Ministers North

Yandicoogina Creek Aquatic Ecosystem Survey

Dry 2022 and Wet 2023

Report to BHP Western Australia Iron Ore

11 November 2024

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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 survey of the aquatic ecosystems of Yandicoogina Creek, located within the Upper Fortescue River Catchment and the Weeli Wolli Creek/ Marillana Creek sub-catchment. This constitutes the fourth round of sampling within permanent pools in a 3.5 km stretch of creekline (hereafter referred to as the Survey Area). Previous surveys were undertaken in the dry season of 2019 (Dry 2019), wet season of 2020 (Wet 2020), dry season of 2020 (Dry 2020), wet season of 2021 (Wet 2021), dry of 2021 (Dry 2021) and wet of 2022 (Wet 2022). Reference sites were sampled elsewhere to provide comparison and contextual information for Yandicoogina Creek. Together the Yandicoogina Creek Survey Area and the Reference sites comprised the Study Area for this project.

Aquatic ecosystem surveys were undertaken at eight sites, four within the Survey Area (labelled YC1 through to YC4), and four Reference sites located elsewhere. Sampling was undertaken in September 2022 (Dry 2022 survey) and March 2023 (Wet 2023 survey). Surveys included habitat assessments and sampling of water quality, macrophytes (submerged and emergent), hyporheos fauna, macroinvertebrates and fish. Due to lowering water levels, the Survey Area was largely dry in the Wet 2023, with only one monitoring site holding water at the time of survey. One site was also dry in the Dry 2022. Sediment samples were collected from all dry sites and rehydrate-emergence trials conducted in the laboratory.

Although the sampling site pools were previously considered to be permanent, the creek has been drying since the Wet 2020, with maximum water depths in pools decreasing over time, and several sites being dry on numerous sampling occasions since that time. In many instances, this has occurred following heavy wet season rainfall and associated flooding in nearby creeklines, and as such, does not appear to be related to climate. The lowering water levels at YC4 were reflected in a strong negative linear regression between maximum pool depth and time. The declining water levels within the Survey Area have led to a reduction in habitat availability and an overall decline in quality of aquatic habitat available. This has included a linear decrease in submerged macrophyte cover at YC4 over time, and emergent macrophyte cover at YC3 and YC4. The loss of fringing vegetation, especially at YC4, has resulted in cattle intrusion into the pool, leading to associated impacts such as bank and vegetation trampling, bank erosion, and grazing of sedges. This coincided with an increase in the number of introduced flora taxa within the Survey Area.

Vegetation of the Survey Area is characterised by an open to closed *Eucalyptus camaldulensis* and *Melaleuca argentea* woodland over *Acacia tumida* var. *pilbarensis* shrubland, with reeds and sedges (*Cyperus vaginatus*, *Schoenoplectus subulatus*, *Typha*

domingensis, *Eleocharis geniculata* and *Fimbristylis sieberiana*) along the waterline. These emergent macrophytes were in poor condition compared to previous years, with reduced cover and fewer mature individuals. Submerged macrophytes present during the current survey included *Vallisneria nana* and *Chara globularis*. The importance of the Survey Area GDE has been previously established however, several of the mesic species were showing signs of water stress, with some either dead or dying.

Water quality within the Survey Area was characterised by fresh, well buffered, clear waters, with low dissolved oxygen (DO) saturation, neutral pH, low concentrations of nitrogen nutrients but high total phosphorus (total P), and low concentrations of dissolved metals. This is generally consistent with previous surveys. While water quality was mostly within ANZG (2018) default guideline values (DGVs) for the protection of lowland river systems of tropical north Australia, DO, total P, dissolved boron (dB), dissolved iron (dFe) and dissolved zinc (dZn) did exceed DGVs in some instances. Several water quality analytes were significantly lower within the Survey Area than Reference sites (incorporating data from all sampling events into the analysis), including electrical conductivity (EC), DO, pH, and concentrations of dissolved copper (dCu), arsenic (dAs), barium (dBa), uranium (dU) and vanadium (dVn). Conversely, total P and dFe concentrations were significantly greater in the Survey Area when compared to Reference sites. DO saturation and total P showed strong decreasing linear trends over time within the Survey Area, while sulfate (S_SO_4) and nitrate (N_NO_4) concentrations have increased over time. The decreasing DO, and increasing S_SO_4 and N_NO_4 may be related to declining water levels, and should be monitored closely.

A diverse range of aquatic fauna was recorded across the Survey Area despite the dry conditions, including 198 invertebrate taxa, and three freshwater fish species. While most invertebrates recorded from the Survey Area were common, widespread species, several species were of significance and/or appear to be restricted or are known from few records. Information relating to these taxa is provided in Table 6.1.

A high richness of groundwater-dependent fauna was recorded from the hyporheic zone, especially at YC3, including several potentially restricted taxa. Considerably fewer groundwater dependent taxa were recorded from Reference sites than the Survey Area. Of the total taxa, 16% are directly dependant on groundwater for their persistence. The percentage of stygobitic taxa recorded from the Survey Area was considerably greater than that reported previously for hyporheic zones of Pilbara springs. This highlights the strong groundwater connection within the Survey Area.

Despite the lowering water levels across the Survey Area, hyporheos habitat is currently maintained in isolated locations across the creek including YC1 and YC3. Although no surface water was present at YC1 in the Dry 2021, the hyporheos yielded the second greatest richness of groundwater dependent taxa across the entire study. Locations such as YC1 and YC3 provide refuges for restricted groundwater dependent taxa. If the remaining hyporheos habitat dries completely, there is the potential for these taxa to be lost from the system.

The composition of macroinvertebrate fauna within the Survey Area was generally similar to most Pilbara pools and was dominated by slow flow and relatively tolerant taxa such as Coleoptera and Diptera. Composition at Reference sites was broadly similar, however, greater numbers of taxa which require faster flows were recorded, especially at Weeli Wolli Spring, Munjina Spring and Skull Springs. This difference was highlighted in the multivariate analysis, with assemblages from Yandicoogina Creek being most similar to Bens Oasis, the only other lentic spring site included in this monitoring program.

Richness in the remaining Survey Area pools was generally high, with the exception of YC2. Particularly high richness was recorded from YC4 in the Dry 2022, which was greater than Skull Springs, a site renowned for high richness of aquatic invertebrate fauna within the Pilbara region. YC4 has consistently recorded a high richness of macroinvertebrate taxa, including several significant species, and likely represents the last refuge for aquatic fauna in the Survey Area as it becomes increasingly dry over time.

In contrast, YC2 has consistently recorded low macroinvertebrate richness which is likely related to low water levels and the highly abundant *Typha* at this site. Current assemblages were also exposed to adverse water quality conditions relating to the very small pool size remaining as waters receded, including exceptionally low DO, higher EC than is usual for Yandicoogina Creek, considerably high turbidity, and high concentrations of ammonia (N_NH_3), nitrogen oxide (N_NOx), total P, dFe, and dZn.

The rehydration-emergence trials undertaken on sediments collected from dry sites in both seasons were successful in that they added a total of 13 invertebrate taxa to the current study (i.e., taxa not recorded from the hyporheic zone or surface waters). The macrophyte *Vallisneria* sp. also emerged from sediments of YC1 and YC2, adding to known macrophytes from these sites, and indicating a viable seedbank at these sites. However, the rehydration trial yielded lower richness than has been recorded from ephemeral creeklines in the Pilbara previously. This is likely because the aquatic fauna of the Survey Area are not adapted to seasonal drying like the fauna found in ephemeral environments. Predictable and persistent drying in isolated temporary waterbodies exerts pressure on fauna to produce desiccation-tolerant and thermally resistant diapausing forms in order to survive. This has implications for the survival and persistence of fauna as the ecosystem's water levels continue to decline.

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

Current results suggest that there has been limited impact of the lowering water levels on fish abundance in the Survey Area, with no significant difference in the abundance of spangled perch or western rainbowfish recorded between sampling events. However, successful breeding and/or recruitment for all three species in the Survey Area was low. As with the invertebrates, the large, deep pool at YC4 is likely buffering the impacts of the lowering groundwater and surface water levels currently, as it provides a refuge for fish, and source of re-colonisation of other pools following wet season rains.

Overall, the Survey Area supports a significant GDE that holds considerable ecological value and importance in the arid Pilbara region. However, the ecosystem is currently stressed and showing adverse impacts from the lowering water levels.

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GLOSSARY

ALA	Atlas of Living Australia
BoM	Bureau of Meteorology
DBCA	Department Biodiversity, Conservation and Attractions
DGV	Default Guideline Value
DO	Dissolved oxygen
DPIRD	Department of Primary Industry and Regional Development
EC	Electrical conductivity
EPBC Act	*Environment Protection and Biodiversity Conservation Act 1999*
GDE	Groundwater dependent ecosystem
GDV	Groundwater dependent vegetation
GS	Gauging station/s
IUCN	International Union for the Conservation of Nature
LOD	Limit of detection
LWD	Large woody debris
MNES	Matters of National Environmental Significance
PBS	Pilbara Biological Survey
SRE	Short-range endemic
WAM	Western Australian Museum

1 Introduction

1.1 Background

Biologic Environmental Survey (Biologic) was commissioned by BHP Western Australia Iron Ore (WAIO) to undertake a two-season baseline survey of the aquatic ecosystems of Yandicoogina Creek, located within the Weeli Wolli Creek/ Marillana Creek 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 two operational BHP WAIO mines; Mining Area C (MAC) to the southwest and Yandi to the north, within the Pilbara bioregion of Western Australia (Figure 1.1).

Three previous aquatic ecosystem surveys have been undertaken in Yandicoogina Creek, with surveys conducted in the dry season of 2019 (Dry 2019) and wet season of 2020 (Wet 2020), dry of 2020 (Dry 2020) and wet of 2021 (Wet 2021), and dry season 2021 (Dry 2021) and wet of 2022 (Wet 2020) (Biologic, 2020, 2022b, 2023c). These surveys identified the presence of a groundwater dependent ecosystem (GDE) and associated permanent pools within the Survey Area. The GDE is characterised by extensive closed *Melaleuca argentea* forest, with *Eucalyptus camaldulensis* over *Acacia tumida* var. *pilbarensis* shrubland, and reeds and sedges (*Cyperus vaginatus*, *Schoenoplectus subulatus* and *Typha domingensis*). The pools associated with the GDE provide important habitat for aquatic fauna and have high ecological value. Such values include:

- Invertebrates with restricted distributions (i.e., stygal amphipods, a stygal copepod, a stygal isopod, and a stygal bathynellid)
- A high diversity of aquatic invertebrate taxa that are endemic to the Pilbara region
- Three invertebrate species listed IUCN Red List of Threatened Species
- A diversity of groundwater dependent flora species
- Three species of freshwater fish (Biologic, 2020, 2022b, 2023c).

Surface water levels in the Survey Area have declined steadily since the Dry 2019, with adverse effects to groundwater dependent vegetation noted. These include a decline in the crown of some *Melaleuca argenta* trees, an obligate groundwater dependent species, as well as the death of some juveniles. Ongoing monitoring of the aquatic ecosystem within Yandicoogina Gorge is vital. As such, BHP WAIO commissioned Biologic to undertake an aquatic ecosystem survey within the Survey Area in the dry season of 2022 (Dry 2022) and wet of 2023 (Wet 2023) (this report), to monitor the effects of declining water levels on the GDE and ecology of the permanent pools. The scope of works included:

- A two-season aquatic survey at all previously established sites, including Reference sites
- Identification of any significant ecological values related to aquatic fauna and their habitats within the Survey Area
- An assessment of the seasonal, temporal and spatial variation in water quality and aquatic fauna, using data from this and previous surveys (Biologic, 2020, 2022b, 2023c).

1.2 Compliance

The survey was carried out in accordance with the Western Australian Environmental Protection Authority (EPA) and BHP WAIO guidelines. There is currently (July 2023) no technical guidance applicable to the EPA's Inland Waters Environmental Factor; however, this survey was carried out in a manner consistent with the following:

- Environmental Factor Guideline, Inland Waters (EPA, 2018)
- Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC & ARMCANZ, 2000; ANZG, 2018)
- Assessing and Managing Water Quality in Temporary Waters (Smith *et al.*, 2020)
- Technical Guidance, Sampling of Short-Range Endemic Invertebrate Fauna (EPA, 2016a)
- Technical Guidance, Terrestrial Fauna Surveys (EPA, 2016b)
- BHP WAIO's Aquatic Fauna Assessment Methods Procedure (0098594) (BHP, 2022)
- BHP WAIO's Biological Survey Spatial Data Requirements (SPR-IEN-EMS-015) (BHP, 2018)
- Similar surveys, including the Pilbara Biological Survey (Pinder *et al.*, 2010) and National Monitoring River Health Initiative (MRHI; Choy & Thompson, 1995), as well as recent surveys undertaken by Biologic in the Survey Area and other BHP projects nearby (Biologic, 2020, 2022a, 2022b, 2023a, 2023c, 2023e).

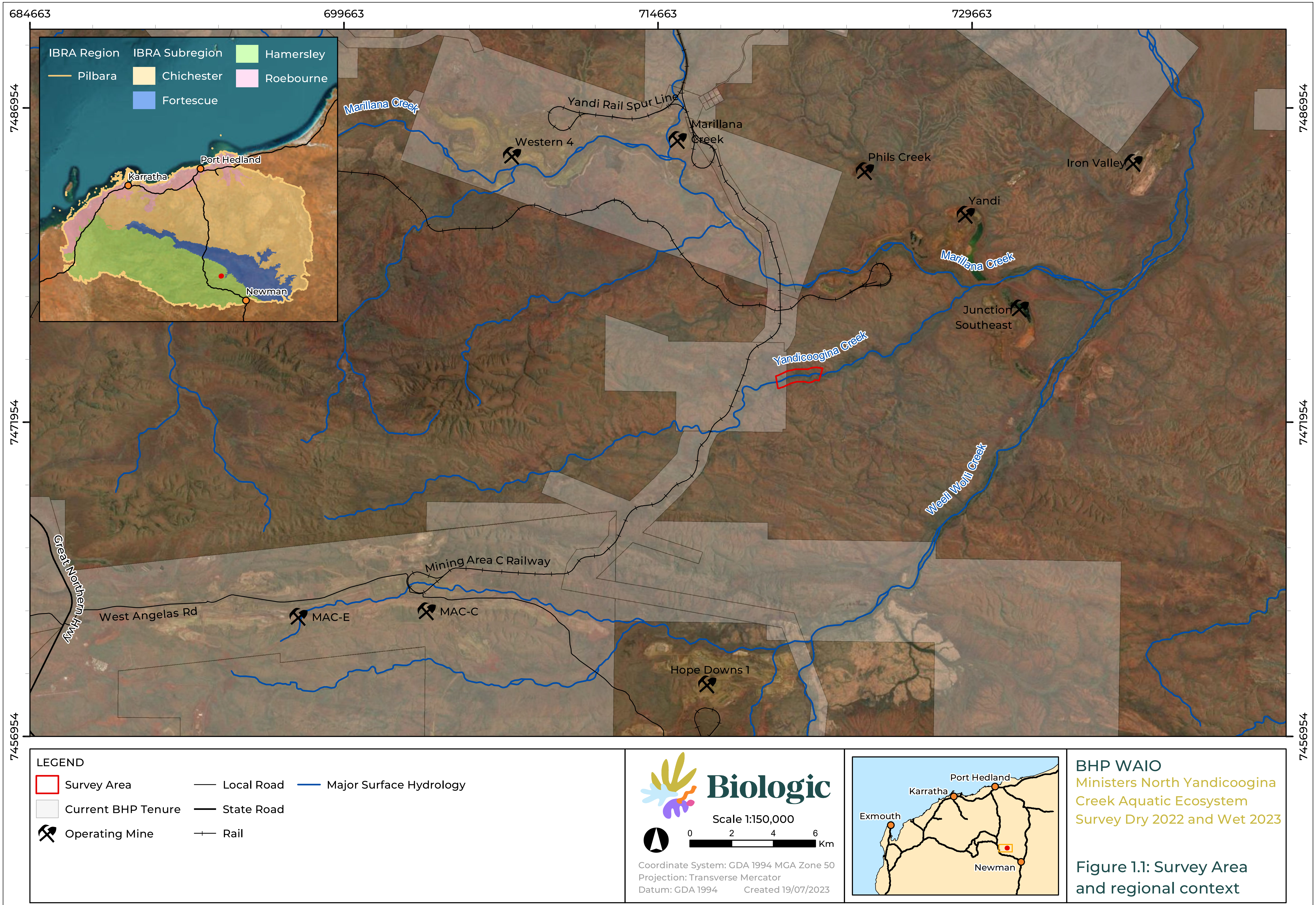

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Figure 1.1: Survey Area and regional context

2 Environment

2.1 Biogeographical Regionalisation of Australia

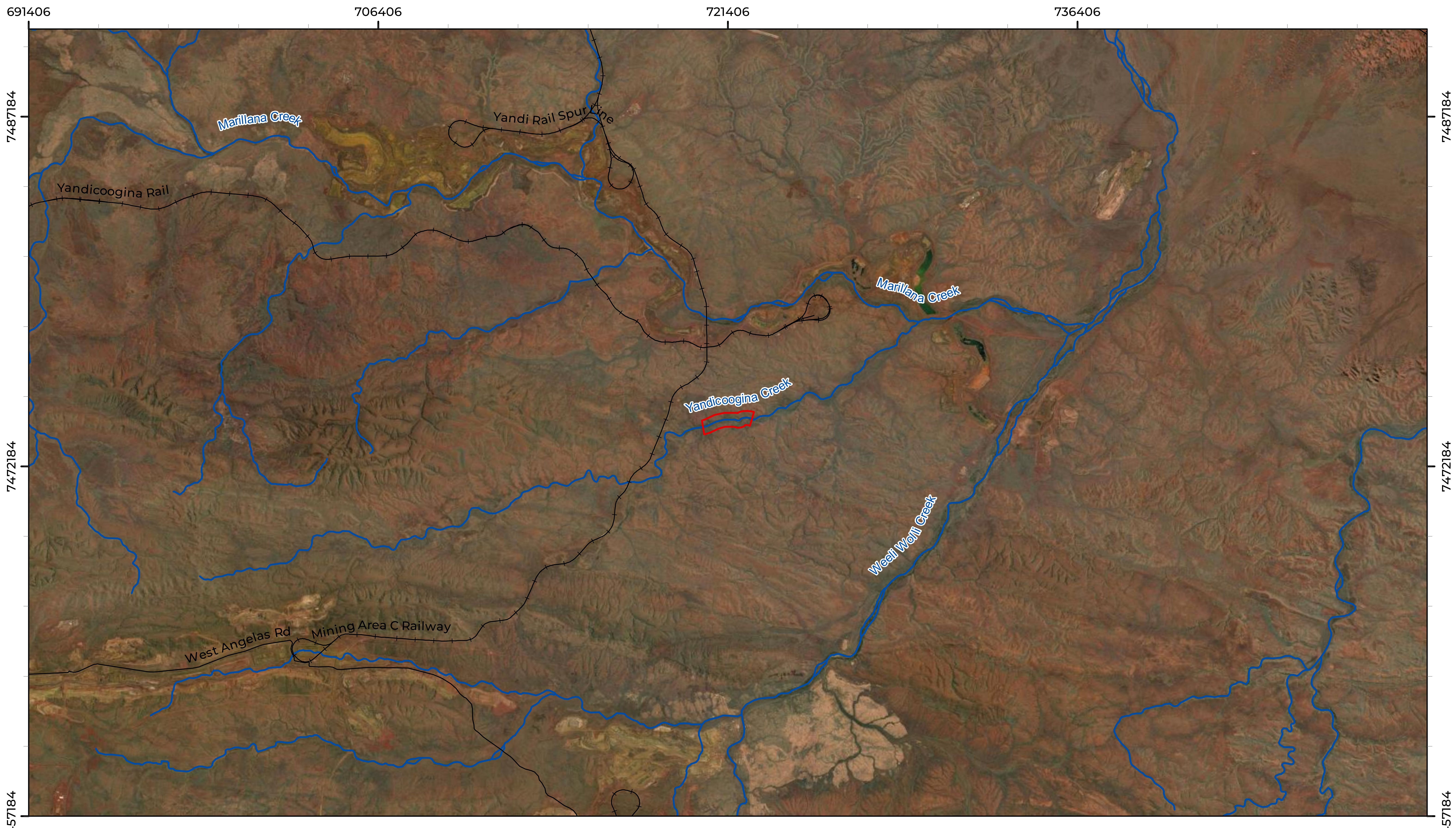
The Survey Area falls within the Pilbara biogeographical region as defined by the Interim Biogeographic Regionalisation of Australia (IBRA) (Thackway & Cresswell, 1995). The Pilbara bioregion is characterised by vast coastal plains and inland mountain ranges with cliffs and deep gorges (Thackway & Cresswell, 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, 2003). 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, 2003).

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, 2003). Drainage is into the Fortescue River to the north, the Ashburton River to the south, or the Robe River to the west (Kendrick, 2003).

2.2 Hydrology

The Survey Area lies within the Weeli Wolli Creek/ Marillana Creek 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 (Figure 2.1).



LEGEND

Survey Area

Major Surface Hydrology

Local Road

Rail

Biologic

Scale 1:150,000

0 2 4 6 Km

Coordinate System: GDA 1994 MGA Zone 50
Projection: Transverse Mercator
Datum: GDA 1994 Created 19/07/2023

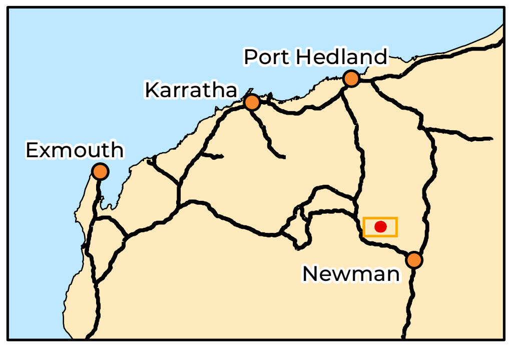


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Figure 2.1: Hydrology of the Survey Area

2.3 Groundwater Dependent Ecosystems (GDE)

Groundwater-Dependent Ecosystems (or GDEs) rely on groundwater for their continued existence (BoM, 2021). GDEs 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 which includes cave and aquifer ecosystems (BoM, 2021).

Above-ground terrestrial GDEs are typically characterised by the presence of flora species that rely on groundwater (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).

Groundwater originates from direct infiltration by rainfall and from surface water flows. Groundwater occurs throughout the Pilbara but is most easily located and accessed near surface water drainage lines (alluvial channels). The most significant aquifers can be grouped into three types: alluvial aquifers that are either unconsolidated sedimentary aquifers or chemically deposited aquifers, consolidated sedimentary (or sedimentary rock) aquifers and fractured rock aquifers. GDEs are subject to impacts resulting from changes in water table levels (above and below surface soil). The rate at which groundwater levels change (depth, rate of recharge, etc.) determines the presence or absence of GDVs.

2.3.1 Groundwater Dependent Species

Above-ground GDEs are typically characterised by the presence of flora species that rely on groundwater. Of the two types of phreatophytes described above, obligate phreatophytes are confined to habitats with continual, seasonal, or episodic access to groundwater due to their complete (or high) reliance on groundwater (Eamus *et al.*, 2016). They can only inhabit areas where they have access to groundwater to satisfy at least some proportion of their ecological water requirement (EWR) (Eamus *et al.*, 2016). This means that obligate phreatophytes are highly sensitive to changes in groundwater regime and respond negatively to rapid groundwater drawdown.

Facultative phreatophytes can access groundwater but are not totally reliant on it for their water requirements. Facultative phreatophytes use groundwater opportunistically, particularly during times of drought when moisture reserves in the unsaturated (vadose) zone of the soil profile become depleted. Facultative phreatophytes are therefore generally associated with the subsurface presence of groundwater, rather than surface expression of groundwater. Most facultative phreatophytes are large woody trees and shrubs with deep root systems capable of accessing the capillary fringe of the water table which may occur at considerable depth within the soil profile.

The Survey Area is known to support both obligate (*Melaleuca argentea*), and facultative phreatophytes (*Eucalyptus camaldulensis* subsp. *obtusa* and *Eucalyptus victrix*). Groundwater dependence and environmental water requirements are well known for *Melaleuca argentea* (Graham *et al.*, 2003; Landman *et al.*, 2003; McLean, 2014; O'Grady *et al.*, 2006) and *Eucalyptus camaldulensis* subsp. *obtusa* (Collof, 2014; Gibson *et al.*, 1994; Marshall *et al.*, 1997; Morris & Collopy, 1999), but there is little information regarding the groundwater use strategies of understorey species. Recent work on Pilbara GDEs has led to the further classification of GDVs, including understorey species, with species ranked according to their correlation with shallow groundwater, from low-level mesophytic and/or hydrophytic[1] indicator species through to very high-level indicator species (Rio Tinto, 2022). At least nine species that occur within the Survey Area indicate the area represents a high-level GDE, with "soil moisture availability or surface water availability that is perennial to sub-perennial" (Rio Tinto, 2022) (Table 2.1).

Table 2.1: Flora species which indicate consistently shallow groundwater and/or perennial surface water (after Rio Tinto, 2022)

Indicator Level	Indicator Species	Presence in the Survey Area
Very high	*Melaleuca argentea* (mature and abundant)	✓
	Sesbania formosa (abundant and mature)	
	Eucalyptus camaldulensis (present in lower abundance)	✓
	Samolus spp. (verging on aquatic)	

[1] Mesophyte - A plant that grows in an environment that has a moderate supply of water. Growing in, or adapted to, a moderately moist environment.

Hydrophyte – A plant that grows in either partially or totally submerged in water, including waterlogged soil.

Indicator Level	Indicator Species	Presence in the Survey Area
	Imperata cylindrica (verging on aquatic)	
	Phragmites karka	
	Cladium procerum	
	Adiantum capillus-veneris	
	Machaerina juncea	
	Machaerina rubiginosa	
	Juncus krausii	
	Ceratopteris thalictroides	
	Nymphoides indica	
	Number of very high indicator species	**2**
High	*Sesbania formosa* (abundant)	
	Melaleuca argentea (present)	✓
	Eucalyptus camaldulensis (open forest and greater)	✓
	Eucalyptus victrix (present but a peripheral component)	✓
	Acacia ampliceps	
	Cullen leucanthum	✓
	Ficus aculeata (common abundance)	
	Imperata cylindrica	✓
	Pteris vittata	
	Schoenus falcatus (abundant)	
	Schoenus punctatus	
	Fimbristylis littoralis	
	Eleocharis spiralis	
	Eleocharis sphacelata	
	Samolus sp. Millstream	
	Fimbristylis sieberiana (present, potential initial groundwater discharge indicator)	✓
	Stylidium weeliwolli	
	Potamogeton spp. (abundant, potential groundwater discharge indicator)	
	Lobelia arnhemiaca	✓
	Vallisneria spp. (potential groundwater discharge indicator)	✓
	Eragrostis elongata	✓
	Number of high indicator species	**9**
Moderate-High	*Sesbania formosa* (present)	
	Melaleuca argentea (present, typically immature)	
	Eucalyptus camaldulensis (open forest and greater)	
	Eucalyptus victrix (present but a peripheral component)	
	Melaleuca bracteata	
	Gymnanthera cunninghamii (common)	
	Adriana tomentosa	
	Ficus aculeata (scattered)	
	Kirganelia baccata (common)	
	Potamogeton spp. (potential groundwater discharge indicator)	
	Schoenus falcatus	
	Eleocharis geniculata (potential initial groundwater discharge indicator)	✓
	Stylidium fluminense	
	Samolus repens	

Indicator Level	Indicator Species	Presence in the Survey Area
	Sonchus hydrophilus	
	Ruppia polycarpa	?
	Ammannia baccifera (abundant)	
	Cyperus polystachyos	
	Cyperus dactylotes	
	Schenkia clementii	
	Ludwigia perennis	
	Najas spp. (abundant)	
	Diplachne fusca	
	Number of moderate-high indicator species	**2**

Although GDEs only cover a comparatively small proportion of the land surface, they provide specific ecosystem functions supporting unique and important biological diversity at both local and regional scales (Boulton & Hancock, 2006; Humphreys, 2006; Murray *et al.*, 2006; Thurgate *et al.*, 2001). In addition to environmental benefits, GDEs often have significant social, economic, and spiritual values (Murray *et al.*, 2006). Protection of GDEs is commonly considered an important criterion in sustainable water resource management, particularly when human water management is in competition with environmental water demands.

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 (Leighton, 2004). Winter rainfall is generally lighter and the result of cold fronts moving north-easterly across the state (Leighton, 2004). 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.

3 Methods

3.1 Field Survey and Laboratory Teams

Field surveys were conducted by Biologic aquatic ecologists Jessica Delaney (Principal Aquatic Ecologist | Manager of Aquatic Ecology), Kim Nguyen (Senior Aquatic Ecologist), Chris Hofmeester (Senior Aquatic Ecologist), Siobhan Paget (Aquatic Ecologist), Aimee Carpenter (Invertebrate Zoologist) and Chao Lyu (Invertebrate Zoologist). All senior members of the field team have extensive experience undertaking aquatic ecosystem surveys throughout the Pilbara.

Macroinvertebrate specimens were identified in-house by Alex Riemer, Kim Nguyen, Siobhan Paget, and Vanessa Nici. Hyporheos fauna were identified in-house by Alex Riemer, Giulia Perina (Principal Taxonomist), and Juliana Pile Arnold (Senior Invertebrate Zoologist). Micro-crustacea were identified by Alex Riemer. Genetic analysis was undertaken in-house on selected specimens by Stephanie Floeckner (Geneticist), Liesel Morgan (Geneticist) and Joel Huey (Principal Geneticist).

Submerged macrophytes were identified by Alex Riemer. The other flora specimens (emergent macrophytes and dominant riparian vegetation) were identified by Biologic's Flora Team, including Samuel Coultas, Kaylin Geelhoed and Ryonen Butcher.

3.2 Licences

Aquatic fauna sampling was conducted under DBCA Fauna Taking (Biological Assessment Regulation 27) Licences BA27000401-2 and BA27000401-3, 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, Licence FB62000428, issued to Kim Nguyen and Licence FB62000429 issued to Alex Riemer. Priority flora was collected under DBCA Authorisation to Take or Disturb Threatened Species Licence TFL 193-2122, issued to Jessica Delaney All team members are listed as having authority to sample under each of the licences.

3.3 Survey Timing, Weather and River Conditions

The field survey comprised two seasons. The Dry 2022 survey was undertaken between the 7th and 12th of September 2022, and the Wet 2023 survey between the 17th and 22nd of March 2023. The Dry 2022 survey was undertaken at a time of below average ambient temperature, with the average September maximum being 3.1 °C cooler than the long-term average of 30.5 °C (Figure 3.1). However, in the four months preceding the survey, both minimum and maximum temperatures were well above the long-term average (Figure 3.1). There was little rainfall in the two months preceding the survey, however during the month of the survey, Newman received 57.2 mm, which is well above the September long-term average of 4.7 mm (Figure 3.1). The Flat Rocks GS also reported higher than average rainfall for September 2022 (80.2 mm compared to 5.6 mm).

The maximum daytime temperatures during the Wet 2023 survey were 2.8 °C warmer compared to the long-term March average of 35.6 °C (Figure 3.1). Similar to the dry season survey, total rainfall in Newman for March 2023 was much greater than the long-term average for that month, receiving 118.4 mm compared to 40.8 mm (Figure 3.1). In comparison, rainfall at the Flat Rocks GS was comparable to the long-term average for March 2023 (51.2 mm compared to 55.5 mm). Rainfall for the two months preceding the survey was lower than the long-term average by an average of 35.4 mm across all GS near the Survey Area. Overall, while conditions were quite dry leading up to both surveys, there was considerable rainfall during each survey month, though this rainfall had high spatial variability.

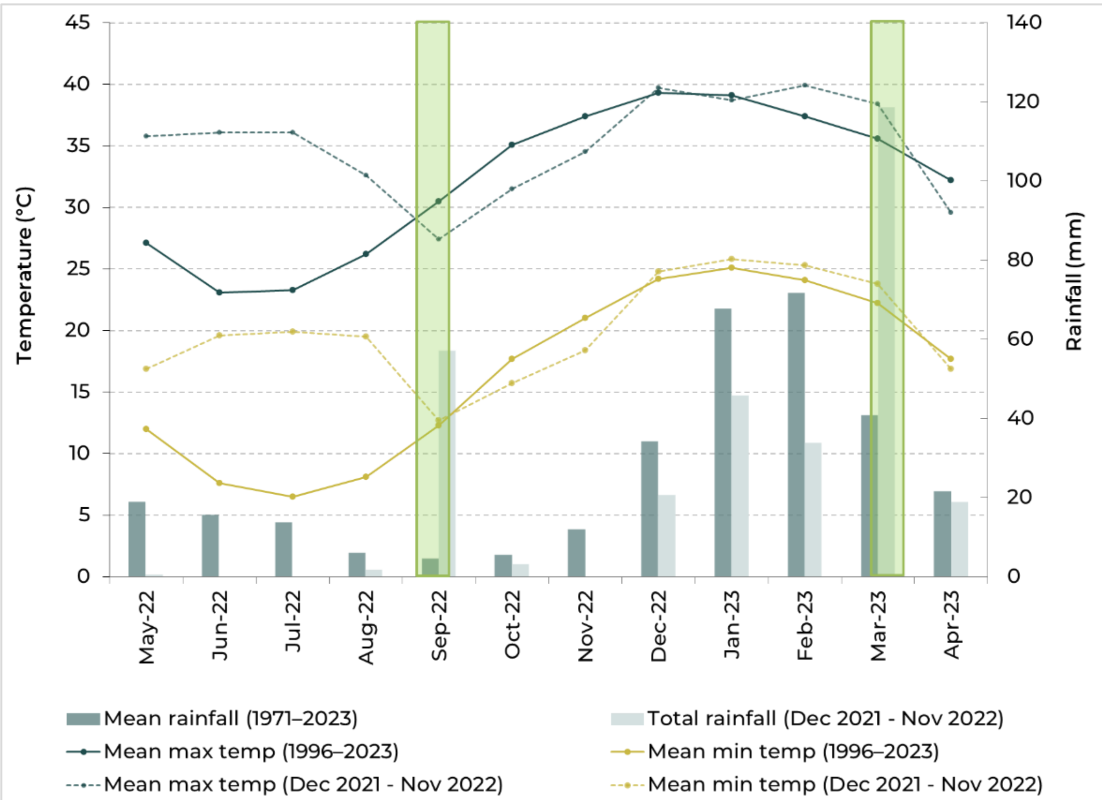


Figure 3.1: Total and long-term average monthly rainfall (mm) recorded from the Newman BoM gauging station in the months preceding the Yandicoogina Creek aquatic survey

Green bars indicate dry and wet season survey timing.

No streamflow stations exist within the Survey Area and the closest stations have no recent data. As such rainfall/streamflow patterns could not be assessed. However, 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.

3.4 Site Selection

A total of eight sites were sampled in both seasons; four located within the Survey Area, and four Reference sites located elsewhere (Table 3.1 and Figure 3.2). Reference sites were selected based on similarities with the Yandicoogina Creek GDE with respect to hydrology, persistence, morphology, and riparian vegetation. A brief description of Survey Area and Reference sites is provided below.

<u>Survey Area</u>

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

<u>Reference Sites</u>

- 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*.
- 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 (2003) 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.

Not all sites in the Survey Area could be sampled in both seasons, as some sites were dry at the time at the time of sampling (Table 3.1). In the Dry 2022, YC2, YC3 and YC4 held water, although YC2 was reduced to a very small pool. Additional hyporheic samples were collected from two extra sites in the dry season, YC5H and YC8H. In the Wet 2023, the majority of the Survey Area was dry, with only YC4 holding water (Table 3.1 and Figure 3.2). Two hyporheic samples were collected from this site in the dry. All Reference sites were inundated in both seasons (Table 3.1).

