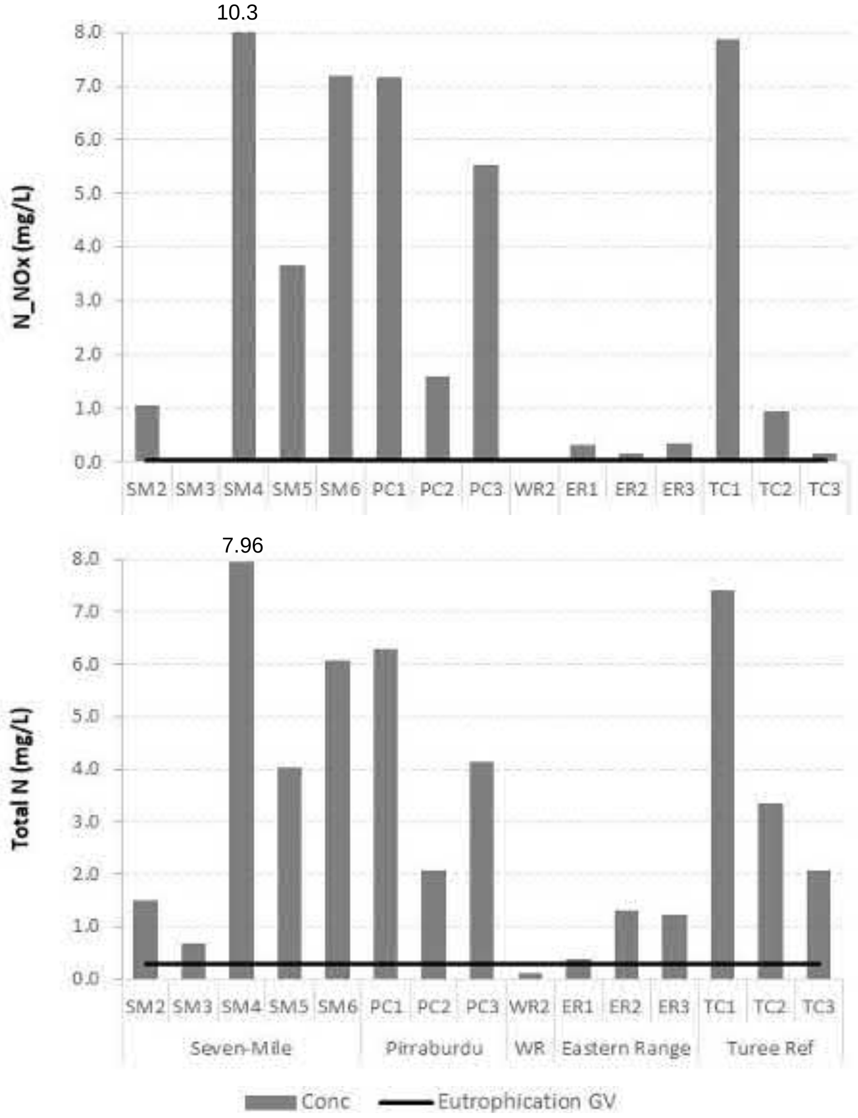


Figure 4.2. Nitrogen oxide (N_NOx) and total nitrogen (TN) concentrations recorded from each site (mg/L), in comparison to default ANZECC/ARMCANZ (2000) eutrophication GVs.

Total phosphorus (TP) was also high across Greater Paraburdoo Iron Ore Hub sites (Figure 4.3). WR2 was the only site which recorded TP concentrations below the default eutrophication GV (Figure 4.3). TP ranged from 0.007 mg/L (at WR2) to 0.19 mg/L (at TC2). Three sites recorded TP concentrations more than ten times the default eutrophication GV; PC2 (0.16 mg/L), TC2 (0.19 mg/L) and TC3 (0.15 mg/L; Figure 4.3).

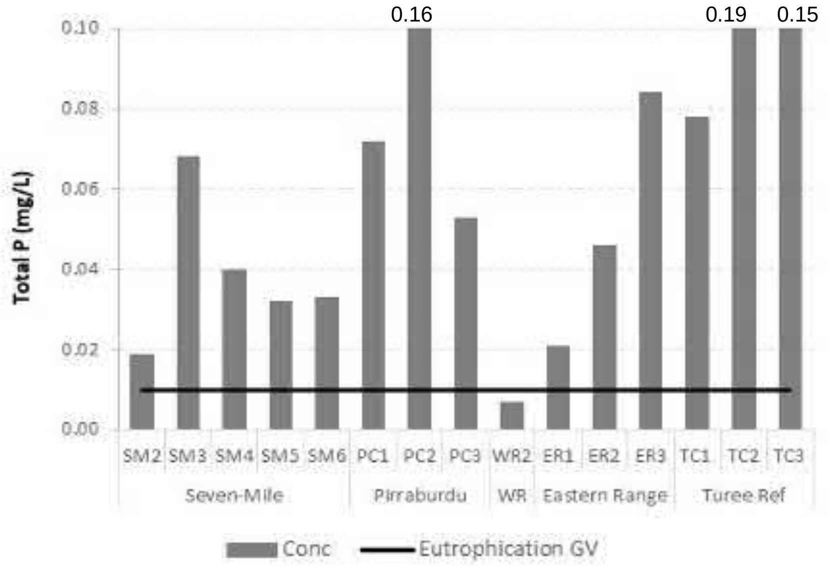


Figure 4.3. Total phosphorus (TP) concentrations recorded from each site (mg/L), in comparison to the default ANZECC/ARMCANZ (2000) eutrophication GV.

The gorge pool in Western Range (WR2) recorded consistently low concentrations of all nutrients, particularly in comparison to other sites sampled during this study.

4.4.4 Dissolved metals

Dissolved metal concentrations were generally low, with some analytes recording concentrations below LODs (i.e. cadmium, lead and nickel). However, a number of dissolved metals were recorded in concentrations in excess of default GVs at some sites (Figure 4.4). Elevated dissolved metals included:

- Dissolved aluminium (dAl) concentrations exceeded the 99% GV at ER1.
- Dissolved arsenic (dAs) concentrations exceeded the 99% GV at a number of sites including SM2, SM3, S5, PC1, PC2, PC3, ER3, TC2 and TC3. There were no exceedances of the 95% GV.
- Dissolved boron (dB) concentrations exceeded the 99% GV at all sites except WR2 and ER1. The 95% GV was also exceeded at SM2, SM3, SM4, SM5, SM6 and TC2.
- Dissolved chromium (dCr) exceeded the 99% GV at TC1.
- Dissolved zinc (dZn) exceeded the 95% GV at SM4. However, once hardness was taken into account, this site did not exceed the HMGV[5] (Figure 4.4).

[5] Hardness is known to ameliorate the toxicity of some metals (Cd, Cr, Pb, Ni, Zn), and therefore the ANZECC/ARMCANZ (2000) guidelines provide formulas to develop alternate GVs which take into account the water hardness recorded at the time of survey. These alternate GVs are known as hardness-modified GVs (HMGVs). Although HMGV algorithms are also provided for dCu within the ANZECC/ARMCANZ (2000) guidelines, recent studies suggest the default HMGV for dCu is not sufficiently conservative to protect sensitive aquatic biota from dCu toxicity (Markich *et al*. 2005), and therefore adjusting for hardness is not recommended for dCu.

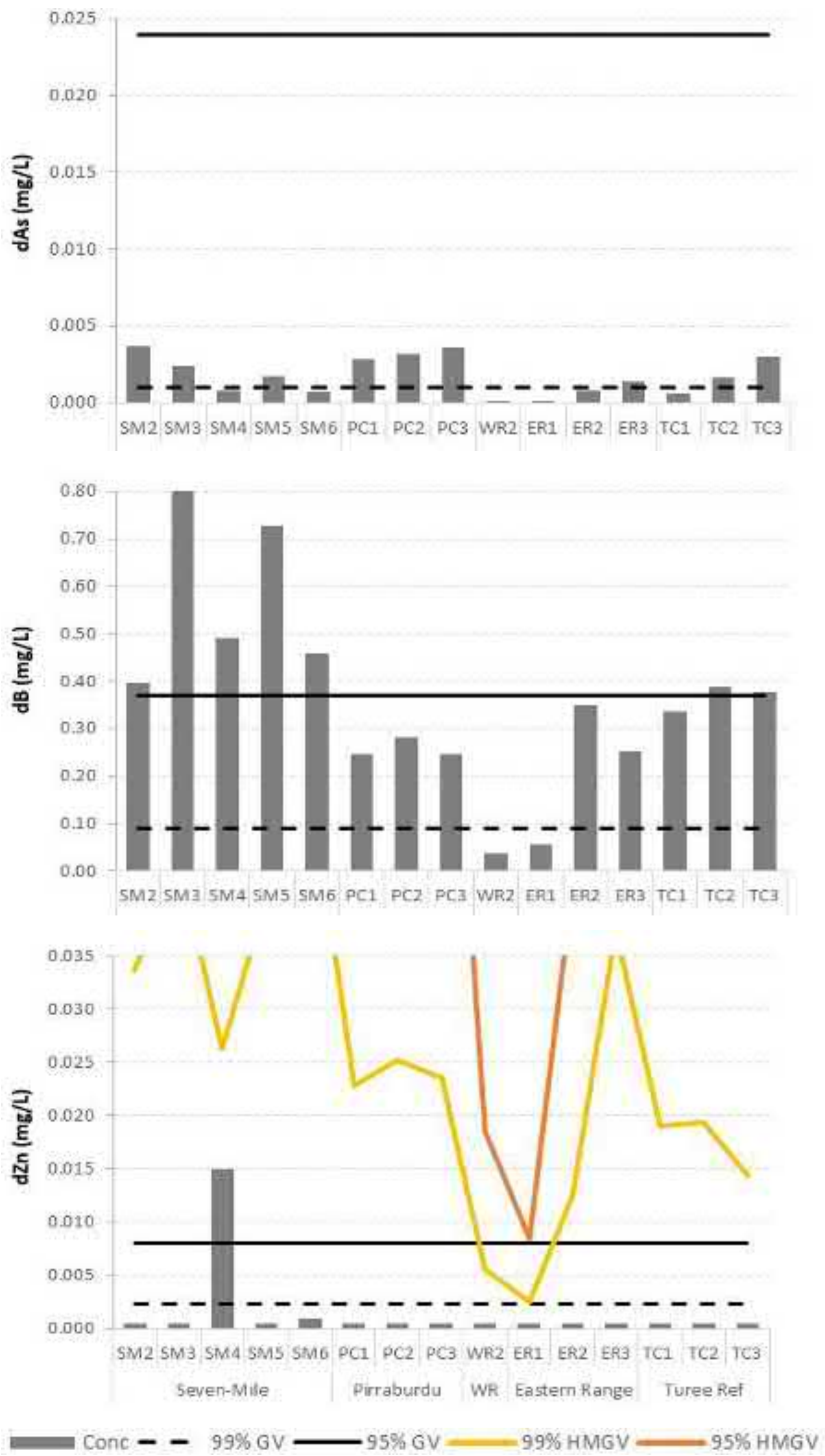


Figure 4.4. Concentrations of selected dissolved metals recorded from each site, in comparison to default 99% ANZECC GVs, default 95 % GVs, and hardness-modified GVs (for zinc only).

4.5 Submerged and emergent vegetation

4.5.1 Taxa composition and richness

A total of 11 macrophyte taxa was collected during the dry season Greater Paraburdoo aquatic survey (Table 4.5). This included five emergent macrophytes and six submerged macrophytes

(Table 4.5). Other riparian vegetation collected included Eucalypts, *Melaleuca*, ghost gum, shrubs, *Acacia* species, *Grevillea*, herbs and grasses (Table 4.5).

Emergent macrophytes included *Cyperus vaginatus*, *Schoenoplectus subulatus* (Plate 4.1) and *Typha domingensis*. Additionally, there were two taxa which could not be definitively identified to species; *Cyperus* ?*vaginatus* and ?*Schoenoplectus* sp. (juv.). Resolution on the former was not possible due to a lack of material (specifically flowering parts), and the latter due to immaturity of the specimens collected. Within the Pilbara bioregion, fringing habitats which access permanent surface groundwater are only present in high abundance along larger river systems. The presence of specific phreatophytic flora taxa is used to indicate dependence of such vegetation on surface and/or subsurface groundwater, which in turn indicates water permanence and potential significance of the system, especially for those not associated with large river or drainage systems (Rio Tinto 2018). All emergent macrophytic flora taxa recorded are known indicators of moisture availability but are common and widespread throughout the Pilbara.

Plate 4.1. *Schoenoplectus subulatus* at SM6 (left) and *Potamogeton tricarinatus* at PC2 (right).

Submerged macrophytes comprised *Chara* sp. nr. *vulgaris*, *Vallisneria annua, Potamogeton tricarinatus* (Plate 4.1)*, Potamogeton tepperi, Ruppia* sp. and *Najas marina*. No macrophytes were recorded from the gorge pools WR3 and ER1, or the dry site on Pirraburdu Creek PC5 (Table 4.5). This is perhaps unsurprising given the ephemeral nature of these sites. No submerged macrophytes were recorded from the hydrocarbon contaminated SM4. Where flora was recorded, diversity was generally low and ranged from one (at SM4, WR1, WR2, ER2 and TC2) to seven (at PC2).

Table 4.5: Flora taxa recorded during the current study.

			Seven-Mile Creek						Pirraburdu Creek					Western Range			Eastern Range			Turee Creek		
Class/Order	**Family**	**Lowest taxon**	**SM1**	**SM2**	**SM3**	**SM4**	**SM5**	**SM6**	**PC1**	**PC2**	**PC3**	**PC4**	**PC5**	**WR1**	**WR2**	**WR3**	**ER1**	**ER2**	**ER3**	**TC1**	**TC2**	**TC3**
CHLOROPHYTA																						
CHAROPHYCEAE																						
Charales	**Characeae**	*Chara* sp. nr. *vulgaris*↓			✓		✓			✓									✓	✓		✓
PLANTAE																						
MAGNOLIOPSIDA																						
Apiales	**Araliaceae**	*Astrotricha hamptonii*													✓							
Asterales	**Asteraceae**	*Pluchea rubelliflora**												✓								
Brassicales	**Capparaceae**	*Capparis spinosa* subsp. *nummularia*													✓							
Caryophyllales	**Chenopodiaceae**	*Dysphania ? kalpari*			✓																	
Fabales	**Fabaceae**	*Acacia ampliceps*				✓			✓											✓		✓
		Acacia citrinoviridis										✓	✓	✓								✓
		Acacia ? citrinoviridis damm.				✓																
		Acacia coriaceae subsp. *pendens*				✓						✓	✓									
		Acacia sclerosperma subsp. *sclerosperma*																			✓	✓
		Acacia tetragonophylla												✓								
		Senna glutinosa ? subsp. *glutinosa*														✓						
		*Sesbania cannibina**					✓															
		Tephrosia rosea var. Fortescue creeks										✓										
		Vachellia farnesiana^				✓																
		Petalostylis labicheoides				✓			✓		✓	✓										
Gentianales	**Rubiaceae**	*Psydrax latifolia*												✓								
Lamiales	**Plantaginaceae**	*Stemodia grossa**												✓								
		*Stemodia viscosa**												✓								

			Seven-Mile Creek						Pirraburdu Creek					Western Range			Eastern Range			Turee Creek		
Class/Order	**Family**	**Lowest taxon**	**SM1**	**SM2**	**SM3**	**SM4**	**SM5**	**SM6**	**PC1**	**PC2**	**PC3**	**PC4**	**PC5**	**WR1**	**WR2**	**WR3**	**ER1**	**ER2**	**ER3**	**TC1**	**TC2**	**TC3**
	Scrophulariaceae	*Eremophila fraseri subsp. fraseri*																				✓
		Eremophila sp.												✓								
Malpighiales	**Euphorbiaceae**	*Adriana tomentosa* var. *tomentosa*							✓													
Myrtales	**Myrtaceae**	*Aluta quadrata* (T)^^														✓						
		Eucalyptus sp.*																✓				
		*Eucalyptus camaldulensis**					✓														✓	✓
		Corymbia ferriticola												✓								
		Melaleuca glomerata				✓						✓							✓		✓	
		Melaleuca bracteata							✓											✓		
Proteales	**Proteaceae**	*Grevillea berryana*													✓							
LILIOPSIDA																						
Alismatales	**Hydrocharitaceae**	*Vallisneria annua*↓				✓			✓		✓				✓				✓			
Poales	**Cyperaceae**	*Cyperus* ? vaginatus*									✓			✓				✓				
		*Cyperus vaginatus**	✓	✓		✓	✓	✓	✓	✓	✓	✓							✓	✓	✓	✓
		*Schoenoplectus subulatus**			✓				✓	✓	✓								✓			
		? *Schoenoplectus* sp. (juv.)*								✓												
	Poaceae	*Cenchrus ciliaris*^									✓											
		Eriachne ? *mucronata*												✓	✓							
Typhales	**Typhaceae**	*Typha domingensis**	✓	✓			✓	✓	✓	✓	✓											
EQUISETOPSIDA																						
Alismatales	**Hydrocharitaceae**	*Najas marina*↓																				✓
	Potamogetonaceae	*Potamogeton tepperi*↓					✓	✓														
		Potamogeton tricarinatusi↓								✓												
	Ruppiaceae	*Ruppia* sp.↓								✓												
Rosales	**Moraceae**	*Ficus brachypoda*												✓	✓		✓					

			Seven-Mile Creek						Pirraburdu Creek					Western Range			Eastern Range			Turee Creek		
Class/Order	**Family**	**Lowest taxon**	**SM1**	**SM2**	**SM3**	**SM4**	**SM5**	**SM6**	**PC1**	**PC2**	**PC3**	**PC4**	**PC5**	**WR1**	**WR2**	**WR3**	**ER1**	**ER2**	**ER3**	**TC1**	**TC2**	**TC3**
Solanales	**Convolvulaceae**	*Duperreya commixta*								✓												
	Solanaceae	*Nicotiana benthamiana*												✓								
		Taxa richness	**2**	**2**	**2**	**8**	**5**	**3**	**8**	**7**	**7**	**6**	**2**	**12**	**6**	**2**	**1**	**2**	**4**	**3**	**4**	**7**

^Introduced species

^^Declared rare flora

*Associated with creeks

**Seasonal wet areas, claypans and rivers

↓ submerged macrophyte

4.5.2 Conservation significant flora

None of the emergent or submerged macrophytes collected were of significance; however, a declared rare flora (DRF), *Aluta quadrata*, was found along the dry creekbed at WR3 in Western Range (Table 4.5). It was not known at the time of collection that this was a DRF. *Aluta quadrata* is a shrub which produces white flowers in June. It is restricted to a banded iron formation that runs east and west of Paraburdoo, in the southern edge of the Hamersley Range. Within this range *A. quadrata* is found on the edge of creeks, base of cliffs, rocky crevices and near the crest of ridges, specifically within three disjunct locations; Western Range, Pirraburdu Creek, and Howie's Hole. Genetic studies have been undertaken on this species to elucidate genetic diversity and guide management and rehabilitation programs (i.e. Byrne *et al.* 2016, Binks *et al.* 2019). Byrne *et al.* (2016) reported that each of these three populations were sufficiently genetically distinct to represent separate management units. The Binks *et al.* (2019) study focussed on the Western Range population and found there was a single metapopulation which displayed a genetic/geographic gradient across the range.

