

Ministers North Aquatic Ecosystem Survey: Dry 2021 – Wet 2022

Biologic Environmental Survey

Report to BHP Western Australia Iron Ore

August 2023

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EXECUTIVE SUMMARY

Biologic Environmental Survey (Biologic) was commissioned by BHP Western Australia Iron Ore (WAIO) to undertake a two-season baseline aquatic ecosystem survey of Yandicoogina Creek (hereafter referred to as the Survey Area), located within the Upper Fortescue River Catchment and the Weeli Wolli Creek/ Marillana Creek sub-catchment. This constitutes the third 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) and wet season of 2020 (Wet 2020) (Biologic, 2020c), and the dry season of 2020 (Dry 2020) and wet season of 2021 (Wet 2021) (Biologic, 2022a). Reference sites were sampled elsewhere to provide comparison and contextual information for Yandicoogina Creek. Together the Yandicoogina Creek reach and the reference sites comprised the Study Area for this project.

Aquatic ecosystem surveys were undertaken at eight sites, with site locations aligning with those previously sampled in the dry and wet seasons of 2019 to 2021. Four sites were sampled within the Survey Area, and four reference sites were located elsewhere. Sampling was undertaken in October 2021 (Dry 2021 survey) and April 2022 (Wet 2022 survey). Ecosystem surveys included habitat assessments and sampling of water quality, wetland flora (submerged and emergent macrophytes), zooplankton, hyporheos, macroinvertebrates and fish. In the Wet 2022 survey, five additional hyporheic samples were collected within the Survey Area to gain a better understanding of the distribution of stygal species previously collected during previous surveys. The hyporheic zone at these locations was dry during the Dry 2021, and therefore additional hyporheic samples were not collected at that time. In addition, two pools which are routine sampling sites were dry during the Dry 2021 (YC1 and YC2). Sediment samples were collected from these sites and rehydration-emergence trials undertaken in the Biologic laboratory.

The Survey Area is a known GDE, 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* and *Fimbristylis siberiana*) along the waterline. In places, this groundwater dependent vegetation (GDV) was dense. Known submerged macrophytes present in-stream include *Vallisneria nana*, *Chara* sp. and *Ruppia* sp. The importance of the Survey Area GDE has been previously established based on the presence of several phreatophytes and mesophytic/hydrophytic indicator species (Biologic, 2020a, 2020c).

Surface water levels in the Survey Area pools have shown a relatively steady decline over time since the Dry 2019. In fact, this was the first survey in which some sites were dry at the time of sampling. Given the connection with groundwater and that the Survey Area occurs within a known spring, this is likely due to a decline in groundwater levels. Effects of lowering water levels on the GDVs are beginning to emerge, particularly within the *Melaleuca argentea*, with a decline in the crown of some trees, and death of some juveniles. *Typha domingensis* stands were also in poor condition, with signs of senescence, particularly at YC2. Reductions in surface water and groundwater levels in the Survey Area also result in reduced habitat availability and extent of hyporheos habitat. The cause of the groundwater level decline within the Survey Area should be investigated.

As previously reported, water quality at Yandicoogina Creek was good and characterised by fresh, clear waters, with low dissolved oxygen saturation, neutral pH, and generally low nitrogen nutrient and dissolved metals concentrations. While water quality was generally within default ANZG (2018) guideline values (DGVs) for the protection of lowland river systems of tropical north Australia, there were some exceedances at some sites (i.e. electrical conductivity, dissolved oxygen, nitrogen oxides, total phosphorous, and dissolved boron in comparison to the 99% toxicity DGV). Of all the water quality variables measured, only one recorded a significant difference between sampling events. Total phosphorus concentrations were found to be significantly lower in the Wet 2022 and Dry 2020 than those recorded in the Dry 2019 and Wet 2020 (but statistically similar to the Wet 2021 and Dry 2021).

Within the hyporheos, a total of 19% of taxa recorded are directly dependant on groundwater for persistence (16% stygobites and 3% permanent hyporheos stygophiles). The percentage of stygobitic taxa was considerably greater than that reported elsewhere for Pilbara hyporheic zones (i.e., 5% stygobitic fauna recorded in Halse *et al*. 2002), highlighting the importance of the groundwater connection in this area. The Survey Area generally recorded low hyporheos fauna taxa richness during the dry season, due to the lack of water, including within the hyporheic zone at this time. However, during the Wet 2022 several sites recorded high richness of groundwater dependent taxa including, YC1 (five taxa), YC5H (seven taxa) and YC9H (five taxa). This suggests that hyporheic habitat must have been maintained at some locations beneath the creekbed, in close proximity to these sampling sites, and that the hyporheic habitat was not entirely lost between the dry season and the Wet 2022.

The richness of occasional hyporheos taxa recorded from the Survey Area has generally increased over time, since surveys in the creek began in 2019. This continued increase in occasional hyporheos taxa recorded within Survey Area hyporheic zones may be due to lowering surface water levels, with an increased number of surface taxa taking refuge in the hyporheic zone. Overall, however, differences in the number of hyporheos fauna, occasional hyporheos taxa or stygobitic taxa richness was not significant between sampling events.

Three troglofauna taxa were recorded from hyporheic zones in the current study. These included the pseudoscorpion Chthoniidae `sp. Biologic-PSEU083`, Diplura Projapygidae `sp. Biologic-DIPL053`, and Symphyla *Hanseniella* `sp. Biologic-SYMP054`. All troglofauna taxa were recorded in the Wet 2022 from the additional hyporheic sampling sites which do not always have an inundated hyporheic zone (i.e., YC6H, YC8H and YC9H). These locations would likely represent a humid, subterranean environment, that is not often inundated in comparison to the other sites sampled for hyporheos fauna within Yandicoogina Creek.

Macroinvertebrate richness within the Survey Area was variable, and while YC3 and YC4 continued to record relatively high richness, there was notable seasonal variation, with a large reduction in the number of taxa recorded from YC4 in the Wet 2022. This was likely due to flooding following the high rainfall event in late March, immediately prior to the survey. Flooding results in increased scouring, transport, and redistribution of sediments and organic matter, which effectively flushes the benthic community downstream (Herbst *et al.*, 2018). As a result, sampling too soon following a flood event can lead to reduced invertebrate richness, if there has been insufficient time for fauna to recolonise and stabilise. While macroinvertebrate richness at YC1 and YC2 have always been low due to sampling difficulties associated with low water depths and the abundance of *Typha* at these sites, the increased inundation, water levels and habitat extent present in the Wet 2022 led to a relatively high richness being recorded from these sites in the wet season.

Macroinvertebrate richness was compared statistically to previous aquatic surveys undertaken nearby. Overall, differences in macroinvertebrate richness were significant between creeks, but not between seasons. Macroinvertebrate richness recorded from Yandicoogina Creek was statistically similar to Weeli Wolli Creek (semi-permanent and permanent pools located on Weeli Wolli Creek upstream of Bens Oasis), Marillana Creek (sampling locations for the BHP MAC Phase 4 aquatic survey, located on Upper Marillana Creek from Flat Rocks upstream), Marillana Creek Downstream (pools on Marillana Creek downstream of Flat Rocks, to just downstream of Rio Tinto's Yandicoogina Oxbow deposit) and Weeli Wolli Spring a Priority 1 Priority Ecological Community, comprising approximately 2 km of flowing creekline), but significantly lower than the Davis River. The reference sites on the Davis are known for their particularly high richness of aquatic invertebrate fauna (Kendrick & McKenzie, 2001). Multivariate analyses on the same dataset indicated that there was also a significant difference in macroinvertebrate assemblages between creeks. Assemblages of the Survey Area were most similar to those from Munjina Spring, Bens Oasis (second occurrence of the Weeli Wolli Spring Priority 1 PEC) and the Yandicoogina Creek tributary (sampled for MAC4, i.e., MACREF1). Survey Area assemblages were notably different to the non-spring sites on Weeli Wolli Creek and Marillana Creek-Downstream.

Analysis of the macroinvertebrate assemblages of Yandicoogina Creek (across all sampling events) showed a strong and significant correlation with four environmental variables, including water temperature, turbidity, concentration of dissolved aluminium, and maximum depth. Linear regression also found a significant correlation between macroinvertebrate richness and maximum water depth in pools, with greater richness recorded from deeper pools. This shows that macroinvertebrates within the Survey Area are responding to the changes in water level, despite there not being a significant decline in macroinvertebrate richness over time (accompanying the lowering water levels) currently. The impact to an overall river reach from lowering groundwater levels is related to the proportion of pools negatively affected, and whether pools remain which can act as refugia. Current macroinvertebrate richness within the Survey Area is still high, and species of conservation significance are still present within pools. This suggests that the large, deep pool at YC4 is acting as a refuge, with reduced impacts from lowering groundwater levels. This pool is likely the source for re-colonisation of nearby pools following inundation in the wet season.

The rehydration emergence trials were relatively unproductive, yielding a total of seven invertebrate taxa and one submerged macrophyte. This low productivity was likely due to the high salinity recorded within the trial tanks, likely limiting the emergence of freshwater biota. The high salinities experienced in the tanks reflect concentrations of stored salts within the sediments, but in the natural system these likely get flushed with the 'first flush' following high rainfall events, which effectively dilutes concentrations within surface waters.