Table 3.1: Site information and sampling effort

						Sampling effort	
	Creek	Site	Code	Latitude	Longitude	Dry 2022	Wet 2023
Survey Area	Yandicoogina Creek	Yandicoogina Creek 1	YC1	-22.8282	119.1499	d h	d
		Yandicoogina Creek 2	YC2	-22.8275	119.1510	✓	d
		Yandicoogina Creek 3	YC3	-22.8246	119.1637	✓	d
		Yandicoogina Creek 4	YC4	-22.8258	119.1628	✓	✓
		Yandicoogina Creek 4 extra Hypo	YC4eH	-22.8258	119.1628	×	h
		Yandicoogina Creek Hypo 5	YC5H	-22.8245	119.1637	h	×
		Yandicoogina Creek Hypo 6	YC6H	-22.8259	119.1575	d	×
		Yandicoogina Creek Hypo 7	YC7H	-22.8256	119.1604	d	×
		Yandicoogina Creek Hypo 8	YC8H	-22.8253	119.1601	h	×
		Yandicoogina Creek Hypo 9	YC9H	-22.8256	119.1579	d	×
Reference	Weeli Wolli Creek	Weeli Wolli Spring	WWS	-22.9181	119.1994	✓	✓
		Bens Oasis	BENS	-23.0558	119.1509	✓	✓
	Munjina Creek	Munjina Spring	MUNJS	-22.5373	118.7046	✓*	✓*^
	Davis River	Skull Springs	SS	-21.8600	121.0114	✓	✓
		Total number of samples (full suite)				**7**	**5**
		Additional hyporheos samples				**3**	**1**
		Rehydration-emergence samples				**1**	**3**

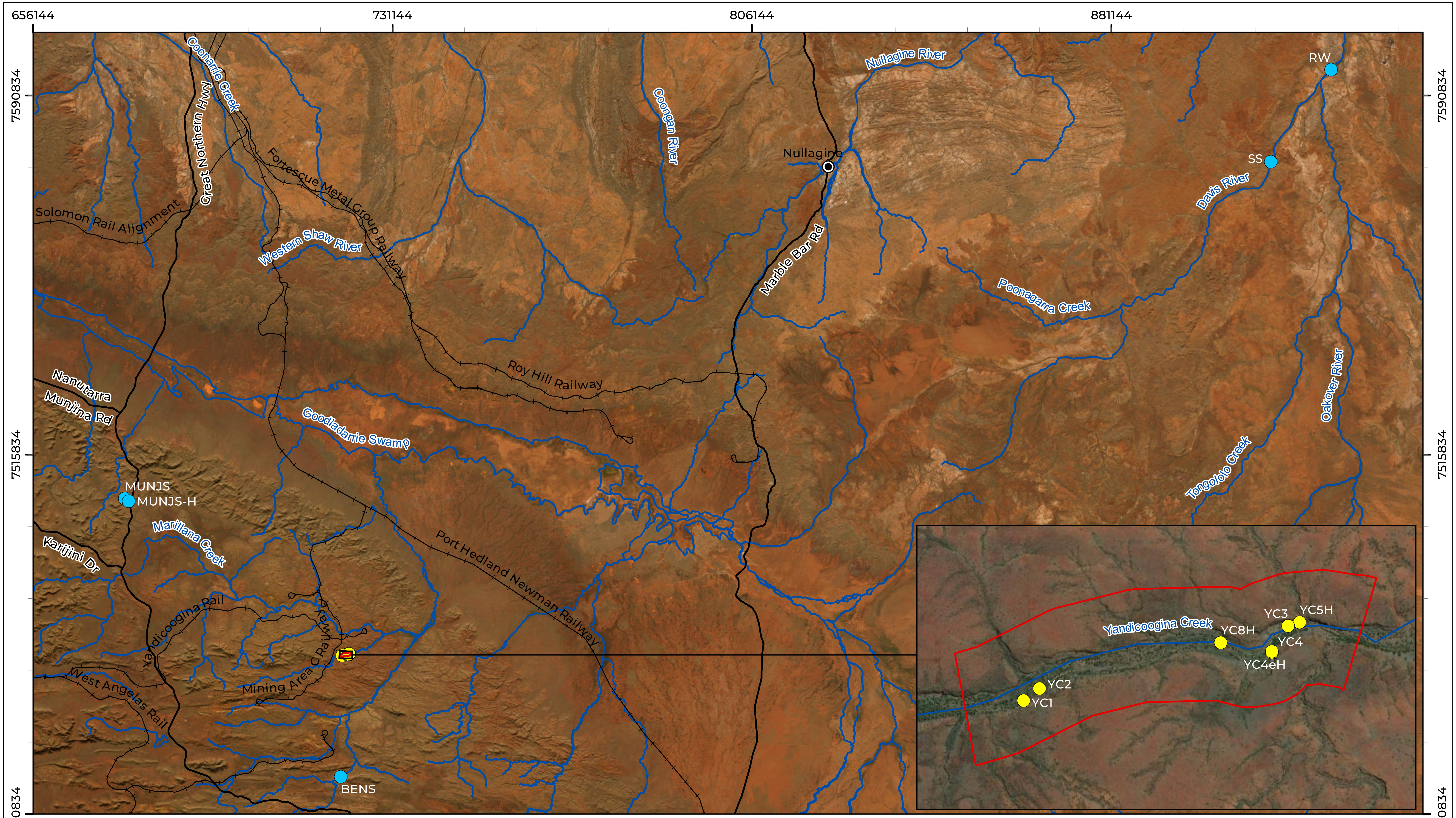
✓ = full suite of sampling methods completed, including water quality, habitat assessment, flora, hyporheos fauna, invertebrates and fish

d = dry at time of sampling, sediments collected, and rehydration-emergence trials undertaken

h = hyporheos sampling undertaken only

✓* = there are no fish present at Reference site MUNJS. Therefore, fish were not sampled at this site

✓^ = water present and most components of the full suite of sampling methods completed, however, no hyporheic sample collected (due to lack of habitat)



LEGEND

Survey Area

State Road

Rail

Major Surface Hydrology

Aquatic Sampling Site

Reference

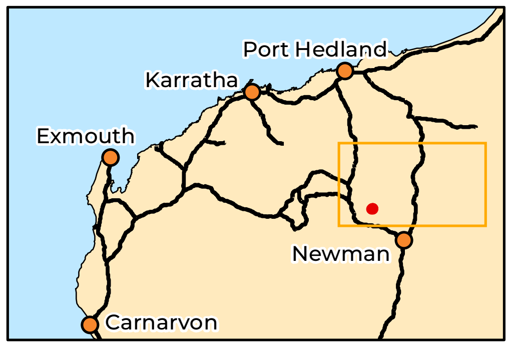
Study Area

Biologic

Scale 1:725,000

0 10 20 30 Km

Coordinate System: GDA 1994 MGA Zone 50
Projection: Transverse Mercator
Datum: GDA 1994 Created 19/07/2023



BHP WAIO
Ministers North Yandicoogina Creek Aquatic Ecosystem Survey Dry 2022 and Wet 2023

Figure 3.3: Aquatic monitoring sites

3.5 Habitat Assessment

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.

3.6 Water Quality

Water quality variables were recorded in situ from each site with a portable YSI Pro Plus multimeter (Plate 3.1). In situ variables included pH, 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.

Plate 3.1: Taking in situ water quality measurements at Reference site MUNJS in the Wet 2022 (Biologic ©)

Water quality variables measured included:

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

- Ionic composition - calcium (Ca), potassium (K), magnesium (Mg), sodium (Na), bicarbonate (HCO_3), chloride (Cl), sulphate (SO_4), carbonate (CO_3), alkalinity and hardness (all mg/L).
- Water clarity – turbidity (NTU) and total suspended solids (TSS).
- 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 mg/L).
- Dissolved metals – aluminium (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 mg/L).

Samples collected for dissolved metals were filtered through 0.45 µm Millipore nitrocellulose filters in the field. 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.

3.7 Macrophytes

Macrophytes (submerged and emergent) and dominant riparian vegetation specimens were collected from each site, where present. Submerged macrophytes were placed in sample containers with sufficient water from the site to ensure collected material did not dry out or degrade. Roots, stem and flowering/fruiting bodies from emergent and riparian sedges, rushes and trees were hand collected, ensuring sufficient material to allow confident identification. The emergent and riparian flora 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.

3.8 Hyporheos Fauna

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. The net was thoroughly cleaned between sites to avoid cross contamination.

Plate 3.2: Sampling the hyporheic zone of YC3 in the Dry 2022 (Biologic ©)

Hyporheic samples were preserved in 95% ethanol, kept cool whilst in the field, and returned to the Biologic laboratory for processing. Hyporheos fauna were removed by sorting under a low power dissecting microscope. Specimens were identified in-house 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). Molecular analysis was used to complement morphological taxonomy for identification of some of the more difficult groups, such as ostracods and amphipods.

3.9 Invertebrates

Aquatic invertebrates were sampled at each site using two separate nets; a 110 µm plankton trawl net to target micro-crustacea, and a 250 µm mesh D-frame pond net for macroinvertebrates. The micro-crustacea (copepods, ostracods and Cladocera) were collected by sweeping through the open water, taking care not to disturb the benthos. For macroinvertebrates, all aquatic microhabitats were sampled with the D-frame pond net, including open water, macrophyte beds, large woody debris, detritus and shoreline/ 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. The kick-sweep method is a commonly used semi-quantitative sampling technique (Armitage & Hogger, 1994; Barbour *et al.*, 1999; DoW, 2009; EPAVictoria, 2021) known to be effective in evaluating biodiversity in aquatic systems (Tubić *et al.*, 2017).

The contents of the D-frame pond net were washed through a 250 µm sieve to remove fine sediment, and leaf litter and other coarse debris were removed by hand. Both nets were thoroughly cleaned between sites to avoid cross contamination. Invertebrate samples were preserved in 95% ethanol and kept cool in the field, prior to being transported to the Biologic laboratory for processing.

In the laboratory, invertebrate samples were sorted 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. All invertebrate groups were identified in-house, with complementary molecular analysis undertaken on some specimens, where required. Micro-crustacea data were added to the main macroinvertebrate dataset for analysis and reporting.

3.10 Rehydrate Emergence Trials

Sediments were collected from dry sites (i.e., YC1 in the Dry 2022, and YC1, YC2 and YC3 in the Wet 2023) to enable rehydration and emergence trials to be conducted in the Biologic laboratory. The aim of these trials was to obtain information on the types of resident fauna the creek supports by identifying those which emerge from desiccation-resistant resting stages following inundation and rehydration. This provides information on aquatic ecosystem values in the absence of surface water.

In the field, sediment samples were collected from areas with low elevation in relation to surrounding topography, i.e., areas that likely hold water after a rainfall event. Approximately 2 kg of surficial sediment was collected from the top 5-10 mm, and samples placed in labelled, breathable calico bags. Each sample was kept in a cool, dark place.

In the Biologic laboratory, each sediment sample was rehydrated in tanks flooded with 7 L of dechlorinated filtered water. Rehydration was undertaken in a controlled temperature room maintained at a temperature comparable to conditions in the field at the time of collection, with a 12-hour light/12-hour dark cycle. Samples were examined every 24 to 48 hours for emergent fauna for up to 58 days after rehydration, or until no new fauna emerged. As cues for emergence and colonisation rates are different for different species, samples were allowed to dry after 28 days and re-wetted, to simulate a second flooding event. Animals were fed on algal pellets for the duration of the emergence trials. Emergent fauna and macrophytes were identified to the lowest level possible, and abundance recorded on a $\log_{10}$ abundance scale.

Water quality was measured every few days over the course of the trial to ensure the water temperature and DO were appropriate for emergence/germination. The EC of surficial waters in rehydration tanks also reflects the dissolution of salts stored in the creek bed sediments, and so provides an indication of the salinity of the creeks when inundated.

3.11 Fish

Fish sampling included a variety of methods to collect as many species and individuals as possible. Methods included the use of light-weight fine mesh gill nets (10 m net with a 2 m drop, using 10 mm, 13 mm, 19 mm, and 25 mm stretched mesh) set across the creek/pool (Plate 3.3), 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 LWD, and up to three seine hauls undertaken per site.

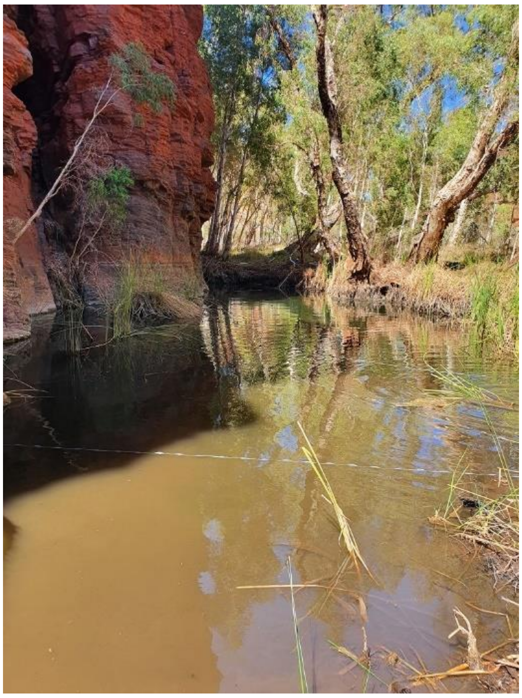


Plate 3.3: Gill nets set across the creek at YC4 in the Wet 2023 (Biologic ©)

3.12 Other Aquatic Fauna

Other aquatic fauna (i.e., turtles, olive pythons, frogs) observed over the course of the survey were recorded for each site. Any introduced species captured were also measured and processed. This included the introduced redclaw crayfish (*Cherax quadricarinatus*). Any crayfish captured were sexed and carapace length (CL) measurements taken. As per DPIRD licencing exemption conditions, no introduced species were released, but instead euthanised humanely using AQUI-S to anaesthetise them before being placed in an ice slurry. Locations of introduced redclaw were reported to DPIRD in accordance with licence conditions.

3.13 Data Analysis

3.13.1 Water Quality

3.13.1.1 Default Guidelines

In the absence of site-specific guideline values (SSGVs) for the Survey Area, water quality data were compared against the ANZG (2018) default 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. All sites sampled in the current study show evidence of varying levels of impact from pastoral use, human activity and introduced species. Therefore, they were classified as slightly to moderately disturbed systems and the 95% toxicity 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). These protection levels are based on the following system types and outcomes:

- 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[2].
- 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.

[2] 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) or updated DGVs. 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.

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 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 (stressor), above which nutrient concentrations are such that algal blooms and eutrophic conditions can be expected (nitrogen oxides, total nitrogen, and total phosphorus).

3.13.1.2 Univariate Analysis

Water quality data were compared to the previous Ministers North surveys using two-way ANOVA to test for difference in concentrations between sampling events (Dry 2019, Wet 2020, Dry 2020, Wet 2021, Dry 2021, Wet 2022, Dry 2022 and Wet 2023) and site type (Survey Area vs Reference sites). Equality of variances was assessed using the Levene's test. All univariate analyses were undertaken in SPSS (subscription build 1.0.0.1447).

Change over time was also investigated for sites which have been successfully sampled on almost all occasions. This included YC3 (all but the Wet 2023 successfully sampled) and YC4 within the Survey Area, and Reference sites WWS and SS. Concentrations of various water quality analytes were plotted and trendlines and linear regression undertaken to determine whether there were any strong relationships between water quality variables and time.

3.13.2 Macrophytes

3.13.2.1 Univariate Analysis

Change in macrophyte richness (submerged and emergent) over time was assessed at YC3, YC4, WWS and SS. This involved plotting richness recorded during each sampling event, creating trendlines and undertaking linear regression to examine the strength of any correlations observed. Two-way ANOVA was undertaken on total macrophyte richness (submerged + emergent) to determine whether there were any significant differences in richness between sampling events and site types.

3.13.3 Invertebrates

3.13.3.1 Classifications, significance and distributions

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
- Stygoxene - species that appear rarely and apparently at random in groundwater habitats, are there by accident and do not have specialised adaptations for groundwater habitats.

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 this cannot be stated 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), and Priority Fauna recognised by the DBCA (see Appendix A). In addition, species were assigned to one of the following categories based on species' distributions:

- Cosmopolitan – found widely across the world.
- Australasian – distributed across Australia, New Guinea and neighbouring islands, including those of Indonesia.
- Australian endemic –only found in Australia.
- Northern Australia – recorded across the northern, tropical regions of Australia.
- North-western Australia – found across northern WA, including the Pilbara and Kimberley regions.
- Western Australian endemic –known only from WA
- Pilbara endemic - restricted to the Pilbara region of WA
- Short range endemic (SRE) – occupies 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.

- Indeterminate distribution – taxa which could not be assigned to one of the above due to insufficient knowledge, either on its distribution or taxonomy to assess the level of endemism.

3.13.3.2Univariate Analysis

Invertebrate data was compared to the previous Ministers North surveys using two-way ANOVA to test for difference in richness (hyporheos fauna taxa richness and macroinvertebrate taxa richness) between sampling events and site type. Equality of variances was assessed using the Levene's test. To undertake this comparison, the dataset had to be amalgamated. For macroinvertebrates, this meant that the micro-crustacea data from previous surveys were incorporated into the dataset. As this survey constitutes the fourth round of sampling within the Survey Area, the three-year zooplankton baseline is now complete. However, micro-crustacea are still sampled, with these taxa included in the macroinvertebrate list for this and previous surveys (to allow appropriate comparisons between datasets). Change in invertebrate richness over time was assessed using linear regression for YC3, YC4, WWS and SS.

3.13.3.3Multivariate Analysis

Macroinvertebrate assemblage data was also 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). Differences in assemblages between sampling events and site type were investigated using Two-way Analysis of Similarity (ANOSIM). Multivariate analysis was undertaken on the current survey (Dry 2022 and Wet 2023) as well as the complete Ministers North dataset (all years).

Using macroinvertebrate data from the Survey Area only, across all sampling events, the relationship between macroinvertebrate assemblages and environmental characteristics (water quality and habitat) was assessed in PERMANOVA using a distance-based linear model (DistLM) (Anderson *et al.*, 2008). This model finds linear combinations of the environmental variables that best predict patterns in the biotic data set (Anderson *et al.*, 2008). Prior to analysis, environmental data was examined using draftsman plots to assess whether the distributions of the covariables were skewed. Transformations (natural log) were made where appropriate. Percentage data was transformed using arcsin transformations on proportions. Once all appropriate transformations had been undertaken, the environmental data was normalised in PRIMER prior to analysis.

3.13.4 Fish

Analysis of population structure and age-class distribution 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 recorded from the Survey Area (spangled perch, western rainbowfish, and Pilbara tandan), 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 3.2).

Table 3.2: Standard lengths used for each age class for each fish species

	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	≥ 51	≥ 71	≥ 91

4 Results

4.1 Habitat Assessment

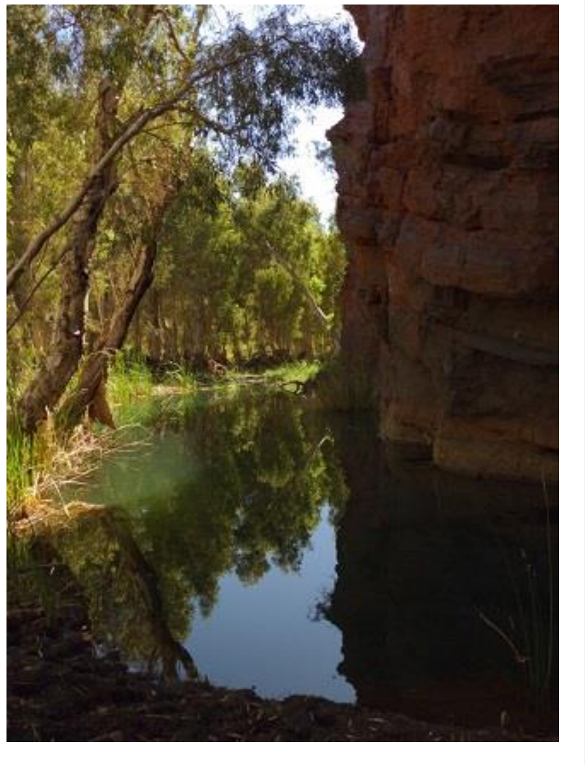
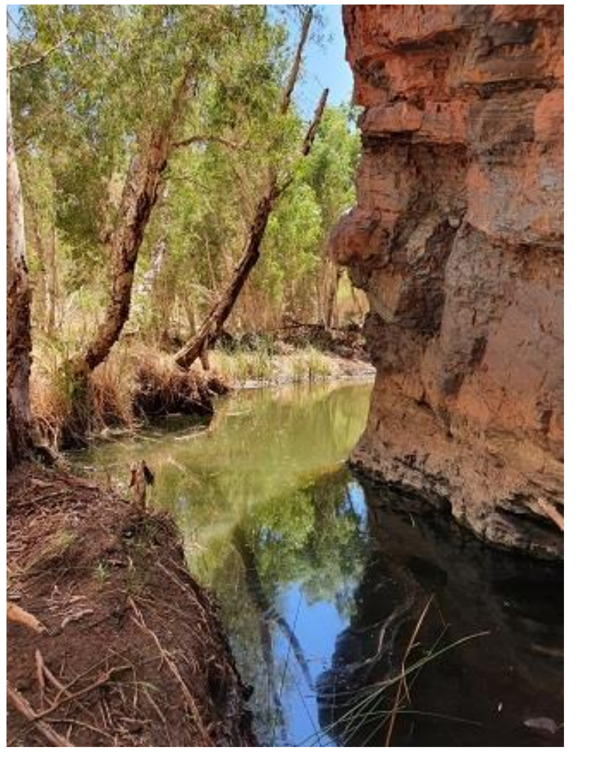
Pools within the Survey Area occur within an extensive closed *Melaleuca argentea* forest, with *Eucalyptus camaldulensis* over *Acacia tumida* var. *pilbarensis* shrubland. *Cyperus vaginatus* and *Typha domingensis* occur along the waterline. Weeds were present throughout the Survey Area. Water levels continue to decline, with no surface water present at YC1 in either season, and YC2 and YC3 in the Wet 2023 (Table 4.1). Sedges such as *Typha domingensis* and *Cyperus vaginatus* were in poor condition at most sites, especially in the Wet 2023, with most plants showing signs of drought stress and appearing to be dead or dying (see site photographs in Table 4.1).

Substrates within the Survey Area were mostly dominated by transmissive sediments such as gravel, pebbles, and sand. At YC4, however, clay and sand dominated the substrate. The creek bed at Reference site MUNJS was different to all others sampled in this monitoring program, being primarily composed of bedrock (Appendix C).

When inundated, most sites within the Survey Area exhibit high in-stream habitat diversity, including complex heterogenous substrates, such as submerged and emergent macrophytes, large woody debris (LWD), root mats, detritus, and trailing vegetation. YC3 and YC4 recorded at least seven discrete habitat types (YC3 = 7 habitat types in the Dry 2022, YC4 = 8 in the Dry 2022, 7 in the Wet 2023), while YC2 had five habitat types in the Dry 2022. This site had receded to a very small pool in the dry season, approximately 0.06 m^2 in area and only 0.1 m deep, and was completely dry in the wet. YC4, which was successfully sampled in both seasons, reduced from a pool of approximately 1,040 m^2 in the Dry 2022 to one around 300 m^2 in the Wet 2023, with maximum pool depth dropping by around 1 m in the intervening 6-month period (Table 4.1). As would be expected from this reduction in pool size, percent cover by trailing vegetation, submerged macrophytes and emergent macrophytes all reduced between seasons. This essentially opened up the pool, leading to increased cattle access and associated impacts, such as trampling of the bank and riparian vegetation, bank erosion, grazing of sedges, and increased turbidity in-stream.

Table 4.1: Summary of aquatic habitats sampled, including site photographs

Site	Pool type	Description	Site Photograph	
			Dry 2022	Wet 2023
YC1	Small pool	Small, shallow seep amongst *Typha*. Overstorey comprising *Melaleuca argentea* and *Eucalyptus camaldulensis*. Dominant emergent vegetation including *Typha domingensis* and *Cyperus vaginatus*. The emergent macrophytes and understorey species were showing signs of water stress, with most being dead or dying by the time of the wet season survey. This site was dry during both the Dry 2022 and Wet 2023 sampling events. In the Dry 2022, the hyporheos was able to be sampled as water was found within the hyporheic zone when a hole was dug.		
YC2	Small pool	Small seep amongst *Typha*. Pool size: Dry 2022 = 0.3 m x 0.2 m Wet 2023 = dry. Maximum water depth: Dry 2022 = 0.1 m Wet 2023 = dry. Riparian vegetation comprising *Eucalyptus camaldulensis* and *Melaleuca argentea* open woodland over patches of sedgeland including highly abundant *Typha domingensis* and some *Cyperus vaginatus*. The emergent macrophytes and understorey species were showing signs of water stress in the wet season, with most being dead or dying. Fringing *Lobelia arnhemiaca* present in the dry season. Mineral substrate comprising cobbles, pebbles, gravel, sand, and silt.		

Site	Pool type	Description	Site Photograph	
			Dry 2022	Wet 2023
YC3	Small pool	Small, shallow seep. Pool size: Dry 2022 = 7 m x 1 m Wet 2023 = dry. Maximum water depth: Dry 2022 = 0.3 m Wet 2023 = dry. *Melaleuca argentea* with scattered *Eucalyptus camaldulensis* as the dominant overstorey. Emergent vegetation comprising *Typha domingensis, Cyperus vaginatus* and *Eleocharis geniculata* sedgeland. Fringing *Lobelia arnhemiaca* present in the dry season. Weeds present, including buffel grass. Mineral substrate comprising gravel, pebbles, cobbles, sand, and silt.		
YC4	Permanent, spring-fed creek pool	Large permanent pool against a cliff face. Pool size: Dry 2022 = 80 m x 13 m Wet 2023 = 30 m x 10 m. Maximum water depth: Dry 2022 = 3 m Wet 2023 =2 m. *Melaleuca argentea* and scattered *Eucalyptus camaldulensis* open woodland over *Typha domingensis* sedgeland. Other emergent macrophytes present include *Cyperus vaginatus, Eleocharis geniculata*, *Schoenoplectus subulatus* and *Fimbristylis sieberiana* (P3). Fringing *Lobelia arnhemiaca* present in both seasons. Submerged macrophyte *Vallisneria nana* present in-stream. Gravel was the dominant mineral substrate followed by clay and sand. This pool has reduced substantially, with *Typha* along the bank either dead or dying. There is obvious cattle access now, and associated impacts, including bank and vegetation trampling, bank erosion, grazing of sedges, increased turbidity in-stream, etc. Two hyporheos samples were collected from this site in the Wet 2023, one from each end of the pool. Although, both were collected primarily from clay substrates.		

Site	Pool type	Description	Site Photograph: Dry 2022	Site Photograph: Wet 2023
YC5H		Not an aquatic sampling site, but the hyporheos was sampled here in the Dry 2022		The hyporheos was dry at this location in the wet season
YC8H		Not an aquatic sampling site, but the hyporheos was sampled here in the Dry 2022		The hyporheos was dry at this location in the wet season
WWS	Spring	Permanent spring on Weeli Wolli Creek comprising a series of pools and interconnecting riffles. Located within Rio Tinto's HD1 discharge area – surface flows maintained by discharge from spurs currently. Pool size: Dry 2022 =90 m x 4 m Wet 2023 =100 x 10 m Maximum water depth: Dry 2022 =1.1 m Wet 2023 =1 m. Overstorey vegetation comprising *Melaleuca argentea* and *Eucalyptus camaldulensis* over a dense shrub layer. Emergent macrophyte comprising *Cyperus vaginatus,* and *Schoenoplectus subulatus*. Fringing *Lobelia arnhemiaca* present in both seasons. WWS is a Priority 1 PEC. Substrate comprising primarily gravel, pebbles, sand, and cobbles.		

<table>
<tr><th rowspan="2">Site</th><th rowspan="2">Pool type</th><th rowspan="2">Description</th><th colspan="2">Site Photograph</th></tr>
<tr><th>Dry 2022</th><th>Wet 2023</th></tr>
<tr><td>BENS</td><td>Spring</td><td>Series of pools and riffles on Weeli Wolli Creek, upstream of the main spring.

Pool size:
Dry 2022 = 200 m x 11 m
Wet 2023 = 30 m x 7 m.

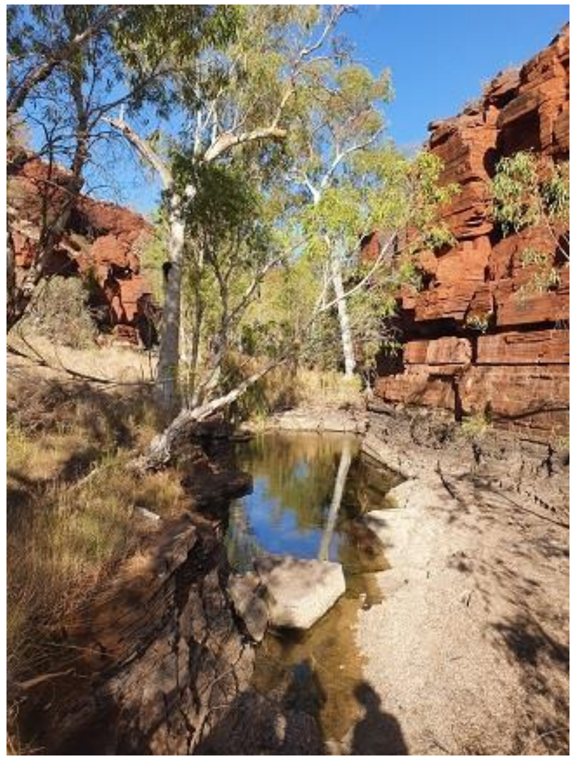
Maximum water depth:
Dry 2022 = 1.5 m
Wet 2023 =0.7 m.

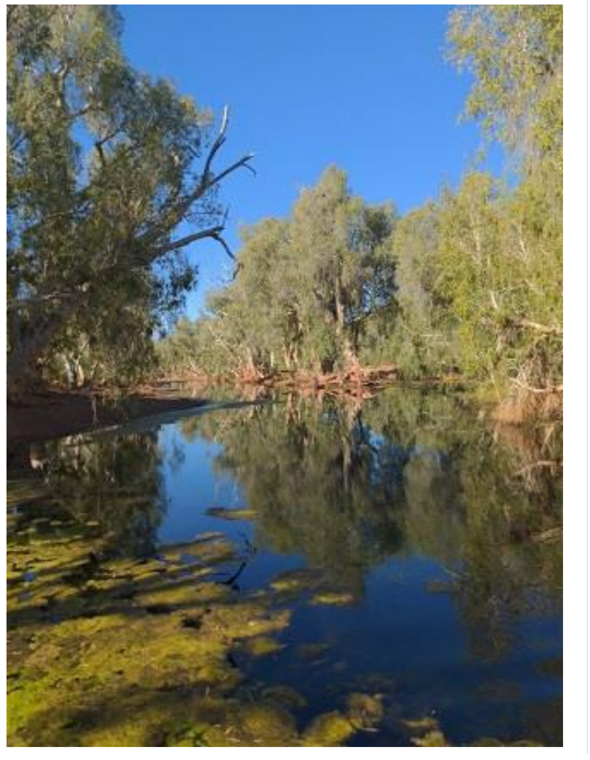
Second occurrence of the WWS PEC, located upstream on Weeli Wolli Creek. Riparian vegetation consisting of Eucalyptus camaldulensis and Melaleuca argentea woodland over Acacia spp. shrubland, and sparse sedges (Cyperus vaginatus). Stylidium weeliwolli (P3) fringing on banks during the dry season, but not the wet season. Detritus and LWD present in-stream. Mineral substrate dominated by transmissive gravel and pebbles, with some sand, silt, bedrock, and boulders.</td><td></td><td></td></tr>
<tr><td>MUNJS</td><td>Permanent creek pools</td><td>A series of long permanent pools over bedrock, with numerous riffle sections.

Pool size:
Dry 2022 = 150 m x 12 m
Wet 2023 = 15 m x 5 m.

Maximum water depth:
Dry 2022 = 4.5 m
Wet 2023 =0.95 m.

Riparian vegetation comprising Eucalyptus camaldulensis, Melaleuca argentea and Melaleuca bracteata. Emergent macrophytes included Typha domingensis, Cyperus vaginatus, Schoenoplectus subulatus, Machaerina juncea, Machaerina rubiginosa, and Eleocharis geniculata. Chara spp., Vallisneria annua and Potamogeton tepperi submerged macrophytes present in-stream. No fish. No obvious signs of disturbance. Stylidium fluminense fringing throughout in the dry. Mineral substrate almost exclusively bedrock overlain by silt and organics.

The main pool was markedly receded in the Wet 2023, having dropped more than 3.5 m since the preceding dry season survey. There was no flow into or out of the pool at this time, unlike all previous surveys at MUNJS since the Dry 2019.</td><td></td><td></td></tr>
</table>

Site	Pool type	Description	Site Photograph Dry 2022	Site Photograph Wet 2023
SS	Spring.	Permanent spring flowing into a series of pools via a braided channel. Pool size: Dry 2022 = 200 m x 22 m Wet 2023 = 200 m x 18 m. Maximum water depth: Dry 2022 = 1.3 m Wet 2023 =1.05 m. Riparian vegetation comprising *Melaleuca argentea* and Acacia coriacea subsp. pendens, as well as sedges (*Cyperus difformis, Cyperus vaginatus Fimbristylis sieberiana* (P3), *Schoenoplectus subulatus* and *Eleocharis geniculata*). High diversity of submerged macrophytes including *Chara fibrosa, Najas marina, Vallisneria annua, Vallisneria nana, Potamogeton tepperi* and *Ruppia* sp. The P2 Priority flora (ground creeper) *Ipomoea racemigera* present. Fringing *Lobelia arnhemiaca* present in the wet season. Mineral substrate heterogenous, dominated by gravel, pebbles, and sand. Disturbances included cattle impacts and introduced vegetation (such as Mexican poppy *Argemone ochroleuca* subsp. *ochroleuca*).		

4.1.1 Habitat comparison with previous surveys

4.1.1.1 Water level

Average maximum pool depth has generally declined in the Survey Area since the Wet 2020, other than a slight increase in the Wet 2022, following a high rainfall event (Figure 4.1). Average maximum depth could not be calculated for the Survey Area in the Wet 2023, as only one site (YC4) held water. It should be noted that this analysis is heavily influenced by YC4, which is a deep pool that has been sampled on all occasions. Overall, there was no significant difference in maximum pool depth between sampling event (Two-way ANOVA; df = 7, F = 0.07, *p* = 0.999) or site type (df = 1, F = 0.295, *p* = 0.590).

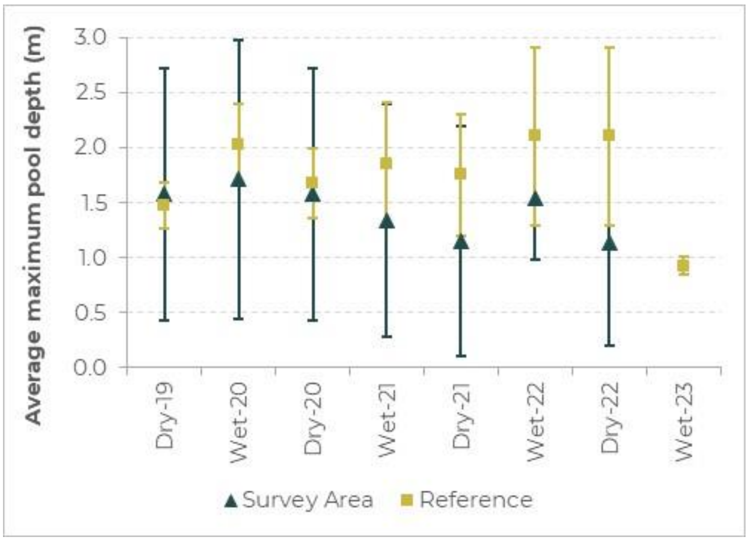


Figure 4.1: Average maximum water depth (m) (± standard error) recorded in each sampling event

To further examine the reduction in water levels at individual sites over time, linear regression was undertaken for sites which have been sampled on almost all occasions (Figure 4.2). There was a strong negative linear relationship between maximum water depth and time at YC4 (r = 0.88), and a weak negative correlation at YC3 (r = 0.37) (Figure 4.2). The weaker relationship at YC3 was due to the shallower depth of this site historically, and therefore, reductions in water level did not appear as severe over time, despite this site being very shallow in the Dry 2021 (0.1 m) and completely dry in the Wet 2023 (Figure 4.2). Negative linear relationships were also recorded from Reference sites WWS and SS, but these reductions in water level were due to pool infilling with sediment following wet season floods.

Figure 4.2: Change in maximum water depth (m) over time

4.1.1.2 Macrophyte cover

Change in macrophyte percent cover was examined using linear regression for sites which have been successfully sampled on all occasions. There was no relationship between cover by submerged macrophytes and time at YC3 (r = 0.15) or WWS (r = 0). At YC4, there was a strong negative relationship (r = 0.94), with submerged macrophyte cover found to be declining over time (Figure 4.3). A similar relationship was also recorded at Reference site SS (r = 0.87), however, this was likely due to habitat recordings being made in different locations across the large site between sampling events, rather than any real reductions in submerged macrophytes overall.

Percent cover by emergent macrophytes has declined over time at both YC3 (r = 0.83) and YC4 (r = 0.81; Figure 4.4). At Reference sites, there was no relationship between emergent macrophyte cover and time at SS (r = 0.40), but a negative correlation at WWS (r = 0.72). The latter is impacted by discharge from Rio Tinto's HD1, and perhaps does not constitute the most appropriate Reference site. However, it was included due to similarities in hydrology (historic spring) and riparian flora (dominance of *Melaleuca argentea*) with the Survey Area, of which few sites in the Pilbara compare.

Figure 4.3: Submerged macrophyte cover (%) regression showing change in cover over time

Figure 4.4: Emergent macrophyte cover (%) regression showing change in cover over time

4.2 Water Quality

All raw water quality data are provided in Appendix D.

4.2.1 In situ

DO was low in comparison to the lower ANZG (2018) DGV at all sites, except Reference site SS in the Dry 2022 (Figure 4.5), likely reflecting the low water levels, particularly in the Survey Area. The very small pool remaining at YC2 in the dry season recorded exceptionally low DO (7.5%). The low water levels at this site also affected EC, with slightly higher values recorded in the Dry 2022 than the rest of the Survey Area, in either season (Figure 4.5).Despite this, EC was fresh at all Survey Area and Reference sites (Figure 4.5).

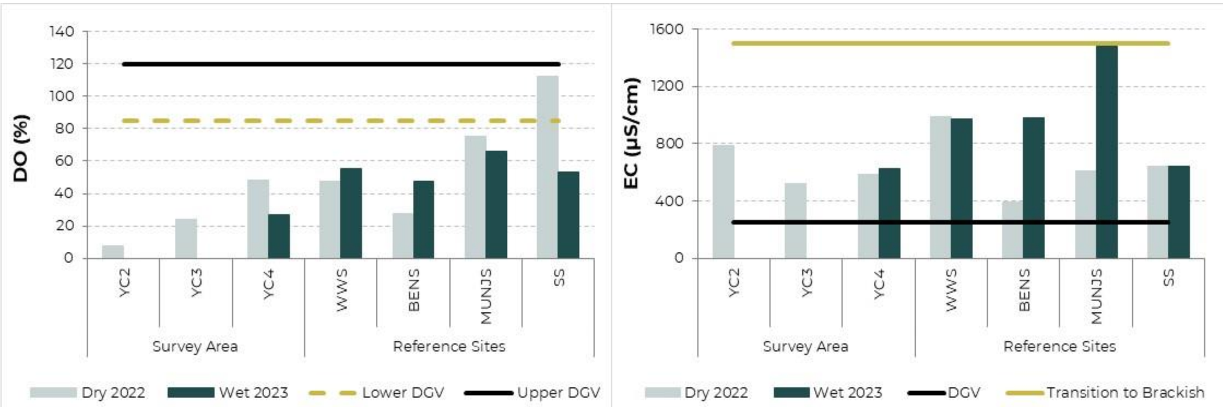


Figure 4.5: DO (left) and EC (right) recorded in each season

Surface water pH within the Survey Area was circum-neutral, with little variability between sites (Appendix D). Lowest pH was recorded from YC2 in the dry season (7.47) and highest was recorded from YC3 (7.86), also in the dry. Reference sites ranged from neutral at WWS in in the wet (7.25) to basic (8.71 at MUNJS in the Wet 2023). Only two sites exceeded the upper ANZG (2018) DGV, both of which were Reference sites (SS and MUNJS). No pH value from any site was considered to be of ecological concern.

4.2.2 Ionic composition and Alkalinity

In the Survey Area, surface waters at all sites were dominated by HCO_3 anions in both seasons. Cation dominance varied between sites, with YC2 and YC3 dominated by Ca, and YC4 dominated by Na (in both seasons). In the dry season, Weeli Wolli Creek Reference sites (BENS and WWS) were dominated by Ca and HCO_3, but in the wet, concentrations of Mg were slightly greater than Ca. The MUNJS Reference site was dominated by Na and Cl in both seasons, while SS experienced some seasonal variation, with Ca and HCO_3 dominance in the dry, and Na and HCO_3 dominance in the wet.

The lowest alkalinity in the current study was recorded from YC2 in the dry season (132 mg/L). Alkalinity of less than 20 mg/L is considered low, and the system would have limited ability to buffer against rapid changes in pH. As such, surface waters of all Survey Area and Reference sites are well-buffered.

4.2.3 Turbidity

Turbidity was generally low, and below ANZG (2018) DGVs, at both Survey Area and Reference sites (Appendix D). The only exception was YC2 in the Dry 2022, when turbidity was 450 NTU. This was thirty times greater than the DGV.

