Ministers North:

Yandicoogina Creek Aquatic Ecosystem Surveys Dry 2020 and Wet 2021

Biologic Environmental Survey

Report to BHP Western Australia Iron Ore

September 2022

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EXECUTIVE SUMMARY

Biologic Environmental Survey (Biologic) was commissioned by BHP Western Australia Iron Ore (WAIO) to undertake a two-season baseline aquatic ecosystem survey of Yandicoogina Creek, located within the Upper Fortescue River Catchment and the Weeli Wolli/ Marillana sub-catchment. This constitutes the second round of sampling within permanent pools in a 3.5 km stretch of creekline (hereafter referred to as the Survey Area), with previous surveys undertaken in the dry season of 2019 (Dry 2019) and wet season of 2020 (Wet 2020) (Biologic, 2020c). Reference sites were sampled elsewhere to provide comparison and contextual information for Yandicoogina Creek. Together the Yandicoogina Creek reach and the reference sites comprised the Study Area for this project.

Aquatic ecosystem surveys were undertaken at eight sites, with site locations aligning with those previously sampled in the Dry 2019 and Wet 2020. Four sites were sampled within the Survey Area, and four reference sites were located elsewhere. Sampling was undertaken in October 2020 (Dry 2020 survey) and April 2021 (Wet 2021 survey). Ecosystem surveys included habitat assessments and sampling of water quality, macrophytes (submerged and emergent), zooplankton, hyporheos, macroinvertebrates and fish. Collection of additional hyporheic samples was attempted within the Survey Area to gain a better understanding of the distribution of stygal species previously collected; however, attempts to sample sites YC5H, YC6H, YC7H, YC8H and YC9H were not successful in either season (logistical constraints in the dry and low groundwater levels in the wet providing no connection with the hyporheic zone).

The Survey Area occurs within an open to closed *Eucalyptus camaldulensis* and *Melaleuca argentea* woodland over *Acacia tumida* var. *pilbarensis* shrubland, with reeds and sedges (*Cyperus vaginatus*, *Schoenoplectus subulatus* and *Typha domingensis*) along the waterline. In places, this groundwater dependent vegetation (GDV) was dense. The presence of several phreatophytes and mesophytic/hydrophytic indicator species highlighted the importance of this area as a high significance groundwater dependent ecosystem (GDE). Three submerged macrophytes are also known from the Survey Area, including *Vallisneria nana*, *Chara* sp. and *Ruppia* sp. *Vallisneria nana* is an indicator of water permanence and perennial moisture availabity, and is known only from perennial creeks and rivers (Rea *et al.*, 2002; Rio Tinto, 2020).

Surface water levels were noticeably lower during the Wet 2021 sampling event compared to the Dry 2020 and previous surveys, despite heavy wet season rainfall and associated flooding in the wet season of 2021. This contrasts with reference sites, where pools recorded higher water levels in the wet season following rainfall and flooding, and lower depths in the dry season prior. The falling water levels documented in the Survey Area in the Wet 2021 was accompanied by adverse changes to vegetation condition. Notably, *Typha domingensis* was in poor condition, with signs of senescence, particularly at YC2. In addition, the connection between the groundwater, hyporheic zone and surface waters was lost at several locations throughout the Survey Area. The fact that groundwater in the area appears to be declining over time is a concern, and the cause for the decline should be investigated further.

Water quality within Yandicoogina Creek was good and characterised by fresh, clear waters, with low dissolved oxygen saturation, neutral pH, and generally low nitrogen nutrient and dissolved metals concentrations. While water quality was generally within default ANZG (2018) guideline values (DGVs) for the protection of lowland river systems of tropical north Australia, there were some exceedances (i.e. electrical conductivity, dissolved oxygen, total nitrogen, total phosphorous, dissolved boron and dissolved iron) at some sites.

A diverse range of aquatic fauna was recorded across the Survey Area, including 238 invertebrate taxa and three freshwater fish species. Generally, the Survey Area supported high invertebrate taxa richness in surface waters and hyporheic zones, including a number of restricted, conservation significant and Pilbara endemic taxa. Two sites in particular (YC3 and YC4), appeared to be of considerable ecological value for invertebrate fauna.

Within the hyporheos, a total of 11% of taxa recorded are directly dependant on groundwater for persistence (11% stygobites and 0% permanent hyporheos stygophiles). The percentage of stygobitic taxa was considerably greater than that reported previously for Pilbara hyporheic zones (i.e., 5% stygobitic fauna recorded in Halse *et al*. 2002), highlighting the importance of the groundwater connection in this area. Greatest richness of groundwater dependent taxa (stygobites and permanent hyporheos stygophiles only) across all sites (including reference sites) was recorded from YC3 in the Dry 2020 (nine taxa).

Several Potential Short-Range Endemic (SRE) species were recorded from the hyporheos of Yandicoogina Creek (all stygal), including:

- The ostracods, *Notacandona boultoni*, *Gomphodella alexanderi* and *Candonopsis* `sp. Biologic-OSTR025`.
- The harpacticoid copepod Canthocamptidae `sp. B01`.
- The amphipods *Chydaekata* `sp. E` and Paramelitidae `sp. Biologic-AMPH023`.
- The isopod *Pygolabis* `sp. Biologic-ISOP035`.

Macroinvertebrate richness was generally high throughout the Survey Area, especially at sites YC3 (62 taxa in the dry 2020) and YC4 (70 taxa in the Wet 2021). Richness was lower at sites YC1 and YC2, which reflected the low water depths and difficulty associated with sampling due to high *Typha* abundance, especially at YC2. While most aquatic macroinvertebrates recorded from the Survey Area were common, ubiquitous species, some taxa were of note, including:

- The Pilbara emerald dragonfly *Hemicordulia koomina* (Vulnerable on the IUCN Redlist).
- The amphipod *Chydaekata* `sp. E` (SRE).
- The water mite *Austraturus* `sp. P2` (Pilbara endemic with a highly disjunct distribution and only known from permanent pools of good ecological condition).

When compared to other aquatic surveys previously undertaken in the area, the Survey Area recorded macroinvertebrate richness statistically similar to Weeli Wolli Creek (permanent pools located on Weeli Wolli Creek upstream of Bens Oasis), Marillana Creek (Biologic's sampling locations for the MAC Phase

4 aquatic survey, located on Upper Marillana Creek from Flat Rocks upstream), Marillana Creek Downstream (pools on Marillana Creek downstream of the pools in and around Flat Rocks, to just downstream of Rio Tinto's Yandicoogina Oxbow deposit) and Weeli Wolli Spring (a Priority 1 Priority Ecological Community, comprising approximately 2 km of flowing creekline), but significantly lower than the Davis River. Multivariate analyses on the same dataset indicated that macroinvertebrate assemblages of the Survey Area were statistically similar to those from Munjina Spring and the reference site on a tributary of Yandicoogina Creek (sampled for MAC Phase 4, i.e., MACREF1).

There were significant correlations between the environmental conditions (water quality and habitat data) and macroinvertebrate assemblages of the Survey Area. Significantly correlated variables included pH, dissolved oxygen, concentrations of total phosphorus, and percentage habitat cover by emergent macrophyte, large woody debris, roots, and bedrock. This highlights the importance of in-stream habitat to macroinvertebrate diversity and assemblage structure, including the importance of vegetation such as emergent macrophytes.

All freshwater fish species likely to populate the Survey Area were recorded, including the western rainbowfish *Melanotaenia australis* (Melanotaeniidae), Pilbara tandan *Neosilurus* sp. (Plotosidae), and spangled perch *Leiopotherapon unicolor* (Terapontidae). Although the Pilbara tandan is endemic to the Pilbara region, none of these species are of conservation significance and all are common and ubiquitous across the Pilbara. No introduced species were recorded.

The presence of relatively high abundances of western rainbowfish new recruits and juveniles within Yandicoogina Creek suggests good levels of breeding and recruitment. Spangled perch recruitment in the Survey Area likely occurred earlier in the wet season, with individuals growing to the size of juveniles by the time of the wet 2021 survey.

Overall, the stretch of Yandicoogina Creek encompassing the Survey Area should be considered an aquatic GDE that holds considerable importance in the region.

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GLOSSARY

ALA	Atlas of Living Australia
BOM	Bureau of Meteorology
DBCA	Department of Biodiversity, Conservation and Attractions
DGV	Default guideline value
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
GDE	Groundwater dependent ecosystem
GDV	Groundwater dependent vegetation
GS	Gauging station
IUCN	International Union for the Conservation of Nature
LWD	Large woody debris
OTU	Operational Taxonomic Unit
PBS	Pilbara Biological Survey
PEC	Priority Ecological Communities
SRE	Short-range endemic
SSGV	Site-specific guideline value
WAM	Western Australian Museum

1. INTRODUCTION

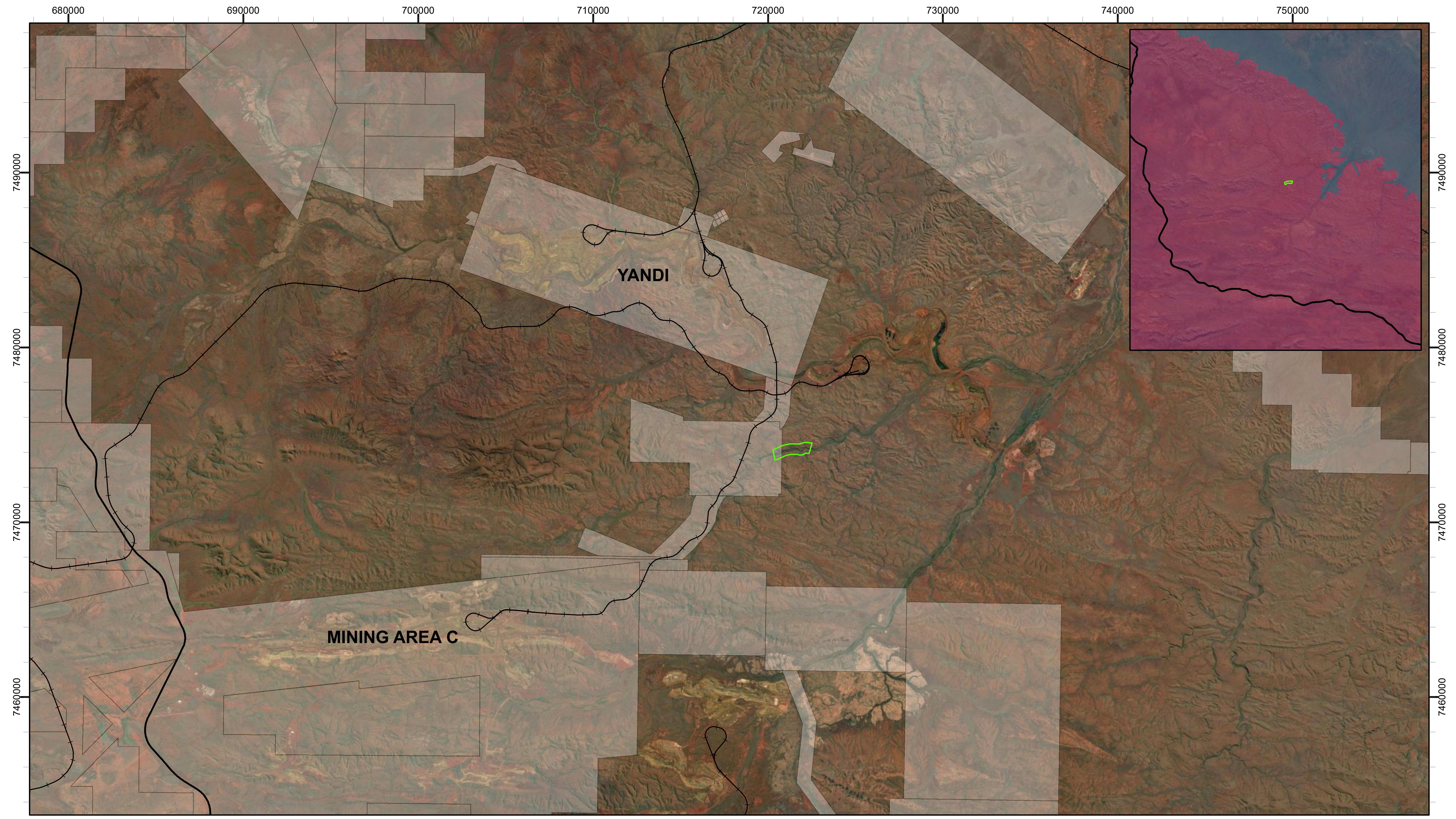
1.1 Background and objectives

Biologic Environmental Survey (Biologic) was commissioned by BHP Western Australia Iron Ore (WAIO) to undertake a two-season baseline aquatic ecosystem survey of Yandicoogina Creek, located within the Weeli Wolli/ Marillana sub-catchment of the Upper Fortescue River Catchment, in the Ministers north area. A 3.5 km stretch of Yandicoogina Creek was the focus of the survey and is hereafter referred to as the Survey Area (Figure 1.1). This reach of Yandicoogina Creek along with reference sites sampled elsewhere comprised the Study Area for the project. The Survey Area lies between the BHP WAIO Mining Area C (MAC) operation to the southwest and BHP WAIO Yandi operation to the north, within the Pilbara bioregion of Western Australia (Figure 1.1).

A previous aquatic survey identified the presence of a groundwater dependent ecosystem (GDE) and associated permanent pools within this 3.5 km stretch of Yandicoogina Creek (the Survey Area) (Biologic, 2020c). The GDE was found to be characterised by extensive closed *Melaleuca argentea* forest, with *Eucalyptus camaldulensis* over *Acacia tumida* var. *pilbarensis* shrubland, and reeds and sedges (e.g., *Cyperus vaginatus*, *Schoenoplectus subulatus* and *Typha domingensis*) along the waterline. Biologic (2020c) found the GDE provided important habitat for aquatic fauna, and supported high ecological values, including:

- Invertebrates with restricted distributions (i.e., stygal amphipods, a stygal isopod, and a stygal bathynellid);
- A high diversity of Pilbara endemic aquatic invertebrate taxa, especially at one site (a deep permanent pool; YC4);
- Conservation significant species which are listed on the IUCN Redlist of Threatened Species (*Eurysticta coolawanyah* and *Hemicordulia koomina*);
- A diversity of mesic flora species; and
- Three species of freshwater fish (Biologic, 2020c).

While the Biologic (2020c) survey was comprehensive, it does not provide a sufficient baseline with which to detect change in water quality and aquatic fauna assemblages associated with any potential developments in the area in future. ANZG (2018) recommends sampling seasonally (wet and dry) over a period of at least three years to develop an appropriate dataset to cover the range in natural variability present within the aquatic ecosystem. As such, BHP commissioned Biologic to undertake further aquatic surveys within the Survey Area in the dry season of 2020 (Dry 2020) and wet of 2021 (Wet 2021) (this report) to complement the baseline dataset.



Legend

▭ Survey Area

☐ Current BHP Tenure

—+— Railway

— Major Highways

IBRA Subregion

🟦 Fortescue

🟪 Hamersley

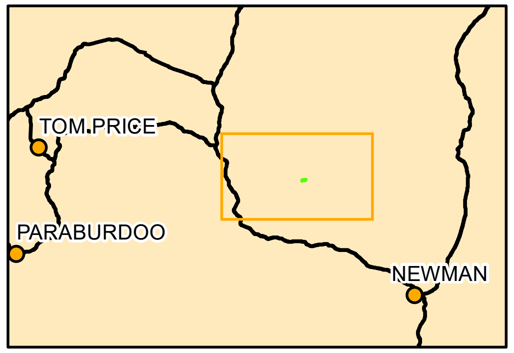
N

biologic
Environmental Survey

Scale: 1:200,000

0 2 4 6 8 10 12 Km

Coordinate System: GDA 1994 MGA Zone 50
Projection: Transverse Mercator
Datum: GDA 1994 Created 07/07/2022



BHP WAIO

Ministers North: Yandicoogina Creek Aquatic Ecosystem Surveys Dry 2020 and Wet 2021

Figure 1.1: Survey Area and regional location

The specific scope of works included:

- A two-season aquatic survey at all previously established sampling sites, including reference sites;
- Identification of any significant ecological values related to aquatic fauna and their habitats within the Survey Area; and
- An assessment of the seasonal, temporal and spatial variation in water quality and aquatic fauna, including data from this and previous surveys (i.e., Dry 2019 and Wet 2020; Biologic, 2020b).

1.2 Legislation and guidance

Key environmental legislation and regulation relating to aquatic ecology include:

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

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

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

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

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

There is currently (August 2022) no technical guidance applicable to the Inland Waters Environmental Factor. However, this survey was carried out in accordance with the EPA and BHP WAIO guidelines and was consistent with the following:

- Environmental Factor Guideline, Inland Waters (EPA, 2018);
- Technical Guidance, Sampling of Short-Range Endemic Invertebrate Fauna (EPA, 2016a);
- Technical Guidance, Terrestrial Fauna Surveys (EPA, 2016b);
- Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC & ARMCANZ, 2000; ANZG, 2018);
- Similar surveys, including the Pilbara Biological Survey (Pinder *et al.*, 2010) and National Monitoring River Health Initiative (MRHI; Choy & Thompson, 1995);
- BHP WAIO’s Aquatic Fauna Assessment Methods Procedure (0098594 V 2.0) (BHP, 2020);
- BHP WAIO’s Biological Survey Spatial Data Requirements (SPR-IEN-EMS-015) (BHP, 2018); and
- Previous surveys in the area (Biologic, 2020c).

2 ENVIRONMENT

2.1 Biogeographical Regionalisation of Australia

The Survey Area falls within the Pilbara biogeographical region as defined by the Interim Biogeographic Regionalisation of Australia (IBRA) (Thackway & Cresswell, 1995). The Pilbara bioregion is characterised by vast coastal plains and inland mountain ranges with cliffs and deep gorges (Thackway & Cresswell, 1995). Vegetation is predominantly mulga low woodlands or snappy gum over bunch and hummock grasses (Bastin, 2008).

The Pilbara bioregion is classified into four separate subregions, Chichester (PIL01), Fortescue (PIL02), Hamersley (PIL03) and Roebourne (PIL04), of which the Survey Area is located within the Hamersley subregion (Figure 1.1). This 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). The Hamersley contains extensive open snappy gum woodland and hummock grassland communities on ranges and plateaus, with low mulga woodlands over bunch grasses on fine textured soils in lower areas and valley floors (Kendrick, 2001).

The significant and dominant feature of this subregion is the Hamersley Range. This prominent range feature is a mountainous plateau, some 450 km in length, which receives considerably higher rainfall than the surrounding subregion. The plateau is dissected by deeply incised gorges, containing extensive permanent spring-fed streams and pools (Kendrick, 2001). 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 Survey Area is located within Weeli Wolli/ Marillana sub-catchment of the Upper Fortescue River Catchment. Several ephemeral creeklines traverse the Ministers North area, including Marillana, Lamb, Herbert and Yandicoogina creeks. Yandicoogina Creek is approximately 42 km in length and flows north-east into Marillana Creek (Figure 2.1). The upper reaches of Yandicoogina Creek comprise a relatively broad, undefined channel. However, in the mid to lower reaches, the creek flows through a gorge system and becomes well defined. It is through this section that the groundwater intercepts the surface, forming a series of seeps and pools that extend for approximately 3.5 km. Of note is one particularly deep pool (YC4). This pool is permanent and maintained partially by aspect and low evaporation (located against a cliff face), as well as groundwater inflow. Yandicoogina Creek meets Marillana Creek approximately 9 km downstream of this pool, where it flows eastwards for 7 km before draining into Weeli Wolli Creek.

Weeli Wolli Creek is approximately 70 km in length and has a catchment area of 4,100 km^2. It flows north, where it drains into the Fortescue River via the ecologically significant Fortescue Marsh (Figure 2.1). The two systems are only connected during flooding associated with intense cyclonic events (Kendrick, 2001). The Marsh is approximately 40 km downstream, and to the north, of Yandicoogina Creek (Figure 2.1). The Fortescue Marsh is a wetland system of national importance under the Directory of Important Wetlands in Australia (Environment Australia, 2001). It is a “good example of an extensive, inland floodplain system which is irregularly inundated”, and is a “unique wetland landform in Western Australia” (Environment Australia, 2001). The Fortescue Marsh extends east from Goodiaderrie Hills and comprises lakes, marshes, and pools along the floodplain in the middle reaches of the Fortescue River, and includes Powellinna Pool, Gnalka Gnoona Pool, Gidyea Pool, Chaddelinna Pool, Mungthannannie, Cook Pool and Moorimoordinia Pools (Environment Australia, 2001). Current and potential threats to the Fortescue Marsh include changes to hydrology, overgrazing by cattle, and pollution of surface inflow water from mine sites (Environment Australia, 2001).

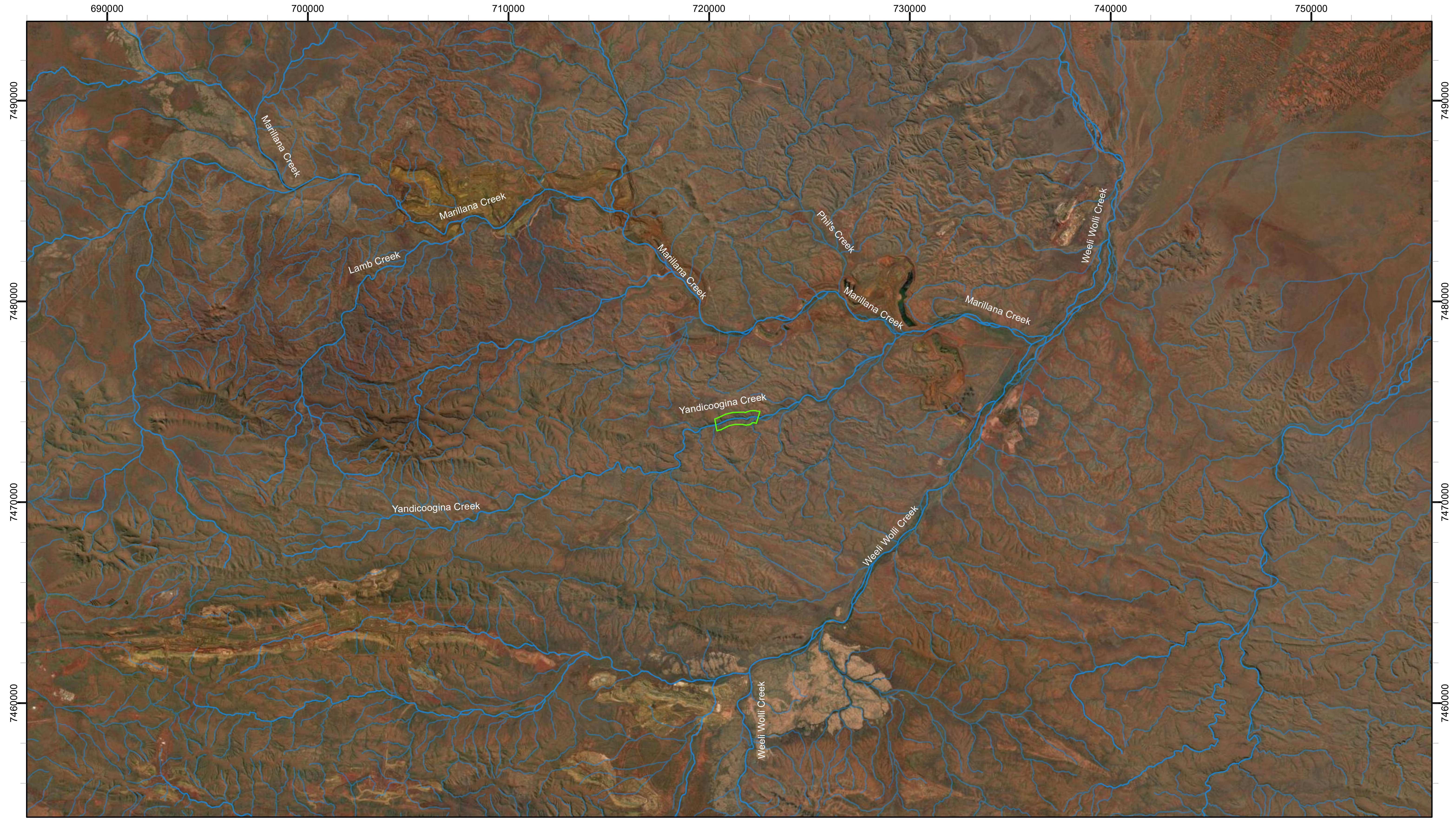
2.3 Groundwater Dependent Ecosystems

Groundwater-Dependent Ecosystems (or GDEs) are ecosystems that rely on groundwater for their continued existence (BoM, 2021). GDE’s can be represented by many different assemblages of biota which rely on groundwater, and as a result come in many forms. For terrestrial ecosystems there are three key types of GDE;

1. Aquatic ecosystems; that rely on the surface expression of groundwater – this includes surface water ecosystems which may have a groundwater component, such as rivers, wetlands and springs.
2. Terrestrial ecosystems; that rely on the subsurface presence of groundwater–this includes all vegetation ecosystems or Groundwater Dependent Vegetation (GDV).
3. Subterranean ecosystems; this includes cave and aquifer ecosystems (BoM, 2021).

Above-ground terrestrial GDE’s are typically characterised by the presence of flora species that rely on groundwater (i.e., phreatophytes). Phreatophytes may be classified as either obligate or facultative phreatophytes depending on their reliance on groundwater:

- Obligate phreatophytes are flora species confined to habitats with access to groundwater.
- Facultative phreatophytes are flora species that can utilise groundwater to satisfy a proportion of their ecological water requirement (EWR) when it is available. However, some individuals may also satisfy their EWR by relying solely on uptake from upper unsaturated soils layers where groundwater is inaccessible (Eamus *et al.*, 2016).



Legend

🟩 Survey Area

— Drainage Lines

N

biologic Environmental Survey

Scale: 1:175,000

0 2 4 6 8 10 Km

Coordinate System: GDA 1994 MGA Zone 50
Projection: Transverse Mercator
Datum: GDA 1994 Created 07/07/2022

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Figure 2.1: Surface hydrology of the Survey Area and surrounds

2.4 Climate

The Pilbara region has a semi-desert to tropical climate, with relatively dry winters and hot summers. Rainfall is highly variable and mostly occurs during the summer. It tends to be 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 (GS) for the Survey Area include the Department of Water and Environmental Regulation (DWER) Marillana Creek - Flat Rocks GS (station number 505011; length of record 1974 to current), located approximately 30 km north-west of Survey Area, and the DWER Marillana Creek - Munjina GS (station number 505004; length of record 1971 to current), located approximately 50 km north-west west of the Survey Area. Average annual rainfall recorded from Marillana Creek - Flat Rocks is 410 mm, compared to 435 mm at Marillana Creek - Munjina (DWER, 2021). Another GS lies approximately 10 km south-east of the Survey Area, DWER Weeli Wolli Creek - Tarina Station (station number 505040; length of record 1985-current); however, this station does not have data available over the course of the survey period. Previous data illustrates the high inter-annual variability in rainfall, with 159 mm total annual rainfall recorded from Tarina in 2010 but as much as 711 mm recorded in 2006.

3 METHODS

3.1 Desktop assessment

A comprehensive desktop assessment was undertaken for the previous survey report, including a database search and literature review (Biologic, 2020c). An additional database search was undertaken for the current study to update information on known aquatic species of conservation significance within the Survey Area, which may have been recorded in the interim.

3.1.1 Database searches

Five databases were searched for aquatic fauna records within and surrounding the Survey Area (Table 3.1).

Table 3.1: Databases searched for the review of previous records

Provider	Database	Reference	Search parameters
Department of Biodiversity, Conservation and Attractions (DBCA)	NatureMap	(DBCA, 2021)	40 km radius centred on the coordinates: -22.8257º, 119.1233º
Department of Agriculture, Water and Environment (DAWE)	Protected Matters Report	(DAWE, 2021)	
Atlas of Living Australia (ALA)	Species Occurrence	(ALA, 2021)	
Western Australian Museum (WAM)	Arachnids and Myriapods	(WAM, 2021a)	
WAM	Crustaceans	(WAM, 2021b)	
WAM	Molluscs	(WAM, 2021c)	

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

Since the previous literature review was conducted (Biologic, 2020c), an additional survey has been undertaken within 40 km of the Survey Area; BHP's MAC 4 aquatic survey along Marillana Creek (Biologic, 2021b). A total of six sites were sampled in a reach of Marillana Creek, upstream of BHP's Yandi operation, approximately 21 km north-east of the Yandicoogina Creek Survey Area. Data from Biologic (2021b) were assessed and used in comparisons with Yandicoogina Creek. A number of other surveys have included aquatic ecosystem sampling to varying degrees, with sites located as close as 4 km to the Yandicoogina Creek Survey Area (i.e., MC9) (Table 3.2, Figure 3.1). None of these surveys included sites within the Survey Area itself. Three of the reference sites utilised in the current survey were within the vicinity of previous survey sites (i.e., Bens Oasis and Weeli Wolli Spring).

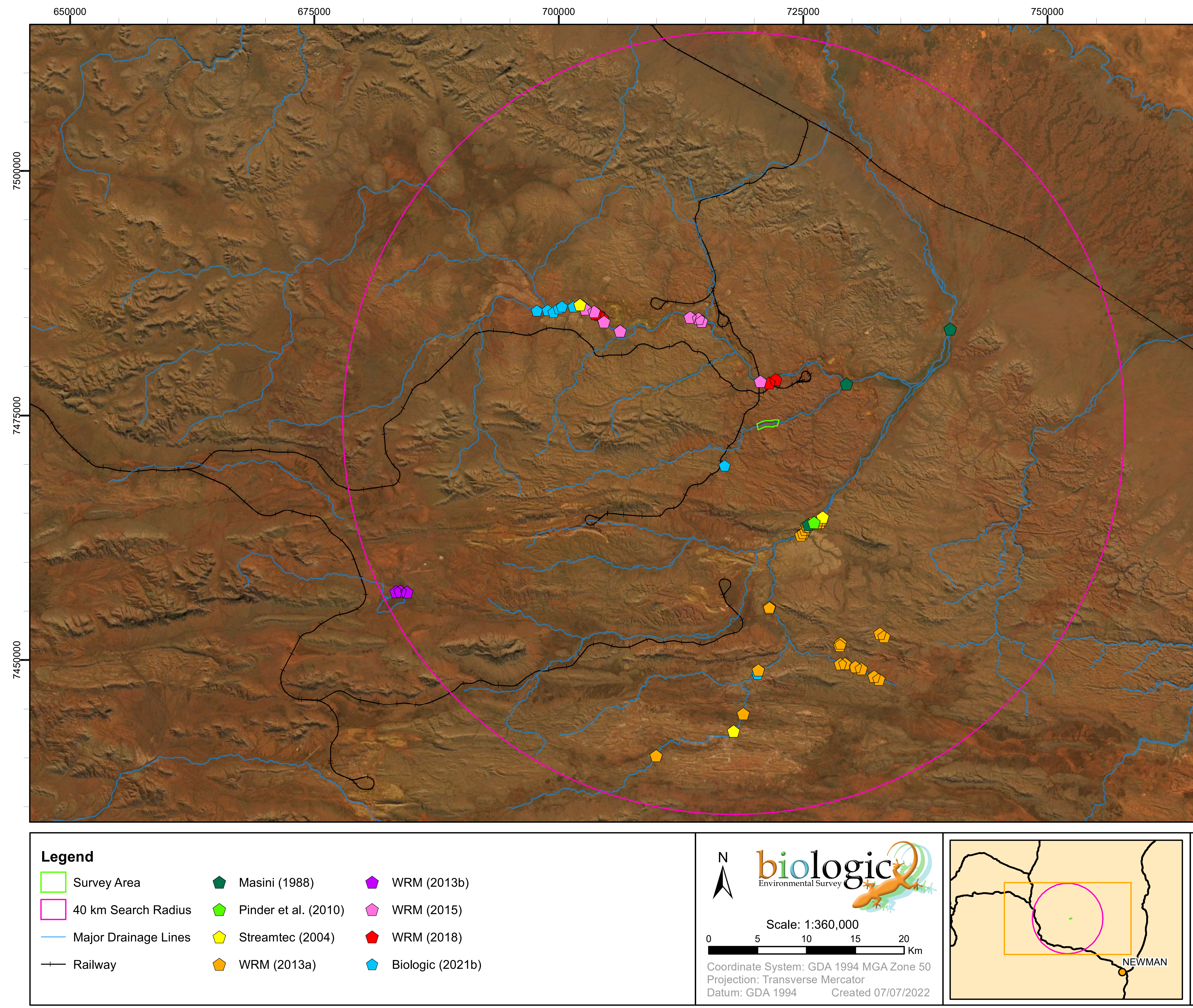

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Figure 3.1: Previous aquatic surveys conducted in the area

Table 3.2: Literature sources used for the review.

Survey Title	Reference	Survey Type	Closest Site to Survey Area (km)
Inland Waters of the Pilbara	Masini (1988)	Water Quality, Aquatic Flora, Waterbirds & Fish	8 km (Sites 24 & 25; Junction Marillana & Yandicoogina)
Aquatic Ecosystems of the Upper Fortescue River Catchment	Streamtec (2004)	Water Quality, Macroinvertebrates & Fish	11 km (Weeli Wolli Spring)
Pilbara Biological Survey	Pinder *et. al.* (2010)	Aquatic Flora, Zooplankton & Macroinvertebrates	11 km (PBS site PSW026 at Weeli Wolli Spring)
Jinidi: Baseline Aquatic Surveys at Weeli Wolli Creek	WRM (2013a)	Water Quality, Habitat, Zooplankton, Hyporheic Fauna, Macroinvertebrates & Fish	11 km (Weeli Wolli Spring, WWS5)
Lake Robinson Aquatic Invertebrate Fauna and Water Quality Surveys	WRM (2013b)	Water Quality, Zooplankton & Macroinvertebrates	23 km (WRM site LR3)
Yandi: Marillana Creek Aquatic Fauna Survey	WRM (2018)	Water Quality, Habitat, Zooplankton, Hyporheic Fauna, Macroinvertebrates & Fish	4.5 km (MC7)
Yandi Aquatic Fauna Survey	WRM (2015)	Water Quality, Habitat, Zooplankton, Hyporheic Fauna, Macroinvertebrates & Fish	4 km (MC9)
MAC Phase 4: Marillana Creek Baseline Aquatic Survey	Biologic (2021b)	Water Quality, Habitat, Zooplankton, Hyporheic Fauna, Macroinvertebrates & Fish	22 km (MarC6)

3.2 Field survey

3.2.1 Survey team

The field surveys were conducted by Biologic aquatic ecologists Jessica Delaney (Principal Zoologist | Manager of Aquatic Ecology), Kim Nguyen and Anton Mittra (Senior Zoologists | Aquatic Ecologists); all with extensive experience undertaking aquatic ecosystem surveys throughout the Pilbara. Morgan Lythe (Senior Zoologist) also provided assistance in the field in the Dry 2020 season, while Isabelle Johansson (Graduate Zoologist) and Suzi Wild (Principal Biodiversity, BHP) provided field assistance during the Wet 2021 survey.

Fauna sampling for this survey was conducted under DBCA Fauna Taking (Biological Assessment Regulation 27) Licence BA27000020 (dry season sampling) and BA27000223 (wet season sampling), and DPIRD Instrument of Exemption to the *Fish Resources Management Act 1994 Section 7 (2)* number: 3266, all issued to Jessica Delaney. Flora was collected under DBCA Flora Taking (Biological Assessment) Licence FB62000095, issued to Jessica Delaney.

Macroinvertebrate specimens were identified in-house by Alex Riemer, Kim Nguyen, Morgan Lythe, Giulia Perina and Juliana Pile-Arnold. Flora samples (submerged and emergent macrophytes) were identified by Biologic's Flora Team, including Clinton van den Bergh, Samuel Coultas and Kaylin Geelhoed, in conjunction with Alex Riemer and Morgan Lythe. Zooplankton samples were processed and identified by Dr Robert Walsh (Australian Water Life).

3.2.2 Survey timing, weather, and river conditions

The field survey comprised two seasons. The dry season survey (hereafter referred to as Dry 2020) was undertaken between the 30th of September and 5th of October 2020. Maximum daytime temperatures during the Dry 2020 survey (37.7°C) were slightly above average (35.3°C). There was no rainfall in the month preceding the survey, but immediately following the survey (after the 6th of October), Newman received a greater amount of rainfall than the October long-term average.

The wet season survey (Wet 2021) was undertaken between the 16th and 21st of April 2021. Maximum daytime temperatures during the wet survey (32.1°C) were comparable to the average temperature of 32.2°C (Figure 3.2). An active tropical low-pressure system (12U) at the start of February 2021 resulted in above average rainfall across much of the state, with Newman Airport GS recording more than double the long-term average rainfall for that month (Figure 3.2). This was followed by another cyclone in April 2021, which also led to above average rainfall at Newman Airport. The Flat Rocks GS on Marillana Creek, located approximately 18 km north-west of the Survey Area, also reported high rainfall for the 2021 wet season (DWER, 2021). February 2021 totals were well above the long-term average for the month (152.8 mm recorded in comparison to the average of 90.6 mm). However, conditions from previous years were very dry, with annual rainfall in 2018 (354 mm) and 2019 (289 mm) being well below the long-term average of 410 mm (DWER, 2021).

No streamflow stations exist within the Survey Area. The nearest DWER streamflow gauging stations are located at Weeli Wolli Creek (Tarina, station number 708014, 8.5 km south-east of the Survey Area), Marillana Creek (Flat Rocks, station number 708001, 18 km north-west of the Survey Area) and lower Weeli Wolli Creek (Waterloo, station number 708013, 21 km north-west of the Survey Area).

Streamflow in the Pilbara occurs as a direct response to rainfall. Monthly flows are typically highest in January and February, before receding over the course of the year (Figure 3.3). This pattern was evident by the high flows and extensive flooding experienced at the nearby Waterloo GS (# 708013) in February and April 2021 (Figure 3.3), when low pressure and cyclonic activity brought heavy rain to the area. Unfortunately, no data were available for either Tarina or Flat Rocks gauging stations from early February 2021, likely because the streamflow gauging stations were damaged during the flood. Therefore, the nearby Waterloo GS station data has been referenced for this period to show the influence of the low pressure system and cyclone on streamflows, with a total of 4,938 ML recorded for the month of April 2021, in comparison to the long-term average of only 1,515 ML (Figure 3.3).

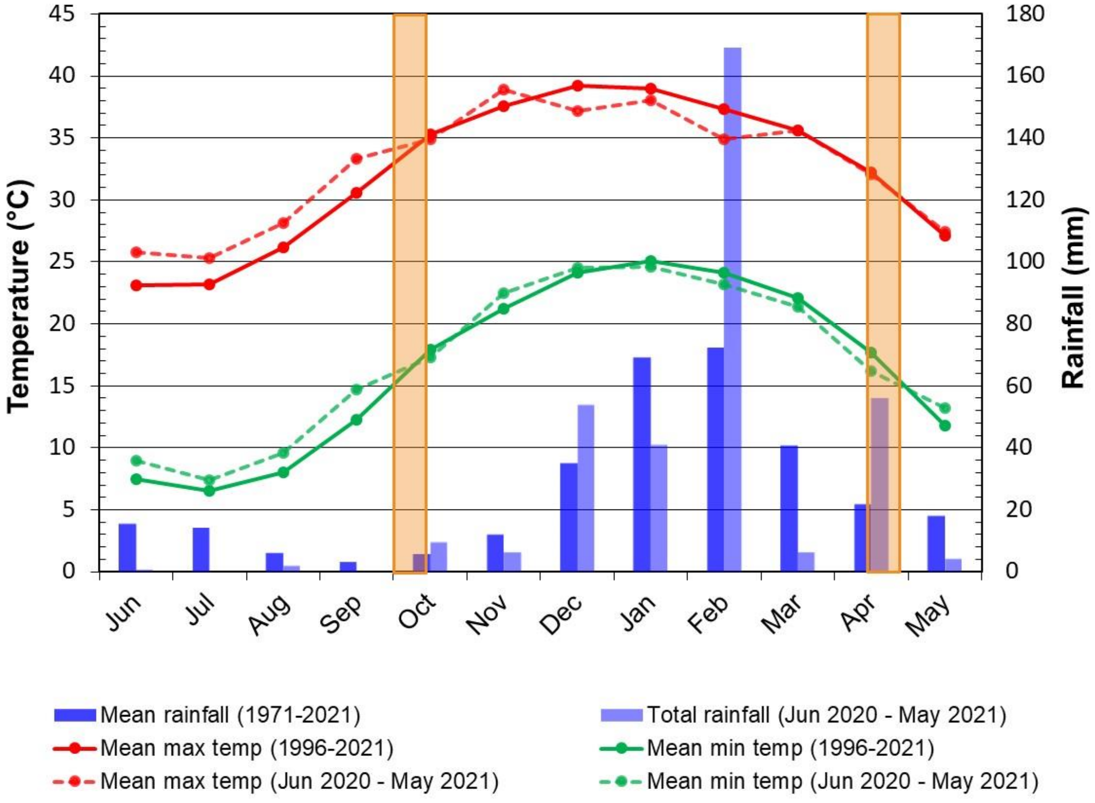

Figure 3.2: Total and long-term average monthly temperature (°C) and rainfall (mm) recorded from the Newman BoM gauging station in the months preceding and during the Yandicoogina Creek baseline aquatic surveys. Orange bars indicate survey timing.