While most aquatic invertebrates recorded from the Survey Area were common, ubiquitous species, several were of conservation significance, and/or have (or are likely to have) restricted distributions. These included:

- The ostracods *Meridiescandona* `sp. Biologic-OSTR074` and *Gomphodella* `sp. Biologic-OSTR077` - potentially restricted taxa.
- The amphipods *Chydaekata* `sp. E` and Paramelitidae `sp. Biologic-AMPH023` - Potential SREs.
- The syncarid *Atopobathynella* `sp. Biologic-PBAT042` - Potential SRE (Data Deficient).
- The syncarid Bathynellidae `sp. Biologic-BATH019` - Potential SRE (Data Deficient).
- The isopod *Pygolabis* `sp. Biologic-ISOP035` - potentially restricted taxon.
- the Pilbara emerald, *Hemicordulia koomina* - Vulnerable on the IUCN Red List.
- the Pilbara pin, *Eurysticta coolawanyah* - Vulnerable on the IUCN Redlist.
- The Pilbara tiger, *Ictinogomphus dobsoni* – Near Threatened on the IUCN Red List.

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

Overall, Yandicoogina Creek within the Survey Area represents a highly significant GDE that holds considerable importance in the region and supports a diverse aquatic ecosystem. Although aquatic invertebrates are showing a response to the lowering groundwater and surface water levels, there has not been an adverse and significant decline in richness currently. Importantly, hyporheic habitat also appears to have been maintained in isolated locations across the Survey Area between the Dry 2021 and Wet 2022 sampling events.

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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
DPaW	Department of Parks and Wildlife
DPIRD	Department of Primary Industry and Regional Development
DRF	Declared Rare Flora
EC	Electrical conductivity
EPA	Western Australian Environmental Protection Authority
EPBC Act	*Environment Protection and Biodiversity Conservation Act 1999*
EWR	Ecological Water Requirements
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
PEC	Priority Ecological Community
SRE	Short-range endemic
WAM	Western Australian Museum

1 INTRODUCTION

1.1 Background and objectives

Biologic Environmental Survey (Biologic) was commissioned by BHP Western Australia Iron Ore (WAIO) to undertake a two-season baseline aquatic fauna survey 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 the BHP WAIO Mining Area C (MAC) operation to the southwest and BHP WAIO Yandi operation to the north, within the Pilbara bioregion of Western Australia (Figure 1.1).

Previous aquatic surveys have identified the presence of a groundwater dependent ecosystem (GDE) and associated permanent pools within this 3.5 km stretch of Yandicoogina Creek (Biologic, 2020c, 2022b). This GDE was found to be characterised by extensive closed *Melaleuca argentea* forest, with *Eucalyptus camaldulensis* over *Acacia tumida* var. *pilbarensis* shrubland, and reeds and sedges (e.g., *Cyperus vaginatus*, *Schoenoplectus subulatus* and *Typha domingensis*) along the waterline. Biologic (2020c) and (2022b) found the GDE provided important habitat for aquatic fauna, and supported high ecological values, including:

- Invertebrates with restricted distributions (i.e., stygal amphipods, a stygal copepod, a stygal isopod, and a stygal bathynellid);
- A high diversity of Pilbara endemic aquatic invertebrate taxa, especially at two sites (YC3 and YC4);
- Conservation significant species which are listed on the IUCN Red List of Threatened Species (*Eurysticta coolawanyah*, *Hemicordulia koomina* and *Ictinogomphus dobsoni*);
- A diversity of mesic flora species; and
- Three species of freshwater fish (Biologic, 2020c, 2022b).

While the two previous surveys were comprehensive (Biologic, 2020c, 2022b), they do not provide a sufficient baseline with which to detect change in water quality and aquatic fauna assemblages associated with any potential developments in the area in future. ANZG (2018) recommends sampling seasonally (wet and dry) over a period of at least three years to develop an appropriate dataset to cover the range in natural variability present within the aquatic ecosystem. As such, BHP commissioned Biologic to undertake an aquatic survey within the Survey Area in the dry season of 2021 (Dry 2021) and wet of 2022 (Wet 2022) (this report) to complement the baseline dataset.

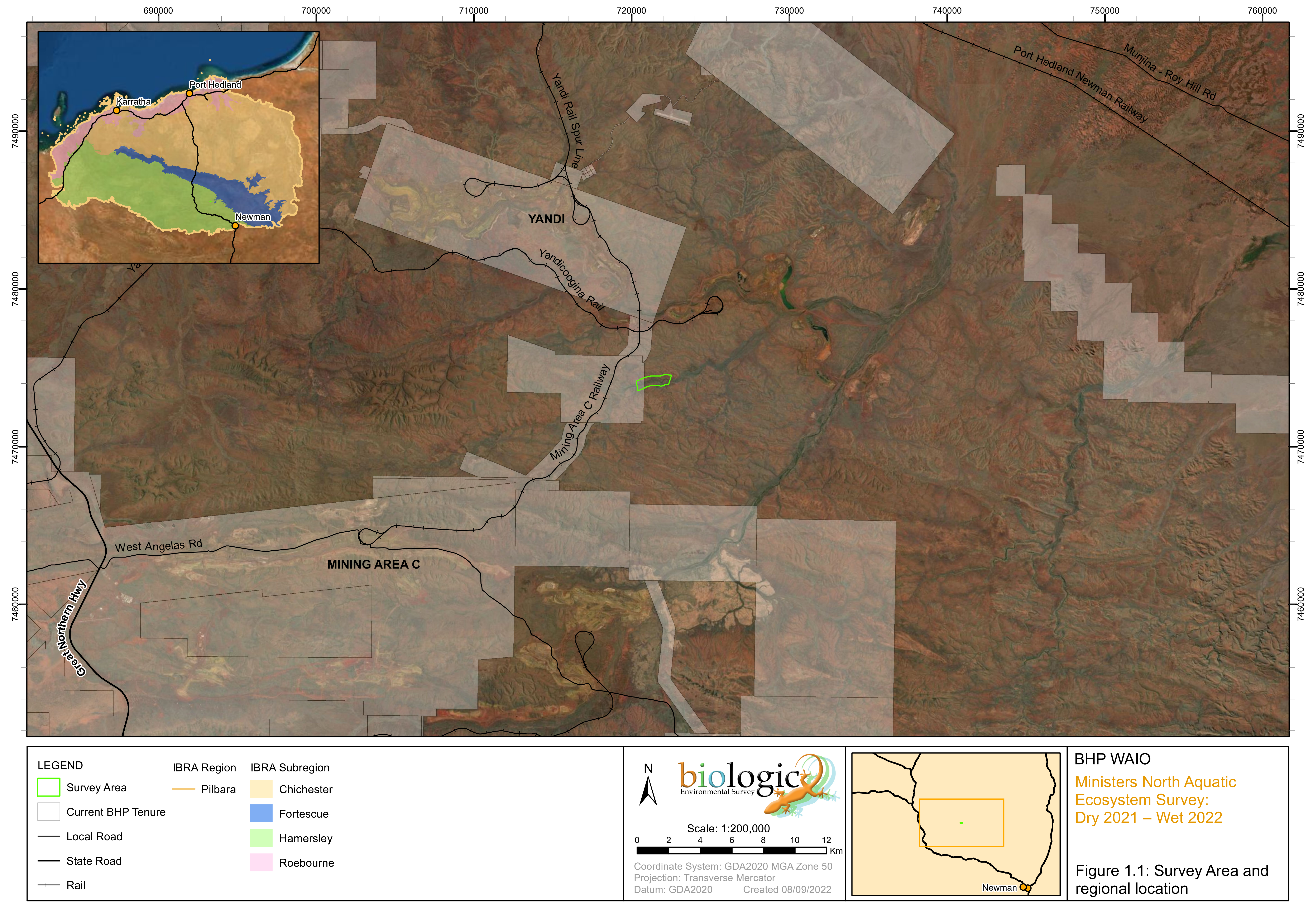


Figure 1.1: Survey Area and regional location

The scope of works included:

- A two-season aquatic survey at all previously established sampling sites, including reference sites;
- Identification of any significant ecological values related to aquatic fauna and their habitats within the Survey Area; and
- An assessment of the seasonal, temporal and spatial variation in water quality and aquatic fauna, including data from this and previous surveys, i.e., Dry 2019, Wet 2020, Dry 2020 and Wet 2021 (Biologic, 2020c, 2022b).

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 (August 2023) no technical guidance applicable to the 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);
- Technical Guidance, Sampling of Short-Range Endemic Invertebrate Fauna (EPA, 2016a);
- Technical Guidance, Terrestrial Fauna Surveys (EPA, 2016b);
- EPA Position Statement No. 3 Terrestrial Biological Surveys as an Element of Biodiversity Protection (EPA, 2002);
- BHP WAIO's Aquatic Fauna Assessment Methods Procedure (0098594) (BHP, 2017);
- BHP WAIO's Biological Survey Spatial Data Requirements (SPR-IEN-EMS-015) (BHP, 2018); and
- 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 for other BHP projects nearby (Biologic, 2020c, 2022a, 2022b, 2023).