4.2.4 Nutrients

Concentrations of nitrogen nutrients were low in comparison to ANZG (2018) toxicity DGVs. In the Survey Area, ammonia concentrations ranged from values less than detection (LOD; < 0.01 mg/L) at YC3 in the dry, to 0.23 mg/L at YC2, also in the dry. All values were below the ANZG (2018) 99% toxicity DGV (i.e., < 0.32 mg/L; Appendix D). Nitrate concentrations were similarly low, with no exceedances of the ANZG (2018) 99% toxicity DGV[3] recorded from either Survey Area or Reference sites (see Appendix D). Concentrations of nitrate ranged from LOD (at YC2, BENS and MUNJS in the dry, and YC4 and MUNJS in the wet) to 0.25 mg/L (at Reference site SS in the wet).

Survey Area sites also recorded low concentrations of nitrogen nutrients in comparison to eutrophication DGVs (ANZG, 2018). Only one Survey Area site recorded elevated concentrations of N_NOx (YC2), and no Survey Area sites recorded elevated total N (Figure 4.6). In contrast, Reference sites WWS and SS recorded elevated N_NOx in both seasons, while total N at MUNJS and SS exceeded the eutrophication DGV in the wet season (Figure 4.6).

Concentrations of total phosphorus were variable, ranging from LOD at YC3, BENS and MUNJS in the dry season, to 0.074 mg/L at Reference site YC2 in the dry (Figure 4.7). Concentrations of total P were in excess of the eutrophication DGV at all sites in at least one season, with the exception of YC3 (Figure 4.7).

[3] 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).

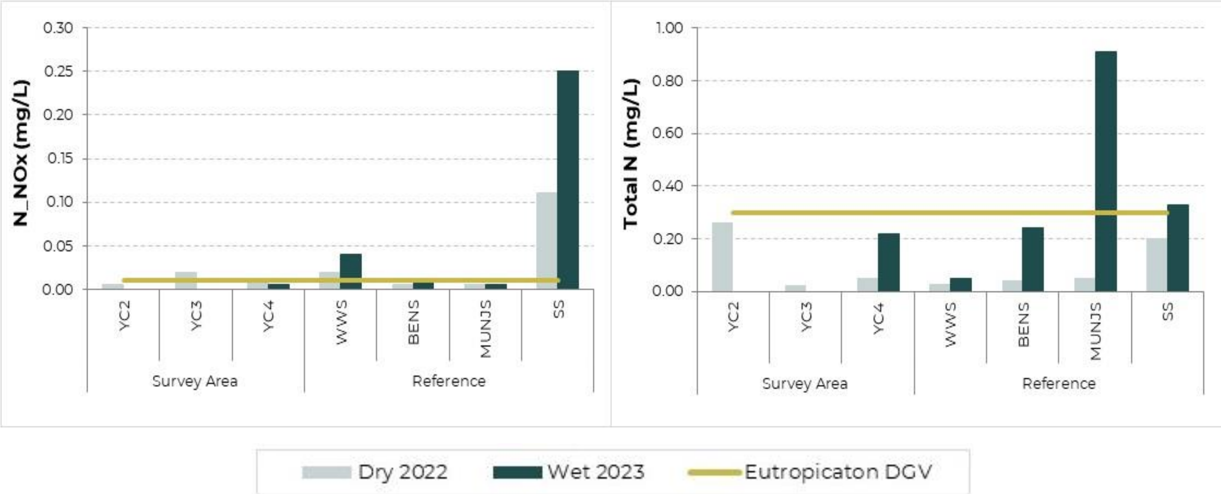


Figure 4.6: Concentrations of N_NOx (left) and total N (right) recorded in each season

Figure 4.7: Concentrations of total P recorded in each season

4.2.5 Dissolved metals

Apart from concentrations of dB, dissolved metals were generally low throughout the Survey Area (Appendix D). Concentrations of dB were elevated in comparison to the 99% toxicity DGV at all Survey Area and Reference sites except BENS in the dry (Figure 4.8). No dB concentrations exceeded the 95% toxicity DGV. The only other exceptions were dFe and dZn, both of which were in excess of DGVs at YC2 in the dry season (Figure 4.8 and Appendix D). In the case of dFe, concentrations exceeded the low reliability trigger[4] at YC4 as well, but no

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

Reference sites (Figure 4.8). Dissolved Zn was elevated in comparison to the 99% toxicity DGV at YC2, but all other concentrations within the Survey Area and Reference sites were low, and generally below the LOD (Appendix D).

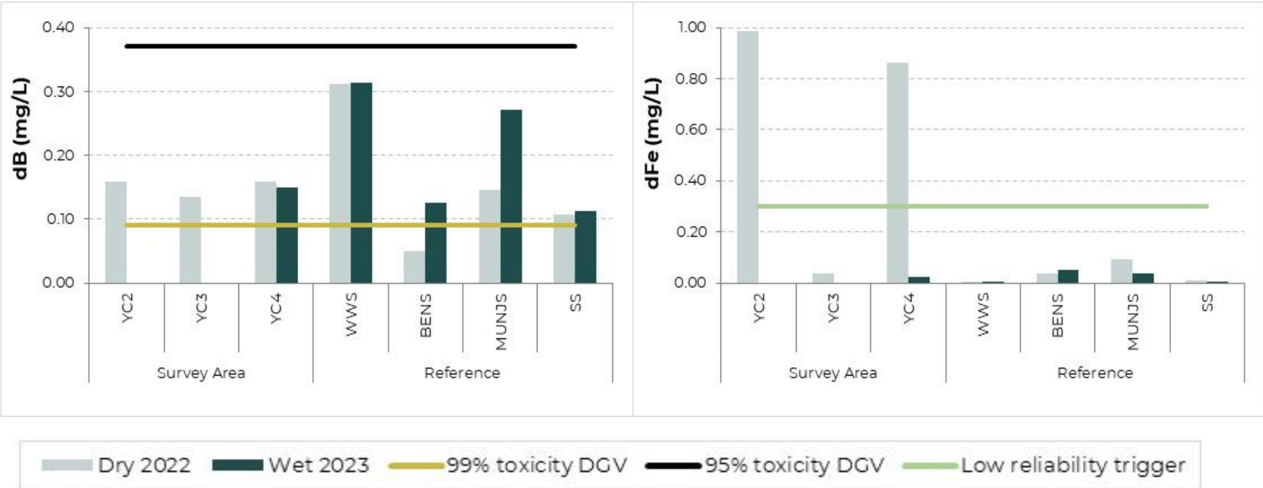


Figure 4.8: Concentrations of selected dissolved metals recorded in each season

4.2.6 Water quality comparison with previous surveys

Current water quality data were compared to all previous Ministers North aquatic sampling events since the Dry 2019. Several analytes were found to be significantly lower in the Survey Area compared to Reference sites, including EC, pH and DO %, as well as concentrations of dCu, dAs, dBa, dU, and dV (Two-way ANOVA; df = 1, $p < 0.05$; Figure 4.9). Total phosphorus and dFe concentrations, however, were significantly greater in the Survey Area than Reference sites (Figure 4.9). In the case of S_SO_4, there was no significant difference in concentration between site type (Two-way ANOVA; df = 2. F = 2.78, p = 0.103) or sampling event (df = 7, F = 0.94, p = 0.488), but there was a significant interaction term (df = 7, F = 2.51, p = 0.030). The significant interaction indicated that the pattern of change was not consistent across all sampling events. This was because concentrations of S_SO_4 were greater at Reference sites between the Dry 2019 and Dry 2020, but after this time there was a switch, when higher S_SO_4 concentrations were recorded from the Survey Area (Figure 4.9).

Total phosphorus and dFe both recorded significant differences in concentrations between sampling events. For dFe, significantly lowest concentrations were recorded in the Dry 2019 and Dry 2021, with significantly highest concentrations being recorded in the Dry 2022 (Figure 4.9). There was no apparent seasonal or temporal pattern to these sampling event differences. This was reflected in the linear regression, where no linear correlations were recorded between dFe and time for Survey Area sites YC3 (r = 0.51) or YC4 (r = 0.44), or Reference sites WWS (r = 0.56) or SS (r = 0.57) (Figure 4.10).

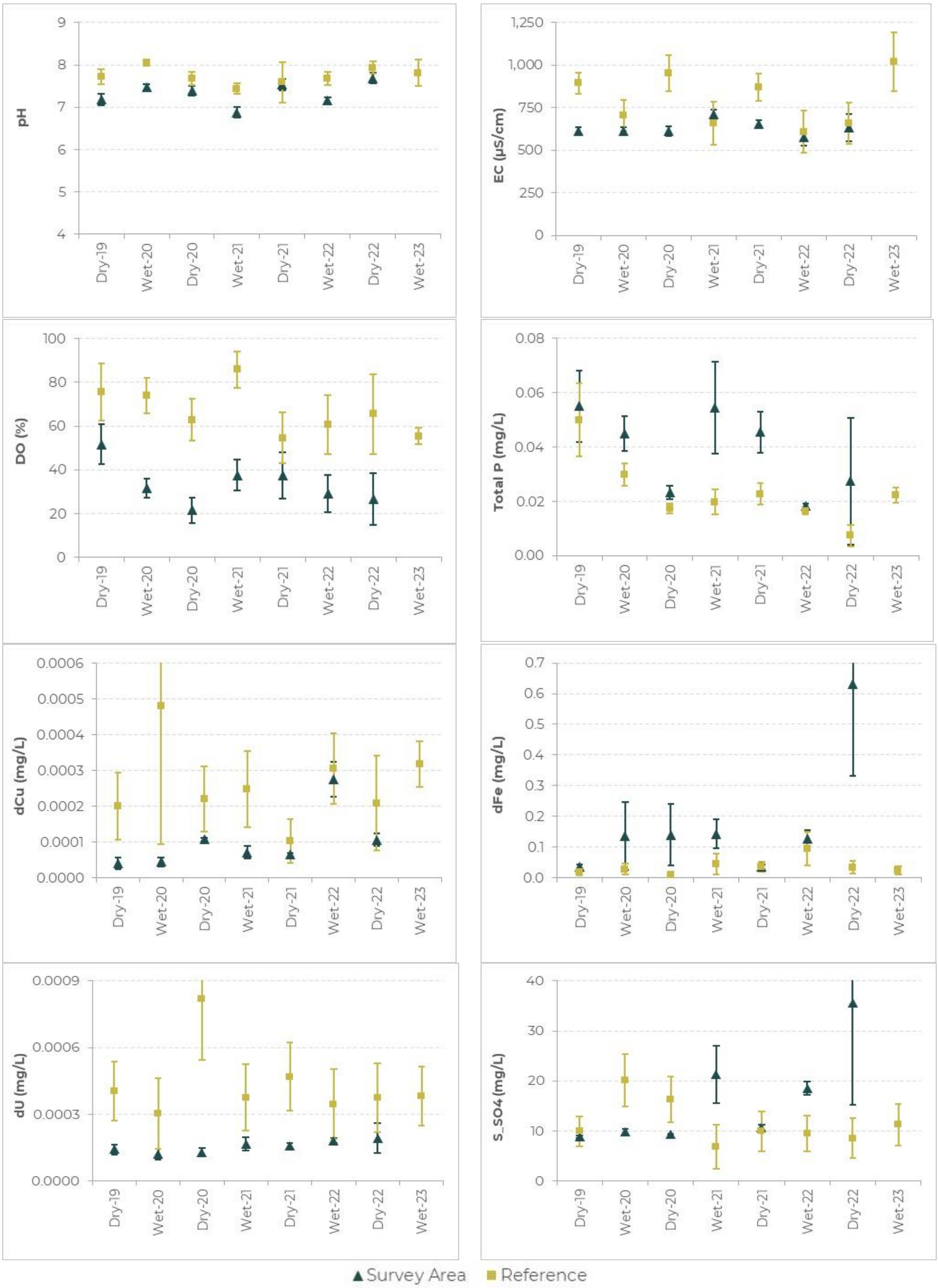


Figure 4.9: Average concentration of selected water quality analytes (± standard error) recorded in each sampling event

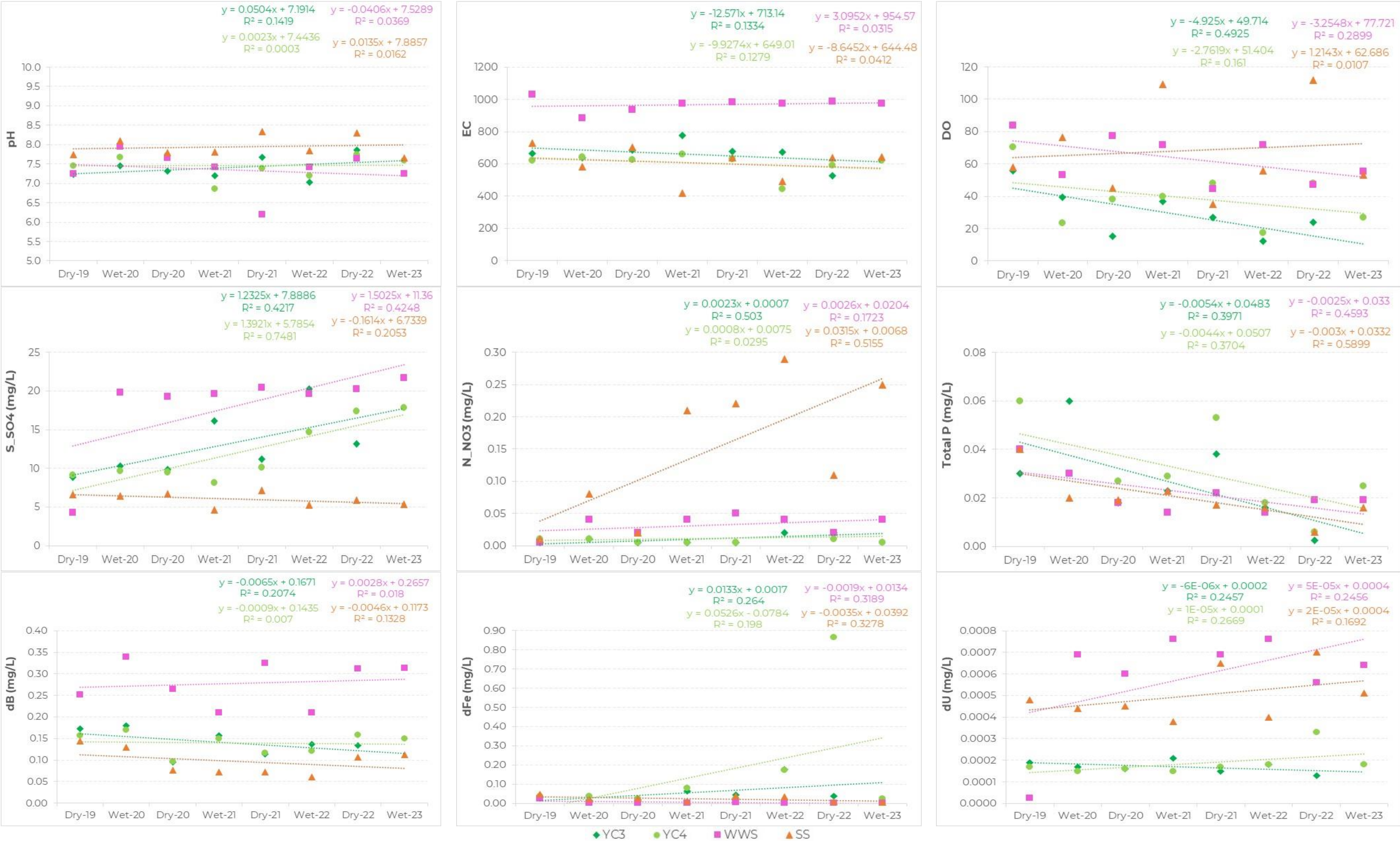


Figure 4.10: Change in concentration of selected water quality analytes over time

For total P, significantly lower concentrations were recorded in the Dry 2022, Wet 2022 and Dry 2020, while significantly highest total P was recorded in the Dry 2019 (Figure 4.9). This indicated a general decline in total P over time across both the Survey Area and Reference sites, which was supported by the linear regression plots for YC3 (r = 0.63), YC4 (r = 0.61), WWS (r = 0.68), and SS (r = 0.77) (Figure 4.10).

Several other analytes also recorded linear changes over time at individual Survey Area sites, despite concentrations being statistically similar between sampling events overall. This included DO, S_SO_4 and N_NO_3. DO experienced a decrease in percent saturation at YC3 over time (r = 0.70). A minor negative correlation (r = 0.54) was recorded from WWS, suggesting a generally decreasing trend in DO over time at this site as well (Figure 4.10). No decline in DO was observed at YC4 or SS. In the case of S_SO_4 and N_NO_3, concentrations have increased over time, with positive correlations recorded for S_SO_4 at YC3 (r = 0.65), YC4 (r = 0.86), and WWS (r = 0.65), and for N_NO_3 at YC3 (r = 0.71) and Skull Springs (r = 0.72) (Figure 4.10).

4.3 Macrophytes

4.3.1 Macrophyte taxa composition and richness

Overall floristic richness ranged between 15-20 taxa within the Survey Area, with maximum numbers recorded at YC1 and YC3 (Appendix E). Floristic diversity was comparatively greater at Reference sites, ranging between 19-36 taxa with maximum numbers recorded from WWS and SS (Appendix E).

Seven macrophytes were recorded from the Survey Area, comprising five emergent macrophytes and two submerged macrophytes (Figure 4.11; Appendix E). An additional five emergent and five submerged macrophytes were recorded from Reference sites (Figure 4.11; Appendix E). Other dominant riparian flora recorded from the Survey Area included the GDV species *Melaleuca argentea* and *Eucalyptus camaldulensis* as well as various herbs, shrubs, and grasses associated with creeks (e.g., *Acacia coriacea* var. *pendens, Pluchea rubelliflora*, *Stemodia grossa, Vigna lanceolata* var. *lanceolata*; Appendix E).

Emergent macrophytes recorded from the Survey Area included *Cyperus vaginatus, Schoenoplectus subulatus, Typha domingensis, Eleocharis geniculata* and *Fimbristylis sieberiana*. The former three were present at all Survey Sites, while the latter two were present at YC4 only (Appendix E).

A greater richness of emergent macrophytes was recorded from Reference sites. Additional species included *Cyperus cunninghamii* subsp. *cunninghamii*, *Machaerina juncea* and *Machaerina rubiginosa* recorded at MUNJS, *Cyperus difformis* recorded from SS, and *Cladium procerum* from WWS. All Reference sites supported *Cyperus vaginatus, Typha* *domingensis* and *Eleocharis geniculata* (except BENS). *Schoenoplectus subulatus* was also present at WWS, MUNJS and SS and *Fimbristylis sieberiana* was present at SS.

Submerged macrophytes recorded from the Survey Area comprised *Vallisneria nana* (at YC4) and *Chara globularis* (at YC3). Again, Reference sites recorded a greater richness of submerged macrophytes than the Survey Area. Species included *Vallisneria nana*, *Najas marina* and *Ruppia* sp. (from SS), *Chara globularis* (from MUNJS), as well as *Chara fibrosa, Vallisneria annua* and *Potamogeton tepperi* (from MUNJS and SS). No submerged macrophytes were present at YC1 and YC2 as these sites were dry during both the Dry 2022 and Wet 2023 surveys. However, *Vallisneria* sp. did emerge during the rehydration trials from sediments collected from these sites (see section 4.6), indicating the presence of submerged macrophytes within the seed bank at YC1 and YC2.

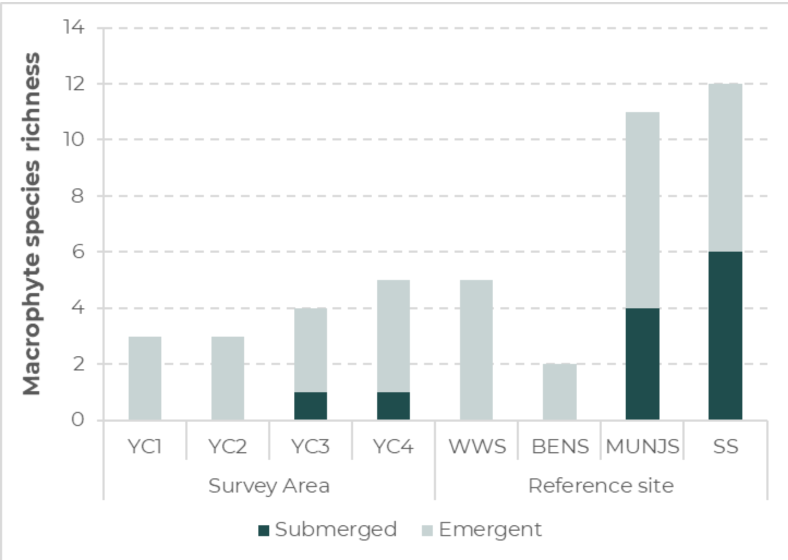


Figure 4.11: Macrophyte richness recorded from each site

4.3.2 Groundwater dependent species

The presence of certain flora species can indicate consistently shallow groundwater and/or perennial surface water (see section 2.3.1). The degree to which these species are associated with groundwater and therefore indicate a GDE, can be classified into Very High, High and Moderate-High indicators (Rio Tinto, 2022). In the current study, a total of two Very High indicator species (mature and abundant *Melaleuca argentea* and *Eucalyptus camaldulensis*), six High indicator species (open, scattered or sporadic *M. argentea* and *E. camaldulensis*, as well as *Fimbristylis sieberiana*, *Lobelia arnhemiaca*, *Vallisneria* sp. and *Eragrostis elongata*) and two Moderate-High indicator species (*Eleocharis geniculata* and *Kirganelia baccata*) were present within the Survey Area. One additional Very High indicator species, *Imperata cylindrica*, is known to occur within the Survey Area, near YC4.

4.3.3 Significant flora

Four species of significant flora were recorded in the current study, one of which was recorded within the Survey Area. *Fimbristylis sieberiana* is a Priority 3 (P3) species (DBCA, 2022), and was recorded from YC4 and Reference site SS. It is described as a shortly rhizomatous tufted perennial sedge which flowers between May and June. It occurs along drainage lines (WAH, 1998 -). *Cladium procerum* is a Priority 2 (P2) species (DBCA, 2022), and was recorded from WWS. It is a densely tufted perennial sedge which occurs along perennial pools (DBCA, 2022).

The remaining priority species were both annual herbs and included *Ipomoea racemigera* and *Stylidium weeliwolli* (Plate 4.1). Both are listed as DBCA Priority Species, P2 and P3, respectively (DBCA, 2022). The former was recorded from SS and the latter from BENS. *Stylidium weeliwolli* is considered to be an indicator of semi-permanent to permanent surface water availability (Rio Tinto, 2022).

Plate 4.1: The priority herb, *Stylidium weeliwolli* (P3), recorded from BENS (Biologic ©)

4.3.4 Introduced flora

Six introduced flora species were recorded from the Survey Area. These were clustered yellow tops (*Flaveria trinervia*), Indian weed (*Sigesbeckia orientalis*), coatbuttons (*Tridax procumbens*), buffel grass (*Cenchrus ciliaris*), natal bush (*Melinis repens*) and whorled pigeon grass (*Setaria verticillata*). Buffel grass was also recorded from Reference site SS. Additional introduced species recorded from Reference sites included prickly lettuce (*Lactuca serriola*), asthma plant (*Euphorbia hirta*), stinking passionflower (*Passiflora foetida*), Mexican poppy (*Argemone ochroleuca* subsp. *ochroleuca*), black berry nightshade (*Solanum nigrum*) and purpletop chloris (*Chloris barbata*).

None of these species are listed as Weeds of National Significance (WoNS) or Declared Pests (DPIRD, 2022). However, buffel grass, whorled pigeon grass, stinking passionflower and purpletop chloris are all considered to be highly invasive and have high ecological impact (DBCA, 2013). These plants disrupt ecological processes by dominating and/or significantly altering vegetation structure, composition or function (DBCA, 2013). Indian weed, Mexican poppy and black berry nightshade are all considered to establish and spread rapidly (DBCA, 2013).

4.3.5 Macrophyte comparison with previous studies

Overall floristic richness in the Survey Area was greater than the previous year by an average of three taxa. However, the Survey Area recorded one less species of macrophyte and double the number of invasive species, compared to the previous year (Biologic, 2023c).

Average submerged macrophyte richness showed similar trends over time, in both the Survey Area and Reference sites, with taxa richness consistently greater at Reference sites (Figure 4.12). Trends were generally seasonal, with submerged macrophyte richness being greatest in the dry.

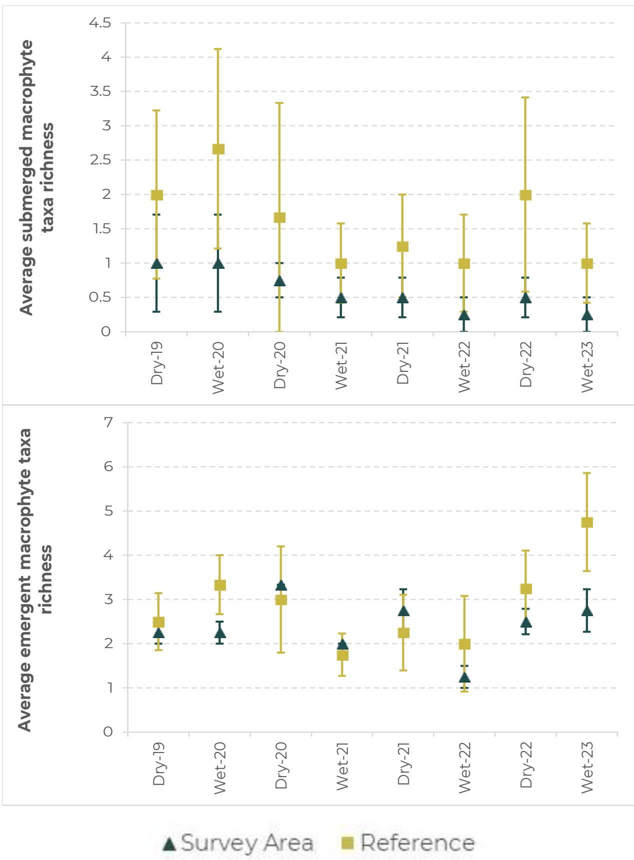


Figure 4.12 Average submerged and emergent macrophyte taxa richness (± standard error)

Emergent macrophyte richness also experienced similar trends over time in both the Survey Area and Reference sites (Figure 4.12). Average taxa richness was generally more comparable between site types, other than in the Wet 2023 when the Survey Area recorded considerably lower richness. There was no obvious change in average emergent macrophyte richness over time within the Survey Area (Figure 4.12).

Total macrophyte richness (submerged + emergent) has generally decreased over time at YC4, although this linear relationship was relatively weak (r = 0.51). There was no apparent linear trend in total macrophyte richness at YC3, or either of the Reference sites included in this analysis (Figure 4.13).

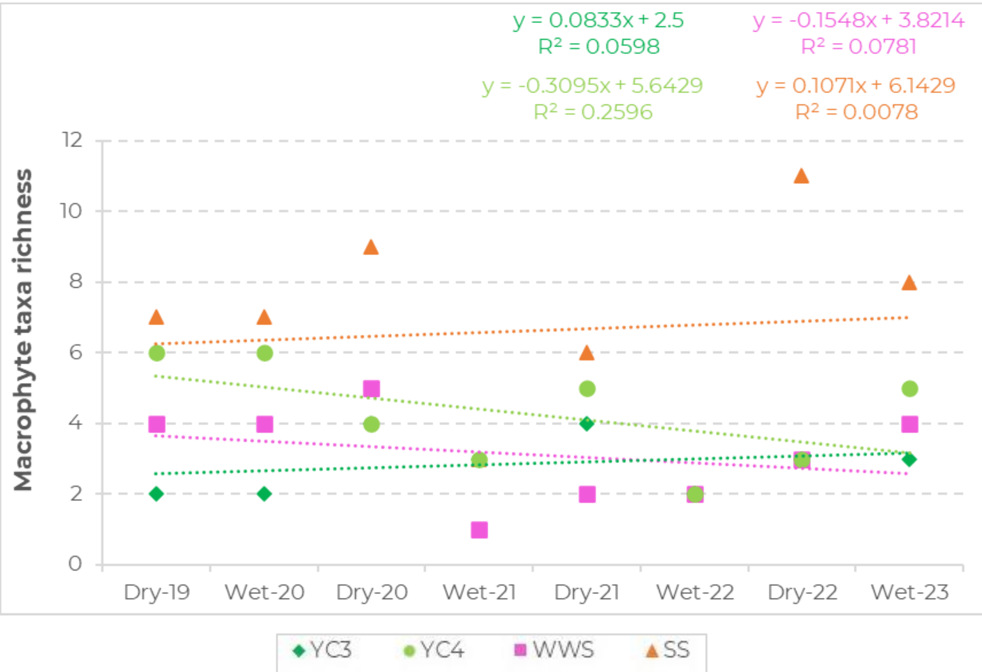


Figure 4.13: Total macrophyte richness change over time (combined submerged and emergent)

Overall, there was no significant difference in total macrophyte richness between sampling events (Two-way ANOVA; df = 7, F = 1.05. p = 0.409), but there was between site type (df = 1, F = 6.440, p = 0.015). Reference sites recorded significantly greater total macrophyte richness than the Survey Area.

4.4 Hyporheos Fauna

Hyporheic samples were successfully collected from six locations in the Survey Area in the Dry 2022, but only two in the Wet 2023, both of which were in the vicinity of YC4. Of the Reference sites, most were able to be sampled for hyporheos fauna except MUNJS in the Wet 2023. The location where the hyporheos can be accessed at Munjina Spring was dry at the time of sampling.

4.4.1 Hyporheos taxa composition and richness

A total of 81 taxa was recorded from hyporheic zones in the Survey Area (see Appendix F for full taxa list). The taxa included specimens from 17 higher taxonomic orders including Cnidaria (freshwater hydra; 1 taxon), Nematoda (round worms; 1 taxon), Mollusca (freshwater snails; 2 taxa), Oligochaeta (segmented worms; 11), Polychaeta (bristle worms; one), Acarina (water mites; 7), Cladocera (clam shrimp; 2), Copepoda (copepods; 11), Ostracoda (seed shrimp; 4), Amphipoda (side swimmers; 3), Isopoda (water slaters; 1), Collembola (springtails; 2), Pauropoda (pauropods; 1 taxon), Coleoptera (beetles; 12), Diptera (two-winged flies; 18), Ephemeroptera (mayflies; 3), and Odonata (dragonfly; 1 taxon).

More than half of the taxa recorded from Yandicoogina Creek hyporheic zones were stygoxene (58%) and do not have specialised adaptations for groundwater habitats (Figure 4.14). Hyporheos fauna, comprising stygobites, permanent hyporheos stygophiles, occasional hyporheos stygophiles and possible hyporheic taxa, made up the remaining taxa collected from the Survey Area. Of these, 16% are directly dependant on groundwater for their persistence (stygobites and permanent hyporheos stygophiles).

Hyporheos fauna recorded from the Survey Area included:

<u>Stygobites</u>

- copepods *Diacyclops* cf. *humphreysi*, *Eucyclops australiensis*, cf. *Australocamptus* `sp. Biologic-HARP064`, cf. *Australocamptus* sp., and *Kinnecaris* `sp. Biologic-HARP037`
- ostracods *Meridiescandona marillanae* (`sp. Biologic-OSTR074`) and *Gomphodella* `sp. Biologic-OSTR012`
- amphipods Paramelitidae sp., Paramelitidae `sp. Biologic-AMPH023` and *Chydaekata* sp. E
- isopod Pygolabis `sp. Biologic-ISOP035`.

<u>Permanent stygophiles</u>

- water mite *Wandesia* `sp. Biologic-ACAR009`
- ostracod *Vestalenula marmonieri*
- diving beetle *Limbodessus occidentalis.*

Occasional hyporheos stygophiles

- oligochaetes *Dero* cf. *sawayai*, *Nais variabilis*, *Pristina aequiseta* and *Pristina longiseta*
- copepods *Mesocyclops notius*, *Microcyclops varicans* and *Paracyclops cf. affinis*
- ostracod *Candonopsis* cf. *tenuis* (`sp. Biologic-OSTR009`)
- beetles *Hydraena* sp., Hydraenidae sp. (L), *Limnebius* sp. and Scirtidae sp. (L).

Possible hyporheic taxa made up 12% of the taxa recorded from the Survey Area included higher-level identifications for which taxa may have belonged to a stygal or hyporheos species. This included Oligochaeta (*Pristina* nr. *osborni*, *Pristina* sp., Phreodrilidae sp.), the polychaete (Aeolosomatidae sp.), Acari sp., copepods (Cyclopoida sp. and *Thermocyclops* sp.), and Baetidae mayflies.

Richness of hyporheos fauna varied between sites and seasons (Figure 4.14). The greatest richness of hyporheos fauna was recorded within the Survey Area from YC3 in the Dry 2022 (17 taxa), followed by YC1 (13 taxa in the dry) and YC2 (12 taxa in the dry; Figure 4.14). In comparison, the greatest richness of hyporheos fauna in Reference sites was ten taxa, recorded from WWS in the Wet 2023. All Survey Area sites recorded stygobites. This was not the case at Reference sites, with SS and MUNJS yielding no stygobitic taxa. BENS recorded two stygobites in the dry season, but none in the wet (Figure 4.14). Overall, the greatest number of groundwater dependent taxa (stygobites and permanent hyporheos stygophiles) was recorded from YC3 in the Dry 2022 (eight taxa), followed by YC1 and YC8H, both with five groundwater dependent taxa in the dry season (Figure 4.14).

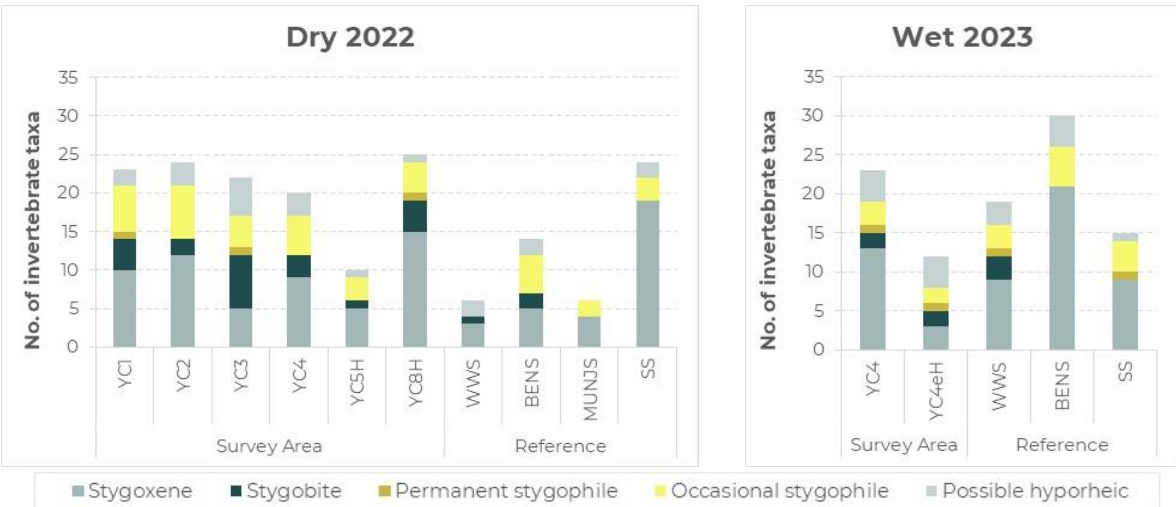


Figure 4.14: Hyporheic invertebrate taxa composition recorded from each site

4.4.2 Significant hyporheos taxa

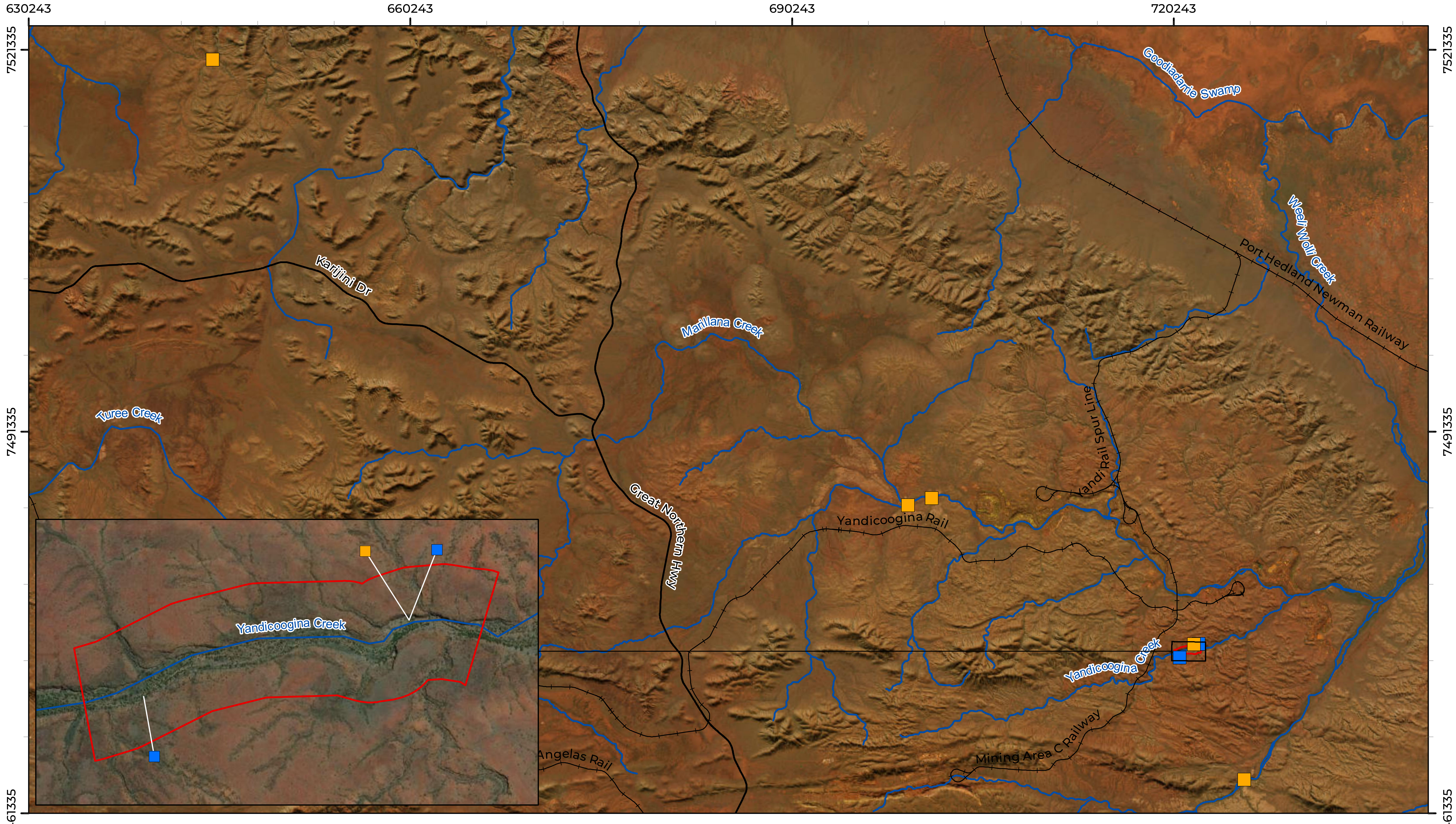
Several taxa from the hyporheos of the Survey Area were potentially significant species, and were either locally restricted or rarely collected. Further information is provided below.