4.5.3 Introduced flora

Two introduced flora species were collected during the current study; the mimosa bush *Vachellia farnesiana* and buffel grass *Cenchrus ciliaris*. The former was recorded from SM4 and the latter from PC3. Other introduced species were observed in the field, including couch grass *Cynodon dactylon* (at SM4) and passion vine *Passiflora foetida* (at PC3).

4.5.4 Flora comparison with previous studies

Data on wetland vegetation of the Pilbara is limited, with varied sampling effort and taxonomic resolution across studies. However, wetland flora was sampled as part of the PBS, with a paper discussing conservation significance and distribution information due for publication next year (Mike Lyons, DBCA, unpub. data). In order to compare species lists with the current study, the DBCA kindly provided Biologic with data specific to the sites near the Study Area (i.e. Bobswim Pool, Fork Spring, Paperbark Spring and Yandabiddy Pool). Generally, macrophyte richness was greater at spring sites and those with more permanent water (Figure 4.5). PC2 recorded the greatest richness of macrophytes (emergent and submerged macrophytes combined) of any site in either study (Figure 4.5). Gorge pools of both Western and Eastern Range recorded low richness in comparison to other sites sampled in current study as well as those sampled during the PBS (Figure 4.5). In comparing sites sampled on both occasions, an additional macrophyte was recorded during the PBS at Fork Spring and an additional three macrophyte taxa from Paperbark Spring.

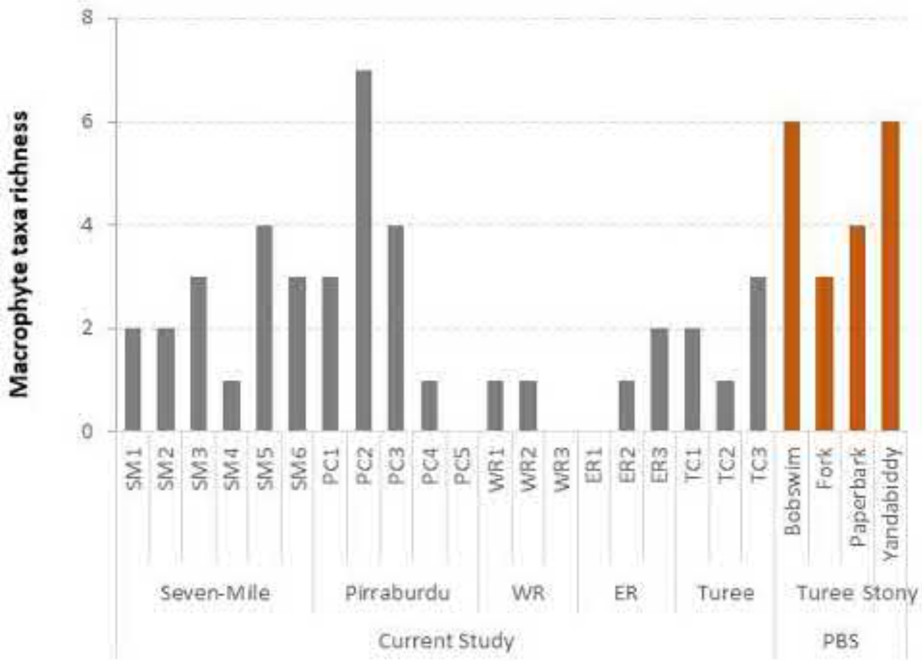


Figure 4.5. Macrophyte (emergent and submerged) richness recorded during in the current study, in comparison to the PBS from nearby sites (Mike Lyons, unpub. data).

4.6 Hyporheos fauna

Hyporheic samples were successfully collected from nine sites. Sediments and habitat at remaining sites were not conducive to sampling of the hyporheic zone either due to *Typha* stands along banks impeding access, or the dominance of clay or bedrock substrates. Although clay is highly porous, it has low hydraulic conductivity and transmissivity and does not provide water flow or habitat (interstitial space) for hyporheos fauna. Similarly, bedrock substrates disconnect surface waters from the hyporheic and groundwater environments.

4.6.1 Taxa composition and richness

A total of 64 invertebrate taxa was recorded from hyporheic zones sampled in the dry of 2019 (see Appendix E for a full taxonomic list). The taxa list included Gastropoda (one taxa), Oligochaeta (seven taxa), Ostracoda (seven), Copepoda (11), Amphipoda (one), Acarina (five), Diptera (18), Coleoptera (11), Hemiptera (one), and Trichoptera (one). Just under half of these were stygoxene (48%) and do not have specialised adaptations for life in groundwater habitats. These taxa were recorded from the hyporheic zone ‘by chance’ but can actively seek out this habitat as a refuge during times of drought or flood. Hyporheos fauna, comprising styogbites, permanent hyporheos stygophiles, occasional hyporheos stygophiles and possible hyporheic taxa, made up 44% of taxa collected. Of these, a total of 11% are directly dependent on groundwater for their persistence. This is consistent with a Pilbara-wide study of the hyporheic zone which reported that generally less than 20% of invertebrate taxa from hyporheic samples are totally reliant on groundwater (Halse *et al.* 2002). In that study, 8% of taxa were considered permanent hyporheos stygophiles and 5% were stygobites (Halse *et al.* 2002), compared with 3% permanent hyporheos styophiles and 8% stygobites recorded in the current study.

Possible hyporheic taxa included higher-level identifications for which taxa may have belonged to a stygal or hyporheos species (i.e. the oligochaetes Oligochaeta sp. imm/dam, Naididae spp., Tubificinae sp., *Pristina* spp., Phreodrilidae spp., copepods *Mesocyclops* sp. and *Thermocyclops* \`BCY066\`, and water mites Trombidiformes sp.), as well as juvenile cyclopoids (cyclopidae copepodites) and ostracods (Cyprinopsinae sp. juv.).

Hyporheos taxa included:

<u>Occasional hyporheos stygophiles:</u>

- ostracod *Cypretta* sp.
- copepods *Australoeucyclops karaytugi*, *Ectocyclops rubescens* and *Microcyclops varicans*
- water mite *Wandesia* sp. \`BAC004\`
- collembola Entomobryoidea spp.
- chironomid Pentaneurini sp. P1 (PSW)
- beetles Hydraenidae spp., *Hydrochus eurypleuron* and Scirtidae spp. (L)

<u>Permanent hyporheos stygophiles:</u>

- the ostracod *Limnocythere dorsosicula*
- water mite *Tillia* sp. \`BAC003\`

<u>Stygobites:</u>

- ostracods *Candonopsis tenuis* and *Vestalenula* sp. (dam.)
- copepods *Diacyclops humphreysi* and *Paracyclops intermedius*
- amphipod *Pilbarus millsi*

Overall, site invertebrate richness ranged from three (at SM1 and SM6) to 28 (at SM2; Figure 4.6). Stygoxenes dominated taxa richness at most sites except those with low overall richness such as SM1, SM6 and ER1. A number of sites recorded no groundwater dependent taxa (stygobites and permanent hyporheos stygophiles), including SM1, SM6, and WR2; although all three of these sites supported occasional stygophiles (Figure 4.6). The lack of stygobitic taxa recorded from SM1 is not surprising given this site was dry at the time of sampling and the groundwater was likely reduced and below the level of the karaman hole. SM6 was located at the extent of current dewatering discharge, where the creek had receded to a series of pools. It is likely the groundwater in this area is affected by dewatering and may not have extended to the level of the karaman hole at the time of sampling. WR2 is a likely permanent gorge pool, maintained by its aspect against the cliff face and the resulting lack of evaporation. As such, there may be no connection with the groundwater in this area, and the lack of permanent hyporheos stygophiles and stygobites is not surprising. The greatest richness of hyporheos taxa (including occasional stygophiles and possible hyporheic taxa) was from SM2, with a total of 15 taxa recorded. PC2 (Ratty Spring) recorded the second highest richness of hyporheic invertebrates with nine taxa (Figure 4.6). These sites have the greatest connection to groundwaters of those successfully sampled for hyporheos fauna.

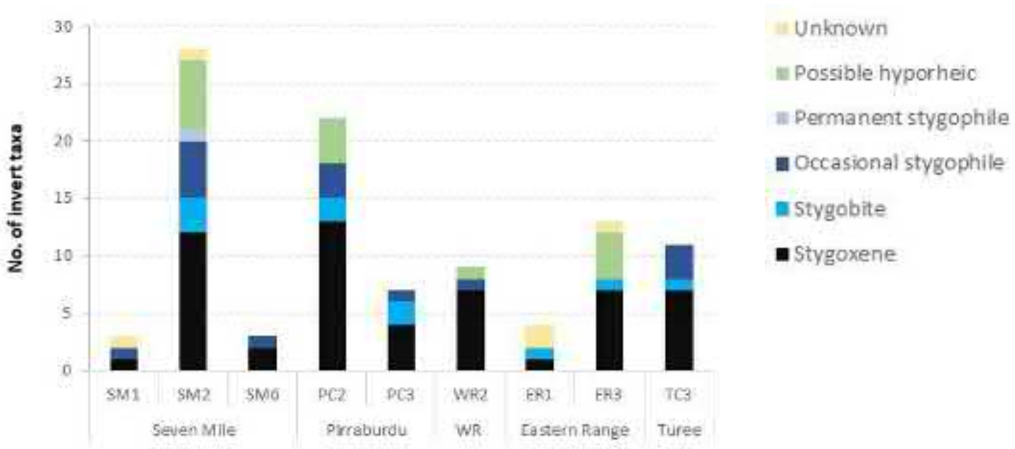


Figure 4.6: Classification of invertebrate taxa recorded from the hyporheic zone in the dry-19.

4.6.2 Conservation significant hyporheos taxa

These taxa are generally common and ubiquitous across the Pilbara; however, the water mites may contain locally significant taxa. The occasional hyporheos stygophile mite, *Wandesia* sp. `BAC004`, may be a species new to science or may belong to a known Pilbara species. The taxonomy of this genus in Western Australia is poorly known and the geographic ranges of the various species have not been determined. All described species of *Wandesia* are known from river interstices in eastern Australia. One known but undescribed species, *Wandesia* sp. P1 (nr *glareosa*), was recorded during the PBS from river pools and springs. The specimen recorded from PC2 in the dry-19 may be this species; however, specimens of *Wandesia* sp. P1 (nr *glareosa*) were not available for comparison.

The record of *Tillia* sp.`BAC003` from Pirraburdu Creek (PC3) likely represents the first record of this genus from the Pilbara and this specimen may be a species new to science. There are currently two species of described *Tillia* current known, both of which appear to be endemic to the south-west of Western Australia (Harvey 1998). *Tillia* have only been recorded from interstitial deposits and cave systems, and as such it was classified as a permanent hyporheos stygophile for the purposes of this study.

The stygal amphipod is not considered to be of conservation significance due to its relatively widespread distribution across the Pilbara. It is known from Weeli Wolli Spring, pools at Millstream, and the Fortescue and Ashburton River catchments.

4.7 Macroinvertebrates

4.7.1 Taxa composition and richness

A total of 210 macroinvertebrate taxa was recorded during the current study, comprising Hydrozoa, Nematoda, four gastropod taxa (freshwater snails), 13 oligochaete taxa (aquatic segmented worms), Hirudinea (leeches), 13 Maxillopoda (copepods), four Cladocera (water fleas), six Ostracoda (seed shrimp), 18 Prostigmata (water mites), 49 Coleoptera (beetles), 43 Diptera (two winged flies), seven Ephemeroptera (mayflies), 27 Hemiptera (true bugs), 17

Odonata (dragonflies and damselflies) and six Trichoptera (caddisflies; see Appendix F for the full taxonomic list).

Of the 210 taxa recorded, 76 were singletons and recorded from one site only. More common taxa, recorded from 75% of sites (11 or more), included cyclopoid copepodites and naupii, juvenile ostracods (Ostracoda spp. juv.), beetles *Hydroglyphus orthogrammus* and *Paracymus spenceri*, and mayfly *Cloeon* sp. Redstripe, as well as some higher-level identifications such as Ceratopogoninae spp., Baetidae spp. (imm), *Procladius* spp. and Anisoptera spp. (imm.).

Within the Greater Paraburdoo Iron Ore Hub area, individual site macroinvertebrate diversity was generally high, with the greatest richness recorded from spring sites or those with considerable connection to the groundwater, i.e. SM2 (68 taxa), PC1 (Ratty Spring; 69 taxa), PC2 (65 taxa), and ER3 (61 taxa; Figure 4.7). Lowest richness was recorded from SM4 (16 taxa), which is likely due to the site being contaminated with hydrocarbons at the time of sampling. The macroinvertebrate fauna remaining at this site was dominated by tolerant taxa such as worms (Nematoda and three taxa of Oligochaeta), beetles (six taxa) and two-winged flies (two taxa). All but the worms were recorded in low abundance, with only one or two individuals present. The Nematoda were highly abundant. Interestingly, taxa richness recorded from the long-term reference sites on Turee Creek was lower than most sites within the Greater Paraburdoo Iron Ore Hub (Figure 4.7). The two spring sites recorded just over half the richness of spring sites within the Study Area (40 taxa at Fork Spring and 38 taxa at Paperbark Spring). Paperbark Spring lacked the in-stream habitat diversity of sites within the Greater Paraburdoo Iron Ore Hub. This was also the case at TC3 (29 taxa), which also comprised low in-stream habitat diversity and heterogeneity for macroinvertebrates.

Most sites were dominated by slow flow and relatively tolerant taxa, i.e. Coleoptera and Diptera. Dominance of Diptera within aquatic macroinvertebrate assemblages of the Pilbara is common (i.e. Pinder *et al.* 2010). Taxa which require fast flows, such as Leiptoptera, Simulidae (Diptera) and *Cheumatopysche* caddisflies (Trichoptera) were absent. The low richness recorded from SM4 was influenced by the absence of sensitive taxa and the dominance of Coloptera, albeit in much lower diversity than all other sites. Invertebrates recorded from SM4 may have been dead on collection, given the hydrocarbon contamination present at this site at the time of sampling.

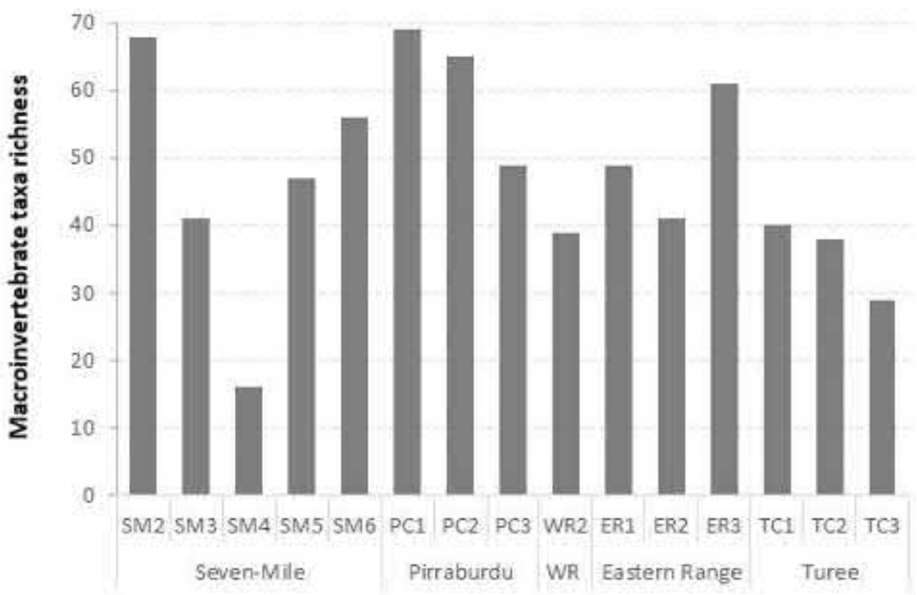


Figure 4.7: Macroinvertebrate taxa richness recorded from each site in the dry-19.

4.7.2 Conservation significant macroinvertebrate taxa

The vast majority of aquatic macroinvertebrates recorded from the Study Area were common, ubiquitous species with distributions extending across north Western Australia (1%), Western Australia (6%), Northern Australia (11%), Australia (20%), Australasia (10%) or the world (cosmopolitan species; 6%). A total of 6% were endemic to the Pilbara. Pilbara endemic taxa were recorded from all sites except SM3 and SM4 (Figure 4.8). This is not surprising given the hydrocarbon contamination at SM4 and the lack of in-stream habitat at SM3, coupled with extremes of water quality, with high salinity and super-saturated DO during the day resulting in anoxic conditions overnight. An anoxic sludge layer covered the creek bed across SM3. Endemic taxa tend to have specific habitat requirements and are generally sensitive to disturbance. As such, they are most commonly recorded from less disturbed sites. The greatest number of Pilbara endemic macroinvertebrate taxa was recorded from SM2 on Seven Mile Creek upstream of current mining impacts (four taxa), followed by SM5 within the zone of dewatering discharge (three taxa), and ER3 (three taxa; Figure 4.8).

Within the Pilbara endemic fauna were three species of further interest; one conservation significant species currently listed on the IUCN Redlist of Threatened Species, and two uncommon species. The Pilbara endemic damselfly, Pilbara pin *Eurysticta coolawanyah* was recorded from Seven Mile Creek, upstream of the Rio Tinto mining operations at SM2. As mentioned above, this species is currently listed on the IUCN Redlist as Vulnerable (IUCN 2019). Records of *Eurysticta coolawanyah* from pools in and around the Study Area are provided in (Figure 4.9).