2 ENVIRONMENT

2.1 Biogeographical Regionalisation of Australia

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

The Pilbara bioregion is classified into four separate subregions, Chichester (PIL01), Fortescue (PIL02), Hamersley (PIL03) and Roebourne (PIL04), of which the Survey Area is located within the Hamersley subregion (Figure 1.1). This subregion contains the southern section of the Pilbara Craton and comprises a mountainous area of Proterozoic sedimentary ranges and plateaux, dissected by basalt, shale and dolerite gorges (Kendrick, 2001). The Hamersley contains extensive open snappy gum woodland and hummock grassland communities on ranges and plateaus, with low mulga woodlands over bunch grasses on fine textured soils in lower areas and valley floors (Kendrick, 2001).

The significant and dominant feature of this subregion is the Hamersley Range. This prominent range feature is a mountainous plateau, some 450 km in length, which receives considerably higher rainfall than the surrounding subregion. The plateau is dissected by deeply incised gorges, containing extensive permanent spring-fed streams and pools (Kendrick, 2001). Drainage is into the Fortescue River to the north, the Ashburton River to the south, or the Robe River to the west (Kendrick, 2001).

2.2 Hydrology

The Survey Area is located within Weeli Wolli 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).

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

2.3 Groundwater Dependent Ecosystems (GDE)

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

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

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

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

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. Broadly, the groundwater associated with the Survey Area is located within fractured and weathered rock aquifers. Groundwater is stored in fractures and voids in the rocks and therefore tends to be localised. Groundwater recharge is also episodic and affected by direct infiltration of rainfall over areas where the rocks are fractured. As a result, 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 absent of groundwater dependent vegetation (GDV).

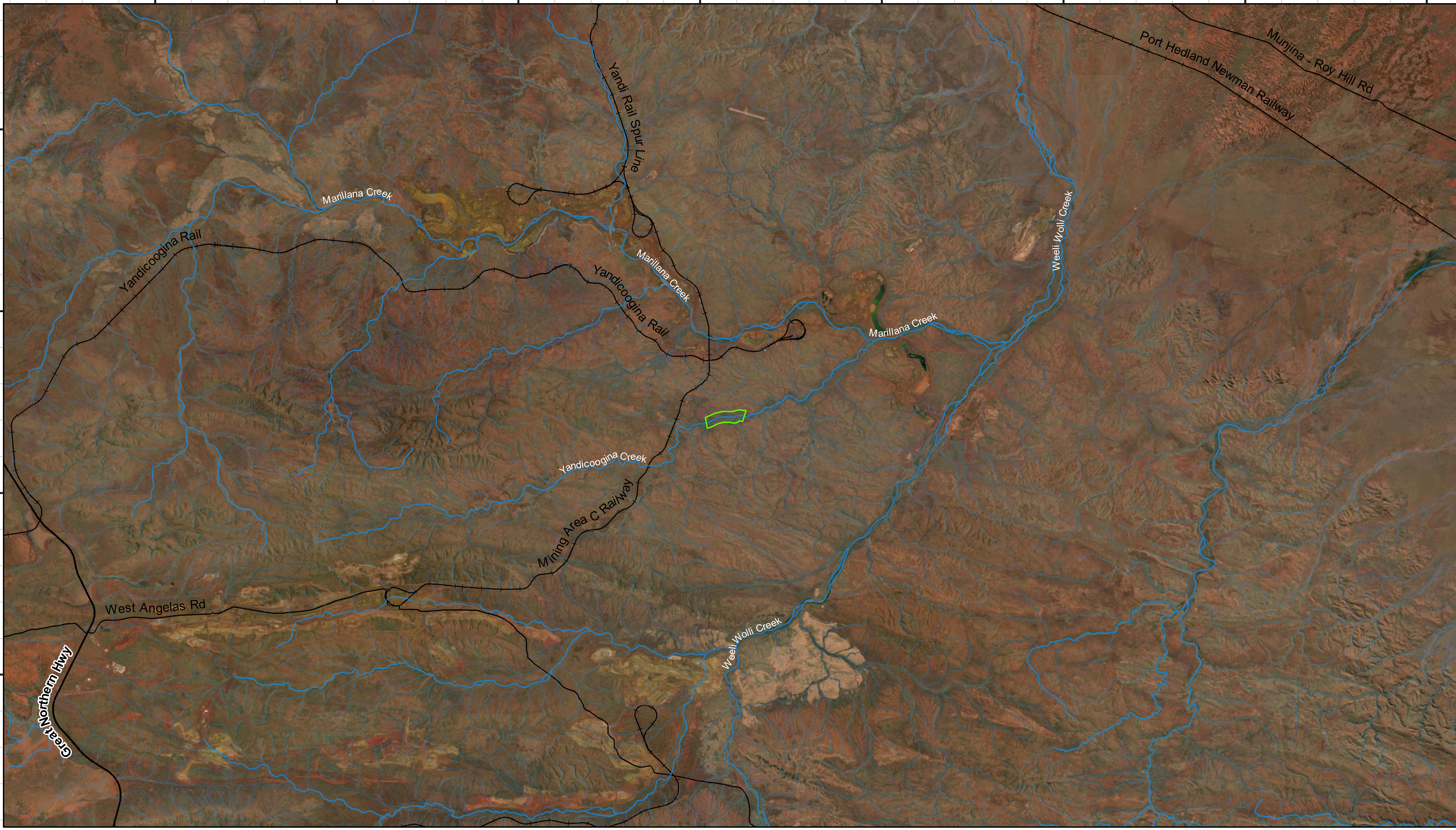
2.3.1 Groundwater Dependent Species

Above-ground GDEs are typically characterised by the presence of flora species that rely on groundwater (i.e., phreatophytes). 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 where they have access to groundwater in order 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. As such, obligate phreatophytes provide a good indicator of consistently shallow groundwater tables, or permanent surface water presence in the Pilbara. Not all phreatophytic species display the same degree of dependency on groundwater and the dependency within species has been shown to vary both spatially and temporally (Eamus *et al.*, 2016).

Facultative phreatophytes are plants that 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 can use groundwater to satisfy a proportion of their 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.*, 2006). 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 Yandicoogina Gorge is known to support both obligate phreatophytic flora, in particular *Melaleuca argentea*, and facultative phreatophytic species (e.g., *Eucalyptus camaldulensis* subsp. *obtusa* and *Eucalyptus victrix*). A substantial amount of literature and knowledge on groundwater and environmental water requirements is 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), while comparatively less information is known on the groundwater use strategies of understorey species. However, they are generally accepted as hydrophytic/ mesophytic and occur in association with drainage lines and groundwater within close proximity to the surface. A regional study of Pilbara GDEs has provided a list of species found to be correlated with shallow groundwater, and representative of GDEs, with varying mesophytic/hydrophytic indicator levels (Rio Tinto, 2021). In addition to *Melaleuca argentea*, other very high-level indicators include *Sesbania formosa*, *Imperata cylindrica*, *Cladium procerum*, *Baumea juncea*, *Juncus krausii*, *Fimbristylis feruginea*, and Nymphaeaceae spp. High level indicators include *Eucalyptus camaldulensis*, *Acacia ampliceps*, *Melaleuca bracteata*, *Ficus aculeata* (common abundance), *Gymnanthera cunninghamii* (abundant), *Schoenus falculatus* (abundant), *Fimbristylis littoralis*, *Fimbistylis sieberiana*, *Eleocharis dulcis*, *Stylidium weeliwolli*, *Ammannia bacifera* (abundant), *Ruppia polycarpa*, and *Potamogeton* spp. (abundant, likely baseflow indicator). Moderate level indicators include *Eucalyptus victrix*, *Gossypium sturtianum*, *Cyperus vaginatus* (abundant), *Eleocharis geniculata*, *Stylidium fluminense*, *Schoenoplectus laevis*, *Ammannia baccifera*, *Chara* spp., and *Najas* spp. (abundant) (Rio Tinto, 2021). Many of these species are known to occur within the Survey Area, and their presence indicates groundwater persists at, or just below, the surface.

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.



LEGEND

- Survey Area
- Drainage Lines
- Local Road
- State Road
- Rail

N

Scale: 1:200,000

0 2 4 6 8 10 12 Km

Coordinate System: GDA2020 MGA Zone 50
Projection: Transverse Mercator
Datum: GDA2020 Created 08/09/2022

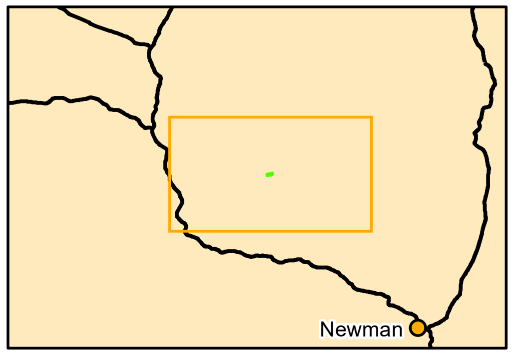


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Figure 2.1: Surface hydrology of the Survey Area and surrounds

2.4 Climate

The Pilbara region has a semi-desert to tropical climate, with relatively dry winters and hot summers. Rainfall is highly variable and mostly occurs during the summer. It tends to be associated with convective thunderstorms, low pressure systems and tropical cyclones that generate ephemeral flows and occasional flooding in creeks and rivers (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.