4.4.2.1 Acari

The permanent hyporheos stygophile *Wandesia* `sp. Biologic-ACAR009` was recorded from the hyporheos of YC1 and YC3 in the Dry 2022 (Figure 4.15). The taxonomy of the *Wandesia* genus in Western Australia is poorly known. The geographic ranges of the various species have not been determined, and all described species are known from river interstices in eastern Australia. One known, but undescribed morphotype, *Wandesia* sp. P1 (nr *glareosa*), was recorded during the Pilbara Biological Survey (PBS) from river pools and springs (Pinder *et al.*, 2010), however specimens are not available to make any genetic comparisons. Identification of *Wandesia* `sp. Biologic-ACAR009` was made through a combined morphological and molecular analysis, with the OTU being more than 15.8 % divergent from its closest relative in the analysis (available sequence database), which was *Wandesia* `sp. Biologic-ACAR017` recorded from Fortescue Falls (Biologic unpub. data). The current records are not the first for this OTU, with the taxon being previously known from Yandicoogina Creek (from YC3 in the Wet 2022), Marillana Creek (Dry 2022), Weeli Wolli Creek (Wet 2021) and Kalamina Gorge in Karijini National Park (Wet 2022) (Biologic, 2023c, 2023d, 2023e) (Figure 4.15). The taxon has a current known linear range of close to 100 km (Biologic, 2023b). All known records are from springs or permanent pools with a strong groundwater connection.

4.4.2.2 Copepods

Three harpacticoid taxa were recorded from the hyporheic zone of Yandicoogina Creek; cf. *Australocamptus* `sp. Biologic-HARP064`, cf. *Australocamptus* sp., and *Kinnecaris* `sp. Biologic-HARP037`. Stygal harpacticoids are often found to have widespread distributions in the Pilbara, though they are assumed to be less vagile than the free-swimming cyclopoids as they predominantly utilise benthic habitats. Regional species distribution patterns have been largely developed on morphological identifications without DNA confirmation. DNA studies in other regions such as the Yilgarn have uncovered significant radiations of unique and highly restricted stygal harpacticoids, in response to discontinuous habitats (Karanovic & Cooper, 2012; Karanovic *et al.*, 2014).



LEGEND

Survey Area

Major Surface Hydrology

State Road

Rail

Current Study

Wandesia `sp. Biologic-ACAR009`

Other Studies

Wandesia `sp. Biologic-ACAR009`

Biologic

Scale 1:275,000

0 5 10 Km

Coordinate System: GDA 1994 MGA Zone 50
Projection: Transverse Mercator
Datum: GDA 1994 Created 19/07/2023

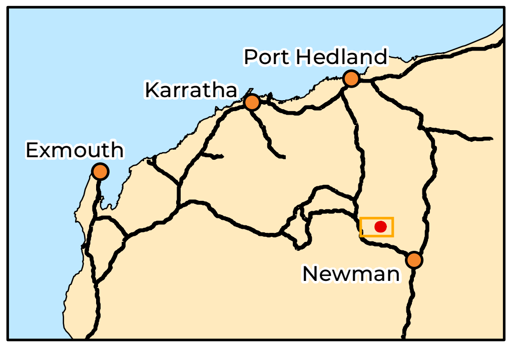


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Figure 4.15: Significant *Wandesia* water mite records

The *Australocamptus* genus is endemic to Australia, with its members strictly occurring in groundwater (Galassi *et al.*, 2009). Three described species are known from Western Australia, all of which are known from the Murchison Region (ALA, 2023). The current *Australocamptus* specimens collected from the hyporheos of YC2 and YC4 could not be definitively identified using morphology alone, and therefore specimens from YC3 were submitted for molecular analysis. The sequence did not match any within the genetic database and a new OTU was assigned, cf. *Australocamptus* `sp. Biologic-HARP064`.

Species of *Kinnecaris* have restricted distributions and often occur at the scale of a single tributary (Bennelongia, 2015). They are rarely collected and tend to occur in low abundance. Their distribution was thought to be restricted to the Yilgarn, however, there is a record from Bungaroo (ALA, 2023). One female was recorded from the hyporheos of YC8H. While gross morphology was similar to *Parastenocaris*, the P5 (leg 5) more closely resembled *Kinnecaris*. Molecular analysis placed it within Kinnecaris, and matching a previously known OTU, Kinnecaris `sp. Biologic-HARP037`. The taxon has a current known linear range of 25 km.

4.4.2.3 Ostracods

Stygal ostracods of the genus *Meridiescandona* were collected from the hyporheos of YC1, YC3, YC4 and YC4eH and submitted for molecular analysis. The specimens matched a known OTU; *Meridiescandona* `sp. Biologic-OSTR074`, previously recorded from Yandicoogina Creek (YC3 and YC4) and Marillana Creek (Biologic, 2022b, 2023a). This OTU is considered likely to represent the described species *Meridiescandona marillanae* given its distribution (Figure 4.16) and gross morphology, however, further morphological and molecular work is required to confirm this. It is referred to as *Meridiescandona marillanae* (`sp. Biologic-OSTR074`) here. In any case, the taxon is considered to represent a Potential SRE (Data Deficient) given the short range of *M. marillanae*, and fact that there are few known records of *Meridiescandona* `sp. Biologic-OSTR074` currently (Figure 4.16).

Gomphodella ostracods were recorded from the hyporheos of YC3 in the Dry 2022. Identification was made through a combination of morphology and molecular analysis. Specimens matched a known OTU, *Gomphodella* `sp. Biologic-OSTR012`, previously recorded from Yandicoogina Creek (YC3) and Weeli Wolli Creek (Biologic, 2023b) (Figure 4.17). It is likely this OTU represents the described species *Gomphodella alexanderi* based on broad morphology and distribution. *Gomphodella alexanderi* was previously known only from interstices of Marillana Creek and groundwater bores at Rio Tinto's Yandi Mine (Karanovic & Humphreys, 2014). However, it has more recently been recorded from the hyporheos of lower Weeli Wolli Creek (Biologic, unpub. data) and Yandicoogina.

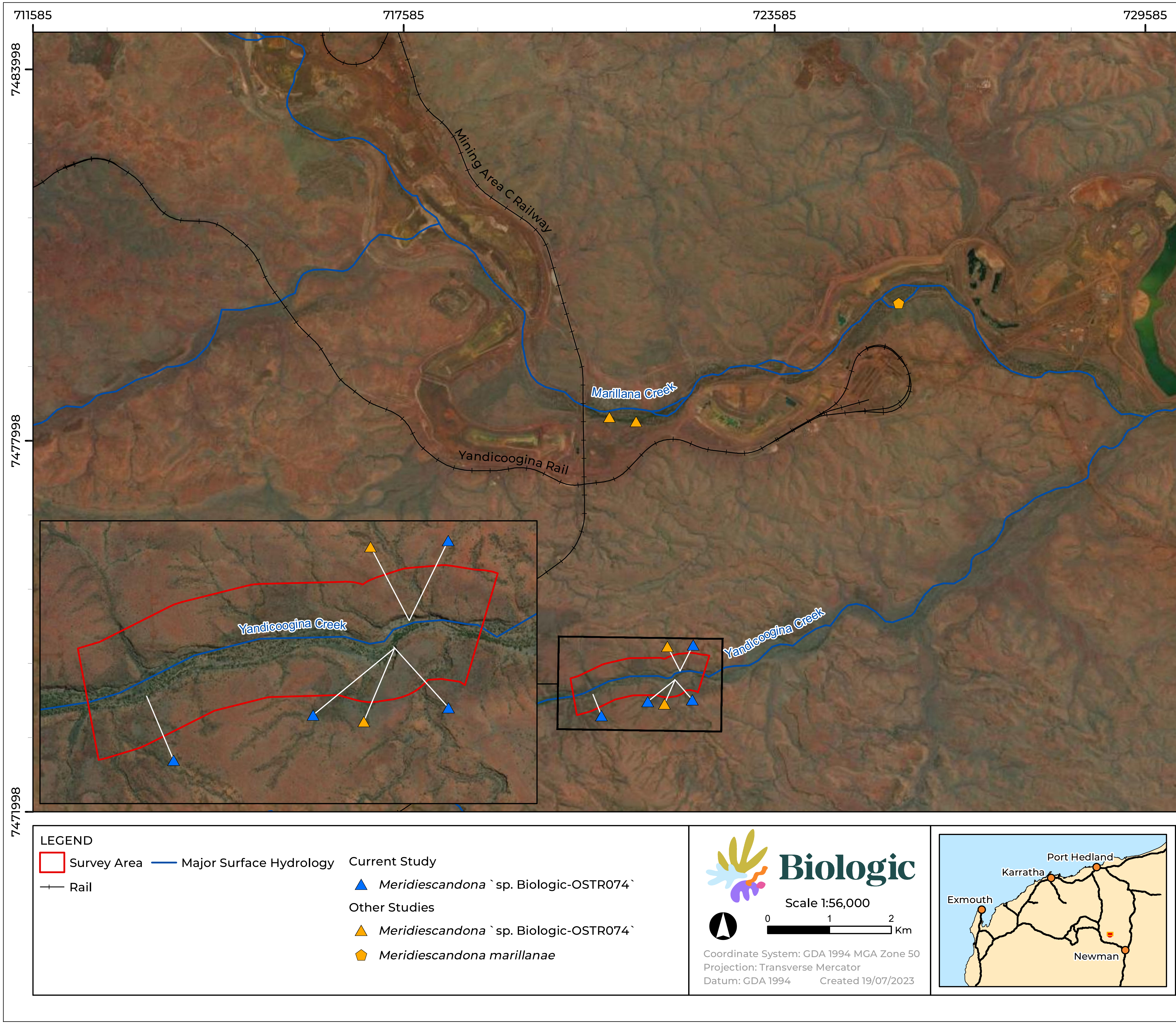

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Figure 4.16: Significant *Meridiescandona* ostracod records

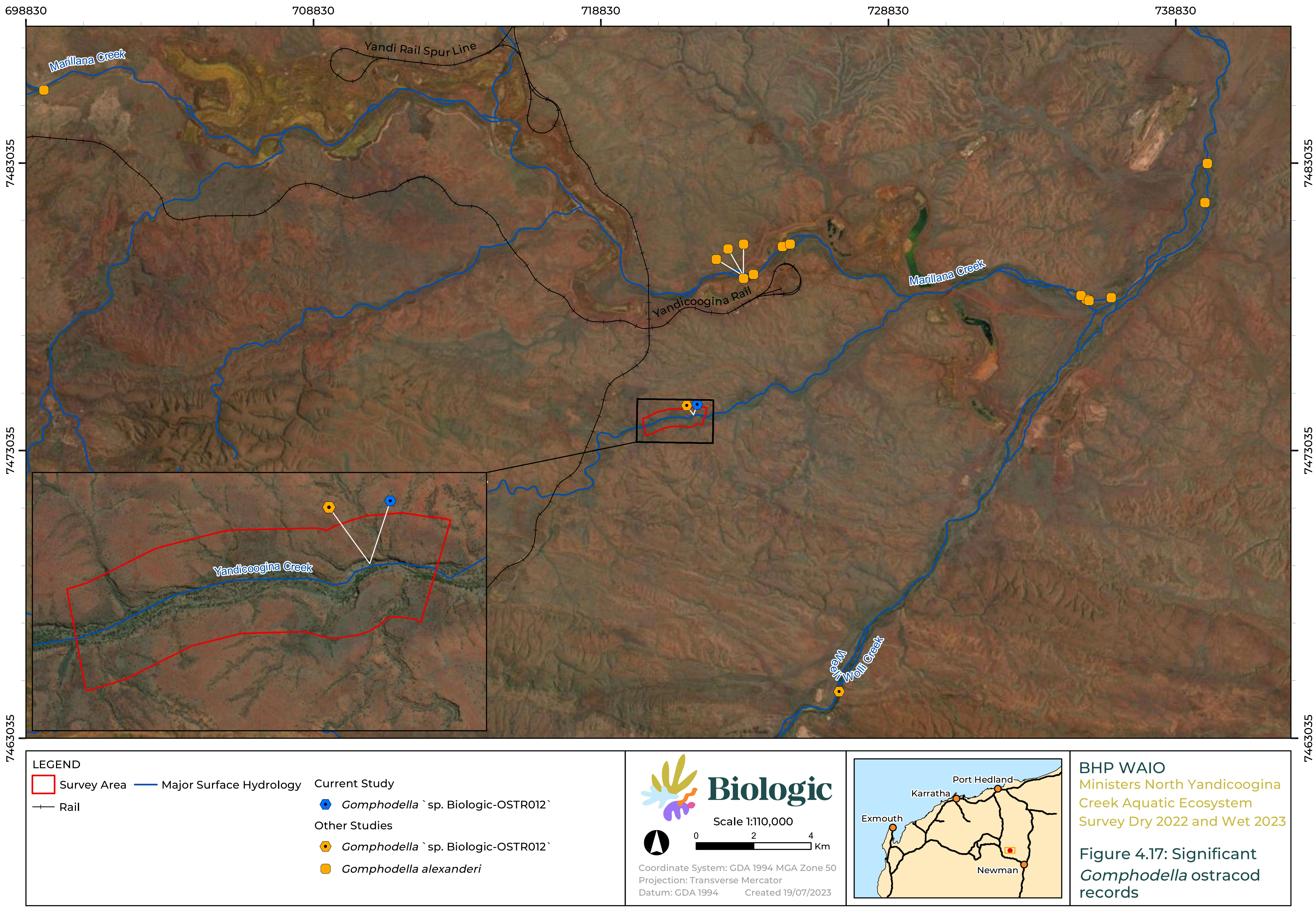


Figure 4.17: Significant *Gomphodella* ostracod records

Gomphodella alexanderi (`sp. Biologic-OSTR012`) is a Potential SRE (Data Deficient). All known records are in areas either currently impacted by, or proposed for future mining.

Vestalenula marmonieri was recorded from YC4 and YC4eH in the Wet 2023. This species is a Pilbara endemic, and is known to occur in surface waters and hyporheic zones across the region. It has been recorded from the Survey Area previous, in the hyporheos of YC3, and surface waters of YC1 and YC4 (Biologic, 2020, 2022b, 2023c).

4.4.2.4 Amphipods

The known but undescribed species, *Chydaekata* `sp. E`, was commonly recorded during the current study, and was found within the hyporheos of YC1, YC3, YC4, YC8H and BENS in the Dry 2022, and YC4 in the Wet 2023 (Figure 4.18). Specimens were identified using a combination of morphological and molecular analysis (Biologic, 2023b). *Chydaekata* 'sp. E' is a Potential SRE known only from Weeli Creek, Marillana Creek and Yandicoogina Creek (Biologic, 2023c; Finston *et al.*, 2007) (Figure 4.18).

Paramelitidae `sp. Biologic-AMPH023` was recorded from the hyporheos of YC5H and YC8H in the Dry 2022, and YC4eH in the Wet 2023 (Figure 4.18). This OTU has been recorded from the hyporheic zone of Yandicoogina Creek during previous surveys (Biologic, 2020, 2022b, 2023c), with molecular analyses indicating that it is also previously known from Marillana Creek (matched non-project sequences that are not publicly available). Therefore, the current known distribution of Paramelitidae `sp. Biologic-AMPH023` is Yandicoogina Creek and Marillana Creek. These creek systems are all in close proximity, with Yandicoogina Creek being a tributary of Marillana Creek, and the Yandicoogina Creek GDE lying a mere 9 km upstream of the confluence. Genetic analysis undertaken by others have indicated that most paramelitid species have ranges in the tributary-scale (Finston *et al.,* 2007, 2008, 2011). Based on the WAM classification system, Paramelitidae `sp. Biologic-AMPH023` would be considered a Potential SRE (Data Deficient). Immature or damaged stygal amphipods were recorded from the hyporheic zone of YC3 in Dry 2022. It is likely these specimens belong to either *Chydaekata* sp. `E` or Paramelitidae `sp. Biologic-AMPH023`.

4.4.2.5 Isopods

Isopods from the the hyporheos of YC1 and YC3 were sequenced and matched a previously recorded OTU, *Pygolabis* `sp. Biologic-ISOP035` (Biologic, 2023b). The taxon is more than 15.5% divergent from any other sequence in the analysis, including the described *Pygolabis weeliwolli*, and has an intraspecific genetic variation less than 0.4% (Biologic, 2023b). *Pygolabis* `sp. Biologic-ISOP035` is restricted to the Survey Area, with a current known linear range of only 1.5 km (Figure 4.19).

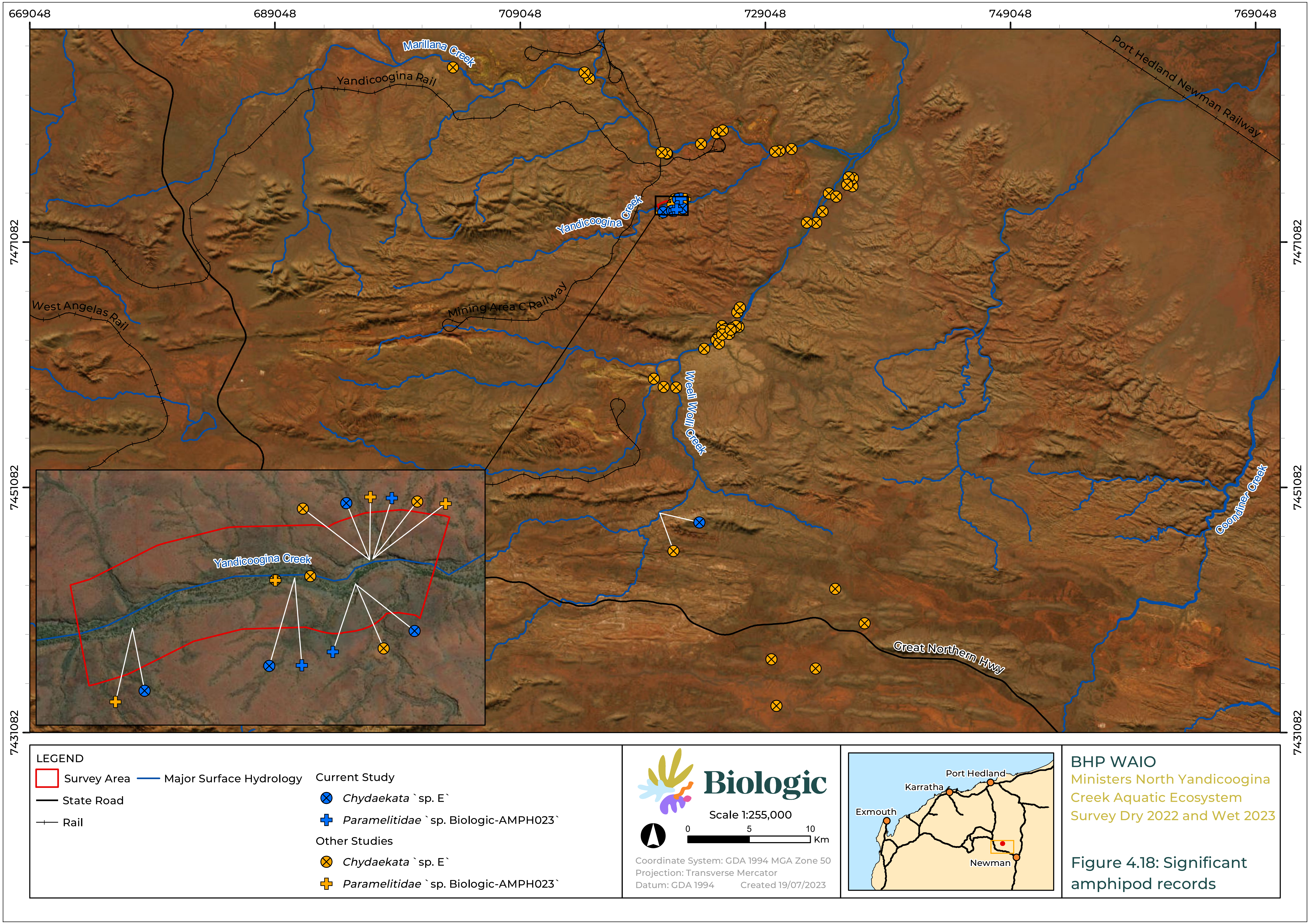
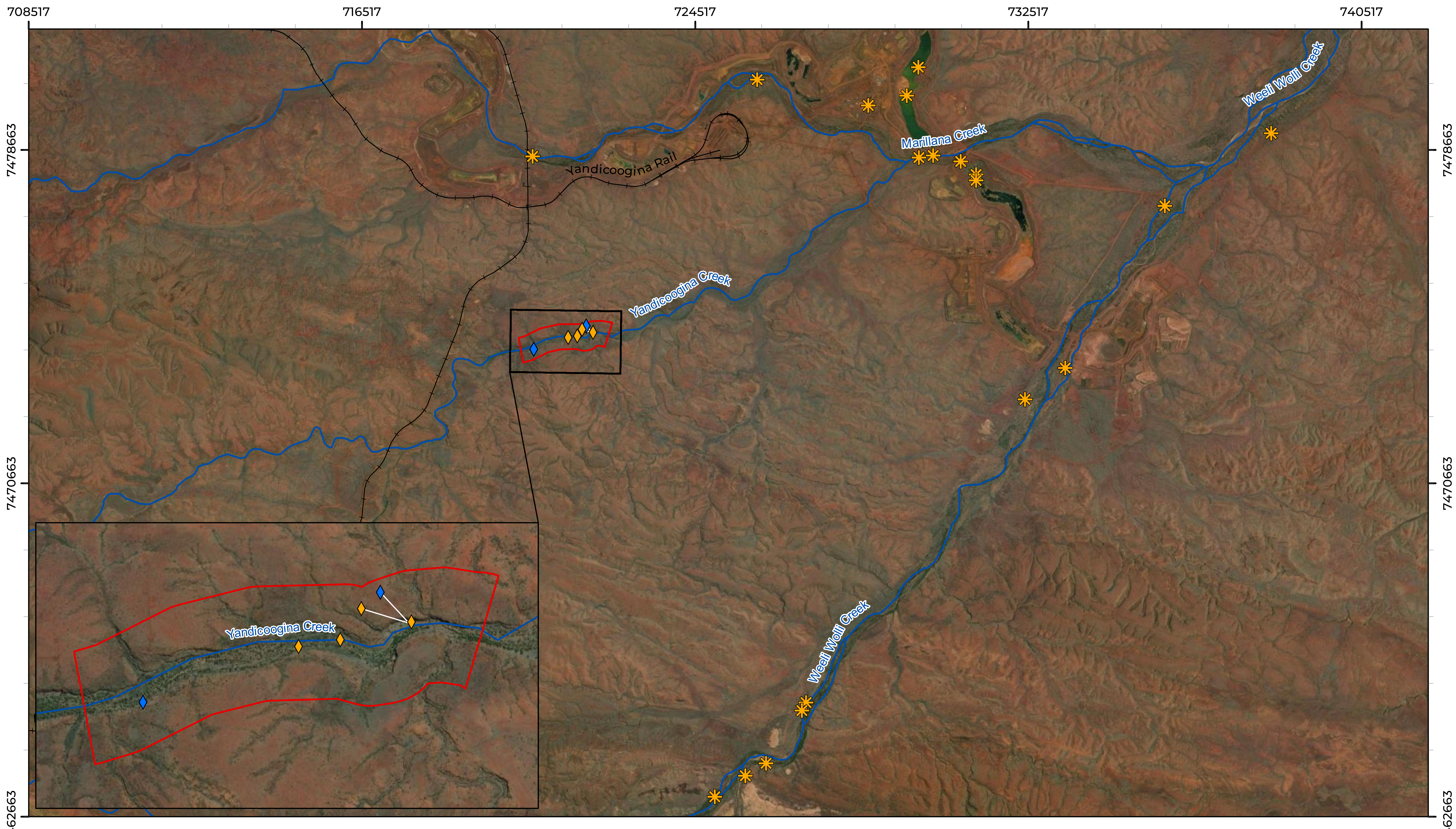


Figure 4.18: Significant amphipod records



LEGEND

Survey Area — Major Surface Hydrology — Rail

Current Study

Pygolabis `sp. Biologic-ISOP035`

Other Studies

Pygolabis `sp. Biologic-ISOP035`

Pygolabis weeliwolli

Biologic

Scale 1:84,000

0 1 2 3 Km

Coordinate System: GDA 1994 MGA Zone 50
Projection: Transverse Mercator
Datum: GDA 1994 Created 19/07/2023

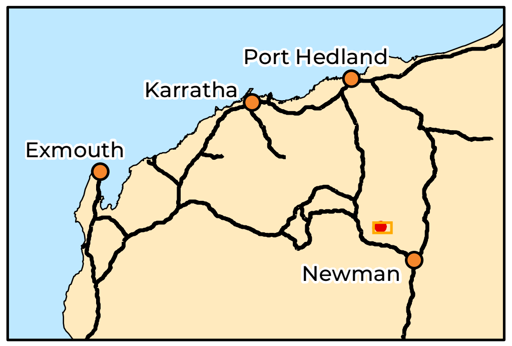


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Figure 4.19: Significant isopod records

4.4.3 Hyporheos comparison with previous surveys

Average hyporheos taxa richness in the Survey Area was similar to that recorded from Reference sites in most sampling events, although in the Dry 2022 average richness was greater in the Survey Area, a pattern which was reversed in the Wet 2023 (Figure 4.20). The average richness of stygobites was greater at Reference Sites in the Dry 2019, but since then has been generally higher in the Survey Area (Figure 4.20). Overall, there was no significant difference in richness of occasional hyporheos taxa or stygobites between sampling events or site types (Two-way ANOVA; $p > 0.05$; Table 4.2).

Table 4.2: Two-way ANOVA results comparing hyporheic taxa richness between sampling event and site type

Source	df	F	*p*-value
Hyporheos fauna taxa richness			
Sampling event	7	0.69	0.681
Type	1	1.53	0.222
Sampling event* Type	7	1.09	0.387
Occasional hyporheos fauna taxa richness			
Sampling event	7	0.58	0.770
Type	1	0.19	0.664
Sampling event* Type	7	0.94	0.487
Stygobitic taxa richness			
Sampling event	7	3.09	0.749
Type	1	7.73	0.225
Sampling event* Type	7	0.71	0.659

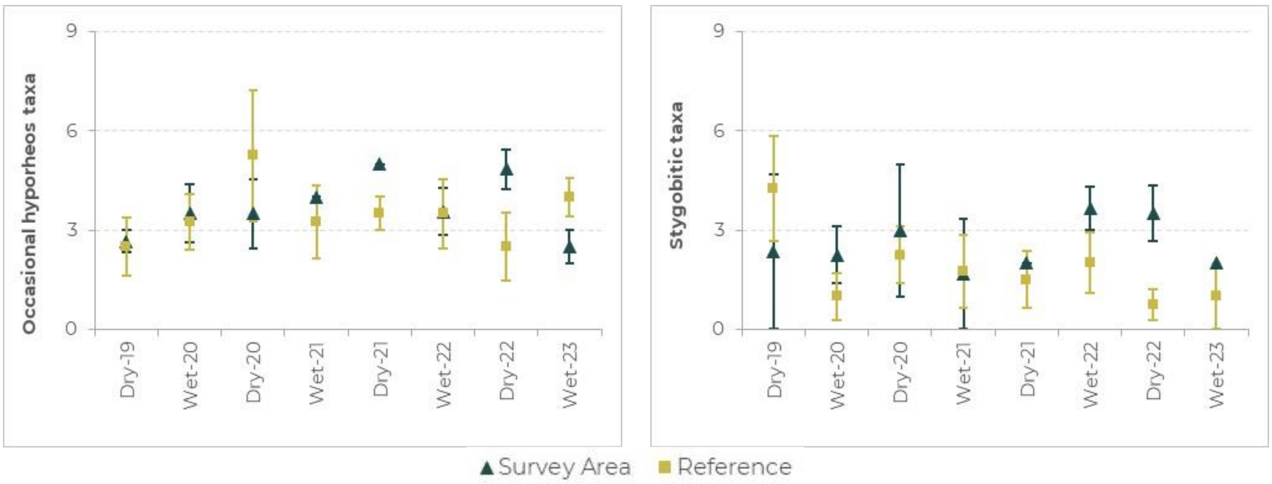


Figure 4.20: Average occasional hyporheos fauna and stygobitic taxa richness(± standard error) recorded in each sampling event

*The Wet 2023 average is based on only two data points (sampling of YC4 and YC4eH).

There were generally no linear relationships between occasional hyporheos taxa richness and time at individual sites (Figure 4.21). The only exception was YC4, where a weak positive correlation was recorded (r = 0.54). However, the increase only occurred between the Wet 2020 and the Wet 2022, since this time, richness of occasional hyporheos taxa has decreased. The number of taxa recorded from YC4 in the Wet 2023 was the same as that recorded in the initial sampling event in the Dry 2019 (three taxa) (Figure 4.21).

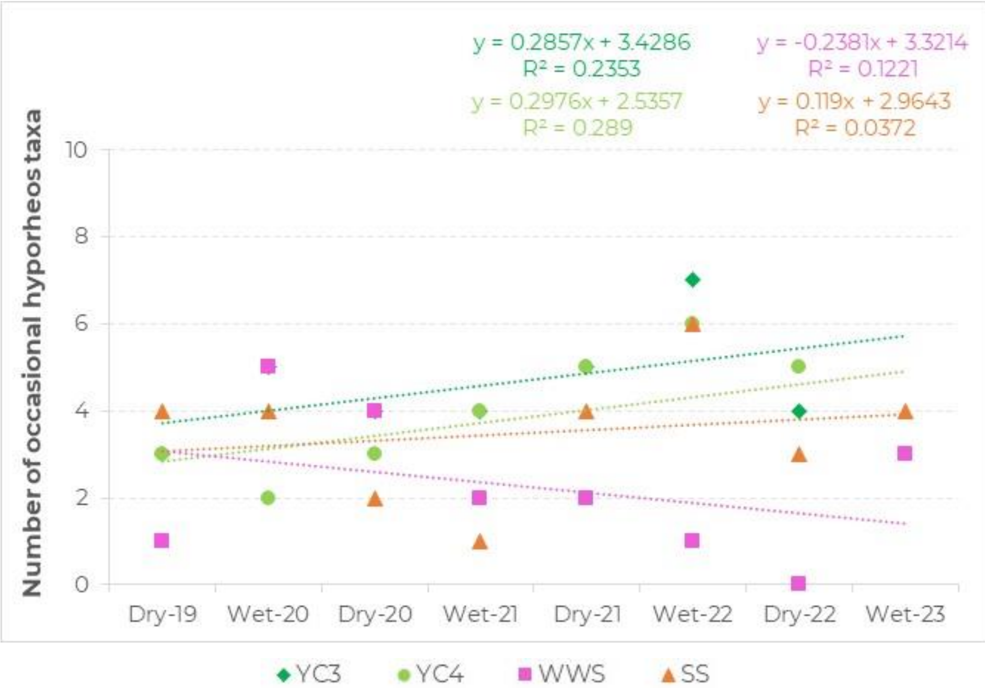


Figure 4.21: Change in the number of occasional hyporheos taxa over time

The number of stygobitic taxa recorded from the hyporheos of YC3 and YC4 has varied over time, but no consistent positive or negative correlations have been recorded (Figure 4.22). Generally, the number of stygobites recorded from YC3 in the Dry 2022 was similar to that recorded in the Dry 2019. No stygobites were recorded from YC4 in the Dry 2019, although the hyporheos was difficult to access at this time, due to steep banks, high water levels and abundant emergent vegetation. Interestingly, the number of stygobitic taxa recorded from Reference site SS has declined over time (r = 0.65), with no stygobites recorded in the most recent Wet 2023 sampling event (Figure 4.22).

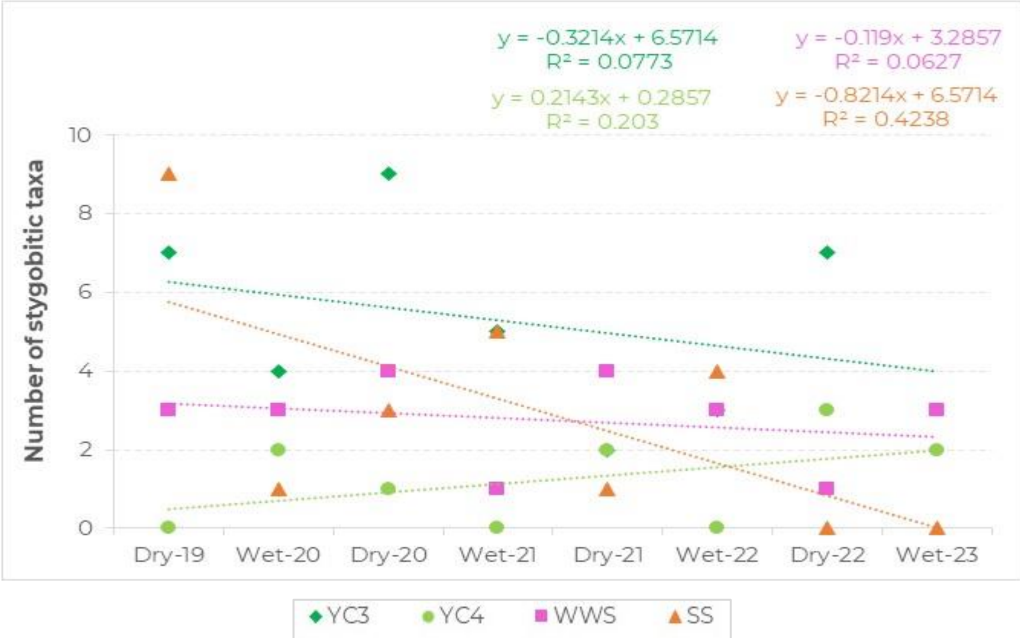


Figure 4.22: Change in the number of stygobitic taxa over time

4.5 Macroinvertebrates

4.5.1 Macroinvertebrate taxa composition and richness

A total of 152 macroinvertebrate taxa was recorded from surface waters across the Survey Area, with 119 taxa recorded in the Dry 2022 from three sites, and 77 in the Wet 2023 from one site (see Appendix G). The taxonomic list included specimens from 15 higher taxonomic orders including Platyhelminthes (flat worms; 1 taxon), Mollusca (freshwater snails; 3 taxa), Oligochaeta (segmented worms; 9), Acarina (water mites; 15), Cladocera (clam shrimp; 3), Copepoda (copepods; 7), Ostracoda (seed shrimp; 6), Amphipoda (side swimmers; 1), Collembola (springtails; 1), Coleoptera (beetles; 33), Diptera (two-winged flies; 32), Ephemeroptera (mayflies; 5), Hemiptera (aquatic true bugs; 16), Odonata (dragonflies and damselflies; 14), and Trichoptera (caddisflies; 6 taxa).

The taxonomic composition of Survey Area sites was generally dominated by slow flow and relatively tolerant taxa, such as Diptera (>26% of the overall taxa composition per site) and Coleoptera (>15% of the taxonomic composition; Figure 4.23). Dominance of Diptera within aquatic macroinvertebrate assemblages of the Pilbara is common (Pinder *et al.*, 2010). The composition of Reference sites was broadly similar, however, WWS recorded a low number of Coleoptera taxa, and greater numbers of taxa which require faster flows (Figure 4.23). Lepidoptera, leptophlebiid mayflies, Simulidae (Diptera), *Cheumatopysche* and *Chimarra* caddisflies (Trichoptera), for example, were all exclusively recorded from Reference sites, particularly WWS, MUNJS and SS.

Within-site macroinvertebrate richness ranged from 27 (at Survey Area site YC2) to 94 (at Reference site MUNJS) in the Dry 2022, and from 52 (Reference site WWS) to 93 (MUNJS) in the Wet 2023 (Figure 4.23). In the Survey Area, YC4 recorded notably high richness in both seasons (82 in the dry and 77 in the wet), equating to the second greatest richness recorded during the Dry 2022 (Figure 4.23). The low richness recorded from Survey Area site YC2 has been previously reported (Biologic, 2020, 2022b).

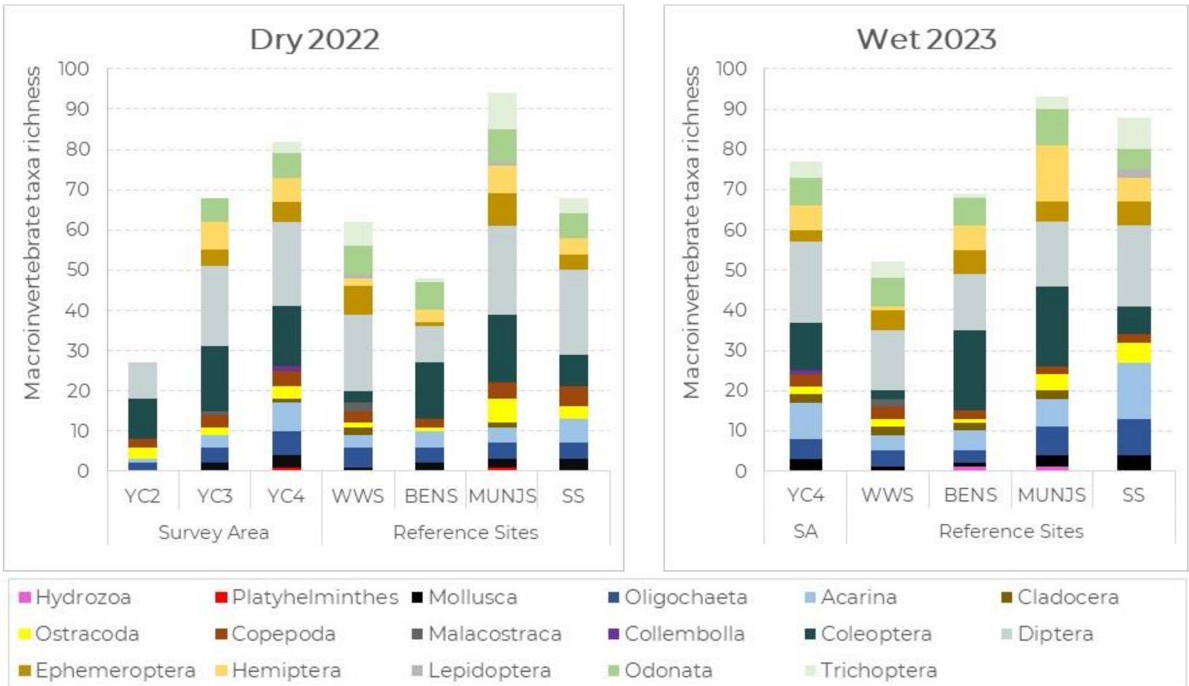


Figure 4.23: Macroinvertebrate taxa composition recorded from each site

4.5.2 Significant macroinvertebrate taxa

Most aquatic macroinvertebrates recorded from the Survey Area were common species with wide distributions. 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 (39%), the world (cosmopolitan taxa; 20%), Northern Australia (19%), or the Australasian region (6%). A total of 4% were endemic to Western Australia, while taxa restricted to the Pilbara region accounted for 13% of the taxa recorded from the Survey Area (of those with known distributions).