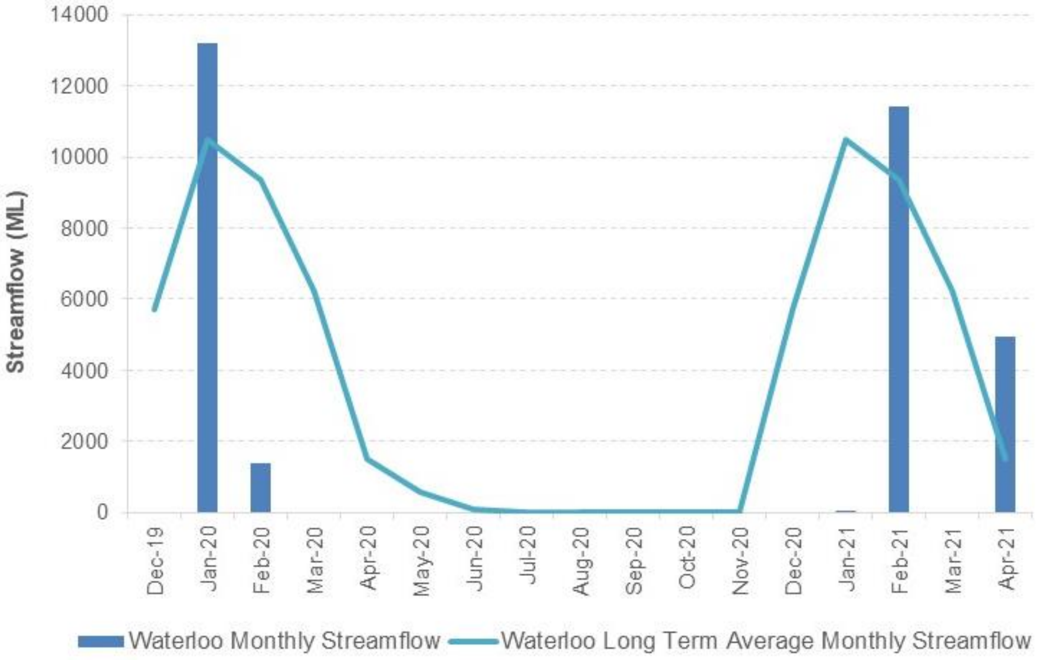

Figure 3.3: Monthly streamflow (ML) data at the DWER Waterloo GS on Weeli Wolli Creek, including monthly totals between Dec-19 and Jan-21 and long-term averages (1984-2020).

Historic data (i.e., not including the current year) from Flat Rocks illustrates the relationship between rainfall and streamflow, with high flows occurring during high rainfall years (Figure 3.4). Flows have been considerably lower since 2010 (mean flows of 182 ML per annum between 2010 and 2019), in comparison to the previous 10-year period (an average of 427 ML per annum between 2000 and 2009; Figure 3.4). Average rainfall from 2010 to 2019 is 395 mm, slightly lower than the previous decade (446 mm).

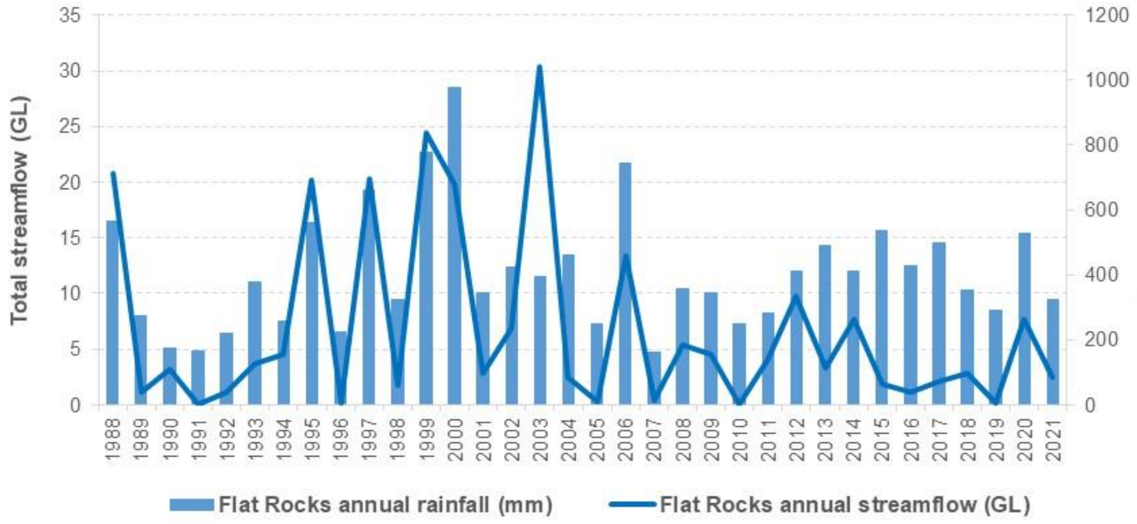

Figure 3.4: Annual rainfall (mm) and streamflow (ML) near the Survey Area, at the DWER Flat Rocks GS on Marillana Creek.

The consecutive tropical lows and cyclone in the wet season of 2021 resulted in widespread flooding across the East Pilbara, including within the Survey Area. Despite this, during the Wet 2021 survey, pools levels were noticeably lower than the preceding surveys, with some sites having receded to very small pools, and emergent vegetation declining. Hyporheic site locations that were successfully sampled in the Wet 2020 no longer provided access to the groundwater. In contrast, reference sites were flushed, and pools were full and flowing at the time of the Wet 2021 sampling event.

3.3 Sampling sites

The Survey Area comprised a section of the Yandicoogina Creek GDE where a series of permanent pools were present. A total of eight sites were sampled in both seasons; four located within the Survey Area, and four reference sites located elsewhere. Table 3.3 provides information on the sites sampled and their locations are shown in Figure 3.5.

The aim of reference site selection was to choose sites most similar to the GDE in Yandicoogina Creek, with respect to hydrology, persistence, morphology, and riparian vegetation, as well as being relatively close by and within the same climatic area. This is difficult in the Pilbara, a semi-arid region with few seeps and springs present, especially ones characterised by *Melaleuca argentea* and *Eucalyptus camaldulensis* riparian vegetation assemblages. As such, one reference site, Skull Springs, was selected for inclusion in this study, despite being located approximately 215 km to the north-east. While this site potentially experiences differences in rainfall and streamflow to the Survey Area, it is more like

Yandicoogina Creek in terms of morphology, hydrology, and vegetation than other sites located in closer proximity.

A brief description of Survey Area and reference sites is provided below:

Within Survey Area

- Yandicoogina Creek: Four sites (YC1, YC2, YC3 and YC4). YC1 through to YC3 are small seeps/pools through *Typha domingensis* beds, and YC4 is a large pool located against a cliff face.

Reference Sites

- Munjina Spring (MUNJS): a spring site located on Munjina Creek, within the Priority 2 Priority Ecological Community (PEC): *Riparian flora and plant communities of springs and river pools with high water permanence of the Pilbara*. This site was only sampled in the wet 2021 due to access issues in the Dry 2020.
- Weeli Wolli Spring (WWS): a spring site on Weeli Wolli Creek, within the Weeli Wolli Spring Priority 1 PEC. While this site is currently impacted by dewatering and discharge from Rio Tinto's Hope Downs 1 mine, the aquatic fauna remains representative of the historic faunal community and occurs within a permanently flowing reach.
- Ben's Oasis (BENS): a spring site on Weeli Wolli Creek which represents a second occurrence of the Weeli Wolli Spring Priority 1 PEC. This site has been impacted in recent years by fire and cattle.
- Skull Spring (SS): spring site on the Davis River. Designated a wetland of subregional significance by Kendrick and McKenzie (2001) due to the presence of permanent springs, large permanent pools, large fish fauna, waterbird use and richness of aquatic vegetation. Skull Springs lies approximately 228 km to the northeast of the Survey Area.
- Running Waters (RW): spring site on the Davis River. Running Waters was also designated a wetland of subregional significance by Kendrick and McKenzie (2001) for the same ecological values as Skull Springs. Running Waters is 23 km downstream of Skull Springs. Running Waters was sampled in the Dry 2020 only as a replacement for Munjina Spring due to access issues to that site (see Table 3.3 and Figure 3.5).

In the previous Biologic (2020c) survey, additional hyporheic sampling sites were added to the program. Although these sites were proposed for sampling in the current survey, issues with access in the Dry 2020 (helicopter issues resulting in no additional time to sample these sites), and lack of water in the Wet 2021 meant they could not be successfully sampled.

Table 3.3: Site locations, indicating site type and sampling effort. NB: D refers to dry season sampling (Dry 2020) and W refers to wet season sampling (Wet 2021). WQ = water quality, Zoop = zooplankton, Macro = macroinvertebrates and Hypo = hyporheic fauna.

					Sampling undertaken													
					Habitat		WQ		Flora		Zoop		Macro		Hypo		Fish	
Type	**Area**	**Site**	**Easting**	**Northing**	**D**	**W**	**D**	**W**	**D**	**W**	**D**	**W**	**D**	**W**	**D**	**W**	**D**	**W**
Survey Area	Yandicoogina Creek	YC1	-22.8282	119.1499	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
		YC2	-22.8275	119.151	✓	✓	✓	✓	✓	✓	✓	✗	✓	✓	✗	✗	✗	✗
		YC3	-22.8246	119.1637	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
		YC4	-22.8258	119.1628	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Reference	Weeli Wolli Creek	WWS	-22.9181	119.1994	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
		BENS	-23.0558	119.1509	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Munjina Spring	MUNJ^	-22.5373	118.7046	✗	✓	✗	✓	✗	✓	✗	✓	✗	✓	✗	✓	✗	✓
	Davis River	SS	-21.8600	121.0114	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
		RW*	-21.6863	121.1248	✓	✗	✓	✗	✓	✗	✓	✗	✓	✗	✓	✗	✓	✗
			Total no. of samples		**8**	**8**	**8**	**8**	**8**	**8**	**8**	**7**	**8**	**8**	**7**	**7**	**7**	**6**

*sampled in the Dry 2020 only.

^sampled in the wet 2021 only.

-Although fish sampling could not be undertaken at YC1, YC2 and YC3 (due to the small pool size, shallow depths and abundance of *Typha* instream) observations were made of the fish present at the time of sampling. There are no fish present at reference site MUNJS and therefore not sampled at this site.

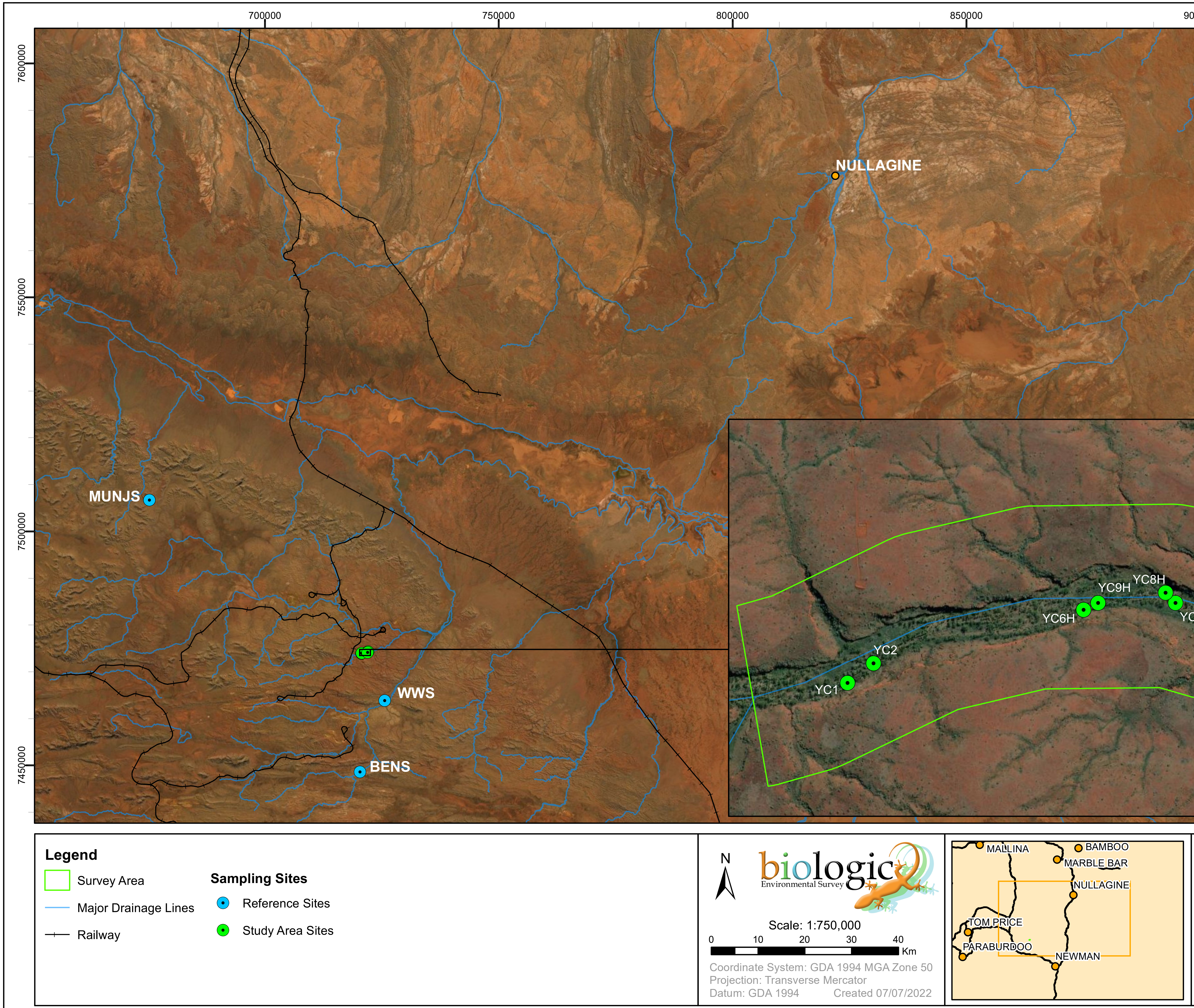

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Figure 3.5: Locations of aquatic ecosystem sampling sites

3.4 Habitat

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

3.5 Water quality

Water quality variables were recorded *in situ* from each site with a portable YSI Pro Plus multimeter. *In situ* variables included pH, 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. All water quality analyses were undertaken by ALS, a NATA accredited chemical analysis laboratory.

Water quality variables measured included:

- *In situ* – pH, DO (% and mg/L), EC (µS/cm), water temperature (°C) and redox (mV);
- Ionic composition – calcium (Ca), potassium (K), magnesium (Mg), sodium (Na), bicarbonate (HCO_3), chloride (Cl), sulfate (S_SO_4), carbonate (CO_3), alkalinity and hardness (all in mg/L);
- Water clarity – turbidity (NTU) and total suspended solids (TSS in mg/L);
- Nutrients – nitrogen nitrite (N_NO_2), nitrogen nitrate (N_NO_3), nitrogen oxides (N_NOx), nitrogen ammonia (N_NH_3), total nitrogen (total N) and total phosphorus (total P) (all in mg/L); and
- Dissolved metals – alumnium (dAl), arsenic (dAs), boron (dB), barium (dBa), cadmium (dCd), cobalt (dCo), chromium (dCr), copper (dCu), iron (dFe), manganese (dMn), molybdenum (dMo), nickel (dNi), lead (dPb), selenium (dSe), uranium (dU), vanadium (dV) and zinc (dZn) (all in mg/L).

Samples collected for dissolved metals were filtered through 0.45 µm Millipore nitrocellulose filters in the field (Plate 3.1). Nutrient samples were not filtered as ALS filters all nutrient samples in the laboratory as part of their analytical methods. Following best practice and to minimise any potential for contamination, all water samples were collected using clean Nalgene sample bottles, and clean/new filters and syringes (Ahlers *et al.*, 1990; Batley, 1989; Madrid & Zayas, 2007). All water quality sampling equipment was stored in polyethylene bags, and samplers wore polyethylene gloves whilst sampling water quality.

All water samples were kept on ice in an esky 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.

Plate 3.1: Filtering dissolved metal samples at MUNJS (photograph by Biologic ©).

3.6 Macrophytes

Macrophytes are important structural and biological components of lowland streams, providing aquatic fauna with habitat, breeding sites, food, and cover from predators. Submerged macrophytes and emergent riparian vegetation were collected from each site, where present. Submerged macrophytes were hand collected and placed in sample containers with sufficient water from the site 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 identification. 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.

3.7 Zooplankton (microinvertebrate fauna)

Zooplankton are microscopic invertebrates living near the surface of a water body, and include micro-crustacea (ostracods, copepods and cladocera) and rotifers. They form a vital component of aquatic food webs, feeding upon phytoplankton, bacteria, and detritus, and provide an important food source for higher invertebrate consumers and fish. They are generally poor swimmers, instead relying on surface flows for dispersal.

Zooplankton can be useful bioindicators of water quality, eutrophication, productivity and disturbance because their development and distribution are subject to both abiotic (temperature, salinity, stratification, presence of pollutants, and water flow) and biotic parameters (limitation of food, predation, and competition) (Ramchandra *et al.*, 2006). Many zooplankton species are known to be highly sensitive to a wide range of pollutants. The use of zooplankton assemblages as bioindicators is most effective in lentic and slow-flowing rivers, where they occur in abundance (ANZG, 2018). In fast-flowing river systems, densities may be greatly reduced due to dilution, or absent where high flows prevent populations from establishing.

Zooplankton samples were collected by gentle sweeping over an approximate 15 m distance with a 53 µm mesh pond net. Samples were preserved in 100% ethanol in the field and sent to Dr Robert Walsh (Zooplankton taxonomist; Australian Waterlife).

In the laboratory, microinvertebrate samples were sorted using a Greiner tray under a low power dissecting microscope. All micro-crustacea were removed from samples and identification made under a compound microscope, to the lowest possible level of taxonomy (genus or species). Rotifera were identified from a 1 ml aliquot taken from the sample, using a Sedgwick rafter counting tray on a compound microscope.

3.8 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 (Boulton, 2001; Dole-Olivier & Marmonier, 1992a; Edwards, 1998). 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 (Bruno *et al.*, 2012; Jacobi & Cary, 1996), and during times of floods (Dole-Olivier & Marmonier, 1992b; Edwards, 1998; Palmer *et al.*, 1992), drought (Coe, 2001; Cooling & Boulton, 1993; 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[1] fauna have been used worldwide as an indicator of ecosystem health, especially in ephemeral creeks, with reported responses to disturbances such as metal pollution and eutrophication (Boulton, 2014; Leigh *et al.*, 2013; Moldovan *et al.*, 2013; Pacioglu & Moldovan, 2016).

At each site, the hyporheic zone was sampled using the Karaman-Chappuis (karaman) method (Chappuis, 1942; Karaman, 1935). 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 a greater diversity of taxa collected (Canton & Chadwick, 2000; Strayer & Bannon-O'Donnell, 1988).

Hyporheic samples were preserved in 95% ethanol in the field and returned to the Biologic laboratory for processing. Hyporheos fauna present were removed by sorting under a low power dissecting

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[1] 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 & Gonser, 1997).

microscope. Specimens were identified in-house, or sent to appropriate taxonomic experts for identification, where necessary (e.g., Jane McRae for micro-crustacea for dry season samples only).

Plate 3.2: Sampling the hyporheic zone of Yandicoogina Creek (photograph by Biologic ©).

3.9 Macroinvertebrates

Aquatic macroinvertebrates are used worldwide as indicators of ecosystem health for a number of reasons: they are ubiquitous; relatively easy to collect; have high species diversity and varying sensitivity to environmental disturbances; have relatively long life cycles; and are continuously exposed to the environmental conditions and constituents of the surface water they inhabit (Bressler *et al.*, 2006; Cain *et al.*, 1992; Carew *et al.*, 2007; Hodkinson & Jackson, 2005). 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 (Choy & Thompson, 1995), the Australian River Assessment System (AusRivAS) (Chessman, 1995, 2003; Wright *et al.*, 1993), and the Framework for the Assessment of River and Wetland Health (Norris *et al.*, 2007).

Macroinvertebrate sampling was conducted with a 250 μm mesh D-net to selectively collect the macroinvertebrate fauna. At each site, sampling was undertaken across as many habitats as possible, including open water, macrophyte beds, large woody debris (LWD), leaf litter and edge habitat. The kick-sweep method was used in open areas, riffles and along edge habitat, whereby the sediments were disturbed (kicked) and the water column immediately swept with the dip net throughout the disturbed area. 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). The net was thoroughly cleaned between sites to avoid cross contamination. Samples were preserved in 95% 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.

Plate 3.3: Macroinvertebrate sampling at RW in the Dry 2020 (photograph by Biologic ©).

3.10 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, 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. Fish were identified in the field and standard length (SL[2]) measured (Plate 3.4). All fish were released alive to the site of collection.

Plate 3.4: Measuring spangled perch to SL at YC4 (photograph by Biologic ©).

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[2] 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).

3.11 Other aquatic fauna

Any other vertebrate fauna observed or caught during aquatic surveys were also recorded for each site. In the case of crayfish, the carapace length (CL) of each individual was measured.

3.12 Data analysis

3.12.1 Water quality

In the absence of site-specific guideline values (SSGVs) for the Survey Area, water quality data were compared against the ANZG (2018) default water quality guideline values (DGVs) 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 < 150 m elevation. DGVs are provided for a range of parameters designed to protect aquatic systems at a low level of risk but are not designed as pass or fail compliance criteria. Exceedances of DGVs provide a trigger which can be used to inform managers and regulators that changes in water quality are occurring and may need to be investigated (ANZG, 2018).

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

- High conservation/ecological value systems – where the goal is to maintain biodiversity with no (or little) change to ambient condition. 99% species protection DGVs for toxicants apply[3].
- Slightly to moderately disturbed systems – where aquatic biodiversity has already been adversely impacted to a small but measurable degree by human activity. The aquatic ecosystem remains in a healthy condition and ecological integrity is largely retained. The aim is to maintain current biodiversity and ecological function. 95% species protection DGVs for toxicants apply.
- Highly disturbed systems – are measurably degraded and of lower ecological value. Guideline aims for these systems may be varied and more flexible, ranging from maintenance of the current yet modified ecosystem that supports management goals, to continual improvement in ecosystem condition. For toxicants, the 90% or 80% species protection DGVs may be applied.

For stressors (pH, DO, EC, turbidity), the ANZG (2018) provide DGVs for slightly disturbed ecosystems only, which are equivalent to the 95% DGVs described above. For analytes which have a lower threshold as well as an upper limit, such as pH and DO, an upper and lower DGV is provided. This is

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

because adverse ecological impacts can occur at low pH and DO levels, as well as high. Two DGVs relating to nutrient concentrations are provided within the guidelines:

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

All sites sampled in the current study show evidence of varying levels of impact from pastoral use or mining activity and were classified as slightly disturbed systems and the 95% DGVs applied. However, where appropriate, the 99% DGVs were also included in water quality plots for comparative purposes, i.e., where 95% DGVs were considerably greater than the maximum value recorded in the current study (and therefore outside the range of the y-axis in plots).

Water quality data from the current survey was compared to the previous Ministers North Survey using SPSS v21 software. Two-way analysis of variance (ANOVA) was undertaken to compare water quality analytes between sampling events and site type (Survey Area vs reference sites). A Levene’s test was used to assess the equality of variances.

3.12.2 Invertebrates

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

- 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, one further hyporheic classification was imposed:

- 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* (BC Act), the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act), the International Union for Conservation of Nature (IUCN), Australian Society for Fish Biology Conservation List 2016, and Priority Fauna recognised by the DBCA (see Appendix A). 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) – an SRE is a species occupying an area of less than 10,000 km^2 (Harvey, 2002). Such species have traits which make them vulnerable to disturbance and changes in habitat, and affords them high conservation value; and
- Indeterminate distribution – taxa could not be assigned to one of the above, as there is currently insufficient knowledge on either its distribution or taxonomy to assess its level of endemism.

Invertebrate data from the current survey was compared to the previous Ministers North survey using two-way ANOVA to test for difference in richness (taxa richness for hyporheos fauna, zooplankton, and macroinvertebrates) between sampling events and site type. Equality of variances was assessed using the Levene's test.

Macroinvertebrate data were also compared against nearby sites sampled during the Pilbara Biological Survey (PBS) and previous aquatic surveys by Biologic and others (see Table 3.4). To undertake this comparison, the dataset was amalgamated, and taxonomy aligned, to ensure any differences in taxonomic knowledge between samplers and years was appropriately accounted for.

Table 3.4: Creeks and areas used in data analysis comparing Yandicoogina Creek to nearby sites sampled previously.

Creek/Area	Description	Sampling events	Reference
Marillana	Upper Marillana Creek, upstream of BHP's Yandi (from Flat Rocks, upstream).	Wet 2014 (Flat Rocks) Dry 2014 (Flat Rocks)	WRM (2015)
		Wet 2017 Dry 2017	WRM (2018)
		Dry 2020 Wet 2021	Biologic (2021b)
Marillana Downstream	Marillana Creek from downstream of the pools in and around Flat Rocks, to just downstream of Rio Tinto's Yandicoogina Oxbow Deposit	Wet 2014 Dry 2014	WRM (2015)
		Wet 2017 Dry 2017	WRM (2018)
Weeli Wolli Spring	The main Priority 1 PEC spring system comprising approximately 2 km of flowing creeklines	Dry 2003 Wet 2005	Pinder *et al.* (2010)
		Dry 2019	Biologic (2020c)

Creek/Area	Description	Sampling events	Reference
		Wet 2020	
		This study (reference site)	
Weeli Wolli Creek	Semi-permanent and permanent pools located upstream of Bens Oasis on Weeli Wolli Creek (i.e., Wunna Munna, etc).	Wet 2014 Dry 2014	WRM (2015)
		Wet 2017 Dry 2017	WRM (2018)
Davis River	Permanent flowing spring pools on the Davis River, including Running Waters and Skull Springs	Dry 2019 Wet 2020	Biologic (2020c)
		Dry 2020	Biologic unpub. data
		This study (reference site)	

Univariate analysis was undertaken was undertaken in SPSS (subscription build 1.0.0.1447). This included two-way ANOVA to compare richness (zooplankton and macroinvertebrate richness) between creeks (the Survey Area vs nearby creeks, as sampled during previous surveys) and between season (dry vs wet). A Levene's test was undertaken prior to analysis to test for equality of variances and ensure assumptions of the ANOVA test were met.

Macroinvertebrate assemblage structure was then analysed using multivariate techniques in PRIMER v7 (Clarke & Gorley, 2015), including cluster analysis and ordination. Ordination was by non-metric Multi-Dimensional Scaling (nMDS), which, unlike other ordination techniques uses rank orders, and therefore can accommodate a variety of different types of data. Ordination was based on the Bray-Curtis similarity matrix (Bray & Curtis, 1957). To test for significant differences in *a priori* groups (i.e., creeks and seasons), two-way ANOSIM was conducted.

The BEST routine was undertaken on the current dataset only (Ministers North Dry 2020 and Wet 2021) to determine whether there were any relationships between biotic assemblages and environmental variables (water quality and in-stream habitat characteristics). BVSTEP was used due to the size of the dataset, in particular the large number of variables included in analysis.

3.12.3 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 (Allen *et al.*, 2002; Puckridge & Walker, 1990) (Table 3.5).

Table 3.5: Standard lengths used for freshwater fish age classes.

	Standard Length (mm)		
Age class	**Western rainbowfish**	**Spangled perch**	**Pilbara tandan**
New recruit	< 30	< 30	< 30
Juvenile	31-40	31-50	31-70
Sub-adult	41-50	51-70	71-90
Adult	>50	>70	>90

4 RESULTS

4.1 Desktop assessment

The database search did not find any fauna of conservation significance within 40 km of the Survey Area, additional to the previous database search for the area (Biologic, 2020c). However, a recent survey undertaken on nearby Marillana Creek recorded five conservation significant taxa not previously identified in the literature (Biologic, 2021b). These taxa (all stygal) include:

- The harpacticoid *Elaphoidella* sp. - undescribed and may be new to science;
- The harpacticoid *Parastenocaris* sp. - represents either an undescribed species or additional records for known fauna;
- The water mite *Aspidiobates pilbara* - Pilbara endemic known only from springs or permanent pools in good ecological condition;
- The water mite *Guineaxonopsis sp.* - species identification unknown, may be uncommon, with a disjunct or restricted distribution in the Pilbara;
- The water mite *Rutacarus sp.* - species identification unknown, may be uncommon, with a disjunct or restricted distribution in the Pilbara.

4.2 Habitat assessment

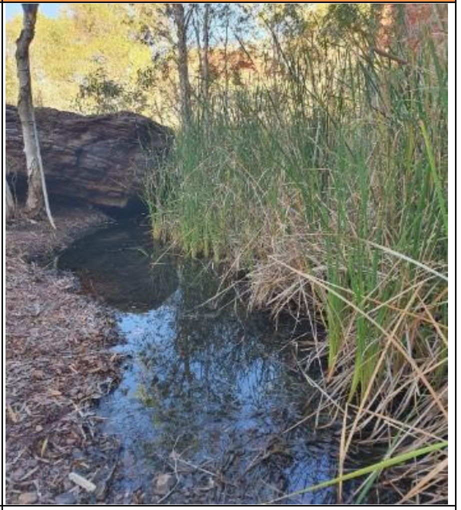
A summary of the overall habitat assessment is provided in (Table 4.1) and all raw data in Appendix C. Sites within the Survey Area occurred within an extensive closed *Melaleuca argentea* forest, with *Eucalyptus camaldulensis* over *Acacia tumida* var. *pilbarensis* shrubland. *Cyperus vaginatus* and *Typha domingensis* occurred along the waterline. Weeds were present throughout the Survey Area. Water levels were noticeably lower in the wet 2021 compared to the Dry 2020, despite heavy wet season rainfall and associated flooding in nearby systems. Vegetation such as *Typha domingensis* was in poor condition, with signs of senescence, particularly at site YC2.

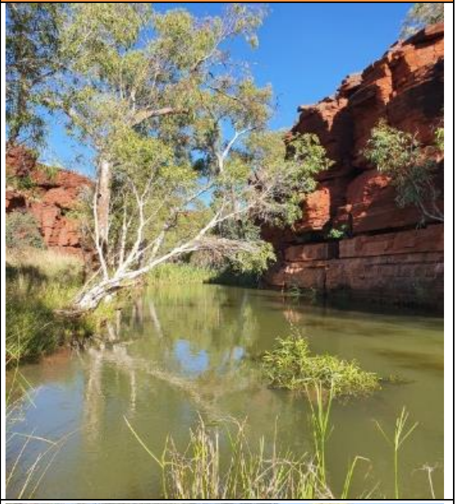
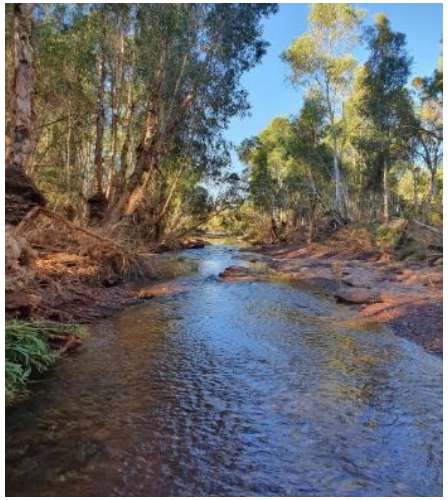
Most sites were dominated by transmissive sediments such as gravel, pebbles and sand. At YC4, however, clay dominated the substrate. Composition by bedrock was greatest at reference site MUNJS.

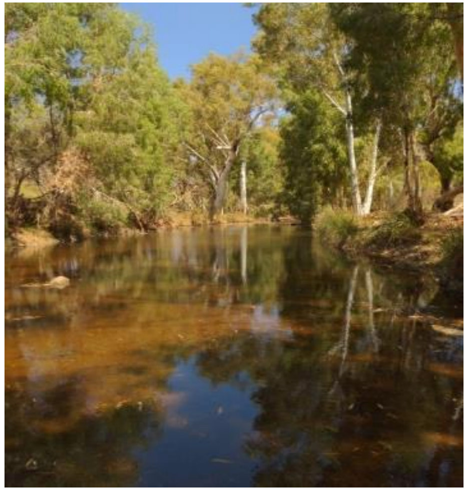
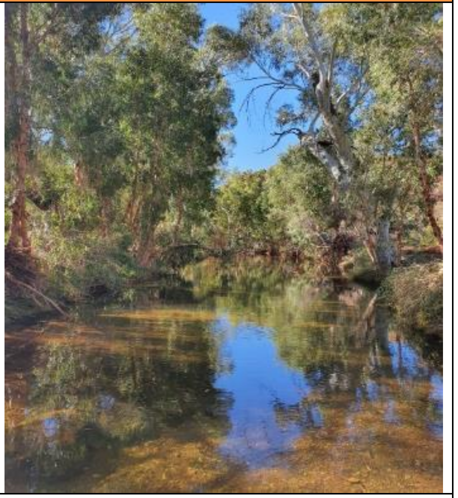
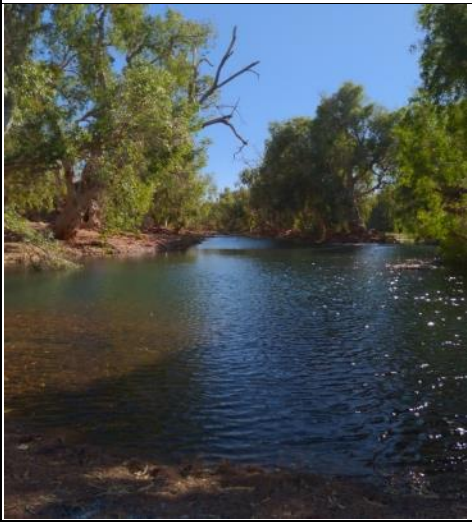
In-stream habitat diversity was high throughout the Survey Area and included complex heterogenous substrates, such as submerged and emergent macrophytes, large woody debris (LWD), root mats, detritus, and trailing vegetation. There was some seasonal change between the Dry 2020 and wet 2021 surveys, with noticeable increases in silt at sites YC1, YC2 and YC4 following the wet season rainfall. Algal cover at YC3 was greater in the wet 2021 (53% cover) compared to the Dry 2020 (43%), while a considerable loss of submerged macrophyte (*Chara* spp.) was recorded at YC1 (15% cover in the Dry 2020 compared to 0% in the wet 2021). This was likely due to the pool having receded to a small puddle less than 1.5 m by 1 m.

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

Site	Habitat	Description	Dry 2020 Site Photo	Wet 2021 Site Photo
YC1	**Small pool**	Small shallow seep. Groundwater dependant vegetation present (*Melaleuca argentea* and *Eucalyptus camaldulensis*). Emergent vegetation dominated by *Typha domingensis*. Submerged macrophyte (*Chara* spp.) recorded in-stream in the Dry 2020 season was not present in the wet. Bedrock was no longer the dominant substrate due to retraction of pool size. More transmissive substrates such as gravel, pebbles and cobbles were present in the wet season. Maximum water depth of 0.4 m in the dry and 0.15 m in the wet.		
YC2	**Small pool**	Small seep area with highly abundant *Typha domingensis*. Riparian vegetation comprising *Eucalyptus camaldulensis* and *Melaleuca argentea* open woodland over patches of *Typha domingensis* and *Cyperus vaginatus* sedgeland. Weeds present (e.g., natal grass (Biologic, 2020a). Mineral substrate comprising gravel, sand, silt and clay. Detritus and LWD present. Maximum water depth of 0.4 m in the dry and 0.3 m in the wet.		

Site	Habitat	Description	Dry 2020 Site Photo	Wet 2021 Site Photo
YC3	**Small pool**	Small, shallow seep area. *Melaleuca argentea* with scattered *Eucalyptus camaldulensis* as the dominant overstorey. Emergent vegetation comprising *Typha domingensis* and *Cyperus vaginatus* sedgeland, with *Lobelia arnhemiaca* present on the banks in the dry. No submerged macrophyte present. Algae bloom on water surface in both seasons. Weeds present, including buffel grass, common sowthistle, flaxleaf fleabane and natal grass (Biologic, 2020a). Mineral substrate comprising gravel, pebbles, cobbles, sand, and silt. Maximum water depth 0.5 m in the dry and 0.4 m in the wet.		
YC4	**Permanent, spring-fed creek pool**	Large permanent pool against a cliff face. *Melaleuca argentea* and scattered *Eucalyptus camaldulensis* open woodland over *Typha domingensis* sedgeland. Emergent macrophyte also included *Cyperus vaginatus* and *Schoenoplectus subulatus*. *Lobelia arnhemiaca* also present in the dry. Low abundances of scattered weeds were present, especially close to the cliff face (e.g., natal grass and flaxleaf fleabane; (Biologic, 2020a). Submerged macrophyte comprising *Chara* spp., *Vallisneria nana* and *Ruppia* sp. present. Clay was the dominant mineral substrate, followed by silt and sand. Maximum water depth of 5 m in the dry and 4.5 m in the wet.		

Site	Habitat	Description	Dry 2020 Site Photo	Wet 2021 Site Photo
MUNJS	**Permanent creek pools**	A series of long permanent pools, with numerous riffle sections. Mineral substrate almost exclusively bedrock. Riparian vegetation comprising *Eucalyptus camaldulensis*, *Melaleuca argentea* and *M. bracteata*. Emergent macrophyte comprising *Typha domingensis, Cyperus vaginatus*, *Schenoplectus subulatus*, and *Schoenus falcatus*. *Vallisneria annua* and *Potamogeton tepperi* submerged macrophytes present in-stream. No fish. No obvious signs of disturbance. *Stylidium fluminense* present throughout in the dry. Maximum water depth of 3.5 m in the wet (not sampled in the dry).	Not sampled	
WWS	**Spring**	Permanent spring comprising a series of pools and interconnecting riffles. Located within Rio Tinto's HD1 discharge area – surface flows maintained by discharge from spurs. Overstorey vegetation comprising *Melaleuca argentea* and *Eucalyptus camaldulensis* over trees of *E. victrix* and a dense shrub layer. Emergent macrophyte comprising *Typha domingensis*, *Cyperus vaginatus,* and *Schoenoplectus subulatus*. Fringing *Lobelia arnhemiaca* throughout, along with Priority 3 species *Stylidium weeliwolli* in the dry (was not present in the wet 2021 in this reach). There was a considerable amount of large woody debris present in the wet, with whole trees and large branches having fallen into the creek during the flood. WWS is a Priority 1 PEC. Maximum water depth was 1.3 m in the dry and 1.1 m in the wet. Pools had been filled with mobile sediments during the flood.		