Nearby rainfall gauging stations (GS) for the Survey Area include the Department of Water and Environmental Regulation (DWER) Marillana Creek - Flat Rocks GS (station number 505011; length of record 1974 to current), located approximately 30 km north-west of Survey Area, and the DWER Marillana Creek - Munjina GS (station number 505004; length of record 1985 to current), located approximately 50 km north-west west of the Survey Area. Average annual rainfall recorded from Marillana Creek - Flat Rocks is 404 mm, compared to 433 mm at Marillana Creek - Munjina (DWER, 2021). Another GS lies approximately 10 km south-east of the Survey Area, DWER Weeli Wolli Creek - Tarina Station (station number 505040; length of record 1985-current); however, this station does not have data available over the course of the survey period. Previous data illustrates the high inter-annual variability in rainfall, with 159 mm total annual rainfall recorded from Tarina in 2010 but as much as 711 mm recorded in 2006.

3 METHODS

3.1 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), Alex Riemer (Senior Aquatic Ecologist), Morgan Lythe (Senior Invertebrate Zoologist), Siobhan Paget (Aquatic Ecologist) and Alice Greenwood (Carbon Project Officer). All senior members of the field team have extensive experience undertaking aquatic ecosystem surveys throughout the Pilbara.

Fauna sampling was conducted under DBCA Fauna Taking (Biological Assessment Regulation 27) Licences BA27000401 and BA27000401-2, 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. All team members are listed as having authority to sample under each of the licences.

Macroinvertebrate specimens were identified in-house by Alex Riemer, Kim Nguyen, Isabelle Johansson, Siobhan Paget, and Vanessa Nici. Hyporheos fauna, including micro-crustacea were identified in-house by Alex Riemer, Giulia Perina (Principal Taxonomist), and Juliana Pile Arnold (Senior Invertebrate Zoologist). Genetic analysis was undertaken in-house on selected micro-crustacea and hyporheos specimens by Stephanie Floeckner (Geneticist) and Joel Huey (Senior Geneticist). Zooplankton samples were processed and identified by Dr Robert Walsh (Australian Water Life).

Flora samples (submerged macrophytes, emergent macrophytes and dominant riparian vegetation) were identified by Alex Riemer and Morgan Lythe, in conjunction with Biologic's Flora Team, including Samuel Coultas, Kaylin Geelhoed and Clinton van den Bergh.

3.2 Survey Timing, Weather and River Conditions

The field survey comprised two seasons. The Dry 2021 survey was undertaken between the 16th and 21st of October 2021, and the Wet 2022 survey between the 1st and 6th of April 2022. The Dry 2021 survey was undertaken at a time of below average ambient temperature, with the average maximum October temperature being 1.5 °C cooler than the long-term average of 35.2 °C (Figure 3.1). There was no rainfall in the three months preceding the survey, but in the month following (November 2021), Newman received a greater amount of rainfall than the November long-term average (Figure 3.1).

The maximum daytime temperatures during the Wet 2022 season survey (32.1 °C) were comparable to the average temperature of 32.2 °C (Figure 3.1). Total rainfall in March 2022 reached 37.0 mm, compared to the long-term average of 40.8 mm (Figure 3.1). While January 2022 (21.8 mm) recorded rainfall well below the long-term average (68.2 mm), rainfall for February and March (73.0 mm and 37.0 mm, respectively) were comparable to the average of 72.3 mm (February) and 40.8 mm (March). The Flat Rocks GS on Marillana Creek, located approximately 18 km north-west of the Survey Area, also reported low rainfall for January 2022 (49.4 mm recorded in comparison to the average of 184.4 mm), but well above the long-term average rainfall for February (296.6 mm recorded in comparison to the average of 189.7 mm) (DWER, 2023).

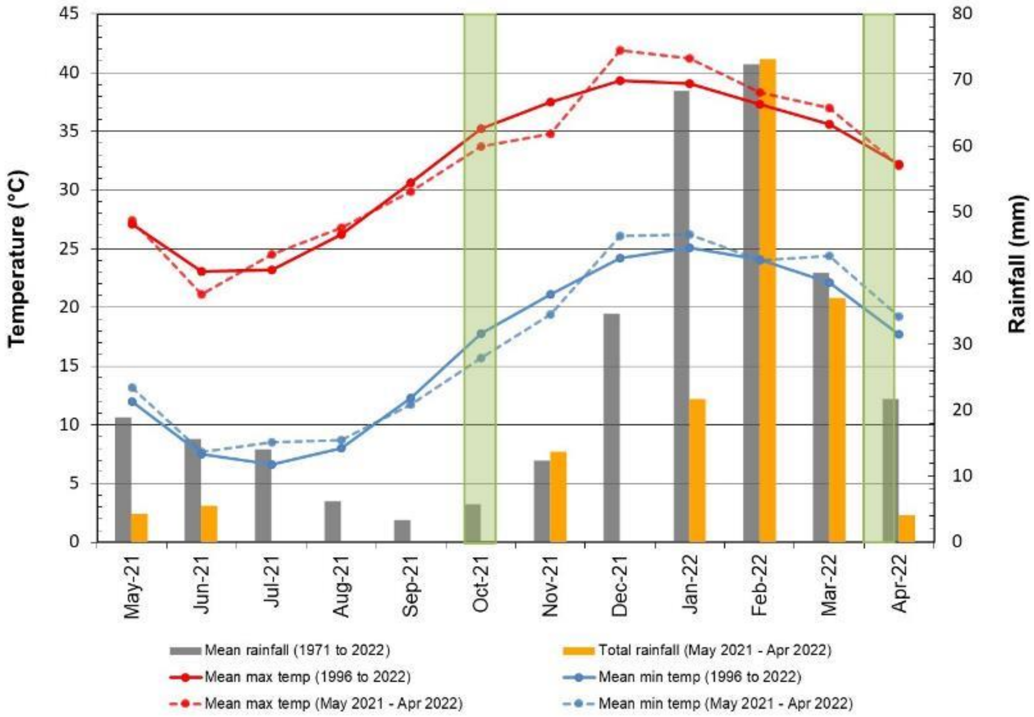


Figure 3.1: Total rainfall and long-term average monthly rainfall (mm) recorded from the Newman BoM gauging station in the months preceding the Yandicoogina Creek aquatic surveys.

Green bars indicate wet and dry season survey timing.

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

Streamflow in the Pilbara occurs as a direct response to rainfall. Monthly flows are typically highest in January and February, before receding over the course of the year (Figure 3.2). The relationship between rainfall and streamflow within nearby Marillana Creek (Flat Rocks GS station) is shown in Figure 3.2, where high flows are recorded during years of heavy rainfall. Rainfall and flows have been considerably lower since 2000, in comparison to the previous 12-year period (Figure 3.2).

Although March 2022 recorded just below the long-term average rainfall, a tropical low (30U) produced heavy rainfall in the days prior to the Wet 2022 survey, with over 76 mm of rain recorded at the Newman GS in four days (29th March – 1st April). The high rainfall days prior to the survey led to flooding in many creeks and river systems in the East Pilbara, including Yandicoogina Creek. The pools in Yandicoogina Creek were flushed and filled up, with the creek flowing at the time of sampling in April 2022, and riffle sequences observed at the time.

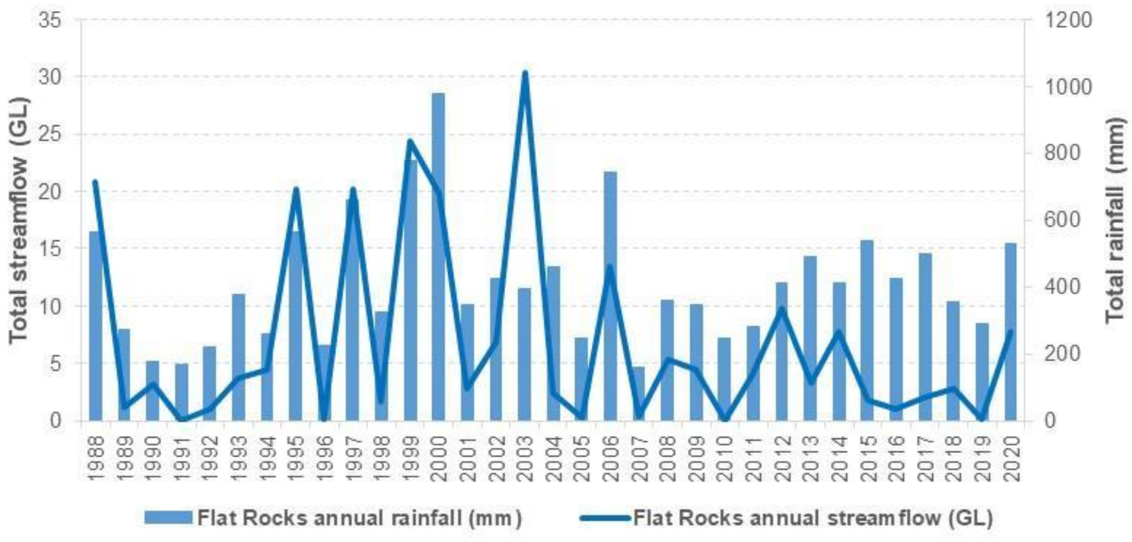


Figure 3.2: Annual rainfall (mm) and streamflow (ML) at the DWER Flat Rocks GS on Marillana Creek.