Seventeen macroinvertebrate taxa that have distributions restricted to the Pilbara were recorded in the current study, across all sites and seasons. Of these, nine were recorded from the Survey Area. All sites recorded at least one Pilbara endemic taxon, with endemic taxa richness ranging from one to five (Figure 4.24). Survey Area site YC2 recorded the lowest number of Pilbara endemic taxa, while YC4, MUNJS and SS all supported the greatest (all with five taxa; Figure 4.24).

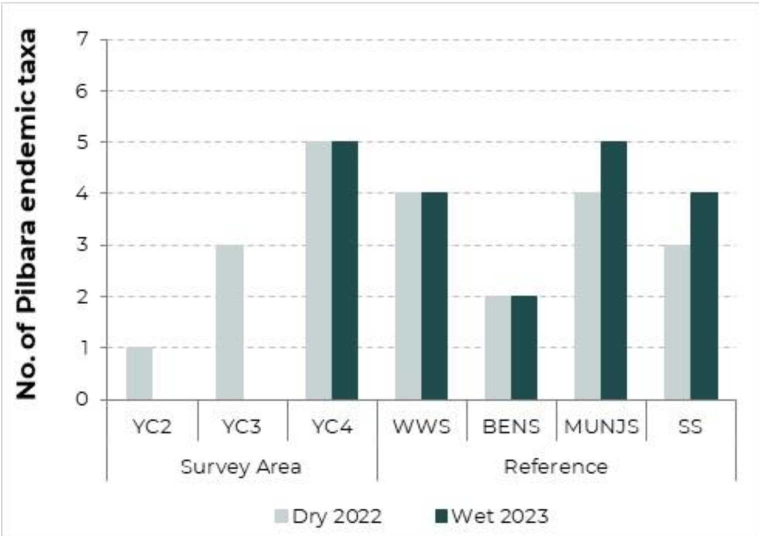


Figure 4.24: Number of Pilbara endemic invertebrate taxa recorded from each site

Four macroinvertebrate taxa recorded from the Survey Area were of further interest, due to being locally restricted or listed species. Further information on these taxa is provided below.

4.5.2.1 Amphipod

In addition to hyporheos records (see section 4.4.2.4), the stygal amphipod *Chydaekata* sp. E was also recorded from surface waters of YC3 and WWS. *Chydaekata* `sp. E` is a well-known, but undescribed taxon which occurs in groundwaters, hyporheic zones and surface waters of Marillana Creek, Yandicoogina Creek and Weeli Wolli Creek.

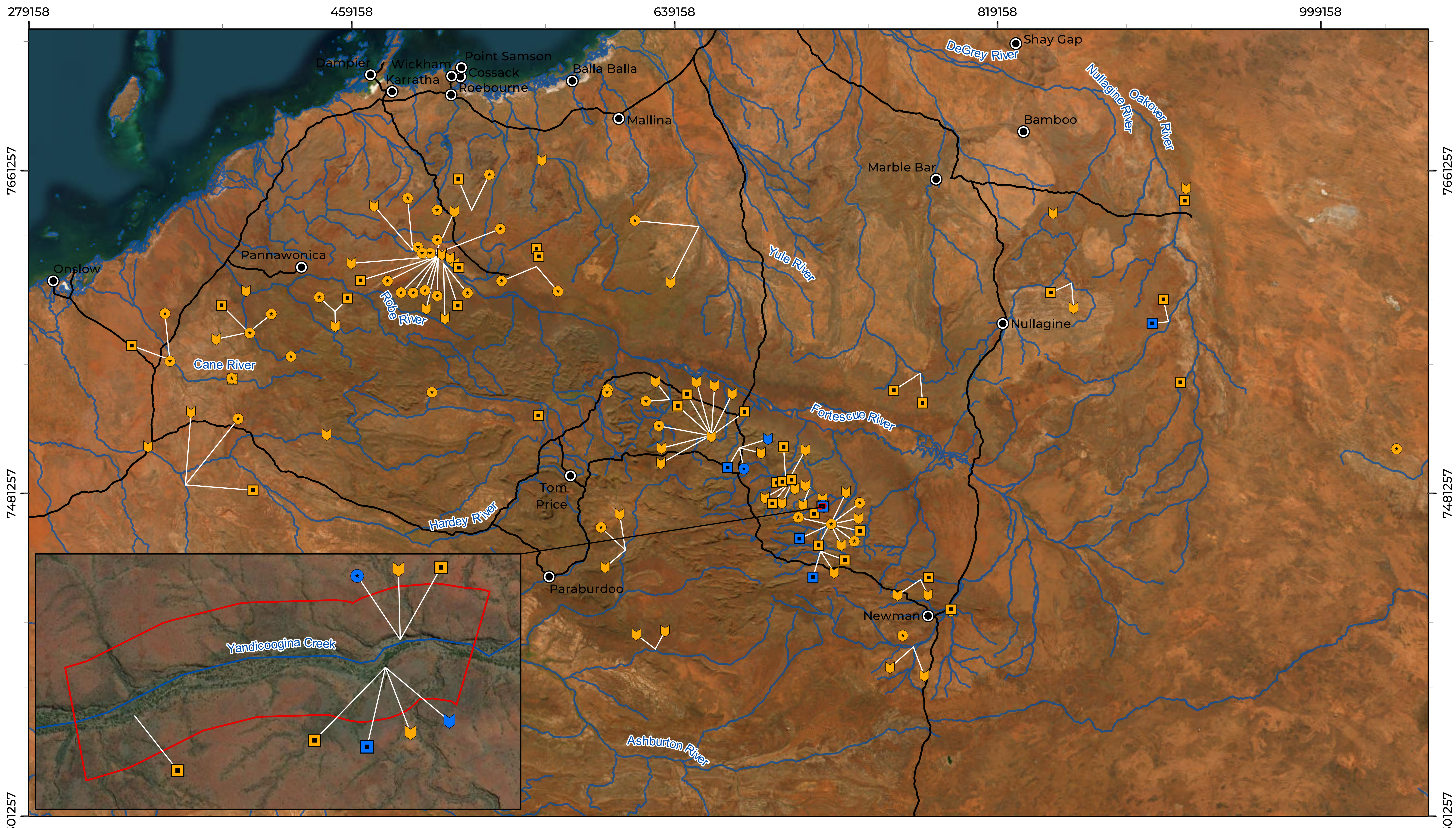
4.5.2.2 Odonates

Three odonate species of significance were recorded from the Survey Area, all of which are listed on the IUCN Red List of Threatened Species (IUCN, 2023). The Pilbara billabongfly, *Austroagrion pindrina,* was recorded from YC3 and MUNJ in the Dry 2022. *Austroagrion pindrina* has been recorded from close to 20 locations across the Pilbara (Figure 4.25), but is generally only known from springs, permanent pools, or sites of high ecological condition, with good water quality and high in-stream habitat diversity and heterogeneity. The Pilbara emerald, *Hemicordulia koomina*, was recorded from Survey Area site YC4 during the current study, as well as all Reference sites (Figure 4.25). This species is known from around 15 sites across the Pilbara, but is considered rare and is infrequently collected (Figure 4.25). Both *A. pindrina* and *H. koomina* are listed as Vulnerable on the IUCN Red List based on their fragmented populations and continuing decline of mature individuals (IUCN, 2023).

The Pilbara tiger *Ictinogomphus dobsoni* is currently listed on the IUCN Red List as Near Threatened (IUCN, 2023). Similar to the other listed odonates, the listing for *I. dobsoni* cited its fragmented population and relatively low number of records (IUCN, 2023). Including grey literature and the PBS, *I. dobsoni* is currently known from at least 15 locations (Figure 4.25). Where present, the Pilbara tiger can occur in high local abundances (Dow, 2017). During the current study, *I. dobsoni* was recorded from YC4 within the Survey Area, as well as Reference site MUNJS (Figure 4.25). Threats to all three odonate species include lowering of groundwater tables and loss of habitat (IUCN, 2023), impacts that would be exacerbated by climate change (Bush *et al*., 2014).

4.5.3 Introduced macroinvertebrate taxa

No introduced macroinvertebrate species were recorded from the Survey Area. A Reference site, WWS, however, did record one introduced species. This was the freshwater crayfish, *Cherax quadricarinatus*, commonly known as redclaw. Abundances, size classes and sex ratios of the population of redclaw at Weeli Wolli Spring is being monitored as part of the Weeli Wolli Spring Aquatic Monitoring surveys for BHP (Biologic, 2023d, 2023e).



LEGEND

Survey Area

State Road

Major Surface Hydrology

Current Study

Austroagrion pindrina

Hemicordulia koomina

Ictinogomphus dobsoni

Other Studies

Austroagrion pindrina

Hemicordulia koomina

Ictinogomphus dobsoni

Biologic

Scale 1:1,950,000

0 40 80 Km

Coordinate System: GDA 1994 MGA Zone 50
Projection: Transverse Mercator
Datum: GDA 1994 Created 20/07/2023

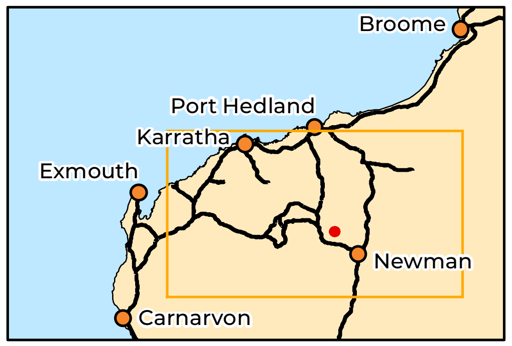


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Figure 4.25: Significant odonate records

4.5.4 Correlations with environmental characteristics

Including data from Yandicoogina Creek only (not Reference sites), collected across all sampling events, correlations between macroinvertebrate assemblages and environmental characteristics (water quality and habitat data) were investigated using DistLM. A model with a strong correlation (r = 0.96) between macroinvertebrate assemblages and six significant predictor variables was produced (Table 4.3). The environmental variables were dissolved oxygen, TSS, and concentrations of dissolved aluminium, sodium, bicarbonate, and sulfate. Together, these environmental variables explained close to one half of the variation amongst the Yandicoogina Creek macroinvertebrate assemblages (41.11%).

Table 4.3: DistLM results examining correlations between Yandicoogina Creek macroinvertebrate assemblages and environmental data (water quality and habitat)

Variable	r	Pseudo-F	*p*-value	% variance explained
DO	0.31	1.63	0.034	6.42
TSS	0.41	1.79	0.015	6.81
Na	0.48	1.71	0.024	6.29
HCO_3	0.58	2.20	0.003	7.66
S_SO_4	0.64	2.20	0.001	7.24
dAl	0.69	2.18	0.001	6.69
		Total % variation explained		**41.11%**

4.5.5 Macroinvertebrate comparison with previous surveys

4.5.5.1 Richness

The average number of macroinvertebrate taxa[5] recorded from the Survey Area has generally undergone a seasonal pattern of change over time, with a tendency for greater macroinvertebrate richness in the dry season (Figure 4.26). The recent survey was the exception to this, with similar richness recorded in the Dry 2022 to the previous Wet 2022 sampling event. A similar seasonal pattern was recorded in average Pilbara endemic taxa richness within the Survey Area, although at Reference sites a slight decline was recorded between the Dry 2019 and Dry 2021, followed by a slight increase to the Wet 2023 (Figure 4.26). Although Reference sites generally recorded greater average richness (both

[5] Richness used in analyses may be different to that reported for individual sampling events in this and previous reports due to the amalgamation process, whereby some taxa may have to be aligned where improvements in taxonomic resolution may have occurred over time.

macroinvertebrates and Pilbara endemic taxa) than the Survey Area, overall, there was no significant difference in richness between site types or sampling events (Two-way ANOVA; *p*> 0.05; Table 4.4). In previous years, the greater macroinvertebrate richness recorded from Reference sites was significant (Biologic, 2023c). Given it was close to significant in the current data (*p* = 0.052; Table 4.4), if higher macroinvertebrate richness continues to be recorded from Reference sites in future surveys, it is likely this difference will become significant again soon.

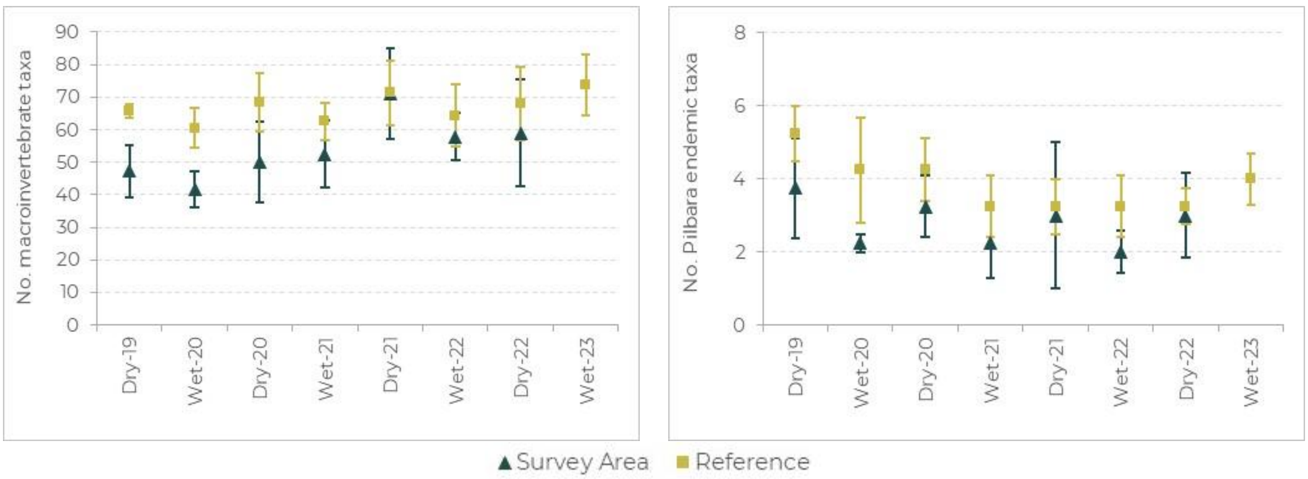


Figure 4.26: Average macroinvertebrate taxa richness and Pilbara endemic taxa richness (± standard error) recorded from the Survey Area and Reference sites in each sampling event

*An average for the Survey Area in the Wet 2023 could not be calculated as only one site held water.

Table 4.4: Two-way ANOVA results comparing macroinvertebrate taxa richness between sampling event and site type

Source	df	F	*p*-value
Macroinvertebrate taxa richness			
Sampling event	7	1.04	0.421
Type	1	3.99	0.052
Sampling event* Type	7	0.32	0.939
Pilbara endemic taxa richness			
Sampling event	7	1.05	0.413
Type	1	2.37	0.131
Sampling event* Type	7	0.33	0.935

A positive linear relationship was recorded between macroinvertebrate taxa richness and time at YC3 (r = 0.71; Figure 4.27). This correlation was not recorded from YC4 or Reference site SS (Figure 4.27). YC4 has recorded consistently high macroinvertebrate richness except in the Wet 2020 and Wet 2022 (Figure 4.27). Interestingly, WWS has undergone a decreasing trend in macroinvertebrate richness, although the trend was relatively weak (r = 0.50).

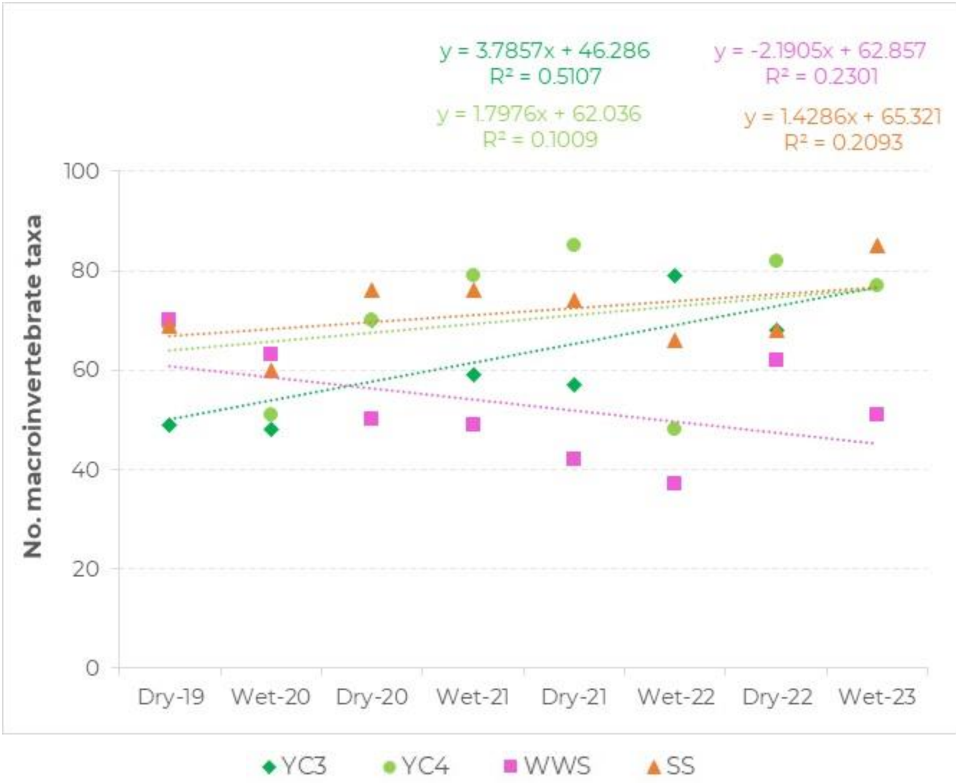


Figure 4.27: Change in the number of macroinvertebrate taxa recorded over time

Although overall macroinvertebrate taxa richness has increased over time at YC3, the number of Pilbara endemic taxa recorded has decreased over the same time period (r = 0.60; Figure 4.28). A similar trend was recorded at Reference site WWS, where a strong negative correlation was found (r = 0.68). Neither YC4 or SS exhibited any decreasing or increasing trends in richness of Pilbara endemic taxa (Figure 4.28).

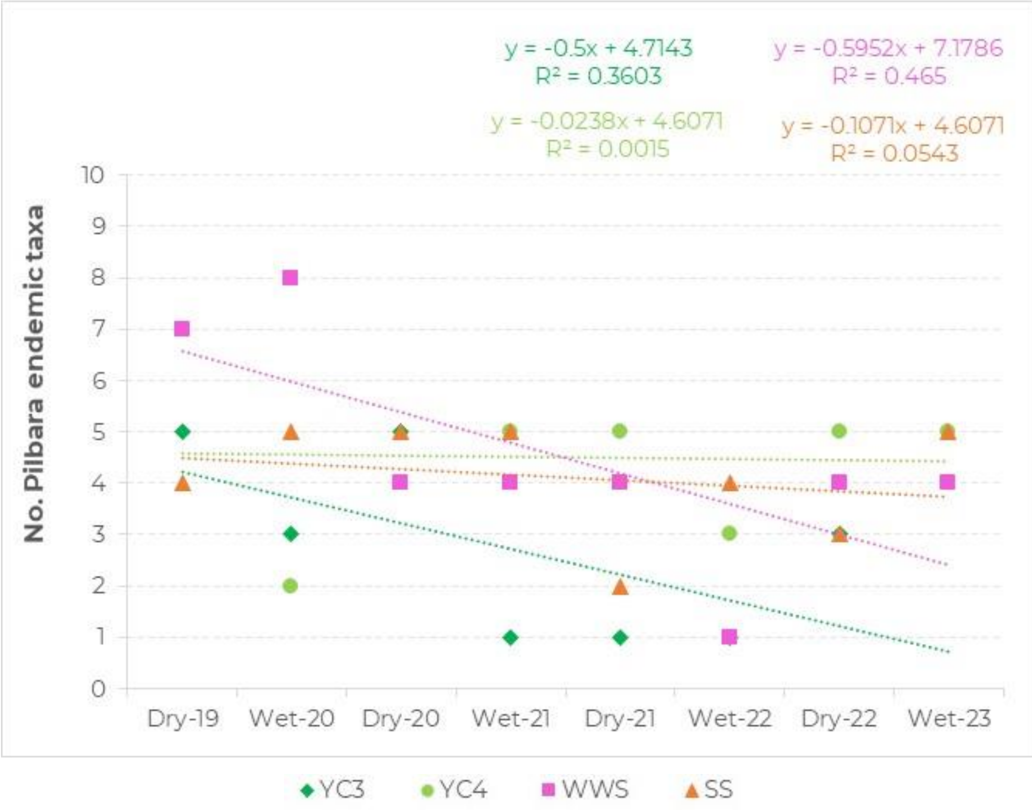


Figure 4.28: Change in the number of Pilbara endemic taxa recorded over time

4.5.5.2 Assemblage composition

Patterns were evident within the nMDS ordination of macroinvertebrate assemblages collected across all sampling events (Figure 4.29). Samples from Yandicoogina Creek tended to form a cluster group, although assemblages were highly variable. YC2 assemblages from the Dry 2020, Wet 2021 and Dry 2022 separated from all other samples. Yandicoogina assemblages were most similar to BENS, with overlap of samples from these two areas, and distinct from WWS assemblages (Figure 4.29). Generally, macroinvertebrate assemblages from the Survey Area sat apart from Reference sites, with the exception of BENS. This difference in macroinvertebrate assemblages between site type was significant (Two-factor PERMANOVA; df = 1, pseudo-F = 4.52, p < 0.001).

Individual sampling events did not form tight clusters, with samples from each sampling event being variable and spread across the ordination (Figure 4.30). However, there did appear to be a distinction between the earlier sampling events and the more recent Wet 2022, Dry 2022 and Wet 2023 event assemblages (Figure 4.30). Overall, a significant difference in assemblages between sampling events was recorded (df = 7, pseudo-F = 2.29, p <0.001). Some sampling events were not significantly different from one another. For example, assemblages recorded in the Dry 2021 were statistically similar to those recorded in the Dry 2020 t = 1.78, *p* = 0.121), Wet 2021 (t = 1.14, *p* = 0.219), Dry 2022 (t = 1.23, *p* = 0.062) and Wet 2023 (t = 1.22, *p* = 0.087). Similarly, there was no significant difference in assemblages between the Dry 2022 and Wet 2022 (t = 1.21, *p* = 0.073), and Dry 2022 and Wet 2023 (t = 1.16, *p* = 0.176).

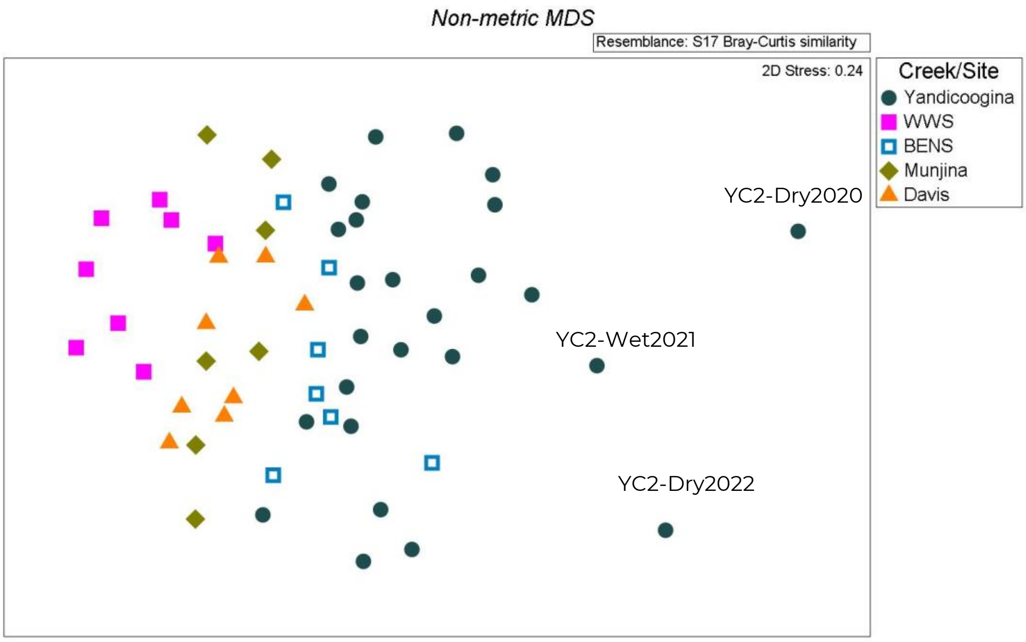


Figure 4.29: nMDS of macroinvertebrate assemblages recorded during this and previous Ministers North surveys, with samples identified by creek/site

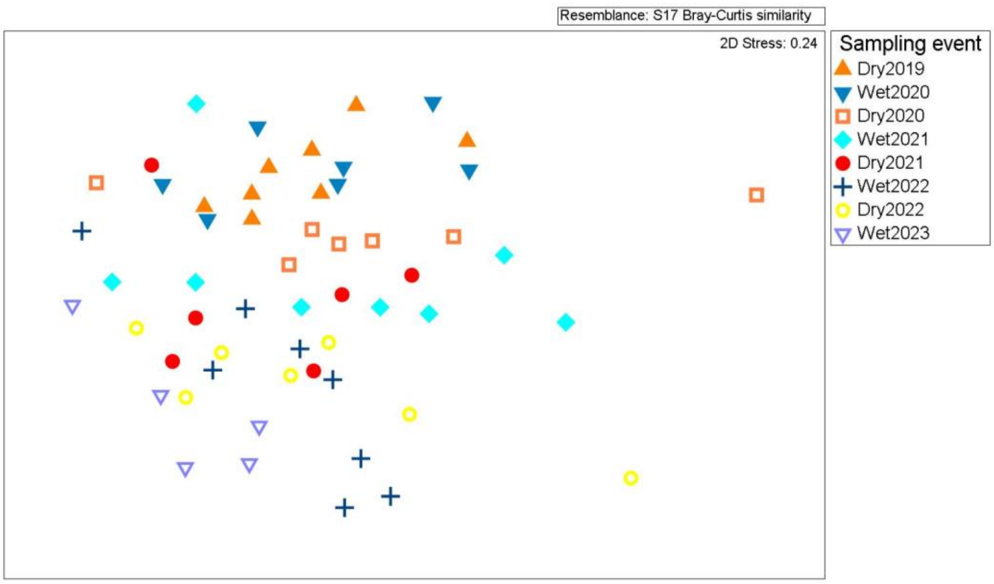


Figure 4.30: nMDS of macroinvertebrate assemblages recorded during this and previous Ministers North surveys, with samples identified by sampling event

4.6 Rehydration Emergence Trials

4.6.1 Trial conditions

Water quality recorded from tanks during rehydrate trials was generally conducive to emergence of fauna and germination of flora. The tanks were mostly clear, however, a slight algal bloom was observed in the YC1 Dry 2022 tank from day 22 in Phase 1, which had re-established by day 2 of Phase 2. Algae started growing in the wet season tanks of both YC1 and YC2 on the final day of Phase 1 (day 28). This did not re-establish during Phase 2.

Water temperatures ranged from 20.6 °C in the wet season YC3 tank (during Phase 1) to 24.5 °C in the dry season YC1 tank (also during Phase 1; Table 4.5). This was broadly similar to field water temperatures, with a range of 18.8 °C to 21.6 °C within pools of the Survey Area in the Dry 2022, and a temperature of 25.6 °C in the only remaining pool in the Wet 2023.

Table 4.5: Summary of water quality recorded during the rehydration trials

Highlighted cells refer to values which are in excess of; ■ > the ANZG 95% DGV.

		Temp °C		pH		EC (µs/cm)		DO %	
Site	Statistic	Phase 1	Phase 2	Phase 1	Phase 2	Phase 1	Phase 2	Phase 1	Phase 2
ANZG DGV				**6-8**		**250**		**85-120**	
Dry 2022									
YC1	min	21.4	25.3	7.96	7.65	951	555	57.1	47.1
	max	24.5	28.4	8.50	8.00	1264	718	87.2	66.1
	mean	23.1	26.2	8.21	7.92	1091	608	68.7	56.4
	se	0.27	0.28	0.05	0.03	24.80	13.97	3.36	1.83
Wet 2023									
YC1	min	21.4	20.9	7.40	6.96	756	977	66.4	59.3
	max	23.4	21.4	8.16	7.77	1113	1165	92.8	101.3
	mean	22.3	21.1	7.70	7.51	1008	1091	84.8	95.1
	se	0.24	0.06	0.10	0.09	51.99	21.26	4.14	5.12
YC2	min	21.4	20.8	6.75	6.85	824	922	67.7	33.6
	max	23.3	21.4	8.03	7.63	1018	1040	91.6	95.2
	mean	22.2	21.0	7.51	7.31	955	998	83.7	85.8
	se	0.22	0.07	0.14	0.10	21.26	12.24	3.99	7.05
YC3	min	20.6	19.9	7.23	7.10	784	916	67.5	57.1
	max	22.6	20.7	8.15	7.74	1022	1079	93.0	101.6
	mean	21.1	20.3	7.65	7.46	928	1004	85.5	94.7
	se	0.26	0.09	0.12	0.08	29.67	16.42	4.09	5.10

As has been recorded for Yandicoogina Creek previously (Biologic, 2023c), pH in the rehydration tanks was slightly more basic than that recorded from inundated pools within the Survey Area. In the field, all pH values were circum-neutral, ranging from 7.47 to 7.86 (both records in the Dry 2022), while pH in trial tanks was higher, with numerous records greater than 8 (Table 4.5). However, the pH recorded within the inundated trial tanks was well within the range experienced in Pilbara pools, especially groundwater fed systems. Therefore, the slightly pH in trial tanks was considered unlikely to adversely affect hatching success.

Another trend that has been reported previously in rehydration trials of Yandicoogina Creek sediments, was the higher EC values recorded in the tanks when compared to field measurements made in situ. However, in this case, EC recorded during rehydration trials were only marginally higher than field records. In the Dry 2022, the greatest EC recorded from pools in Yandicoogina Creek was 784 µS/cm. All EC values recorded during Phase 1 were higher than this, but none of the records from Phase 2 greater. In the Wet 2023, EC in the field was 622 µS/cm. All values recorded from rehydration tanks in both phases exceeded this value. The minimum EC recorded from trials conducted on Wet 2023 sediments was 756 µS/cm (in the YC1 tank Phase 1) and the maximum was 1165 µS/cm (again YC1, but Phase 2; Table 4.5). All EC values recorded during the trials were indicative of fresh waters, and none would be considered likely to impeded emergences.

4.6.2 Taxonomic composition and species richness

The rehydration-emergence trials yielded around 1,500 individuals from 20 invertebrate taxa and one macrophyte taxa (Table 4.6). The submerged macrophyte *Vallisneria* sp. was recorded in both YC1 and YC2 tanks. Invertebrate taxa included Amoeba (one taxon), Tardigrada (water bears; one taxon), Turbellaria (flat worms; one taxon), Rotifera (rotifers; one taxon[6]), Nematoda (round worms; one taxon), Acarina (aquatic mite; one taxon), Cladocera (water fleas; 6 taxa), Ostracoda (seed shrimp; 6 taxa), and Diptera (two-winged flies; 2 taxa). The record of the beetle, *Hydroglyphus grammopterus*, from YC1 Dry 2022 sediments (Table 4.6), does not represent an actual emergence. Although collected at the time of harvest, the specimen was no longer intact. It is likely the beetle had died prior to the survey and was lying in the sediment prior to collection. Beetles do not have physiological adaptations to survive drying such as diapause or dormant life history stages (Strachan *et al.*, 2015), but as aerial adults are able to recolonise more suitable nearby habitats.

[6] Rotifers collected from rehydrate-emergence trials were not sent to the taxonomic expert and therefore were not identified past Rotifera.

Table 4.6: Emergent taxa recorded during rehydration trials. W1 = first wetting and W2 = second wetting

Values are log10 abundance classes

			Dry 2022		Wet 2023					
			YC1		YC1		YC2		YC3	
Kingdom/Phylum/Class/Order	Family	Lowest taxon	W1	W2	W1	W2	W1	W2	W1	W2
PLANTAE										
LILIOPSIDA										
Alismatales	Hydrocharitaceae	*Vallisneria* sp.	2	2	2	2	2	2	0	0
PROTISTA										
AMOEBOZOA										
Tubulinea										
Arcellinida		Testate Amoeba sp.	0	0	0	0	0	0	0	2
ANIMALIA										
TARDIGRADA		Tardigrada sp.	3	0	0	0	0	0	0	2
PLATYHELMINTHES										
Turbellaria		Turbellaria sp.	0	1	0	0	0	2	0	0
ROTIFERA		Rotifera sp.	5	2	3	1	2	3	0	3
NEMATODA		Nematoda sp.	0	0	2	2	0	0	0	2
ARTHROPODA										

			Dry 2022		Wet 2023					
			YC1		YC1		YC2		YC3	
Kingdom/Phylum/Class/Order	Family	Lowest taxon	W1	W2	W1	W2	W1	W2	W1	W2
Arachnida		Acari sp.	0	0	0	0	0	0	0	2
CRUSTACEA										
Branchiopoda										
Diplostraca		Cladocera sp.	0	0	2	0	0	0	0	0
	Chydoridae	*Alona rectangula*	4	0	0	0	0	0	0	0
		Alona rigidicaudis	0	0	2	2	0	0	3	3
		Leberis cf. *diaphanus*	0	5	0	0	0	0	0	0
		Chydorus eurynotus	0	0	0	0	0	2	0	0
	Macrothrichidae	*Macrothrix spinosa*	4	0	0	1	0	3	0	0
Ostracoda										
Podocopida	Cyprididae	Cyprididae sp.	0	0	0	1	0	0	2	2
		Cypridopsis sp.	0	3	0	0	0	0	0	0
		Ilyodromus `sp. Biologic-OSTR014`	0	2	0	0	0	0	0	0
		Riocypris cf. *fitzroyi*	0	0	0	0	0	0	1	0
		Stenocypris major	0	3	0	0	0	0	0	0
	Limnocytheridae	*Limnocythere dorsosicula*	0	0	0	0	0	0	0	1
INSECTA										
Diptera	Chironomidae	*Parakiefferiella* sp.	0	0	1	0	0	0	0	0
	Culicidae	*Anopheles* sp.	0	0	0	0	0	0	1	0
Coleoptera	Dytiscidae	*Hydroglyphus grammopterus**	0	1	0	0	0	0	0	0
		Taxa richness	**5**	**8**	**6**	**6**	**2**	**5**	**4**	**8**
*does not represent an actual emergence			**11**		**8**		**5**		**10**	

Rotifera and Ostracoda tended to emerge in trial tanks first, and were generally present by day 10 of the trials. Macrophytes began germinating around day 6. Crustacea was the richest group (12 of the 20 taxa), of which both Cladocera and Ostracoda recorded an equal six taxa. Rotifers and crustaceans typically make up a large proportion of the invertebrate assemblage in temporary waters due to their ability to produce desiccation resistant propagules (also known as resting stages) capable of withstanding long periods of drought (Rossi *et al.*, 2013; Timms, 1993). However, in the current study, richness within the Rotifera was not quantified.

Within-site richness ranged from five taxa from YC2 Wet 2023 sediments to 11 taxa from YC1 Dry 2022 sediments, including macrophytes (Table 4.6). Individual wetting events within a site recorded richness ranging from 2 (YC2 W1 in the Wet 2023) to 8 (YC1 W2 Dry 2022, and YC3 W2 Wet 2023). Many taxa emerged during one wetting event of the trial only, and generally, the second wetting event was more productive than the first (Table 4.6).

Thirteen invertebrate taxa that emerged during rehydration trials were not recorded from inundated pools during the current study (i.e. not recorded in the hyporheos or surface water macroinvertebrate samples). These taxa included testate Amoeba sp., Rotifera sp., Tardigrada sp., the ostracods Cyprididae sp., *Ilyodromus* `sp. Biologic-OSTR014`, *Riocypris* cf. *fitzroyi* and *Limnocythere dorsosicula*, the Cladocera *Alona rigidicaudis*, *Leberis* cf. *diaphanus*, *Chydorus eurynotus*, *Macrothrix spinosa*, and Cladocera sp., and the chironomid *Parakiefferiella* sp. While all are relatively common, widespread taxa and none are listed as being of significance, several constitute new records for the Survey Area. These include Tardigrada sp., *Ilyodromus* `sp. Biologic-OSTR014`, and the Cladocera *Alona rigidicaudis, Leberis* cf. *diaphanous, Chydorus eurynotus* and *Macrothrix spinosa*.

Although the submerged macrophyte, *Vallisneria* sp., has not been previously recorded from YC1 and YC2 when inundated, it did germinate during rehydration trials previously from sediments collected from these two sites (Biologic, 2023c).

4.6.3 Significance of emergent fauna

None of the taxa which emerged from Survey Area sediments are listed, restricted or of significance.

4.7 Fish

4.7.1 Fish species composition and richness

Four freshwater fish species were recorded during the current study: western rainbowfish

Melanotaenia australis (Melanotaeniidae), Pilbara tandan *Neosilurus* sp.[7] (Plotosidae), Pilbara bony bream *Nematalosa* sp.[8] (Clupeidae) and spangled perch *Leiopotherapon unicolor* (Terapontidae). Of these, all but Pilbara bony bream were found in the Survey Area.

4.7.2 Abundance

A total of 955 individual fish was recorded in the current study, with 421 recorded in the Dry 2022 (77 from the Survey Area and 344 from Reference sites), and 534 in the Wet 2023 (74 from the Survey Area and 460 from Reference sites; Table 4.7). Within the Survey Area, only YC4 had fish present. No fish were recorded from YC2 and YC3 during the Dry 2022, despite water being present. Fish have been recorded from YC3, but not YC2 previously (Biologic, 2022b, 2023c). This compares to a maximum of 162 individuals recorded from Reference sites in the Dry 2022 (WWS), and 224 in the Wet 2023 (SS).

Spangled perch, western rainbowfish, and Pilbara tandan were recorded in the Survey Area at YC4 in both seasons, except for Pilbara tandan which was not present in the Dry 2022 (Table 4.7). Pilbara tandan has been recorded from YC4 previously (Biologic, 2022b). The highest fish diversity was recorded from Reference site SS, with all four fish species recorded in the Wet 2023. Western rainbowfish was the most widespread species overall, being recorded at YC4, WWS, BENS and SS across both seasons. Spangled perch was also widely distributed, though not recorded from WWS during the Wet 2023 (Table 4.7).