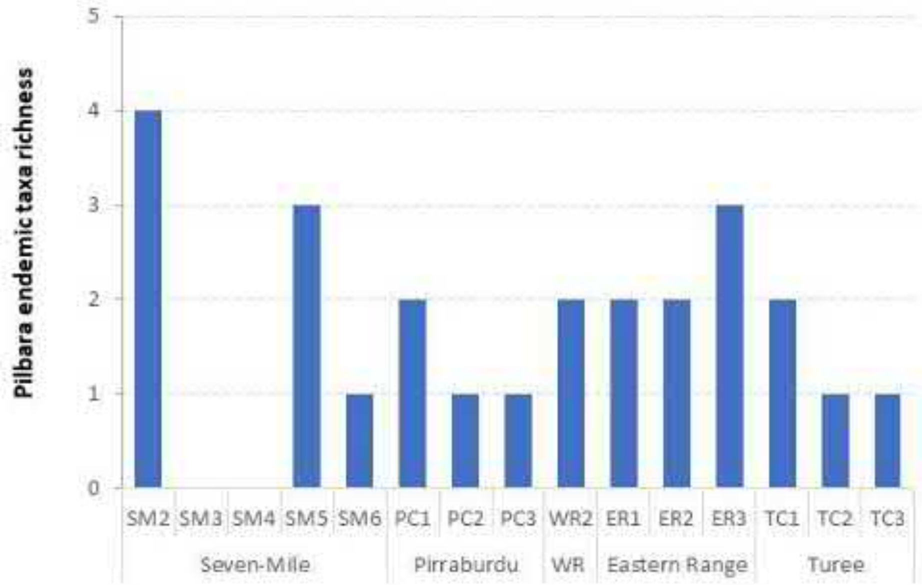
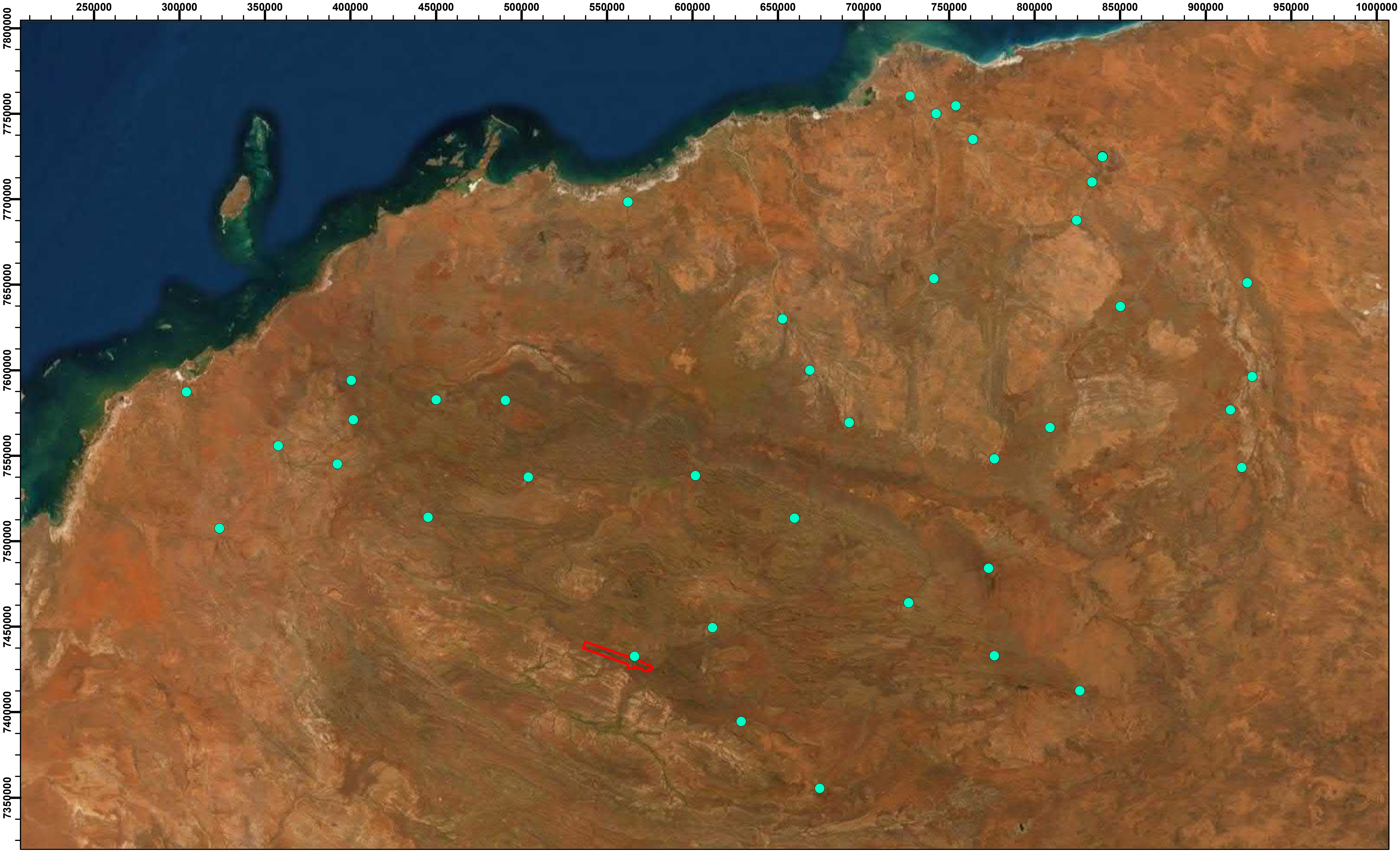


Figure 4.8: Number of Pilbara endemic taxa recorded from each site in the dry-19.

The backswimmer *Anisops nabillus* recorded from SM5, ER1 and ER2 is a relatively uncommon Pilbara endemic, with a relatively broad, disjunct distribution across the region. During the PBS, *A. nabillus* was recorded from three locations only; Desert Queen Baths (Rudall River NP), Watrara Creek Pool (Rudall River NP) and Harding River Pool at Millstream (Pinder *et al*. 2010). Since this time the species has been recorded from Koodaideri Spring (Bennelongia 2011), Duck Creek, Kalamina Gorge, Marillana Creek, Weeli Wolli Creek and the nearby Turee Creek (ALA 2019).

The water mite *Unionicola* nr *minutissima* was recorded from SM5 and ER3 during the current study. This species displays a highly disjunct distribution and appears to be rarely collected. It was previously recorded during the PBS from seven locations including Gregory Gorge (Fortescue River near Millstream), Duck Creek Pool (Ashburton), Carleecarleethong Pool and Pool on Tongolock (DeGrey), Running Waters and Skull Springs (Davis River), and Cangan Pool (Yule River). The furthest of these sites is located approximately 370 km away from the Greater Paraburdoo Iron Ore Hub.



Legend

Study Area

Known locations of the Pilbara Pin

biologic

Rio Tinto Iron Ore

Greater Paraburdoo Aquatic Fauna Survey

Fig 4.9: Location of known records of the Pilbara Pin

Coordinate System: GDA 1994 MGA Zone 50
Projection: Transverse Mercator
Datum: GDA 1994

Size A3. Created 11/12/2019

4.7.3 EPT taxa

EPT taxa richness ranged from two (at SM2, SM4, ER3, TC1 and TC2) to nine at PC1 (Figure 4.10). The generally low richness of EPT taxa across the Study Area was likely a reflection of the high nutrient concentrations and EC.

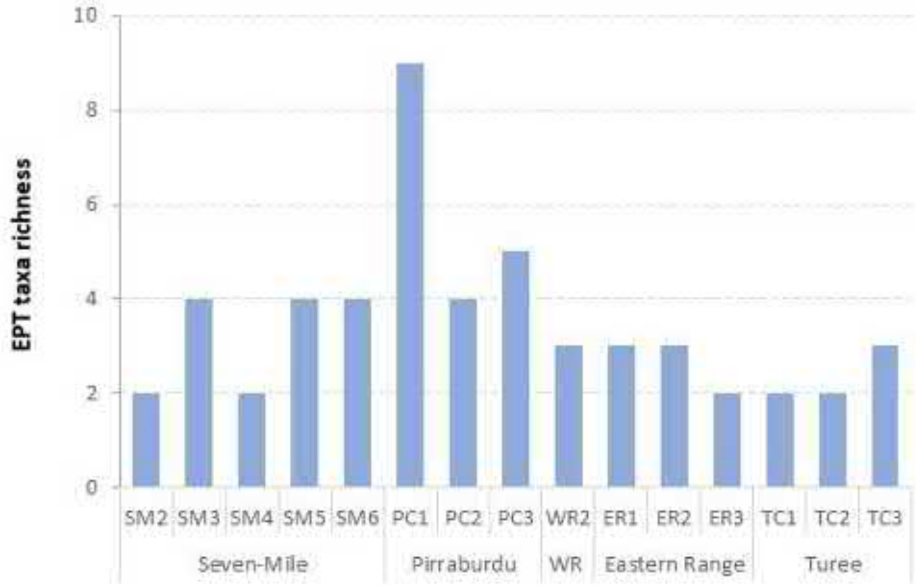


Figure 4.10: Number of EPT taxa recorded from each site in the dry-19.

4.7.4 Introduced macroinvertebrate taxa

There were no introduced macroinvertebrate taxa recorded from the Greater Paraburdoo Iron Ore Hub and long-term reference sites in the dry-19.

4.7.5 Macroinvertebrate comparison between site types

There was no significant difference in any of the macroinvertebrate metrics (overall macroinvertebrate richness, Pilbara endemic taxa richness, richness of EPT taxa) between reference, currently impacted (sites receiving dewatering discharge) and potential impact sites across the Study Area (Table 4.6). Although macroinvertebrate richness was slightly higher in reference sites compared to currently impacted and potential impact sites for overall richness and EPT taxa (Figure 4.11), these differences were not significant (Table 4.6).

Table 4.6: One-way ANOVA results testing for significant ($p<0.05$) differences in macroinvertebrate richness between reference (Ref), currently impacted (CI) and potential impact (PI) sites.

Test	df	MS	F	p-value
Overall macroinvertebrate richness	2	113.93	0.48	0.631
Pilbara endemic richness	2	0.96	0.75	0.495
EPT taxa richness	2	1.72	0.49	0.625

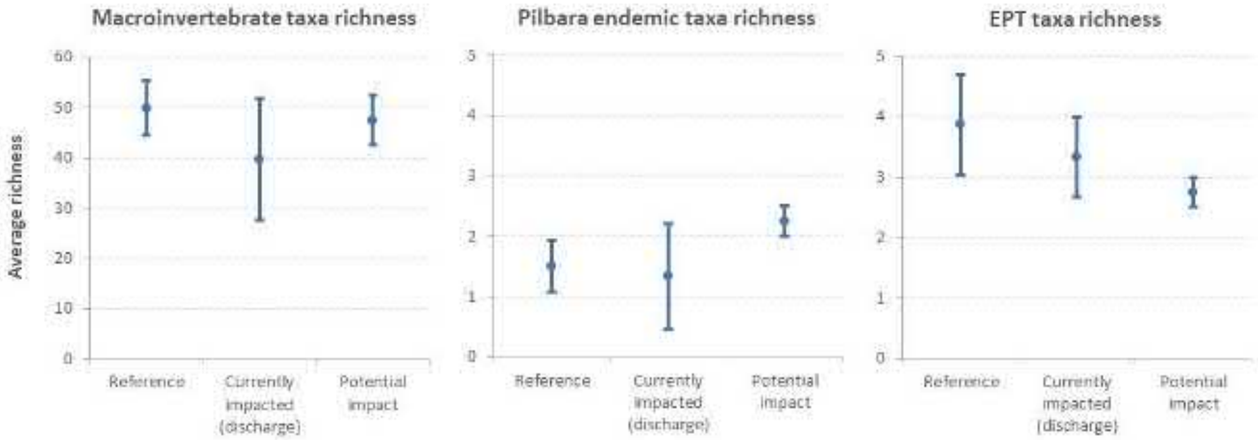


Figure 4.11. Average macroinvertebrate richness recorded from each site type (reference, currently impacted or potential impact) ± standard error for overall macroinvertebrate richness (left), Pilbara endemic taxa richness (middle) and EPT taxa richness (right).

4.7.6 Macroinvertebrate comparison with previous studies

Macroinvertebrate richness was compared to the previous PBS study (Figure 4.12). Despite the seemingly high diversity recorded in the current study, the number of taxa recorded was generally low in comparison to the PBS. In comparing sites sampled on both occasions, an additional 38 taxa were recorded during the PBS at Fork Spring (in September 2004) and 22 taxa from Paperbark Spring (in September 2005). Water quality data were not available for comparison, but these previous surveys were undertaken following a much wetter period, and as such, nutrients and ions were likely considerably less concentrated than they were in the dry season of 2019. Richness recorded from SM2, PC1, PC2 and ER3 in the dry-19 was greater than that recorded from Paperbark Spring in September 2005.

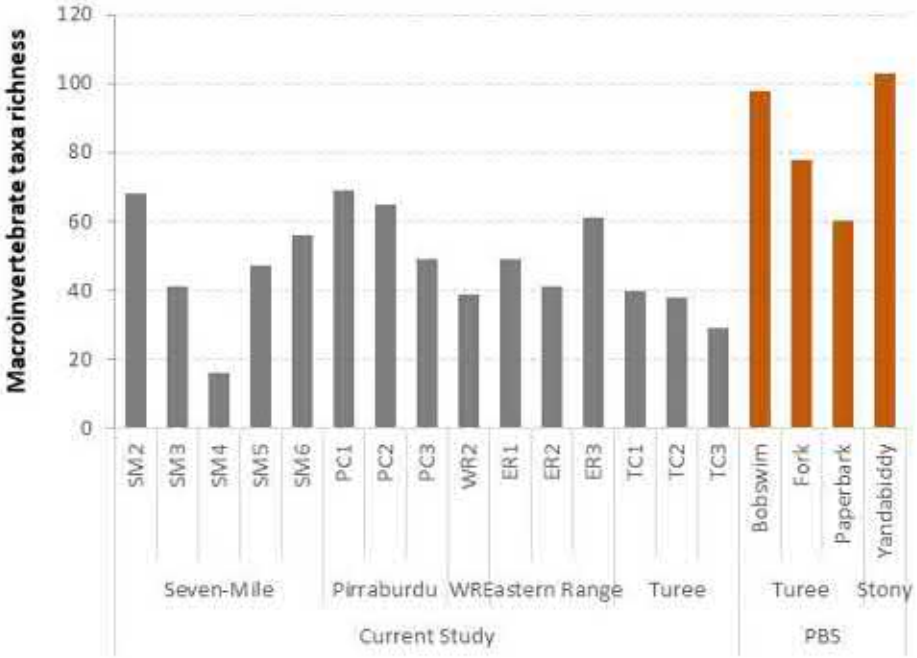


Figure 4.12: Comparison of macroinvertebrate richness recorded during the current study and PBS (dry season 2003, 2004 and 2005).

Given the above, macroinvertebrate assemblages recorded in the current study generally separated from those of the PBS in ordination space (Figure 4.13). SIMPROF detected six significant cluster groupings:

- Group 1 – Turee Creek reference sites TC2 and TC3, Seven Mile Creek site SM3 (Kelly's Pool) and the Western Range gorge pool (WR2), all from the dry-19.
- Group 2 – Seven Mile Creek currently impacted sites SM5 and SM6 with permanent creek pool ER3 (Stony Creek), all from the dry-19.
- Group 3 –Spring and groundwater fed pools SM2, PC1, PC2 and PC3 (all dry-19).
- Group 4 –The two Eastern Range gorge pools ER1 and ER2.
- Group 5 –TC1 (Fork Spring) sampled in the dry-19 and Paperbark Spring sampled during the PBS in September 2004.
- Group 6 –The remaining PBS sites sampled in 2003 and 2005, Fork Spring, Bobswim Pool and Yandabiddy Pool.

The contaminated SM4 did not group with any of these clusters and separated from all sites in ordination space (Figure 4.13).

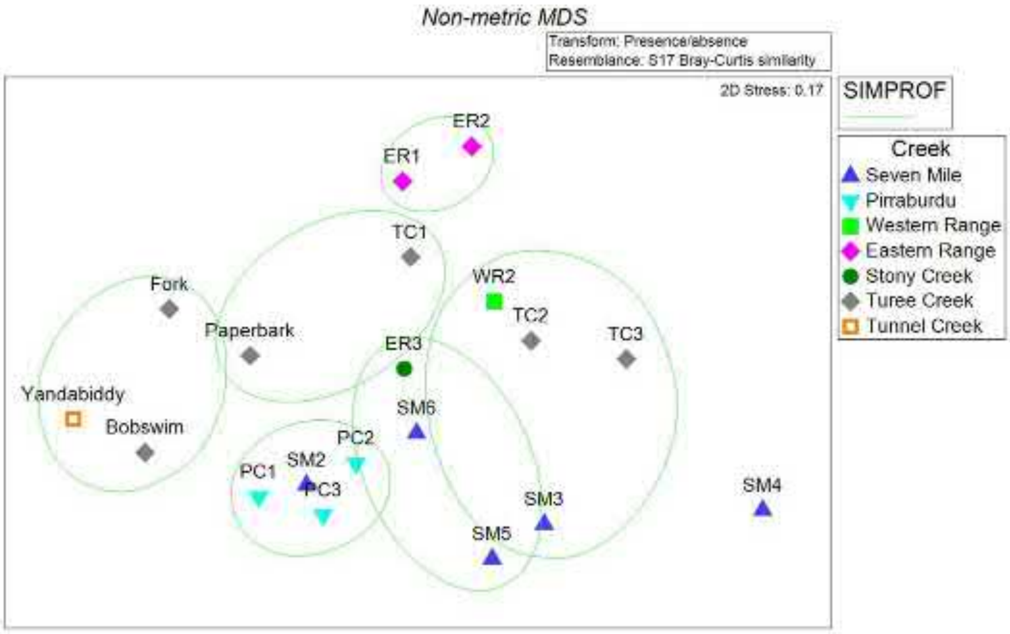


Figure 4.13: nMDS of macroinvertebrate assemblages recorded during the current study, with nearby PBS sites included. Samples are identified by creek and grouped within green circles based on significantly separate cluster groups as determined by SIMPROF.