3.3 Site Selection

The Survey Area comprised a section of the Yandicoogina Creek GDE where a series of perennial and semi-permanent pools were present. A total of eight sites were sampled in both seasons; four located within the Survey Area, and four reference sites located elsewhere. Table 3.1 provides information on the sites sampled and their locations are shown in Figure 3.3. A brief description of Survey Area and reference sites is provided below:

<u>Within Survey Area</u>

- Yandicoogina Creek: Four sites (YC1, YC2, YC3 and YC4). YC1 through to YC3 are small groundwater seeps through *Typha domingensis* beds, while YC4 is a large pool located 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 (2001) due to the presence of permanent springs, large

permanent pools, large fish fauna, waterbird use and richness of aquatic vegetation. Skull Springs lies approximately 228 km to the northeast of the Survey Area.

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

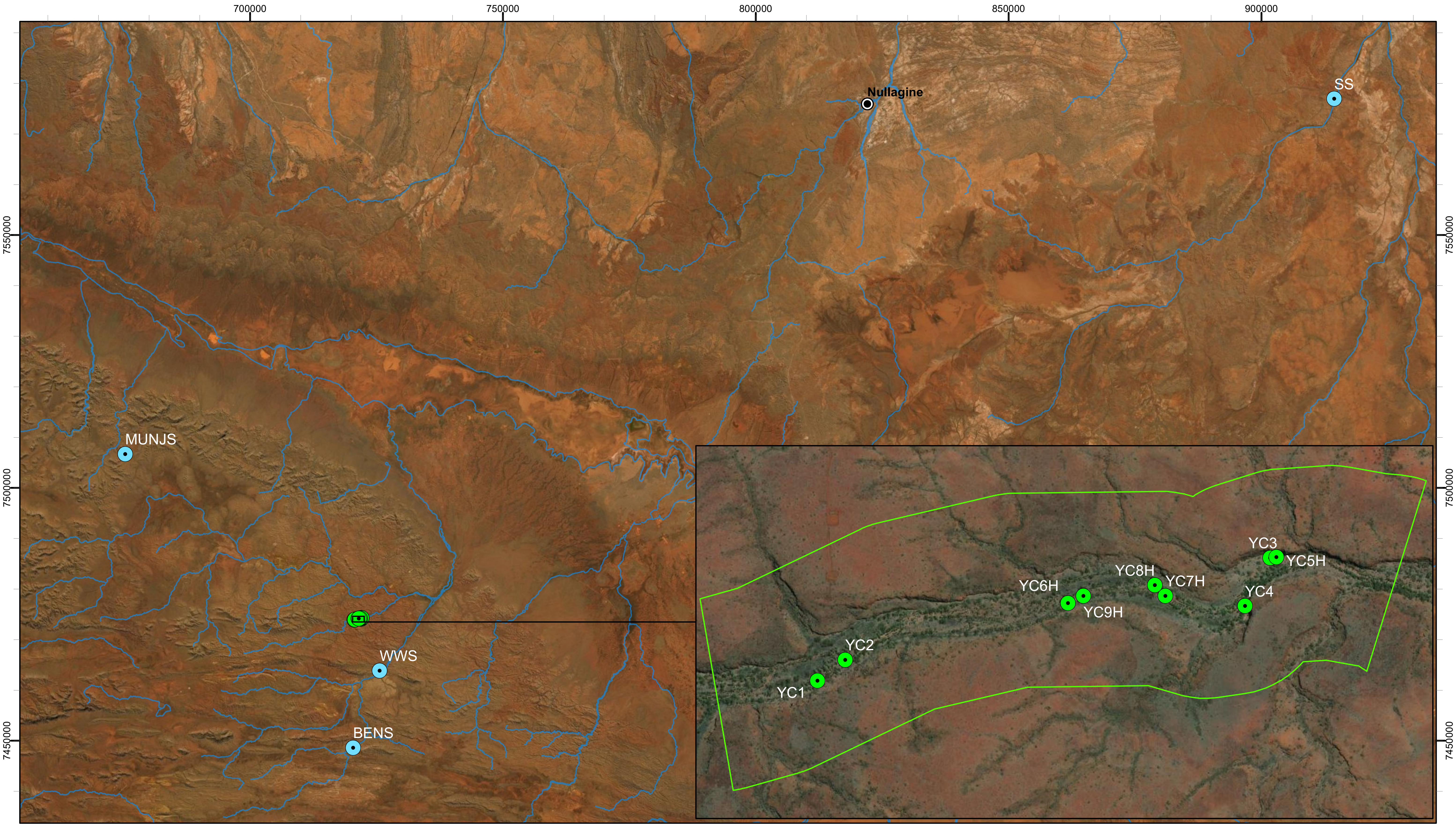
In the Wet 2022, additional hyporheic samples were collected within the Survey Area to gain a better understanding of the distribution of some of the stygal species collected in previous surveys (Biologic, 2020c, 2022b). These sites were YC5H, YC6H, YC7H, YC8H and YC9H (Table 3.1; Figure 3.3).

Table 3.1: Site information and sampling effort.

						Sampling effort	
	Creek/System	**Site**	**Code**	**Latitude**	**Longitude**	**Dry 2021**	**Wet 2022**
Survey Area	Yandicoogina Creek	Yandicoogina Creek 1	YC1	-22.8282	119.1499	×	✓
		Yandicoogina Creek 2	YC2	-22.8275	119.1510	×	✓
		Yandicoogina Creek 3	YC3	-22.8246	119.1637	✓	✓
		Yandicoogina Creek 4	YC4	-22.8258	119.1628	✓	✓
		Yandicoogina Creek 5 Hypo	YC5H	-22.8245	119.1637	-	*
		Yandicoogina Creek 6 Hypo	YC6H	-22.8259	119.1575	-	*
		Yandicoogina Creek 7 Hypo	YC7H	-22.8256	119.1604	-	*
		Yandicoogina Creek 8 Hypo	YC8H	-22.8253	119.1601	-	*
		Yandicoogina Creek 9 Hypo	YC9H	-22.8256	119.1579	-	*
Reference	Weeli Wolli Creek	Weeli Wolli Spring	WWS	-22.9181	119.1994	✓	✓
		Bens Oasis	BENS	-23.0558	119.1509	✓	✓
	Munjina Spring	Munjina Spring	MUNJS	-22.5373	118.7046	✓	✓
	Davis River	Skull Springs	SS	-21.8600	121.0114	✓	✓
			Total sites sampled (full suite)			**6**	**8**
			Rehydration-emergence samples			**2**	**0**

✓ Full suite of methods completed
× Dry at time of sampling, sediments collected, and rehydration-emergence trials undertaken
* Hypo only
- No access, not sampled

There are no fish present at reference site MUNJS and therefore fish were not sampled at this site.



LEGEND

Survey Area

Drainage Lines

Aquatic Sampling Sites

Study Area Sites

Reference Sites

N

biologic Environmental Survey

Scale: 1:700,000

0 5 10 15 20 25 30 35 40 Km

Coordinate System: GDA2020 MGA Zone 50
Projection: Transverse Mercator
Datum: GDA2020 Created 08/09/2022

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Figure 3.3: Aquatic sampling site locations

3.3.1 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.

3.3.2 Water Quality

Water quality variables were recorded in situ from each site with a portable YSI Pro Plus multimeter. 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.

Water quality variables measured included:

- In situ – pH, DO (% and mg/L), EC (µS/cm) and water temperature (°C).
- Ionic composition - Ca, K, Mg, Na, HCO_3, Cl, SO_4, CO_3, alkalinity and hardness (all mg/L).
- Water clarity – turbidity (NTU) and total suspended solids (TSS).
- Nutrients – 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.

3.3.3 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.

3.3.4 Zooplankton (Microinvertebrate Fauna)

Zooplankton samples were collected by gentle sweeping over an approximate 15 m distance with a 53 μm mesh pond net. The net was thoroughly cleaned between sites to avoid cross contamination. Samples were preserved in 95% ethanol in the field and sent to Dr Robert Walsh (Zooplankton taxonomist; Australian Waterlife).

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

3.3.5 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 3.1). 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 3.1: Sampling the hyporheic zone of YC9H in the Wet 2022 (Biologic ©).