Site	Habitat	Description	Dry 2020 Site Photo	Wet 2021 Site Photo
BENS	**Spring**	Second occurrence of the WWS PEC, located upstream on Weeli Wolli Creek. Riparian vegetation consisting of *Eucalyptus camaldulensis* and *Melaleuca argentea* woodland over *Acacia* spp*.* shrubland, and sparse sedges (*Cyperus vaginatus*). *Stylidium weeliwolli* fringing on banks during the dry season, but not the wet season. Likely flushed out during the wet season flooding events. Detritus and LWD present in-stream. Mineral substrate dominated by transmissive gravel and pebbles, with some sand, silt, bedrock and boulders. Obvious impacts by cattle, with sedges grazed, and erosion of banks. Maximum water depth of 1.1 m in the dry and 1.6 m in the wet.		
SS	**Spring**	Permanent spring flowing into a series of pools via a braided channel. Riparian vegetation comprising *Melaleuca argentea* and sedges (*Cyperus vaginatus* and *Eleocharis geliculata*). Submerged macrophyte comprising *Nitella* spp., *Najas marina*, *Vallisneria annua*, *Potamogeton tepperi* and *Ruppia* sp. P2 Priority flora (ground creeper *Ipomoea racemigera*) present. Mineral substrate heterogenous, dominated by gravel, pebbles, and sand. Disturbances included cattle impacts and introduced vegetation (such as Mexican poppy *Argemone ochroleuca* subsp. *ochroleuca*). Maximum water depth of 2.5 m in the dry and 1.2 m in the wet. This site had undergone considerable change between seasons, with deep pools infilled by mobile sediment, and movement of the main braided channels.		

Site	Habitat	Description	Dry 2020 Site Photo	Wet 2021 Site Photo
RW	**Spring**	Permanent groundwater fed pool and riffles on the Davis River. Small series of pools also located upstream of the spring. Riparian vegetation comprising *Melaleuca argentea* over *Cyperus vaginatus*. In-stream habitat predominantly open sediment and detritus, with some LWD, submerged macrophyte (*Potamogeton tepperi*), root mats, algae and trailing vegetation. Bedrock substrate dominant upstream, with boulders, cobbles, pebbles, gravel, sand and silt present in the main pool. Maximum water depth of 1.8 m in the dry.		Not sampled

Reference sites also recorded high in-stream habitat diversity. Unlike sites within the Survey Area, reference sites were flushed and full following wet season rainfall, with site RW still in flood at time of sampling in the wet 2021. Sites WWS and SS had noticeably changed between seasons, with mobile gravel sediments filling in deeper sections following flood. Algae had largely been flushed from WWS.

4.2.1 Water level comparison with previous survey

Average maximum water depth within sites of the Survey Area has decreased steadily since the Wet 2020 sampling event (Figure 4.1). This pattern was not evident in reference sites, with increases apparent in the wet seasons (2020 and 2021) and slight decreases in the dry seasons (2019 and 2020), as would be expected for Pilbara waterbodies. Overall, there was no significant difference in maximum water depth between site type (Survey Area vs reference; Two-way ANOVA; df = 1, F = 0.115, *p* = 0.738), nor between sampling events (df = 3, F = 0.061, *p* = 0.980). The large standard errors bars for Survey Area are due to the large difference in pool depths along the length of the creek, with YC1 and YC2 being less than 0.5 m deep, but YC4 having a maximum depth of up to 5 m.

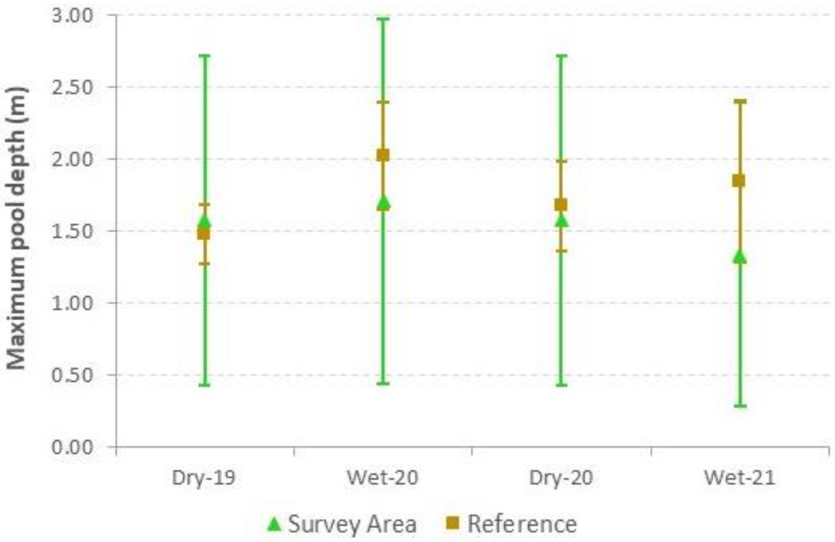


Figure 4.1: Average maximum water depth (± standard error) in the Survey Area and Reference sites recorded during each sampling event since the Dry 2019.

4.3 Water quality

All raw water quality data are provided in Appendix D.

4.3.1 In situ

Electrical conductivity (EC) within Yandicoogina Creek was fresh in both seasons and ranged from 552 µS/cm (YC2) to 684 µS/cm (YC3) in the Dry 2020, and 661 µS/cm (YC4) to 776 µS/cm (YC3) in the wet 2021 Figure 4.2. While all Yandicoogina Creek and reference sites recorded EC in excess of the ANZG (2018) default guideline value (DGV), none were considered to pose a threat to aquatic life. 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. All Survey Area sites and reference site WWS recorded low levels of seasonal variation in EC, likely reflecting their strong connection to groundwaters (Figure 4.2).

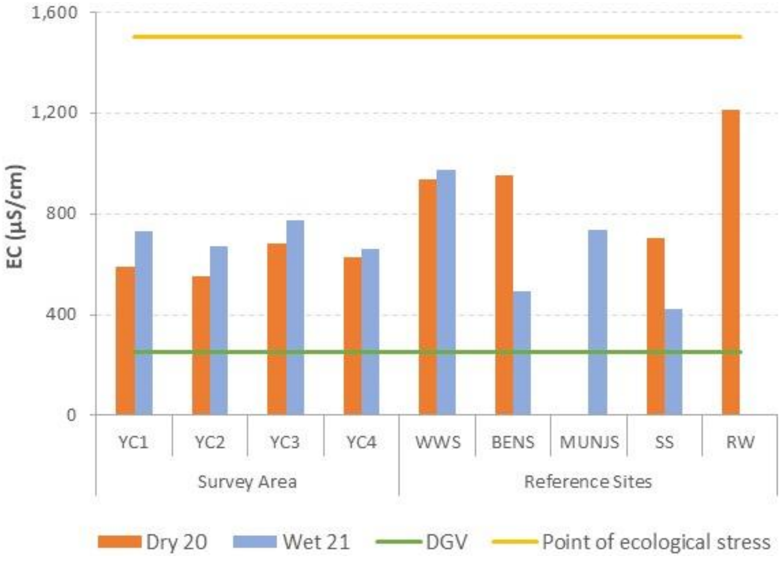


Figure 4.2: Electrical conductivity (EC; µS/cm) recorded from all sites, in comparison to the ANZG (2018) DGV and point of ecological stress.

Dissolved oxygen (DO) ranged from 11.5% (at YC2) to 81.3% (at RW) in the Dry 2020, and 19.8% (YC2) to 109.2% (SS) in the wet 2021. DO concentrations within Yandicoogina Creek were generally low, with all sites recording saturation levels below the lower DGV in both seasons (Figure 4.3). DO within the Survey Area was slightly higher in the wet season. Several reference sites also recorded low DO in at least one season. SS In the wet 2021, SS recorded the only DO saturation within ANZG (2018) DGVs (Figure 4.3).

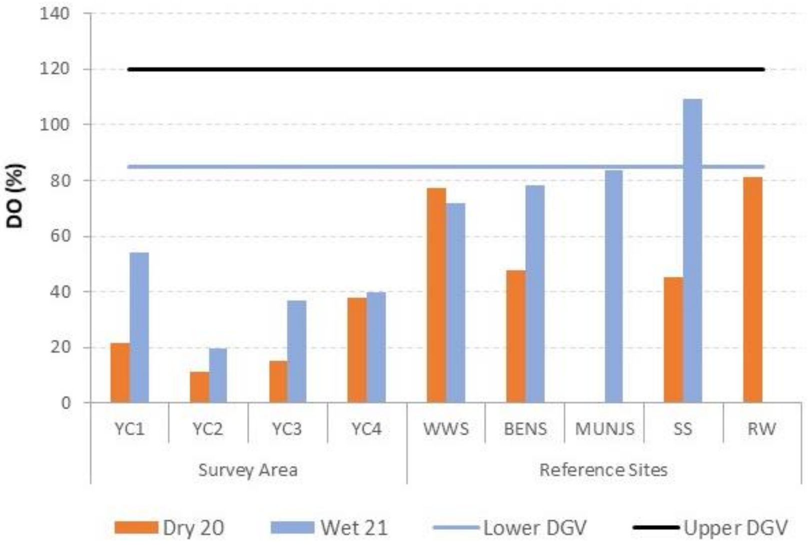


Figure 4.3: Dissolved oxygen (DO; percentage) recorded from all sites, in comparison to the ANZG (2018) upper and lower DGVs.

Surface waters within the Survey Area were slightly acidic to circum-neutral, and generally similar at reference sites, albeit slightly more basic at some sites (i.e., BENS and SS). Lowest pH was recorded from YC1 in the wet 2021 (6.60) and highest from BENS in the Dry 2020 (8.00). Generally lower pH was recorded in the wet season at all sites, but particularly within the Survey Area. pH at all sites fell within the ANZG (2018) DGVs for the protection of lowland rivers in the tropical north of WA.

Turbidity was low at all Yandicoogina Creek sites in the Dry 2020, indicating high water clarity and light penetration. However, there was a considerable increase in turbidity in the wet 2021, with YC1 and YC2 recording notably higher turbidity than all other sites sampled, and YC2 being in excess of the ANZG (2018) DGV (Figure 4.4). The higher turbidity recorded in the wet season from YC1 and YC2 was likely due to catchment runoff associated with wet season rains and flooding, and the increase in silt observed in-stream at this time.

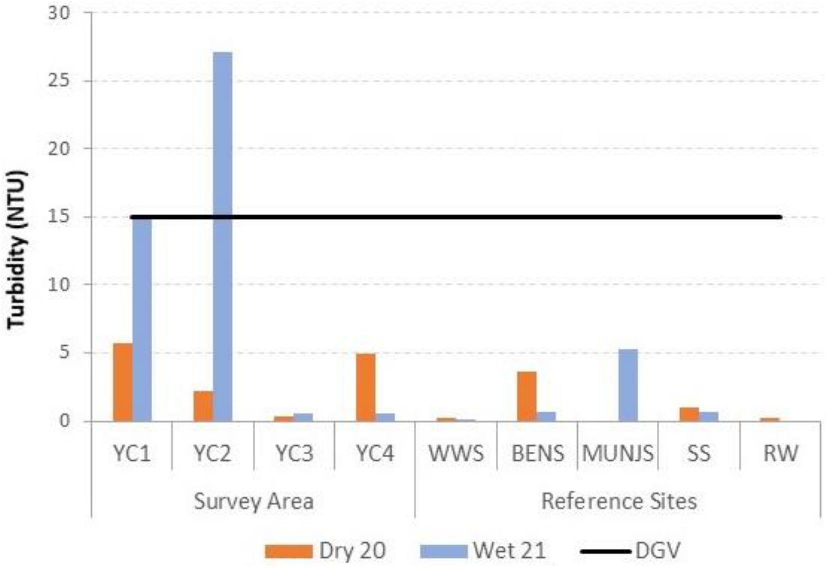


Figure 4.4: Turbidity (NTUs) recorded from all sites, in comparison to the ANZG (2018) DGV.

4.3.2 Ionic composition

Ionic composition at all Yandicoogina Creek sites was generally dominated by calcium (Ca) cations and hydrogen carbonate (HCO_3) anions, but with YC3 and YC4 being dominated by sodium (Na) and HCO_3 in the dry season. This contrasts with the previous survey, where no seasonal variation in ionic dominance was recorded. Most reference sites were dominated by Ca and HCO_3, except for SS and RW in the dry and MUNJS in the wet, all of which were dominated by Na and HCO_3. The dominance of Ca and HCO_3 in surface waters often indicates connection to groundwater, while Na dominance tends to indicate contribution by rainfall.

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 limited ability to buffer against rapid changes in pH. Alkalinity recorded in the current study was generally high, with all sites recording values between 219 mg/L (YC2 in the dry) and 283 mg/L (YC3 in the wet).

Only one site recorded alkalinity below 200 mg/L; SS in the Wet 2020 (158 mg/L). However, alkalinity recorded from this site was still well above the threshold of 20 mg/L.

4.3.3 Nutrients

Nitrogen ammonia (N_NH_3) concentrations were low at all sites sampled. In both seasons all values were below the limit of detection (LOD; i.e. < 0.01 mg/L), except for YC1 (0.04 mg/L) and YC2 (0.10 mg/L) in the wet season. All concentrations were well below ANZG (2018) toxicity DGV for the protection of 99% of species. Nitrogen nitrate (N_NO_3) concentrations were also low within the Survey Area. N_NO_3 ranged from values below the LOD (< 0.01 mg/L; at all Survey Area sites in both season, and BENS in the dry and MUNJS in the wet) to 1.73 mg/L (at RW in the Dry 2020) (Figure 4.5). The reference site RW recorded a nitrate concentration in excess of the 99% toxicity DGV[4]; (Figure 4.5). This concentration was within the 95% toxicity DGV.

As nitrate generally comprises the largest portion of nitrogen oxide (N_NOx) concentrations, with negligible contribution by nitrite, N_NOx concentrations were similarly variable, i.e., ranged from below LODs to 1.73 mg/L (at RW in the Dry 2020, Figure 4.6). All N_NOx concentrations recorded from the Survey Area were below the eutrophication DGV, in both seasons. In contrast, all reference sites except MUNJS in the wet 2021 recorded N_NOx in excess of the eutrophication DGV (Figure 4.6).

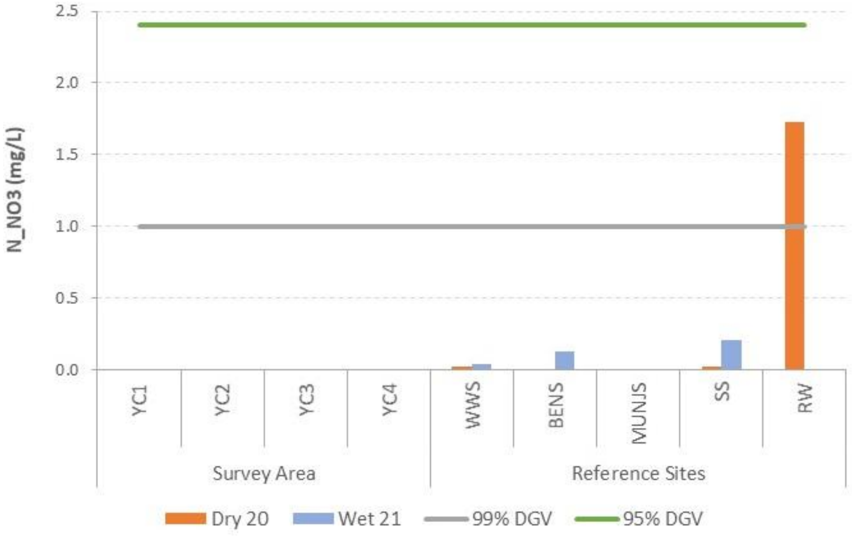


Figure 4.5: Nitrate (N_NO_3) concentrations recorded from each site (mg/L), in comparison to ANZG (2018) 99% and 95% toxicity DGVs.

Concentrations of total nitrogen (total N) in the Survey Area were low and ranged from 0.05 mg/L (at YC1 in the Dry 2020) to 0.60 mg/L (at YC2 in the wet 2021; Figure 4.6). Only one Survey Area site

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[4] There is no current, available toxicity DGV for N_NO_3. Historic ANZECC & ARMCANZ (2000) GVs were found to be erroneous and notably low/conservative (ANZG, 2018). It was anticipated that values would be updated in the recent online, interactive version of the ANZECC guidelines (ANZG, 2018), however this has not been the case. In the absence of updated ANZECC DGVs for N_NO_3, ANZG (2018) suggest referring to the current New Zealand nitrate toxicity guidelines, specifically the 'Grading' GVs published in the '*Updating Nitrate Toxicity Effects on Freshwater Aquatic Species*' report (NIWA, 2013).

exceeded the total N eutrophication DGV; YC2 in the wet. Exceedances were also recorded from reference sites SS (in the wet) and RW (in the dry).

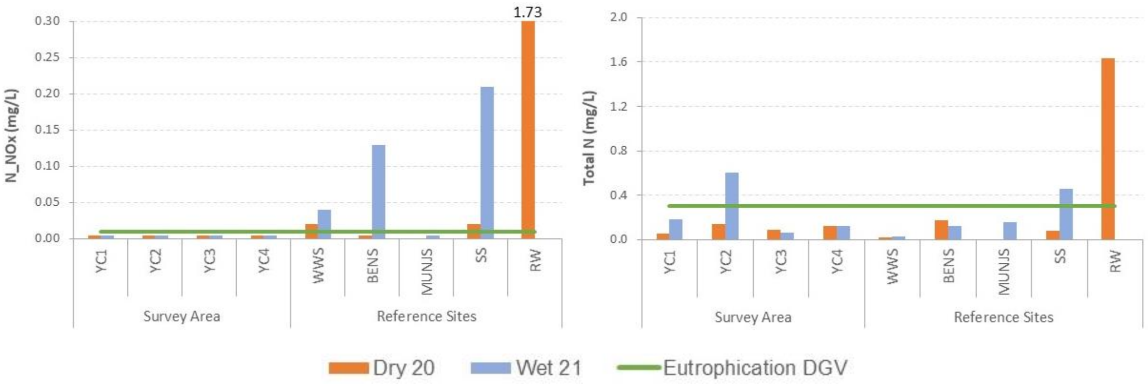

Figure 4.6: Nitrogen oxide (N_NOx; left) and total nitrogen (TN; right) concentrations recorded from each site (mg/L), in comparison to ANZG (2018) eutrophication DGVs. NB: y-axis scales are different for each analyte.

Total phosphorous (total P) concentrations were relatively high, and in excess of the eutrophication DGV at all sites, both within the Survey Area and at reference sites, in both seasons (Figure 4.7). Within the Survey Area, concentrations ranged from 0.018 mg/L (at YC3 in the dry) to 0.092 mg/L (at YC2 in the wet). Concentrations at YC1 and YC2 were considerably higher in the Wet 2021, with total P being more than seven times the DGV (Figure 4.7). Total P concentrations recorded from reference sites were similar to YC3 and YC4.

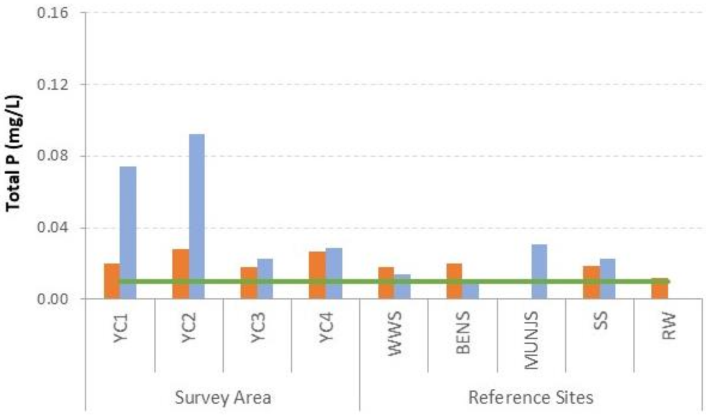

Figure 4.7: Total phosphorus (total P) concentrations recorded from each site (mg/L), in comparison to default ANZG (2018) eutrophication DGV.

4.3.4 Dissolved metals

Dissolved metal concentrations within Yandicoogina Creek were low, with many analytes recording concentrations below LODs at most, if not all sites (i.e., aluminium, cadmium, cobalt, nickel, lead, selenium, and zinc). However, two dissolved metals were recorded in concentrations greater than DGVs at some sites.

Dissolved boron (dB) concentrations exceeded the 99% DGV at all Yandicoogina sites, in both seasons, except YC2 in the dry. Exceedances of the 99% DGV were also recorded from reference sites (WWS, MUNJS and RW). There were no exceedances of the 95% DGV (Figure 4.8)

Figure 4.8: Dissolved boron concentrations recorded from each site (mg/L), in comparison to default ANZG (2018) 99% and 95% toxicity GVs.

Dissolved iron (dFe) recorded from YC1 in the Dry 2020 was greater than the interim indicative working level[5] provided in the ANZG (2018) guidelines. dFe recorded from all other sites was within the interim working level, although concentrations from YC2 in the wet 2021 were approaching the guideline (Figure 4.9). Concentrations from YC2 were elevated previously (Wet 2020).

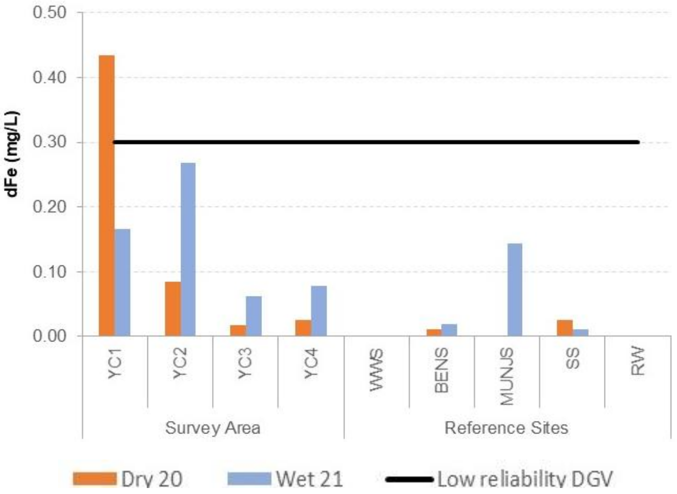

Figure 4.9: Dissolved iron concentrations recorded from each site (mg/L), in comparison to default ANZG (2018) low reliability trigger.

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[5] ANZG (2018) had insufficient toxicity data with which to derive a reliable GV for dFe, and instead deferred to the current Canadian guideline of 0.30 mg/L. This was provided as an interim indicative working level, with further work required to establish a concentration appropriate for Australian waters.

Dissolved chromium (dCr) could not be compared against the 99% DGV as the LOD (< 0.0002 mg/L) was higher than the DGV (0.00001 mg/L). No dCr concentrations were in excess of the 95% toxicity DGV.

4.3.5 Water quality comparison with the previous survey

EC within the Survey Area was relatively stable over time, except for a slight increase in the wet 2021 (Figure 4.10). In contrast, reference sites experienced greater variation in EC between sampling events, with increases in the dry season and decreases in the wet. Although this pattern is common in Pilbara waterbodies, all reference sites are spring systems and generally experience little seasonal variation due to ongoing contributions by groundwater. Overall, there was a significant difference in EC between site type, with reference sites recording significantly higher EC, i.e., the Survey Area was fresher (Table 4.2, Figure 4.10). While there was no significant difference in EC between sampling events, there was a significant interaction between sampling event and site type (Table 4.2), due to the increase in EC within the Survey Area during the wet 2021, which meant that EC was similar to reference sites at that time (Figure 4.10).

DO recorded from Survey Area pools decreased steadily between the Dry 2019 and Dry 2020, with an increase in the wet 2021 (to a saturation similar to that recorded in the Wet 2020; Figure 4.10). DO was significantly lower from the Survey Area in comparison to reference sites, but there was no significant difference in DO between sampling events (Table 4.2, Figure 4.10).

Table 4.2: Two-way ANOVA results, comparing *in situ* water quality analytes between sampling events and site type (Survey Area vs reference). Significant *p*-values are shown in red.

Analyte	Source	df	F	*p*-value
EC	Sampling event	3	1.31	0.295
	Type	1	10.51	0.003
	Sampling event*type	3	3.13	0.045
	Corrected total	31		
DO	Sampling event	3	2.68	0.070
	Type	1	42.19	0.000
	Sampling event*type	3	0.76	0.529
	Corrected total	31		
pH	Sampling event	3	7.77	0.001
	Type	1	30.98	0.000
	Sampling event*type	3	0.60	0.621
	Corrected total	31		
Turbidity	Sampling event	3	1.23	0.322
	Type	1	5.45	0.028
	Sampling event*type	3	0.96	0.428
	Corrected total	31		

pH was significantly lower within the Survey Area compared to reference sites (Table 4.2, Figure 4.10). This difference equated to a pH difference of more slightly basic (reference) to circum-neutral conditions (Survey Area). Change over time was evident at both Survey Area and reference sites, with an increase between the Dry 2019 and Wet 2020, and then consistent decrease to the wet 2021. This same pattern was evident at both Survey Area and reference sites (Figure 4.10). Overall, there was a significant difference in pH between site type and sampling events (Table 4.2). The Tukey's post-hoc test found the pH recorded during the wet 2021 was significantly lower than all other sampling events, except the Dry 2019.

While turbidity was relatively consistent over time within reference sites, there was notable variation within the Survey Area, both between and within sampling events (Figure 4.10). Higher turbidity was recorded in the wet season, and lower in the dry. This is not unexpected in Pilbara systems, with wet season flows and runoff from the surrounding catchment contributing suspended sediments to creeks. Overall, there was no significant difference between sampling events, but a significant difference between site type, with significant higher turbidity recorded from the Survey Area (Table 4.2, Figure 4.10).

There was minimal change in nitrogen nitrate concentrations within the Survey Area over time (Figure 4.11). Overall, there was no significant difference in nitrate concentrations between sampling events or between site type (Table 4.3).

Total P concentrations underwent a similar pattern of change over time at both reference and Survey Area sites, with a continual decrease between the Dry 2019 and Dry 2020, and an increase in the Wet 2021 (Figure 4.11). The increase in the Wet 2021 was more marked at Survey Area sites (Figure 4.11). Overall, there was a significant difference in total P between sampling events and between site type, with significantly higher concentrations recorded from the Survey Area in comparison to reference sites (Table 4.3, Figure 4.11). The Tukey's post-hoc test indicated total P concentrations were significantly lowest in the Dry 2020 and highest in the Dry 2019. The interaction between sampling event and site type was not significant, suggesting the pattern of change between sampling events was statistically similar at both reference and Survey Area sites.

Table 4.3: Two-way ANOVA results, comparing selected nutrient analytes between sampling events and site type (Survey Area vs reference). Significant *p*-values are shown in red.

Analyte	Source	df	F	*p*-value
Nitrate	Sampling event	3	0.84	0.486
	Type	1	1.62	0.216
	Sampling event*type	3	0.90	0.454
	Corrected total	31		
Total P	Sampling event	3	3.79	0.023
	Type	1	5.04	0.034
	Sampling event*type	3	1.04	0.393
	Corrected total	31		

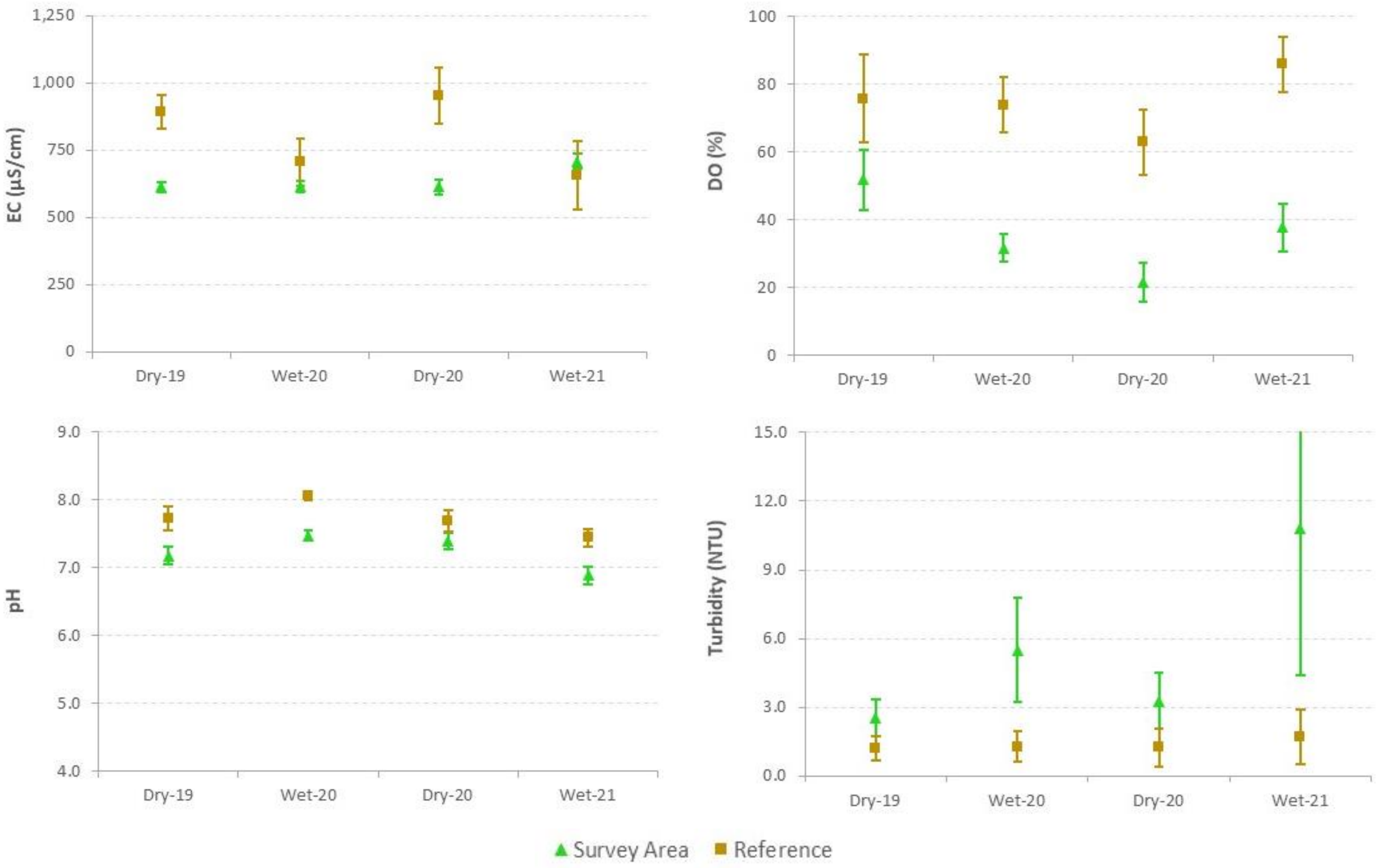

Figure 4.10: Comparison of *in situ* water quality analytes between sampling events(average ± standard error).

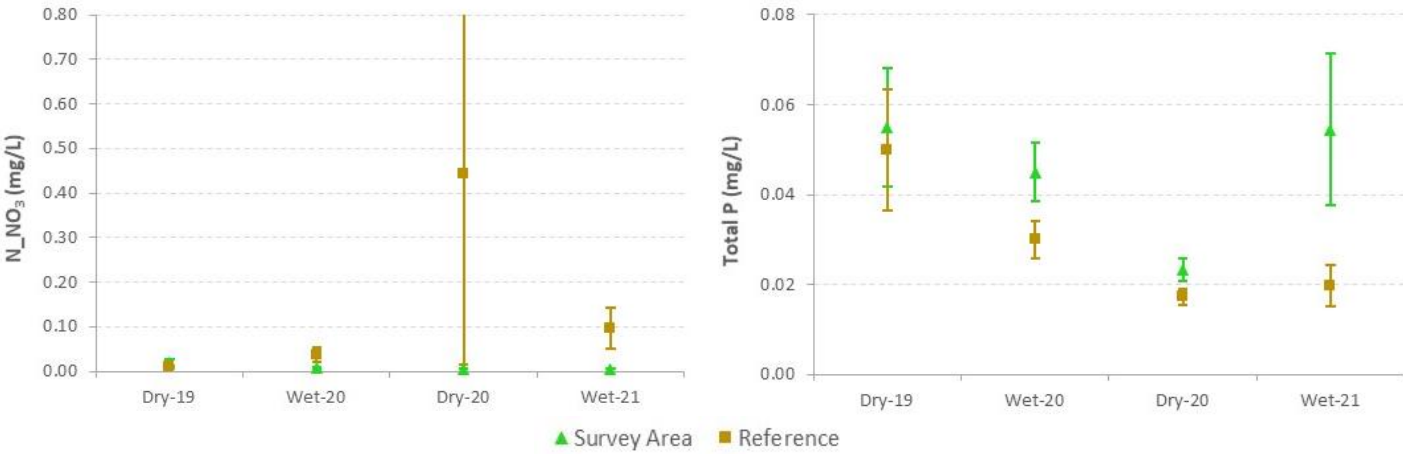

Figure 4.11: Comparison of selected nutrient analytes between sampling events(average ± standard error).

Concentrations of dAs, dBa, dU and dB were significantly higher at reference sites than Survey Area sites (Table 4.4, Figure 4.12). Although dB, dCu and dMn concentrations were also generally greater at reference sites, the large variation within sampling events at reference sites meant that overall, the difference was not significant. One dissolved metal was recorded in significantly higher concentration from the Survey Area; dFe (Table 4.4, Figure 4.12).

Table 4.4: Two-way ANOVA results, comparing selected dissolved metal analytes between sampling events and site type (Survey Area vs reference). Significant *p*-values are shown in red.

Analyte	Source	df	F	*p*-value
Dissolved boron	Sampling event	3	1.69	0.195
	Type	1	1.67	0.209
	Sampling event*type	3	1.06	0.384
	Corrected total	31		
Dissolved copper	Sampling event	3	0.328	0.805
	Type	1	4.36	0.048
	Sampling event*type	3	0.47	0.704
	Corrected total	31		
Dissolved iron	Sampling event	3	0.53	0.669
	Type	1	4.94	0.036
	Sampling event*type	3	0.39	0.764
	Corrected total	31		
Dissolved arsenic	Sampling event	3	1.37	0.275
	Type	1	19.35	<0.000
	Sampling event*type	3	1.23	0.320
	Corrected total	31		
Dissolved barium	Sampling event	3	0.27	0.848
	Type	1	4.61	0.042
	Sampling event*type	3	0.33	0.800
	Corrected total	31		
Dissolved manganese	Sampling event	3	0.45	0.722
	Type	1	2.71	0.113
	Sampling event*type	3	0.61	0.615
	Corrected total	31		
Dissolved uranium	Sampling event	3	1.46	0.251
	Type	1	12.49	0.002
	Sampling event*type	3	1.58	0.219
	Corrected total	31		
Dissolved vanadium	Sampling event	3	0.07	0.977
	Type	1	12.30	0.002
	Sampling event*type	3	0.47	0.704
	Corrected total	31		

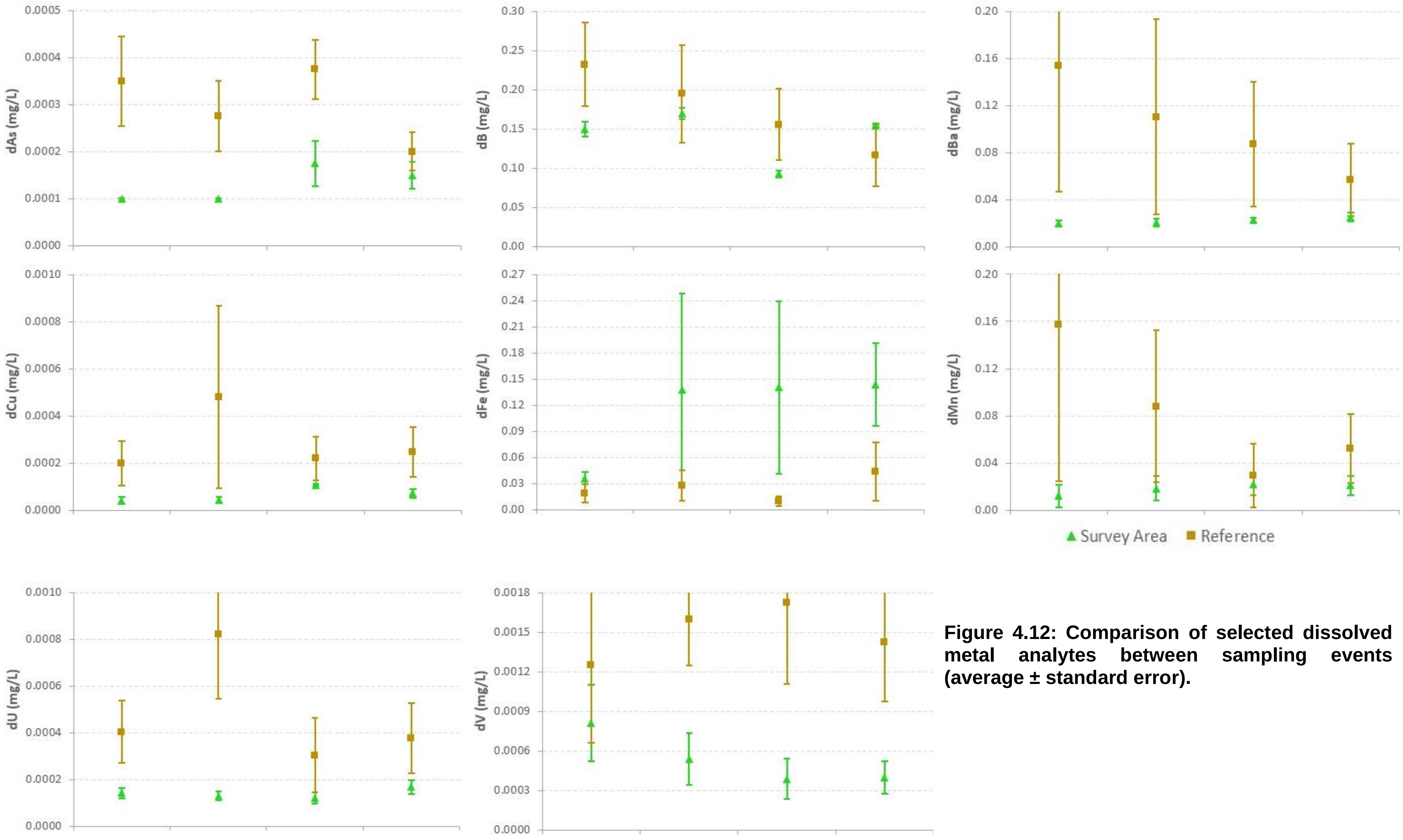

Figure 4.12: Comparison of selected dissolved metal analytes between sampling events (average ± standard error).

None of these aforementioned dissolved metals recorded significantly different concentrations between sampling events (Table 4.4). However, there were some general trends over time, some of which were similar between reference and Survey Area sites, and some of which were unique to the Survey Area. For example, dB concentrations generally decreased over time at reference sites, whilst in the Survey Area, concentrations increased in the wet and decreased in the dry. Concentrations of dCu and dU remained relatively consistent over time at Survey Area sites, but at reference sites there was a notable increase in both dissolved metals during the Wet 2020 (Figure 4.12). However, there was large variation in dCu and dU concentrations at reference sites at this time, suggesting the large increase in concentrations weren't consistent across all reference sites. Within the Survey Area, dFe concentrations increased considerably between the Dry 2019 and the Wet 2020, and then remained relatively stable to the wet 2021. In contrast, reference sites underwent marginal change in dFe concentrations over time, with a small reduction in the Dry 2020 and an increase in the wet 2021. In the case of dV, concentrations underwent almost the exact opposite trend of change over time between Survey Area and reference sites (Figure 4.12). At Survey Area sites, dV decreased to the Dry 2020.