4.8 Fish

4.8.1 Species composition and richness

Five freshwater fish species from three families were recorded in the dry season of 2019; the western rainbowfish *Melanotaenia australis* (Melanotaeniidae), Pilbara tandan *Neosilurus* sp.[6]

[6] The *Neosilurus* catfish known from the Pilbara is genetically distinct to the described species *Neosilurus hyrtlii* (Unmack 2013). The Pilbara species is currently known as *Neosilurus* sp. until further taxonomic work has been undertaken and descriptions have been made.

(Plotosidae), spangled perch *Leiopotherapon unicolor* (Terapontidae), Fortescue grunter *Leiopotherapon aheneus* (Terapontidae), and Terapontid hybrids. Results from this study are not unexpected given the fish fauna of the Pilbara is known to be characterised by low species diversity (Masini 1988, Allen *et al.* 2002, Morgan *et al.* 2014). The sparse freshwater fish fauna of the Pilbara is due to its aridity (Allen *et al*. 2002). Greatest freshwater fish diversity in the region is reported from relatively clear, permanent and semi-permanent pools, as was the case in the current study (PC1).

A total of eight freshwater fish and five estuarine species are known from the Ashburton River (Morgan and Gill 2004). Additional species to those recorded here include the freshwater species Pilbara bony bream *Nematalosa* sp., lesser salmon catfish *Arius graeffei*, barred grunter *Amniataba percoides*, flat head goby *Glossogobius giurus*, and estuarine species milkfish *Chanos chanos*, sea mullet *Mugil cephalus*, barramundi *Lates calcarifer*, Mangrove jack *Lutjanus argentimaculatus*, and roach silverbiddy *Gerres subfasciatus*. Of these, only three (the Pilbara bony bream, barred grunter and flat head goby) are likely to occur within the Study Area. Additional sampling in the wet season 2020 may locate these species within the Study Area. The remaining species all occur in the lowermost reaches of the Ashburton River, closer to the coast, and are not likely to be present within the Study Area.

No introduced species are currently known from the Ashburton River system.

4.8.2 Abundance

A total of 364 freshwater fish were recorded in the dry season of 2019. The greatest abundance was recorded from PC1 (187 individual fish), followed by PC2 (65) and TC3 (63; Figure 4.14). Of the sites which supported fish (six sites), the lowest abundance was recorded from SM2 (Figure 4.14). Diversity was greatest at PC1, with all five species present, and lowest at SM5 and TC3 (both recording two species).

Western rainbowfish was the most abundant species (186 individuals recorded across all sites), followed by the Fortescue grunter (81 individuals). Spangled perch was the most widespread and common species across the Study Area, being recorded from all six sites which yielded fish. Terapontid hybrids were the least common (recorded from two sites) and least abundant (seven individuals) species (Figure 4.14).

The two sites on Seven-Mile Creek which did not yield fish were SM3 (Kelly's Pool) and SM4. SM3 lacked in-stream habitat and exhibited extremes of water quality, including high salinity and super-saturated DO during the day, which would likely lead to anoxic conditions overnight. Super-saturated DO such as that exhibited at SM3 can result in gas bubble disease which, in conjunction with high salinities, may preclude the presence of fish at this site. Gas bubble disease can occur when total dissolved gases, either oxygen or nitrogen become super-saturated, and can lead to emboli in the blood, heart and gill filaments of fish (Wang *et al.* 2018). Effects can vary from mild to fatal depending on the extent of supersaturation, water temperature, and species, life history stage, and general health of the fish (Beeman *et al.* 2003).

SM4 was contaminated with hydrocarbons at the time of sampling, which undoubtedly affected the potential for this site to support fish.

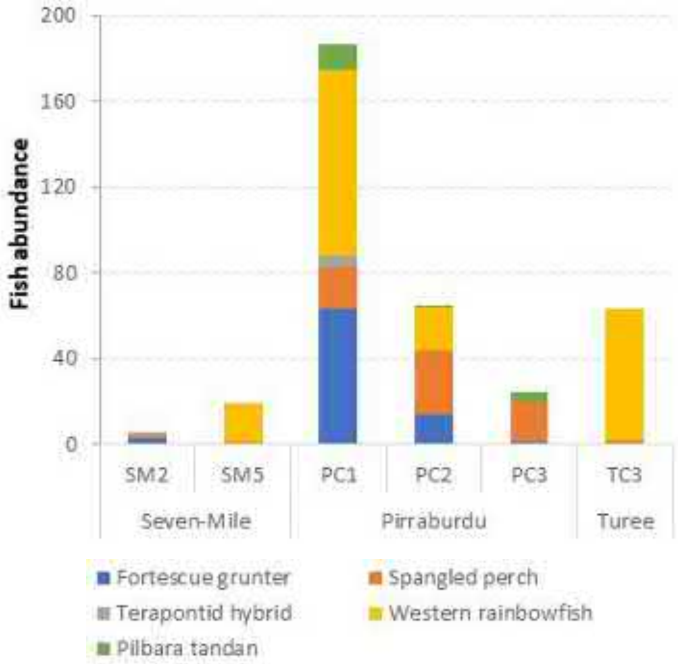


Figure 4.14: Abundance of each freshwater fish species recorded from each site.

The Western Range pool (WR2) and two Eastern Range gorge pools (ER1 and ER2) did not record fish either, likely due to their lack of connection with other systems and/or location upstream of waterfalls which would impede dispersal. Fish were also absent from two of the long-term monitoring sites; TC1 and TC2. The former (Fork Spring), was sampled at the spring source, which was disconnected from the main creekline at the time of sampling, and likely for a long period beforehand. TC2 (Paperbark Spring) comprised a series of shallow, small pools at the time of sampling, with little in-stream habitat and little in the way of shade or protection from predators.

4.8.3 Conservation significant fish species

Despite the low diversity of freshwater fishes in the Pilbara, the region does support high endemicity (56%; Morgan *et al.* 2014). One species recorded during the current study is endemic to the region and listed for conservation significance; the Fortescue grunter *Leiopotherapon aheneus*. This species is known only from the Ashburton, Fortescue and Robe rivers in the Pilbara (Allen *et al.* 2002), but within these systems it can be fairly abundant. It is currently listed as a Priority 4 (P4) species on the DBCA Threatened and Priority Fauna Species List (DBCA 2019b) and Endangered on the IUCN Redlist of Threatened Species (IUCN 2019). This listing was recently revised and upgraded from Near Threatened (IUCN 2019). The estimated extent of occurrence for the Fortescue grunter is 37,155 km^2, but the population is severely fragmented and a continuing decline in the number of mature individuals was noted in the listing (IUCN 2019). Morgan *et al.* (2009) reported that upper pools on the Fortescue River, especially Hamersley Gorge and Fern Pool in Karijini NP, are important refuges for the species.

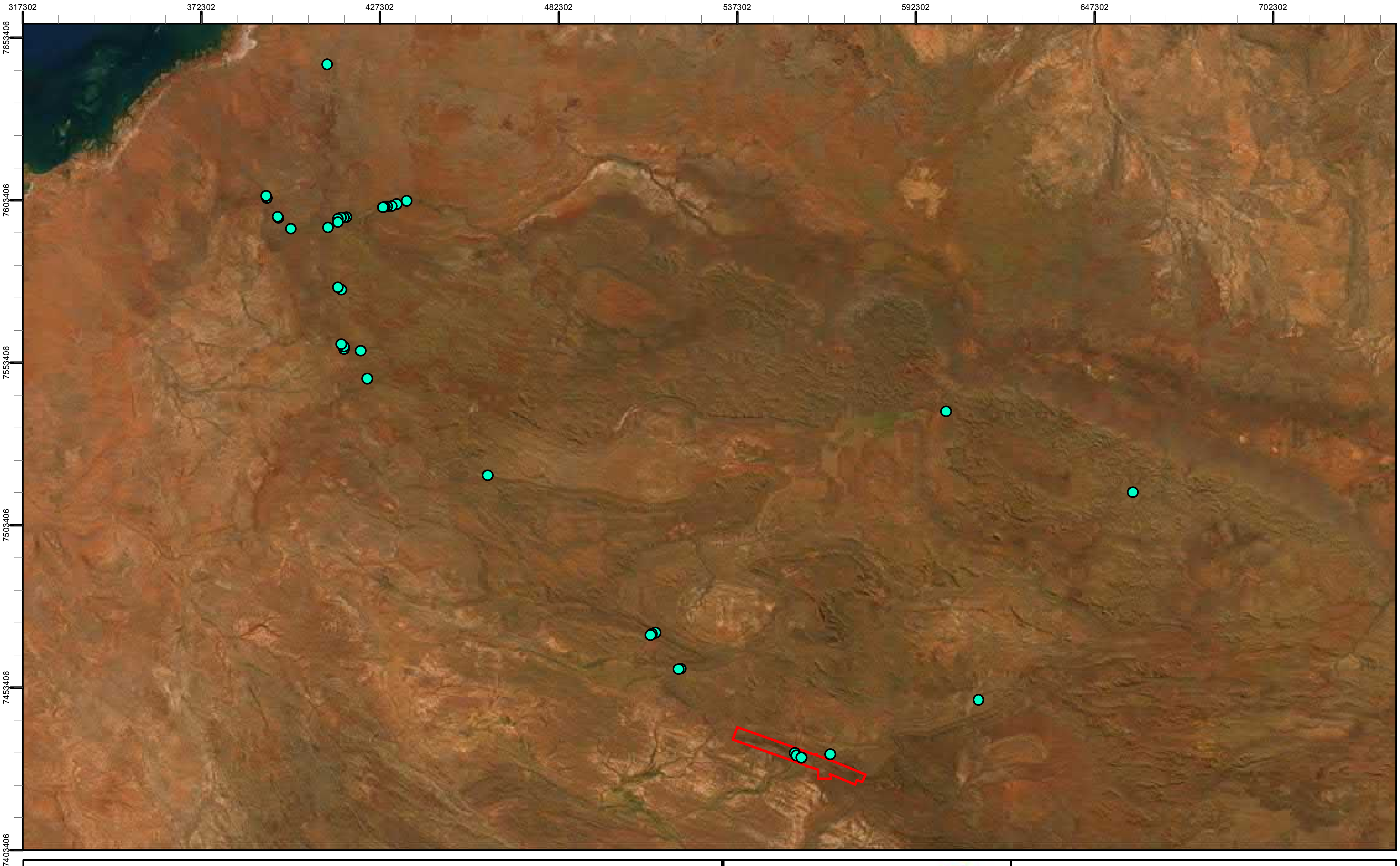
Major threats to the Fortescue grunter are considered to include livestock and the pastoral industry, mining, fire and fire suppression, and invasive species (IUCN 2019). During the current study, it was recorded from SM2, PC1, PC2 and PC3. Known records of the conservation significant Fortescue grunter in and around the Study Area are shown in Figure 4.15.

4.8.4 Hybridisation

Terapontid hybrids were recorded from SM2 and PC1. These were likely hybrids between Fortescue grunter and spangled perch. Similar hybridisation by terapontids has been previously reported in the Pilbara. Morgan *et al.* (2009) collected a terapontid from Billanoo Pool, lower Fortescue River, that they suggested was either a new species or a hybrid, based on "parentage from *Amniataba percoides* and one of the other two resident *Leiopotherapon* species". Morgan and Gill (2006) also reported natural hybridisation of spangled perch with an estuarine terapontid, the yellowtail trumpeter *Amniataba caudivittata*, in the Murchison River. Hybridisation between fish species is not uncommon; a list of nearly 4000 references was compiled by Schwartz (1972, 1981) which reported either natural or artificial hybridisation between various species. Despite this, the mechanisms behind species' hybridisations are not often understood. Additionally, in the Pilbara, the question of whether offspring are reproductively viable remains unanswered. Yet the importance of this cannot be understated, given the presence and apparent hybridisation of a State and internationally listed species of conservation significance (the Fortescue grunter). There is the potential for hybridisation to result in the loss of species through replacement by their hybrids, or the formation of a new species (if there is evidence of incipient speciation). Further research into the hybridisation of terapontids in Pilbara waterbodies is required.

4.8.5 Length-frequency analysis

Reproductive strategies of Pilbara freshwater fish, such as fecundity and size at maturity, fall between opportunistic and periodic (Beesley 2006), and vary between river systems and rainfall zones. This reflects the seasonal, yet unpredictable nature of rainfall and streamflow in the region. Most species are known to breed during the wet season, a time when new recruits and juveniles have the greatest chance of survival owing to the greater persistence of water/habitat, increased ecosystem productivity, and availability of food resources. Larvae have only a short window, usually in the order of a few days, with which to locate food or risk starving.



Legend

Study Area

Known locations of the Fortescue Grunter

biologic
Environmental Survey

N

1:1,500,000

0 15 30 60 km

Rio Tinto Iron Ore

Greater Paraburdoo Aquatic Fauna Survey

Figure 4.15: Known locations of the conservation significant Fortescue Grunter

Coordinate System: GDA 1994 MGA Zone 50
Projection: Transverse Mercator
Datum: GDA 1994

Size A4. Created 4/11/2019

Populations persist by the addition of new individuals to replace those lost through mortality or migration. New individuals arrive either through breeding within the system, or migration from connecting tributaries. Analysis of population structure and age-classes represented provides a way of characterising recruitment, the health of local fish assemblages, and therefore the environmental conditions present which can support or impede recruitment. Length-frequency analysis was undertaken for all fish species which were recorded in sufficient abundance. As few Pilbara tandan and Terapontid hybrids were recorded, they were excluded from this analysis.

Western rainbowfish have multiple spawning events throughout the year which take advantage of the intermittent rainfall and streamflows characteristic of the Pilbara (Beesley 2006). Maximum size is generally around 110 mm TL[7] (Morgan *et al.* 2002). Size at first maturity varies between river systems and sex, but for the purposes of this study is considered to be 50 mm SL. Close to a quarter (23%) of the western rainbowfish recorded during the current study were new recruits, indicating good levels of breeding and recruitment within the area, despite the dry conditions (Figure 4.16). New recruits were recorded from all sites where rainbowfish were recorded. Representatives from all other age classes were also recorded, although sub-adults and adults were only recorded from PC1 and PC2 (Figure 4.16). Rainbowfish abundances at TC3 followed a bell-shaped curve, with lowest numbers of new recruits and adults, and highest numbers of juveniles.

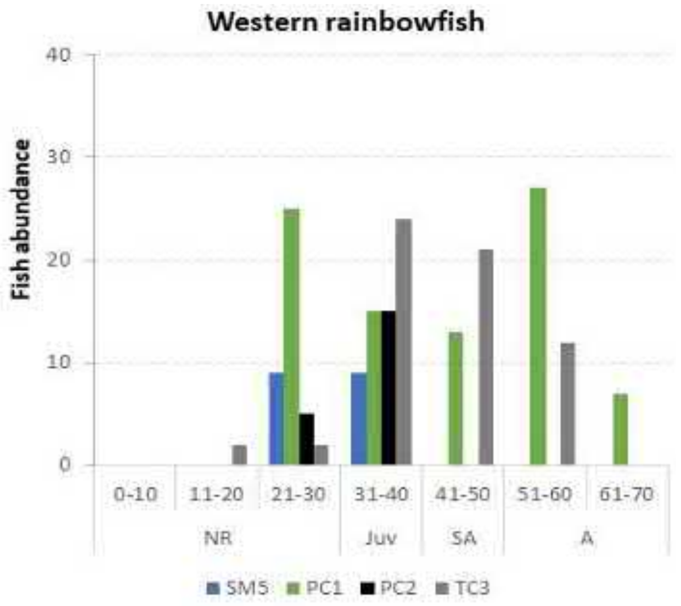


Figure 4.16. Length-frequency analysis for western rainbowfish.

In the Pilbara, spangled perch breed during the wet season, between late November and March (Beesley 2006, Morgan *et al*. 2002). Several spawning events will occur during this time (Beesley 2006). Morgan *et al.* (2002) found that in the Fitzroy River, spawning coincided with flooding. Maturity is attained after the first year, at around 58 mm TL for males and 78 mm TL

[7] Measurements of TL (total length) include the tail.

for females. To allow for field determination of age-class (without knowing sex), size at maturity was considered to be 70 mm SL for the purposes of this study. Maximum size of spangled perch is 300 mm TL. Greatest proportions of spangled perch recorded during the current study were sub-adults (over 51%), followed by juveniles (26%; Figure 4.17). Smaller numbers of new recruits (3%) and adults (19%) were also recorded. Length-frequency analysis indicated good wet season recruitment, with these recruits growing to juvenile size by the time of the survey.

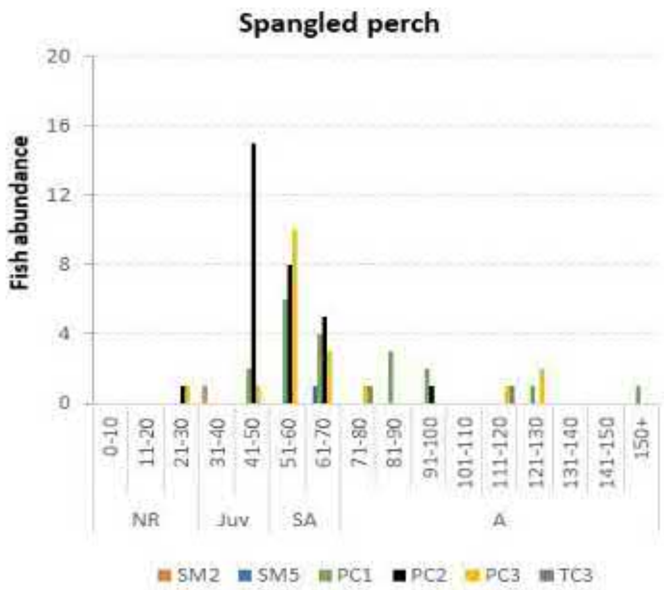


Figure 4.17. Length frequency analysis for spangled perch.

Little is known regarding the breeding biology of the Fortescue grunter, *Leiopotherapon aheneus*, and as such classification by age classes was not possible. Generally, low abundances of Fortescue grunter were recorded from each site, with the exception of PC1 (Figure 4.18). The majority of individuals from this site were between 81 and 100 mm SL, and likely represented adults (Figure 4.18). Individuals likely to represent new recruits (≤ 30 mm SL) were recorded from SM2 and PC2, indicating recent recruitment at these sites.