Western rainbowfish was the most abundant fish in the Survey Area, with 51 individuals recorded during the Dry 2022 and 67 during the Wet 2023 (Table 4.7). Spangled perch was the next most abundant species in the Survey Area, with 26 individuals recorded in the Dry 2022 and two individuals in the Wet 2023. Only five individual Pilbara tandan were recorded in the Survey Area in the Wet 2022. Western rainbowfish were also the most abundant fish at Reference sites, with 217 individuals recorded during the Dry 2022, and 338 during Wet 2023. Pilbara tandan and spangled perch occurred in relatively low numbers at Reference sites, with the exception of the latter at SS (97 individuals in Dry 2022 and 31 individuals in Wet 2023). Pilbara bony bream was only recorded at one Reference site (SS), with 45 individuals recorded during the Wet 2023 (Table 4.7).

[7] 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.

[8] Similarly, the *Nematalosa* bony bream from the Pilbara is genetically distinct to the described *Nematalosa erebi*. The Pilbara species is referred to as *Nematalosa* sp. until further taxonomic work has been undertaken.

Table 4.7: Abundance of each freshwater fish species recorded from each site

		Leiopotherapon unicolor Spangled perch		*Melanotaenia australis* Western rainbowfish		*Neosilurus* sp. Pilbara tandan		*Nematolosa* sp. Pilbara bony bream		Abundance		Diversity	
Type	Site	W	D	W	D	W	D	W	D	W	D	W	D
Yandicoogina Creek	YC1	-	-	-	-	-	-	-	-	-	-	-	-
	YC2	0	-	0	-	0	-	0	-	0	-	0	-
	YC3	0	-	0	-	0	-	0	-	0	-	0	-
	YC4	26	2	51	67	0	5	0	0	77	74	2	3
Reference	WWS	6	0	142	109	14	5	0	0	**162**	**114**	**3**	
	BENS	3	21	69	90	0	11	0	0	**72**	**122**	**2**	**3**
	MUNJS*												
	SS	97	31	6	139	7	9	0	45	**110**	**224**	**3**	**4**
	Abundance	**132**	**54**	**268**	**405**	**21**	**30**	**0**	**45**	**421**	**534**		
										955			

- = site was dry, as opposed to 0, which means no fish were recorded despite water being present

* = No fish have been recorded from MUNJS, likely due to the presence of waterfalls, or some other impediment downstream limiting fish movement to the site

4.7.3 Significant fish species

While no significant fish species were recorded from the Survey Area, the Pilbara tandan and Pilbara bony bream are endemic to the region. The Pilbara tandan is generally less commonly recorded, but this is likely a sampling artefact due to its cryptic nature, being commonly found under snags and undercuts.

4.7.4 Length-frequency analysis

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[9] for males and 78 mm TL for females. To allow for determination of age-classes (without knowing sex), size at maturity was estimated at 70 mm SL for the purposes of this study.

In the Survey Area, adults comprised the greatest proportion of spangled perch during both the Dry 2022 and Wet 2023 (54% and 100%, respectively; Figure 4.31). No new recruits or juveniles were recorded in the Survey Area during the current study. Juveniles constituted the greatest proportion of spangled perch at Reference sites during the Dry 2022 (41%), while subadults made up the greatest proportion in the Wet 2023 (44%).

Western rainbowfish

Western rainbowfish have multiple spawning events throughout the year which take advantage of the intermittent rainfall and streamflow characteristics of the Pilbara (Beesley, 2006). Maximum size is generally around 110 mm TL (Morgan *et al.*, 2002). Size at first maturity varies between river systems and sex, but for the purposes of this study was estimated to be 50 mm SL.

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

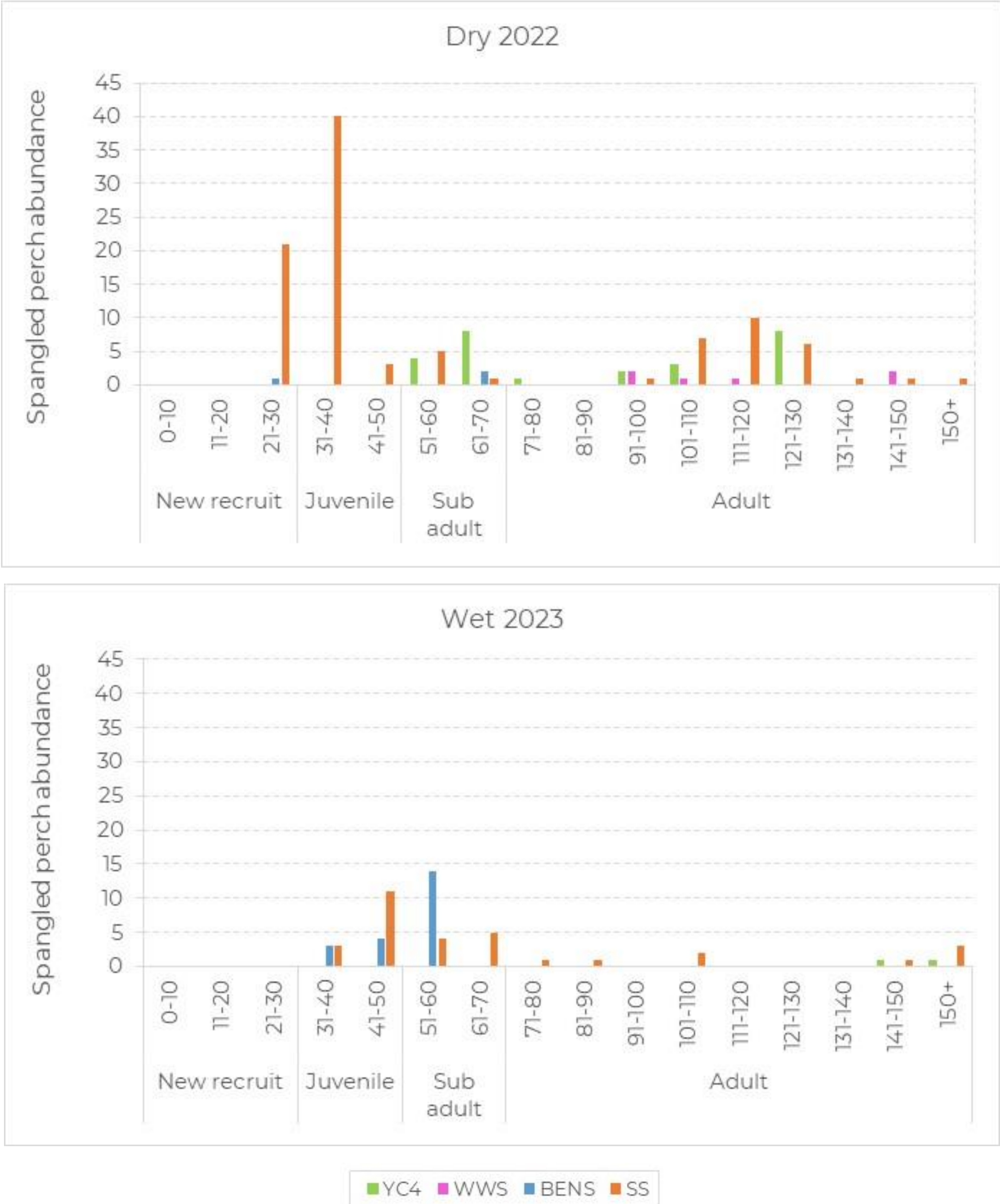


Figure 4.31: Length frequency analysis for spangled perch in the Dry 2022 and the Wet 2023

In the Survey Area, adults constituted the greatest proportion of western rainbowfish recorded in the Dry 2022 (32%), and juveniles made up the greatest proportion in the Wet 2023 (33%; Figure 4.32). No subadults were recorded in the Survey Area during the Wet 2023, with a very small proportion recorded in the Dry 2022 (2%). In the Dry 2022, adults made up the greatest proportion of western rainbowfish at Reference sites (29%), though proportions were relatively similar across all age classes. During the Wet 2023, juveniles comprised the greatest proportion (38%).

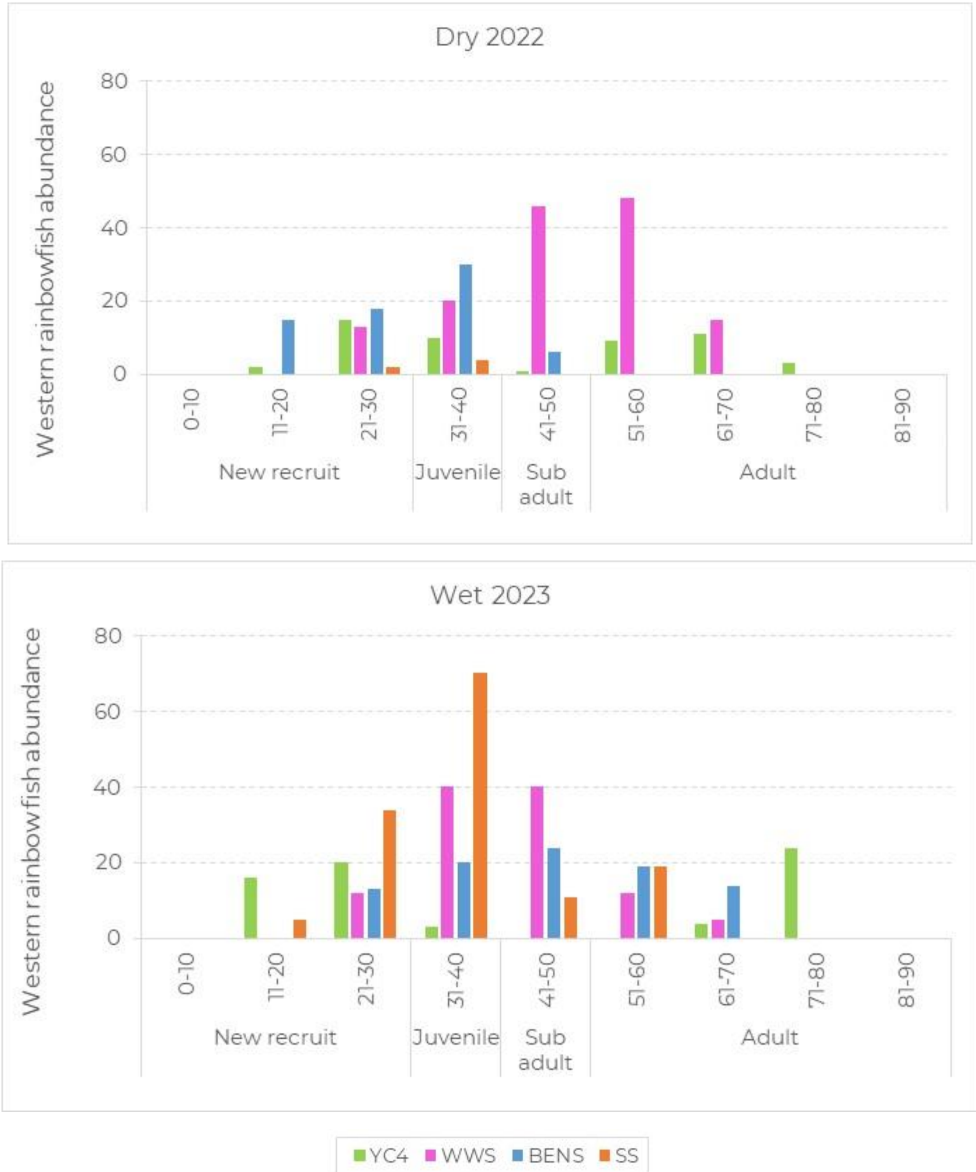


Figure 4.32: Length frequency analysis for western rainbowfish in the Dry 2022 and the Wet 2023

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 this threshold was used in the present study for Pilbara tandan (Bishop *et al.*, 2001).

Only five adult Pilbara tandan were recorded from the Survey Area during the current study (Figure 4.33). Adults also comprised the main proportion of Pilbara tandan recorded from Reference sites in both the Dry 2022 and Wet 2023 (80% and 71%, respectively). No new recruits or juveniles were recorded during the current study.

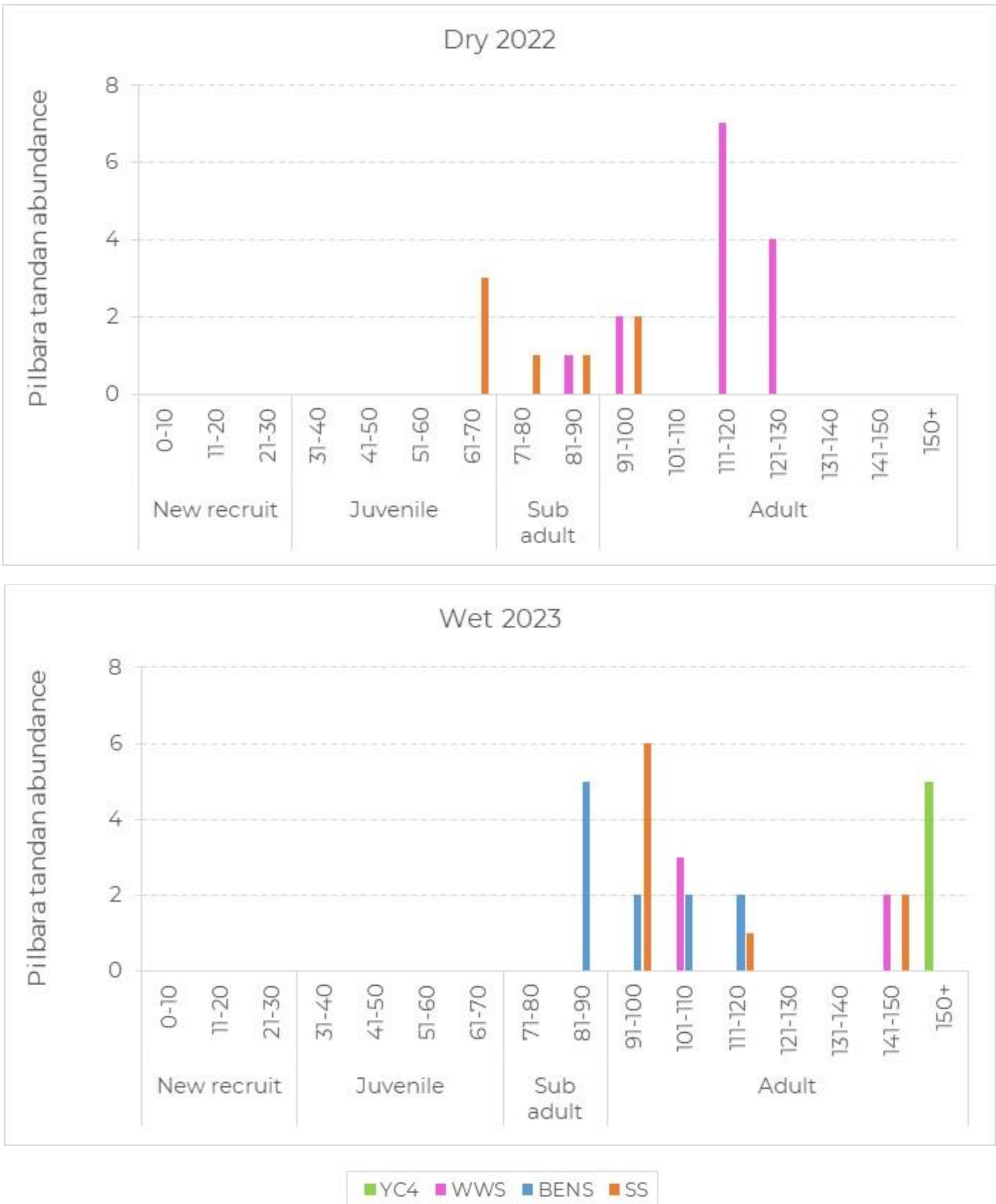


Figure 4.33: Length frequency analysis for Pilbara tandan in the Dry 2022 and the Wet 2023

4.7.5 Fish change over time

Differences in total fish abundance recorded between sampling events and site type were examined for the two most common and abundant species, spangled perch and western rainbowfish. The abundance of both species was consistently greater at Reference sites than the Survey Area (Figure 4.34). Within the Survey Area, spangled perch have persisted at low numbers, with the lowest abundance recorded during the Wet 2023 (Figure 4.34). At Reference sites, there has been a gradual decline in numbers since the Wet 2021 (Figure 4.34). Western rainbowfish numbers have remained relatively constant over time both within the Survey Area and at Reference sites (Figure 4.34).

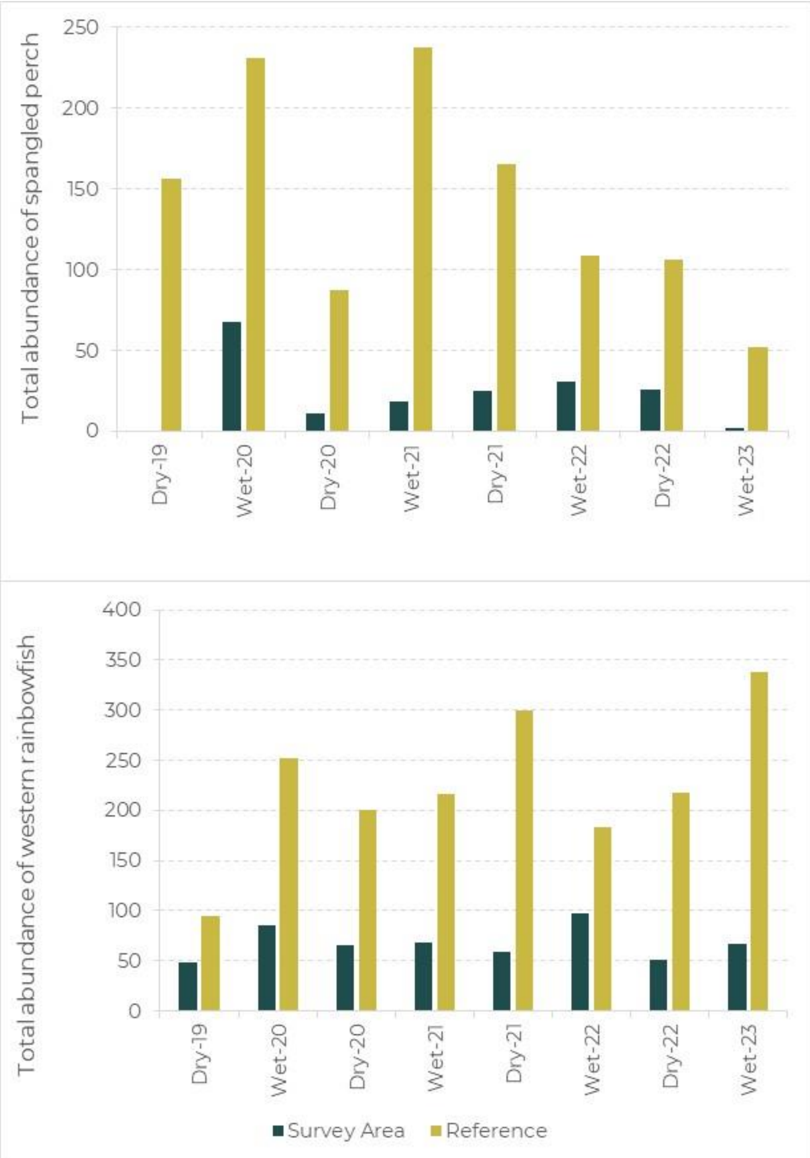


Figure 4.34: Total abundance of spangled perch and western rainbowfish from the Survey Area and Reference Sites in each sampling event

As would be expected, given the above results, there were no obvious linear trends in spangled perch abundance at YC3 ($r<0.005$) or YC4 ($r=0.12$) over time (Figure 4.35). Although there was a general trend for declining spangled perch abundance at YC4 over time, the correlation was very weak (Figure 4.35). Slightly stronger negative correlations between spangled perch abundance and time were recorded from Reference sites (WWS; $r=0.46$ and SS; $r=0.55$).

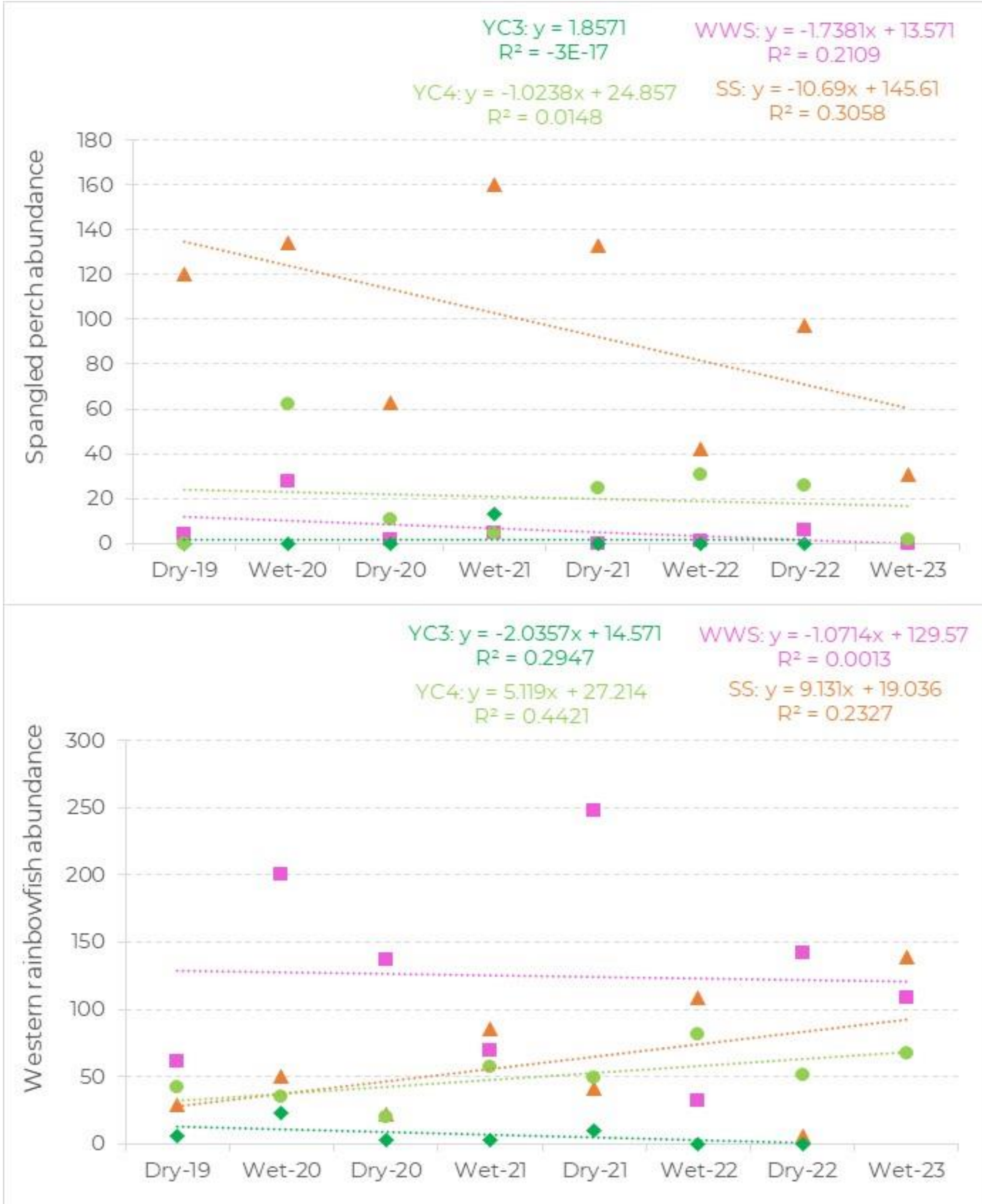


Figure 4.35: Change in abundance of spangled perch and western rainbowfish

There has been a slight decline in western rainbowfish abundance over time at YC3 ($r=0.54$), though numbers have been low since the Dry 2019 (Figure 4.35). In contrast, western rainbowfish abundance has appeared to have increased at YC4 (r=0.66; Figure 4.35). This result may be an artefact of improved sampling efficiency due to reducing pool depth over time and should be interpreted with caution. Western rainbowfish abundance at Reference site WWS has been consistently greater than at YC3 and YC4, however there was a slight decrease over time (r=0.04; Figure 4.35). In contrast, western rainbowfish numbers have increased over time at SS (r=0.48; Figure 4.35).

Overall, there was no significant difference in fish abundance between sampling event for either species (Two-way ANOVA; df = 7, $p > 0.882$). However, western rainbowfish, spangled perch and Pilbara tandan all recorded significantly lower abundances within the Survey Area in comparison to Reference sites (df = 1, $p < 0.020$).

4.8 Other Vertebrate Fauna

4.8.1 Frogs

Tadpoles were observed at YC3 and MUNJS in the Dry 2022. Based on tadpole morphology (size and shape), along with calls heard at the time of survey, both the Pilbara toadlet (*Uperoleia saxatilis*) and desert tree frog (*Litoria rubella*) were present at YC3, while Main's frog (*Cyclorana maini*) occurred at MUNJS.

4.8.2 Waterbirds

No waterbirds were observed within the Survey Area, however an individual Nankeen night heron (*Nycticorax caledonicus*) was recorded at SS. These birds are associated with permanent water and will occur in large numbers under optimal wet (Birdlife Australia, 2023). An individual blue-winged kookaburra (*Dacelo leachii*) was also recorded at BENS. Though not considered a waterbird, blue-winged kookaburras are known to inhabit *Melaleuca* swamplands (WAM, 2022).

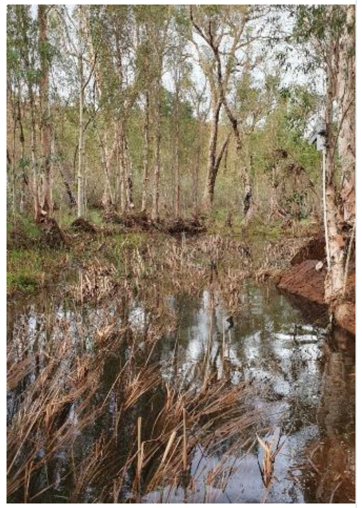
5 Discussion

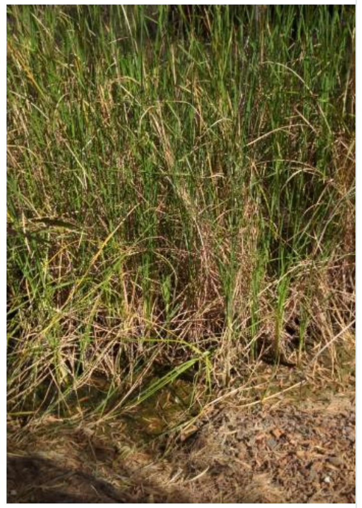
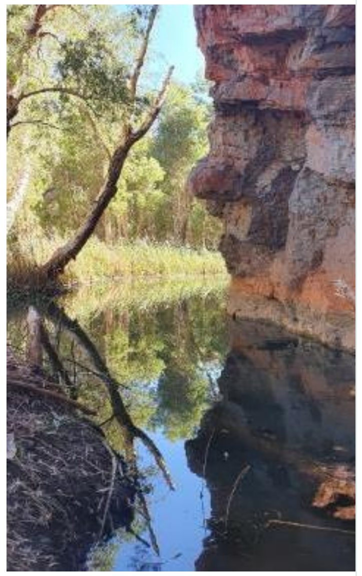
5.1 Habitat Assessment

Although the sampling site pools were previously considered to be permanent, all previous sampling locations along Yandicoogina Creek were dry at the time of the Wet 2023 survey except YC4. The drying of the creek has been occurring since the Wet 2020, with maximum water depths in pools decreasing over time, and sites being dry on numerous sampling occasions since that time (Table 5.1). In many instances, this occurred following heavy wet season rainfall and associated flooding in nearby creeklines (Biologic, 2022b, 2023c). Surface water within Yandicoogina Creek, appears to be draining quickly, rather than being maintained by groundwater intersecting the surface. Maximum pool depth at YC4 recorded a strong negative correlation with time. Negative linear relationships were also recorded from Reference sites WWS and SS, although these relationships were not as strong as YC4. Reductions in water levels at these Reference sites was due to pool infilling and mobilisation of sediment following wet season floods, rather than any actual reduction in the extent and availability of aquatic habitat.

The reduction in water levels in the Survey Area translates to a reduction in aquatic habitat availability, with YC4 providing the only refuge for aquatic fauna in the Wet 2023. However, this site was also impacted by lowering water levels, with a reported drop of 1 m between the Dry 2022 and Wet 2023. Despite water remaining at YC4, the lowering pool depth has led to other impacts to aquatic habitat, including a decline in emergent macrophyte cover. There was a strong negative correlation between macrophyte cover and time. In-stream, submerged macrophyte cover has also declined, with a strong negative linear relationship between cover and time recorded. A similar decline in emergent macrophyte cover was also recorded from YC3 in the Survey Area, and reference site WWS. The latter is impacted by discharge from Rio Tinto's HD1, which may account for the change in macrophyte cover. The site was included in this study due to similarities in hydrology (historic spring) and riparian flora (dominance of *Melaleuca argentea*) with the Survey Area, of which few sites in the Pilbara compare.

Table 5.1: Photographs showing water level and aquatic habitat changes within the Survey Area between the Dry 2019 and Wet 2023

Dry 2019	Wet 2020	Dry 2020	Wet 2021	Dry 2021	Wet 2022	Dry 2022	Wet 2023
YC1							
							
Max depth: 0.4 m	**Max depth: 0.60 m**	**Max depth: 0.4 m**	**Max depth: 0.15 m**	**Max depth: Dry**	**Max depth: 1.2 m**	**Max depth: Dry**	**Max depth: Dry**
YC2							
							
Max depth: 0.6 m	**Max depth: 0.15 m**	**Max depth: 0.4 m**	**Max depth: 0.3 m**	**Max depth: Dry**	**Max depth: 1 m**	**Max depth: 0.1 m**	**Max depth: Dry**

Dry 2019	Wet 2020	Dry 2020	Wet 2021	Dry 2021	Wet 2022	Dry 2022	Wet 2023
YC3							
							
Max depth: 0.3 m	**Max depth: 0.6 m**	**Max depth: 0.5 m**	**Max depth: 0.4 m**	**Max depth: 0.1 m**	**Max depth: 0.75 m**	**Max depth: 0.3 m**	**Max depth: Dry**
YC4							
							
Max depth: 5 m	**Max depth: 5.5**	**Max depth: 5 m**	**Max depth: 4.5**	**Max depth: 2.2 m**	**Max depth: 3.2 m**	**Max depth: 3 m**	**Max depth: 2 m**

5.2 Water Quality

As previously reported, water quality in remaining Yandicoogina Creek pools was good and characterised by fresh, clear waters, with low dissolved oxygen saturation, neutral pH, low nitrogen nutrient and generally low 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, with all sites recording EC less than 1,500 µS/cm. This is the known ecological threshold, whereby there is a considerable shift in fauna assemblages to occur (Hart *et al.*, 1991; Horrigan *et al.*, 2005). The very small pool remaining at YC2 in the Dry 2022 had clearly undergone evapoconcentration effects as the pool receded, because although still fresh, the EC at this site was noticeably higher than all other values recorded from the Survey Area. There was no significant difference in EC between sampling events, but the Survey Area did record significantly lower EC than Reference sites.

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, YC2 recorded exceptionally low DO in the dry season due to the low water levels (7.5%). 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. Low DO has been recorded from the Survey Area previously (Biologic, 2020, 2022b, 2023c), albeit not to the extent of the current YC2 saturation. Aquatic biota may be adversely affected by low DO, especially since these levels appear to be sustained over relatively long periods. The low DO recorded from the Survey Area is likely a combination of low water levels, coupled with the decay of algae and organic matter surrounding the *Typha* beds, with bacteria consuming oxygen in the water as part of this process. Although some reference sites also recorded DO saturation below the lower ANZG (2018) DGV in the current study, overall, DO within the Survey Area was significantly lower than that recorded from Reference sites. In addition, DO saturation at YC3 is declining over time, with a strong negative relationship recorded.

pH at Yandicoogina Creek is neutral and consistent throughout the Survey Area. Including all previous data in comparisons, the pH recorded from the Survey Area was significantly lower than that recorded from Reference sites. Overall, there has been minimal change in pH over time within the Survey Area or Reference sites, and as such, there was no significant difference in pH between sampling events. Alkalinity within the Survey Area also suggests surface waters are well buffered against rapid changes in pH.

Ionic composition generally reflected groundwater, but with greater inputs from rainfall and evapoconcentration effects now evident at some sites than has been previously recorded from the Yandicoogina Creek. In particular, S_SO4 concentrations have increased within the Survey Area over time. Initially, concentrations in the Survey Area were lower than Reference sites, however, in the Dry 2019 there was a switch, and after this time, S_SO4 was consistently higher in the Survey Area compared to Reference sites. This result was reflected in a significantly interaction term between sampling events and site type. It also resulted in a strong positive correlation between S_SO_4 concentration and time at YC3 and YC4, indicating increasing concentrations over time. As there is no DGV for sulfate, it is difficult to determine whether current concentrations are high or low, despite the increasing trend. Although sulfate has relatively low toxicity compared with other major ions, it can be toxic to aquatic biota above certain thresholds (Dunlop *et al.*, 2016; van Dam *et al.*, 2009), and increasing concentrations can often be associated with acid mine drainage or neutral mine drainage. As such, the increasing sulfate concentrations at Yandicoogina Creek should continue to be closely monitored.

Nutrient concentrations in the Survey Area were low and below toxicity DGVs. Concentrations were generally low in comparison to eutrophication DGVs as well, with the exception of N_NOx (elevated at YC2) and total P (elevated at all sites except YC3). Eutrophication DGVs are 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 N_NOx and total N concentrations were relatively low within Yandicoogina Creek currently suggests there is a relatively low risk of eutrophication.

Although the concentrations of N_NO_3 within the Survey Area were generally low, they have shown an increase over time at YC3. This site recorded a strong positive correlation between N_NO_3 and time. Nitrate is a naturally occurring nutrient that is of significance in agriculture, aquaculture, urban and mining areas worldwide (Van Dam *et al.*, 2022), and cause toxic effects in algae, plants and aquatic fauna at high concentrations (Camargo *et al.*, 2005). While the increase in N_NO_3 concentration at YC3 is of note and should continue to be monitored, current concentrations are still well below the ANZG (2018) 99% DGV of 1 mg/L (adapted from the New Zealand nitrate toxicity guidelines (Hickey, 2013; NIWA, 2013). They are lower still than the nitrate SSGVs recently developed for Pilbara waters of 7.6 mg/L which take into account the hard waters characteristic of surface waters of the region (Van Dam *et al.*, 2022). Given this, and the fact that Yandicoogina Creek pools are known to have high hardness (>160 mg/L as CaCO3) as defined by Van Dam *et al.* (2022), the risk of nitrate toxicity is currently low.

Phosphorus concentrations within the creek were high, with significantly greater Total P recorded from the Survey Area than Reference sites (incorporating all sampling events in the analysis). However, total P concentrations in the Survey Area, and at Reference sites, have been declining over time. The significantly highest concentration was recorded during the initial sampling event in the Dry 2019, with significantly lower concentrations recorded more recently in the Dry 2022, Wet 2022 and Dry 2020. Strong negative correlations between total P and time were also recorded from YC3, YC4, WWS and SS.

Dissolved metal concentrations were generally low across the Survey Area, and in fact some were recorded in concentrations significantly lower than Reference sites (dCu, dAs, dBa, dU, and dV). The only elevated dissolved metals within the Survey Area were:

- dB, which was elevated in comparison to the 99% toxicity DGV at all Survey Area sites (and most Reference sites)
- dFe, which exceeded the interim working level at YC2 and YC4
- dZn, which was in excess of the 99% toxicity DGV at YC2.

Concentrations of dFe were significantly greater in the Survey Area when compared to Reference sites. There was also a significant difference in dFe between sampling events, although there was no obvious temporal or seasonal pattern to this difference and no linear change over time.

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.

5.3 Macrophytes

As noted previously (Biologic, 2020, 2022b, 2023c), the Survey Area classifies as a groundwater dependent ecosystem (GDE), being comprised of numerous high and moderate-level key species which indicate subsurface groundwater and/or permanent surface water (see sections 2.3 and 4.3.2). The record of a Moderate-High indicator species, *Kirganelia baccata* was the first of this taxon during an aquatic survey in Yandicoogina Creek. In-stream, *Vallisneria nana* (YC4) and *Chara globularis* (YC3) were present. *Vallisneria nana* indicates water permanence and is known only from perennial creeks and rivers (Rea *et al.*, 2002; Rio

Tinto, 2022). However, submerged macrophyte richness has decreased over time within the Survey Area, largely due to the drying of the creek.

While vegetation within the Survey Area has previously been dense in places, in the current study, large *Typha* beds surrounding YC4 were significantly reduced and showing obvious signs of water stress (being dead or dying). *Cyperus vaginatus* cover was also reduced. Reduced emergent macrophyte abundance was exacerbated by increased cattle grazing and trampling of pool banks and vegetation in the current survey. Increased cattle activity also coincided with an increase in the diversity of introduced flora within the Survey Area.

GDVs within the Survey Area are showing signs of the lowering water levels. Other than observations made in the current study, the Biologic flora team noted that mature individuals of *Fimbristylis sieberiana* (P3) had died-off, with only juveniles present at YC4 (Biologic, unpub. data). Canopy cover of *Melaleuca argentea* and *Eucalyptus camaldulensis* within the Survey Area has decreased since 2020 (Biologic, unpub. data), and during the current aquatic survey many juvenile *Melaleuca argentea* trees were in the lower end of the Survey Area were dead. The *Imperata cylindrica* bed near YC4 was also in poor condition in January 2023, showing obvious signs of yellowing (Biologic, unpub. data). These observations indicate that groundwater is lowering beyond the depth of the root zone of these GVs, and at a rapid rate. Detrimental impacts to the tree health of *Melaleuca argentea* trees have been reported with as little as a 0.5 m decrease in groundwater levels (McLean, 2014).

5.4 Hyporheos Fauna

The Survey Area continues to support a high proportion of groundwater dependent taxa within the hyporheic zone. Of the total invertebrate taxa recorded from the hyporheos, 16% are directly dependant on groundwater for their persistence. In particular, the Survey Area has consistently recorded high richness and composition of stygobites, with 13% reported for the Dry 2019 and Wet 2020 survey (Biologic, 2020), 11% in the Dry 2020 and Wet 2021 (Biologic, 2022b), and 19% in the Dry 2021 and Wet 2022 (Biologic, 2023c). This is considerably greater than that reported previously for hyporheic zones of Pilbara springs (i.e., 5% stygobitic fauna recorded in Halse *et al*., 2002). The high proportion of stygobitic taxa reflects the strong groundwater connection within this reach of Yandicoogina Creek.

The greatest richness of groundwater dependent taxa was recorded within the Survey Area from YC3 (eight taxa), followed by YC1 (five). Considerably fewer groundwater dependent taxa were recorded from Reference sites, with the greatest richness recorded from Weeli Wolli Spring and being half that of the YC3 richness.

Overall, there were no linear trends in occasional hyporheos taxa richness or stygobitic taxa richness over time. Therefore, it would appear that despite the lowering water levels across the Survey Area, hyporheos habitat is currently maintained in isolated locations across the creek including YC1 and YC3. Although no surface water was present at YC1 in the Dry 2021, a hyporheic sample was successfully collected, with water being present within the zone beneath the surface. This site yielded the second greatest richness of groundwater dependent taxa across the entire study.