4.4 Macrophytes

4.4.1 Taxa composition and richness

A total of six macrophyte taxa was recorded from Yandicoogina Creek, including four emergent taxa and two submerged macrophytes (Table 4.5). A further six submerged macrophyte taxa were recorded from reference sites (Table 4.5). Other riparian vegetation taxa recorded from the Survey Area included *Eucalyptus camaldulensis*, *Melaleuca argentea*, *Acacia tumida* var. *pilbarensis*, various herbs, shrubs, and grasses (Table 4.5).

Emergent macrophytes recorded from the Survey Area included *Cyperus vaginatus*, *Eleocharis geniculata*, *Schoenoplectus subulatus,* and *Typha domingensis* (Table 4.5). Emergent macrophytes were present at all sites during the dry season, reflecting the presence of permanent water. The greatest diversity of emergent macrophytes was five taxa, which was recorded from reference site WWS, followed by four taxa at SS. Survey Area sites generally recorded three emergent macrophyte taxa (i.e., YC2, YC3 and YC4; Table 4.5).

Table 4.5: Flora taxa recorded during the current study. NB. D = recorded during dry season, W = recorded during wet season

Class/Order	Family	Lowest taxon	Yandicoogina Creek				Reference Sites				
			YC1	YC2	YC3	YC4	WWS	BENS	RW	SS	MUNJS
CHLOROPHYTA											
CHAROPHYCEAE											
Charales	**Characeae**	*Chara* spp.↓	D		DW						W
		Nitella spp.↓								D	
PLANTAE											
MAGNOLIOPSIDA											
	Asteraceae	*Blumea tenella^*							D		
		*Pluchea rubelliflora^^*		D	D						
		**Tridax procumbens*				W					
	Campanulaceae	*Lobelia arnhemiaca^*		D	D		D				
	Stylidiaceae	*Stylidium weeliwolli^* (P3)					D	D			
	Fabaceae	*Acacia tumida* var. *pilbarensis*		D							
		Cullen leucanthum		D	D						
	Gentianaceae	*Schenkia clementii*							D		
	Plantaginaceae	*Stemodia grossa*					D				
		Stemodia viscosa								D	
Laurales	**Lauraceae**	*Cassytha filiformis*					D				
	Malvaceae	*Androcalva luteiflora*					D				
		Gossypium robinsonii	D	D							
Myrtales	**Lythraceae**	*Ammannia baccifera^*								D	
	Myrtaceae	*Eucalyptus camaldulensis^*	DW	DW	DW	DW	DW	DW			W
		*Melaleuca argentea^*	DW	DW	DW	DW	DW	DW	D	DW	W
Ranunculales	**Papaveraceae**	**Argemone ochroleuca* subsp. *ochroleuca*								D	
Rosales	**Moraceae**	*Ficus* sp.	D								
Solanales	**Convolvulaceae**	*Ipomoea racemigera* (P2)								D	
LILIOPSIDA											
Alismatales	**Hydrocharitaceae**	*Najas marina*↓								D	
		Vallisneria sp.↓									W
		Vallisneria annua↓								D	
		Vallisneria nana↓				DW				W	
	Potamogetonaceae	*Potamogeton tepperi*↓								DW	
	Ruppiaceae	*Ruppia* sp.↓								D	
Poales	**Cyperaceae**	*Cyperus* sp.					D				
		*Cyperus vaginatus^*	DW	DW	DW	DW	D	DW	D	DW	W
		*Eleocharis geniculata^*			D		D		D	D	W
		*Schoenoplectus subulatus^*	D	D		DW	D			D	W

Class/Order	**Family**	**Lowest taxon**	**Yandicoogina Creek**				**Reference Sites**				
			YC1	**YC2**	**YC3**	**YC4**	**WWS**	**BENS**	**RW**	**SS**	**MUNJS**
	Poaceae	Poaceae sp.									W
		Cymbopogon ambiguus			D	W					
		Eragrostis elongata				W					
		Eragrostis tenellula					D				
		Eriachne mucronata									W
		Eulalia aurea		W							W
		**Melinis repens*		W							
		Sorghum plumosum									W
		Themeda triandra	D	D			D				
	Typhaceae	*Typha domingensis*^	DW	DW	DW	D	DW			D	
		Taxa richness	**9**	**13**	**10**	**9**	**14**	**4**	**5**	**15**	**11**

Submerged macrophytes recorded from the Survey Area comprised *Vallisneria nana* and C*hara* sp., *Ruppia* sp. was also recorded previously (from YC4 in the Dry 2019 and Wet 2020). Taxonomic limitations for Pilbara species of *Chara* and *Nitella* precluded identification to species. Submerged macrophytes were recorded from YC1, YC3 and YC4 (Table 4.5). Reference site SS recorded the greatest diversity of submerged macrophytes (six taxa).

4.4.2 Conservation significant flora

Two species of conservation significant flora were recorded in the current study, neither of which was recorded from Yandicoogina Creek. Both annual herb species, *Ipomoea racemigera* and *Stylidium weeliwolli*, are listed as DBCA Priority Species, P2 and P3, respectively. The former was recorded from SS and the latter from WWS. *Stylidium weeliwolli* is considered to be an indicator of soil moisture or semi-permanent to permanent surface water availability (Rio Tinto, 2020).

4.4.3 Introduced flora

Two introduced species, one grass (**Melinis repens*) and one herb (**Tridax procumbens*), were recorded from Yandicoogina Creek. One additional introduced species (**Argemone ochroleuca* subsp. o*chroleuca*) was collected from reference site Skull Springs. None of these species are listed as Weeds of National Significance (WoNS). However, **Argemone ochroleuca* subsp. o*chroleuca,* is considered to be highly invasive and able to establish rapidly (DBCA, 2013).

4.4.4 Flora comparison with other studies

Data on wetland vegetation of the Pilbara is limited, with varied sampling effort and taxonomic resolution across studies. However, macrophytes were sampled as part of the PBS, with a paper discussing conservation significance and distribution information due for publication later this year (Mike Lyons, DBCA, unpub. data). To compare species lists with the current study, the DBCA kindly provided Biologic with data from the PBS for sites in the East Pilbara, relatively close to the Survey Area.

Submerged and emergent macrophyte richness from all Yandicoogina Creek sites was greater than or comparable to Homestead Creek, but lower than the other two sites sampled during the PBS (Figure 4.13). There was a notable reduction in macrophyte richness at WWS between the PBS and current survey. However, this area is currently impacted by dewatering and discharge operations from HD1, as well as more recently being affected by the introduction of the invasive redclaw (*Cherax quadricarinatus*), which feed on submerged macrophytes, as well as detritus and zooplankton (DPIRD, 2020; Haubrock *et al.*, 2021; Marufu *et al.*, 2018). It should be noted that site locations at Weeli Wolli Spring differed slightly between surveys, with the PBS site being located approximately 660 m downstream of the WWS site sampled during the current survey.

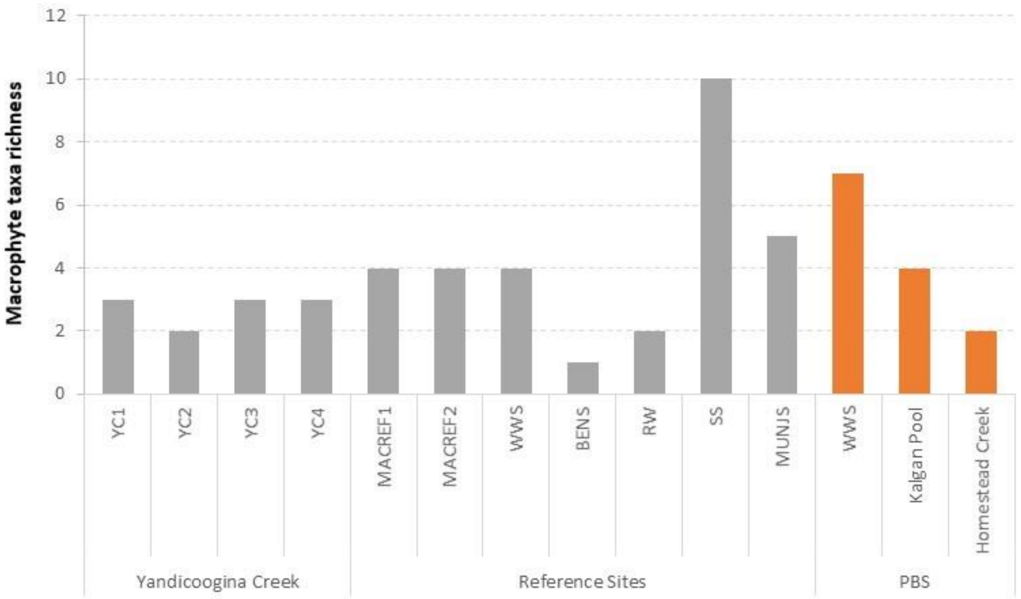

Figure 4.13: Macrophyte (emergent and submerged) richness recorded during in the current study (dry and wet seasons combined), in comparison to the PBS from Homestead Creek headwaters (January 2006), Kalgan Pool (September 2004 and April 2005) and Weeli Wolli Spring (September 2003 and May 2005; Mike Lyons, unpub. data).

4.5 Zooplankton

4.5.1 Taxa composition and richness

Zooplankton samples were successfully collected from all sites except for YC2 in the dry season. Pools at the time of sampling were very small and receded, with turbid waters, which precluded sampling at this site. A total of 49 zooplankton taxa[6] were recorded from Yandicoogina Creek, comprising three Protista, 20 Rotifera, 13 Maxillopoda (Copepoda), four Cladocera and nine Ostracoda (see Appendix E for full taxa list).

In the dry season, zooplankton richness ranged from 11 (at YC1) to 20 (at SS), and in the wet season ranged from two taxa (at WWS) to 17 (at YC3; Figure 4.14). Generally, richness recorded from Yandicoogina Creek was comparable, if not higher than reference sites. Richness at Yandicoogina Creek showed minimal seasonal variation, particularly when compared to reference sites. Reference sites that were sampled in both seasons (i.e., WWS, BENS and SS) recorded considerably lower richness in the Wet 2021 season compared to the previous dry (Figure 4.14). These sites were still showing recent signs of flooding at time of sampling.

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[6] As not all specimens could be identified to species due to immaturity, damage, unknown or unresolved taxonomy and/or a lack of suitable keys, taxa refers to the lowest level of identification possible (generally genus).

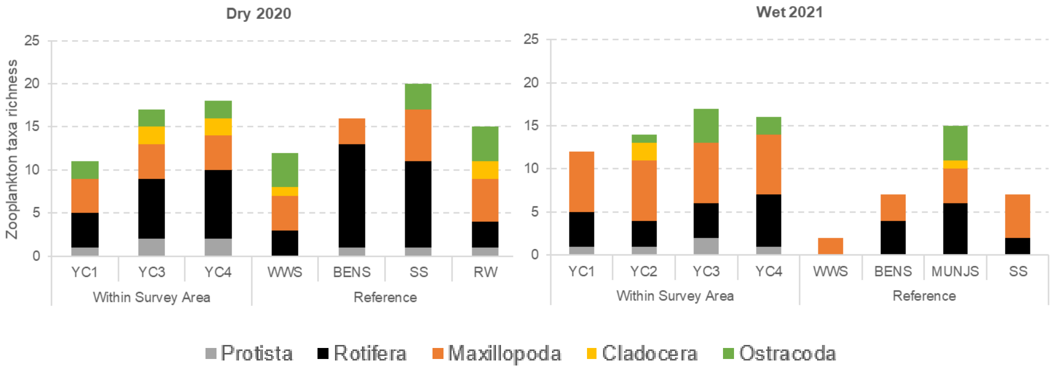


Figure 4.14: Zooplankton taxa richness recorded from each site in the Dry 2020 (left) and Wet 2021 (right).

In the dry season, zooplankton composition was generally dominated by rotifers, followed by Maxillopoda (Figure 4.14). In the wet, Maxillopoda were the dominant taxa, followed by rotifers. Ostracods were present at all sites within the Survey Area across both seasons, except YC1 in the wet season. Diversity of Cladocera and Ostracoda across all sites was generally low, with some sites recording no individuals from these groups (Figure 4.14).

Ostracod molecular results

Several ostracod specimens underwent genetic sequencing as part of Biologic's ostracod molecular studies for BHP (Biologic, 2021a, 2022a). Morphological identification of Pilbara ostracods is complicated by a lack of taxonomy and suitable keys, variation within species, minor morphological differences between species, and developmental differences. There are known similarities in carapace morphology between different species within similar hydrogeological settings, for example (Reeves *et al.*, 2007). Therefore, undertaking molecular sequencing in conjunction with morphological taxonomy is required to identify Pilbara ostracods more accurately, and determine species' distributions with any confidence.

Molecular analysis of ostracods indicated that specimens from YC1 and YC4 identified morphologically as *Vestalenula maltidae* grouped with GenBank sequences of *Vestalenula marmonieri* (Biologic, 2022a). Meanwhile, specimens identified morphologically as *Vestalenula marmonieri* (from reference site SS) grouped with GenBank sequences of *Vestalenula maltidae* (Biologic, 2022a). These comparative sequences from GenBank were from a phylogeographic paper (Schön *et al.*, 2010) that was co-authored by one of the taxonomic authorities for these species, Koen Martens. Therefore, it is considered that the species identifications of sequences on GenBank are correct. Several other Operational Taxonomic Units (OTUs) were assigned to ostracod specimens collected from surface waters, however, most were recorded from reference sites only (Biologic, 2022a), and therefore are not discussed further here. One additional OTU was recorded from Yandicoogina Creek and is discussed further below (section 4.5.2).

4.5.2 Conservation significant zooplankton taxa

Most zooplankton taxa recorded are widely distributed across northern Australia or the world (cosmopolitan species). One known, described species, *Vestalenula marmonieri*, recorded from YC1 and YC4 in the Dry 2020 and YC3 and YC4 in the wet 2021 is a Pilbara endemic. This species is known to occur in surface waters across the Pilbara.

4.5.3 Zooplankton comparison with the previous survey

The pattern of change over time in zooplankton taxa richness was generally similar between Survey Area and reference sites, with an increase in the Dry 2020 and decrease in the wet 2021 (Figure 4.15). Overall, there was no significant difference in zooplankton taxa richness between sampling events (Two-way ANOVA; df = 3, $p = 0.215$), nor between site type (df = 1, $p = 0.173$).

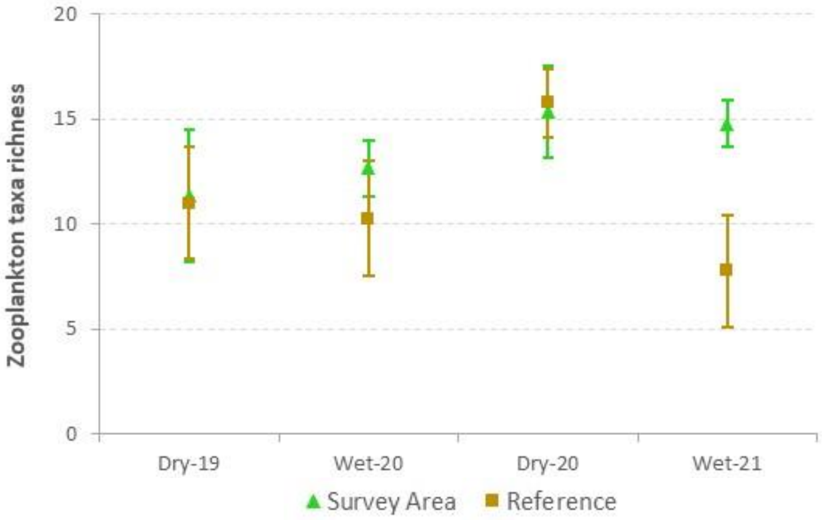


Figure 4.15: Average zooplankton taxa richness (± standard error) in the Survey Area and Reference sites recorded during each sampling event since the Dry 2019.

4.5.4 Zooplankton comparison with other studies

Zooplankton richness from the Survey Area was compared with previous studies detailed in section 4.2 above, for those studies which sampled more than one replicate site within a creek system. Weeli Wolli Creek sites were split into Weeli Wolli Spring (recorded from the historic spring area) and Weeli Wolli Creek (upper Weeli Wolli Creek river pools), to reflect differences in water permanence and hydrology between these two areas; factors which would influence zooplankton assemblages. Two sites could not be included in this analysis due to a lack of replication (MACREF2 and BENS). As detailed in the methods, the dataset was amalgamated, and taxonomy aligned, prior to analysis to ensure any differences in taxonomic knowledge between samplers and years was accounted for.

The Survey Area generally recorded average zooplankton richness similar to nearby creek systems (Figure 4.16). There was no difference in zooplankton richness between seasons in the Survey Area, compared with a higher average richness at nearby Marillana Creek, Upper Weeli Wolli Creek and Munjina Spring (Figure 4.16). In contrast, Weeli Wolli Spring and the Davis River all recorded higher average zooplankton richness in the dry season, although seasonal variation was notably low in the Survey Area (Figure 4.16). The large standard error bars reflect the high within-system variability in zooplankton richness. Interestingly, variability within the Survey Area was noticeably lower than all other creeks systems except for Munjina Spring, in the wet season (Figure 4.16).

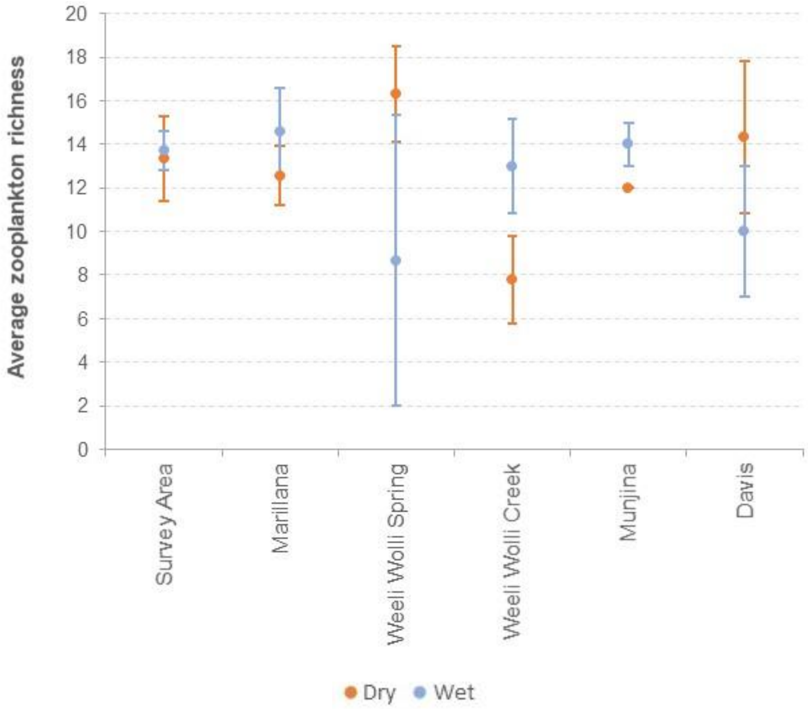


Figure 4.16: Average zooplankton taxa richness (± se) recorded from the Survey Area, in comparison to other studies and nearby creek systems, in both seasons.

Overall, any differences in zooplankton richness were not significant between creeks (Two-way ANOVA; df = 5, F = 0.52, p = 0.764) or seasons (df = 1, F = 0.21, p = 0.649). There was also no significant interaction between creek and season (df = 5, F = 0.99, p = 0.431).

4.6 Hyporheos fauna

Hyporheic samples were successfully collected from all sites except YC2 in the Wet 2021. Conditions at the time precluded hyporheic sampling at this site, particularly the dense *Typha* stands along banks impeding access to the hyporheos. Attempts to sample sites YC5H, YC6H, YC7H, YC8H and YC9H were not successful in either season. In the Dry 2020, logistical and time constraints meant there was no time to undertake additional hyporheic sampling within the creek, and in the Wet 2021 water levels were reduced to such an extent that the additional locations sampled previously (Wet 2020) were now dry.

4.6.1 Taxa composition and richness

A total of 88 invertebrate taxa were recorded from hyporheic zones in Yandicoogina Creek (see Appendix F for a full taxonomic list). The taxonomic list included Nematoda (roundworm; one taxon), Mollusca (freshwater snail; one taxon), Oligochaeta (aquatic segmented worm; 12 taxa), Acarina (water mites; seven taxa), Ostracoda (seed shrimp; five taxa), Copepoda (14 taxa), Amphipoda (side swimmers; three taxa), Isopoda (one taxa), Collembola (springtails; two taxa), Coleoptera (beetles; 17 taxa), Diptera (two-winged flies; 23 taxa), Lepidoptera (moth larvae; one taxon) and Odonata (dragonflies; one taxon). More than half of these were stygoxene (59%) and do not have specialised adaptations for groundwater habitats. Hyporheos fauna, comprising stygobites, occasional hyporheos stygophiles and possible hyporheic taxa made up the remaining 41% of taxa collected. Interestingly, no permanent hyporheos stygophiles were recorded from the Survey Area in either season (Figure 4.17). Previously, one permanent hyporheos stygophile, the ostracod *Limnocythere dorsosicula*, was recorded from the hyporheic zone of YC4 in the Dry 2019, and YC8H in the Wet 2020 (Biologic, 2020c). In the current survey, a total of 11% of taxa recorded are stygobitic and directly dependant on groundwater for their persistence. This is considerably greater than the percentage of hyporheic fauna reported by Halse *et al.* (2002) (5% stygobitic fauna).

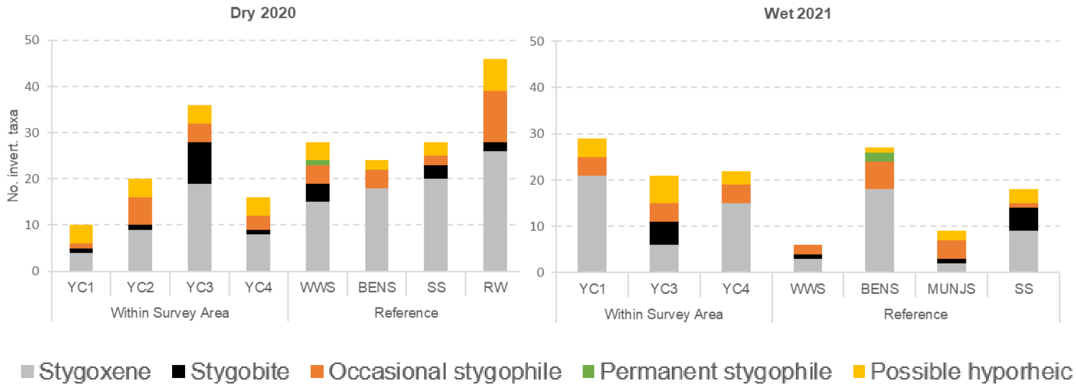


Figure 4.17: Classification of invertebrate taxa recorded from the hyporheic zone.

Possible hyporheic taxa included higher-level identifications for which taxa may have belonged to a stygal or hyporheos species. These include Nematoda sp. roundworms, the oligochaetes Oligochaeta sp. (imm./dam.), Naididae sp. (imm./dam.), *Pristina* sp. (imm./dam.), *Pristina* nr. *osborni*, Phreodrilidae sp. and *Antarctodrilus* sp., immature or damaged water mites (Acarina sp.), juvenile ostracods Ostracoda sp. (imm./dam.) and Candonidae sp. (imm./dam.), immature or damaged copepods (Copepoda sp. (imm./dam.), Cyclopoid sp. (imm./dam.), *Paracyclops* sp. and *Tropocyclops* sp.), and beetle larvae Bidessini sp. and Hydrophilidae sp.

Hyporheos taxa recorded from the Survey Area included:

<u>Occasional hyporheos stygophiles:</u>

- oligochaetes *Pristina aequiseta*, *Pristina jenkinae* and *Pristina longiseta.*
- copepods *Australoeucyclops* sp., *Mesocyclops notius* and *Microcyclops varicans.*
- beetles Hydraenidae sp. (L), *Georissus* sp. and Scirtidae sp. (L).

<u>Stygobites:</u>

- ostracods *Notacandona boultoni*, *Gomphodella alexanderi*, and *Candonopsis* `sp. Biologic-OSTR025`, and.
- copepods *Diacyclops* nr. *cockingi*, *Diacyclops* nr. *humphreysi* and Canthocamptidae `sp. B01`.

- amphipods Paramelitidae sp., *Chydaekata* `sp. E`, and Paramelitidae `sp. Biologic-AMPH023`.
- isopod *Pygolabis* `sp. Biologic-ISOP035`.

4.6.2 Conservation significant hyporheos taxa

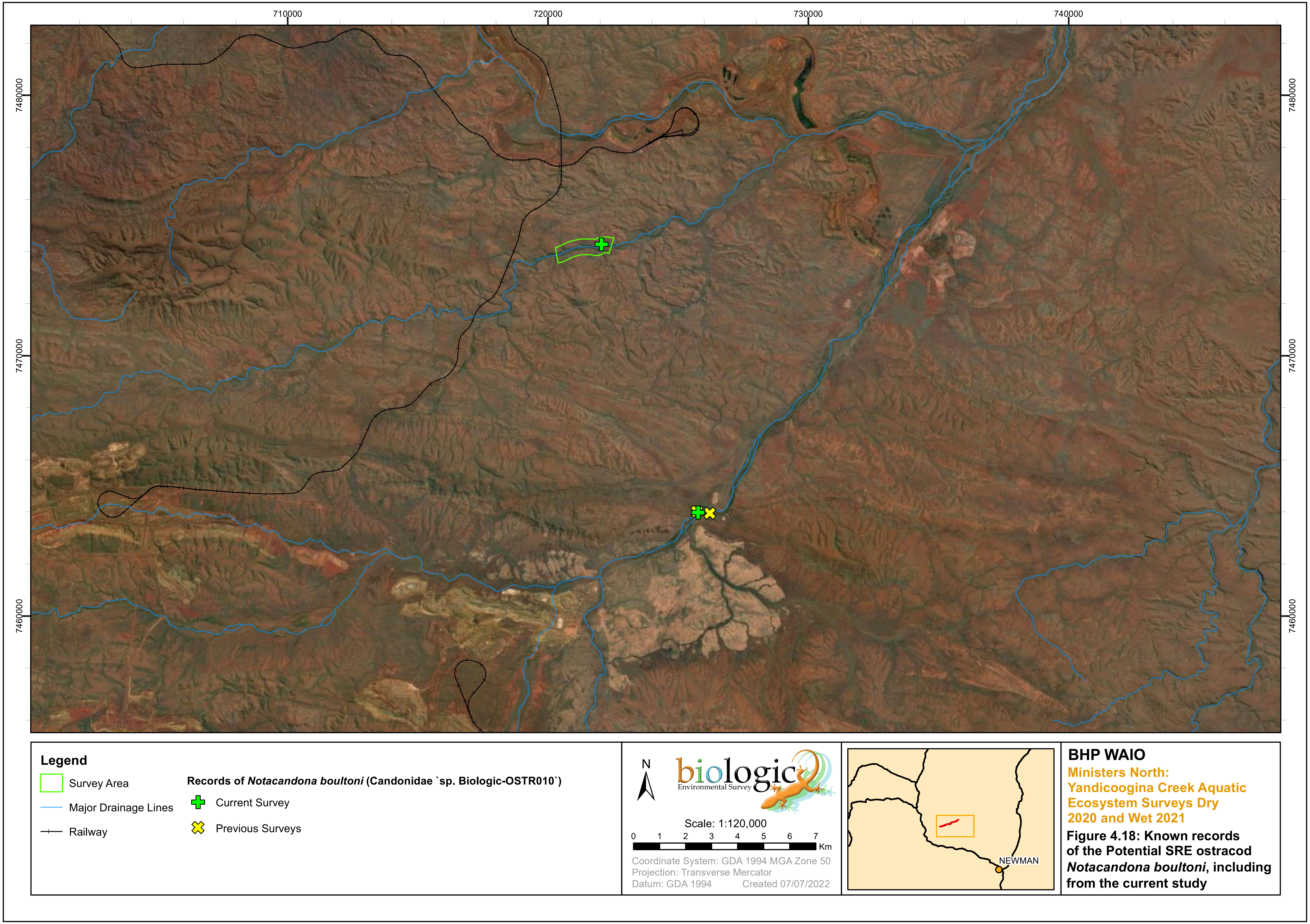
While most of these taxa are generally common and ubiquitous across the Pilbara, a number are of conservation significance and are either locally restricted or rarely collected. Further information regarding these taxa is provided below.

Ostracoda

Ostracod specimens recorded from Yandicoogina Creek (YC3) and Weeli Wolli Creek (WWS) morphologically identified as *Notacandona boultoni* were submitted for genetic analysis because some specimens were damaged or immature. Unfortunately, there was no sequence data available for this described species in GenBank, and therefore a new OTU was assigned: Candonidae `sp. Biologic-OSTR010` (Biologic, 2021a, 2022a). However, given the morphology and distribution matched the known species, it was considered highly likely that Candonidae `sp. Biologic-OSTR010` represents N. boultoni. Therefore, the OTU name will not be used, and all specimens which genetically match Candonidae `sp. Biologic-OSTR010` will hereafter be referred to as *N. boultoni*. *Notacandona boultoni* has a restricted range and is currently known only from Yandicoogina and Weeli Wolli Creeks (Figure 4.18). It is considered a Potential SRE.

Other ostracod specimens were morphologically identified as *Gomphodella alexanderi*, however, due to immaturity the specimens were also submitted for genetic analysis to confirm the identification. Unfortunately, there are currently no sequences publicly available for *Gomphodella alexanderi* for comparison, and the taxon was assigned a new OTU: *Gomphodella* `sp. Biologic-OSTR012` (Biologic, 2021a, 2022a). Given the morphological identification and fact that the distribution matches the known species, *Gomphodella* `sp. Biologic-OSTR012` is considered to represent *G. alexanderi* and will be considered as such hereafter. *G. alexanderi* is known only from Marillana Creek, groundwater bores within and surrounding the Yandi mine, Yandicoogina Creek, and lower Weeli Wolli Creek (Figure 4.19). During the current study, this species was collected from the hyporheic zone of YC3, in both seasons. *G. alexanderi* species is considered a Potential SRE (sub-category Data Deficient). While its known range is < 10,000 km^2 (or linear range < 100 km), there is insufficient taxonomic and distribution information to confirm SRE status. All known records of this species are in areas either currently impacted by mining activities or those proposed for future mining.

Further genetic analysis identified a specimen of Candonidae ostracod from YC1 to represent an additional OTU, *Candonopsis* `sp. Biologic-OSTR025` (Biologic, 2021a, 2022a). It was morphologically identified as belonging to the *Candonopsis* genus, noting slight differences in shell morphology to the common *Candonopsis tenuis* (Alex Riemer, Biologic, pers comm.). Molecular analyses indicated the specimen was genetically nested within Candonidae, but 20% divergent from other known Candonidae and therefore assigned the OTU *Candonopsis* `sp. Biologic-OSTR025`. The collection of *Candonopsis* `sp. Biologic-OSTR025` in this study constitutes the first record of this OTU. However, further molecular work will likely increase its known distribution in the future.



Legend

🟩 Survey Area

Major Drainage Lines

Railway

Records of *Notacandona boultoni* (Candonidae `sp. Biologic-OSTR010`)

✚ Current Survey

✖ Previous Surveys

Scale: 1:120,000

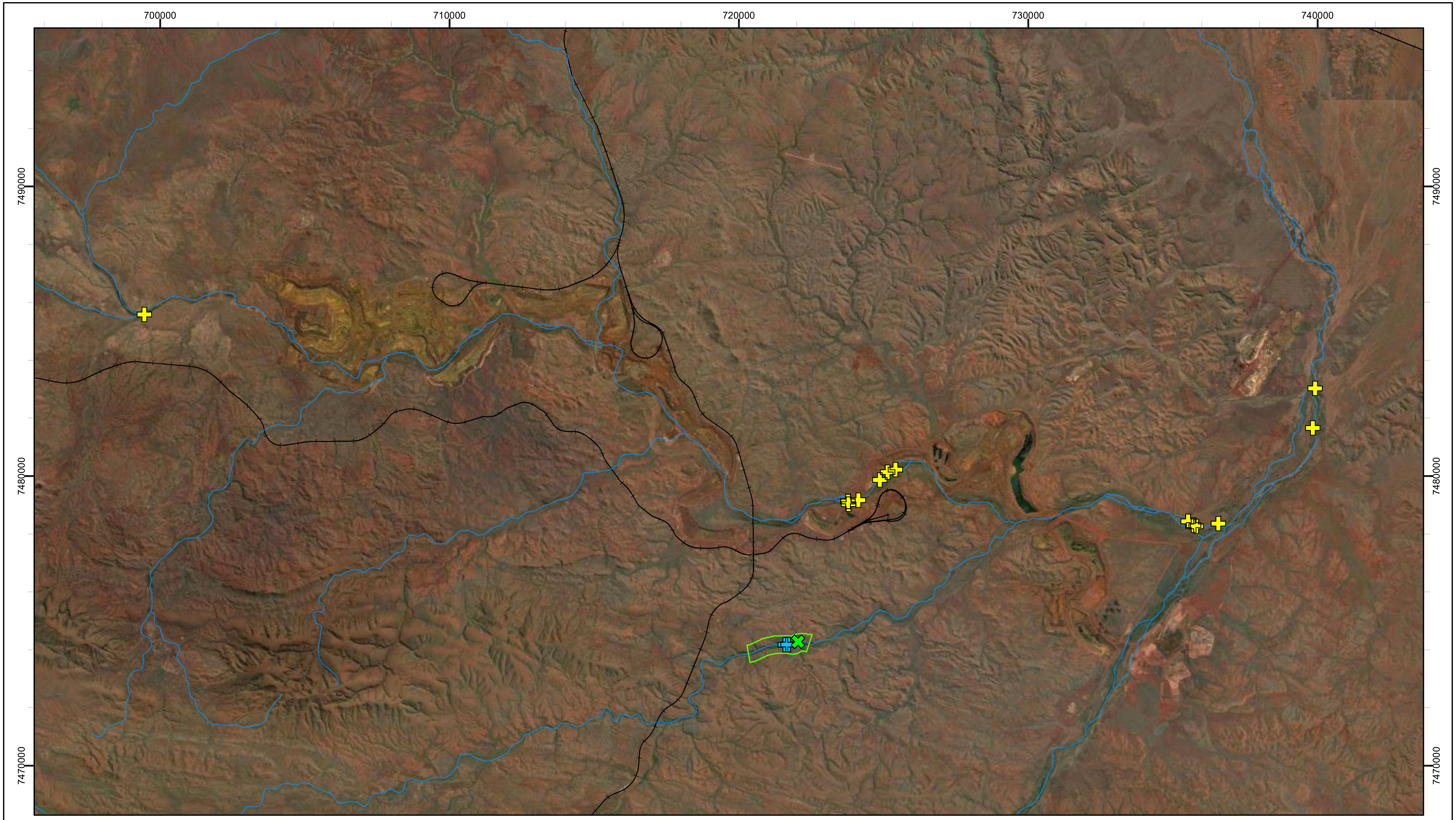
0 1 2 3 4 5 6 7 Km

Coordinate System: GDA 1994 MGA Zone 50
Projection: Transverse Mercator
Datum: GDA 1994 Created 07/07/2022

BHP WAIO

Ministers North: Yandicoogina Creek Aquatic Ecosystem Surveys Dry 2020 and Wet 2021

Figure 4.18: Known records of the Potential SRE ostracod *Notacandona boultoni*, including from the current study



Legend

- 🟩 Survey Area
- Major Drainage Lines
- Railway

Records of *Gomphodella alexanderi*

- ✖ Current Survey
- ✚ Previous Ministers North Survey
- ✚ Previous Surveys

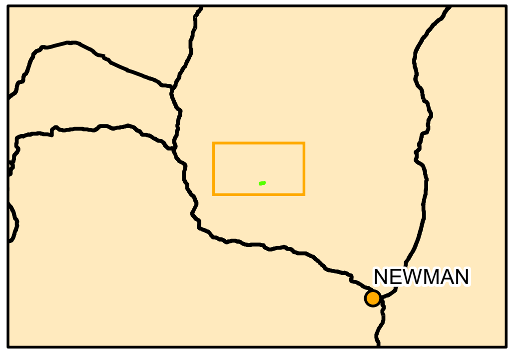
N

biologic
Environmental Survey

Scale: 1:120,000

0 2 4 6 Km

Coordinate System: GDA 1994 MGA Zone 50
Projection: Transverse Mercator
Datum: GDA 1994 Created 07/07/2022



BHP WAIO

Ministers North: Yandicoogina Creek Aquatic Ecosystem Surveys Dry 2020 and Wet 2021

Figure 4.19: Known records for the Potential SRE ostracod *Gomphodella alexanderi*, including from the current study

Copepoda

The harpacticoid copepod Canthocamptidae `sp. B01` is an undescribed species, but belongs to a previously known morphotype. It has been recorded previously from bores in the Yandi area (Jane McRae, pers. comms.) and is likely to have a restricted distribution. This species was recorded from the hyporheos of YC3 in the dry season.

Amphipoda

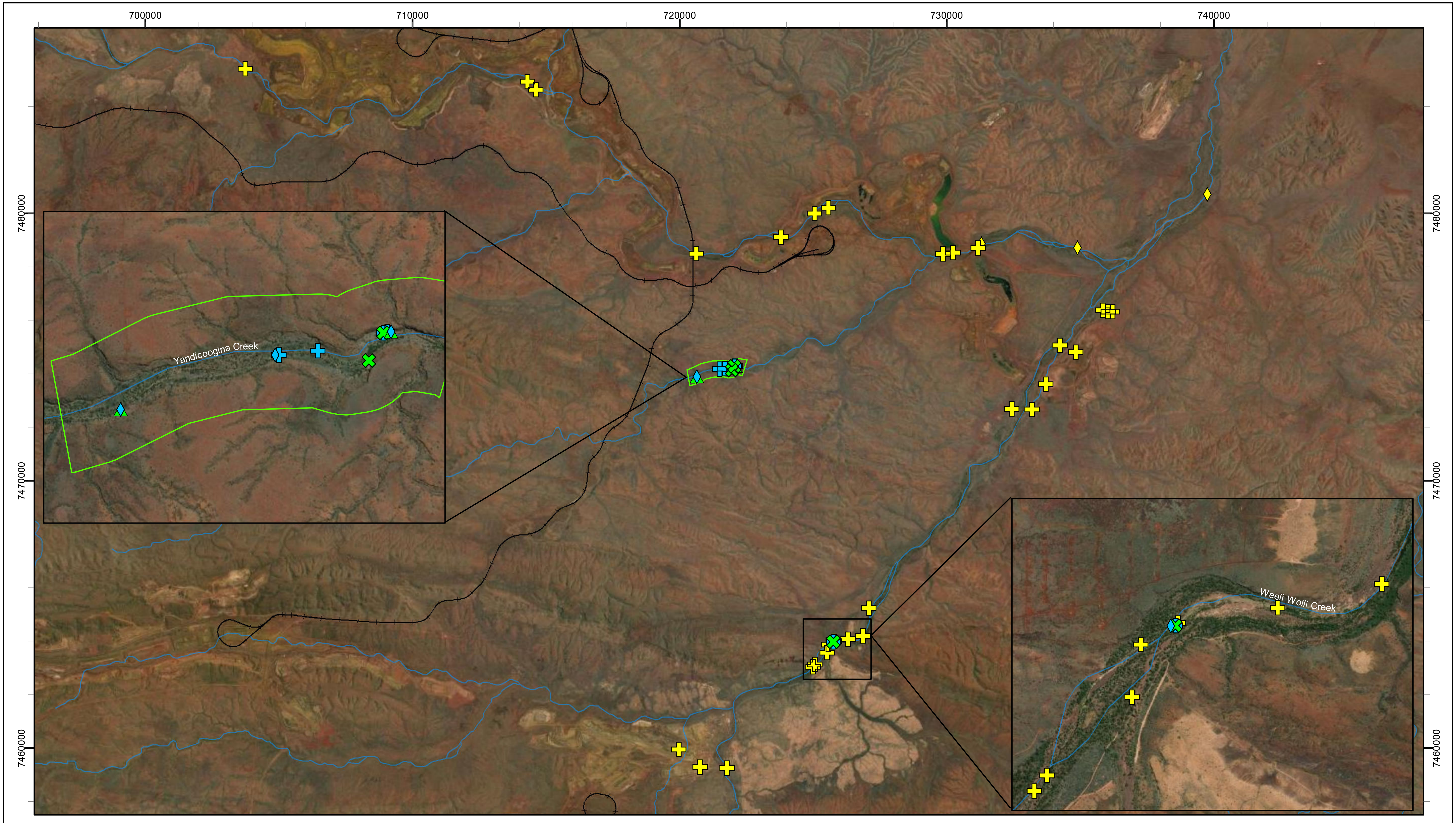
Molecular analysis was undertaken on stygal amphipods collected from the Survey Area and nearby Weeli Wolli Spring (Biologic, 2020b, 2022a). Outcomes from this work indicated the Survey Area supports two species of stygal amphipods; *Chydaekata* `sp. E` and Paramelitidae `sp. Biologic-AMPH023` (Biologic, 2020b, 2022a). *Chydaekata* `sp. E` is an undescribed morphotype that belongs to a previously published OTU (Finston *et al.*, 2007). In that study, *Chydaekata* 'sp. E' was recorded from Marillana Creek and Weeli Creek (Finston *et al.*, 2007). Given additional records, the species appears to be restricted to Marillana, Weeli Wolli and Yandicoogina Creeks (Figure 4.20). It was recorded from the hyporheos of YC3 and YC4, as well as reference site WWS.