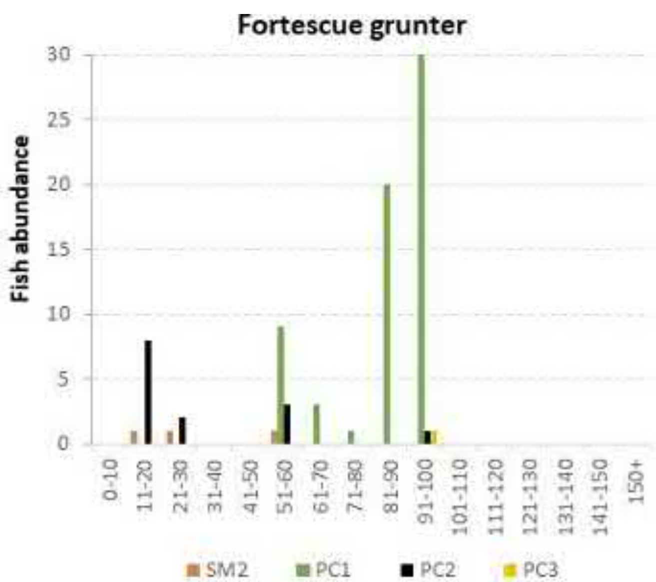


Figure 4.18: Length frequency analysis for Fortescue grunter.

4.9 Other vertebrate fauna

A flat-shelled (or dinner plate) turtle, *Chelodina steindachneri*, was recorded from SM2 (Table 4.7, Plate 4.2). Although little is known of their breeding biology, males are thought to attain sexual maturity at around 120 mm carapace length (CL) and females at 146 mm CL. Based on this, the female recorded from SM2 was undoubtedly an adult (Table 4.7).

Table 4.7. Turtle measurements (mm).

		Carapace		Plastron		Shell
Site	Sex	Length	Width	Midline length	Max. width	Height
SM2	Female	205	185	145	90	55

Table 4.7. Turtle measurements (mm).*Chelodina steindachneri* are known only from Western Australia, between the De Grey River in the north and the Irwin River in the south. They are found in both permanent and ephemeral systems and survive drought by aestivating in the riverbed or bank and emerging following heavy rain (Cann 1998). They have been recorded from systems that dry for more than two years. *Chelodina steindachneri* is not currently listed on any conservation lists.


Plate 4.2. Flat shelled turtle (*Chelodina steindachneri*) recorded from SM2.

4.10 Rehydration-emergence trials

4.10.1 Water quality

In situ water quality monitoring began on the fourth day of Phase 1 and second day of Phase 2 to allow time for parameters to stabilise. Unfortunately, a technical issue with the pH probe meant that no pH readings were able to be accurately recorded for the first half of Phase 1.

Overall, water quality was more variable in the first phase of rehydration trials and stabilised during the second phase (Figure 4.19). This is likely due to solutes within sediments being disturbed and mobilised during trial establishment and the first inundation event. The removal and replacement of water in the second phase produced more stable water quality results.

Most sites were fresh, with EC ranging from 259 µS/cm (at WR1 Phase 1) to 4,351 µS/cm (at SM1 Phase 1). During Phase 1, SM1 was brackish and some of the higher values were approaching saline. EC stabilised considerably during the second phase of the trial and ranged from 544 µS/cm (at WR3) to 1,288 µS/cm (at SM1). SM1 recorded the highest salinity throughout the trials but the values reduced considerably in Phase 2. While the first phase of the trials displayed an overall variable EC and salinity trend, a slightly increasing trend was recorded in the second phase, as evaporation resulted in the concentration of ions, as would be expected (Figure 4.19).

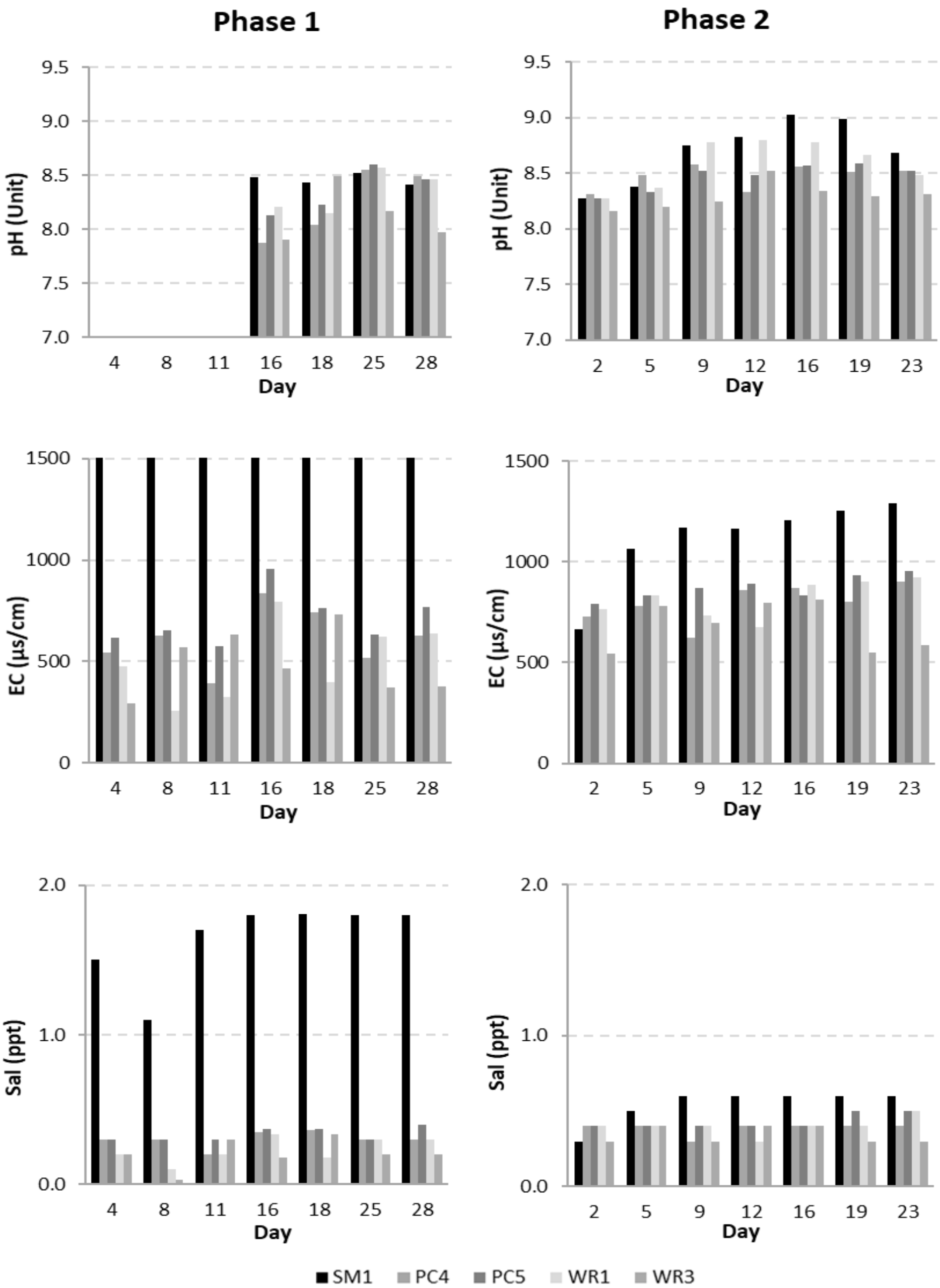


Figure 4.19: *In situ* water quality recorded during Phase 1 (left) and Phase 2 (right) of the Greater Paraburdoo rehydration trials.

Overall EC recorded during the rehydration trials was comparable to that recorded during the field survey at surface water sites, especially during Phase 2. The exception was the Western Range sites, WR1 and WR3, which had a higher EC during both phases of the trial. The Seven Mile Creek site (SM1) and Pirraburdu Creek sites (PC4 and PC5) recorded lower EC than comparable surface water sites, during at least one phase of the trials (see section 4.4.1 and Appendix C). Although the lowland river default ANZECC/ARMCANZ (2000) GV for EC was exceeded at all sites throughout the rehydration trial, EC at these sites is not considered to be of ecological concern. Ephemeral systems in the Pilbara are known to have a wide-ranging EC, where the first flush following rainfall may result in temporarily high EC due to flushing from the catchment and mobilisation of ions from sediments, continued high rainfall and flow leads to dilution of salts and solutes resulting in reduced EC, and receding water in the dry season leads to evapoconcentration and increased EC.

pH was alkaline and ranged from 7.87 (at PC4 Phase 1) to 9.03 (SM1 Phase 2). pH was variable throughout both phases, with generally higher pH recorded during Phase 2. While all pH values exceeded the default ANZECC GV, all were within the range recorded from surface waters during the field survey (see section 4.4.1 and Appendix C). pH values between 6.5 and 9 are generally considered satisfactory for supporting aquatic life (Robertson-Bryan 2004).

Extensive algal growth was observed for all sites during Phase 1 of the trial which likely indicate eutrophic conditions and the mobilisation of stored nutrients. SM1 and WR1 were the most affected and recorded high abundances of algal and macrophyte growth (Plate 4.3). While there was some algal growth present during Phase 2, it was much reduced and not to the extent observed in Phase 1. The physical removal of algae, combined with fresh water flushing while establishing Phase 2, appeared to limit eutrophic conditions and associated algal growth in Phase 2.

Plate 4.3: Extensive algal growth observed in SM1 (left) and WR1 (right) during Phase 1 of the rehydration trials.

4.10.2 Taxonomic composition and species richness

The Greater Paraburdoo rehydration trials were highly productive and yielded over 10,000 specimens, representing 26 taxa including both invertebrates and primary producers[8] (Table

[8] A number of specimens collected during Phase 2 are currently with taxonomic experts for ID, and as such the total richness is likely greater than reported here. Species lists and taxa richness numbers will be updated for the final report.

4.8). Overall taxa richness (Phase 1 and 2 combined) ranged from two (at PC5) to 13 (at WR1) (Figure 4.20). The richest group was the Rotifera which was represented by eight different taxa, followed by Diplostraca (water fleas and clam shrimp; five taxa; Figure 4.20). Interestingly, Insecta were represented in Phase 2 of this trial (Chironominae), which is uncommon but not undocumented. Several taxa emerged during one phase of the trial only, such as *Limnadopsis pilbarensis* and Chironominae sp. (Table 4.8).

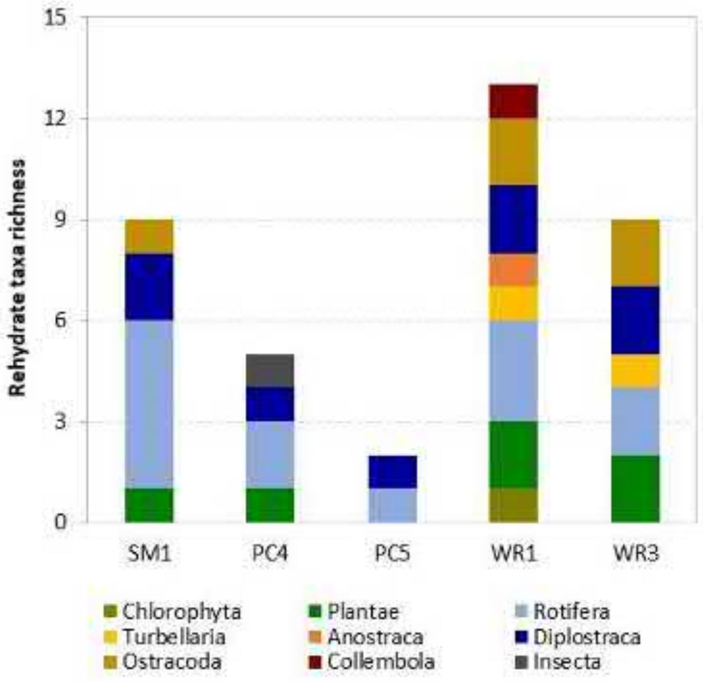


Figure 4.20: Taxa richness recorded from each site during the Greater Paraburdoo rehydration trails (Phase 1 and 2 combined).

The Greater Paraburdoo rehydration trial yielded a total of 22 invertebrate taxa, consisting primarily of crustaceans and rotifers, as is typical of rehydration trials (Rodman *et al.* 2016). These groups often make up a large proportion of the invertebrate assemblage in temporary waters due to their ability to produce resting stages capable of withstanding long periods of drought (Timms 1993, Rossi *et al.* 2013). While insects such as Hemiptera and Coleoptera are seldom recorded in rehydration trials, as they colonise ephemeral waters from neighbouring areas, chironomid larvae (non-biting midge) were recorded from PC4 during Phase 2 of the trial. Unlike most other aquatic insects, some species of chironomid, such as *Polypedilum vanderplanki,* are known to produce desiccation-resistant eggs that can remain viable several years without inundation (Timms 1993, Rossi *et al.* 2013, Strachan *et al.* 2015). While the recording of chironomids in rehydration trials is not unheard of, it is uncommon (Table 4.8). The Chironominae specimens which emerged from PC4 in Phase 2 are currently undergoing further taxonomic dentification. Final species-level identification will be provided in the final report.

Table 4.8: Aquatic taxa recorded during the Greater Paraburdoo rehydration trials.

			Phase 1					Phase 2				
Class/Order	**Family**	**Lowest taxon**	**SM1**	**PC4**	**PC5**	**WR1**	**WR3**	**SM1**	**PC4**	**PC5**	**WR1**	**WR3**
CHLOROPHYTA												
CHAROPHYCEAE												
Charales	**Characeae**	*Chara* sp. (imm.)				✓					✓	
PLANTAE												
LILIOPSIDA												
Alismatales	**Hydrocharitaceae**	*Vallisneria annua*	✓				✓	✓				✓
	Ruppiaceae	*Ruppia* sp. (imm.)							✓		✓	
MARCHANTIOPSIDA												
Marchantiales	**Ricciaceae**	Ricciaceae sp. (gametophyte)^				✓					✓	
		Riccia sp.^					✓					✓
ROTIFERA												
		Rotifera spp.*^						✓	✓	✓	✓	✓
BDELLOIDEA		Bdelloidea sp. 2:2^		✓		✓						
MONOGONONTA												
Flosculariacea	**Flosculariidae**	Flosculariidae sp.*^						✓				
		Lacinularia sp.^			✓							
		Euchlanis sp.^	✓									
		Euchlanis dilatata^					✓					
	Lecanidae	*Lecane bulla*^				✓	✓					
		Lecane closterocerca^	✓			✓						
		Lecane papuana^	✓									
	Notommatidae	Notommatidae sp.^	✓									
PLATYHELMINTHES												
TURBELLARIA		Turbellaria sp.^					✓#				✓	✓#
ARTHROPODA												
CRUSTACEA												
BRANCHIOPODA												
Anostraca		Anostraca sp. unident ^ #				✓						

			Phase 1					Phase 2				
Class/Order	**Family**	**Lowest taxon**	**SM1**	**PC4**	**PC5**	**WR1**	**WR3**	**SM1**	**PC4**	**PC5**	**WR1**	**WR3**
Diplostraca		Cladocera spp. unident*						✓	✓	✓	✓	✓
	Chydoridae	*Alona* sp. 1^	✓									
		Alona sp. 2^				✓						
	Daphniidae	*Ceriodaphnia* aff. *laticaudata*^				✓						
		Simocephalus heilongjiangensis	✓									
	Limnadiidae	*Limnadopsis pilbarensis* ^					✓					
OSTRACODA												
		Ostracoda spp. unident.*						✓			✓	✓
Podocopida	**Cyprididae**	*Cypretta* sp. (imm.)	✓									
		Cypricercus \`BOS911\`^				✓	✓					
		Heterocypris sp.^					✓					
		Ilyodromus \`413\` (nr *candonites*) (PSW)^				✓						
HEXAPODA												
COLLEMBOLA												
Symphypleona		Symphypleona sp.^				✓					✓	
INSECTA												
Diptera	**Chironomidae**	Chironominae sp. unident *							✓			
		Taxa richness	**8**	**1**	**1**	**10**	**8**	**5**	**4**	**2**	**8**	**6**

*Denotes specimens awaiting further taxonomic resolution, ^ denotes taxa recorded in rehydration emergence trials only, and # indicates taxa was observed during trials but not collected during not present during the final harvest.

Rotifers were the most commonly occurring invertebrate group and were recorded from all trial sites during both phases. Diplostraca (water fleas and clam shrimp) were also commonly occurring and were recorded at all sites in at least one phase. Monogononta (rotifers) and Branchiopoda (water fleas, clam shrimp and shield shrimp) were the richest classes, with eight and six taxa represented, respectively (Table 4.8).

The period of greatest emergence occurred between days seven and ten in Phase 1, after which diversity fluctuated slightly until stabilising around day 17 (Figure 4.21). There were two periods of high emergence activity during Phase 2, one at the start of the trial, through to day four, and one between day 17 and 19 (Figure 4.21). Interestingly, there was a reduction in diversity during Phase 2 between day 14 and 17 (Figure 4.21). The changes in diversity reflect succession, where different species emerge early and die out following short life cycles, other species predate or out-compete others, and changing water quality favour certain taxa over the course of the trials. Cladocera were generally the first to emerge and then populations fluctuated throughout the trial. Other taxa such as Ostracods and Turbellaria tended to have more variable timing for emergence. The colonial Flosculariid Rotifers and Chironominae (non-biting midge) larvae emerged later in the trials, after day 14.

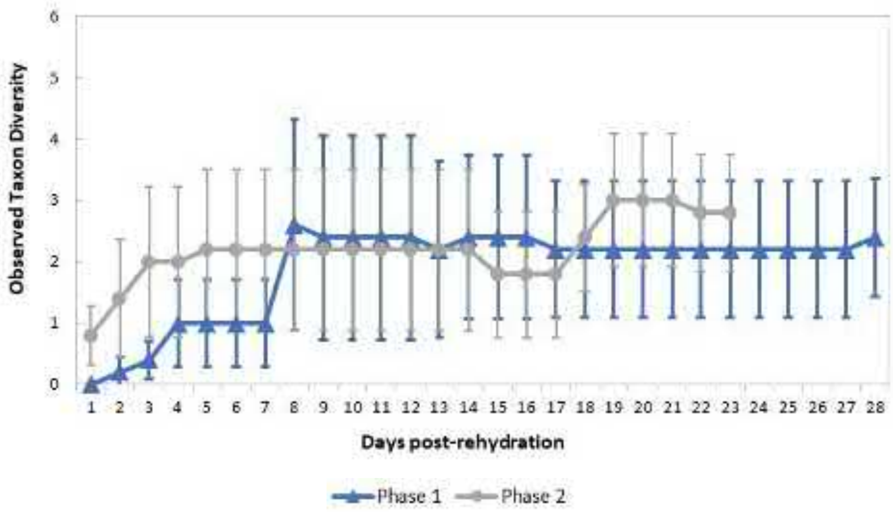


Figure 4.21: Cumulative observed taxa richness (mean ± standard error) of emergences observed during Greater Paraburdoo rehydration trials in each phase.