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

3.3.6 Macroinvertebrates

Macroinvertebrate sampling was conducted with a 250 μm mesh D-net across as many habitats as possible, including open water, macrophyte beds, large woody debris (LWD), leaf litter, and edge habitat. The kick-sweep method was used in open areas, riffles and along edge habitat, whereby the sediments were disturbed (kicked) and the water column immediately swept with the dip net (Plate 3.1). Each sample was washed through a 250 μm sieve to remove fine sediment. Leaf litter and other coarse debris were removed by hand. The net was thoroughly cleaned between sites to avoid cross contamination.

Samples were preserved in 95% ethanol in the field and transported to the Biologic laboratory for processing. Sorting was conducted under a low power dissecting microscope. Specimens were identified to the lowest possible level (genus or species level) and enumerated to log_{10} scale abundance classes (i.e., 1 = 1 individual, 2 = 2 - 10 individuals, 3 = 11 - 100 individuals, 4 = 101-1000 individuals, 5 = >1000). All macroinvertebrate groups were identified in-house.

Plate 3.2: Sampling for macroinvertebrates at MUNJS in the Wet 2022 (Biologic ©).

3.3.7 Rehydrate Emergence Trials

Sediments were collected from dry sites (i.e., YC1 and YC2 in the Dry 2021) 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 was identified to as low a level as possible, and abundance recorded on a $\log_{10}$ abundance scale. The conservation status of emergent taxa was determined. Macrophytes which germinated were also identified to as low as level as possible.

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.

3.3.8 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 2022 (Biologic ©).

3.3.9 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*) if present. 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.

3.4 Data Analysis

3.4.1 Water Quality

In the absence of site-specific guideline values (SSGVs) for the Survey Area, water quality data were compared against the ANZG (2018) default guideline values (DGVs) for the protection of aquatic ecosystems in the tropical north-west of Western Australia (see Appendix B for default values). For this purpose, sites sampled in the current study were classified as lowland rivers (< 150 m elevation). DGVs are provided for a range of parameters designed to protect aquatic systems at a low level of risk but are not designed as pass or fail compliance criteria. Exceedances of DGVs provide a trigger which can be used to inform managers and regulators that changes in water quality are occurring and may need to be investigated (ANZG, 2018).

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

- High conservation/ecological value systems – where the goal is to maintain biodiversity with no (or little) change to ambient condition. 99% species protection DGVs for toxicants apply[1].
- Slightly to moderately disturbed systems – where aquatic biodiversity has already been adversely impacted to a small but measurable degree by human activity. The aquatic ecosystem remains in a healthy condition and ecological integrity is largely retained. The aim is to maintain current biodiversity and ecological function. 95% species protection DGVs for toxicants apply.
- Highly disturbed systems – are measurably degraded and of lower ecological value. Guideline aims for these systems may be varied and more flexible, ranging from maintenance of the current yet modified ecosystem that supports management goals, to continual improvement in ecosystem condition. For toxicants, the 90% or 80% species protection DGVs may be applied.

[1] 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).

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).

3.4.2 Macrophytes

Data on wetland vegetation of the Pilbara is limited, with varied sampling effort and taxonomic resolution across studies. However, macrophytes were sampled as part of the PBS, with a paper discussing conservation significance and distribution information due for publication (Mike Lyons, DBCA, unpub. data). To compare species lists with the current study, the DBCA kindly provided Biologic with macrophyte and dominant riparian flora data from appropriate PBS sites. Sites included in this comparison were Weeli Wolli Spring (PSW026), Kalgan Pool (PSW066), and Homestead Creek (PSW093). Flora data from these PBS sites were amalgamated with the current dataset, and a histogram produced displaying overall macrophyte richness recorded from each site.

3.4.3 Invertebrates

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

- Stygobite – obligate groundwater species, with special adaptations to survive such conditions;
- Permanent hyporheos stygophiles - epigean species (living on or near the surface of the ground) which can occur in both surface- and groundwaters, but is a permanent inhabitant of the hyporheos;
- Occasional hyporheos stygophiles – use the hyporheic zone seasonally or during early life history stages; and
- Stygoxene - species that appear rarely and apparently at random in groundwater habitats, 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 the Australia;
- North-western Australia – found across northern W.A., including the Pilbara and Kimberley regions;
- Western Australian endemic –known only from W.A.;
- Pilbara endemic - restricted to the Pilbara region of Western Australia;
- 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; and
- 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.

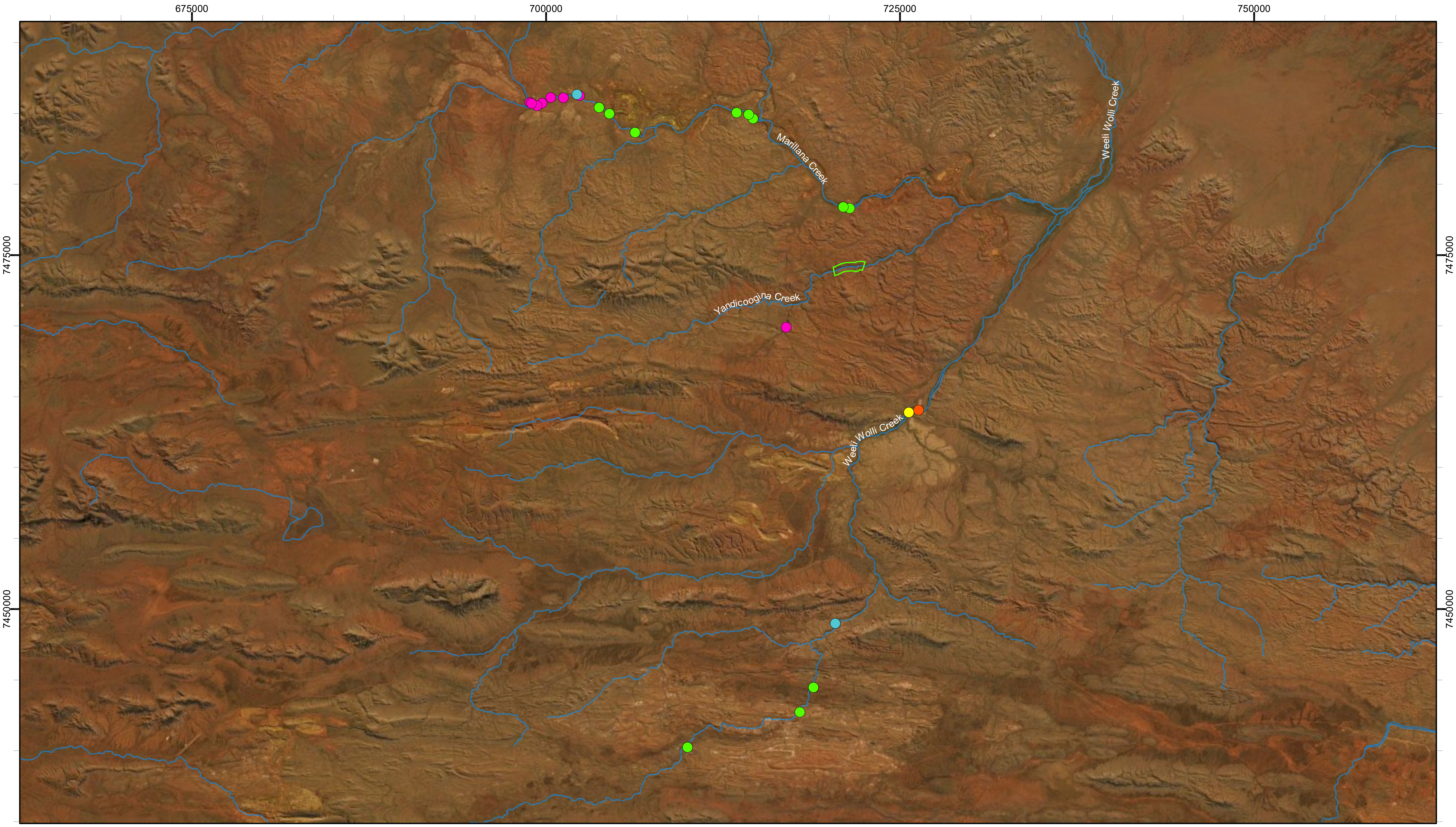
Invertebrate data was compared to the previous Ministers North surveys using two-way ANOVA to test for difference in richness (taxa richness for hyporheos fauna, zooplankton, and macroinvertebrates) between sampling events (Dry 2019, Wet 2020, Dry 2020, Wet 2021, Dry 2021, Wet 2022) and site type (Yandicoogina Creek vs Reference sites). Equality of variances was assessed using the Levene's test. Invertebrate data was also compared in this way to nearby sites sampled during the Pilbara Biological Survey (PBS), using the sites outlined above for macrophytes (Weeli Wolli Spring, Kalgan Pool, and Homestead Creek), and previous aquatic surveys by Biologic and others (see Table 3.2). To undertake this comparison, the dataset had to be amalgamated, and taxonomy aligned, to ensure any differences in taxonomic knowledge between samplers and years was appropriately accounted for. All univariate analyses were undertaken in SPSS (subscription build 1.0.0.1447).