Paramelitidae `sp. Biologic-AMPH023` was previously known only from Marillana Creek and lower Weeli Wolli Creek (downstream of the confluence with Marillana), but has recently been recorded from Yandicoogina Creek within the Survey Area (Biologic, 2020b, 2022a). The taxon is known to occur over a 20.3 km linear distance and was 9.9% divergent from Paramelitidae `sp. Biologic-AMPH024`, known from Weeli Wolli Spring (Biologic, 2020b). During the current study, Paramelitidae `sp. Biologic-AMPH023` was recorded from YC1 and YC3. It is also previously known from YC5H and YC9H (Biologic, 2020c). It appears to be well distributed throughout the Survey Area. Based on the WAM classification system, the stygal amphipods recorded from Yandicoogina Creek would be considered Potential SREs (Data Deficient). Genetic analyses have previously indicated that most paramelitid species have distribution ranges on the tributary-scale (Finston *et al.*, 2007).

Immature or damaged specimens of Paramelitidae sp. were also recorded in the wet season from YC3. These are likely to represent specimens of *Chydaekata* `sp. E` or Paramelitidae `sp. Biologic-AMPH023`. The *Chydaekata* species recorded from reference site SS, more than 200 km away, represents a different species, Paramelitidae `sp. Biologic-AMPH049` (Biologic, 2022a).

Isopoda

The stygobitic *Pygolabis* isopod collected from the hyporheic zone of YC3 was submitted for genetic sequencing. The specimen was found to be more than 15% divergent from *Pygolabis weeliwolli*, an SRE known from nearby (Weeli Wolli Creek) (Biologic, 2022a), and was around 7.6% divergent from its closest relative, *Pygolabis* `sp. Biologic-ISOP020` (collected from a shallow bore approximately 33 km from the Survey Area). As such, the Yandicoogina Creek *Pygolabis* was assigned a new OTU, *Pygolabis* `sp. Biologic-ISOP035`. *Pygolabis weeliwolli* is known to be restricted to groundwaters and hyporheos of Weeli Wolli Creek and Marillana Creek, and groundwater bores within the Yandicoogina tenement (Biota, 2010) (Figure 4.21). Much of this work was based on morphological identification alone, and it may be that are additional species of *Pygolabis* in the area based on genetic analysis.



Legend

☐ Survey Area

— Major Drainage Lines

┼ Railway

Records of *Chydaekata* sp. E

✖ Current Survey

✚ Previous Ministers North Survey

✚ Previous Surveys

Records of Paramelitidae `sp. Biologic-AMPH023`

▲ Current Survey

◆ Previous Ministers North Survey

◆ Previous Survey

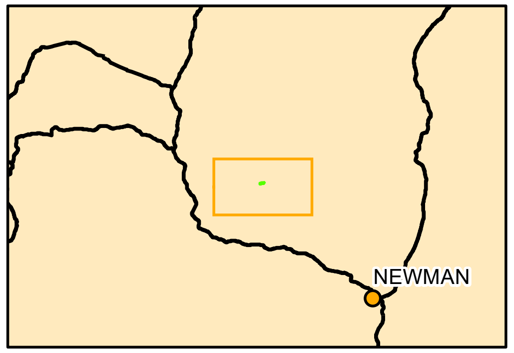
N

biologic
Environmental Survey

Scale: 1:130,000

0 2 4 6 Km

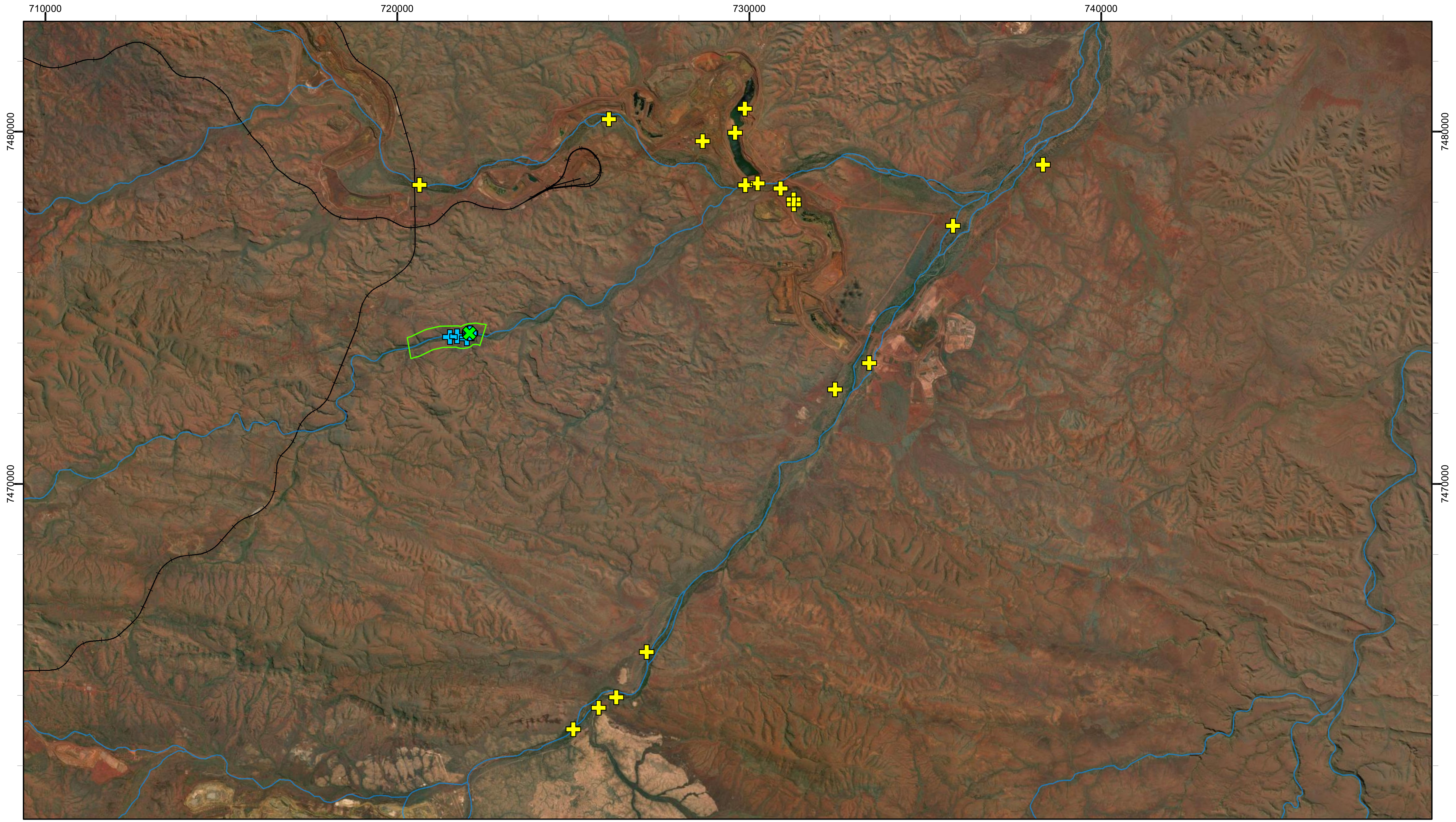
Coordinate System: GDA 1994 MGA Zone 50
Projection: Transverse Mercator
Datum: GDA 1994 Created 09/09/2022



BHP WAIO

Ministers North: Yandicoogina Creek Aquatic Ecosystem Surveys Dry 2020 and Wet 2021

Figure 4.20: Known records of the Potential SRE stygal amphipods



Legend

- Survey Area
- Major Drainage Lines
- Railway

Records of *Pygolabis*

- ✖ Current Survey - *Pygolabis* `sp. Biologic-ISOP035`
- ✚ Previous Ministers North Survey - *Pygolabis* cf. `sp. Biologic-ISOP035`
- ✚ Previous Surveys - *Pygolabis weeliwolli*

N

Scale: 1:100,000

0 1 2 3 4 5 6 Km

Coordinate System: GDA 1994 MGA Zone 50
Projection: Transverse Mercator
Datum: GDA 1994
Created 07/07/2022

BHP WAIO

Ministers North: Yandicoogina Creek Aquatic Ecosystem Surveys Dry 2020 and Wet 2021

Figure 4.21: Known records of the Potential SRE stygal isopod *Pygolabis*, including from the current study

Other species of interest

Other species of interest were recorded from reference sites only and were not found to be present in the Survey Area (i.e., *Hesperomomonia humphreysi*, *Elaphoidella* sp., Paramelitidae `sp. Biologic-AMPH024`, Paramelitidae `sp. Biologic-AMPH049` and *Atopobathynella* sp.). The water mite *Hesperomomonia humphreysi* is a permanent stygophile which appears to be restricted to Weeli Wolli Spring. The stygobitic harpacticoid *Elaphoidella* sp. is not commonly recorded and was collected from reference site SS. Paramelitidae `sp. Biologic-AMPH024` was identified through molecular analysis (Biologic, 2021a, 2022a). This stygal amphipod species appears to be restricted to Weeli Wolli Creek. Morphological characters of this species are very similar to Paramelitidae `sp. Biologic-AMPH023` and are very difficult to distinguish currently. Paramelitidae `sp. Biologic-AMPH049` is currently known only from SS on the Davis River. *Atopobathynella* sp. was recorded from the hyporheos of SS in both seasons. Many parabathynellid species have been found to be restricted to a single calcrete (Guzik *et al.*, 2008), with more than two-thirds of species having a range of less than 10 km (Bennelongia, 2008).

4.6.3 Hyporheos fauna taxa comparison with the previous survey

Hyporheos fauna taxa richness at reference sites was higher in the dry season and lower in the wet (Figure 4.22). This seasonal pattern was not evident in the Survey Area, with hyporheos fauna taxa richness remaining relatively consistent between the Dry 2019 and Wet 2020, followed by an increase in the Dry 2020 and marginal decrease in the wet 2021 (Figure 4.22).

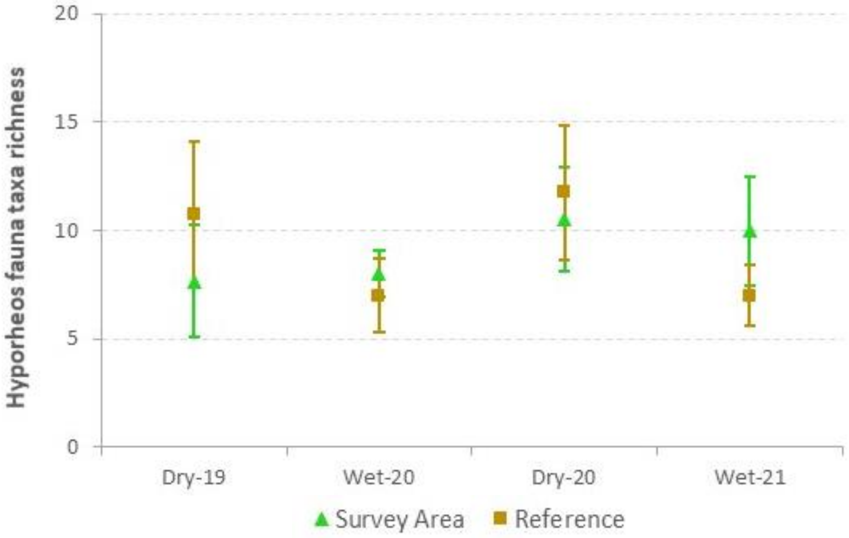


Figure 4.22: Average hyporheos fauna taxa richness (± standard error) in the Survey Area and Reference sites recorded during each sampling event since the Dry 2019.

The number of occasional hyporheos taxa recorded from the Survey Area has generally increased over time (Figure 4.23). Although there was also an increase in occasional hyporheos taxa richness at reference sites between the Dry 2019, there was a notable decrease in the Wet 2021 (Figure 4.23). Stygobitic taxa richness followed a similar pattern of change as overall hyporheos fauna taxa richness, within both reference and Survey Area sites. One difference was evident though; a notable decrease in stygobitic taxa recorded from the Survey Area in the wet 2021 (Figure 4.23). While decline in stygobitic taxa richness was also observed within reference sites, the decrease within the Survey Area was more marked.

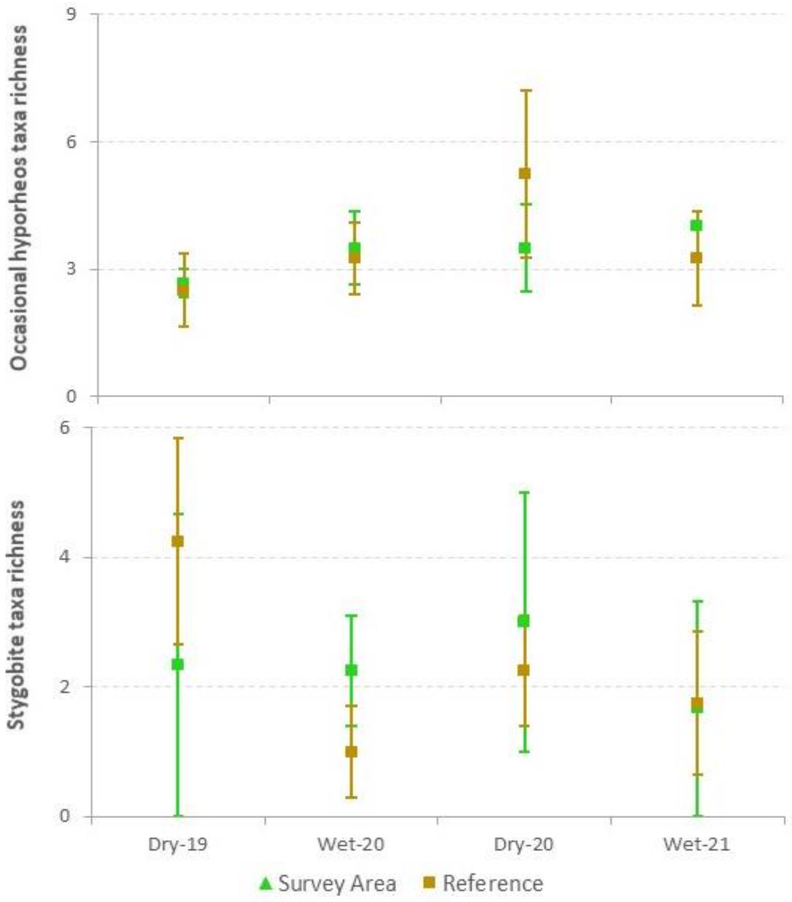


Figure 4.23: Average occasional hyporheos fauna taxa richness (± standard error) (top) and stygobite taxa richness (bottom) (± standard error) in the Survey Area and Reference sites ecorded during each sampling event since the Dry 2019.

Overall, none of the differences in hyporheos fauna, occasional hyporheos taxa or stygobitic taxa richness were significant, either between site type or between sampling event (Table 4.6).

Table 4.6: Two-way ANOVA results, comparing hyporheos fauna richness between sampling events and site type (Survey Area vs reference). Significant *p*-values are shown in red.

Analyte	Source	df	F	*p*-value
Overall hyporheos fauna taxa richness	Sampling event	3	0.87	0.470
	Type	1	0.00	0.961
	Sampling event*type	3	0.57	0.637
	Corrected total	31		
Occasional hyporheos taxa richness	Sampling event	3	0.87	0.471
	Type	1	0.03	0.856
	Sampling event*type	3	0.50	0.684
	Corrected total	31		
Stygobite taxa richness	Sampling event	3	0.60	0.621
	Type	1	0.00	1.000
	Sampling event*type	3	0.46	0.711
	Corrected total	31		

4.7 Macroinvertebrates

4.7.1 Taxa composition and richness

A total of 145 macroinvertebrate taxa was recorded from Yandicoogina Creek within the Survey Area (see Appendix G for the full taxonomic list). The macroinvertebrate fauna of the Survey Area comprised three gastropod taxa (freshwater snails), 13 oligochaete taxa (aquatic segmented worms), 11 Acarina taxa (water mites), one Crustacea taxon (stygal Amphipoda), one Collembolla taxon (spring tails), 38 Coleoptera taxa (beetles), 36 Diptera taxa (two winged flies), six Ephemeroptera taxa (mayflies), 11 Hemiptera taxa (true bugs), 18 Odonata taxa (dragonflies and damselflies) and seven Trichoptera taxa (caddisflies).

Of the 145 taxa recorded from the Survey Area, 60 were singletons and recorded from one sample only (one site in one season). More common taxa, recorded from 75% of samples (six or more samples), included the gastropod *Ferrissia petterdi*, oligochaete *Pristina aequiseta*, beetles *Sternolophus marginicollis* and larval Scirtidae sp., the biting midges Ceratopogoninae sp. and *Dasyhelea* sp., non-biting midge larvae *Chironomus* aff. *alternans*, *Kiefferulus intertinctus*, *Tanytarsus* sp., and *Paramerina* `sp. 1`, and giant water bug *Diplonychus eques*.

Within-site macroinvertebrate richness ranged from 18 (at YC2) to 79 (at RW) in the Dry 2020, and from 26 (at YC1) to 71 (at SS) in the wet 2021 (Figure 4.24). Although richness at YC1 and YC2 was low in both seasons, YC3 and YC4 recorded high macroinvertebrate richness, comparable, if not higher than most reference sites (Figure 4.24). The low richness recorded from YC1 and YC2 was influenced by a low diversity of Diptera, Hemiptera and Odonata compared to other sites, as well as a complete lack of *Hydra*, Turbellaria, Nematoda, Crustacea, Ephemeroptera and Trichoptera (Figure 4.24). The low richness at these sites likely reflected the low water depths and difficulties associated with sampling. At YC1 there was very little surface water remaining for sampling, and at YC2, the high abundance of *Typha*, with little open water provided limited space with which to kick-sweep sample effectively.

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 (Pinder *et al.*, 2010). Taxa which require faster flows, such as Lepidoptera, leptophlebiid mayflies, Simulidae (Diptera) and *Cheumatopysche* caddisflies (Trichoptera) were generally restricted to the flowing reference sites, including Weeli Wolli Spring, Munjina Spring and Skull Spring (Figure 4.24). Yandicoogina Creek generally recorded a low richness of Trichoptera in comparison to reference sites, especially from YC1, YC2 and YC3.

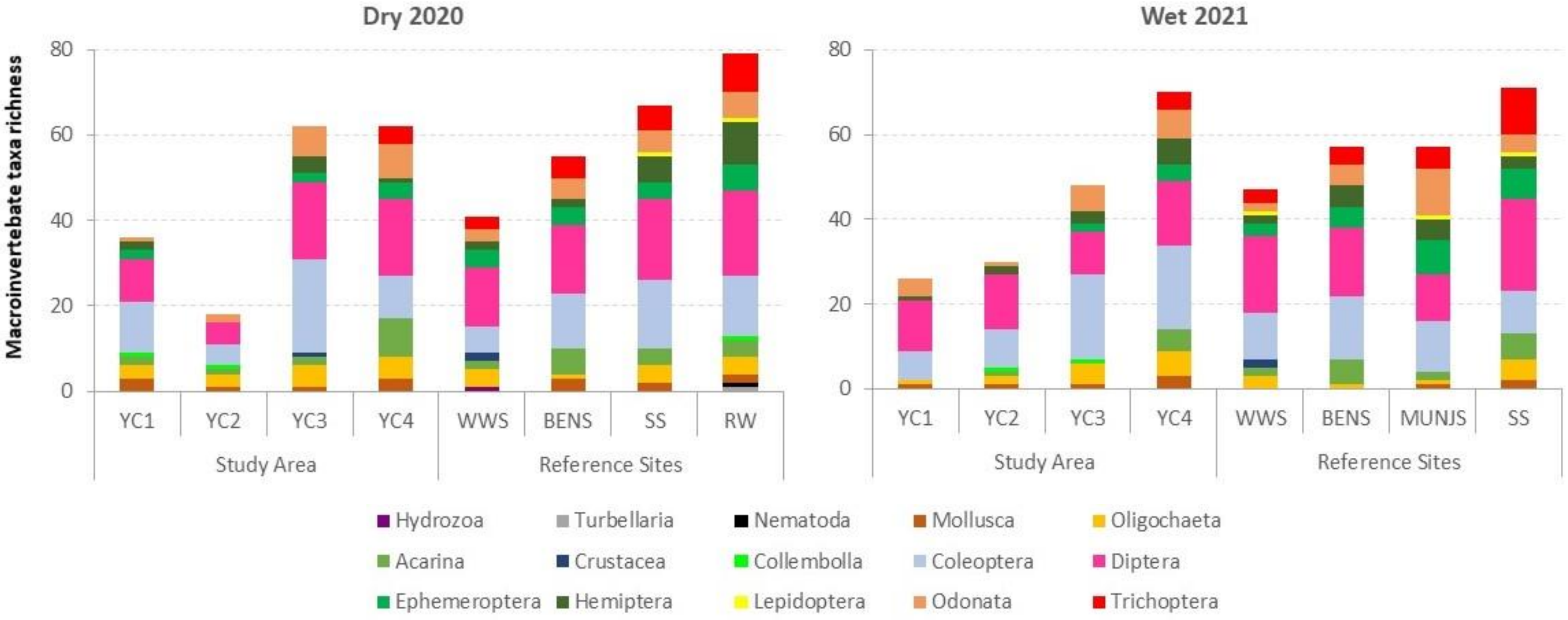


Figure 4.24: Macroinvertebrate taxa richness recorded from each site in each season.

4.7.2 Conservation significant macroinvertebrate taxa

The vast majority of aquatic macroinvertebrates recorded from the Survey Area were common, ubiquitous species. Excluding taxa which could not be assigned a distribution status due to insufficient information or taxonomy (juveniles/damaged specimens), most remaining taxa had distributions extending across Australia (26%), Northern Australia (20%), or the Australasian region (17%). A total of 12% were cosmopolitan, 7% endemic to Western Australia, 3% found across northern Western Australia, and 1% were introduced. Taxa restricted to the Pilbara region accounted for 14% of the taxa recorded (of those with known distributions). Pilbara endemic taxa were recorded from all sites, with the greatest number being recorded from reference site BENS in the Dry 2020 (six taxa; Figure 4.25). This was closely followed by YC3 and SS, both of which recorded five Pilbara endemic taxa (Figure 4.25).

Figure 4.25: Number of Pilbara endemic macroinvertebrate taxa recorded from each site in each season.

Within the Pilbara endemic fauna were four taxa of further interest; conservation significant species currently listed on the IUCN Redlist of Threatened Species, short-range endemics and an uncommon species.

Odonata

The Pilbara emerald, *Hemicordulia koomina*, is currently listed on the IUCN (2021) as Vulnerable. Its listing was based on it being known from only five sites in the Pilbara (Millstream station, Koomina Pools on Tanberry Creek, Palm Pool south of Karratha, Fortescue Crossing, and Millstream Spring). Lowering water levels from groundwater abstraction and climate change were highlighted as a considerable threat to this species, as well as its severely fragmented distribution (IUCN, 2021). The IUCN listing for *H. koomina* was updated recently (2016), but the update did not appear to take into account grey literature records or those recorded during baseline surveys for developments. Including known locations reported in Pinder *et al.,* (2010) and sites known by the authors, *H. koomina* likely occurs at more than 15 sites across the Pilbara. The IUCN listing did indicate that its maximum known extent of occurrence was 6,504 km^2 (Dow, 2019); however, Bush *et al.* (2014) provided an estimate of the current extent of suitable habitat as 119,416 km^2. This species is still considered rare and is infrequently collected and rarely recorded. It was recorded from YC1, YC3 and BENs during the current survey, and is previously known from YC4 (Wet 2020) (Biologic, 2020c).

Amphipoda

The amphipods recorded from Yandicoogina Creek surface waters during the current study were stygal and are known to belong to the same species recorded from the hyporheic zone, *Chydaekata* `sp. E`. This species was recorded from surface waters at YC3, as well as reference site WWS. It has previously been recorded from surface waters at YC4 (Dry 2019) (Biologic, 2020c). *Chydaekata* `sp. E` is a Potential SRE (sub-category data deficient) known only from Yandicoogina Creek, Marillana Creek, and Upper Weeli Wolli Creek.

Acarina

The water mite recorded from YC4 in both the Dry 2020 and wet 2021, *Austraturus* `sp. P2`, is a Pilbara endemic species with a highly disjunct distribution. This is an undescribed species, but the morphotype is previously known and appears to be restricted to permanent pools of good ecological condition. During the PBS, *Austraturus* `sp. P2` was recorded from only four sites; Hamersley Gorge, Gregory Gorge, Nyeetbury Pool and Yandabiddy Pool. The closest of these is located approximately 116 km from the Survey Area (Yandabiddy), and the furthest approximately 280 km away (Nyeetbury). This species appears to be uncommon.

Other species of interest

Pilbara pin damselfly *Eurysticta coolawanyah* was recorded from reference sites WWS, BENS (Dry 2020) and SS (wet 2021). The Pilbara pin is known from Yandicoogina Creek and was recorded from YC4 in the Dry 2019 season (Biologic, 2020c).

4.7.3 Introduced macroinvertebrate taxa

Only one introduced macroinvertebrate species was recorded during the current study, from reference site WWS. The redclaw (*Cherax quadricarinatus*), a species of freshwater crayfish, was recorded in both seasons and is discussed further below (section 4.8).

4.7.4 Macroinvertebrate comparison with the previous survey

There was minimal seasonal or temporal change in macroinvertebrate taxa richness within both the Survey Area and reference sites (Figure 4.26). In contrast, the number of Pilbara endemic taxa has generally declined since the Dry 2019, in both Survey Area and reference sites (Figure 4.26). Overall, there was no significant difference in macroinvertebrate taxa richness (Two-way ANOVA; df = 3, p = 0.804) or Pilbara endemic taxa richness (df = 3, p = 0.212) between sampling events.

Both macroinvertebrate richness (Two-way ANOVA; df = 1, p = 0.004) and Pilbara endemic taxa richness (df = 1, p = 0.039) was significantly greater at reference sites in comparison to Survey Area sites (Figure 4.26). The lower richness within the Survey Area was primarily due to the low richness recorded consistently from YC2. Sampling of this site was hampered by the abundant *Typha* growth and difficulty manoeuvring the dip net to undertake kick sweep sampling effectively.

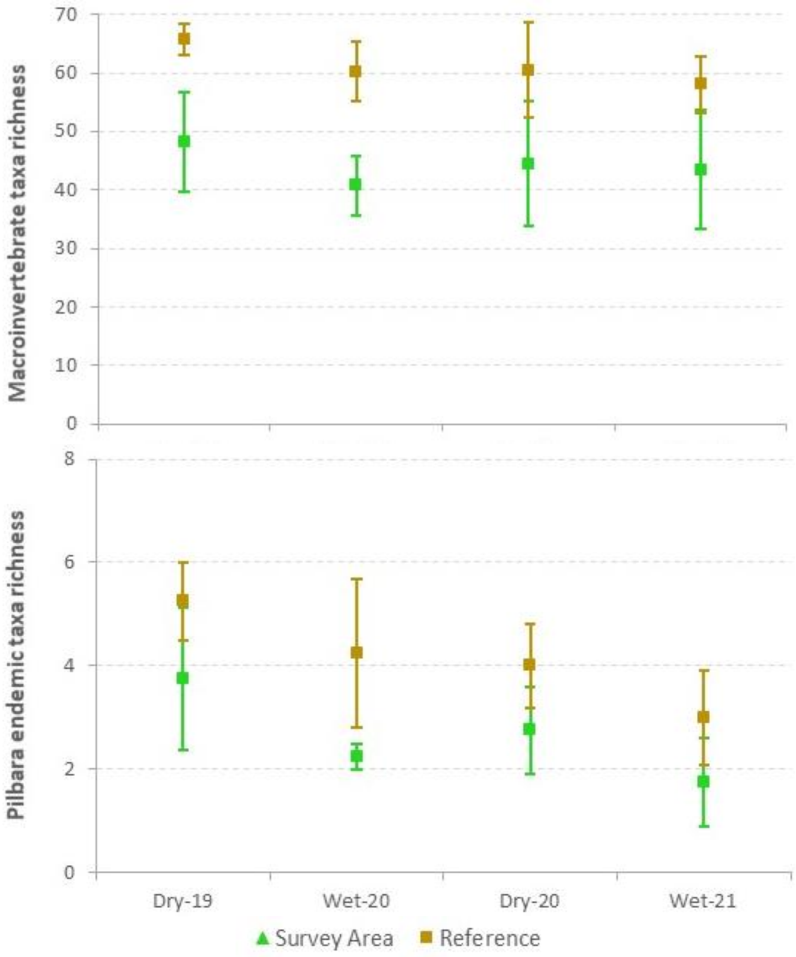


Figure 4.26: Average macroinvertebrate taxa richness (± standard error) (top) and Pilbara endemic taxa richness (bottom) (± standard error) in the Survey Area and Reference sites recorded during each sampling event since the Dry 2019.

4.7.5 Macroinvertebrate comparison with other studies

Macroinvertebrate richness was compared to the other aquatic studies undertaken in the area detailed in section 4.2 above (for those studies which sampled more than one replicate site within a creek system). As with the zooplankton data, Weeli Wolli Creek sites were split into Weeli Wolli Spring and Weeli Wolli Creek, and some reference sites were removed due to a lack of replication within a sampling event (i.e., BENS, MUNJS and MACREF1). The macroinvertebrate dataset was amalgamated, and taxonomy aligned, prior to analysis to ensure any differences in taxonomic knowledge between samplers and years was accounted for.

Yandicoogina Creek generally recorded similar average richness to nearby Marillana Creek, but lower than the highly diverse Weeli Wolli Spring PEC or the Davis River (Figure 4.27). Overall, differences in macroinvertebrate richness were significant between creeks (Two-way ANOVA; df = 5, F = 7.28, $p < 0.001$), but not between season (df = 1, F = 0.06, $p = 0.814$). There was no significant interaction between creek and season (df = 5, F = 0.43, $p = 0.825$). The Tukey's post-hoc test indicated that richness recorded from Yandicoogina Creek was statistically similar to Weeli Wolli Creek, Marillana Creek, Marillana Creek Downstream and Weeli Wolli Spring, but significantly lower than the Davis River (Figure 4.27).

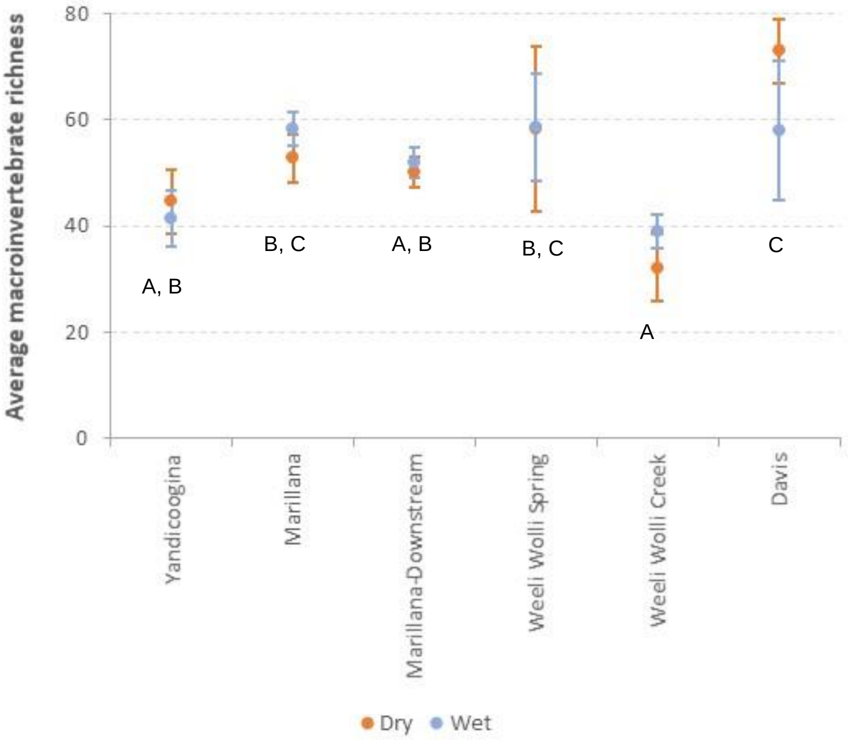


Figure 4.27: Average macroinvertebrate taxa richness (± se) recorded from Yandicoogina Creek, in comparison to other studies and nearby creek systems, in both seasons.

For multivariate analyses, all data were included, i.e., BENS, MUNJS and MACREF1 were also incorporated into the dataset. Data were transformed using presence/absence as this was the level of information provided in the PBS.

Macroinvertebrate assemblages of Yandicoogina Creek generally formed a relatively tight cluster, with the exception of the YC2 samples from the Dry 2020 and Wet 2021, and the YC1 sample from the Wet 2021 (Figure 4.28). Macroinvertebrate richness within these samples was considerably lower than all other Survey Area samples. The bulk of the Survey Area macroinvertebrate samples sat closest in ordination space to the Yandicoogina Creek Reference site, Munjina Spring samples, and some BENS (WWS2) and Marillana Creek samples (upper Marillana Creek as sampled by Biologic in the Dry 2020 and Wet 2021 for MAC4) (Figure 4.28). There was considerable separation between Survey Area samples and those from non-spring sites on Weeli Wolli Creek.

Overall, there was a significant difference in macroinvertebrate assemblages between creeks (Two-way ANOSIM; R = 0.42, $p < 0.001$), but not between season (R = 0.07, $p = 0.054$; Figure 4.29). Pairwise post-hoc results indicated that macroinvertebrate assemblages of the Survey Area were most similar to assemblages of Munjina Spring and the reference site on Yandicoogina Creek (sampled for MAC4, i.e., MACREF1; Table 4.7).

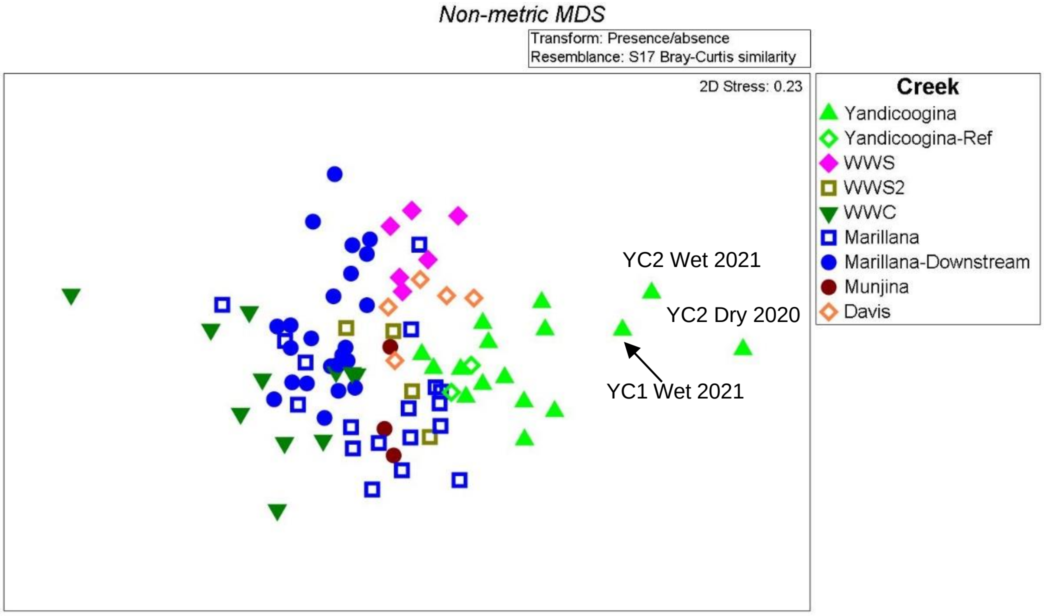


Figure 4.28: nMDS of macroinvertebrate assemblages recorded during the current study, with data from previous studies included. Samples are identified by creek.

Table 4.7: Post-hoc pairwise results comparing macroinvertebrate assemblages of Yandicoogina Creek to other creeks/reaches nearby. NB: significant separations are indicated by red font).

Creek/reach	R	*p*-value
Yandicoogina-Ref	-0.10	0.679
WWS	0.59	<0.0001
WWS2	0.40	0.013
WWC	0.63	<0.0001
Marillana	0.50	<0.0001
Marillana-Down	0.73	<0.0001
Munjina	0.36	0.064
Davis	0.34	0.015

Including data from the current Ministers North study only, seven environmental (water quality and habitat) variables were found to significantly influence the macroinvertebrate assemblages (BVSTEP; correlation = 0.74, $p < 0.0001$). These were pH, dissolved oxygen, concentrations of total phosphorus, and percentage habitat cover by emergent macrophyte, large woody debris, roots, and bedrock.

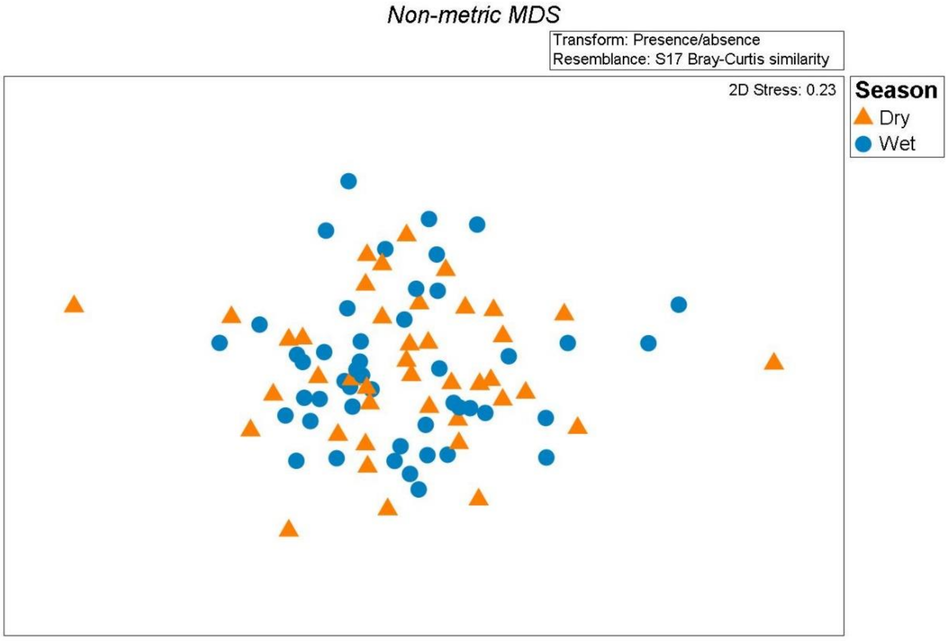


Figure 4.29: nMDS ordination of macroinvertebrate assemblages as above, but with samples identified by season.