Taxa richness varied between site and phase (Table 4.8, Figure 4.22). Generally greater richness was recorded during Phase 1 (Figure 4.22), however, it is anticipated that richness will increase in Phase 2 once further taxonomic resolution for a number of groups becomes available. Completing a second phase of the trial maximised taxa richness and aimed to allow macrophytes to grow to maturity for identification purposes.

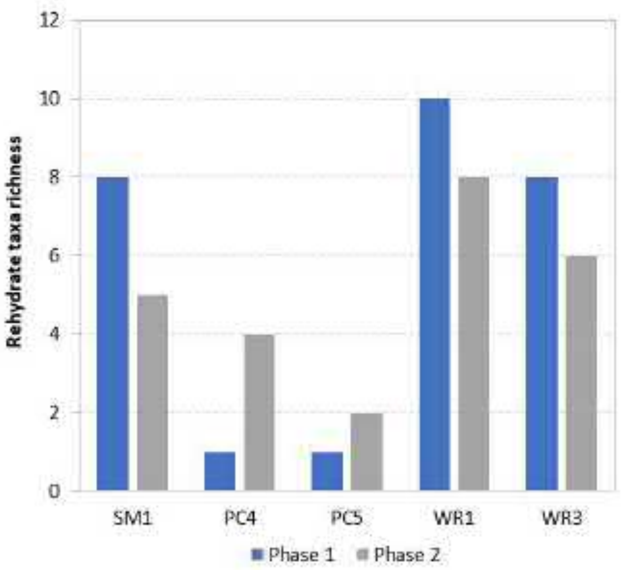


Figure 4.22: Comparison of taxa richness recorded in each phase of the Greater Paraburdoo rehydration trials.

*Taxa richness for Phase 2 will likely increase pending further taxonomic resolution of some specimens.

Submerged macrophytes often produce desiccation resistant seeds and spores which allow them to withstand long periods of drought and quickly colonise ephemeral wetlands during flooding events (Garcia 1999). Macrophytes germinated in all sites except PC5, and were represented by three plant genera (*Vallisneria*, *Ruppia* and *Riccia*) and one algae genus (*Chara*) (Table 4.8). A gametophyte life stage of the liverwort Ricciaceae (Plate 4.4**Error! Reference source not found.**) also germinated during the trial. The Ricciaceae sp. (gametophyte) and *Riccia* sp. were not recorded during the field survey.

Plate 4.4: The Ricciaceae sp. (gametophyte), which germinated from WR1 during rehydration trials (photo by Syngeon Rodman/Biologic).

The rehydration trials added an additional 18 invertebrate taxa known from the Study Area; i.e. taxa that were not recorded from hyporheic or macroinvertebrate samples. These were; the

Rotifera Bdelloidea sp. 2:2, *Lacinularia* sp., *Euchlanis* sp., *Euchlanis dilatata*, *Lecane bulla, Lecane closterocerca, Lecane papuana,* Notommatidae sp., the Cladocera *Alona* sp. 1 and 2; *Ceriodaphnia* aff. *laticaudata*; the Conchostraca *Limnadopsis pilbarensis;* the Ostracoda *Cypricercus* `BOS911`, *Heterocypris* sp., *Ilyodromus* `413` (nr *candonites*) (PSW), Anostraca, Turbellaria and the Collembolla Symphypleona sp.

4.10.3 Conservation significance of emergent fauna

Most taxa recorded during the Greater Paraburdoo rehydration trials are widely distributed and none are listed as being of conservation significance. The only species of interest was the clam shrimp *Limnadopsis pilbarensis*. This species is a Pilbara endemic, but is relatively uncommon, being recorded from temporary pools only. During the PBS, it was only recorded from one site, Burrup Rockhole northeast of Dampier (Pinder *et al.* 2010). It has also been recorded from Beabea Creek, Ratty Spring (our PC1 on Pirraburdu Creek) and Glen Ross Creek (Timms 2009). In the current study, *Limnadopsis pilbarensis* emerged from sediments collected from Western Range site WR3.

4.10.4 Comparison with other sediment rehydration studies

No studies undertaken in the vicinity of the Study Area, including the PBS, incorporated sediment rehydration trials. Therefore, comparison was made to trials conducted within the State which were publicly available (i.e. WRM 2016, Rodman *et al.* 2016, Bennelongia 2017). Results of the few rehydration trials conducted on Pilbara sediments are variable, with trials yielding fairly depauperate (ten taxa) to considerably rich invertebrate assemblages (20 taxa; Figure 4.23). Looking more broadly across Western Australia, invertebrate richness reported in available studies ranged from three to 37 taxa (Figure 4.23). Greater Paraburdoo generally recorded high invertebrate taxa richness (22 taxa) in comparison to these other studies, including the Coolibah wetlands (WRM 2016) of the Pilbara and ephemeral creeklands and lake playas in inland Western Australia (Rodman *et al.* 2016, Bennelongia 2017; Figure 4.23). Only one study undertaken in the Goldfields on the Fisher East wetlands, recorded higher diversity than the current study with a comparable amount of sites (six sites) (Rodman *et al.* 2016; Figure 4.23). It is also expected that taxa diversity will increase with further taxonomic resolution of some Phase 2 specimens. Overall, Greater Paraburdoo assemblages were consistent with those recorded in previous studies, largely comprising rotifers and crustaceans, such as Diplostraca and Ostracoda (Rodman *et al.* 2016, WRM 2016). This trial suggests that that the water bodies of the Study Area have a diverse viable dormant egg / seed bank. In general, rehydration trials are undertaken with sediments from ten or more sites (Rodman *et al.* 2016, WRM 2016). It is likely that taxa diversity would increase considerably with incorporation of additional sites into any future rehydration trials undertaken within the Study Area.

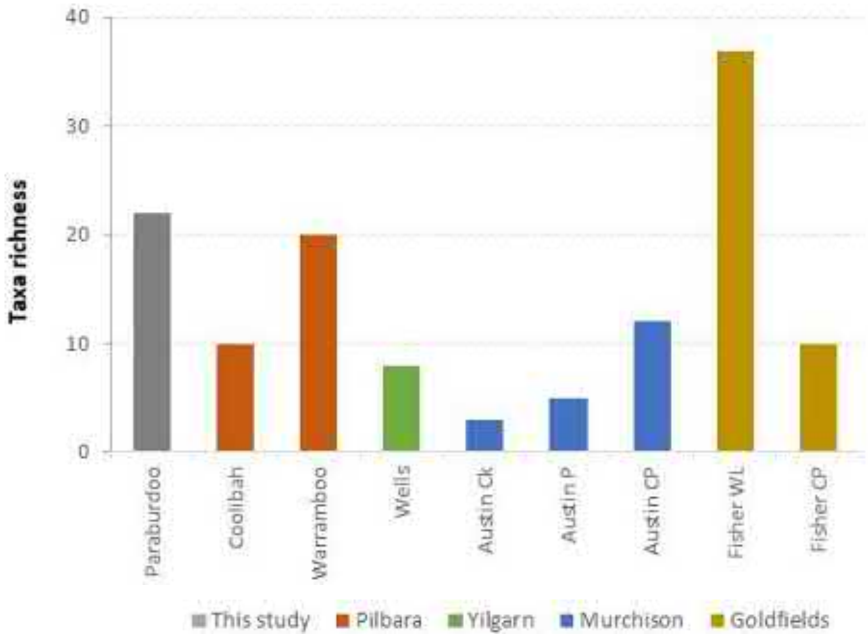


Figure 4.23: Comparison of invertebrate taxon richness recorded during the Greater Paraburdoo rehydration trials and other rehydration trials conducted on sediments from inland WA.

5 CONCLUSIONS

5.1 Water quality and habitats

Pools within the Greater Paraburdoo Iron Ore Hub and surrounds (long-term reference sites on Turee Creek) were showing the effects of successive dry years. Low rainfall and lack of flushing has led to creeks and waterholes receding and undergoing evapoconcentration of ions and nutrients. The general lack of water in the area also meant that cattle were concentrated around these remaining pools, leading to increased nutrient loads. This, coupled with the high light intensity, resulted in abundant algal and macrophyte growth. Signs of trampling by cattle were also apparent in and around pools, and emergent macrophytes along the creek banks had obviously been eaten. Extremes in DO were also recorded across the Study Area, which was likely associated with the high algal and macrophyte growth. Eight sites recorded relatively high salinity which would be considered brackish, and in excess of the known point of ecological stress for aquatic fauna. Dissolved metal concentrations were generally low across all sites, with some exceptions (noted below).

Water quality concentrations outside default ANZECC/ARMCANZ (2000) GVs were recorded for several analytes from most sites. Exceedances of default GVs included:

- EC – at all sites except ER1 and WR2.
- DO - SM2, SM6, PC1, PC3 and TC3 recorded insufficient DO, below the lower default GV.
- DO – SM3 recorded super-saturated DO, in excess of the default GV.
- pH – ER1 recorded acidic pH, below the lower default GV.
- pH - SM3 recorded basic pH which was greater than the default GV.
- Turbidity – exceeded the default GV at SM4 and PC2.
- N_NH_3 - concentrations from TC3 exceeded the default 95% toxicity GV.
- N_NO_3 – most sites exceeded the default 95 % toxicity GV, including SM2, SM4, SM5, SM6, PC1, PC2, PC3, ER1, ER3, TC1 and TC2.
- N_NOx - exceeded the default eutrophication GV at all sites.
- TN – all sites except WR2 exceeded the default eutrophication GV.
- TP – concentrations were higher than the default eutrophication GV at all sites except WR2.
- dAl – was greater than the default 99% GV at ER1.
- dAs - exceeded the 99% GV at a number of sites including SM2, SM3, S5, PC1, PC2, PC3, ER3, TC2 and TC3.
- dB - was greater than the 99% GV at all sites except WR2 and ER1. The 95% GV was also exceeded at SM2, SM3, SM4, SM5, SM6 and TC2.
- dCr – concentrations were above the 99% GV at TC1.
- dZn - exceeded the 95% GV at SM4. However, once hardness was considered, this site did not exceed the HMGV.

Elevated nitrogen nutrients were likely the result of direct cattle access to waters at some sites, and discharge of groundwater with high nutrient concentrations downstream of the current discharge point.

Water quality of the gorge pool at Western Range (WR2) was notably different to all other sites. Concentrations of ions were much lower, likely reflecting the lack of evaporation and therefore evapoconcentration. Correspondingly, EC was also low and fresh at this site. Although DO was slightly below the default lower GV, the value was considered sufficient to sustain aquatic life (82%). Nutrient and dissolved metal levels were generally low, and considerably lower than other sites.

In-stream habitats of most sites comprised a diversity of complex, heterogenous structures with which to support aquatic fauna. Exceptions to this were the Eastern Range gorge pools ER1 and ER2, and Seven-Mile Creek site SM3 (Kelly's Pool). These sites were dominated by open cover of inorganic sediments, with some debris.

5.2 Aquatic Flora

A total of 11 macrophyte taxa was collected; five emergent taxa and six submerged macrophyte taxa. Other riparian vegetation collected included Eucalypts, *Melaleuca*, ghost gum, shrubs, *Acacia* species, *Grevillea*, herbs and grasses. Emergent macrophytes included *Cyperus vaginatus*, *Schoenoplectus subulatus* and *Typha domingensis*, as well as two taxa which could not be definitively identified to species; *Cyperus ?vaginatus* and ?*Schoenoplectus* sp. (juv.). Submerged macrophytes comprised *Chara* sp. nr. *vulgaris*, *Vallisneria annua, Potamogeton tricarinatus, Potamogeton tepperi, Ruppia* sp. and *Najas marina*. No macrophytes were recorded from the gorge pools WR3 and ER1, or the dry site on Pirraburdu Creek PC5. This is not surprising given the ephemeral nature of these sites. No submerged macrophytes were recorded from the hydrocarbon contaminated SM4. Where flora was recorded, diversity was generally low and ranged from one (at SM4, WR1, WR2, ER2 and TC2) to seven (at PC2).

None of the emergent or submerged macrophytes collected were of significance; however, a declared rare flora (DRF), *Aluta quadrata*, was found along the dry creekbed at WR3 in Western Range. *Aluta quadrata* is restricted to a banded iron formation that runs east and west of Paraburdoo, in the southern edge of the Hamersley Range. There are three known disjunct populations; Western Range, Pirraburdu Creek, and Howie's Hole.

Four introduced flora species were recorded during the current study; the mimosa bush *Vachellia farnesiana* (SM4), buffel grass *Cenchrus ciliaris* (PC3), couch grass *Cynodon dactylon* (at SM4) and passion vine *Passiflora foetida* (PC3).

5.3 Aquatic Fauna

Despite the obvious stress these pools and creeklines were under at the time of sampling, they still supported a diverse range of aquatic fauna, including 263 invertebrate taxa[9], one species of turtle, and five freshwater fish species.

Sites of high ecological value were SM2, PC1 and PC2. These sites generally recorded a high macroinvertebrate diversity, high richness of hyporheos fauna (SM2 and PC2), and high Pilbara endemic taxa richness. PC1 also recorded high richness of sensitive EPT taxa. The greatest diversity and abundance of fish was recorded from PC1 and PC2, and SM2 supported the flat-shelled turtle *Chelodina steindachneri*.

The aquatic fauna assemblage of SM4 was displaying effects of hydrocarbon contamination at the time of sampling, with low diversity of macroinvertebrates, high abundance of tolerant and nuisance taxa such as Nematoda, lack of sensitive and Pilbara endemic taxa, and no fish. Some of the invertebrates recorded from SM4 may have been dead on collection.

Interestingly, taxa richness recorded from the long-term reference sites on Turee Creek was lower than most sites within the Greater Paraburdoo Iron Ore Hub. The two spring sites recorded just over half the richness of spring sites within the Study Area. This is likely because Paperbark Spring (TC2) and TC3 comprised low in-stream habitat diversity and heterogeneity for macroinvertebrates, in comparison to sites within the Greater Paraburdoo Iron Ore Hub.

Despite the seemingly high diversity recorded in the current study, the number of macroinvertebrate taxa recorded was generally low in comparison to the PBS. In comparing sites sampled on both occasions, an additional 38 taxa were recorded during the PBS at Fork Spring and 22 taxa from Paperbark Spring. Water quality data were not available for comparison, but these previous surveys were undertaken following a much wetter period, and as such, nutrients and ions were likely considerably less concentrated than they were in the dry season of 2019, and aquatic habitats generally less stressed.

Two species recorded during the current study are listed and therefore of conservation significance (*Eurysticta coolawanyah* and *Leiopotherapon aheneus*). The Pilbara pin damselfly *Eurysticta coolawanyah* (Vulnerable IUCN Redlist) was recorded from SM2. The Fortescue grunter, *Leiopotherapon aheneus* (DBCA Priority 4 species and IUCN Near Threatened) was recorded from SM2, PC1, PC2 and PC3.

In addition to the Pilbara pin and Fortescue grunter, several taxa were considered to be of scientific interest. These include;

- The clam shrimp *Limnadopsis pilbarensis* which emerged from WR3 is a relatively uncommon Pilbara endemic. It is known only from a small number of temporary pools across the region.

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[9] The total invertebrate richness includes taxa recorded in both hyporheic and macroinvertebrate samples, as well as emergences during rehydration trials (noting that some IDs are still pending for Phase 2 of the rehydrate trials).

- The water mite *Wandesia* sp. `BAC004`recorded from the hyporheic zone of PC2.
- The water mite *Tillia* sp.`BAC003` from a hyporheic sample collected from Pirraburdu Creek (PC3) likely represents the first record of this genus from the Pilbara and this specimen may be a species new to science.
- The water mite *Unionicola* nr *minutissima* was recorded from SM5 and ER3. This species displays a highly disjunct distribution and appears to be rarely collected.
- The backswimmer *Anisops nabillus* from SM5, ER1 and ER2 is a relatively uncommon Pilbara endemic, with a relatively broad, disjunct distribution across the region, but few records.
- the Pilbara tandan *Neosilurus* sp. - Pilbara endemic recorded from CG1 and CG3.

5.4 Final remarks

This study represents the first aquatic ecosystem survey undertaken in the Greater Paraburdoo Iron Ore Hub. Results from this survey provide a snapshot of the ecological values and health of aquatic systems in the area. An additional field survey is planned for the wet season 2020 which will provide an indication of natural seasonal variability and will likely yield additional species.

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APPENDICES

Appendix A: Conservation Status Codes

International Union for Conservation of Nature

Category	Definition
Extinct (EX)	A taxon is Extinct when there is no reasonable doubt that the last individual has died. A taxon is presumed Extinct when exhaustive surveys in known and/or expected habitat, at appropriate times (diurnal, seasonal, annual), throughout its historic range have failed to record an individual. Surveys should be over a time frame appropriate to the taxon's life cycle and life form.
Extinct in the Wild (EW)	A taxon is Extinct in the Wild when it is known only to survive in cultivation, in captivity or as a naturalized population (or populations) well outside the past range. A taxon is presumed Extinct in the Wild when exhaustive surveys in known and/or expected habitat, at appropriate times (diurnal, seasonal, annual), throughout its historic range have failed to record an individual. Surveys should be over a time frame appropriate to the taxon's life cycle and life form.
Critically Endangered (CR)	A taxon is Critically Endangered when the best available evidence indicates that it meets any of the criteria A to E for Critically Endangered (see Section V), and it is therefore considered to be facing an extremely high risk of extinction in the wild.
Endangered (EN)	A taxon is Endangered when the best available evidence indicates that it meets any of the criteria A to E for Endangered (see Section V), and it is therefore considered to be facing a very high risk of extinction in the wild.
Vulnerable (VU)	A taxon is Vulnerable when the best available evidence indicates that it meets any of the criteria A to E for Vulnerable (see Section V), and it is therefore considered to be facing a high risk of extinction in the wild.
Near Threatened (NT)	A taxon is 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
Data Deficient (DD)	A taxon is Data Deficient when there is inadequate information to make a direct, or indirect, assessment of its risk of extinction based on its distribution and/or population status. A taxon in this category may be well studied, and its biology well known, but appropriate data on abundance and/or distribution are lacking. Data Deficient is therefore not a category of threat. Listing of taxa in this category indicates that more information is required and acknowledges the possibility that future research will show that threatened classification is appropriate. It is important to make positive use of whatever data are available. In many cases, great care should be exercised in choosing between DD and a threatened status. If the range of a taxon is suspected to be relatively circumscribed, and a considerable period of time has elapsed since the last record of the taxon, threatened status may well be justified.