Locations such as YC1 and YC3 provide refuges for restricted groundwater dependent taxa such as Paramelitidae `sp. Biologic-AMPH023`, *Meridiescandona* `sp. Biologic-OSTR074` and *Pygolabis* `sp. Biologic-ISOP035`. While these taxa were recorded in the current study, other restricted taxa previously known from the creek were not. Two syncarid taxa, *Atopobathynella* `sp. Biologic-PBAT042` and Bathynellidae `sp. Biologic-BATH019` were recorded from YC1 in the Wet 2022. The former has two records, one from Yandicoogina Creek and one from nearby Marillana Creek, close to the confluence with Yandicoogina Creek, with a linear distance of only 4.5 km. Other closely related *Atopobathynella* OTUs are known from nearby locations, which, together may comprise a species complex. Further work is currently being undertaken on *Atopobathynella*. The latter OTU, Bathynellidae `sp. Biologic-BATH019`, is currently known only from one record. It is possible that these syncarid taxa still reside in isolated hyporheic or groundwater habitats beneath Yandicoogina Creek, and have simply not been recorded from the available surface sites sampled under the current study. If the remaining hyporheos habitat dries completely, restricted taxa may be lost from the system. Increased survey effort should be made across the hyporheic zone of Yandicoogina Creek in future, including locations not currently covered by this monitoring program, especially following rainfall events to provide further information on species' distributions and available hyporheos habitat throughout the creek.

5.5 Macroinvertebrates

A total of 152 macroinvertebrate taxa was recorded from the Survey Area during the current study, with 119 taxa recorded in the Dry 2022 from three sites, and 77 in the Wet 2023 from one site. The composition of macroinvertebrate fauna within the Survey Area was generally similar to most Pilbara pools and was dominated by slow flow and relatively tolerant taxa such as Coleoptera and Diptera. Composition at Reference sites was broadly similar, however, greater numbers of taxa which require faster flows were recorded, including Lepidoptera, leptophlebiid mayflies, Simulidae (Diptera), *Cheumatopysche* and *Chimarra* caddisflies (Trichoptera), especially from Weeli Wolli Spring, Munjina Spring and Skull Springs.

Richness in the pools remaining in the Survey Area was generally high, with the exception of YC2. YC2 has consistently recorded low macroinvertebrate richness which is likely related to habitat factors including the low water levels and highly abundant *Typha* at this site (Biologic, 2020, 2022b). In the current survey, the pool had receded substantially and was very small. Aquatic fauna remaining at this site were subject to the exceptionally low DO, higher EC than is usual for Yandicoogina Creek, considerably high turbidity, and high concentrations of N_NH_3, N_NOx, total P, dFe, and dZn.

Notably, macroinvertebrate richness at YC4 in the Dry 2022 was greater than that of Skull Springs, a site known for its particularly high richness of aquatic invertebrate fauna within the Pilbara region (Kendrick & McKenzie, 2003). YC4 has consistently recorded a high richness of macroinvertebrate taxa, and represents the last refuge for aquatic fauna in Yandicoogina Creek when all other pools have dried. Although smaller, YC3 is also relatively persistent in comparison to YC1 and YC2. This site has recorded a positive linear relationship between macroinvertebrate taxa richness and time, indicating an increase in richness at this site since the Dry 2019. This relationship was not recorded from any other Survey Area or Reference site.

A relatively high number of Pilbara endemic taxa still occur throughout the Survey Area, especially at YC4. Additionally, populations of several listed odonate species continue to reside in Survey Area pools, including *Austroagrion pindrina, Hemicordulia koomina* and *Ictinogomphus dobsoni*. Pinder *et al.* (2010) found that the rare and/or restricted elements of the macroinvertebrate fauna tended to be found within the permanently flowing springs, or alternatively within ephemeral wetlands such as the Fortescue Marsh and freshwater claypans.

Remnant pools within ephemeral systems are known to provide important refuge habitat during drought conditions where habitat, quality and pool size remain suitable (Bogan *et al.*, 2019). Therefore, the current condition of YC4 is of concern, given the rapidly decreasing pool depth and size, and accompanying death of emergent macrophytes, as well as the fact that cattle can now easily access the pool. The continued decline of water levels at this site would lead to adverse impacts to aquatic fauna, including to local populations of Pilbara endemic and significant species. Hydrological processes, including the timing, frequency and extent of flows, and persistence of surface water are known to be important natural drivers for aquatic ecosystems in arid zones (Boulton, 1999; Walker *et al.*, 1995). In their study of over 100 Pilbara pools, Pinder *et al.* (2010) found that flow and hydrological persistence were two of the environmental variables most strongly correlated with macroinvertebrate assemblages and patterns of occurrence, along with turbidity, salinity, sediment and macrophytes, all of which are related to flows and pool persistence.

Yandicoogina Creek macroinvertebrate assemblages were most similar to Bens Oasis. Being the only other site in the current program which does not exhibit perennial flows, it is perhaps the most similar to the Survey Area in terms of hydrology.

5.6 Rehydrates

While few rehydration studies are publicly available for Pilbara systems, and reported results are highly variable, the current study recorded lower taxa richness than has been recorded from ephemeral creeklines in the region previously (WRM, 2016; Biologic, 2022c; Biologic, unpub. data). The highest richness recorded from an individual site in the current study was 11, in comparison to up to 17 taxa recorded from ephemeral sites near Paraburdoo (Table 5.2). The highest richness in Yandicoogina Creek was also recorded from one of the least persistent pools YC1, which has been dry on numerous occasions over the entire monitoring period. Aquatic fauna of permanent pools such as those within the Survey Area would not historically be adapted to seasonal drying. Strategies such as diapause or having dormant life history stages (typically eggs) are adaptations typically found in aquatic invertebrates which inhabit harsh or unstable environments (Radzikowski, 2013). Predictable and persistent drying in isolated temporary waterbodies exerts pressure on species which inhabit these environments to produce desiccation-tolerant and thermally resistant diapausing forms in order to survive (Radzikowski, 2013; Strachan *et al.*, 2015). Given it is an adaptive response, resistance abilities would differ between organisms inhabiting permanent aquatic habitats in comparison to temporary ones. The resistance of dormant forms originating from permanent habitats has been shown to be lower than that of their relatives from more variable, ephemeral habitats (Caprioli & Ricci, 2001; Radzikowski, 2013; Ricci, 1998).

Table 5.2: Taxa richness recorded during rehydration studies in the Pilbara

			Individual site richness	
Area	Study	No. of sites sampled	Min	Max
Paraburdoo	Biologic (unpub. data)	3	7	17
Western Ridge	Biologic (2023f)	9	9	16
Ministers North	This Study	4	5	11

*all richness values are excluding Rotifera species-level identifications to allow comparison to the current study.

Of the taxa which were recorded during the current emergence trials, several different strategies can be employed to survive drying. Although strategies employed by Crustacea to withstand desiccation are commonly understood, often strategies of other invertebrates are overlooked. However, this study shows that a variety of invertebrate fauna can utilise strategies to avoid drought stress, including Nematoda (anhydrobiosis[10], diapause[10] and aestivation[10]), Turbellaria (anhydrobiosis and diapause), Rotifera (anhydrobiosis and diapause), Tardigrada (anhydrobiosis[10]), Acari (diapause, aestivation and quiescence[10]), and Diptera (diapause) (Radzikowski, 2013; Strachan *et al.*, 2015; Wallace & Uyhelji, 2009).

Survival of invertebrates when utilising one of the aforementioned strategies depends not only on the length of time between inundation events (Radzikowski, 2013; Stubbington *et al.*, 2016), but also the rate of initial pool drying (Strachan *et al.*, 2015). The highest rates of survival in the invertebrate egg bank following desiccation have been reported following slow drying, which allows sufficient time for individuals to adjust their metabolism and/or enact a strategy to survive the drought (Strachan *et al.*, 2015). This has implications for systems undergoing artificial drying due to groundwater drawdown from mining operations, with invertebrates potentially not able to respond quickly enough to pool drying.

5.7 Fish

Only three native freshwater fish species occur within the upper Fortescue River catchment (within which the Survey Area occurs); western rainbowfish, spangled perch and Pilbara tandan (Allen *et al.*, 2002; Masini, 1988; Morgan *et al.*, 2014). As such, all freshwater fish species likely to populate the Survey Area were recorded. Although the Pilbara tandan is endemic to the region, each of the three species recorded from the Survey Area are common and ubiquitous across the Pilbara, and none are listed as being of significance. No introduced fish species were recorded within the Survey Area, despite the known occurrence of sailfin molly further downstream on the Fortescue River (Thorburn *et al.*, 2018).

No spangled perch new recruits were recorded within the Survey Area, with only adult fish present during the Wet 2023 survey. A high percentage of western rainbowfish new recruits, but low numbers of juvenile and subadults within the Survey Area suggests while breeding is successful in this species, survivorship of new recruits is perhaps low. The steep banks at YC4, however, make fishing at this site difficult, which may reduce the number of juvenile fish captured.

[10] Anhydrobiosis - where an organisms can withstand dehydration at a particular life history stage and remain in this state for extended periods until water becomes available.
Diapause - type of dormancy, slowing of the metabolism cued by season and biological clock which doesn't end until diapause is broken (not when favourable conditions return)
Aestivation - a halt to the metabolism, or state where the organism is physically dormant during certain times of the year (usually seasonal)
Quiescence – an immediate response to a change in environmental conditions, where the metabolism and development is resumed immediately once conditions improve.

Current results suggest that there has been limited impact of the lowering water levels on fish abundance in the Survey Area, with no significant difference in the abundance of spangled perch or western rainbowfish recorded between sampling events. Western rainbowfish abundance was higher than in previous survey years, despite only YC4 containing fish. As discussed above, this deep pool is difficult to sample for fish, especially when it is full, and the gill nets do not reach the creek bed. With reducing pool size and depth, fish numbers are likely concentrated and easier to capture in the current survey and therefore it is difficult to elucidate true population dynamics from sampling efficacy.

As with the invertebrates, the large, deep pool at YC4 is likely buffering the impacts of the lowering groundwater and surface water levels currently, as it provides a refuge for fish, and source of re-colonisation of other pools following wet season rains.

5.8 Other Vertebrate Fauna

Two frog species were recorded from the Survey Area during the current study. The record of the Pilbara toadlet (*Uperoleia saxatilis*) from YC3 was made via calls and identification of tadpoles (although in the field based on size and gross morphology). This constitutes the first record of this species from Yandicoogina Creek. Although endemic to the Pilbara, *U. saxatilis* is widespread throughout the region. It is a burrowing frog and is known to occur in rocky habitats (ALA, 2023). Other tadpoles observed at YC3 were identified as belonging to the desert tree frog (*Litoria rubella*). This species has been recorded previously within the Survey Area (Biologic, 2023c). It is a common, widespread species.

Other vertebrate fauna that could potentially occur within the Survey Area include the flat-shelled turtle (*Chelodina steindachneri*) and the Pilbara olive python (*Liasis olivaceus barroni*). The flat-shelled turtle is found 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). From our experience with this species in the Pilbara, it tends to prefer clay-dominated creek beds, such as those of YC2.

The Matter of National Environmental Significance (MNES) listed Pilbara olive python is restricted to the Pilbara region and can be found in gorges, waterholes and on escarpments, such as at YC4. It is currently listed as Vulnerable on both Federal (EPBC Act) and State (BC Act) conservation lists. Threats to Pilbara olive python habitat include fire, foxes, and development of mining infrastructure.

6 Conclusion

6.1 Main Findings

The Survey Area constitutes a significant GDE, comprising several flora species which indicate subsurface groundwater and/or permanent surface water, including *Melaleuca argentea*, *Eucalyptus camaldulensis*, *Imperata cylindrica* (recorded by the Biologic flora team near YC4), *Cyperus vaginatus* (highly abundant), *Fimbristylis sieberiana*, *Lobelia arnhemiaca* and *Eragrostris elongata*. A total of 198 invertebrates were recorded from the remaining hyporheos habitat and surface water pools, along with three species of freshwater fish and two species of frog. However, the ecosystem is starting to show impacts of the declining water levels which have resulted in drying of surface water pools, hyporheic zones and water stress for aquatic biota. Adverse changes to the ecosystem recorded during the current study, and related to the declining water levels, include:

- Decreasing DO (at YC3)
- Increasing S_SO_4 (at YC3 and YC4)
- Increasing N_NO_3 (at YC3)
- Decreasing cover by submerged macrophytes (at YC4)
- Decreasing cover by emergent macrophytes (at YC3 and YC4)
- Decreasing total macrophyte richness (submerged + emergent macrophytes; at YC4)
- Decreasing richness of Pilbara endemic macroinvertebrate taxa (at YC3)
- Low fish recruitment

Conversely, macroinvertebrate richness has increased over time at YC3, up to the Dry 2022, likely reflecting the fact it was one of the more persistent pools and may have been acting as a refuge along with YC4. However, this site was dry in the Wet 2023, and no longer provided any such refuge for aquatic fauna.

While the Survey Area still supports high ecological value, including significant species (Table 6.1), if water levels continue to decline the health, condition and value of the system are likely to continue to deteriorate.

6.2 Final Remarks

This study represents the fourth aquatic ecosystem survey undertaken in Yandicoogina Creek, comprising eight individual sampling events covering two seasons. Results from this survey provide an assessment of the ecological values and health of aquatic systems within the Survey Area, and important data towards understanding the temporal, seasonal and spatial variation within the creek.

This reach of Yandicoogina Creek is significant in the Pilbara in terms of its water permanence, GDE status, GDV composition, stygofauna 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 greater faunal richness than ephemeral water-bodies and provide a refuge for many species during drought (Halse *et al.*, 2002; Kay *et al.*, 1999).

Groundwater in the area appears to be declining over time, and the cause for the decline should be investigated further. The changes in surface water depths are not seasonal like those which have occurred at Reference sites, and appear to indicate a decline in groundwater levels in the area. The fact that permanent pools completely dried in the Wet 2023 and negative impacts to GDV's are being observed is of concern.

Table 6.1: Significant taxa recorded from the Survey Area during the current study

Type	Species	Sites Recorded			Significance/Distribution
		Within Survey Area	Reference Sites	Previous Survey (Biologic, 2023c)	
Stygal ostracods	*Meridiescandona marillanae* (`sp. Biologic-OSTR074`)	YC1, YC3, YC4 and YC4eH (hyporheos)		YC3, YC4 and YC5 (hyporheos)	Known from Weeli Wolli Creek, Marillana Creek, Upper Fortescue.
	Gomphodella alexanderi (`sp. Biologic-OSTR012`)	WWDD3 (hyporheos)			Potential SRE restricted to Marillana Creek, Weeli Wolli Creek and Yandicoogina Creek.
Stygal copepods	cf. *Australocamptus* `sp. Biologic-HARP064`	YC3 (hyporheos)			Potential SRE. First record of this OTU
	cf. *Australocamptus* sp.	YC2 (hyporheos)			Potential SRE.
	Kinnecaris `sp. Biologic-HARP037`	YC8H (hyporheos)			Potential SRE. Current known linear range 25 km
Stygal amphipods	*Chydaekata* `sp. E`	YC1, YC3, YC4 and YC8H (hyporheos)	BENS (hyporheos)	YC3 (hyporheos) YC4 (surface waters)	Potential SRE known only from Weeli Wolli Creek, Marillana Creek and Yandicoogina Creek.
	Paramelitidae `sp. Biologic-AMPH023`	YC4eH, YC5H and YC8 (hyporheos)		YC3 (hyporheos & surface waters)	SRE; known only from Yandicoogina Creek, Marillana Creek and lower Weeli Wolli Creek (downstream of the confluence with Marillana).
Isopoda	*Pygolabis* `sp. Biologic-ISOP035`	YC1 and YC3 (hyporheos)		YC5H, YC8H and YC9H (hyporheos)	Potential SRE. Currently known only from Yandicoogina Creek.
Water mite	*Wandesia* `sp. Biologic-ACAR009`	YC1 and YC3 (hyporheos)		YC3 (hyporheos)	Pilbara endemic known only from springs and permanent pools at Marillana Creek, Yandicoogina Creek, Weeli Wolli Creek and Karijini Nation Park.
Dragonflies	*Ictinogomphus dobsoni*	YC4 (surface waters)	MUNJS (surface waters)	YC4 and BENS (surface waters)	Near Threatened IUCN Red List.
	Hemicordulia koomina	YC4 (surface waters)	MUNJS (surface waters)	YC4 and BENS (surface waters)	Vulnerable IUCN Red List.
Damselfly	*Austroagrion pindrina*	YC3 (surface waters)	MUNJS (surface waters)		Vulnerable IUCN Red List.

7 References

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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 Attraction 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 ANZG (2018) 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).

Aquatic Ecosystem	Analyte						
	TP	FRP	TN	NOx	NH_4^+	DO	pH
Units	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**% saturation**	
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). Exceptions are *Moderate Reliability* for freshwater Al (ph>6.5) and Mn.

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

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

B = Chemicals for which possible bioaccumulation and secondary poisoning effects should be considered

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 [N_NH3] at pH 8.

E = Chlorine as Total Chlorine, as [Cl]

F = Figures protect against toxicity and do not relate to eutrophication issues.

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 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: Raw Habitat Data

Percentage cover by each of the in-stream substrate types

Dry 2022

	Site	Bedrock	Boulders	Cobbles	Pebbles	Gravel	Sand	Silt	Clay
Survey Area	YC1	Dry at the time of sampling							
	YC2	0	0	0	0	1	10	1	88
	YC3	0	1	20	34	28	12	5	0
	YC4	2	1	2	12	20	30	6	37
Reference	WWS	5	1	9	30	28	18	9	0
	BENS	5	2	2	38	43	8	2	0
	MUNJS	83	0	1	3	2	1	4	6
	SS	1	2	8	30	37	18	3	1

Wet 2023

	Site	Bedrock	Boulders	Cobbles	Pebbles	Gravel	Sand	Silt	Clay
Survey Area	YC1	Dry at the time of sampling							
	YC2	Dry at the time of sampling							
	YC3	Dry at the time of sampling							
	YC4	1	1	1	8	12	30	8	39
Reference	WWS	5	1	9	30	28	18	9	0
	BENS	1	1	2	40	50	1	5	0
	MUNJS	95	2	0	0	0	0	3	0
	SS	1	2	8	29	34	20	5	1

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

Dry 2022

	Site	Inorganic Seds	Sub Mac	Emerg Mac	Algae	LWD	Detritus	Roots	Trailing Veg
Survey Area	YC1	Dry at the time of sampling							
	YC2	14	0	82	0	1	1	0	2
	YC3	38	12	13	19	1	5	0	12
	YC4	52	4	8	5	8	15	6	2
Reference	WWS	77	0	2	1	3	5	10	2
	BENS	50	0	2	2	8	12	18	8
	MUNJS	65	6	11	9	4	2	2	1
	SS	18	6	4	45	5	8	12	2

Wet 2023

	Site	Inorganic Seds	Sub Mac	Emerg Mac	Algae	LWD	Detritus	Roots	Trailing Veg
Survey Area	YC1	Dry at the time of sampling							
	YC2	Dry at the time of sampling							
	YC3	Dry at the time of sampling							
	YC4	55	2	4	3	10	20	6	0
Reference	WWS	86	0	1	1	3	5	3	1
	BENS	70	0	0	0	2	21	5	2
	MUNJS	71	4	1	20	3	1	0	0
	SS	28	7	4	43	5	6	5	2

Appendix D: Raw Water Quality Data

Dry 2022

Analyte	Units	ANZG (2018) Guideline		Survey Area			Reference			
		99% DGV	95% DGV	YC2	YC3	YC4	WWS	BENS	MUNJS	SS
Temperature	ºC			21.6	19.1	18.8	26.1	18.7	16.4	27.6
Conductivity (EC)	µS/cm		250	784	525	589	988	395	609	640
pH	pH units		6-8	7.47	7.86	7.74	7.64	7.76	8.03	8.30
Redox	mV			-66.9	-26.0	61.7	46.5	61.3	38.5	15.8
DO	%		85-120	7.5	23.9	48.1	47.2	27.4	75.2	112.0
Turbidity	NTU		15	450.0	1.3	1.6	0.2	0.4	0.6	1.4
TSS	mg/L			126	<1	1	<1	<1	<1	6
Alkalinity	mg/L			132	223	249	366	200	159	246
Hardness	mg/L			343	210	240	364	196	196	223
Na	mg/L			37.2	38.3	51.6	43.3	8.2	65.9	39.0
Ca	mg/L			75.1	41.3	47.9	61.9	36.2	26.2	41.8
Mg	mg/L			37.8	26.0	29.2	50.8	25.7	31.8	28.8
K	mg/L			11.7	9.8	10.9	9.2	2.5	8.9	4.7
HCO_3	mg/L			132	223	249	366	200	159	235
Cl	mg/L			38	27	41	78	13	137	39
S_SO_4	mg/L			76.0	13.2	17.4	20.3	4.4	3.8	5.9
CO_3	mg/L			<1	<1	<1	<1	<1	<1	11
S	mg/L			83.5	12.3	17.6	21.0	4.2	4.1	6.9
dAl	mg/L	0.027	0.055	<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	0.0003	0.0003	0.0003	<0.0002	0.0002
dB	mg/L	0.09	0.37	0.158	0.134	0.158	0.312	0.050	0.145	0.107

Analyte	Units	ANZG (2018) Guideline		Survey Area			Reference			
		99% DGV	95% DGV	YC2	YC3	YC4	WWS	BENS	MUNJS	SS
dBa	mg/L			0.0452	0.0245	0.0249	0.0115	0.0176	0.0500	0.1940
dCd	mg/L	0.00006	0.0002	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005
dCo	mg/L			0.0016	<0.0001	0.0002	<0.0001	0.0002	<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
dCu	mg/L	0.001	0.0014	0.00014	0.00010	0.00008	<0.00005	0.00060	0.00007	0.00014
dFe	mg/L	0.300*		0.987	0.039	0.864	<0.002	0.036	0.093	0.008
dMn	mg/L	1.2	1.9	0.0858	0.0047	0.009	<0.0005	0.0933	0.0058	0.0643
dMo	mg/L			0.0003	0.0001	0.0002	0.0001	0.0001	<0.0001	0.0002
dNi	mg/L	0.008	0.011	0.0027	<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
dSe	mg/L	0.005	0.011	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	0.0003
dU	mg/L			0.00012	0.00013	0.00033	0.00056	0.00021	<0.00005	0.0007
dV	mg/L			<0.0001	0.0009	0.0007	0.0021	0.0018	0.0002	0.0018
dZn	mg/L	0.0024	0.008	0.0060	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
N_NH_3	mg/L	0.32	0.90	0.23	<0.01	0.11	0.01	0.04	<0.01	0.02
N_NO_3	mg/L	1.00	2.40	<0.01	0.02	0.01	0.02	<0.01	<0.01	0.11
N_NOx	mg/L		0.01	<0.01	0.02	0.01	0.02	<0.01	<0.01	0.11
Total N	mg/L		0.30	0.26	<0.05	0.05	0.03	0.04	0.05	0.20
Total P	mg/L		0.010	0.074	<0.005	0.006	0.019	<0.005	<0.005	0.006

Wet 2023

Analyte	Units	ANZG (2018) Guideline		Survey Area	Reference			
		99% DGV	95% DGV	YC4	WWS	BENS	MUNJS	SS
Temperature	°C			25.6	25.6	28.4	24.5	29.0
Conductivity (EC)	µS/cm		250	622	975	981	1482	642
pH	pH units		6-8	7.59	7.25	7.64	8.71	7.66
Redox	mV			11.0	-2.0	113.8	84.5	111.3
DO	%		85-120	27.0	55.2	47.4	65.8	53.3
Turbidity	NTU		15	1.6	<0.1	2.0	1.9	0.5
TSS	mg/L			1	<1	6	3	<1
Alkalinity	mg/L			208	382	382	192	250
Hardness	mg/L			186	412	414	310	190
Na	mg/L			38.5	47.1	27.7	156.0	35.4
Ca	mg/L			32.5	62.0	62.5	23.0	32.7
Mg	mg/L			25.4	62.4	62.6	61.4	26.2
K	mg/L			10.2	8.4	5.5	22.6	4.6
HCO_3	mg/L			208	382	382	177	250
Cl	mg/L			38	94	60	386	37
S_SO_4	mg/L			17.8	21.7	14.2	4.1	5.3
CO_3	mg/L			<1	<1	<1	15	<1
S	mg/L			17.2	20.1	14.3	4.7	6.0
dAl	mg/L	0.027	0.055	0.005	<0.005	<0.005	<0.005	<0.005
dAs	mg/L	0.001	0.024	0.0004	0.0004	0.0007	0.0012	0.0002
dB	mg/L	0.09	0.37	0.149	0.313	0.125	0.271	0.112
dBa	mg/L			0.020	0.011	0.127	0.075	0.146
dCd	mg/L	0.00006	0.0002	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005

Analyte	Units	ANZG (2018) Guideline		Survey Area	Reference			
		99% DGV	95% DGV	YC4	WWS	BENS	MUNJS	SS
dCo	mg/L			<0.0001	0.0002	0.0006	0.0001	<0.0001
dCr	mg/L	0.00001	0.001	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002
dCu	mg/L	0.001	0.0014	0.00018	0.0002	0.0004	0.00045	0.00022
dFe	mg/L	0.300*		0.024	<0.002	0.052	0.039	0.006
dMn	mg/L	1.2	1.9	0.0039	<0.0005	0.58	0.0083	0.0338
dMo	mg/L			0.0002	0.0002	0.0003	<0.0001	0.0002
dNi	mg/L	0.008	0.011	<0.0005	<0.0005	0.0006	<0.0005	<0.0005
dPb	mg/L	0.001	0.0034	<0.0001	<0.0001	0.0002	<0.0001	0.0002
dSe	mg/L	0.005	0.011	<0.0002	<0.0002	<0.0002	<0.0002	0.0004
dU	mg/L			0.00018	0.00064	0.00036	<0.00005	0.00051
dV	mg/L			0.0011	0.0027	0.0011	0.0002	0.0016
dZn	mg/L	0.0024	0.008	<0.001	<0.001	<0.001	<0.001	0.001
N_NH_3	mg/L	0.32	0.90	0.12	0.01	0.06	0.08	0.11
N_NO_3	mg/L	1.00	2.40	<0.01	0.04	0.01	<0.01	0.25
N_NOx	mg/L		0.01	<0.01	0.04	0.01	<0.01	0.25
Total N	mg/L		0.30	0.22	0.05	0.24	0.91	0.33
Total P	mg/L		0.010	0.025	0.019	0.028	0.026	0.016

Appendix E: Flora Data

Class/Order	Family	Lowest taxon	Yandicoogina Creek				Reference Sites			
			YC1	YC2	YC3	YC4	WWS	BENS	MUNJS	SS
CHLOROPHYTA										
CHAROPHYCEAE										
Charales	Characeae	*Chara fibrosa*↓^							X	X
		Chara globularis↓^			X				X	
PLANTAE										
MAGNOLIOPSIDA										
Asterales	Asteraceae	*Centipeda minima* subsp. *macrocephala*	X							
		**Flaveria trinervia*	X							
		**Lactuca serriola*					X			
		Pluchea dentex^					X			
		Pluchea rubelliflora^	X	X	X	X	X	X		X
		Pseudognaphalium luteoalbum	X							
		Rhodanthe margarethae							X	
		**Sigesbeckia orientalis*	X							
		**Tridax procumbens*	X			X				
	Campanulaceae	*Lobelia arnhemiaca*^^		X	X	X	X			X
		Wahlenbergia tumidifructa^	X							
	Stylidiaceae	*Stylidium fluminense*^^							X	
		Stylidium weeliwolli^^ (P3)						X		
Brassicales	Cleomaceae	*Arivella viscosa*								X
Caryophyllales	Amaranthaceae	*Achyranthes aspera*							X	
		Ptilotus calostachyus							X	
Fabales	Fabaceae	*Acacia bivenosa*	X				X		X	
		Acacia colei var. *colei*	X							
		Acacia coriacea subsp. *pendens*^			X		X	X	X	X
		Acacia citrinoviridis					X			
		Acacia pyrifollia var. *pyrifolia*			X					X
		Acacia tumida var. *pilbarensis*		X	X	X	X		X	
		Crotalaria medicaginea var. *neglecta*						X		
		Glycine canescens					X			
		Indigofera monophylla			X					
		Petalostylis labicheoides			X		X	X		X
		Rhynchosia minima					X	X		X
		Sesbania cannabina^					X			
		Vigna lanceolata var. *lanceolata*^								X
	Surianaceae	*Stylobasium spathulatum*^						X		
Gentianales	Apocynaceae	*Cynanchum viminale subsp. australe*							X	
Lamiales	Lamiaceae	*Clerodendrum tomentosum*					X			
	Plantaginaceae	*Stemodia grossa*^			X	X	X	X	X	X
		Stemodia viscosa							X	X
		Nellica maderaspatensis								X
Laurales	Lauraceae	*Cassytha capillaris*					X			
Malpighiales	Euphorbiaceae	*Euphorbia careyi*								X
		**Euphorbia hirta*					X			

Class/Order	Family	Lowest taxon	Yandicoogina Creek				Reference Sites			
			YC1	YC2	YC3	YC4	WWS	BENS	MUNJS	SS
		Euphorbia vaccaria var. *vaccaria*					X			
	Passifloraceae	*Passiflora foetida								X
	Phyllanthaceae	*Kirganelia baccata*^^			X					
Malvales	Malvaceae	*Abutilon* sp. Dioicum (A.A. Mitchell PRP 1618)					X			
		Androcalva luteiflora					X			
		Corchorus crozophorifolius^					X			
		Corchorus lasiocarpus			X					X
		Gossypium robinsonii	X	X	X	X	X	X		X
		Gossypium sturtianum var. *sturtianum*^					X	X		
Myrtales	Lythraceae	*Ammannia baccifera*^^								X
		Ammannia multiflora^								X
	Myrtaceae	*Eucalyptus camaldulensis*^^	X	X	X	X	X	X	X	
		Eucalyptus victrix^^					X			
		Melaleuca argentea^^	X	X	X	X	X	X	X	X
		Melaleuca bracteata^^							X	
		Melaleuca glomerata^						X		
		Melaleuca sp.^		X						
	Papaveraceae	*Argemone ochroleuca subsp. ochroleuca								X
Rosales	Moraceae	*Ficus* sp.							X	
		Ficus brachypoda							X	
		?Ficus virens^^				X				
Sapindales	Sapindaceae	*Atalaya hemiglauca*^					X		X	X
		Dodonaea viscosa subsp. *mucronata*						X		
		Dodonaea pachyneura							X	
		Dodonaea petiolaris						X		
Solanales	Convolvulaceae	*Ipomoea plebeia*						X		
		Ipomoea racemigera (P2)								X
	Solanaceae	*Solanum nigrum					X			
		Solanum sp.						X		
LILIOPSIDA										
Alismatales	Hydrocharitaceae	*Najas marina*↓^^								X
		Vallisneria annua↓^^							X	X
		Vallisneria nana↓^^				X				X
	Potamogetonaceae	*Potamogeton tepperi*↓^^							X	X
	Ruppiaceae	*Ruppia* sp.↓^^								X
Poales	Cyperaceae	*Cladium procerum*Δ^^ (P2)					X			
		Cyperus cunninghamii subsp. *cunninghamii*Δ^							X	
		*Cyperus difformis*Δ^								X
		*Cyperus vaginatus*Δ^	X	X	X	X	X	X	X	X
		*Eleocharis geniculata*Δ^^				X	X		X	X
		*Fimbristylis sieberiana*Δ^^ (P3)				X				X
		*Machaerina juncea*Δ^^							X	
		*Machaerina rubiginosa*Δ^^							X	
		*Schoenoplectus subulatus*Δ^	X	X	X	X	X		X	X
	Poaceae	*Aristida burbidgeae*							X	
		*Cenchrus ciliaris			X					X

Class/Order	Family	Lowest taxon	Yandicoogina Creek				Reference Sites			
			YC1	YC2	YC3	YC4	WWS	BENS	MUNJS	SS
		*Chloris barbata								X
		Chloris virgata								X
		Cymbopogon ambiguus	X	X	X		X		X	
		Cynodon convergens					X			
		Eragrostis elongata^^				X				
		Eragrostis tenellula	X							
		Eriachne mucronata							X	
		Eulalia aurea^	X	X	X					
		Imperata cylindrica^^							X	
		*Melinis repens	X	X						
		*Setaria verticillata				X				
		Sorghum plumosum		X		X				
		Sorghum timorense					X			
		Themeda triandra	X	X			X		X	
	Typhaceae	_Typha domingensis_Δ^	X	X	X	X	X	X	X	X
		Taxa richness	20	15	20	18	36	19	33	36

* Introduced species
(P3) Priority 3 flora species
(P2) Priority 2 flora species
^ Associated with creeks and/or Moderate to Low GDE indicator species
^^ Very High to Moderate-High GDE indicator species
↓ submerged macrophyte
Δ emergent macrophyte

Appendix F: Hyporheos fauna taxonomic list

Dry 2022

Phylum/Class/Order	Family	Lowest taxon	Survey Area						Reference			
			YC1	YC2	YC3	YC4	YC5H	YC8H	WWS	BENS	MUNJS	SS
CNIDARIA												
Hydrozoa												
Anthoathecata	Hydridae	*Hydra* sp.	0	0	0	1	0	0	0	0	0	0
NEMATODA		Nematoda sp.	0	0	0	0	0	1	0	0	2	0
MOLLUSCA												
Gastropoda												
Hygrophila	Planorbidae	Glyptophysa sp.	1	0	0	0	0	0	0	0	0	0
		Gyraulus sp.	0	0	0	0	0	3	0	0	0	0
ANNELIDA												
Oligochaeta												
Tubificida		Oligochaeta sp. (earthworm)	0	0	0	0	0	2	0	0	0	0
	Naididae	*Nais variabilis*	0	1	0	2	0	0	0	0	0	0
		Pristina aequiseta	2	3	1	2	0	0	0	2	0	0
		Pristina leidyi	0	0	0	0	0	0	0	3	0	3
		Pristina longiseta	0	1	0	0	0	0	0	3	0	0
		Pristina nr. *osborni*	3	0	0	0	0	0	0	0	0	0
		Pristina sp.	0	0	1	0	0	0	0	0	0	0
	Phreodrilidae	Phreodrilidae sp.	0	1	1	2	0	0	0	0	0	3
Polychaeta	Aeolosomatidae	Aeolosomatidae sp.	0	0	1	0	0	0	0	0	0	0
ARTHROPODA												
ARACHNIDA		Acari sp.	2	2	0	0	0	0	0	0	0	0
Mesostigmata		Mesostigmata sp.	0	0	0	0	0	2	0	0	2	2
Sarcoptiformes		Oribatida sp.	0	0	1	0	0	0	0	0	0	0
Trombidiformes		Trombidioidea sp.	0	0	0	0	0	0	1	0	0	0
	Halacaridae	Pezidae `sp. Biologic-ACAR003`	0	0	1	0	0	0	0	0	0	0
	Hydryphantidae	*Wandesia* `sp. Biologic-ACAR009`	1	0	1	0	0	0	0	0	0	0
	Pezidae	Pezidae sp.	1	0	0	0	0	0	0	0	0	0
CRUSTACEA												
Branchiopoda												
Diplostraca	Chydoridae	Cladocera sp.	0	0	0	0	1	0	0	0	0	0
		Alona rectangula	0	0	1	0	0	0	0	0	0	0
Maxillopoda												
Cyclopoida		Cyclopoida sp.	0	2	2	2	0	0	0	0	0	0
	Cyclopidae	*Diacyclops* cf. *humphreysi*	3	1	1	0	0	2	0	1	0	0
		Eucyclops australiensis	0	0	0	3	0	0	0	0	0	0
		Mesocyclops notius	0	0	0	0	3	0	0	0	0	0
		Microcyclops varicans	2	3	3	0	3	2	0	2	2	2

Phylum/Class/Order	Family	Lowest taxon	Survey Area						Reference			
			YC1	YC2	YC3	YC4	YC5H	YC8H	WWS	BENS	MUNJS	SS
		Paracyclops cf. affinis	3	6	2	3	0	2	0	1	0	0
		Thermocyclops sp.	0	0	0	0	4	2	0	0	0	0
Harpacticoida	Canthocamptidae	cf. *Australocamptus* `sp. Biologic-HARP064`	0	0	2	0	0	0	0	0	0	0
		cf. *Australocamptus* sp.	0	2	0	0	0	0	0	0	0	0
	Parastenocaridae	*Kinnecaris* `sp. Biologic-HARP037`	0	0	0	0	0	1	0	0	0	0
Ostracoda												
Podocopida	Candonidae	*Candonopsis* cf. *tenuis* (`sp. Biologic-OSTR009`)	3	4	0	2	3	0	0	0	2	0
		Meridiescandona marillanae (`sp. Biologic-OSTR074`)	2	0	1	2	0	0	0	0	0	0
	Limnocytheridae	*Gomphodella alexanderi* (`sp. Biologic-OSTR012`)	0	0	3	0	0	0	0	0	0	0
Malacostraca												
Amphipoda	Paramelitidae	*Chydaekata* sp. E	2	0	3	2	0	3	0	3	0	0
		Paramelitidae `sp. Biologic-AMPH023`	0	0	0	0	1	1	0	0	0	0
		Paramelitidae `sp. Biologic-AMPH024`	0	0	0	0	0	0	1	0	0	0
		Paramelitidae sp.	0	0	3	0	0	0	0	0	0	0
Isopoda	Tainisopidae	*Pygolabis* `sp. Biologic-ISOP035`	2	0	2	0	0	0	0	0	0	0
COLLEMBOLLA												
Poduromorpha												
Poduroidea		Poduroidea sp.	0	0	0	0	0	0	0	0	0	1
Symphypleona		Symphypleona sp.	0	0	0	0	0	0	0	2	0	2
Entomobryomorpha												
Entomobryoidea		Entomobryoidea sp.	0	0	1	0	0	2	0	0	0	0
MYRIAPODA												
Pauropoda		Pauropoda sp.	0	0	0	0	0	2	0	0	0	0
INSECTA												
Coleoptera	Carabidae	Carabidae sp.	0	0	0	0	1	0	0	0	0	1
		Carabidae sp. (L)	0	2	0	0	0	0	0	0	0	0
	Dytiscidae	*Copelatus irregularis*	0	0	0	0	1	0	0	0	0	0
		Limbodessus occidentalis	0	0	0	0	0	2	0	0	0	0
		Neobidessodes denticulatus	0	0	0	0	0	1	0	0	0	0
	Georissidae	*Georissus* sp.	0	0	0	0	0	0	1	0	0	0
	Hydraenidae	*Hydraena* sp.	2	0	0	0	0	3	0	0	0	0
		Hydraenidae sp. (L)	0	0	0	0	0	2	0	0	0	2
		Limnebius sp.	0	0	0	0	0	0	0	0	0	1
	Hydrophilidae	*Chaetarthria nigerrima* (L)	0	0	0	0	0	0	0	0	0	3
		Helochares sp. (L)	0	0	0	0	0	0	0	0	0	1
		Hydrophilidae sp. (L)	0	0	0	0	0	0	1	2	0	3
		Laccobius sp. (L)	0	0	0	0	0	0	0	0	0	2
	Limnichidae	Limnichidae sp. A	0	1	0	0	0	0	0	0	0	0
	Noteridae	*Notomicrus tenellus*	2	0	0	0	0	1	0	0	0	0
	Ptiliidae	Ptiliidae sp.	0	0	0	0	0	1	0	0	0	0
	Scirtidae	Scirtidae sp. (A)	0	0	0	0	0	0	0	0	0	2
		Scirtidae sp. (L)	2	2	3	2	0	0	0	2	0	0
	Staphylinidae	Staphylinidae sp.	1	0	0	0	0	0	0	0	0	0