4.8 Crayfish

A total of 16 individual invasive redclaw were removed from reference site WWS during the current study; with four individuals captured during the dry season (dip net), and 12 individuals removed during the wet (electrofishing). The sex ratio was 1:1, with no juveniles captured during the entire study (Table 4.8).

Table 4.8: Sex ratio for redclaw removed from WWS.

Sex	Dry 2020	Wet 2021	Total
Juvenile	0	0	0
Female	0	6	6
Male	0	6	6
Unknown	4	0	4
Total	**4**	**12**	**16**

As few individuals were recorded in the Dry 2020, age-class structures were only examined for the Wet 2021 specimens (Figure 4.30). Carapace length ranged from 39 to 63 mm in males and 40 to 60 mm in females. The highest abundance of individuals was within the 41 - 50 mm size class, which accounted for 31% of the total population removed (Figure 4.30). One berried[7] female was removed. The redclaw population at WWS is abundant, healthy, and self-sustaining (Biologic, 2020d).

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[7] In berried females, the eggs can clearly be seen under the tail.

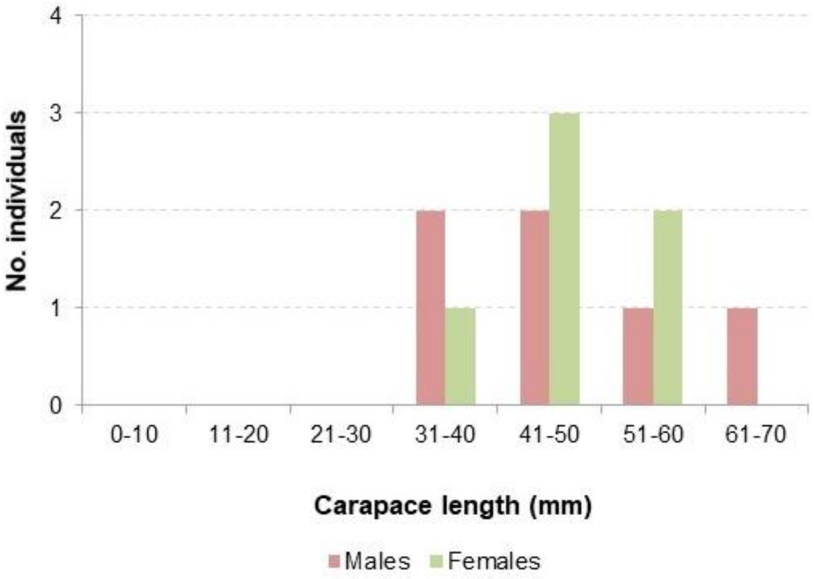

Figure 4.30: Size (mm CL) of redclaw removed from reference site WWS in the Wet 2021.

4.9 Fish

4.9.1 Species composition and richness

Three freshwater fish species were recorded from the Survey Area; the western rainbowfish *Melanotaenia australis* (Melanotaeniidae), Pilbara tandan *Neosilurus* sp.[8] (Plotosidae) and spangled perch *Leiopotherapon unicolor* (Terapontidae). Pilbara bony bream *Nematalosa* sp. (Clupeidae) were also recorded at two reference sites; Skull Springs and Running Waters. No introduced species were recorded or are currently known from the Survey Area.

Results from this study are not unexpected given the fish fauna of the Pilbara is known to be characterised by low species diversity, which is considered to be due to the region's aridity (Allen *et al.*, 2002; Masini, 1988; Morgan *et al.*, 2014). 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 (i.e., from reference site SS).

4.9.2 Abundance

A total of 1,137 freshwater fish were recorded in the current study, 444 in the Dry 2020 and 693 in the Wet 2021 (Table 4.9). Of these, 164 freshwater fish were recorded in the Survey Area, 77 in the Dry 2020 and 87 in the Wet 2021. Reference site SS recorded the greatest abundance (314 individuals in the wet), followed by WWS (153 individuals in Wet 2021 and 142 individuals in Dry 2020; Table 4.9). The greatest abundance from the Survey Area was recorded from YC4 in the wet (63 individuals). The

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[8] 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.

lowest abundance overall was recorded from YC3 in the Dry 2020 (three Western rainbowfish observed). Diversity was greatest at SS in the Wet 2021, with four species recorded. No fish were recorded from YC2 or Munjina Spring. YC2 was not able to be sampled for fish and observations were hampered by the highly abundant *Typha* growth, while it is known that Munjina Spring does not support fish populations (Biologic, 2020c).

Western rainbowfish was the most widespread and abundant species recorded within the Survey Area, and in fact across the entire study. A total of 280 individuals were recorded in the Dry 2020 and 288 in the Wet 2021 (across all sites). Spangled perch were the next most common species across the entire study with a total of 147 individuals recorded in the Dry 2020 and 262 in the Wet 2021 (Table 4.9). Pilbara tandan was recorded from YC4 in the Survey Area, and WWS, BENS and SS reference sites. Although Pilbara tandan tend to be recorded in low abundances due to their elusive and cryptic nature, they were observed in notably high abundance at WWS in the Wet 2021 (79 individuals), where they were observed congregatingin a pool below a flowing riffle/run. Pilbara tandan were also recorded in relatively high numbers from SS in the Wet 2021 (34 individuals), but sampling at that site was facilitated by the use of an electrofisher which was utilised as part of sampling for a different project (Biologic, 2022b). Pilbara bony bream were the least abundant and widespread species and were only recorded from the two Davis River reference sites (Table 4.9).

4.9.3 Conservation significant fish species

Despite the low diversity known from the Pilbara, the region does support high endemicity in freshwater fishes (56%; Morgan *et al.* 2014). Two species recorded during the current study are endemic to the region; the Pilbara bony bream and the Pilbara tandan (recorded from the Survey Area). Both are representatives of genera which are wide-ranging across northern Australia; however, the species' recorded from the Pilbara are genetically distinct to common and widespread congeners (i.e., *Nematalosa erebi* or *Neosilurus hyrtlii*) (Unmack, 2013). Both species occur widely throughout the Pilbara, and neither are currently listed as being of conservation significance. The Pilbara tandan is generally less commonly recorded, however, likely due to its cryptic nature, being commonly found under snags and undercuts.

Table 4.9: Abundance of each freshwater fish species recorded from each site.

NB: D refers to dry season records, and W refers to wet season records. RW was not sampled in the Wet 2021, and Munjina Spring does not support fish.

		L. unicolor		***M. australis***		***Neosilurus* sp.**		***Nematalosa* sp.**					
		Spangled perch		**Western rainbowfish**		**Pilbara tandan**		**Pilbara bony bream**		**Abundance**		**Diversity**	
Creek	**Site**	**D**	**W**	**D**	**W**	**D**	**W**	**D**	**W**	**D**	**W**	**D**	**W**
Yandicoogina Creek	**YC1**	0	0	42	8	0	0	0	0	**42**	**8**	**1**	**1**
	YC3	0	13	3	3	0	0	0	0	**3**	**16**	**1**	**2**
	YC4	11	5	20	57	1	1	0	0	**32**	**63**	**3**	**3**
Weeli Wolli Creek	**WWS**	2	5	137	69	3	79	0	0	**142**	**153**	**3**	**3**
	BENS	22	73	42	62	9	4	0	0	**73**	**139**	**3**	**3**
Davis River	**SS**	63	166	22	89	0	34	1	25	**86**	**314**	**3**	**4**
	RW	49	N/A	14	N/A	0	N/A	3	N/A	**66**	**N/A**	**3**	**N/A**
Total abundance		**147**	**262**	**280**	**288**	**13**	**118**	**4**	**25**	**444**	**693**	**3**	**4**
										1,137			

4.9.4 Length-frequency analysis

The seasonal, yet unpredictable nature of rainfall and streamflow in the Pilbara is reflected in the opportunistic and periodic reproductive strategies of Pilbara freshwater fish (Beesley, 2006). Most species 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.

Analysis of population structure and age-classes present 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 Pilbara bony bream were recorded in low abundances, and only from two reference sites, this species was excluded from further analysis.

Western rainbowfish

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[9] (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.

Over all sites, new recruits accounted for 17% and 29% of all western rainbows recorded in the Dry 2020 and Wet 2021, respectively. Within the Survey Area, however, a much higher proportion of rainbowfish were new recruits in the dry season (55% in the dry, 29% in the wet). In the case of juveniles, similar proportions were recorded across the entire study and within Survey Area sites in the dry (26% of western rainbowfish), but lower proportions were recorded in the wet (27% across all sites, and 16% in the Survey Area). The presence of relatively high abundances of new recruits and juveniles suggests good levels of breeding and recruitment within the Survey Area (Figure 4.31).

Spangled perch

Spangled perch breed during the wet season, between late November and March (Beesley, 2006), with spawning generally coinciding with flooding events (Morgan *et al.*, 2002). Several spawning events will occur over the wet season (Beesley, 2006). Maturity is attained after the first year, at around 58 mm TL for males and 78 mm TL for females. To allow for determination of age-classes (without knowing sex), size at maturity was considered to be 70 mm SL for the purposes of this study. Maximum size is ~ 300 mm TL.

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

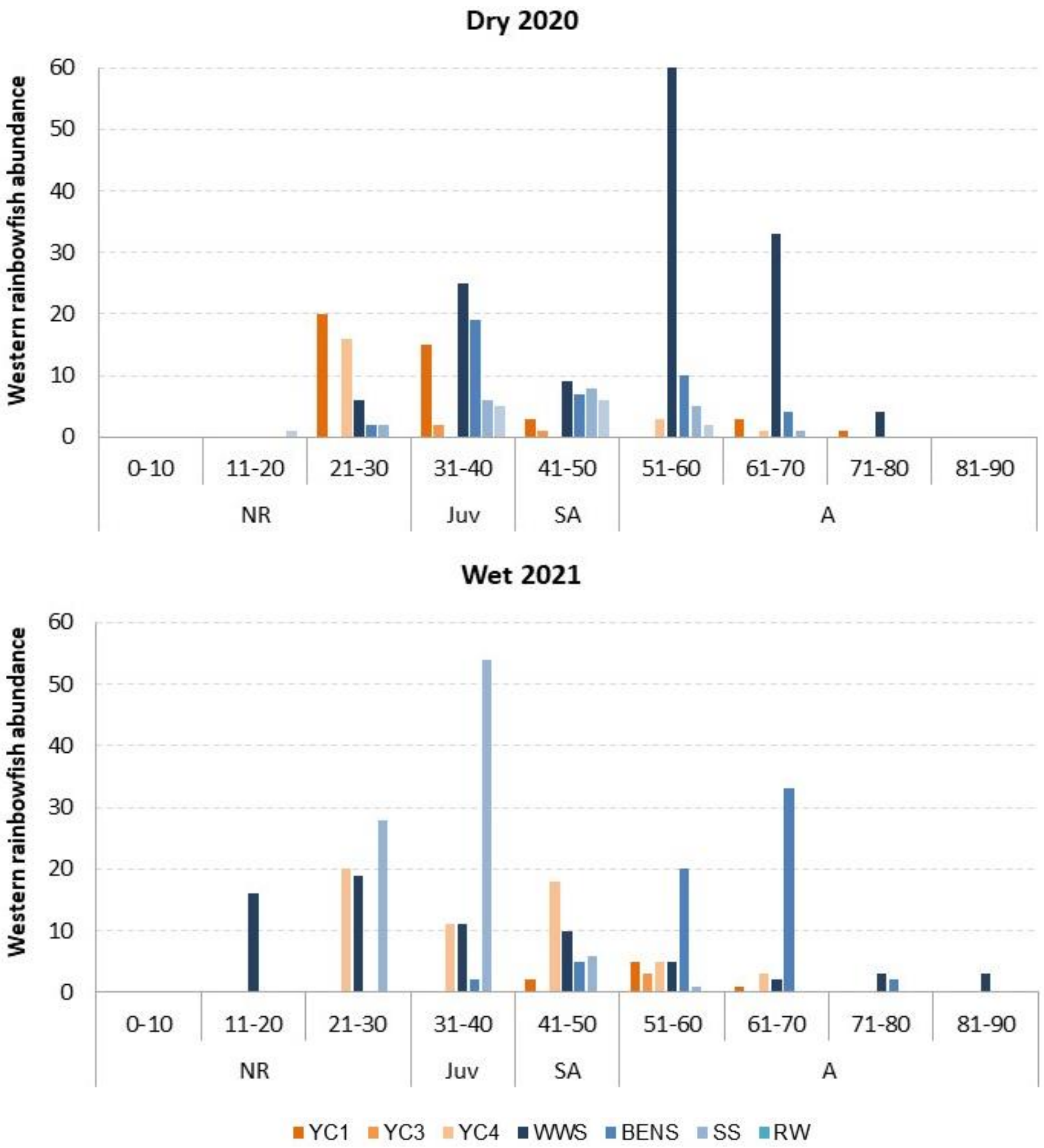

Figure 4.31: Length frequency analysis for western rainbowfish.

During the current study, greatest proportions of spangled perch were adults (79% in the Wet 2021), or sub adults (57% in the Dry 2020; Figure 4.32). While no spangled perch new recruits were recorded from any site, in either season, most of the spangled perch recorded from the Survey Area in the Wet 2021 were juveniles (55%). This suggests a breeding and recruitment event likely occurred earlier in the wet season, with these individuals growing to juvenile size by the time of the Wet 2021 survey. In the Dry 2020, all spangled perch recorded from the Survey Area were adults (Figure 4.32).

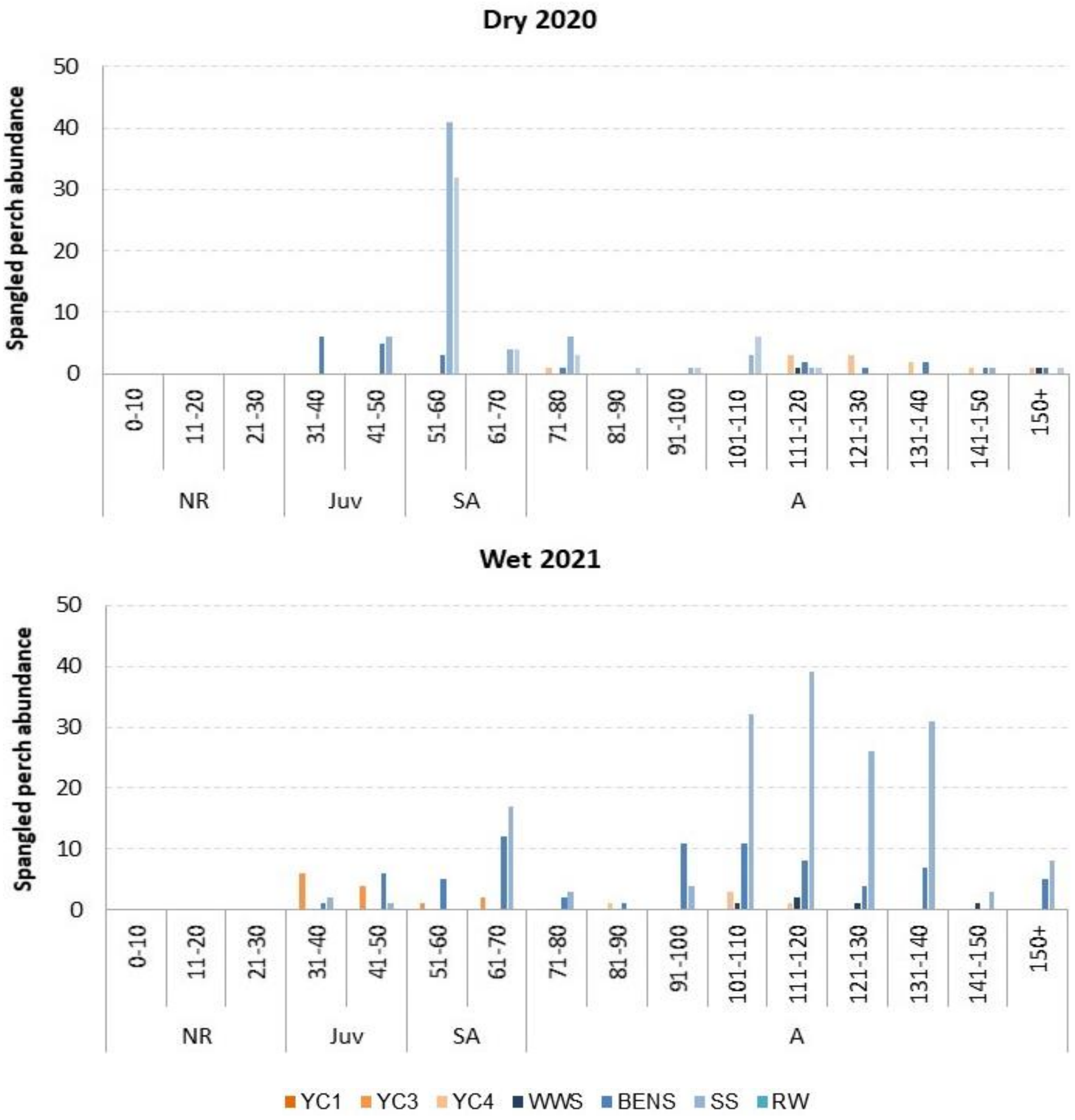

Figure 4.32: Length frequency analysis for spangled perch.

Pilbara tandan

As it is a relatively new, undescribed species, the breeding ecology of the Pilbara tandan is unknown; however, information relating to congeneric species may provide some insight. In northern populations of the closely related *Neosilurus hyrtlii,* breeding occurs early in the wet season in shallow, sandy/gravelly areas of the upper reaches of creeks (Allen *et al.*, 2002) and fecundity ranges from 1,600 to 15,300 eggs (Orr & Milward, 1984). While other eel-tailed catfish, such as *Tandanus tandanus*, construct a unique nest into which eggs are spawned (Burndred *et al.*, 2017), the available evidence suggests that *N. hyrtlii* simply scatter fertilised eggs over the substrate (Orr & Milward, 1984). Sexual maturity in *N.hyrtlii* is attained at around 90 mm SL and they reach a maximum size of 400 mm TL (Bishop *et al.*, 2001).

Sub adults and adults accounted for 46% and 96% of Pilbara tandan recorded across all sites in the Dry 2020 and Wet 2021, respectively. There were no new recruits recorded in the Survey Area, or at any site, in either season. Individuals recorded from the Survey Area were both adults (Figure 4.33).

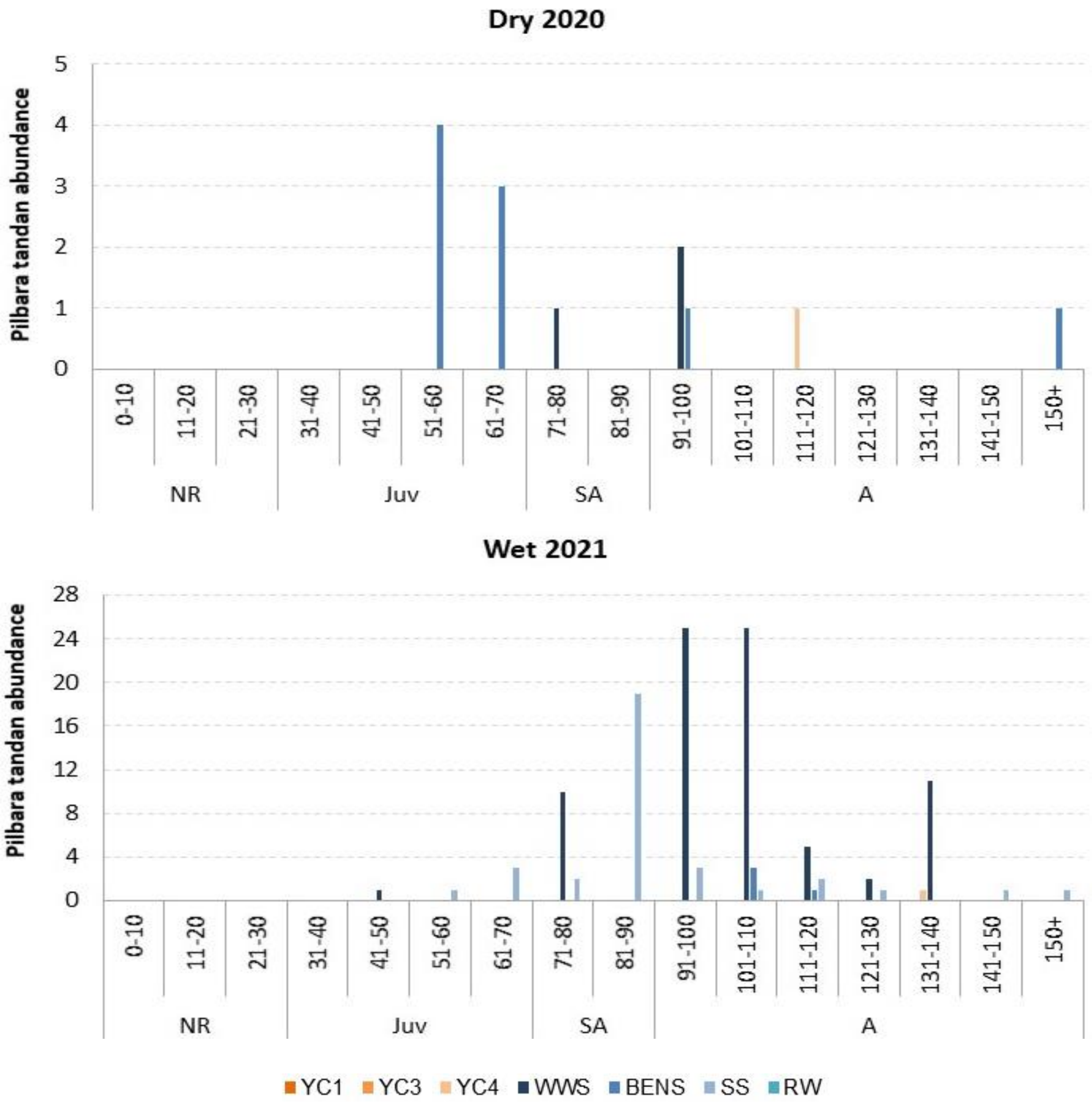

Figure 4.33: Length frequency analysis for Pilbara tandan.

4.10 Other vertebrate fauna

While no other vertebrate fauna was recorded during the current study, several species likely occur within the Survey Area, based on database search results and the authors experience in and around the Survey Area. These include:

Frogs

- Desert tree frog (*Litoria rubella*)
- Pilbara toadlet (*Uperoleia saxatilis*)
- Mains frog (*Cyclorana maini*).

None of the aforementioned species are restricted or listed for conservation significance. All are relatively widespread along creeklines in the Pilbara region.

Turtle

- Flat-shelled, or dinner plate turtle (*Chelodina steindachneri*).

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 in response to 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.

Python

- Pilbara olive python (*Liasis olivaceus barroni*).

The Pilbara olive python is restricted to the Pilbara region and can be found in gorges, waterholes and on escarpments. It is currently listed as Vulnerable on both Federal (EPBC Act) and State (BC Act) conservation lists. Threats to their habitat include fire, foxes, and development of mining infrastructure.

5 DISCUSSION

5.1 Habitat assessment

Numerous permanent pool and riffle sequences occur along the length of the Survey Area. Within the pools sampled, in-stream habitat diversity was high and comprised a variety of complex, heterogenous structures with which to support aquatic fauna, including submerged and emergent macrophytes, large woody debris (LWD), root mats, detritus, and trailing vegetation.

Surface water levels in the pools sampled were noticeably lower during the Wet 2021 sampling event compared to the Dry 2020 and previous surveys (Table 5.1), despite heavy wet season rainfall and associated flooding in the wet season of 2021. The pool at YC1 had receded to a very small pool by the time of the Wet 2021 survey, less than 1.5 m x 1 m in size (Table 5.1). In fact, there appears to have been a steady decline in maximum water depth over time within the Survey Area. This is in contrast to reference sites, where seasonal change was evident in pool depths, with greater maximum depth recorded in the wet season, following rainfall and flooding, and lower depths in the dry season. Reference sites and other pools sampled elsewhere in the East Pilbara by the authors, all underwent an increase in maximum water depth between the Dry 2020 and wet season of 2021 due to the high rainfall and flooding experienced across the region at this time. While the change in maximum water depth between sampling events was not statistically significant, this was likely due, at least in part, to the large variation in depth within a sampling event, particularly within the Survey Area. YC1 and YC2, for example, were shallow and generally less than 0.5 m deep, but YC4 recorded a maximum depth of up to 5 m. The lowering water levels in the Wet 2021 were accompanied by adverse changes to vegetation condition. Notably, *Typha domingensis* was in poor condition, with signs of senescence, particularly at YC2.

Table 5.1: Water level changes at YC1 between the Dry 2019 and Wet 2021.

Dry 2019	Wet 2020	Dry 2020	Wet 2021
			
Max depth: 0.40 m	Max depth: 0.60 m	Max depth: 0.40	Max depth: 0.15

5.2 Water quality

As previously reported, water quality at Yandicoogina Creek was good and characterised by fresh, clear waters, with low dissolved oxygen saturation, neutral pH, and generally low nitrogen nutrient and dissolved metals concentrations. While all sites within Yandicoogina Creek recorded EC in excess of the ANZG (2018) DGV, none were considered to pose a threat to aquatic life. 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 (Hart *et al.*, 1991; Horrigan *et al.*, 2005). Many Pilbara waters have wide-ranging EC, with large temporal and seasonal variability due to waters receding in the drier months and evapoconcentration of ions. Interestingly, all sites within the Survey Area recorded marginally higher EC values in the wet season. This likely reflects the influence of rainwater on surface waters in the wet season, and importantly, the lack of evapoconcentration during the dry season. Similar seasonal variation was recorded from reference site WWS, a permanent spring site.

Dissolved oxygen (DO) concentrations within the Survey Area were low, with all sites recording DO below the lower ANZG (2018) DGV, in both seasons. Additionally, some sites (YC1 and YC3 in the dry and YC2 in both seasons) recorded DO below the point of ecological stress (~30%). Although oxygen needs of aquatic biota differ between species and life history stage, Butler and Burrows (2007) reported acute toxicity between 25% and 30% for six tropical, northern Australian freshwater species. Aquatic biota may be adversely affected by low DO if these levels are sustained over long periods. DO saturation recorded from these sites was likely related to the decay of algae and organic matter surrounding the *Typha* beds, with bacteria consuming oxygen in the water as part of this process. Several reference sites also recorded low DO, in at least one season.

Ionic composition at all Yandicoogina Creek sites was generally dominated by calcium (Ca) cations and hydrogen carbonate (HCO_3) anions, but with YC3 and YC4 being dominated by sodium (Na) and HCO_3 in the dry season. This is in contrast to the previous survey, where no seasonal variation in ionic dominance was recorded (Biologic, 2020c). The dominance of Ca and HCO_3 in surface waters often indicates connection to groundwater, while Na and Cl dominance tends to indicate contribution by rainfall and evapoconcentration effects. The seasonal variation in ionic composition may be a result of lowering groundwater levels and reduced connectivity with surface waters in some areas.

Nutrient concentrations within Yandicoogina Creek were low and below toxicity DGVs and most eutrophication DGVs. The only exceptions were total N at YC2 (which was double the eutrophication DGV in the wet season) and total P at all Survey Area sites, in both seasons. Comparably high total N concentrations were recorded from reference site SS. Total P was high at all sites. Concentrations at YC1 and YC2 were considerably higher in the Wet 2021, with total P being more than seven times the DGV. The eutrophication DGV is designed to protect aquatic ecosystems from the effects of nuisance algal and macrophyte growth. Excessive plant growth can physically smother aquatic invertebrates, as well as deplete oxygen in the water, due to increased biological oxygen demand as plants decay and are decomposed by bacteria. The relationship between nitrate-enrichment and enhanced algal growth in freshwaters is well documented, often resulting in very high density/ abundance, but low species richness (Camargo & Alonso, 2006; Wagenhoff *et al.*, 2011). While the idea that phosphorus (as FRP or total P) is the primary limiting factor for algal growth in freshwaters has been challenged as too simplistic (Beck & Hall, 2018; Elser *et al.*, 2007; Muhid & Burford, 2012), the fact that both total N and total P are enriched in surface waters of Yandicoogina Creek, suggests that any additional nutrient inputs to the Survey Area (such as from cattle or inputs from groundwater discharge) would increase the risk of eutrophication.

Dissolved metal concentrations were generally low within the Survey Area. However, dB exceeded the 99% toxicity DGV at all Survey Area sites, as well as some reference sites. The seemingly high dB concentrations recorded in the current study are not atypical for Pilbara surface waters, with many pools and springs commonly recording values in the range seen here. The ANZG (2018) DGVs for dB are perhaps too conservative for freshwater ecosystems of the region. In addition to dB, dFe exceeded the interim indicative working level provided in the ANZG (2018) guidelines at one site within the Survey Area; YC1 in the Dry 2020. dFe was also elevated at YC2 previously (Biologic, 2020c). Reference sites did not record any elevated dFe concentrations during this or the previous survey (Biologic, 2020c).

5.3 Macrophytes

Groundwater Dependent Ecosystems (GDEs) and their associated vegetation is dependent on the presence of groundwater to meet some, or all, of their water requirements, either through surface expression or subsurface presence of groundwater (Hatton & Evans, 1998). The presence of specific phreatophytic (groundwater dependent) flora taxa indicates 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). As noted previously (Biologic, 2020c), the Survey Area classifies as a high significance GDE, being comprised of numerous high level key mesophytic/ hydrophytic indicator species, such as *Melaleuca argentea*, *Eucalyptus camaldulensis, Imperata cylindrica* and *Fimbristylis sieberiana* (recorded by the Biologic flora team near YC4; Biologic, 2020a), as well as moderate-level indicator species *Cyperus vaginatus* (highly abundant) and *Schoenoplectus subulatus*. In places, this groundwater dependent vegetation was dense. In-stream, a total of three submerged macrophyte taxa are currently known from the Survey Area; *Vallisneria nana*, *Chara* sp. and *Ruppia* sp. (not recorded in the current survey, but collected previously from YC4). Given taxonomic limitations with *Chara* and *Ruppia*, this list likely represents numerous additional species. Of the aforementioned macrophytes, *Vallisneria nana* indicates water permanence as it is known only from perennial creeks and rivers.

5.4 Zooplankton

A total of 49 zooplankton taxa was recorded from Yandicoogina Creek within the Survey Area, including protists, rotifers, copepods, Cladocera and ostracods. No taxa recorded from the Survey Area were restricted or considered to be of conservation significance. In general, zooplankton richness from Yandicoogina Creek was comparable to, if not higher than, reference sites. Seasonal variation within reference sites was high, with lower zooplankton richness recorded from sites showing recent signs of flooding (i.e., WWS, BENS and SS). Being planktonic, zooplankton are highly responsive to increases in flow and flooding events, with high flows likely flushing zooplankton taxa from these reference sites, with the population yet to fully re-establish by the time of survey. Within the Survey Area, overall zooplankton richness was similar between seasons. However, there were some changes in fauna assemblages, with a change in dominance of Maxillopoda over rotifers in the wet season. These changes likely reflect the varying stages of succession, with some taxa being yet to re-establish, whilst others have been prompted to emerge and colonise.

Zooplankton richness recorded during the current study was compared to previous surveys undertaken in nearby creek systems. The Survey Area generally recorded average zooplankton richness similar to nearby creek systems, and statistical results indicated that overall, there was no significant difference between creeks or seasons. This was likely due to the high variability in zooplankton richness, within a creek system, within a season, as evidenced by the large standard error bars. Zooplankton are known to be patchily distributed, with notably high spatial and temporal variability (Klais *et al.*, 2016; Zhang *et al.*, 2019). Interestingly, variability within the Survey Area was noticeably lower than all other creeks systems except Marillana Creek, both within seasons and between seasons. This is likely due to the permanent nature of the pools within Yandicoogina Creek, coupled with the slower flows and reduced impacts in this system compared to others such as Weeli Wolli Spring, and therefore greater persistence of zooplankton habitat.

5.5 Hyporheos fauna

A total of 88 invertebrate taxa was recorded from hyporheic zones of Yandicoogina Creek within the Survey Area. Of these, a total of 11% are directly dependant on groundwater for persistence (i.e., 11% stygobites and 0% permanent hyporheos stygophiles). The percentage of stygobitic taxa recorded from the Survey Area was high in comparison to that reported previously for Pilbara hyporheic zones (i.e., 5% stygobitic fauna recorded in Halse *et al*. 2002). As identified previously (Biologic, 2020c), the high proportion of stygobitic taxa reflects the strong groundwater connection within this reach of Yandicoogina Creek.

Of the sites sampled, YC3 consistently recorded high richness of stygobitic fauna over both seasons, with nine taxa in the dry and five in the wet. The dense *Typha* stands precluded sampling of the hyporheos at YC2 in the wet, and attempts to sample the additional hyporheic locations were unsuccessful due to logistical constraints in the dry season, and a lack of water in the wet season. This was unexpected in the Wet 2021, given the high rainfall experienced in both February and April 2021 and corresponding flooding events, prior to the wet season survey. It was anticipated that water levels, including those within the groundwater, would be high at this time.

Several Potential SRE species were recorded from the hyporheos of Yandicoogina Creek (all stygal), including:

- The ostracod *Notacandona boultoni* (YC3 in the current survey) - identified through morphoplogy and molecular analysis (Biologic, 2021a, 2022a), known only from Weeli Wolli Creek prior to the current survey.

- The ostracod *Gomphodella alexanderi* (YC3) – identified through a combination of morphology and molecular analysis. *G. alexanderi* is known only from Marillana Creek, groundwater bores at Yandi, Yandicoogina Creek, and lower Weeli Wolli Creek. Specimens identified as *Gomphodella alexanderi* were previously recorded from the Survey Area at YC7H and YC8H (Biologic, 2020c).
- The ostracod *Candonopsis* \`sp. Biologic-OSTR025\` - identified through a combination of morphology and molecular analysis. This study constitutes the first record of this OTU. However, further morphological and molecular work will likely increase its known distribution in the future.
- The harpacticoid copepod Canthocamptidae \`sp. B01\` (YC3) - known only from bores within the Yandi area.
- The amphipod *Chydaekata* \`sp. E\` (YC3 and YC4) - restricted to Marillana, Upper Weeli Wolli and Yandicoogina Creeks (previously also recorded from the Survey Area at sites YC3, YC4, YC5H, YC7H and YC9H).
- The amphipod Paramelitidae \`sp. Biologic-AMPH023\` (YC1 and YC3 in the current survey, and YC1, YC3, YC5H and YC9H in the previous survey) – known only from Yandicoogina Creek, Marillana Creek and lower Weeli Wolli Creek (downstream of the confluence with Marillana).
- The isopod *Pygolabis* \`sp. Biologic-ISOP035\` (YC3 in the current survey) – a new, undescribed OTU which is genetically distinct to the known *Pygolabis weeliwolli* recorded nearby.

The number of occasional hyporheos taxa recorded from the Survey Area has generally increased over time, since surveys in the creek began in 2019. The continued increase in occasional hyporheos taxa recorded within Survey Area hyporheic zones, may be due to lowering surface water levels, with an increased number of surface taxa taking refuge in the hyporheic zone.

5.6 Macroinvertebrates

A total of 145 macroinvertebrate taxa was recorded from Yandicoogina Creek within the Survey Area during the current study. The composition of macroinvertebrate fauna within the Survey Area was similar to most Pilbara pools, and was dominated by slow flow and relatively tolerant taxa, i.e., Coleoptera and Diptera. Although richness at YC1 and YC2 was low in both seasons, YC3 and YC4 recorded high macroinvertebrate richness, comparable, if not higher than most reference sites. The low richness at these sites likely reflected the low water depths and difficulties associated with sampling. At YC1 there was very little surface water remaining for sampling, and at YC2, the high abundance of *Typha*, with little open water provided limited space with which to kick-sweep sample effectively.

Macroinvertebrate richness was compared statistically to previous aquatic surveys undertaken nearby. Overall, differences in macroinvertebrate richness were significant between creeks, but not between seasons. The Tukey's post-hoc test indicated that richness recorded from Yandicoogina Creek was statistically similar to Weeli Wolli Creek, Marillana Creek, Marillana Creek Downstream and Weeli Wolli Spring, but significantly lower than the Davis River. The reference sites on the Davis are known for their particularly high richness of aquatic invertebrate fauna (Kendrick & McKenzie, 2001).

Multivariate analyses on the same dataset of current and previous surveys indicated that macroinvertebrate assemblages of the Survey Area were statistically similar to assemblages of Munjina Spring and the reference site on Yandicoogina Creek (sampled for MAC4, i.e., MACREF1). Survey Area assemblages were notably different to the non-spring sites on Weeli Wolli Creek.

There were significant correlations between the environmental conditions (water quality and habitat data) and macroinvertebrate assemblages of Yandicoogina Creek within the Survey Area. Significantly correlated variables included pH, dissolved oxygen, concentrations of total phosphorus, and percentage habitat cover by emergent macrophyte, large woody debris, roots, and bedrock. This highlights the importance of in-stream habitat to macroinvertebrate diversity and assemblage structure, including the importance of vegetation such as emergent macrophytes.

While most aquatic macroinvertebrates recorded from the Survey Area were common, ubiquitous species, several species were of conservation significance, including:

- the Pilbara emerald, *Hemicordulia koomina* (YC1 and YC3, as well as reference site BENS) - Vulnerable on the IUCN Redlist.
- the stygal Potential SRE amphipod *Chydaekata* \`sp. E\` (surface waters of YC3, and reference site WWS) - known only from Yandicoogina Creek, Marillana Creek, and Upper Weeli Wolli Creek.
- The water mite *Austraturus* \`sp. P2\` (YC4 in both seasons) – undescribed species, but the morphotype is uncommon and known to have a highly disjunct distribution in the Pilbara. Appears be restricted to permanent pools of good ecological condition.

The conservation significant Pilbara pin damselfly *Eurysticta coolawanyah* (Vulnerable, IUCN), which was recorded from the Survey Area previously (YC4 and a reference site BENS) (Biologic, 2020c), was not recorded from the Survey Area during the current study. It likely still occurs in the area, but was not recorded during sampling. Continued sampling in the Survey Area will provide a more accurate representation of whether this conservation significant still occurs there.

While no introduced macroinvertebrate taxa were recorded from the Survey Area, the introduced redclaw, *Cherax quadricarinatus* (a species of freshwater crayfish) was recorded from reference site WWS.

5.7 Fish

All freshwater fish species likely to populate the Survey Area were recorded; western rainbowfish *Melanotaenia australis* (Melanotaeniidae), spangled perch *Leiopotherapon unicolor* (Terapontidae) and Pilbara tandan *Neosilurus* sp. (Plotosidae). Although the Pilbara tandan is endemic to the Pilbara region, none of the freshwater fish species recorded are of conservation significance and all are common and ubiquitous across the Pilbara. The presence of relatively high abundances of western rainbowfish new recruits and juveniles within Yandicoogina Creek suggests good levels of breeding and recruitment. Spangled perch recruitment in the Survey Area likely occurred earlier in the wet season, with individuals growing to the size of juveniles by the time of the Wet 2021 survey. Pilbara tandan were the least abundant and widespread species recorded in the Survey Area, but this result was affected by difficulties sampling tandan due to their cryptic nature, coupled with the abundant *Typha* growth. During the current study, they appear to be restricted to the large permanent pool at YC4, but Pilbara tandan were previously observed elsewhere throughout the Survey Area during the reconnaissance trip in May 2019. No introduced fish species were recorded from the Survey Area or reference sites.

6 CONCLUSIONS

6.1 Main findings

The Survey Area constitutes a high significance GDE. Several phreatophytes and mesophytic/ hydrophytic indicator species were present throughout the Survey Area, including *Melaleuca argentea*, *Eucalyptus camaldulensis*, *Imperata cylindrica* (recorded by the Biologic flora team near YC4; (Biologic, 2020a), *Cyperus vaginatus* (highly abundant) and *Schoenoplectus subulatus*. The presence of submerged macrophytes indicative of water permanence (i.e., *Vallisneria nana*) further highlights the persistence of surface water throughout this area.