Environment Protection and Biodiversity Conservation Act 1999

Category	Definition
Extinct (EX)	Taxa not definitely located in the wild during the past 50 years.
Extinct in the Wild (EW)	Taxa known to survive only in captivity.
Critically Endangered (CE)	Taxa facing an extremely high risk of extinction in the wild in the immediate future.
Endangered (EN)	Taxa facing a very high risk of extinction in the wild in the near future.
Vulnerable (VU)	Taxa facing a high risk of extinction in the wild in the medium-term future.
Migratory (MG)	Consists of species listed under the following International Conventions: Japan-Australia Migratory Bird Agreement (JAMBA) China-Australia Migratory Bird Agreement (CAMBA) Convention on the Conservation of Migratory Species of Wild animals (Bonn Convention)

Biodiversity Conservation Act 2016

Category	Definition
CR	Rare or likely to become extinct, as *critically endangered* fauna.
EN	Rare or likely to become extinct, as *endangered* fauna.
VU	Rare or likely to become extinct, as *vulnerable* fauna.
EX	Being fauna that is presumed to be extinct.
MI	Birds that are subject to international agreements relating to the protection of migratory birds.
CD	Special conservation need being species dependent on ongoing conservation intervention. (Conservation Dependant)
OS	In need of special protection, otherwise than for the reasons pertaining to Schedule 1 through to Schedule 6 Fauna. (Other specially protected species

Department of Biodiversity, Conservation and Attractions Priority codes

Category	Definition
Priority 1 (P1)	Taxa with few, poorly known populations on threatened lands.
Priority 2 (P2)	Taxa with few, poorly known populations on conservation lands; or taxa with several, poorly known populations not on conservation lands.
Priority 3 (P3)	Taxa with several, poorly known populations, some on conservation lands.
Priority 4 (P4)	Taxa in need of monitoring. Taxa which are considered to have been adequately surveyed, or for which sufficient knowledge is available, and which are considered not currently threatened or in need of special protection but could be if present circumstances change.

Appendix B: **Default ANZECC/ARMCANZ (2000) water quality guidelines.**

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

Aquatic Ecosystem	Analyte						
	TP mg/L	FRP mg/L	TN mg/L	NOx mg/L	NH_4^+ mg/L	DO % saturation[f]	pH
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-	0.35-1.2[g]	0.01	0.01	90[b]-120 [b]	6.0-8.0

b = Northern Territory values are 0.005mg/L 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.

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

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

Guideline values for toxicants at alternative levels of protection. Values in grey shading are applicable to typical *slightly-moderately disturbed systems* (ANZECC/ARMCANZ 2000).

Chemical			Guideline values for freshwater mg/L Level of protection (% species)			
			99%	95%	90%	80%
Metals and metalloids						
Aluminium	pH > 6.5		0.027	0.055	0.08	0.15
Aluminium	pH < 6.5		ID	ID	ID	ID
Arsenic (As III)			0.001	0.024	0.094[C]	0.36[C]
Arsenic (AsV)			0.0008	0.013	0.042	0.14[C]
Boron			0.09	0.37[C]	0.68[C]	1.3[C]
Cadmium		H	0.00006	0.0002	0.0004	0.0008[C]
Chromium (Cr III)		H	ID	ID	ID	ID
Chromium (Cr IV)			0.00001	0.001[C]	0.006[A]	0.04[A]
Cobalt			ID	ID	ID	ID
Copper		H	0.001	0.0014	0.0018[C]	0.0025[C]
Iron		G	ID	ID	ID	ID
Lead		H	0.001	0.0034	0.0056	0.0094[C]
Manganese			1.2	1.9[C]	2.5[C]	3.6[C]
Mercury (inorganic)		B	0.00006	0.0006	0.0019[C]	0.0054[A]
Mercury (methyl)			ID	ID	ID	ID
Molybdenum			ID	ID	ID	ID
Nickel		H	0.008	0.011	0.013	0.017[C]
Selenium (Total)		B	0.005	0.011	0.018	0.034
Selenium (SelV)		B	ID	ID	ID	ID
Uranium			ID	ID	ID	ID
Vanadium			ID	ID	ID	ID
Zinc		H	0.0024	0.008[C]	0.015[C]	0.031[C]
Non-metallic inorganics						
Ammonia		D	0.32	0.9[C]	1.43[A]	2.3[A]
Chlorine		E	0.0004	0.003	0.006[A]	0.013[A]
Nitrate		E	0.017	0.7	3.4[C]	17[A]

Notes:

Where the final water quality guideline to be applied to a site is below the current analytical practical quantitation limits (see Section 3.4.3.3 for guidance)

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

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

A = Figure may not protect key test species from acute toxicity (and chronic) - check Section 8.3.7 for spread of data and its significance, 'A' indicates that guideline value > acute toxicity figure; note that guideline value should be <1/3 of acute figure (Section 8.3.4.4)

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

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

D = Ammonia as TOTAL ammonia as [NH_3_N] at pH 8. For changes in trigger value with pH refer to Section 8.3.7.2

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

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

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

H = Chemicals for which algorithms have been provided in table 3.4.3 to account for the effects of hardness. The values have been calculated using a hardness of 30 mg/L $CaCO_3$. These should be adjusted to the site-specific hardness (see Section 3.4.3)

Appendix C. Habitat results. September 2019.

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

Creek/Area	Site	Bedrock	Boulders	Cobbles	Pebbles	Gravel	Sand	Silt	Clay
Seven-Mile Creek	SM2	0	3	9	25	38	0	5	20
	SM3	0	1	1	5	0	0	4	89
	SM4	0	9	16	18	21	5	11	20
	SM5	1	1	1	6	5	0	11	75
	SM6	0	0	0	3	5	0	12	80
Pirraburdu Creek	PC1	2	2	4	20	30	33	9	0
	PC2	2	2	18	15	16	37	7	3
	PC3	0	1	9	29	21	10	9	21
Western Range	WR2	9	5	6	23	26	20	11	0
Eastern Range	ER1	20	0	5	20	30	15	10	0
	ER2	57	0	0	0	3	10	20	10
	ER3	51	1	0	8	12	10	18	0
Turee Creek Reference	TC1	2	1	5	15	20	27	30	0
	TC2	65	0	1	2	6	9	12	5
	TC3	2	1	0	3	11	10	15	58

Percentage cover by each of the in-stream habitat types. NB: Sub. Mac = submerged macrophyte, Emerg. Mac. = emergent macrophyte and Trailing Veg. = trailing vegetation.

Creek/Area	Site	Inorganic seds	Sub. Mac.	Emerg. Mac.	Algae	LWD	Detritus	Roots	Trailing Veg.	Habitat diversity
Seven-Mile Creek	SM2	21	0	11	41	5	16	2	4	**7**
	SM3	34	55	1	0	1	9	0	0	**5**
	SM4	42	0	19	10	9	6	2	12	**7**
	SM5	12	30	3	30	6	12	5	2	**8**
	SM6	28	7	6	40	2	7	4	6	**8**
Pirraburdu Creek	PC1	8	4	11	50	5	9	3	10	**8**
	PC2	20	18	5	30	6	15	4	2	**8**
	PC3	15	1	3	66	3	10	1	1	**8**
Western Range	WR2	74	1	0	15	1	9	0	0	**5**
Eastern Range	ER1	81	0	0	0	1	18	0	0	**3**
	ER2	73	0	0	0	9	18	0	0	**3**
	ER3	20	19	31	6	4	17	2	1	**8**
Turee Creek Reference	TC1	56	5	1	15	8	10	4	1	**8**
	TC2	56	0	1	25	1	15	1	1	**7**
	TC3	47	1	1	12	9	28	2	0	**7**

Appendix D. Water quality results. September 2019

Highlighted cells refer to values which are in excess of: > the 99% ANZECC default GV, > the 95% default ANZECC GV, and > point of ecological stress.

		ANZECC default GV		Seven Mile Creek					Pirraburdu Creek			Western R	Eastern Range			Turee Creek		
	Units	99% GV	95%	SM2	SM3	SM4	SM5	SM6	PC1	PC2	PC3	WR2	ER1	ER2	ER3	TC1	TC2	TC3
Temp	°C			22.2	31.9	23.5	21.1	17.8	23.8	20.5	25.5	20.4	18.9	20.9	20	21.8	23.8	17.5
pH	pH units		6-8	7.19	9.28	7.88	7.99	7.27	6.91	7.36	6.9	6.66	5.97	7.09	7.92	6.78	7.47	6.91
EC	µS/cm		250	2440	4332	2628	3279	3536	1473	1526	1723	229	132	1119	2888	1140	1104	804
DO	%		85-120	64.8	225.7	71.2	22.2	122.2	36.7	94.6	42.8	82	61.4	47.2	83.6	50.3	112.2	15.7
Turbidity	NTU		15	5.8	4	16.5	1.4	4.4	0.4	21.9	0.4	1	2.5	4.4	1.2	3.9	4.6	12.2
Alkalinity	mg/L			505	335	296	424	565	510	508	534	88	28	223	1020	345	356	289
Hardness	mg/L			670	920	502	831	1110	425	478	441	81	32	208	756	343	350	246
Na	mg/L			193	338	240	301	321	94.3	123	118	4.6	4.8	85.2	340	57.7	69.1	53.8
Ca	mg/L			73.9	25.6	61.6	60.8	110	59.3	54.4	50.6	22.6	7.7	33.9	55.2	70.6	45.3	48.7
Mg	mg/L			118	208	84.6	165	204	67.2	83	76.4	5.9	3.1	30	150	40.4	57.6	30.2
K	mg/L			2.9	0.8	11.2	5.6	5.2	1.2	2	1.4	4.1	5.2	30.6	2.4	8.1	16.8	9.9
HCO3	mg/L			505	95	286	396	565	510	508	534	88	28	223	957	345	346	289
Cl	mg/L			333	627	435	584	723	96	117	120	8	13	196	265	91	117	66
SO4_S	mg/L			84	185	<0.100	132	150	21.5	29.4	25.3	2.38	2.33	7.77	62.7	16	16.5	8.6
CO3	mg/L			<1	240	10	28	<1	<1	<1	<1	<1	<1	<1	67	<1	9	<1
Al	mg/L	0.027	0.055	<0.005	0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	0.042	0.008	<0.005	<0.005	<0.005	0.02
As	mg/L	0.001	0.024	0.0037	0.0024	0.0008	0.0017	0.0007	0.0028	0.0032	0.0036	<0.0002	<0.0002	0.0008	0.0014	0.0006	0.0016	0.003
B	mg/L	0.09	0.37	0.395	1.37	0.491	0.728	0.458	0.248	0.282	0.247	0.037	0.056	0.349	0.251	0.336	0.388	0.376
Ba	mg/L			0.0333	0.0138	0.0343	0.0142	0.0446	0.026	0.0121	0.0221	0.0193	0.122	0.0917	0.0237	0.14	0.0811	0.0775
Cd	mg/L	0.00006	0.0002	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005
Co	mg/L			0.0001	0.0003	0.0003	0.0005	0.0003	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0002	0.0002	<0.0001	<0.0001	0.0002
Cr	mg/L	0.00001	0.001	<0.0002	0.0002	0.0008	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	0.0017	0.0005	<0.0002
Cu	mg/L	0.001	0.0014	0.00008	0.00084	0.00037	0.00006	<0.00005	<0.00005	<0.00005	<0.00005	0.00022	<0.00005	0.00052	0.00039	<0.00005	0.00021	<0.00005
Fe	mg/L			0.008	0.014	0.042	0.006	0.011	0.002	0.012	0.002	<0.002	0.026	0.047	0.023	0.004	0.049	0.775
Mn	mg/L	1.2	1.9	0.0279	0.0022	0.0283	0.0072	0.0512	0.0028	0.0189	0.0042	0.0024	0.0035	0.0754	0.0231	0.0033	0.0059	0.207
Mo	mg/L			0.0029	0.006	0.0034	0.0028	0.003	0.0028	0.0042	0.0036	0.0002	<0.0001	0.0008	0.0035	0.0007	0.0008	0.0011
Ni	mg/L	0.008	0.011	<0.0005	0.0009	<0.0005	0.0008	0.0007	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	0.0013	<0.0005	<0.0005	<0.0005	<0.0005
Pb	mg/L	0.001	0.0034	<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	<0.0001	<0.0001
S	mg/L			82.2	183	92.9	124	143	21.3	26.3	25.2	2.4	2.3	8.6	60.4	16.4	14.4	9.1
Se	mg/L	0.005	0.011	0.005	0.0028	0.0039	0.0032	0.0042	0.0032	0.0034	0.0039	<0.0002	<0.0002	0.0004	0.0014	0.0017	0.0006	0.0005
U	mg/L			0.00306	0.00289	0.00166	0.0024	0.00378	0.00347	0.00428	0.00404	<0.00005	<0.00005	0.00014	0.00244	0.00114	0.00163	0.00028
V	mg/L			0.0232	0.0254	0.0042	0.0108	0.0025	0.0279	0.0326	0.0314	0.0005	0.0002	0.0002	0.0232	0.0067	0.0213	0.0032
Zn	mg/L	0.0024	0.008	<0.001	<0.001	0.015	<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	mg/L	0.26	0.73	0.06	0.03	0.15	0.02	0.07	0.01	0.05	<0.01	0.01	0.02	0.03	0.01	0.01	0.40	0.75
N_NO_3	mg/L	0.004	0.16	1.02	0.04	9.77	3.60	7.14	7.13	1.55	5.50	0.03	0.32	0.14	0.30	7.86	0.87	0.11
N_NOx	mg/L		0.01	1.05	0.04	10.30	3.65	7.20	7.17	1.59	5.54	0.03	0.32	0.14	0.33	7.88	0.93	0.16
N_total	mg/L		0.3	1.51	0.68	7.96	4.03	6.08	6.29	2.06	4.14	0.12	0.38	1.31	1.24	7.40	3.35	2.06
P_total	mg/L		0.01	0.019	0.068	0.040	0.032	0.033	0.072	0.155	0.053	0.007	0.021	0.046	0.084	0.078	0.192	0.154

Appendix E. Hyporheos fauna taxonomic list. September 2019.

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

***Indicates stygobitic and permanent hyporheos stygophile species**

			Seven-Mile			Pirraburdu		WR	Eastern Range		Turee
Phylum/Class/Order	**Family**	**Lowest taxon**	**SM1**	**SM2**	**SM6**	**PC2**	**PC3**	**WR2**	**ER1**	**ER3**	**TC3**
MOLLUSCA											
GASTROPODA	**Planorbidae**	*Gyraulus* sp.	0	2	0	0	0	0	0	0	0
ANNELIDA											
OLIGOCHAETA		Oligochaeta spp. (imm/dam)	0	0	0	0	0	0	0	3	0
		Earthworm spp	0	0	2	0	0	0	0	2	0
	Enchytraeidae	Enchytraeidae 'BOL036'	0	0	0	0	0	0	1	0	0
	Naididae	Naididae spp.	0	3	0	2	0	0	0	2	0
		Tubificinae sp.	0	2	0	0	0	0	0	0	0
		Pristina spp.	0	2	0	2	0	0	0	0	0
	Phreodrilidae	Phreodrilidae spp	0	0	0	0	0	0	0	3	0
ARTHROPODA											
CRUSTACEA											
OSTRACODA											
Popocopida	**Cyprididae**	*Cypretta* sp.	0	1	0	0	0	0	0	0	0
		Cyprinopsinae sp. (juv.)	0	0	0	1	0	0	0	0	0
		Stenocypris major	0	0	0	0	0	1	0	0	0
	Candonidae	Candonidae 'BOS1365' (imm./dam.)	0	1	0	0	0	0	1	0	0
		*Candonopsis tenuis**	0	1	0	2	1	0	1	3	1
	Darwinulidae	*Vestalenula* sp. (dam.)*	0	1	0	0	0	0	0	0	0
	Limnocytheridae	*Limnocythere dorsosicula**	0	1	0	0	0	0	0	0	0
MAXILLOPODA											
Copepoda											
Cyclopoida		Cyclopidae copepodite	0	2	0	0	0	0	0	0	0
	Cyclopidae	*Australoeucyclops karaytugi*	0	0	0	0	0	1	0	0	0
		*Diacyclops humphreysi**	0	1	0	0	0	0	0	0	0
		Ectocyclops phaleratus	0	0	0	0	0	0	0	0	1
		Ectocyclops rubescens	0	1	0	0	0	0	0	0	0
		Mesocyclops darwini	0	1	0	0	0	0	0	0	0
		Mesocyclops sp.	0	0	0	0	0	0	0	4	0
		Microcyclops varicans	0	0	0	1	1	0	0	0	1
		Paracyclops sp. 8 (PSW)	0	1	0	1	0	0	0	0	0
		*Paracyclops intermedius**	0	0	0	1	0	0	0	0	0
		Thermocyclops 'BCY066'	0	0	0	0	0	1	0	0	0
MALACOSTRACA											
AMPHIPODA	**Paramelitidae**	*Pilbarus millsi**	0	0	0	0	1	0	0	0	0
CHELICERATA											
ARACHNIDA											
Trombidiformes		Trombidiformes sp.	0	1	0	0	0	0	0	0	0
Prostigmata	**Hydryphantidae**	*Wandesia* sp. 'BAC004'	0	0	0	1	0	0	0	0	0
	Mideopsidae	*Tillia* sp. 'BAC003'*	0	0	0	0	1	0	0	0	0
	Unionicolidae	*Neumania* sp.	0	0	0	0	0	1	0	0	0
Sarcoptiformes		Oribatida spp.	0	0	0	0	1	1	0	0	0
HEXAPODA											
COLLEMBOLLA											
Entomobryoidea		Entomobryoidea spp.	1	3	1	0	0	0	0	0	0
INSECTA											
DIPTERA	**Ceratopogonidae**	Ceratopogoninae spp.	2	3	0	3	3	2	0	4	3
		Dasyheleinae spp.	0	3	0	2	0	0	0	2	2
		Forcypomyiinae spp.	0	0	0	0	0	0	0	2	0
	Chironomidae										
	Chironominae	*Polypedilum* sp. K1 (PSW)	0	0	0	0	2	0	0	0	0
		Polypedilum sp. S01 (PSW)	0	0	0	0	0	0	0	0	2
		Tanytarsus sp. D (SAP)	0	1	0	0	0	0	0	0	0
		Tanytarsus sp. P09 (PSW)	0	1	0	0	1	0	0	0	0
	Orthocladiinae	nr. *Gymnometriocnemus* sp.	0	2	0	0	0	0	0	0	0
	Tanypodinae	*Larsia ?albiceps*	0	0	0	0	0	2	0	0	0