Phylum/Class/Order	Family	Lowest taxon	Survey Area						Reference			
			YC1	YC2	YC3	YC4	YC5H	YC8H	WWS	BENS	MUNJS	SS
Diptera	Cecidomyiidae	Cecidomyiidae sp.	0	1	0	0	0	0	0	0	0	0
	Ceratopogonidae	Ceratopogonidae sp. (P)	0	2	0	0	0	0	0	0	0	0
		Ceratopogoninae sp.	3	4	0	2	1	2	2	2	2	3
		Dasyhelea sp.	2	3	0	0	2	0	0	0	0	0
		Forcipomyiinae sp.	0	1	0	0	0	0	0	0	0	0
	Chironomidae	?*Australopelopia* sp.	0	0	0	0	0	0	0	1	0	0
		Chironomidae sp. (P)	2	0	0	0	0	0	0	0	0	2
		Cladotanytarsus sp.	0	0	0	0	0	0	0	0	0	2
		Larsia ?albiceps	0	0	0	0	0	1	0	2	0	2
		nr. *Gymnometriocnemus* sp.	2	0	0	1	0	0	0	0	3	1
		Orthocladiinae sp.	0	0	0	0	0	2	0	0	0	0
		Orthocladiinae sp. BES12662	0	3	0	1	0	0	0	0	0	0
		Paramerina sp. 1	0	0	2	1	0	0	0	0	0	1
		Paramerina sp. 2	0	0	0	2	0	0	0	2	0	2
		Tanytarsus sp.	0	1	0	0	0	0	0	0	0	3
	Dolichopodidae	Dolichopodidae sp.	0	2	0	0	0	2	0	0	0	0
	Ephydridae	Ephydridae sp.	1	1	0	0	0	1	0	0	0	0
	Psychodidae	Psychodidae sp.	0	2	0	0	0	0	0	0	0	0
	Sciaridae	Sciaridae sp.	0	0	0	0	0	2	0	0	0	0
	Tipulidae	Tipulidae sp.	2	0	0	1	0	0	0	0	0	4
Ephemeroptera	Baetidae	Baetidae sp.	0	0	1	2	0	0	0	0	0	0
		Cloeon fluviatile	0	0	0	2	0	0	0	0	0	0
		Cloeon sp. Red Stripe	0	0	0	2	0	0	0	0	0	0
		Offadens G1 sp. WA2	0	0	0	0	0	0	1	0	0	0
	Caenidae	Caenidae sp.	0	0	0	0	0	0	0	0	0	2
		Taxa richness	**23**	**24**	**22**	**20**	**10**	**25**	**6**	**14**	**6**	**24**

<u>**Wet 2023**</u>

Phylum/Class/Order	Family	Lowest taxon	Survey Area		References		
			YC4	YC4eH	WWS	BENS	SS
NEMATODA		Nematoda sp.	2	0	0	0	0
ANNELIDA							
Oligochaeta							
Tubificida	Naididae	*Dero* cf. sawayai	0	1	0	0	0
		Dero nivea	0	0	0	2	0
		Dero sp.	1	2	0	3	0
		Naidinae sp.	2	2	0	0	0
		Pristina aequiseta	2	2	0	0	3
		Pristina leidyi	1	0	2	0	0
		Pristina longiseta	1	0	2	0	0
	Phreodrilidae	Phreodrilidae sp.	2	2	1	0	3
ARTHROPODA							
ARACHNIDA		Acari sp.	0	0	2	2	0
Mesostigmata		Mesostigmata sp.	1	0	0	2	0
Sarcoptiformes		Oribatida sp.	1	0	0	0	3
Trombidiformes	Anisitsiellidae	*Rutacarus* `sp. Biologic-ACAR005`	0	0	1	0	0
	Halacaridae	Halacaridae sp.	2	2	2	0	2
CRUSTACEA							
Maxillopoda							
Cyclopoida	Cyclopidae	*Ectocyclops phaleratus*	2	2	2	3	0
		Microcyclops varicans	0	0	2	3	0
		Paracyclops fimbriatus	0	0	0	0	1
		Thermocyclops sp.	2	2	0	0	0
Ostracoda							
Podocopida	Candonidae	*Candonopsis* cf. *tenuis* (`sp. Biologic-OSTR009`)	0	0	0	2	0
		Meridiescandona marillanae (`sp. Biologic-OSTR074`)	2	2	0	0	0
		Notacandona boultoni	0	0	3	0	0
		Notacandona modesta	0	0	2	0	0
	Cyprididae	*Cypretta* sp.	0	0	3	0	0
		Stenocypris major	0	0	0	0	2
	Darwinulidae	*Vestalenula marmonieri*	2	2	0	0	3
Malacostraca							
Amphipoda	Paramelitidae	*Chydaekata* sp. E	2	0	0	0	0
		Paramelitidae `sp. Biologic-AMPH023`	0	2	0	0	0
		Paramelitidae `sp. Biologic-AMPH045`	0	0	2	0	0
COLLEMBOLLA							
Entomobryomorpha							
Entomobryoidea		Entomobryoidea sp.	0	0	2	2	0
Poduromorpha							
Poduroidea		Poduroidea sp.	1	0	0	0	0

Phylum/Class/Order	Family	Lowest taxon	Survey Area YC4	Survey Area YC4eH	References WWS	References BENS	References SS
INSECTA							
Coleoptera	Carabidae	Carabidae sp. (L)	0	0	1	0	0
	Dytiscidae	*Hydroglyphus grammopterus*	0	0	0	2	0
		Hydroglyphus orthogrammus	0	0	0	1	0
	Elmidae	*Austrolimnius* sp. (L)	0	0	0	0	2
	Georissidae	*Georissus* sp.	0	0	0	1	0
	Hydraenidae	*Hydraena* sp.	0	0	0	3	0
	Hydrophilidae	*Agraphydrus coomani*	0	0	0	1	0
		Anacaena horni	0	0	0	1	0
		Chaetarthria nigerrima (L)	0	0	1	0	0
		Helochares sp. (L)	0	0	0	1	0
		Helochares tatei	0	0	0	2	0
		Hydrophilidae sp. (L)	0	0	2	2	0
		Sternolophus sp. (L)	0	0	0	1	0
	Noteridae	*Notomicrus tenellus*	1	0	0	0	0
	Scirtidae	Scirtidae sp. (L)	2	0	1	3	2
Diptera	Ceratopogonidae	Ceratopogonidae sp. (P)	1	3	0	2	0
		Ceratopogoninae sp.	4	0	2	3	3
		Dasyhelea sp.	2	0	2	0	0
	Chironomidae	Chironomidae sp. (P)	0	0	0	1	0
		Cryptochironomus griseidorsum	0	0	0	0	1
		Dicrotendipes sp. `CA1`	0	0	0	2	0
		Larsia ?albiceps	0	0	0	0	2
		Orthocladiinae sp. BES12662	0	0	0	1	0
		Paramerina sp. 1	0	0	0	0	2
		Paramerina sp. 2	0	0	0	3	0
		Skusella sp.	0	0	0	0	1
		Tanytarsus sp.	0	0	0	3	0
	Ephydridae	Ephydridae sp.	1	0	0	2	0
	Tipulidae	Tipulidae sp.	0	0	1	2	0
Ephemeroptera	Baetidae	Baetidae sp.	0	0	0	1	0
	Caenidae	Caenidae sp.	0	0	0	2	1
Odonata							
Anisoptera		Anisoptera sp.	1	0	0	0	0
		Taxa richness	**23**	**12**	**20**	**30**	**15**

Appendix G: Macroinvertebrate fauna taxonomic list

Dry 2022

Phylum/Class/Order	Family	Lowest taxon	Survey Area			Reference			
			YC2	YC3	YC4	WWS	BENS	MUNJS	SS
PLATYHELMINTHES		Turbellaria sp.	0	0	2	0	0	1	0
MOLLUSCA									
Gastropoda									
Hygrophila	Lymnaeidae	*Bullastra vinosa*	0	0	3	0	0	2	3
	Planorbidae	*Ferrissia petterdi*	0	3	2	4	2	0	2
		Gyraulus sp.	0	4	2	0	2	4	2
ANNELIDA									
Oligochaeta									
Tubificida	Naididae	*Allonais paraguayensis*	0	0	0	3	0	0	0
		Allonais pectinata	0	0	0	3	0	3	2
		Dero furcata	0	3	0	0	0	0	0
		Dero nivea	0	4	1	3	2	0	0
		Dero sp.	0	4	0	0	2	0	0
		Naidinae sp.	0	0	4	0	0	3	0
		Nais variabilis	0	0	4	0	0	0	0
		Pristina aequiseta	3	0	3	0	0	4	0
		Pristina leidyi	2	0	3	3	1	3	2
		Pristina longiseta	0	3	4	3	2	0	2
	Phreodrilidae	Phreodrilidae sp.	0	0	0	0	0	0	2
ARTHROPODA									
Arachnida		Acari sp.	0	2	2	0	2	2	2
Mesostigmata		Mesostigmata sp.	2	0	2	2	1	2	0
Sarcoptiformes		Oribatida sp.	0	0	2	4	0	0	0
Trombidiformes		Trombidioidea sp.	0	0	0	0	2	0	0
	Aturidae	*Albia* sp.	0	0	1	0	0	0	0
	Hygrobatidae	*Australiobates* sp.	0	0	0	2	0	0	0
		Coaustraliobates minor	0	0	1	0	0	0	0
		Procorticacarus sp.	0	0	0	0	0	0	1
	Limnesiidae	*Limnesia parasolida*	0	0	0	0	2	2	2
		Limnesia sp. `solida group`	0	3	2	0	0	3	2
	Oxidae	*Oxus spinosa*	0	0	0	0	0	0	1
	Unionicolidae	*Neumania* sp.	0	0	2	0	0	0	2
		Unionicolidae sp.	0	2	0	0	0	0	0
Crustacea									
Branchiopoda									
Diplostraca	Chydoridae	*Leberis* cf. *diaphanus*	0	0	0	2	0	0	0
		Alona sp.	0	0	0	0	0	3	0
		Chydorus sp.	0	0	4	0	0	0	0

Phylum/Class/Order	Family	Lowest taxon	Survey Area			Reference			
			YC2	YC3	YC4	WWS	BENS	MUNJS	SS
		Dunhevedia crassa	0	0	0	3	0	0	0
Ostracoda									
Podocopida		Ostracoda sp.	2	0	0	0	0	0	0
	Candonidae	*Candonopsis tenuis* (`sp. Biologic-OSTR009`)	3	0	2	0	2	3	0
	Cyprididae	*Bennelongia strellyensis*	0	0	0	0	0	4	0
		Cypretta sp.	0	0	3	0	0	0	0
		Cypridopsis sp.	2	3	0	4	0	0	0
		Ilyodromus `sp. Biologic-OSTR014`	0	0	0	0	0	3	0
		Ilyodromus sp.	0	0	0	0	0	0	2
		Stenocypris major	0	4	0	0	0	3	2
	Darwinulidae	*Vestalenula marmonieri*	0	0	2	0	0	3	1
	Notodromadidae	*Newnhamia fenestrata*	0	0	0	0	0	3	0
Maxillopoda									
Cyclopoida	Cyclopidae	*Ectocyclops* cf. *phaleratus*	2	4	0	1	0	0	0
		Eucyclops australiensis	0	0	4	3	0	0	2
		Mesocyclops darwini	0	4	4	0	0	3	2
		Mesocyclops notius	0	0	0	0	2	3	2
		Mesocyclops sp.	0	0	4	0	0	0	0
		Microcyclops varicans	0	3	4	2	1	3	2
		Paracyclops cf. *affinis*	3	0	0	0	0	0	0
		Paracyclops cf. *fimbriatus*	0	0	0	0	0	3	1
Malacostraca									
Amphipoda	Paramelitidae	*Chydaekata* sp. E	0	3	0	3	0	0	0
Decapoda	Parastacidae	*Cherax quadricarinatus*	0	0	0	1	0	0	0
Collembolla									
Entomobryomorpha		Entomobryoidea sp.	0	0	1	0	0	0	0
Insecta									
Coleoptera	Carabidae	Carabidae sp.	2	0	0	1	0	0	0
	Dytiscidae	*Allodessus bistrigatus*	0	0	0	1	0	1	0
		Bidessini sp. (L)	0	1	0	0	0	2	0
		Copelatus irregularis	1	0	0	0	0	0	0
		Cybister tripunctatus	0	0	1	0	1	0	0
		Dytiscidae sp. (L)	0	1	1	0	0	0	0
		Hydaticus consanguineus	0	1	0	0	0	0	0
		Hydaticus daemeli	0	2	0	0	0	0	0
		Hydroglyphus orthogrammus	0	0	3	0	3	0	2
		Hydrovatus opacus	2	0	2	0	1	0	0
		Hydrovatus sp. (L)	1	2	2	0	0	1	0
		Hyphydrus elegans	0	0	0	0	2	0	0
		Hyphydrus lyratus	0	0	0	0	2	2	0
		Hyphydrus sp. (L)	0	0	0	0	0	0	1
		Laccophilus sharpi	0	0	0	0	0	1	0
		Limbodessus compactus	2	3	0	0	0	1	0
		Necterosoma regulare	0	0	0	0	1	0	0

Phylum/Class/Order	Family	Lowest taxon	Survey Area			Reference			
			YC2	YC3	YC4	WWS	BENS	MUNJS	SS
		Neobidessodes denticulatus	0	0	3	0	0	0	0
		Platynectes decempunctatus var. *decempunctatus*	0	0	0	0	0	1	0
		Platynectes sp. (L)	0	0	0	0	0	2	0
		Rhantaticus congestus	0	1	0	0	0	1	0
		Tiporus tambreyi	0	0	0	0	1	0	0
	Elmidae	*Austrolimnius* sp.	0	0	0	0	0	0	1
		Austrolimnius sp. (L)	0	0	0	0	0	0	2
	Gyrinidae	*Dineutus australis*	0	0	0	0	0	3	0
		Macrogyrus sp. (L)	0	0	0	0	0	3	0
	Hydraenidae	*Hydraena* sp.	2	3	3	0	2	1	0
	Hydrochidae	*Hydrochus interioris*	0	2	3	0	2	0	0
		Hydrochus obscuroaeneus	0	1	3	0	2	0	0
	Hydrophilidae	*Anacaena horni*	0	0	2	0	1	1	0
		Berosus dallasi	0	0	0	0	0	0	1
		Chaetarthria nigerrima (L)	0	0	0	0	1	0	0
		Helochares sp. (L)	0	0	0	0	0	2	0
		Hydrophilidae sp. (L)	0	0	1	0	0	0	0
		nr. *Anacaena* sp.	2	2	2	0	0	0	0
		Paracymus sp. (L)	0	0	1	0	0	0	0
		Paracymus spenceri	0	1	0	0	0	1	0
		Regimbartia attenuata	0	2	0	0	1	1	0
		Sternolophus australis	0	2	0	0	0	0	0
		Sternolophus marginicollis	0	3	0	0	0	0	1
		Sternolophus sp.	0	0	1	0	0	0	0
		Sternolophus sp. (L)	0	0	0	0	0	0	1
	Noteridae	*Neohydrocoptus subfasciatus*	1	0	0	0	0	0	0
	Scirtidae	Scirtidae sp. (L)	3	3	3	3	2	3	2
	Staphylinidae	Staphylinidae sp.	1	0	0	0	0	0	0
Diptera	Ceratopogonidae	Ceratopogonidae sp. (P)	0	2	2	2	0	2	3
		Ceratopogoninae sp.	2	3	3	3	3	4	3
		Dasyhelea sp.	0	3	2	3	0	4	2
		Forcipomyiinae sp.	0	2	1	2	0	0	0
	Chironomidae	*Ablabesmyia hilli*	0	1	3	2	0	4	3
		Chironomidae sp. (P)	3	2	2	2	2	3	0
		Chironomus aff. *alternans*	1	3	0	3	4	4	2
		Corynoneura sp.	0	0	0	4	0	3	0
		Cricotopus sp. 2	0	0	0	3	0	0	2
		Cryptochironomus griseidorsum	0	0	0	0	0	0	2
		Dicrotendipes sp. `CA1`	0	2	3	0	4	4	0
		Dicrotendipes sp. P4	0	0	3	0	0	0	0
		Kiefferulus intertinctus	0	2	3	0	0	0	0
		Larsia ?albiceps	0	2	3	3	0	4	3
		nr. *Gymnometriocnemus* sp.	0	0	1	0	0	0	0
		nr. *Parametriocnemus* sp.	0	0	0	0	0	4	3
		Orthocladiinae sp. BES12662	1	0	0	0	0	0	0
		Parakiefferiella sp.	0	0	0	0	0	3	0

Phylum/Class/Order	Family	Lowest taxon	Survey Area			Reference			
			YC2	YC3	YC4	WWS	BENS	MUNJS	SS
		Paramerina sp. 1	0	3	4	4	0	0	3
		Paramerina sp. 2	0	3	0	0	0	0	2
		Pentaneurini sp.	0	0	0	0	0	4	0
		Polypedilum (*Pentapedilum*) *leei*	0	0	4	0	0	0	0
		Polypedilum nubifer	0	0	3	0	0	0	0
		Polypedilum sp. K1	0	0	0	0	0	0	2
		Procladius sp.	0	2	0	0	3	4	3
		Rheocricotopus sp.	0	0	0	3	0	4	3
		Stenochironomus watsoni	0	0	0	2	0	0	1
		Tanytarsus sp.	0	3	4	4	4	4	3
		Thienemanniella sp.	0	0	0	4	0	4	2
	Culicidae	*Aedes* sp.	0	1	0	0	0	0	0
		Anopheles sp.	0	2	2	2	0	2	0
		Culex sp.	0	0	0	2	0	1	0
	Dolichopodidae	Dolichopodidae sp.	2	0	2	2	2	1	2
	Ephydridae	Ephydridae sp.	2	1	0	0	0	0	0
	Muscidae	Muscidae sp.	0	0	0	0	0	0	1
	Psychodidae	Psychodidae sp.	2	0	2	0	1	0	0
	Sciaridae	Sciaridae sp.	0	1	0	0	0	0	0
	Sciomyzidae	Sciomyzidae sp.	0	0	0	0	0	1	0
	Simuliidae	Simuliidae sp.	0	0	0	0	0	5	3
	Stratiomyidae	Stratiomyidae sp.	2	2	2	1	0	2	2
	Tabanidae	Tabanidae sp.	1	0	1	0	1	0	0
	Tipulidae	Tipulidae sp.	0	2	2	0	0	0	0
Ephemeroptera	Baetidae	Baetidae sp.	0	3	3	3	0	5	2
		Cloeon fluviatile	0	0	4	3	0	3	2
		Cloeon sp. Red Stripe	0	3	4	3	0	4	0
		Offadens G1 sp. WA2	0	0	0	5	0	3	0
		Pseudocloeon hypodelum	0	0	0	3	0	0	0
	Caenidae	Caenidae sp.	0	3	2	3	0	5	3
		Tasmanocoenis sp.	0	0	0	0	2	0	0
		Tasmanocoenis sp. M	0	0	0	0	0	3	0
		Tasmanocoenis sp. P/*arcuata*	0	2	1	1	0	4	3
	Leptophlebiidae	*Atalophlebia* sp. AV17	0	0	0	0	0	4	0
Hemiptera	Belostomatidae	*Diplonychus eques*	0	0	0	0	0	0	1
	Gerridae	Gerridae sp.	0	0	2	2	0	2	0
		Limnogonus luctuosus	0	0	0	0	3	0	3
	Hebridae	Hebridae sp.	0	0	0	0	0	1	0
		Hebrus axillaris	0	1	0	0	0	1	0
	Micronectidae	*Austronecta bartzarum*	0	0	2	0	0	0	0
	Nepidae	*Laccotrephes tristis*	0	0	1	0	0	0	0
		Ranatra sp.	0	0	2	0	0	0	0
	Notonectidae	*Anisops elstoni*	0	3	0	0	0	1	0
		Anisops sp.	0	2	0	0	0	0	0
		Enithares woodwardi	0	1	0	0	0	0	0
		Notonectidae sp.	0	2	0	0	0	2	0

Phylum/Class/Order	Family	Lowest taxon	Survey Area			Reference			
			YC2	YC3	YC4	WWS	BENS	MUNJS	SS
	Pleidae	*Paraplea brunni*	0	0	0	0	1	1	0
		Pleidae sp.	0	0	0	0	0	0	1
	Veliidae	*Nesidovelia peramoena*	0	1	1	0	0	0	0
		Nesidovelia sp.	0	0	0	0	1	0	2
		Veliidae sp.	0	1	2	2	0	1	0
Lepidoptera	Crambidae	Acentropinae sp.	0	0	0	1	0	0	0
		Margarosticha sp. 3	0	0	0	0	0	2	0
Odonata									
Anisoptera		Anisoptera sp.	0	2	0	3	2	3	2
	Aeshnidae	*Adversaeschna brevistyla*	0	0	0	0	0	2	0
		Hemianax papuensis	0	2	0	0	0	2	0
	Corduliidae	*Hemicordulia tau*	0	1	1	0	0	0	0
	Gomphidae	*Austrogomphus gordoni*	0	0	0	0	1	0	1
	Libellulidae	*Diplacodes haematodes*	0	2	2	2	1	2	0
		Nannophlebia injibandi	0	0	0	2	0	0	2
		Orthetrum migratum	0	0	0	0	0	1	0
		Tramea sp.	0	0	0	0	0	2	0
		Zyxomma elgneri	0	0	0	2	2	0	0
Zygoptera		Zygoptera sp.	0	2	2	3	1	3	1
	Coenagrionidae	*Argiocnemis rubescens*	0	0	2	0	1	0	1
		Austroagrion pindrina	0	1	0	0	0	2	0
		Ischnura aurora	0	0	1	0	0	0	0
		Pseudagrion aureofrons	0	0	1	2	0	0	1
	Isostictidae	*Eurysticta coolawanyah*	0	0	0	0	1	0	0
	Protoneuridae	*Nososticta pilbara*	0	0	0	2	0	0	0
Trichoptera	Ecnomidae	Ecnomidae sp.	0	0	0	1	0	0	0
		Ecnomina sp. F group	0	0	0	0	0	4	0
		Ecnomus pilbarensis	0	0	1	1	0	0	0
	Hydropsychidae	*Cheumatopsyche wellsae*	0	0	0	3	0	2	3
	Hydroptilidae	*Hellyethira* sp.	0	0	2	0	0	3	0
		Orthotrichia sp.	0	0	0	2	0	0	0
	Leptoceridae	Leptoceridae sp.	0	0	0	1	0	2	0
		Oecetis sp.	0	0	0	0	1	0	2
		Oecetis sp. Pilbara 4	0	0	2	0	0	2	0
		Triaenodes sp.	0	0	0	0	0	1	0
		Triplectides ciuskus seductus	0	0	0	0	0	1	2
		Triplectides sp.	0	0	0	0	0	1	0
	Philopotamidae	*Chimarra* sp. AV17	0	0	0	0	0	0	4
		Philopotamidae sp.	0	0	0	2	0	0	0
	Polycentropodidae	Polycentropodidae sp.	0	0	0	0	0	1	0
		Taxa richness	**27**	**68**	**82**	**62**	**48**	**94**	**68**

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			Survey Area	Reference			
Phylum/Class/Order	Family	Lowest taxon	YC4	WWS	BENS	MUNJS	SS
CNIDARIA							
Hydrozoa							
Anthoathecata	Hydridae	*Hydra* sp.	0	0	1	2	0
MOLLUSCA							
Gastropoda							
Cerithimorpha	Thiaridae	*Plotiopsis balonnensis*	0	0	0	0	2
Hygrophila	Lymnaeidae	*Bullastra vinosa*	2	0	0	4	2
	Planorbidae	*Ferrissia petterdi*	3	2	0	2	2
		Gyraulus sp.	1	0	4	3	3
ANNELIDA							
Oligochaeta							
Tubificida		Naidinae sp.	4	0	4	4	4
	Naididae	*Allonais paraguayensis*	0	1	0	0	0
		Allonais pectinata	0	1	0	4	3
		Allonais ranauana	0	0	0	3	0
		Dero digitata	0	0	0	3	0
		Dero furcata	3	0	3	0	3
		Dero nivea	0	0	4	3	3
		Dero sp.	0	0	0	3	3
		Nais communis	3	0	0	0	0
		Nais variabilis	3	0	0	0	3
		Pristina aequiseta	0	0	0	0	3
		Pristina longiseta	2	2	0	3	3
	Phreodrilidae	Phreodrilidae sp.	0	2	0	0	3
ARTHROPODA							
Arachnida		Acari sp.	0	2	0	3	3
Trombidiformes		Trombidioidea sp.	2	0	3	0	0
	Anisitsiellidae	Anisitsiellidae sp.	0	2	0	0	0
	Arrenuridae	*Arrenurus* (*Brevicadaturus*) sp.	0	0	0	4	0
		Arrenurus sp.	0	0	0	0	3
	Aturidae	*Albia* sp.	0	0	0	0	3
		Austraturus sp.	4	0	0	0	0
	Eylaidae	*Eylais* sp.	0	0	0	0	3
	Hydrachnidae	*Hydrachna* sp.	0	0	0	3	0
	Hydrodromidae	Hydrodroma sp.	0	0	0	3	0
	Hydryphantidae	*Pseudohydryphantes* sp.	2	2	0	1	0
	Hygrobatidae	*Australiobates* sp.	0	1	0	0	3
		Coaustraliobates minor	0	0	0	0	3
		Coaustraliobates sp.	2	0	0	0	0
		Procorticacarus sp.	0	0	0	0	3
	Limnesiidae	*Limnesia parasolida*	3	0	0	0	4

			Survey Area	Reference			
Phylum/Class/Order	Family	Lowest taxon	YC4	WWS	BENS	MUNJS	SS
		Limnesia sp. `*solida group*`	4	0	3	4	3
	Mideopsidae	*Gretacarus* sp.	3	0	0	0	0
	Oxidae	*Oxus* sp.	0	0	3	0	3
	Piersigiidae	*Stygolimnochares* `sp. Biologic-ACAR026`	0	0	0	0	2
	Unionicolidae	Unionicolidae sp.	0	0	3	0	0
		Koenikea sp.	2	0	0	0	0
		Neumania sp.	4	0	4	0	3
		Recifella sp.	0	0	0	0	3
Sarcoptiformes		Oribatida sp.	0	0	0	3	3
Crustacea							
Branchiopoda							
Diplostraca		Cladocera sp.	4	0	3	0	0
	Chydoridae	Leberis cf. diaphanus	0	3	0	0	0
		Alona rigidicaudis	0	0	0	2	0
		Dunhevedia crassa	0	2	0	0	0
	Daphniidae	*Simocephalus* sp.	3	0	3	3	0
Ostracoda							
Podocopida		Ostracoda sp.	0	0	1	0	0
	Candonidae	*Candonopsis tenuis*	0	0	0	0	2
	Cyprididae	*Bennelongia strellyensis*	0	0	0	2	0
		Cypretta `sp. Biologic-OSTR029`	0	3	0	0	3
		Cypretta sp.	4	0	0	0	
		Cypridopsis `sp. Biologic-OSTR011`	0	0	0	3	0
		Ilyodromus sp.	0	0	0	3	0
		Riocypris cf. *fitzroyi*	0	0	0	0	3
		Stenocypris major	0	0	0	0	3
	Darwinulidae	*Vestalenula marmonieri*	3	2	0	0	4
	Notodromadidae	*Newnhamia fenestrata*	0	0	0	4	0
Maxillopoda							
Cyclopoida	Cyclopidae	*Eucyclops australiensis*	0	2	0	0	0
		Mesocyclops brooksi	3	0	0	0	0
		Mesocyclops darwini	4	0	0	3	4
		Mesocyclops notius	0	0	3	2	0
		Microcyclops varicans	3	3	0	0	4
		Paracyclops fimbriatus	0	2	0	0	0
		Thermocyclops sp.	0	0	4	0	0
Malacostraca							
Amphipoda	Paramelitidae	*Chydaekata* sp. E	0	3	0	0	0
Decapoda	Parastacidae	*Cherax quadricarinatus*	0	1	0	0	0
Collembola							
Entomobryomorpha		Entomobryoidea sp.	1	0	0	0	0
Insecta							

			Survey Area	Reference			
Phylum/Class/Order	Family	Lowest taxon	YC4	WWS	BENS	MUNJS	SS
Coleoptera	Dytiscidae	*Allodessus bistrigatus*	0	0	1	2	0
		Bidessini sp. (L)	0	0	0	0	1
		Copelatus irregularis	1	0	0	0	0
		Cybister tripunctatus	1	0	2	0	0
		Hydaticus daemeli	0	0	0	2	0
		Hydroglyphus grammopterus	2	0	2	2	1
		Hydroglyphus orthogrammus	0	0	2	2	0
		Hydrovatus opacus	0	0	2	0	0
		Hydrovatus sp. (L)	2	0	3	3	1
		Hyphydrus lyratus	0	0	1	0	0
		Limbodessus compactus	0	0	0	1	1
		Necterosoma regulare	0	0	2	0	0
		Necterosoma undecimlineatum	0	0	2	0	0
		Neobidessodes denticulatus	2	0	0	0	0
		Onychohydrus sp. (L)	0	0	0	1	0
		Platynectes decempunctatus var. *decempunctatus*	0	0	0	2	0
		Rhantaticus congestus	0	0	0	2	0
		Tiporus tambreyi	0	0	2	0	0
	Elmidae	*Austrolimnius* sp. (L)	0	0	0	0	4
	Gyrinidae	*Dineutus australis*	0	0	0	2	0
		Macrogyrus gibbosus	0	0	0	2	0
		Macrogyrus paradoxus	0	2	0	0	0
	Hydraenidae	*Hydraena* sp.	3	0	1	2	0
		Limnebius sp.	1	0	0	0	0
	Hydrochidae	*Hydrochus eurypleuron*	0	0	2	1	0
		Hydrochus interioris	0	0	1	0	0
		Hydrochus obscuroaeneus	2	0	2	1	0
	Hydrophilidae	*Anacaena horni*	2	0	2	2	0
		Berosus dallasi	0	0	2	0	0
		Berosus sp. (L)	0	0	1	0	0
		Helochares sp. (L)	0	0	2	2	0
		Hydrochus macroaquilonius	0	0	1	1	0
		nr. *Anacaena* sp.	2	0	0	0	0
		Paracymus spenceri	0	0	0	2	1
		Regimbartia attenuata	0	0	0	2	0
		Sternolophus marginicollis	0	0	0	0	2
		Sternolophus sp. (L)	0	0	0	1	0
	Noteridae	*Notomicrus tenellus*	1	0	0	0	0
	Scirtidae	Scirtidae sp. (L)	3	3	2	0	0
Diptera	Ceratopogonidae	Ceratopogonidae sp. (P)	1	0	3	2	1
		Ceratopogoninae sp.	3	1	2	4	3
		Dasyhelea sp.	0	2	0	3	2
	Chironomidae	*Ablabesmyia hilli*	3	0	0	3	0
		Chironomidae sp. (P)	0	1	0	3	3
		Chironomus aff. *alternans*	0	0	4	0	0

			Survey Area	Reference			
Phylum/Class/Order	Family	Lowest taxon	YC4	WWS	BENS	MUNJS	SS
		Cladopelma curtivalva	4	0	3	3	0
		Cladotanytarsus sp.	0	0	3	0	0
		Corynoneura sp.	0	2	0	0	2
		Cricotopus albitarsis	0	2	0	0	2
		Cryptochironomus griseidorsum	3	0	0	0	0
		Dicrotendipes sp.	0	0	3	0	0
		Dicrotendipes sp. `Bio1`	0	0	0	0	4
		Dicrotendipes sp. `CA1`	4	0	0	4	4
		Kiefferulus intertinctus	4	0	4	0	0
		Larsia ?albiceps	4	2	5	4	4
		Paracladopelma sp.	3	0	0	0	0
		Paracladopelma sp. M1	0	0	0	3	0
		Parakiefferiella sp.	0	0	0	2	0
		Paramerina sp. 1	4	2	3	0	3
		Paramerina sp. 2	3	0	0	3	2
		Parametriocnemus sp.	0	1	0	0	0
		Paratanytarsus sp.	0	2	0	0	0
		Paratendipes sp. `K1`	0	0	0	0	4
		Polypedilum (*Pentapedilum*) *leei*	4	0	0	0	0
		Polypedilum nr. *watsoni*	3	0	0	0	0
		Procladius sp.	4	0	3	4	4
		Rheocricotopus sp.	0	1	0	0	2
		Stempellinella sp.	0	0	0	3	0
		Stenochironomus watsoni	0	1	0	0	0
		Tanytarsus sp.	4	3	4	4	4
		Thienemanniella sp.	0	3	0	0	2
		Thienemannimyia sp.	0	1	0	0	0
	Culicidae	*Anopheles* sp.	2	2	0	0	1
		Culex sp.	0	0	0	3	2
		Culicidae sp.	0	0	2	0	0
	Dolichopodidae	Dolichopodidae sp.	1	0	0	0	2
	Ephydridae	Ephydridae sp.	0	1	0	0	0
	Simuliidae	Simuliidae sp.	0	0	0	0	3
	Stratiomyidae	Stratiomyidae sp.	1	0	1	0	0
	Tabanidae	Tabanidae sp.	2	0	1	1	0
	Tipulidae	Tipulidae sp.	2	0	0	0	0
Ephemeroptera	Baetidae	Baetidae sp.	4	3	3	4	0
		Cloeon fluviatile	4	3	3	0	4
		Cloeon sp.	0	0	0	4	0
		Cloeon sp. Red Stripe	0	0	3	0	4
		Offadens G1 sp. WA2	0	3	0	0	0
		Pseudocloeon hypodelum	0	0	0	0	4
	Caenidae	Caenidae sp.	3	2	3	0	0
		Tasmanocoenis sp.	0	0	0	0	3
		Tasmanocoenis sp. M	0	0	1	0	2

			Survey Area	Reference			
Phylum/Class/Order	Family	Lowest taxon	YC4	WWS	BENS	MUNJS	SS
		Tasmanocoenis sp. P/*arcuata*	0	2	2	5	4
	Leptophlebiidae	*Atalophlebia* sp. AV17	0	0	0	2	0
		Leptophlebiidae sp.	0	0	0	2	0
Hemiptera	Belostomatidae	*Diplonychus eques*	1	0	2	3	3
	Corixidae	Corixidae sp.	2	0	0	0	0
	Gelastocoridae	*Nerthra* sp.	0	0	0	0	1
	Gerridae	Gerridae sp.	0	2	0	2	0
		Limnogonus luctuosus	1	0	0	0	2
		Rhagadotarsus anomalus	0	0	2	0	0
	Hebridae	Hebridae sp.	1	0	0	0	0
		Merragata hackeri	0	0	0	1	0
	Mesoveliidae	*Mesovelia hungerfordi*	0	0	0	2	0
		Mesoveliidae sp.	0	0	0	2	0
	Micronectidae	*Micronecta annae*	0	0	1	0	0
		Micronecta paragoga	0	0	0	1	0
		Micronecta sp.	2	0	0	0	0
		Micronectidae sp.	0	0	2	0	0
	Nepidae	*Laccotrephes tristis*	1	0	0	0	1
		Ranatra dispar	0	0	0	0	1
	Notonectidae	*Anisops elstoni*	0	0	0	2	0
		Anisops hackeri	0	0	0	1	0
		Anisops sp.	0	0	1	1	0
		Enithares woodwardi	0	0	0	1	0
		Notonectidae sp.	0	0	0	3	0
	Pleidae	*Paraplea brunni*	0	0	2	2	3
	Veliidae	*Nesidovelia peramoena*	0	0	0	2	0
		Nesidovelia sp.	0	0	0	2	0
Lepidoptera	Crambidae	Acentropinae sp.	0	0	0	0	3
		Margarosticha sp. 3	0	0	0	0	3
Odonata							
Anisoptera		Anisoptera sp.	3	2	3	4	2
	Aeshnidae	Aeshnidae sp.	0	0	2	0	0
		Adversaeschna brevistyla	0	0	0	3	0
		Hemianax papuensis	0	0	3	0	0
	Corduliidae	Corduliidae sp.	0	0	2	0	0
		Hemicordulia koomina	3	2	2	4	2
	Gomphidae	*Austrogomphus gordoni*	3	1	0	2	0
	Libellulidae	*Diplacodes haematodes*	0	2	0	3	0
		Orthetrum caledonicum	3	0	0	0	0
		Tramea sp.	0	0	0	4	0
	Lindeniidae	*Ictinogomphus dobsoni*	3	0	0	2	0
Zygoptera		Zygoptera sp.	4	2	3	4	2
	Coenagrionidae	*Austroagrion* sp.	0	0	0	2	0
		Coenagrionidae sp.	0	0	0	0	2
		Pseudagrion aureofrons	0	0	0	0	1
		Pseudagrion sp.	0	1	0	0	0

			Survey Area	Reference			
Phylum/Class/Order	Family	Lowest taxon	YC4	WWS	BENS	MUNJS	SS
	Isostictidae	*Austrosticta fieldi*	4	0	0	0	0
		Isostictidae sp.	0	0	1	0	0
	Platycnemididae	*Nososticta pilbara*	0	2	0	0	0
Trichoptera	Ecnomidae	Ecnomidae sp.	2	0	0	0	0
		Ecnomina sp. F group	0	0	0	4	0
		Ecnomus pilbarensis	0	1	0	1	2
	Hydropsychidae	*Cheumatopsyche wellsae*	0	3	0	0	4
	Hydroptilidae	*Hellyethira* sp.	0	0	0	0	2
		Orthotrichia sp.	1	2	0	0	2
	Leptoceridae	Leptoceridae sp.	2	0	0	0	0
		Oecetis sp. Pilbara 4	3	0	0	1	2
		Triaenodes sp.	0	0	0	0	2
		Triplectides ciuskus seductus	0	0	1	0	2
	Philopotamidae	*Chimarra* sp. AV17	0	2	0	0	3
		Taxa richness	**77**	**53**	**69**	**93**	**88**