Of concern, was the fact that lowering water levels were observed in the Wet 2021, both in surface water pools and within the hyporheos, indicating a reduction in groundwater connection. This occurred at a time when water levels were expected to be high, given the high rainfall and flooding experienced throughout the region during the wet season of 2021. Overall, maximum water depth in pools sampled within the Survey Area have shown continual decline since the first sampling event in the Dry 2019. The apparent reduction in groundwater levels, which is likely influencing surface waters in this area, should be investigated further.

Yandicoogina Creek within the Survey Area was found to support a diverse range of aquatic fauna, including 238 invertebrate taxa[10] and three freshwater fish species. Although macroinvertebrate richness varied throughout the Survey Area, mostly due to difficulties associated with sampling at some sites, overall, macroinvertebrate richness was statistically similar to the Weeli Wolli Spring PEC. Overall, two sites were found to hold considerable ecological value. These were:

1. **YC3** which recorded a relatively high richness of GDV species, high richness of groundwater dependent invertebrate taxa (including stygobites within the surface water), conservation significant stygobitic species, species listed on the IUCN Redlist of Threatened Species, and a relatively high richness of macroinvertebrate taxa.
2. **YC4** which recorded a relatively high richness of GDV species, high richness of groundwater dependent invertebrate taxa (including stygobites within the surface water), taxa which appear to be restricted to permanent pools of good ecological condition, and overall a high macroinvertebrate taxa richness.

While most of the taxa recorded from the Survey Area are generally common and ubiquitous across the Pilbara, a number are of conservation significance, and are either locally restricted or rarely collected (Table 6.1). Aside from notable invertebrate taxa recorded during the current study, several additional restricted species were considered likely to occur from the desktop assessment, database search and literature review (Table 6.2). Additional species of potential conservation significance which were considered to have the potential to occur within the Survey Area included, the stygal ostracods

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[10] The total invertebrate richness includes taxa recorded in zooplankton, hyporheic and macroinvertebrate samples.

Meridiescandona marillanae, *Neocandona* \`sp. 1\`, the stygal amphipod *Marrka weeliwolli*, the damselflies *Agriocnemis kunjina* and *Austroagrion pindrina*, and the Pilbara olive python (Table 6.2).

6.2 Final remarks

This study represents the second aquatic ecosystem survey undertaken in Yandicoogina Creek. Results from this survey provide an assessment of the ecological values and health of aquatic systems within the Survey Area, and provide additional data towards developing a robust dataset with which to detect any potential future impacts. A third survey is planned for the dry season of 2021 and wet season of 2022 which will add to this baseline dataset and further our understanding of the temporal, seasonal and spatial variation within the creek.

This reach of Yandicoogina Creek has been found to be highly significant in the Pilbara in terms of its water permanence, GDE status, GDV composition, stygobitic fauna found throughout the profile (in both the hyporheos and surface waters), and high invertebrate richness, including restricted and listed species. Due to the aridity of the Pilbara, rivers of the region tend to be ephemeral. Streamflow is highly seasonal and variable, and generally occurs over the summer months in response to cyclonic events and thunderstorms. As such, permanent water sources, such as that found within the Survey Area, are relatively scarce in the region and restricted to springs and permanent pools. Such predictable sources of water have high conservation importance as they support richer faunas than ephemeral water-bodies and provide a refuge for many species during drought (Halse *et al.*, 2002; Kay *et al.*, 1999).

The fact that groundwater in the area appears to be declining over time is a concern, and the cause for the decline should be investigated further. The most recent decline occurred at a time when high rainfall and flooding occurred in the area, so the lowering surface water levels and lack of hyporheos habitat (no groundwater present in the hyporheic zone) during the Wet 2021 was not expected. Similar declines did not occur in reference sites.

Table 6.1: Conservation significant taxa recorded from the Survey Area during this and the previous Ministers North Survey.

Type	Species	Sites Recorded			Conservation significance / Distribution
		Within Survey Area	Reference Sites	Previous surveys (Biologic, 2020c)	
Stygal ostracods	*Meridiescandona facies*			YC1 (hyporheos) YC9H (hyporheos)	Known from Weeli Wolli Creek and the central and eastern Fortescue (and more recently Yandicoogina Creek)
	Notacandona boultoni	YC3 (hyporheos)			SRE; Known from Weeli Wolli Creek, and now Yandicoogina Creek.
	Gomphodella yandii			YC7H (hyporheos)	SRE; known only from Weeli Wolli Creek, Marillana Creek and now Yandicoogina Creek.
	Gomphodella alexanderi	YC3 (hyporheos)			SRE; known only from Marillana Creek and now Yandicoogina Creek, as well as groundwater bores at Yandi.
	Candonopsis `sp. Biologic-OSTR025`	YC1 (hyporheos)			First record of this OTU (but likely to be more widespread)
Harpacticoid	Canthocamptidae sp. B01	YC3 (hyporheos)			SRE; previously known only from bores within the Yandi area.
Syncarida	Bathynelllidae `sp. Biologic-BATH008`			YC9H (hyporheos)	New genus. Not previously known. More than 18% divergent from all other sequences in the genetic analysis (Biologic, 2022a).
Stygal amphipods	*Chydaekata* sp. `E`	YC3 (hyporheos & surface waters)	WWS (hyporheos & surface waters)	YC3 (hyporheos & surface waters) YC4 (surface waters) YC5H (hyporheos) YC7H (hyporheos) YC9H (hyporheos)	SRE; known only from Marillana Creek and Upper Weeli Wolli Creek.
	Paramelitidae 'sp. Biologic-AMPH023'	YC1 (hyporheos) YC3 (hyporheos)		YC1 (hyporheos) YC3 (hyporheos) YC5H (hyporheos) YC9H (hyporheos)	SRE; known only from Yandicoogina Creek, Marillana Creek and lower Weeli Wolli Creek (downstream of the confluence with Marillana).
Stygal isopod	*Pygolabis* `sp. Biologic-ISOP035`	YC3 (hyporheos)		YC3 (hyporheos)* YC4 (hyporheos)* YC5H (hyporheos*) YC7H (hyporheos)* YC9H (hyporheos)*	Potential SRE, first record. Currently known only from Yandicoogina Creek.
Water mites	*Austraturus* sp. P2	YC4 (surface waters)			Undescribed Species. Morphotype with a disjunct distribution in the Pilbara. Appears to be restricted to permanent pools of good ecological condition.
	Wandesia sp.			YC3 (hyporheos) YC6H (hyporheos)	Species identification unknown, may be uncommon, with a disjunct distribution in the Pilbara
Damselfly	*Eurysticta coolawanyah*		BENS (surface waters)	YC4 (surface waters)	Vulnerable IUCN Redlist
Dragonflies	*Hemicordulia koomina*	YC1 (surface waters) YC3 (surface waters)	BENS (surface waters)	YC4 (surface waters)	Vulnerable IUCN Redlist
	Ictinogomphus dobsoni	YC3 (surface waters) YC4 (surface waters)	BENS (surface waters)	Within Survey Area (Flat Rocks)	Near Threatened IUCN Redlist

* morphologically identified as *Pygolabis weeliwolli*, but given the recent genetic results, all previous records are likely to represent *Pygolabis* `sp. Biologic-ISOP035`.

Table 6.2 Conservation significant fauna considered likely to occur within the Survey Area.

Type	Species	Distance to nearest record from Survey Area	Potential habitat within Survey Area	Recorded within Survey Area	Likelihood of occurrence	Conservation significance
Stygal ostracods	*Meridiescandona marillanae*	~13 km	Yes	No	Possible	Known only from bores on Marillana Creek
	Neocandona sp. 1	~17 km	Yes	No	Possible	Known only from bores on Marillana Creek
Stygal amphipods	*Maarka weeliwolli*	~13 km	Yes	No	Possible	Known only from Marillana and Weeli Wolli Creeks
Damselfly	*Agriocnemis kunjina*	~13 km	Yes	No	Possible	VU (IUCN)
	Austroagrion pindrina	~13 km	Yes	No	Possible	VU (IUCN)
Pilbara olive python	*Liasis olivaceus barroni*	~13 km	Yes	No	Likely	VU (WA & EPBC)

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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	0.01	0.005	0.35[c]	0.01[b]	0.01	90-120	6.0-8.0
Wetlands[3]	0.01-0.05[g]	0.05-0.025[g]	0.35-1.2[g]	0.01	0.01	90[b]-120 [b]	6.0-8.0

b = Northern Territory values are 0.005mg/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 reduced due to evaporation
Turbidity	**(NTU)**	
Aquatic Ecosystem		
Upland & lowland rivers	2-15	Can depend on degree of catchment modification and seasonal rainfall runoff
Lakes, reservoirs & wetlands	2-200	Most deep lakes have low turbidity. However, shallow lakes have higher turbidity naturally due to wind-induced re-suspension of sediments. Wetlands vary greatly in turbidity depending on the general condition of the catchment, recent flow events and the water level in the wetland.

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

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

Notes:

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

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

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

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

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

D = Ammonia as TOTAL ammonia as [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).

J = Figures relate to toxicity (not eutrophication). The ANZECC & ARMCANZ (2000) DGVs for nitrate have been found to be erroneous (ANZG, 2018). In the absence of updated values, ANZG (2018) suggest reference is made to current New Zealand nitrate toxicity guidelines, specifically the ‘Grading’ GVs published in the ‘*Updating Nitrate Toxicity Effects on Freshwater Aquatic Species*’ report (NIWA, 2013). These New Zealand Grading DGVs for N_NO_3 are provided above.

Appendix C: Habitat results

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

Dry 2020

Type	Site	Bedrock	Boulders	Cobbles	Pebbles	Gravel	Sand	Silt	Clay
Within Survey Area	YC1	10	1	18	30	35	5	1	0
	YC2	1	1	3	22	39	26	8	0
	YC3	0	1	5	40	38	13	3	0
	YC4	3	0	5	10	18	5	12	47
Reference sites	WWS	3	2	10	22	38	23	2	0
	BENS	5	7	12	20	27	15	12	2
	SS	5	12	2	20	30	29	1	1
	RW	15	5	10	17	25	26	2	0

Wet 2021

Type	Site	Bedrock	Boulders	Cobbles	Pebbles	Gravel	Sand	Silt	Clay
Within Survey Area	YC1	8	1	30	26	20	5	10	0
	YC2	1	1	12	20	30	21	15	0
	YC3	0	1	5	39	37	13	5	0
	YC4	2	0	4	11	10	13	28	32
Reference sites	WWS	3	2	10	22	38	23	2	0
	BENS	4	8	15	20	27	12	12	2
	MUNJS	89	1	0	0	0	0	10	0
	SS	2	8	6	20	29	26	8	1

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

Dry 2020

Area	Site	Inorganic seds	Sub.Mac.	Emerg.Mac.	Algae	LWD	Detritus	Roots	Trailing Veg.	Habitat Diversity
Within Survey Area	YC1	25	15	40	1	1	12	4	2	8
	YC2	2	0	75	0	0	5	10	8	5
	YC3	8	5	17	53	1	8	5	3	8
	YC4	52	18	15	0	2	10	2	1	7
Reference sites	WWS	38	0	5	25	2	10	15	5	7
	BENS	35	5	7	10	12	20	8	3	8
	SS	27	35	2	5	7	20	3	1	8
	RW	52	7	0	2	10	20	8	1	7

Wet 2021

Area	Site	Inorganic seds	Sub.Mac.	Emerg.Mac.	Algae	LWD	Detritus	Roots	Trailing Veg.	Habitat Diversity
Within Survey Area	YC1	23	0	47	4	1	11	11	3	8
	YC2	2	0	77	0	1	5	8	7	6
	YC3	5	2	38	43	1	8	2	1	8
	YC4	51	9	17	2	9	10	1	1	8
Reference sites	WWS	62	0	1	8	4	6	18	1	7
	BENS	44	0	3	8	12	22	8	3	7
	MUNJS	42	10	10	13	8	11	3	3	8
	SS	42	12	8	2	5	18	12	1	8

Appendix D: Water quality results

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

Dry 2020

		ANZECC DGV		Within Study Area				Reference Sites			
	Units	**99% GV**	**95% GV**	**YC1**	**YC2**	**YC3**	**YC4**	**WWS**	**BENS**	**SS**	**RW**
Temperature	ºC			21.4	20.5	26.0	21.8	25.2	22.2	21.8	28.9
Conductivity (EC)	µS/cm		250	592	552	684	627	938	953	702	1211
pH	pH units		6-8	7.25	7.27	7.31	7.73	7.65	8.00	7.80	7.27
Redox	mV			41.6	80.5	182.0	224.3	210.1	199.9	159.6	236.7
DO	%		85-120	21.4	11.5	15.1	37.9	77.5	47.7	45.1	81.3
Turbidity	NTU		15	5.7	2.2	0.3	4.9	0.2	3.6	1.0	0.1
TSS	mg/L			2	4	<1	8	<1	11	<1	<1
Alkalinity	mg/L			243	228	268	248	323	416	357	304
Hardness	mg/L			237	219	230	228	408	456	251	382
Na	mg/L			37.1	35.2	51.4	51.1	44	29	53	84
Ca	mg/L			46.2	44.0	43.8	43.3	71	65	44	64
Mg	mg/L			29.5	26.5	29.2	29.1	56	72	35	54
K	mg/L			10.5	10.4	11.2	11.5	9.6	6.8	5.2	10.9
HCO_3	mg/L			243	228	268	248	318	416	357	304
Cl	mg/L			38	34	44	46	74	61	54	148
S_SO_4	mg/L			27.3	26.3	29.4	28.5	58.0	35.4	20.1	82.7
CO_3	mg/L			<1	<1	<1	<1	6	<1	<1	<1
dAl	mg/L	0.027	0.055	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
dAs	mg/L	0.001	0.024	<0.0002	<0.0002	<0.0002	<0.0002	0.0004	0.0004	0.0002	<0.0002
dB	mg/L	0.09	0.37	0.099	0.080	0.095	0.096	0.265	0.084	0.076	0.197
dBa	mg/L			0.0169	0.0159	0.0311	0.0178	0.010	0.057	0.357	0.017
dCd	mg/L	0.00006	0.0002	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005
dCo	mg/L			<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0003	0.0001	<0.0001
dCr	mg/L	0.00001	0.001	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	0.0004
dCu	mg/L	0.001	0.0014	0.00012	0.00010	0.00010	0.00011	0.00016	0.00049	0.00015	0.00008
dFe	mg/L			0.434	0.085	0.017	0.026	<0.002	0.011	0.025	<0.002
dMn	mg/L	1.2	1.9	0.0478	0.0095	0.0144	0.0022	<0.0005	0.0772	0.2740	0.0007
dMo	mg/L			0.0002	0.0002	0.0001	0.0002	0.0002	0.0003	0.0004	0.0003
dNi	mg/L	0.008	0.011	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
dPb	mg/L	0.001	0.0034	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
dS	mg/L			8.7	8.4	9.6	8.9	17.5	10.9	6.2	27.1
dSe	mg/L	0.005	0.011	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	0.0018
dU	mg/L			0.00012	0.00008	0.00016	0.00016	0.00060	0.00059	0.00045	0.00164
dV	mg/L			<0.0001	0.0004	0.0008	0.0009	0.0025	0.0014	0.0008	0.0017
dZn	mg/L	0.0024	0.008	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
N_NH_3	mg/L	0.32	0.90	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
N_NO_3	mg/L	1.00	2.40	<0.01	<0.01	<0.01	<0.01	0.02	<0.01	0.02	1.73
N_NOx	mg/L		0.01	<0.01	<0.01	<0.01	<0.01	0.02	<0.01	0.02	1.73
TN	mg/L		0.30	0.05	0.14	0.09	0.12	0.02	0.17	0.08	1.63
TP	mg/L		0.01	0.020	0.028	0.018	0.027	0.018	0.020	0.019	0.012

Highlighted cells refer to values which are in excess of: 🟨 > the 99% ANZECC D GV, 🟧 > the 95% DGV, and ■ > low reliability ANZECC DGV.

Wet 2021

		ANZECC DGV		Within Study Area				Reference Sites			
	Units	**99% GV**	**95% GV**	**YC1**	**YC2**	**YC3**	**YC4**	**WWS**	**BENS**	**MUNJS**	**SS**
Temperature	°C			23.0	21.8	25.2	23.8	25.7	25.0	27.1	24.6
Conductivity (EC)	µS/cm		250	729	673	776	661	975	493	737	420
pH	pH units		6-8	6.60	6.86	7.20	6.86	7.42	7.22	7.31	7.81
Redox	mV			112.2	42.5	39.5	59.5	124.7	183.7	148.2	146.8
DO	%		85-120	53.9	19.8	36.9	39.8	71.7	78.4	83.8	109.2
Turbidity	NTU		15	15.0	27.1	0.5	0.6	<0.1	0.7	5.3	0.7
TSS	mg/L			10	40	<1	1	<1	<1	1	<1
Alkalinity	mg/L			202	222	265	249	303	254	177	162
Hardness	mg/L			279	282	283	240	382	238	239	158
Na	mg/L			38.8	38.3	50.8	43.4	41.4	6.6	58.8	28.4
Ca	mg/L			57.3	58.2	56.3	47.1	68.4	45.7	34.4	32.8
Mg	mg/L			33.0	33.2	34.6	29.6	51.2	30.2	37.2	18.4
K	mg/L			12.5	12.0	12.4	11.6	8.9	3.1	10.7	4.3
HCO_3	mg/L			202	222	265	249	303	254	177	162
Cl	mg/L			48	44	48	45	83	13	150	31
S_SO_4	mg/L			102.0	80.8	48.4	24.3	58.9	8.3	1.4	13.8
CO_3	mg/L			<1	<1	<1	<1	<1	<1	<1	<1
dAl	mg/L	0.027	0.055	<0.005	0.007	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
dAs	mg/L	0.001	0.024	0.0002	<0.0002	<0.0002	0.0002	0.0003	0.0002	0.0002	<0.0002
dB	mg/L	0.09	0.37	0.159	0.152	0.157	0.149	0.210	0.034	0.150	0.072
dBa	mg/L			0.0234	0.0209	0.0354	0.0215	0.011	0.021	0.0514	0.145
dCd	mg/L	0.00006	0.0002	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005
dCo	mg/L			0.0004	0.0002	<0.0001	<0.0001	<0.0001	<0.0001	0.0001	<0.0001
dCr	mg/L	0.00001	0.001	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002
dCu	mg/L	0.001	0.0014	0.00008	0.00007	0.00011	<0.00005	0.00017	0.00055	0.00006	0.00021
dFe	mg/L			0.166	0.268	0.062	0.078	<0.002	0.019	0.144	0.011
dMn	mg/L	1.2	1.9	0.0405	0.0291	0.0084	0.0055	<0.0005	0.0210	0.1320	0.0559
dMo	mg/L			0.0003	0.0002	0.0002	0.0002	0.0002	0.0002	<0.0001	0.0003
dNi	mg/L	0.008	0.011	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
dPb	mg/L	0.001	0.0034	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
dS	mg/L			33.1	24.1	15.5	8.0	20.0	3.0	0.6	4.6
dSe	mg/L	0.005	0.011	<0.0002	<0.0002	<0.0002	<0.0002	0.0002	<0.0002	<0.0002	0.0002
dU	mg/L			0.00022	0.00009	0.00021	0.00015	0.00076	0.00034	<0.00005	0.00038
dV	mg/L			0.0002	0.0002	0.0005	0.0007	0.0018	0.0017	0.0001	0.0021
dZn	mg/L	0.0024	0.008	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
N_NH_3	mg/L	0.32	0.90	0.04	0.10	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
N_NO_3	mg/L	1.00	2.40	<0.01	<0.01	<0.01	<0.01	0.04	0.13	<0.01	0.21
N_NOx	mg/L		0.01	<0.01	<0.01	<0.01	<0.01	0.04	0.13	<0.01	0.21
TN	mg/L		0.30	0.18	0.60	0.06	0.12	0.03	0.12	0.16	0.46
TP	mg/L		0.01	0.074	0.092	0.023	0.029	0.014	0.011	0.031	0.023

Appendix E: Zooplankton taxonomic list

Values are total abundances.

Dry 2020

			Survey Area			Reference			
Phylum/Class/Order	**Family**	**Lowest taxon**	**YC1**	**YC3**	**YC4**	**WWS**	**BENS**	**SS**	**RW**
PROTISTA									
CILIOPHORA		Ciliate indet.	1	2	0	0	0	0	2
Prostomatea									
Prorodontida	**Colepidae**	*Coleps* sp.	0	2	3	0	0	0	0
Spirotrichea		cf. Hypotrichia sp.	0	0	2	0	2	2	0
ROTIFERA									
		Unidentified Rotifera	0	0	2	0	2	2	0
Bdelloidea		Bdelloidea spp. indet.	0	2	0	0	1	0	1
Monogononta									
Flosculariaceae	**Trochosphaeridae**	*Horaella sp.*	0	0	0	0	0	2	0
Ploima	**Brachionidae**	*Brachionus angularis*	3	1	0	0	4	2	3
		Keratella sp.	0	0	0	1	0	1	0
		Keratella australis	0	0	1	0	0	0	0
		Keratella cf. *slacki*	2	0	0	0	3	0	0
		Keratella procurva	0	0	0	0	4	0	0
		Keratella tropica	0	0	1	0	0	0	0
		Keratella valga	0	1	0	0	3	0	3
	Dicranophoridae	*Dicranophorous* sp.	0	0	1	0	0	0	0
	Euchlanidae	*Euchlanis* sp.	0	0	0	0	2	1	0
	Habrotrochidae	Habrotrochidae spp.	0	0	0	0	1	0	0
	Lecanidae	*Lecane* sp.	0	0	0	1	0	0	0
		Lecane bulla	0	2	0	0	1	0	0
		Lecane closterocerca	0	2	0	0	0	0	0
		Lecane hamata	0	2	1	0	0	0	0
	Lepadellidae	*Lepadella sp.*	0	2	2	0	2	2	0
		Lepadella cf *vitrea*	0	0	0	0	3	0	0
	Synchaetidae	*Polyarthra cf. dolichoptera*	0	0	0	0	0	2	0
	Testudinellidae	cf. *Pomphylox* sp.	0	0	0	0	0	2	0
		Testudinella sp.	0	0	2	0	0	4	0
	Trichocercidae	*Trichocerca* sp.	1	0	0	1	0	0	0
		Trichocerca similis	2	0	4	0	4	2	0
ARTHROPODA									
CRUSTACEA									
Maxillopoda									

			Survey Area			Reference			
Phylum/Class/Order	**Family**	**Lowest taxon**	**YC1**	**YC3**	**YC4**	**WWS**	**BENS**	**SS**	**RW**
Calanoida	**Centropagidae**	*Eodiaptomus lumholtzi*	0	0	0	0	0	0	4
Cyclopoida		Cyclopoid copepodite	0	0	0	2	0	0	0
		Cyclopoid nauplii	3	3	5	2	4	4	3
	Cyclopidae	*Ectocyclops phaleratus*	0	0	0	0	0	0	3
		Eucyclops australiensis	0	0	0	2	0	0	0
		Mesocyclops darwini	3	0	0	0	0	0	0
		Mesocyclops notius	2	3	4	0	2	2	4
		Microcyclops varicans	0	1	0	2	0	2	1
		Paracyclops sp. 5 (SAP)	0	0	0	0	0	2	0
		Thermocyclops affinis	0	0	4	0	0	2	0
		Tropocyclops confinis confinis	3	3	5	0	4	4	0
Branchiopoda									
Cladocera	**Daphniidae**	*Ceriodaphnia* sp.	0	0	1	0	0	0	2
		Simocephalus heilongjiangensis	0	0	0	0	0	0	1
	Chydoridae	*Alona* sp.	0	1	0	0	0	0	0
		Chydorus sp.	0	3	0	2	0	0	0
	Ilyocryptidae	*Ilyocryptus* sp.	0	0	1	0	0	0	0
Ostracoda									
Podocopida	**Cyprididae**	*Stenocypris major*	0	0	0	0	0	3	3
		Cypretta sp. \`PSW074\`	0	0	2	0	0	1	2
		Cypridopsis sp. \`BOS1401\`	0	1	0	0	0	0	0
		Diacypcris sp.	0	0	0	3	0	0	0
		Ilyodromus sp.	0	0	0	1	0	0	0
		Sarscypridopsis sp.	0	0	0	2	0	0	3
	Darwinulidae	*Penthesilenula brasiliensis*	1	1	0	0	0	0	0
		Vestalenula sp.	0	0	0	0	0	0	2
		Vestalenula marmonieri	1	0	1	0	0	0	0
		Vestalenula matildae	0	0	0	0	0	1	0
	Limnocytheridae	*Limnocythere* sp.	0	0	0	2	0	0	0
		Taxa richness	**11**	**17**	**18**	**12**	**16**	**20**	**15**

Wet 2021

			Within Survey Area				Reference			
Phylum/Class/Order	**Family**	**Lowest taxon**	**YC1**	**YC2**	**YC3**	**YC4**	**WWS**	**BENS**	**MUNJS**	**SS**
PROTISTA										
CILIOPHORA		Ciliate indet.	0	2	2	2	0	0	0	0
Prostomatea										
Prorodontida	**Colepidae**	*Coleps* sp.	1	0	1	0	0	0	0	0
ROTIFERA		Unidentified Rotifera	2	0	0	0	0	0	0	0
Bdelloidea		Bdelloidea spp. indet.	0	0	0	1	0	0	0	0
Monogononta										
Flosculariaceae	**Haexarthridae**	cf. *Hexarthra* sp.	0	0	0	0	0	0	1	0
Ploima	**Brachionidae**	*Brachionus falcatus*	0	0	0	0	0	0	1	0
		Keratella sp.	0	1	0	0	0	0	0	0
		Keratella valga	1	1	0	1	0	2	0	0
		Keratella tropica	0	0	2	0	0	0	0	0
	Euchlanidae	*Euchlanis sp.*	0	0	0	0	0	0	0	0
	Lecanidae	*Lecane* sp.	1	1	1	1	0	0	0	0
		Lecane cf. *aculeata*	0	0	0	1	0	0	0	0
		Lecane bulla	1	0	0	0	0	0	1	0
		Lecane cf. *hastata*	0	0	0	0	0	0	0	0
		Lecane lunaris	0	0	1	0	0	0	0	0
		Lecane ungulata	0	0	0	0	0	0	0	0
	Lepadellidae	*Colurella uncinata*	0	0	0	0	0	0	0	1
		Lepadella cf. *latusinus*	0	0	2	0	0	0	0	0
		Lepadella cf. *ovalis*	0	0	0	0	0	0	1	0
	Synchaetidae	*Polyarthra* cf. *dolichoptera*	0	0	0	0	0	1	0	0
	Trichocercidae	*Trichocerca* sp.	0	0	0	1	0	1	1	0
		Trichocerca cf. *bicrastata*	0	0	0	0	0	1	0	2
		Trichocerca similis	0	0	0	1	0	0	2	0
ARTHROPODA										
CRUSTACEA										
Maxillopoda										
Calanoida		Calanoid copepodite	0	3	0	4	0	0	1	0
Cyclopoida		Cyclopoid copepodite	2	2	2	0	2	0	3	2
		Cyclopoid nauplii	2	3	1	3	1	2	3	2
	Cyclopidae	*Ectocyclops* sp.	2	0	0	0	0	0	0	0
		Ectocyclops phaleratus	0	2	3	2	0	0	0	0
		Microcyclops varicans	2	2	3	0	0	0	0	2
		Mesocyclops sp.	2	0	2	3	0	0	0	0
		Mesocyclops darwini	3	3	3	2	0	0	0	0

			Within Survey Area				Reference			
Phylum/Class/Order	**Family**	**Lowest taxon**	**YC1**	**YC2**	**YC3**	**YC4**	**WWS**	**BENS**	**MUNJS**	**SS**
		Mesocyclops notius	0	0	0	0	0	3	0	3
		Paracyclops chiltoni	0	3	0	0	0	0	0	0
		Thermocyclops cf. *crassus*	0	0	0	3	0	0	0	0
		Tropocyclops confinis confinis	2	0	1	4	0	1	2	2
Branchiopoda										
Diplostraca	**Chydoridae**	*Alona* sp.	0	1	0	0	0	0	0	0
		Chydorus sp.	0	1	0	0	0	0	0	0
	Daphniidae	*Ceriodaphnia* sp.	0	0	0	0	0	0	1	0
Ostracoda		Ostracoda sp. indet.	0	0	2	0	0	0	0	0
	Cyprididae	Cyprididae sp.	0	0	0	0	0	1	0	0
		Cyprididae `sp. Biologic-OSTR019`	0	0	0	0	0	0	0	1
		Cyprididae `sp. Biologic-OSTR029`	0	0	0	1	0	0	0	0
		Bennelongia strellyensis	0	0	0	0	0	0	3	0
		Diacypcris sp.	0	0	1	0	0	0	0	0
		Cyprididae `sp. Biologic-OSTR014`	0	0	0	0	0	0	2	0
		Stenocypris major	0	0	0	0	0	0	3	1
	Candonidae	*Candonopsis* cf. *tenuis*	0	0	0	0	0	1	0	0
	Darwinulidae	*Darwinula* sp.	0	0	2	0	0	0	0	0
		Vestalenula marmonieri	0	0	2	3	0	0	0	0
	Limnocytheridae	*Limnocythere* sp.	0	1	0	0	0	0	0	0
	Notodromadidae	*Newnhamia fenestrata*	0	0	0	0	0	0	1	0
		Taxa richness	**12**	**14**	**17**	**16**	**2**	**9**	**15**	**9**

Appendix F: Hyporheos fauna taxonomic list

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**

Dry 2020

			Survey Area				Reference			
Phylum/Class/Order	**Family**	**Lowest taxon**	**YC1**	**YC2**	**YC3**	**YC4**	**WWS**	**BENS**	**SS**	**RW**
CNIDARIA										
Hydrozoa										
Anthoathecata	**Hydridae**	*Hydra* sp.	0	0	0	0	0	0	0	1
PLATYHELMINTHES		Turbellaria sp.	0	0	0	0	0	3	0	0
NEMATODA		Nematoda sp.	0	0	0	0	0	0	0	2
MOLLUSCA										
Gastropoda										
Hygrophila	**Lymnaeidae**	*Bullastra vinosa*	0	0	0	0	0	1	0	0
	Planorbidae	*Gyraulus* sp.	0	0	1	0	0	0	0	1
ANNELIDA										
Polychaeta		Polychaeta sp. (imm./dam.)	0	0	0	0	0	0	0	1
Oligochaeta		Oligochaeta sp. (imm./dam.)	0	1	0	1	0	0	0	0
Tubificida	**Naididae**	Naididae sp. (imm./dam.)	3	0	0	0	2	2	0	0
		Naidinae sp. (imm./dam.)	0	2	0	2	0	0	2	3
		Allonais pectinata	0	0	0	0	0	0	0	2
		Allonais ranauana	0	0	0	0	0	0	0	3
		Nais communis	0	0	2	0	0	0	0	0
		Pristina sp. (imm./dam.)	0	0	2	0	3	0	0	2
		Pristina aequiseta	0	0	0	0	0	0	0	3
		Pristina jenkinae	0	2	0	1	0	0	0	2
		Pristina leidyi	0	0	0	0	0	0	3	0
		Pristina longiseta	0	0	2	0	0	0	0	0
	Phreodrilidae	Phreodrilidae sp.	2	1	0	2	0	0	2	3
		Antarctodrilus sp.	2	0	0	0	0	0	0	0
ARTHROPODA										
CHELICERATA										
Arachnida		Acarina sp. (imm./dam.)	0	0	1	0	0	1	0	2
Mesostigmata		Mesostigmata sp.	0	0	0	0	0	0	3	2

			Survey Area				Reference			
Phylum/Class/Order	**Family**	**Lowest taxon**	**YC1**	**YC2**	**YC3**	**YC4**	**WWS**	**BENS**	**SS**	**RW**
Sarcoptiformes		Oribatida sp.	0	0	0	0	0	0	0	2
Trombidiformes		Trombidioidea sp.	0	0	2	0	0	0	1	0
	Hydryphantidae	*Wandesia* sp.	0	0	0	0	1	0	0	0
	Momoniidae	*Hesperomomonia humphreysi*	0	0	0	0	1	0	0	0
	Pezidae	Pezidae sp.	0	0	2	0	0	0	0	0
CRUSTACEA										
Branchiopoda										
Diplostraca	**Chydoridae**	*Alona rigidicaudis*	0	0	0	0	0	0	0	1
Ostracoda		Ostracoda sp. (imm./dam.)	0	0	2	0	0	0	0	0
Podocopida	**Candonidae**	*Notacandona boultoni*	0	0	2	0	3	0	0	0
	Cyprididae	*Stenocypris major*	0	0	0	0	0	0	0	4
	Darwinulidae	*Vestalenula matildae*	0	0	0	0	0	0	2	0
	Limnocytheridae	*Gomphodella alexanderi*	0	0	2	0	0	0	0	0
Maxillopoda		Copepoda sp. (imm./dam.)	0	2	0	1	0	0	0	0
Cyclopoida		Cyclopoida sp. (imm./dam.)	1	0	0	0	0	0	0	0
	Cyclopidae	Cyclopidae sp. (imm./dam.)	0	0	0	0	2	0	0	0
		Australoeucyclops sp.	0	1	0	1	0	0	0	0
		Diacyclops nr. *cockingi*	0	0	2	0	0	0	0	0
		Diacyclops nr. *humphreysi*	0	1	2	0	0	0	0	0
		Ectocyclops sp.	0	0	0	1	0	0	0	0
		Ectocyclops cf. *phaleratus*	0	1	0	0	0	0	0	3
		Ectocyclops phaleratus	0	0	0	0	2	0	0	0
		Mesocyclops notius	0	2	0	0	1	0	0	0
		Microcyclops varicans	0	2	2	0	1	2	2	2
		Paracyclops cf. *affinis*	0	0	2	2	0	0	0	0
Harpacticoida	**Canthocamptidae**	Canthocamptidae sp. B01	0	0	2	0	0	0	0	0
	Parastenocarididae	*Parastenocaris* sp.	0	0	0	0	0	0	1	1
Malacostraca										
Bathynellacea	**Parabathynellidae**	*Atopobathynella* sp.	0	0	0	0	0	0	3	0
Amphipoda	**Paramelitidae**	*Chydaekata* sp. E	0	0	3	1	1	0	0	0
		Paramelitidae sp.	0	0	0	0	0	0	0	3
		Paramelitidae `sp. Biologic-AMPH023`	2	0	3	0	0	0	0	0
		Paramelitidae `sp. Biologic-AMPH024`	0	0	0	0	3	0	0	0
Isopoda	**Tainisopidae**	*Pygolabis* `sp. Biologic-ISOP035`	0	0	2	0	0	0	0	0
HEXAPODA										
Entognatha										
Entomobryomorpha		Entomobryoidea sp.	1	2	3	0	1	0	0	2
Symphypleona		Symphypleona sp.	0	0	0	0	0	0	2	0
Insecta										
Coleoptera	**Carabidae**	Carabidae sp. (L)	1	0	0	0	0	0	0	0
		Carabidae sp.	0	0	1	0	0	3	0	0

			Survey Area				Reference			
Phylum/Class/Order	**Family**	**Lowest taxon**	**YC1**	**YC2**	**YC3**	**YC4**	**WWS**	**BENS**	**SS**	**RW**
	Elmidae	*Austrolimnius* sp. (L)	0	0	0	0	0	0	0	1
	Georissidae	*Georissus* sp.	0	0	1	0	0	2	0	2
	Heteroceridae	*Heterocerus* sp. (L)	0	2	0	0	0	0	0	0
		Heterocerus sp.	0	0	1	0	0	2	0	0
	Hydraenidae	*Hydraena* sp.	0	0	0	0	2	3	0	3
		Limnebius sp.	0	0	0	0	0	0	0	2
		Ochthebius sp.	0	0	0	0	0	3	0	0
	Hydrophilidae	Hydrophilidae sp. (L)	0	0	2	0	1	0	1	0
		Chaetarthria nigerrima (L)	0	0	0	0	3	0	3	3
		Chaetarthria nigerrima	0	0	0	0	0	1	2	1
		Coelostoma fabricii	0	0	2	0	0	1	0	0
		Enochrus sp. (L)	0	0	0	0	2	0	0	0
		Helochares sp. (L)	0	0	0	0	0	0	1	2
		Paracymus sp. (L)	0	0	2	0	1	0	0	0
	Limnichidae	Limnichidae sp. A	0	0	1	0	0	0	0	0
		Limnichidae sp. B	0	0	1	0	1	3	0	0
	Ptiliidae	Ptiliidae sp.	0	0	0	0	0	3	2	0
	Scirtidae	Scirtidae sp. (L)	0	2	0	2	0	0	0	2
	Staphylinidae	Staphylinidae sp. (L)	0	1	1	0	0	0	0	0
		Staphylinidae sp.	0	0	0	0	0	3	2	0
Diptera										
	Ceratopogonidae									
		Ceratopogonidae sp. (P)	0	0	1	1	2	2	2	1
		Ceratopogoninae sp.	3	1	0	3	3	4	3	3
		Dasyhelea sp.	0	1	3	1	3	2	3	3
		Forcipomyiinae sp.	0	0	0	0	0	0	0	1
	Chironomidae	Chironomidae sp. (P)	0	0	0	1	0	0	0	1
	Chironominae									
	Chironomini	Chironomini sp.	2	0	0	0	0	0	0	0
		Demicryptochironomus (*Irmakia*) sp.	0	0	0	0	0	0	0	2
		Polypedilum sp.	0	0	0	1	0	0	0	2
		Polypedilum nubifer	0	0	0	0	0	3	0	0
	Tanytarsini	*Paratanytarsus* sp.	0	0	0	0	0	0	2	0
		Rheotanytarsus sp.	0	0	0	0	0	0	1	3
		Tanytarsus sp.	0	0	2	0	2	3	3	3
	Orthocladiinae	nr. *Gymnometriocnemus* sp.	0	0	0	2	1	0	1	0
		Rheocricotopus sp.	0	2	0	0	0	0	0	0
	Tanypodinae	?*Australopelopia* sp.	0	0	0	0	0	0	1	0
		Larsia ?*albiceps*	2	3	0	0	2	0	2	3
		Paramerina sp. 1	0	1	2	0	2	0	3	2
		Procladius sp.	0	0	0	0	0	4	0	0

			Survey Area				Reference			
Phylum/Class/Order	**Family**	**Lowest taxon**	**YC1**	**YC2**	**YC3**	**YC4**	**WWS**	**BENS**	**SS**	**RW**
	Culicidae	*Anopheles* sp.	0	0	0	0	1	0	0	3
	Dolichopodidae	Dolichopodidae sp.	0	0	0	0	0	3	0	0
	Ephydridae	Ephydridae sp.	0	0	1	0	0	0	0	3
	Stratiomyidae	Stratiomyidae sp.	0	0	0	0	0	0	0	1
	Thaumaleidae	Thaumaleidae sp.	0	0	0	0	1	0	0	0
	Tipulidae	Tipulidae sp.	0	2	1	0	0	0	3	2
Ephemeroptera	**Caenidae**	Caenidae sp. (imm./dam.)	0	0	0	0	0	0	0	2
		Tasmanocoenis sp. P/*arcuata*	0	0	0	0	0	0	0	2
Hemiptera	**Gelastocoridae**	*Nerthra* sp.	0	0	0	0	0	0	1	0
	Hebridae	*Hebrus axillaris*	0	0	0	0	0	2	0	0
Lepidoptera	**Crambidae**	Acentropinae sp. (imm./dam.)	0	0	2	0	2	0	0	0
Thysanoptera		Thysanoptera sp.	0	0	0	0	0	1	0	0
		Taxa richness	**10**	**20**	**36**	**16**	**28**	**24**	**28**	**46**