			Seven-Mile			Pirraburdu		WR	Eastern Range		Turee
Phylum/Class/Order	**Family**	**Lowest taxon**	**SM1**	**SM2**	**SM6**	**PC2**	**PC3**	**WR2**	**ER1**	**ER3**	**TC3**
		Paramerina 'A' (?parva) (SAP)	0	0	0	0	0	0	0	0	1
		Paramerina sp 1	0	0	0	0	0	1	0	0	0
		Procladius spp.	0	2	0	2	0	0	0	0	0
		Pentaneurini sp. P1 (PSW)	0	0	0	0	0	0	0	0	1
	Dolichopodidae	Dolichopodidae spp.	0	0	0	2	0	2	0	0	0
	Ephydridae	Ephydridae spp.	0	0	0	2	0	0	0	0	0
	Muscidae	Muscidae spp.	0	1	0	0	0	0	0	0	0
	Stratiomyidae	Stratiomyidae spp.	0	2	0	1	0	0	0	0	0
	Tipulidae	Tipulidae spp.	0	0	1	3	0	0	0	2	0
COLEOPTERA	**Carabidae**	Carabidae spp.	0	1	0	1	0	0	0	1	0
	Heteroceridae	*Heterocerus* sp.	1	0	0	0	0	0	0	0	0
	Hydraenidae	Hydraenidae spp.	0	1	0	0	0	0	0	0	0
	Hydrochidae	*Hydrochus eurypleuron*	0	0	0	1	0	0	0	0	0
	Hydrophilidae	*Chaetarthria* sp.	0	1	0	2	0	0	0	0	0
		Helochares sp. (L)	0	0	0	2	0	0	0	0	0
		Helochares tatei	0	0	0	1	0	0	0	0	0
		nr. *Anacaena* sp.	0	0	0	0	0	0	0	1	0
		Paracymus sp. (L)	0	0	0	2	0	0	0	0	0
		Paracymus spenceri	0	0	0	2	0	0	0	0	0
	Scirtidae	Scirtidae spp. (L)	0	2	0	0	0	0	0	0	2
HEMIPTERA	**Notonectidae**	Notonectidae spp. (juv.)	0	0	0	0	0	0	1	2	1
TRICHOPTERA	**Hydroptilidae**	*Hellyethira* sp.	0	0	0	0	0	0	0	0	1
		Taxa richness	**3**	**28**	**3**	**22**	**8**	**9**	**4**	**13**	**11**

Appendix F. Macroinvertebrate taxonomic list. September 2019.

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

			Seven-Mile					Pirraburdu			WR	Eastern Range			Turee		
Phylum/Class/Order	**Family**	**Lowest taxon**	**SM2**	**SM3**	**SM4**	**SM5**	**SM6**	**PC1**	**PC2**	**PC3**	**WR2**	**ER1**	**ER2**	**ER3**	**TC1**	**TC2**	**TC3**
CNIDARIA																	
HYDROZOA	**Hydridae**	*Hydra* sp.	4			2		1	2								
NEMATODA		Nematoda sp.			5												
MOLLUSCA																	
GASTROPODA	**Lymnaeidae**	*Bullastra vinosa*		2		4	3	3	3	2	2			1	3		1
	Planorbidae	*Bayardella* sp.									1	3	2				
		Ferrissia petterdi							1					1			
		Gyraulus sp.	2	3		4	3	4	3					3			1
ANNELIDA																	
OLIGOCHAETA																	
	Enchytraeidae	Enchytraeidae `BOL036`										1					
	Naididae	Tubificinae spp.			5									3			
		Naididae spp. (imm./dam.)	3		3			3	3					6	3		
		Naidinae sp. (imm.)				3	2					1					
		Allonais pectinata													2		
		Allonais ranauana	3					1									
		Dero furcatus						1									
		Nais communis						1									
		Nais variabilis							2								1
		Pristina leidyi							3								
		Pristina longiseta	3		3	3		3	3						3		
		Pristina nr. *sima*	3					1									
		Pristina spp. (imm./dam.)				3			3					3			
HIRUDINIDA		Hirudinea sp.									2						
ARTHROPODA																	
CRUSTACEA																	
MAXILLIPODA		Cyclopoid copepodite (imm.)	4	3		3	3	5	3	3	2	5	1	3	3	4	4

Phylum/Class/Order	Family	Lowest taxon	Seven-Mile					Pirraburdu			WR	Eastern Range			Turee		
			SM2	SM3	SM4	SM5	SM6	PC1	PC2	PC3	WR2	ER1	ER2	ER3	TC1	TC2	TC3
		Cyclopoid nauplii (imm.)	3	3	2	3	3	3	3	2	2	3	3	3	2	2	2
Cyclopoida	**Cyclopidae**	*Ectocyclops phaleratus*				4											
		Eucyclops cf. *australiensis*													2		
		Mesocyclops sp.										2					
		Mesocyclops cf. *affinis*						4					2				
		Mesocyclops brooksi				3											
		Mesocyclops notius		3													
		Microcyclops varicans							3	2					2	4	4
		Thermocyclops crassus	4														
		Tropocyclops prasinus				4		3	2	3		5		3	1		
		Tropocyclops confinus															3
Harpacticoida		Harpacticioida spp. (imm.)				3	2	2									
DIPLOSTRACA																	
CLADOCERA	**Daphnidae**	*Ceriodaphnia* sp.	1														
		Simocephalus heilongjiangensis				2											
	Macrothricidae	*Macrothrix spinosa*														4	2
	Chydoridae	*Alonella* cf. *excisa*								2							
OSTRACODA																	
PODOCOPIDA		Ostracoda spp. (imm.)	2			2	2	2	2	2	3	3	1	3		3	2
	Notodromadidae	*Newnhamia fenestrata*								3	5	5	5	3			
	Cyprididae	*Cypretta* sp									3			3			
		cf. *Candonocypris* sp.						1									
		Sarcypridopsis sp.													2		
	Ilyocyprididae	*Ilyocpris australiensis*	2				3	1	2								
CHELICERATA																	
ARACHNIDA																	
Prostigmata		Prostigmata sp. (imm.)											1				
		Halacaroidea sp.		2													
	Arrenuridae	*Arrenurus* sp. `BAC005`										1					
		Arrenurus vanderpalae	1			1											
	Eylaidae	*Eylais* sp.														3	
	Hydrachnidae	*Hydrachna* sp.											2				
		Hydrachna sp. 3 (PSW)									1						
	Hydrodromidae	Hydrodromidae sp. (imm.)					1										
		Hydrodroma sp.		1													

			Seven-Mile					Pirraburdu			WR	Eastern Range			Turee		
Phylum/Class/Order	**Family**	**Lowest taxon**	**SM2**	**SM3**	**SM4**	**SM5**	**SM6**	**PC1**	**PC2**	**PC3**	**WR2**	**ER1**	**ER2**	**ER3**	**TC1**	**TC2**	**TC3**
	Limnesiidae	*Limnesia* sp.		1					2	2							
		Limnesia sp. 4 (PSW)	1			2		1			1			2			
	Pionidae	*Piona cumberlandensis*				1								1			
	Unionicolidae	Unionicolidae sp.					2										
		Neumania sp.								2				1			
		Recifella tinka												1			
		Unionicola neoaffinis				1						2					
		Unionicola nr *minutissima* (PSW)				1								1			
Sarcoptiformes		Oribatida spp.									2	1		1			
HEXAPODA																	
INSECTA																	
COLEOPTERA	**Carabidae**	Carabidae sp.										1					
	Dytiscidae	*Allodessus bistrigatus*			1		1										
		Austrodytes insularis							1								
		Copelatus irregularis					1				1	2					1
		Copelatus nigrolineatus						1									
		Eretes australis														2	1
		Hydaticus consanguineus							2	1							
		Hydaticus daemeli										1					
		Hydroglyphus grammopterus	2	1													
		Hydroglyphus orthogrammus	2	2				2	2	2	1	2	2	2	2	2	
		Hydrovatus opacus	2			1	1	2									
		Hydrovatus sp. (L)	1				2	1		1					1		
		Hyphydrus elegans	1	1					2		1		1				
		Hyphydrus lyratus	2	1		1			1		1					1	
		Hyphydrus sp. (L)		2							1			1			
		Laccophilus sharpi												1			
		Laccophilus sp. (L)		1													
		Limbodessus compactus	1	1	2	1	1	2			1	1				1	
		Necterosoma regulare	2	3	2	2	1		1	1	1						3
		Necterosoma undecimlineatum									2	2			1		
		Necterosoma sp. (L)	2		2		2						2				
		Neobidessodes denticulatus	2	2		2			2	2							
		Platynectes decempunctatus var. *decem.*					1							1	2		
		Rhantaticus congestus							1							1	

			Seven-Mile					Pirraburdu			WR	Eastern Range			Turee		
Phylum/Class/Order	**Family**	**Lowest taxon**	**SM2**	**SM3**	**SM4**	**SM5**	**SM6**	**PC1**	**PC2**	**PC3**	**WR2**	**ER1**	**ER2**	**ER3**	**TC1**	**TC2**	**TC3**
		Tiporus lachlani									2	2	2				
		Tiporus sp. (L)											2				
	Gyrinidae	*Dineutus australis*														2	2
		Macrogyrus gibbosus									1						
	Hydraenidae	*Hydraena* sp.	2					3	2	2		3	2	1			
		Limnebius sp.	2					2	2	1							
		Ochthebius sp.	2	1				2		1							
	Hydrophilidae	*Anacaena horni*	2					2		2				2			
		Berosus dallasae		2	1			1						1			1
		Berosus sp. (L)		2													
		Enochrus deserticola					1	2			1					1	
		Helochares tatei	2				1	2	1	1							
		Helochares sp. (L)	3				2	3	2	2						1	
		Hydrochus eurypleuron	3					2	2			1					
		Hydrochus group 3 `black` (PSW)	1														
		Hydrochus laeteviridis						2									
		Hydrochus obscuroaeneus	2					2									
		Paracymus sp. (L)					1										
		Paracymus spenceri	2	2	2		1	3	2	2	2	2	2	1		2	
		Regimbartia attenuata	1					1									
		Sternolophus australis										2	3				
		Sternolophus marginicollis						2		1							
		Sternolophus sp. (L)					2										
	Noteridae	*Neohydrocoptus subfasciatus*	1														
	Scirtidae	Scirtidae sp. (L)	2					2						2	1		
DIPTERA	**Ceratopogonidae**	Ceratopogonidae spp. (P)	2				2			2				1		2	
		Dasyheleinae spp.	3				3	3	5	3						1	
		Ceratopogoninae spp.	3	3				2	2	2	2	3	3	2	3	3	3
		Forcipomyinae spp.	1														
	Chironomidae	Chironomidae spp. (P)	3				3			2		1	3	2	1		
	Chironominae	Chironomini sp.								1		1			1		
		Chironomus aff. *alternans*	1				1		1				1	2	2	2	1
		Cladopelma curtivalva							1								
		Dicrodentipes sp. Bio1												2			
		Dicrotendipes `CA1`									3						

			Seven-Mile					Pirraburdu			WR	Eastern Range			Turee		
Phylum/Class/Order	**Family**	**Lowest taxon**	**SM2**	**SM3**	**SM4**	**SM5**	**SM6**	**PC1**	**PC2**	**PC3**	**WR2**	**ER1**	**ER2**	**ER3**	**TC1**	**TC2**	**TC3**
		Cryptochironomus griseidorsum						1									
		Kiefferulus intertinctus											1	2			
		Paratanytarsus sp.											1				
		Polypedilum (*Pentapedilum*) *leei*								1		2	1			1	
		Polypedilum (*Polypedilum*) *nubifer*						2							2		
		Polypedilum sp. S01 (PSW)										1			1		
		Polypedilum sp.							1								
		Rheotanytarsus juliae													1		
		Rheotanytarsus sp.												1			
		Tanytarsus fuscithorax/semibarbitarsus		1		2											
		Tanytarsus sp. D (SAP)	1					1	3	1							
		Tanytarsus sp. H (SAP)						1		1							
		Tanytarsus sp. P01 (PSW)					1								1		
		Tanytarsus sp. P06 (PSW)															3
		Tanytarsus sp. P09 (PSW)	2						1	1			1			2	
		Tanytarsus spp.				1	3	2				2	3	2	2	3	2
	Tanypodinae	*Ablabesmyia hilli*											3	1			
		Fittkauimyia ?disparipes						2									
		Larsia ?albiceps	3			3	2	4	4	3	2	2					
		Paramerina sp. 1					3	3	3		2	2	4	3	2		2
		Paramerina sp. 2					3		3	2				1			
		Procladius (*Procladius*) *paludicola*				2											
		Procladius spp.	4	4	1	3	4	2	4	1	3	3	4	3	4	4	4
	Orthocladiinae	*Corynoneura* sp.										2	2				
	Culicidae	Culicidae sp. (P)					2		2				1	3		1	
		Aedes sp.												1			
		Anopheles sp.	2	3					3			3	2	3	2	2	
		Culex sp.			2	2	3		2			1		2		2	1
	Dolichopodidae	Dolichopodidae spp.										1					
	Ephydridae	Ephydridae spp.	3				3	1	2	1							
	Sciomyzidae	Sciomyzidae spp.				1	1		1					1			
	Stratiomyidae	Stratiomyidae sp.	2			1	2	2	2	2				2	1		
	Tabanidae	Tabanidae sp.	2				2	1	2	2	1	2			2	1	
EPHEMEROPTERA	**Baetidae**	Baetidae spp. (imm)	1	3	1	3	2	3		1	2	3	3	3	3	2	2
		Cloeon sp. (imm/dam)		4			1	2		2							

			Seven-Mile					Pirraburdu			WR	Eastern Range			Turee		
Phylum/Class/Order	**Family**	**Lowest taxon**	**SM2**	**SM3**	**SM4**	**SM5**	**SM6**	**PC1**	**PC2**	**PC3**	**WR2**	**ER1**	**ER2**	**ER3**	**TC1**	**TC2**	**TC3**
		Cloeon fluviatile				3	1										
		Cloeon sp. Redstripe		4	1	4	3	2	3	2	2	1	1	4	3	3	2
	Caenidae	Caenidae spp. (imm)						1									
		Tasmanocoenis sp.							4	2							
		Tasmanocoenis sp. p/*arcuata*	2					1	2	1							
HEMIPTERA	**Belostomatidae**	Belostomatidae sp. (imm.)					2							2			
		Diplonychus eques					1	2	2	2				1			
	Corixidae	Corixidae spp. (imm.)										1					1
		Agraptocorixa parvipunctata							2					2	1		
		Agraptocorixa sp.		1												2	
	Gerridae	Gerridae sp.		1													
		Limnogonus fossarum gilguy						2	2							1	
	Mesoveliidae	*Mesovelia hungerfordi*	1														
	Micronectidae	Micronectidae spp. (imm./dam.)		4		3			2								
		Micronecta annae		4		3			1								1
		Micronecta sp.	1														
	Nepidae	*Laccotrephes tristis*										3	2				
		Ranatra occidentalis							2								
	Notonectidae	Notonectidae spp. (imm)		3							3				2		
		Anisops spp. (F/imm/dam)	1	2		3					1	2	3	4		3	
		Anisops elstoni												2	1		
		Anisops hackeri	2	2		2					2			3		2	2
		Anisops nabillus				2						2	2				
		Anisops nasutus														1	
		Anisops stali											2				
		Anisops thienemanni		1												1	
		Enithares woodwardi									2	3	2		2		
	Pleidae	*Paraplea brunni*	3			3								1			
		Paraplea sp.						2									
	Veliidae	Veliidae sp.				1	2	2				2	2	2	1		
		Nesidovelia peramoena	2				2					2					
		Microvelia sp. (F/imm/dam)	2														
ODONATA																	
Zygoptera		Zygoptera spp. (imm./dam.)	2	3	1		2	2	2					3			

Phylum/Class/Order	Family	Lowest taxon	Seven-Mile					Pirraburdu			WR	Eastern Range			Turee		
			SM2	**SM3**	**SM4**	**SM5**	**SM6**	**PC1**	**PC2**	**PC3**	**WR2**	**ER1**	**ER2**	**ER3**	**TC1**	**TC2**	**TC3**
	Coenagrionidae	*Agriocnemis rubescens*	2											1			
		Agriocnemis sp.		2													
		Ischnura aurora	2	3		2	2		3	1				3	1		
		Ischnura heterosticta					2										
	Isostictidae	*Eurysticta coolawanyah*	1														
Anisoptera		Anisoptera spp. (imm.)	2			2	2	1	1	1	1	1	3	2		1	
	Aeshnidae	*Anax papuensis*				1	3		2					2			
	Corduliidae	*Hemicordulia tau*	1				2					2	3				
	Gomphidae	*Austrogomphus gordoni*							1	1							
	Libellulidae	*Diplacodes bipunctata*						1									
		Diplacodes haematodes		1		1	2		2	1	1			1	2	3	2
		Orthetrum caledonicum	1						2		2				3	2	2
		Orthetrum migratum					1										
		Tramea sp.													1		
		Zyxomma elgneri	2							1							
	Lindeniidae	*Ictinogomphus dobsoni*						1									
TRICHOPTERA	**Ecnomidae**	*Ecnomus pilbarensis*									2	1	2				
	Hydroptilidae	*Hellyethira* sp.				2			2								1
	Leptoceridae	Leptoceridae sp. (imm)		1				1									
		Oecetis sp.						2									
		Triplectides ciuskus seductus						3									
		Triplectides sp.						2									
		Taxa richness	**68**	**41**	**16**	**47**	**56**	**69**	**65**	**49**	**39**	**49**	**41**	**61**	**40**	**38**	**29**