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 complete Ministers North dataset, and separately on the expanded and amalgamated dataset which included previous surveys from nearby sites (PBS and others listed in Table 3.2). Locations of sites sampled in previous studies for which data was used in comparisons with the current study are shown in Figure 3.4.

Table 3.2: Data used in analysis comparing Yandicoogina Creek to nearby sites sampled previously.

Creek/Area	Description	Sampling events	Reference
Marillana	Upper Marillana Creek, upstream of BHP's Yandi (from Flat Rocks, upstream).	Wet 2014 (Flat Rocks) Dry 2014 (Flat Rocks)	WRM (2015)
		Wet 2017 Dry 2017	WRM (2018)
		Dry 2020 Wet 2021	Biologic (2022a)
Marillana Downstream	Marillana Creek from downstream of the pools in and around Flat Rocks, to just downstream of Rio Tinto's Yandicoogina Oxbow Deposit	Wet 2014 Dry 2014	WRM (2015)
		Wet 2017 Dry 2017	WRM (2018)
Weeli Wolli Spring	The main Priority 1 PEC spring system comprising approximately 2 km of flowing creeklines	Dry 2003 Wet 2005	Pinder *et al.* (2010)
		Dry 2019 Wet 2020	Biologic (2020c)
		Dry 2020 Wet 2021	Biologic (2022b)
		This study (reference site)	
Weeli Wolli Creek	Semi-permanent and permanent pools located upstream of Bens Oasis on Weeli Wolli Creek (i.e., Wunna Munna, etc).	Wet 2014 Dry 2014	WRM (2015)
		Wet 2017 Dry 2017	WRM (2018)
Davis River	Permanent flowing spring pools on the Davis River, including Running Waters and Skull Springs	Dry 2019 Wet 2020	Biologic (2020c)
		Dry 2020	Biologic (2022b)
		This study (reference site)	

Using macroinvertebrate data from Yandicoogina Creek 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.



LEGEND

Survey Area

Drainage Lines

Previous Sampling Sites

- Biologic (2019b)
- Biologic (2020c)
- Pinder et al. (2010)
- WRM (2015)
- WRM (2018)

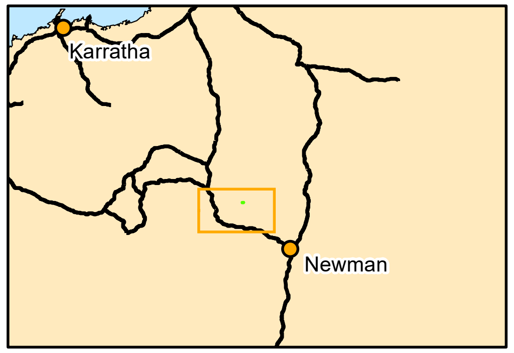
N

biologic Environmental Survey

Scale: 1:250,000

0 2 4 6 8 10 12 14 Km

Coordinate System: GDA2020 MGA Zone 50
Projection: Transverse Mercator
Datum: GDA2020 Created 08/09/2022



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Ministers North Aquatic Ecosystem Survey: Dry 2021 – Wet 2022

Figure 3.4: Locations of previous sampling sites used in comparisons with the current study

3.4.4 Fish

Length-frequency analysis was undertaken for each fish species recorded, whereby each species was classified into four age classes based on body size (SL mm). Age classes were determined from the literature (Allen *et al.*, 2002; Puckridge & Walker, 1990) (Table 3.3).

Table 3.3: Standard lengths used for each age class for each species recorded.

	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

A summary of the overall habitat assessment is provided in (Table 4.1) and all raw data in Appendix C. Sites within the Survey Area occurred within an extensive closed *Melaleuca argentea* forest, with *Eucalyptus camaldulensis* over *Acacia tumida* var. *pilbarensis* shrubland. *Cyperus vaginatus* and *Typha domingensis* occurred along the waterline. Weeds were present throughout the Survey Area. Water levels in the Dry 2021 continued to lower from those observed in the Wet 2021 (Biologic, 2022b), with sites YC1 and YC2 being completely dry at time of sampling. Vegetation such as *Typha domingensis* was in poor condition at all sites, with signs of senescence. In the Wet 2022, recent heavy rainfall resulted in surface water throughout the Survey Area, with the creek still showing signs of flood.

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

In-stream habitat diversity was high throughout the Survey Area and included complex heterogenous substrates, such as submerged and emergent macrophytes, large woody debris (LWD), root mats, detritus, and trailing vegetation. There was some seasonal change between seasons, with noticeable flushing of algae following the wet season rainfall. At YC3, algal cover decreased from 40% in the Dry 2021 to 11% in the Wet 2022, while algae at YC4 was the same in both seasons (2%). Algae was also considerably higher in the Dry 2021 at reference sites WWS (32% cover) and SS (48%) compared to the Wet 2022 (2% at WWS and 10% at SS). At BENS, algae cover increased from 1% in the dry season to 11% in the wet. Silt was higher at all sites in the Wet 2022 compared to the Dry 2021. In the wet season, only one Survey Area site recorded submerged macrophyte cover (1% cover at YC4). This was likely due to sites YC1 and YC2 having completely dried in the Dry 2021, while YC3 had receded to a pool 2 m in length and 1 m in width. The recent rainfall observed in the Wet 2022 may also have washed away some of the submerged macrophytes at YC4.

4.1.1 Water level comparison with previous surveys

There was a steady decline in average maximum water depth in the Survey Area between the Wet 2020 and Dry 2021 (Figure 4.1). Following the high rainfall event in late March (see section 3.2), there was a notable increase in pool depth observed in the Wet 2022 sampling event. It is not known how long surface water remained following this rainfall event and the Wet 2022 aquatic survey, but most of the creekline, including YC1 and YC2, was dry by the 27th of July 2022[2] (Jess Delaney, Biologic, pers. obs.). The pool at YC3 was also very shallow by this time and likely dried up shortly after. This is noteworthy because the creek is a known seep, with groundwater intersecting the surface at sites selected for this survey, and as such, the additional wet season rainfall should keep pools inundated. The decline in maximum water depth over time has not been observed at reference sites. Instead, seasonal changes have been apparent, with greater depths in the wet season and lower in the dry, as

[2] Jess assisted the flora team with the Yandicoogina Creek tree health monitoring between the 27th and 29th of July 2022 and made observations on surface water and pool depths at this time.

would be expected for Pilbara waterbodies (Figure 4.1). Therefore, the decline at Yandicoogina Creek is not due to natural, seasonal change. Infiltration rates at Yandicoogina Creek would be high given the gravel creek bed, therefore, groundwater levels must be declining in this area, leading to decreases in surface water. The cause for the groundwater decline should be investigated.

Overall, there was no significant difference in maximum water depth between site type (Survey Area vs reference; Two-way ANOVA; df = 1, F = 0.47, p = 0.499), nor between sampling events (df = 5, F = 0.07, p = 0.996). The large standard errors bars for Survey Area are due to the large difference in pool depths along the length of the creek, with YC1 and YC2 generally being less than 0.5 m deep, but YC4 having a maximum depth of up to 5 m.