Wet 2021

			Within Survey Area			Reference			
Phylum/Class/Order	**Family**	**Lowest taxon**	**YC1**	**YC3**	**YC4**	**WWS**	**BENS**	**MUNJS**	**SS**
NEMATODA		Nematoda sp.	0	0	1	0	0	0	0
ANNELIDA									
Oligochaeta									
Tubificida	**Naididae**	*Pristina aequiseta*	3	0	3	0	2	0	2
		Pristina leidyi	2	0	0	0	0	0	0
		Pristina nr. *osborni*	2	0	0	0	0	0	0
	Phreodrilidae	Phreodrilidae sp.	0	2	2	0	0	0	2
		Antarctodrilus sp.	0	0	0	0	0	0	1
ARTHROPODA									
CHELICERATA									
Arachnida		Acarina sp. (imm./dam.)	0	0	0	0	0	3	0
Mesostigmata		Mesostigmata sp.	2	0	2	0	0	0	1
Sarcoptiformes		Oribatida sp.	0	0	0	0	0	0	3
Trombidiformes	**Anisitsiellidae**	*Rutacarus* sp.	0	0	0	0	1	0	0
	Halacaridae	Halacaridae sp.	0	1	0	0	0	0	2
	Limnesiidae	*Limnesia* sp. `solida group`	0	0	0	0	1	0	0
	Oxidae	*Oxus orientalis*	1	0	0	0	0	0	0
	Pezidae	Pezidae `sp. Biologic-ACAR003`	2	2	0	0	0	0	0
	Unionicolidae	Unionicolidae sp.	0	0	1	0	0	0	0
CRUSTACEA									
Ostracoda									
Podocopida	**Candonidae**	Candonidae sp. (imm./dam.)	0	3	0	0	0	0	0
		Candonopsis `sp. Biologic-OSTR025`	2	0	0	0	0	0	0
		Candonopsis cf. *tenuis*	0	0	0	0	0	3	0
	Limnocytheridae	*Gomphodella alexanderi*	0	2	0	0	0	0	0
Maxillopoda									
Cyclopoida		Cyclopoida sp. (imm./dam.)	0	2	3	0	0	0	0
	Cyclopidae	*Diacyclops* nr. *humphreysi*	0	2	0	0	0	0	2
		Mesocyclops sp. (imm./dam.)	0	0	0	0	0	2	0
		Mesocyclops darwini	3	0	3	0	0	0	0
		Mesocyclops notius	0	0	0	0	2	0	0
		Microcyclops varicans	0	2	2	2	3	1	0
		Paracyclops sp.	3	0	0	0	0	0	0
		Thermocyclops sp.	0	0	0	0	2	0	0
		Tropocyclops sp.	0	1	0	0	0	0	0
Harpacticoida	**Canthocamptidae**	*Elaphoidella* sp.	0	0	0	0	0	0	1
Malacostraca									

			Within Survey Area			Reference			
Phylum/Class/Order	**Family**	**Lowest taxon**	**YC1**	**YC3**	**YC4**	**WWS**	**BENS**	**MUNJS**	**SS**
Bathynellacea	**Parabathynellidae**	*Atopobathynella* sp.	0	0	0	0	0	0	1
Amphipoda	**Paramelitidae**	Paramelitidae sp.	0	3	0	0	0	0	0
		Paramelitidae `sp. Biologic-AMPH023`	0	2	0	0	0	0	0
		Paramelitidae `sp. Biologic-AMPH049`	0	0	0	0	0	0	2
		Chydaekata sp. E	0	0	0	3	0	0	0
Isopoda	**Tainisopidae**	*Pygolabis* `sp. Biologic-ISOP035`	0	1	0	0	0	0	0
HEXAPODA									
Entognatha									
Entomobryomorpha		Entomobryoidea sp.	2	1	3	0	0	1	0
Poduromorpha		Poduroidea sp.	0	0	0	0	2	2	0
Symphypleona		Symphypleona sp.	0	1	0	0	2	0	0
Insecta									
Coleoptera	**Carabidae**	Carabidae sp. (L)	0	0	1	0	0	0	0
		Carabidae sp.	0	0	0	0	0	0	1
	Dytiscidae	Bidessini sp. (L)	0	1	0	0	0	0	0
		Limbodessus compactus	0	0	2	0	0	0	0
		Neobidessodes denticulatus	0	0	2	0	0	0	0
	Heteroceridae	*Heterocerus* sp.	1	0	0	0	0	0	0
	Hydraenidae	Hydraenidae sp. (L)	2	0	0	0	0	0	0
		Hydraena sp.	0	0	0	0	2	0	0
	Hydrophilidae	Hydrophilidae sp. (L) (imm./dam.)	1	2	0	0	0	0	2
		Enochrus sp. (L)	0	0	0	1	1	0	2
	Noteridae	*Neohydrocoptus subfasciatus*	1	0	0	0	0	0	0
	Scirtidae	Scirtidae sp. (L)	3	2	2	1	0	1	0
Diptera	**Cecidomyiidae**	Cecidomyiidae sp.	0	0	1	0	0	0	2
	Ceratopogonidae	Ceratopogonidae sp. (P)	2	0	2	0	0	0	2
		Ceratopogoninae sp.	2	0	3	0	2	2	2
		Dasyhelea sp.	3	0	3	0	1	0	0
		Forcipomyiinae sp.	0	2	2	0	0	0	0
	Chironomidae								
	Chironominae								
	Chironomini	*Chironomus* aff. *alternans*	1	0	0	0	0	0	0
		Dicrotendipes sp. `CA1`	2	0	0	0	0	0	0
		Polypedilum sp.	0	0	0	0	2	0	0
		Polypedilum sp. K1	2	0	2	0	0	0	0
	Tanytarsini	*Paratanytarsus* sp.	1	0	0	0	1	0	0
		Tanytarsus sp.	3	0	2	0	1	0	0
	Orthocladiinae	nr. *Gymnometriocnemus* sp.	2	0	0	0	0	0	0
		nr. *Parametriocnemus* sp.	0	0	0	0	1	0	0
	Tanypodinae	?*Australopelopia* sp.	0	0	0	0	1	0	2
		Larsia ?*albiceps*	0	0	0	1	2	0	0

Phylum/Class/Order	Family	Lowest taxon	Within Survey Area YC1	YC3	YC4	Reference WWS	BENS	MUNJS	SS
		Paramerina sp. 1	1	0	0	0	3	0	0
		Procladius sp.	0	0	0	0	2	0	0
		Tanypodinae sp. BES10593	0	0	0	1	0	0	0
	Culicidae	*Anopheles* sp.	0	0	0	0	1	0	0
		Culex sp.	2	0	0	0	0	0	0
	Ephydridae	Ephydridae sp.	0	2	2	0	0	1	0
	Muscidae	Muscidae sp.	0	0	2	0	0	0	0
	Psychodidae	Psychodidae sp.	1	0	0	0	0	0	0
	Sciaridae	Sciaridae sp.	0	3	0	0	0	0	0
	Stratiomyidae	Stratiomyidae sp.	0	0	0	0	1	0	0
Ephemeroptera	**Baetidae**	Baetidae sp. (imm./dam.)	0	0	0	0	2	0	0
	Caenidae	Caenidae sp. (imm./dam.)	0	0	0	0	2	0	0
Lepidoptera	**Crambidae**	Acentropinae sp. (imm./dam.)	1	0	0	0	0	0	0
Odonata		Anisoptera sp. (imm./dam.)	2	1	0	0	0	0	0
		Zygoptera sp. (imm./dam.)	0	0	0	0	2	0	0
Trichoptera		Trichoptera sp. (imm./dam.)	0	0	0	0	2	0	0
	Ecnomidae	*Ecnomus* sp. (imm./dam.)	0	0	0	0	2	0	0
		Taxa richness	**29**	**21**	**22**	**6**	**27**	**9**	**17**

Appendix H: Macroinvertebrate taxonomic list

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

Dry 2020

			Survey Area				Reference			
Phylum/Class/Order	**Family**	**Lowest taxon**	**YC1**	**YC2**	**YC3**	**YC4**	**WWS**	**BENS**	**SS**	**RW**
CNIDARIA										
Hydrozoa										
Anthoathecata	**Hydridae**	*Hydra* sp.	0	0	0	0	1	0	0	0
PLATYHELMINTHES		Turbellaria sp.	0	0	0	0	0	0	0	1
NEMATODA		Nematoda sp.	0	0	0	0	0	0	0	1
MOLLUSCA										
Gastropoda										
Cerithimorpha	**Thiaridae**	Thiaridae sp.	0	0	0	0	0	0	1	0
Hygrophila	**Lymnaeidae**	*Bullastra vinosa*	2	0	0	2	0	3	0	0
	Planorbidae	*Ferrissia petterdi*	2	2	0	2	0	2	0	1
		Gyraulus sp.	2	0	2	2	0	3	2	1
ANNELIDA										
Oligochaeta										
Tubificida	**Naididae**	Naididae sp. (imm./dam.)	2	0	0	0	0	0	0	0
		Naidinae sp. (imm./dam.)	0	2	2	3	2	2	2	4
		Allonais paraguayensis	0	0	1	0	0	0	0	0
		Allonais pectinata	0	0	0	0	0	0	0	3
		Allonais ranauana	0	0	0	0	0	0	0	3
		Nais communis	0	2	0	0	0	0	0	0
		Nais variabilis	0	0	1	3	2	0	0	3
		Pristina sp. (imm./dam.)	0	0	1	0	2	0	3	0
		Pristina aequiseta	3	2	0	2	0	0	2	0
		Pristina jenkinae	0	0	0	2	0	0	0	0
		Pristina leidyi	0	0	0	2	0	0	0	0
		Pristina longiseta	2	0	1	0	3	0	3	0
ARTHROPODA										
CHELICERATA										
Arachnida										
Trombidiformes		Prostigmata sp. (imm./dam.)	0	0	0	0	0	2	0	0
	Arrenuridae	Arrenuridae sp. (imm./dam.)	0	0	0	2	0	0	0	0
		Arrenurus sp.	0	0	0	0	0	0	0	1
		Arrenurus ensifer	0	0	0	0	1	0	0	0

			Survey Area				Reference			
Phylum/Class/Order	**Family**	**Lowest taxon**	**YC1**	**YC2**	**YC3**	**YC4**	**WWS**	**BENS**	**SS**	**RW**
	Aturidae	*Austraturus* sp. P2	0	0	0	2	0	0	0	0
	Hydrodromidae	*Hydrodroma* sp.	0	0	0	0	1	0	0	0
		Hydryphantes sp.	0	0	0	0	0	0	1	0
	Hydryphantidae	Hydryphantidae sp.	0	0	0	0	0	1	0	0
	Hygrobatidae	*Australiobates* sp.	0	0	0	0	0	1	0	0
		Coaustraliobates minor	0	0	0	2	0	2	0	0
	Limnesiidae	*Limnesia* sp.	0	0	1	2	0	2	0	0
		Limnesia sp. 4	2	0	2	2	0	2	2	0
	Momoniidae	*Momoniella* sp.	0	0	0	0	0	0	0	2
		Momoniella australica	0	0	0	2	0	0	0	0
	Oxidae	*Oxus* sp.	0	0	0	0	0	0	0	2
		Oxus orientalis	0	0	0	0	0	0	1	0
		Pezidae sp.	0	1	0	0	0	0	0	0
	Trombidiidae	Trombidiidae sp.	0	0	0	0	0	0	1	0
	Unionicolidae	*Koenikea* sp.	0	0	0	2	0	0	0	0
		Neumania sp.	3	0	0	2	0	0	0	1
		Unionicola sp.	0	0	0	2	0	0	0	0
CRUSTACEA										
Malacostraca										
Amphipoda	**Paramelitidae**	*Chydaekata* sp. E	0	0	3	0	2	0	0	0
Decapoda	**Parastacidae**	*Cherax quadricarinatus*	0	0	0	0	2	0	0	0
HEXAPODA										
Entognatha										
Entomobryomorpha		Entomobryoidea sp.	1	2	0	0	0	0	0	1
Insecta										
Coleoptera										
	Carabidae	Carabidae sp.	1	0	2	0	0	0	0	0
	Curculionidae	Curculionidae sp. (L)	0	0	0	0	0	0	1	0
	Dytiscidae	*Batrachomatus wingii*	0	0	0	0	0	0	0	1
		Bidessini sp. (L)	1	0	2	1	0	0	2	0
		Copelatus nigrolineatus	0	0	0	1	0	0	0	0
		Copelatus irregularis	0	0	0	1	0	1	0	0
		Cybister tripunctatus	0	0	0	0	0	2	0	1
		Hydaticus consanguineus	2	0	0	0	0	0	0	2
		Hydaticus daemeli	1	0	2	0	0	0	0	0
		Hydroglyphus orthogrammus	0	0	0	0	0	3	3	2
		Hydrovatus sp. (L)	0	0	0	0	0	0	1	0
		Hydrovatus opacus	1	0	2	0	0	0	0	0
		Hyphydrus elegans	0	0	1	0	1	0	2	0
		Hyphydrus lyratus	0	0	0	0	1	0	0	0

			Survey Area				Reference			
Phylum/Class/Order	**Family**	**Lowest taxon**	**YC1**	**YC2**	**YC3**	**YC4**	**WWS**	**BENS**	**SS**	**RW**
		Laccophilus sharpi	0	0	1	0	0	0	0	0
		Limbodessus compactus	0	0	1	2	0	0	0	0
		Necterosoma regulare	0	0	0	0	0	2	0	0
		Neobidessodes denticulatus	1	0	2	1	0	0	0	0
		Platynectes decempunctatus var. *decempunctatus*	0	0	1	1	0	0	0	0
		Rhantaticus congestus	1	0	1	0	0	0	0	0
		Tiporus tambreyi	0	0	0	0	0	2	0	0
	Elmidae	*Austrolimnius* sp. (L)	0	0	0	0	0	0	2	3
	Georissidae	*Georissus* sp.	0	0	2	0	0	0	0	0
	Gyrinidae	*Dineutus australis*	0	0	0	0	1	0	0	0
		Macrogyrus sp. (L)	0	0	0	0	1	0	0	0
		Macrogyrus paradoxus	0	0	0	0	2	0	0	0
	Hydraenidae	*Hydraena* sp.	1	0	2	2	0	3	2	0
		Limnebius sp.	0	0	0	0	0	2	1	0
	Hydrochidae	*Hydrochus* sp. P1	0	0	0	0	0	0	2	1
		Hydrochus eurypleuron	0	0	0	2	0	2	0	1
		Hydrochus interioris	0	0	0	0	0	0	1	1
		Hydrochus obscuroaeneus	0	0	1	0	0	1	0	0
	Hydrophilidae	nr. *Anacaena* sp.	0	0	2	0	0	0	0	0
		Anacaena horni	0	1	3	0	0	2	0	0
		Berosus dallasi	0	0	2	0	0	0	3	0
		Coelostoma fabricii	0	0	2	0	0	0	0	0
		Helochares sp. (L)	0	0	0	0	0	0	1	2
		Paracymus spenceri	1	0	3	0	0	2	2	2
		Regimbartia attenuata	0	1	2	0	0	0	0	0
		Sternolophus sp. (L)	0	0	0	0	0	0	2	1
		Sternolophus immarginatus	2	0	2	0	0	0	0	1
		Sternolophus marginicollis	3	2	3	2	0	0	2	2
	Scirtidae	Scirtidae sp. (L)	2	1	3	2	2	2	2	1
	Spercheidae	*Spercheus* sp. (L)	0	0	0	0	0	1	0	0
	Staphylinidae	Staphylinidae sp.	0	2	0	0	0	0	0	0
Diptera	**Ceratopogonidae**	Ceratopogonidae sp. (P)	0	1	2	1	2	0	2	2
		Ceratopogoninae sp.	2	0	2	2	3	3	3	2
		Dasyhelea sp.	2	0	3	3	2	0	3	3
	Chironomidae	Chironomidae sp. (P)	0	0	1	1	1	1	0	2
	Chironominae									
	Chironomini	*Chironomus* aff. *alternans*	3	3	3	0	0	2	3	2
		Cryptochironomus griseidorsum	0	0	0	0	0	1	1	0
		Dicrotendpes sp.	0	0	0	3	0	0	0	0
		Dicrotendipes sp. `CA1`	0	0	0	3	1	0	0	0
		Dicrotendipes sp. P4	0	0	0	0	2	0	0	0

			Survey Area				Reference			
Phylum/Class/Order	**Family**	**Lowest taxon**	**YC1**	**YC2**	**YC3**	**YC4**	**WWS**	**BENS**	**SS**	**RW**
		Fittkauimyia ?disparipes	0	0	1	1	0	0	0	0
		Kiefferulus intertinctus	3	1	0	2	0	1	0	0
		Paracladopelma sp.	1	0	0	0	0	0	0	0
		Polypedilum (Pentapedilum) leei	0	0	0	0	0	0	0	1
		Polypedilum sp. K1	0	0	1	2	0	2	0	0
		Polypedilum sp. S1	1	1	1	0	0	0	0	0
		Stempellinella sp.	0	0	0	0	0	0	0	1
	Tanytarsini	*Cladotanytarsus* sp.	0	0	0	2	0	0	1	2
		Paratanytarsus sp.	1	0	0	2	0	0	2	3
		Tanytarsus sp.	2	0	3	3	2	3	3	2
	Orthocladiinae	*Corynoneura* sp.	0	0	2	2	2	0	1	0
		Rheocricotopus sp.	0	0	0	0	1	0	2	1
		Thienemanniella sp.	0	0	1	0	0	0	1	1
	Tanypodinae	*Ablabesmyia hilli*	0	0	0	0	0	2	0	0
		Ablabesmyia notabilis	0	0	0	2	0	0	0	0
		Larsia ?albiceps	0	0	2	2	1	2	2	3
		Paramerina sp. 1	2	0	2	3	0	2	2	3
		Paramerina sp. 2	0	0	2	0	0	2	2	2
		Procladius sp.	0	0	1	2	1	3	0	2
	Culicidae	Culicidae sp. (P)	0	0	0	0	0	1	0	0
		Anopheles sp.	0	0	2	0	0	1	0	0
		Culex sp.	0	0	0	0	1	0	3	2
	Dolichopodidae	Dolichopodidae sp.	0	0	0	0	0	0	2	2
	Ephydridae	Ephydridae sp.	0	0	0	0	0	0	2	0
	Muscidae	Muscidae sp.	0	1	0	0	0	0	0	0
	Stratiomyidae	Stratiomyidae sp.	1	0	2	2	1	2	3	2
	Tabanidae	Tabanidae sp.	0	0	1	0	2	2	2	2
Ephemeroptera	**Baetidae**	Baetidae sp. (imm./dam.)	2	0	2	0	2	2	0	3
		Cloeon sp. (imm./dam.)	0	0	0	2	0	0	2	0
		Cloeon sp. Red Stripe	2	0	2	3	3	1	2	2
		Offadens sp. (imm./dam.)	0	0	0	0	0	0	0	1
		Offadens G1 sp. WA2	0	0	0	0	1	0	0	1
		Pseudocloeon hypodelum	0	0	0	0	2	0	0	0
	Caenidae	Caenidae sp. (imm./dam.)	0	0	0	0	0	3	0	2
		Tasmanocoenis sp. (imm./dam.)	0	0	0	2	0	0	1	0
		Tasmanocoenis sp. P/*arcuata*	0	0	0	2	0	2	2	3
Hemiptera	**Belostomatidae**	Belostomatidae sp. (imm./dam.)	0	0	0	0	1	0	0	0
		Diplonychus eques	2	0	3	0	0	0	3	2
	Gerridae	Gerridae sp. (imm./dam.)	0	0	1	0	0	0	0	1
		Limnogonus sp. (imm./dam.)	0	0	0	0	0	0	2	3
		Limnogonus fossarum gilguy	2	0	0	0	2	0	0	0

			Survey Area				Reference			
Phylum/Class/Order	**Family**	**Lowest taxon**	**YC1**	**YC2**	**YC3**	**YC4**	**WWS**	**BENS**	**SS**	**RW**
		Limnogonus luctuosus	0	0	0	0	0	1	0	0
		Rhagadotarsus anomalus	0	0	0	1	0	0	3	3
	Hebridae	Hebridae sp. (imm./dam.)	0	0	0	0	0	0	0	2
	Hydrometridae	*Hydrometra* sp.	0	0	0	0	0	0	0	1
	Mesoveliidae	Mesoveliidae sp. (imm./dam.)	0	0	0	0	0	0	0	1
	Nepidae	*Laccotrephes tristis*	0	0	0	0	0	0	1	1
	Pleidae	*Paraplea* sp. (imm./dam.)	0	0	2	0	0	1	2	2
	Veliidae	Veliidae sp. (imm./dam.)	0	0	2	0	0	0	1	0
		Nesidovelia herberti	0	0	0	0	0	0	0	1
Lepidoptera	**Crambidae**	Acentropinae sp. (imm./dam.)	0	0	0	0	0	0	2	0
		Margarosticha sp. 3	0	0	0	0	0	0	0	2
Odonata										
Zygoptera		Zygoptera sp. (imm./dam.)	0	1	1	3	0	0	2	0
	Coenagrionidae	*Agriocnemis* sp.	0	0	0	1	0	0	0	0
		Argiocnemis rubescens	0	1	0	2	0	0	0	0
		Ischnura heterosticta	0	0	0	1	0	0	0	0
		Pseudagrion sp. (imm./dam.)	0	0	0	1	0	0	0	0
		Pseudagrion aureofrons	0	0	0	2	2	0	0	1
	Isostictidae	*Eurysticta coolawanyah*	0	0	0	0	1	1	0	0
Anisoptera		Anisoptera sp. (imm./dam.)	0	0	0	1	0	0	1	2
	Corduliidae	*Hemicordulia koomina*	1	0	1	0	0	2	0	0
		Hemicordulia tau	0	0	1	0	0	0	0	0
	Gomphidae	*Austrogomphus gordoni*	0	0	0	0	0	2	0	1
	Libellulidae	*Crocothemis nigrifrons*	0	0	1	0	0	0	0	0
		Diplacodes haematodes	0	0	1	0	1	1	0	2
		Nannophlebia injibandi	0	0	0	0	0	0	2	0
		Orthetrum caledonicum	0	0	0	0	0	2	1	2
		Orthetrum migratum	0	0	0	0	0	0	0	2
		Rhodothemis lieftincki	0	0	1	0	0	0	1	0
		Zyxomma elgneri	0	0	1	0	0	0	0	0
	Lindeniidae	*Ictinogomphus dobsoni*	0	0	0	1	0	0	0	0
Trichoptera		Trichoptera sp. (imm./dam.)	0	0	0	0	0	0	0	2
	Ecnomidae	*Ecnomus pilbarensis*	0	0	0	0	0	0	0	2
	Hydropsychidae	*Cheumatopsyche wellsae*	0	0	0	0	3	0	3	3
	Hydroptilidae	*Hellyethira* sp.	0	0	0	0	3	1	2	1
		Orthotrichia sp.	0	0	0	1	2	0	0	0
	Leptoceridae	Leptoceridae sp. (imm./dam.)	0	0	0	2	0	0	0	2
		Oecetis sp. 4	0	0	0	0	0	1	2	0
		Oecetis sp. 5	0	0	0	0	0	1	0	0
		Triaenodes sp.	0	0	0	0	0	1	2	2
		Triplectides ciuskus seductus	0	0	0	2	0	3	1	2

Phylum/Class/Order	Family	Lowest taxon	Survey Area YC1	YC2	YC3	YC4	Reference WWS	BENS	SS	RW
	Philopotamidae	*Chimarra* sp. (imm./dam.)	0	0	0	0	0	0	0	2
		Chimarra sp. AV17	0	0	0	0	0	0	3	1
	Polycentropodidae	*Paranyctiophylax* sp. AV5	0	0	0	1	0	0	0	0
		Taxa richness	**36**	**18**	**62**	**62**	**41**	**55**	**67**	**79**

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			Survey Area				Reference			
Phylum/Class/Order	**Family**	**Lowest taxon**	**YC1**	**YC2**	**YC3**	**YC4**	**WWS**	**BENS**	**MUNJS**	**SS**
MOLLUSCA										
Gastropoda										
Hygrophila	**Lymnaeidae**	*Bullastra vinosa*	0	0	0	1	0	0	0	2
	Planorbidae	*Ferrissia petterdi*	2	2	2	3	0	0	0	0
		Gyraulus sp.	0	0	0	1	0	0	2	2
ANNELIDA										
Oligochaeta		Oligochaeta sp. (imm./dam.)	0	0	0	0	1	0	0	0
Tubificida	**Naididae**	*Dero* sp. (imm./dam.)	0	0	1	0	0	0	0	0
		Dero furcata	0	0	0	2	0	0	0	0
		Dero nivea	0	0	0	3	0	0	0	0
		Nais communis	0	0	2	0	0	0	2	1
		Nais variabilis	0	0	0	2	0	0	0	0
		Pristina aequiseta	0	2	2	2	0	2	0	2
		Pristina jenkinae	0	0	2	2	0	0	0	1
		Pristina leidyi	1	3	0	2	1	0	0	0
		Pristina longiseta	0	0	2	0	0	0	0	1
	Phreodrilidae	Phreodrilidae sp.	0	0	0	0	2	0	0	3
ARTHROPODA										
CHELICERATA										
Arachnida		Acarina sp. (imm./dam.)	0	1	0	1	1	2	0	1
Mesostigmata		Mesostigmata sp. (imm./dam.)	0	0	0	0	0	1	0	0
Sarcoptiformes		Oribatida sp.	0	0	0	0	0	0	0	1
Trombidiformes		Trombidioidea sp.	0	0	0	0	0	1	0	0
	Arrenuridae	*Arrenurus* sp.	0	0	0	0	0	0	1	0
	Aturidae	*Austraturus* sp. P2	0	0	0	2	0	0	0	0
	Hygrobatidae	*Australiobates* sp.	0	0	0	0	0	0	0	2
		Coaustraliobates minor	0	0	0	2	0	1	0	2
	Limnesiidae	*Limnesia* sp. `solida group`	0	0	0	3	1	2	2	3
	Mideopsidae	*Gretacarus* sp.	0	0	0	2	0	0	0	0
	Unionicolidae	*Neumania* sp.	0	0	0	0	0	0	0	1
		Recifella sp.	0	0	0	0	0	1	0	0
CRUSTACEA										
Malacostraca										
Amphipoda	**Paramelitidae**	Paramelitidae sp.	0	0	0	0	3	0	0	0
		Chydaekata sp. E	0	0	0	0	3	0	0	0
HEXAPODA										

			Survey Area				Reference			
Phylum/Class/Order	**Family**	**Lowest taxon**	**YC1**	**YC2**	**YC3**	**YC4**	**WWS**	**BENS**	**MUNJS**	**SS**
Entognatha										
Entomobryomorpha		Entomobryoidea sp.	0	2	2	0	0	0	0	0
Insecta										
Coleoptera		Coleoptera sp. (L)	0	0	0	0	0	2	0	0
	Carabidae	Carabidae sp.	0	0	0	0	1	0	0	0
	Dytiscidae	Bidessini sp. (L)	0	0	1	0	0	0	0	0
		Cybister sp. (L)	0	0	0	1	0	0	0	0
		Cybister tripunctatus	0	0	1	2	0	0	0	0
		Hydaticus consanguineus	3	2	1	2	0	0	0	0
		Hydaticus daemeli	2	0	2	2	0	0	0	0
		Hydroglyphus grammopterus	0	0	0	0	1	1	0	0
		Hydroglyphus leai	0	0	1	1	0	0	2	0
		Hydroglyphus orthogrammus	0	0	1	2	0	3	1	2
		Hydrovatus sp. (L)	1	2	2	0	0	2	2	0
		Hydrovatus opacus	0	2	1	0	0	1	0	0
		Hyphydrus sp. (L)	0	0	0	1	0	0	0	0
		Hyphydrus elegans	1	0	0	2	0	0	0	0
		Hyphydrus lyratus	0	0	1	2	0	0	2	0
		Laccophilus sharpi	0	0	0	0	0	0	2	0
		Limbodessus occidentalis	0	0	0	0	1	0	0	0
		Necterosoma regulare	0	0	0	0	0	1	0	0
		Neobidessodes denticulatus	0	0	1	2	0	0	0	0
		Platynectes sp. (L)	0	0	0	0	1	0	0	0
		Rhantaticus congestus	0	0	0	2	0	0	1	0
		Tiporus tambreyi	0	0	0	0	0	2	0	1
	Elmidae	*Austrolimnius* sp. (L)	0	0	0	0	2	0	0	3
	Gyrinidae	Gyrinidae sp. (imm./dam.)	0	0	0	0	0	2	0	0
		Dineutus australis	0	0	0	0	0	0	1	0
		Macrogyrus paradoxus	0	0	0	0	2	0	0	0
	Hydraenidae	*Hydraena* sp.	0	0	3	3	2	3	0	0
	Hydrochidae	*Hydrochus* sp. Group 3 'black'	0	0	0	0	0	1	0	0
		Hydrochus eurypleuron	0	0	0	0	1	0	0	0
		Hydrochus interioris	0	0	0	0	0	0	0	1
		Hydrochus obscuroaeneus	0	0	2	2	0	2	0	0
	Hydrophilidae	*Agraphydrus coomani*	0	0	0	0	2	0	0	0
		nr. *Anacaena* sp.	0	0	0	1	0	0	0	0
		Anacaena horni	0	0	1	0	0	1	0	0
		Berosus sp. (L)	0	0	0	0	0	0	0	1
		Berosus dallasi	0	0	0	0	0	0	0	3
		Berosus pulchellus	0	0	0	0	0	0	0	2
		Coelostoma fabricii	0	1	1	0	0	0	0	0

			Survey Area				Reference			
Phylum/Class/Order	**Family**	**Lowest taxon**	**YC1**	**YC2**	**YC3**	**YC4**	**WWS**	**BENS**	**MUNJS**	**SS**
		Enochrus sp. (L)	0	0	0	0	1	0	0	0
		Enochrus deserticola	0	0	1	2	0	0	3	0
		Helochares sp. (L)	0	0	0	0	0	0	1	0
		Laccobius billi	0	0	0	0	0	0	0	1
		Paracymus sp. (L)	0	0	0	0	0	0	0	1
		Paracymus spenceri	0	0	1	1	0	1	2	0
		Regimbartia attenuata	0	0	2	1	0	0	2	0
		Sternolophus australis	2	0	0	0	0	0	0	0
		Sternolophus immarginatus	0	0	1	1	0	0	0	0
		Sternolophus marginicollis	3	3	3	2	0	0	0	0
	Limnichidae	Limnichidae sp. A	0	2	0	0	0	0	0	0
	Noteridae	*Neohydrocoptus subfasciatus*	0	2	1	0	0	0	0	0
	Scirtidae	Scirtidae sp. (L)	2	3	0	2	3	2	0	1
	Staphylinidae	Staphylinidae sp.	0	1	0	0	0	1	1	0
Diptera	**Cecidomyiidae**	Cecidomyiidae sp.	1	0	0	0	0	2	0	0
	Ceratopogonidae	Ceratopogonidae sp. (P)	0	1	0	0	1	0	0	1
		Ceratopogoninae sp.	2	2	3	1	3	3	1	3
		Dasyhelea sp.	2	0	3	1	2	2	3	2
		Forcipomyiinae sp.	0	0	0	0	0	0	1	0
	Chironomidae	Chironomidae sp. (P)	0	0	0	2	3	1	0	2
	Chironominae									
	Chironomini	Chironomini sp. (imm./dam.)	2	0	0	0	0	0	0	2
		Chironomus aff. *alternans*	3	3	2	2	0	0	0	0
		Cryptochironomus griseidorsum	0	0	0	0	2	0	0	2
		Dicrotendipes sp. `CA1`	2	2	0	0	2	0	0	1
		Dicrotendipes sp. P4	2	1	0	0	3	0	0	2
		Kiefferulus intertinctus	2	0	2	3	0	2	0	0
		Parachironomus sp.	0	0	0	1	0	0	0	0
		Paracladopelma sp. K2	0	0	0	0	2	0	0	0
		Parakiefferiella sp.	0	0	0	0	0	0	2	0
		Polypedilum sp.	0	0	0	0	0	2	0	2
		Polypedilum sp. K1	0	0	0	2	0	0	0	0
		Polypedilum watsoni	0	0	0	0	0	2	0	0
		Stenochironomus watsoni	0	0	0	1	0	0	0	0
	Tanytarsini	*Rheotanytarsus* sp.	0	0	0	0	2	1	0	0
		Tanytarsus sp.	3	0	3	3	2	2	3	3
	Orthocladiinae	*Corynoneura* sp.	0	0	0	0	1	0	0	2
		Cricotopus albitarsis	0	0	0	0	3	0	0	0
		nr. *Gymnometriocnemus* sp.	0	0	0	0	0	0	0	2
		Rheocricotopus sp.	0	0	0	0	0	0	0	3
		Thienemanniella sp.	0	0	0	0	3	0	0	2

			Survey Area				**Reference**			
Phylum/Class/Order	**Family**	**Lowest taxon**	**YC1**	**YC2**	**YC3**	**YC4**	**WWS**	**BENS**	**MUNJS**	**SS**
	Tanypodinae	?*Telmatopelopia* sp.	0	0	0	0	0	0	3	0
		Ablabesmyia hilli	0	0	0	0	0	2	0	0
		Ablabesmyia notabilis	0	0	0	0	0	0	0	2
		Larsia ?albiceps	0	1	3	1	1	2	3	2
		Paramerina sp. 1	1	1	2	3	3	3	1	2
		Paramerina sp. 2	0	0	2	0	0	2	0	0
		Procladius sp.	0	0	0	2	0	2	2	3
	Culicidae	*Aedes* sp.	0	1	0	0	0	0	0	0
		Anopheles sp.	0	0	0	0	2	0	0	0
		Culex sp.	2	3	0	1	0	0	0	0
	Dolichopodidae	Dolichopodidae sp.	0	0	0	0	2	0	0	3
	Psychodidae	Psychodidae sp.	0	2	0	1	0	1	0	0
	Simuliidae	Simuliidae sp.	0	0	0	0	0	0	0	3
	Stratiomyidae	Stratiomyidae sp.	0	2	0	0	2	2	2	2
	Syrphidae	Syrphidae sp.	1	2	0	0	0	0	0	0
	Tabanidae	Tabanidae sp.	0	0	1	0	0	0	2	0
	Tipulidae	Tipulidae sp.	0	2	1	1	0	0	0	2
Ephemeroptera	**Baetidae**	Baetidae sp. (imm./dam.)	0	0	2	3	3	3	0	3
		Cloeon fluviatile	0	0	0	2	0	2	0	0
		Cloeon sp. Red Stripe	0	0	2	2	0	1	2	1
		Offadens sp. (imm./dam.)	0	0	0	0	0	0	0	2
		Offadens G1 sp. WA2	0	0	0	0	0	0	1	1
		Pseudocloeon hypodelum	0	0	0	0	3	0	0	0
	Caenidae	Caenidae sp. (imm./dam.)	0	0	0	0	0	3	3	3
		Tasmanocoenis sp. M	0	0	0	0	0	0	2	2
		Tasmanocoenis sp. P/*arcuata*	0	0	0	2	3	3	3	2
	Leptophlebiidae	Leptophlebiidae sp. (imm./dam.)	0	0	0	0	0	0	2	0
		Atalophlebia sp. (imm./dam.)	0	0	0	0	0	0	2	0
		Atalophlebia sp. AV5	0	0	0	0	0	0	2	0
Hemiptera	**Belostomatidae**	*Diplonychus eques*	2	2	3	2	0	0	2	2
	Gerridae	Gerridae sp. (imm./dam.)	0	0	0	2	2	0	0	0
		Limnogonus fossarum gilguy	0	0	0	0	0	0	1	1
		Limnogonus luctuosus	0	0	2	0	0	2	0	0
	Micronectidae	Micronectidae sp. (imm./dam.)	0	0	0	0	0	1	0	0
		Austronecta bartzarum	0	0	0	1	0	0	0	0
		Micronecta annae	0	0	0	0	0	1	0	0
	Nepidae	*Laccotrephes tristis*	0	0	1	0	0	0	0	0
	Notonectidae	*Anisops* sp. (imm./dam.)	0	0	0	0	0	0	1	0
		Enithares sp. (imm./dam./F)	0	0	0	0	0	0	2	0
		Enithares woodwardi	0	0	0	0	0	0	1	0
	Pleidae	*Paraplea* sp.	0	0	0	0	0	1	0	0

			Survey Area				Reference			
Phylum/Class/Order	**Family**	**Lowest taxon**	**YC1**	**YC2**	**YC3**	**YC4**	**WWS**	**BENS**	**MUNJS**	**SS**
	Veliidae	Veliidae sp. (imm./dam.)	0	2	0	2	1	0	0	0
		Microvelia sp. (imm./dam.)	0	0	0	2	0	1	0	0
		Nesidovelia herberti	0	0	0	0	0	0	0	1
		Nesidovelia peramoena	0	0	0	1	0	0	0	0
Lepidoptera	**Crambidae**	Acentropinae sp. (imm./dam.)	0	0	0	0	3	0	0	2
		Margarosticha sp. 3	0	0	0	0	0	0	3	0
Odonata		Zygoptera sp. (imm./dam.)	1	0	0	2	0	3	2	2
Zygoptera	**Coenagrionidae**	*Argiocnemis rubescens*	0	0	1	2	1	1	2	2
		Ischnura aurora	0	0	0	0	0	0	2	0
		Pseudagrion aureofrons	0	0	0	1	0	0	0	0
	Isostictidae	*Eurysticta coolawanyah*	0	0	0	0	0	0	0	1
Anisoptera		Anisoptera sp. (imm./dam.)	2	0	3	2	3	2	3	2
	Aeshnidae	Aeshnidae sp. (imm./dam.)	0	0	0	1	0	0	0	0
		Adversaeschna brevistyla	0	0	2	0	0	0	1	0
		Hemianax papuensis	0	0	0	0	0	0	2	0
	Corduliidae	*Hemicordulia koomina*	1	0	0	0	0	0	0	0
	Gomphidae	*Austrogomphus gordoni*	0	0	0	2	0	0	1	0
	Libellulidae	*Crocothemis nigrifrons*	0	0	1	0	0	0	0	0
		Diplacodes haematodes	0	0	1	0	0	2	2	0
		Orthetrum sp. (imm./dam.)	0	0	0	0	0	0	1	0
		Orthetrum migratum	2	2	0	0	0	0	2	0
		Tramea sp.	0	0	0	0	0	0	2	0
		Zyxomma elgneri	0	0	0	2	0	0	0	0
	Lindeniidae	*Ictinogomphus dobsoni*	0	0	1	0	0	1	0	0
Trichoptera	**Ecnomidae**	*Ecnomus pilbarensis*	0	0	0	2	0	0	1	2
	Hydropsychidae	*Cheumatopsyche* sp.	0	0	0	0	0	0	0	3
		Cheumatopsyche wellsae	0	0	0	0	3	0	1	4
	Hydroptilidae	*Hellyethira* sp.	0	0	0	1	2	0	0	0
		Orthotrichia sp.	0	0	0	0	0	0	0	2
	Leptoceridae	Leptoceridae sp. (imm./dam.)	0	0	0	0	0	0	0	2
		Oecetis sp. (imm./dam.)	0	0	0	0	0	0	2	1
		Oecetis sp. Pilbara 4	0	0	0	0	0	1	0	1
		Triaenodes sp.	0	0	0	0	0	1	2	0
		Triplectides sp. (imm./dam.)	0	0	0	0	0	3	1	2
		Triplectides australis	0	0	0	2	0	0	0	0
		Triplectides ciuskus seductus	0	0	0	1	0	0	0	3
	Philopotamidae	*Chimarra* sp. (imm./dam.)	0	0	0	0	0	0	0	2
		Chimarra sp. AV17	0	0	0	0	2	1	0	3
		Taxa richness	**26**	**30**	**48**	**70**	**47**	**57**	**57**	**71**