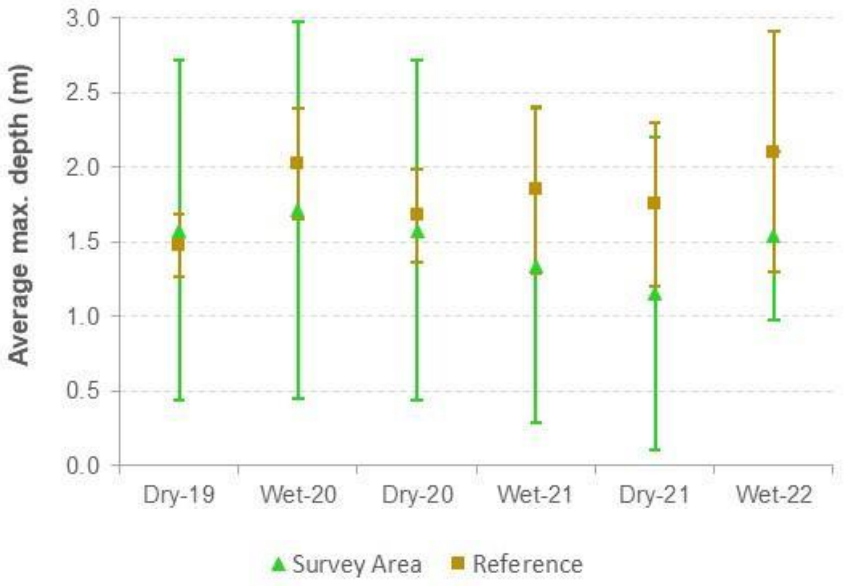
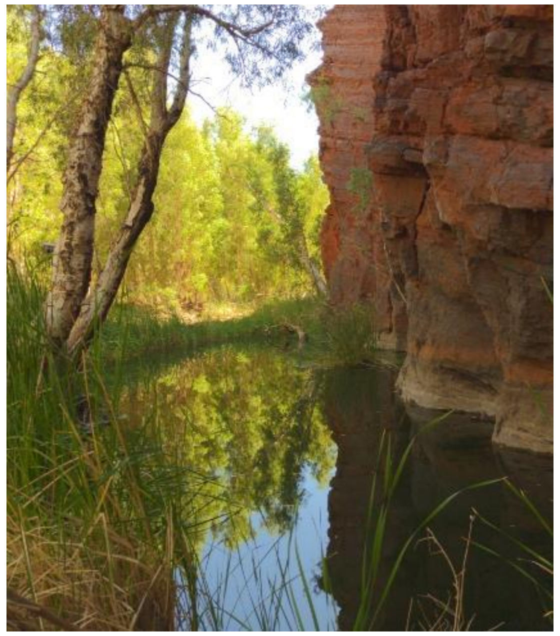
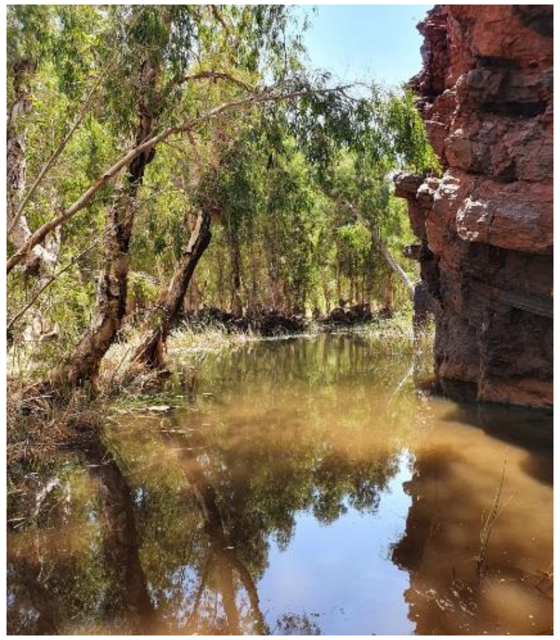
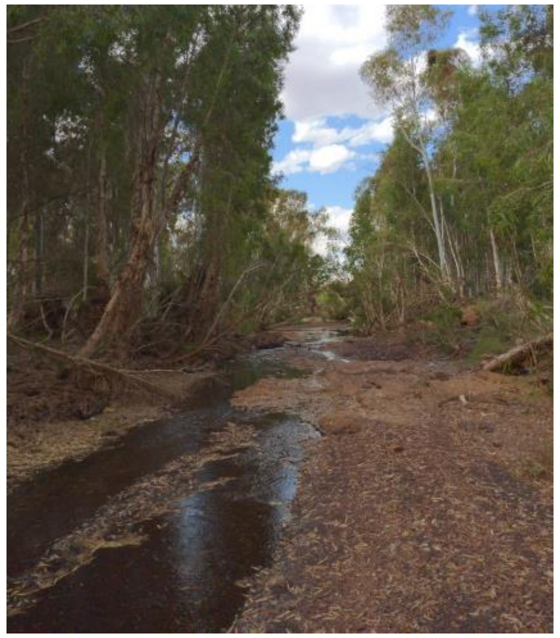
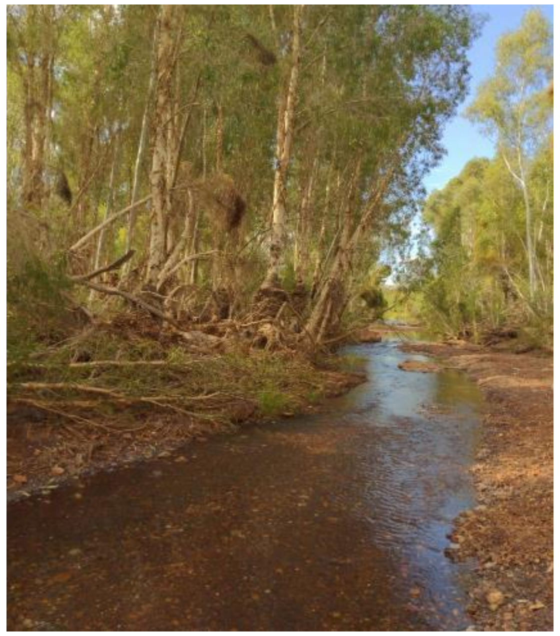
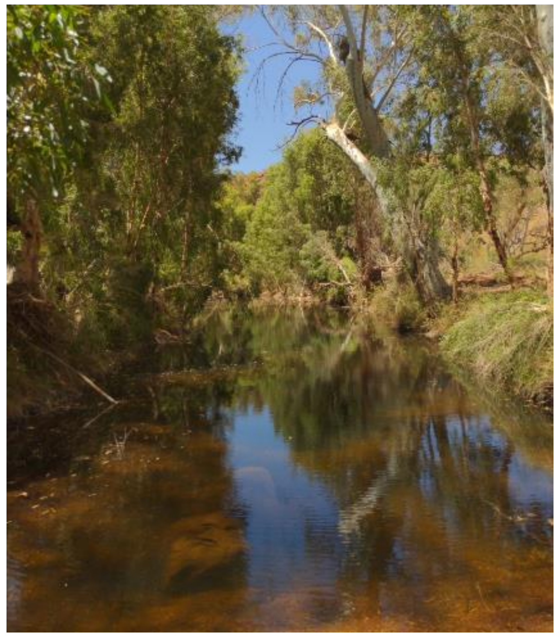


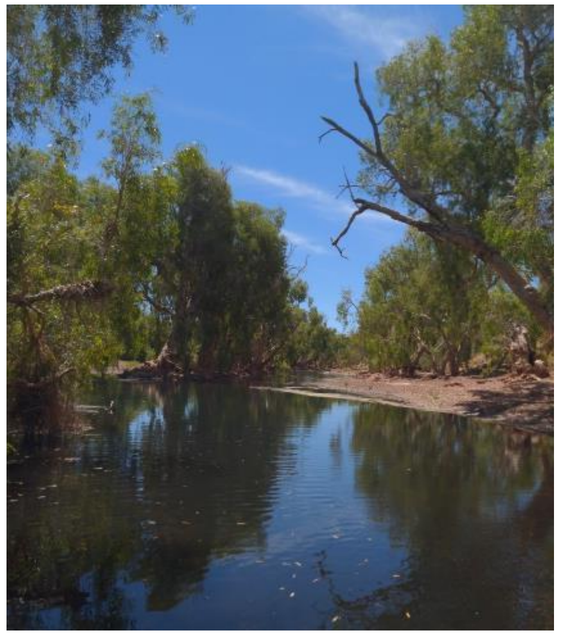
Figure 4.1: Average maximum water depth (± standard error) in the Survey Area and Reference sites in each sampling event since the dry 2019.

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

Site	Habitat	Description	Site Photo: Dry Season Survey	Site Photo: Wet Season Survey
YC1	**Small pool**	Small, shallow seep. Dry 2021 = dry Wet 2022 = 180 m x 10 m. Groundwater dependant vegetation present including *Melaleuca argentea* and *Eucalyptus camaldulensis*. Dominant emergent vegetation included *Typha domingensis* and *Cyperus vaginatus*. Mineral substrate comprising gravel, pebbles, and cobbles. Detritus and LWD present. Maximum water depth: Wet 2022 = 1.2 m.		
YC2	**Small pool**	Small seep. Dry 2021 = dry Wet 2022 = 150 m x 4 m. Riparian vegetation comprising *Eucalyptus camaldulensis* and *Melaleuca argentea* open woodland over patches of sedgeland including highly abundant *Typha domingensis* and some *Cyperus vaginatus*. Mineral substrate comprising cobbles, pebbles, gravel, sand, and silt. Maximum water depth: Wet 2022 = 1 m.		

Site	Habitat	Description	Site Photo	
			Dry Season Survey	**Wet Season Survey**
YC3	**Small pool**	Small, shallow seep. Dry 2021: 2 m x 1 m Wet 2022: 80 m x 4 m. *Melaleuca argentea* with scattered *Eucalyptus camaldulensis* as the dominant overstorey. Emergent vegetation comprising *Typha domingensis, Cyperus vaginatus* and *Eleocharis geniculata* sedgeland, with submerged macrophyte *Chara* 'fibrosa' present in the Dry 21. No submerged macrophytes were observed in the Wet 22. Algae bloom in the dry with some algae present in the wet. Weeds present, including buffel grass. Mineral substrate comprising gravel, pebbles, cobbles, sand, and silt. Maximum water depth: Dry 2021: 0.1 m Wet 2022: 0.75 m.		
YC4	**Permanent, spring-fed creek pool**	Large permanent pool against a cliff face. Dry 2021: 60 m x 13 m Wet 2022: 150 m x 15 m. *Melaleuca argentea* and scattered *Eucalyptus camaldulensis* open woodland over *Typha domingensis* sedgeland. Emergent macrophyte also included *Cyperus vaginatus, Eleocharis geniculata*, *Schoenoplectus subulatus* and *Fimbristylis sieberiana* (P3). *Typha* showed signs of senescence in the Dry 21 and had been recently flooded in the Wet 22. Submerged macrophyte *Vallisneria nana* present in-stream. Gravel was the dominant mineral substrate followed by clay and sand. Maximum water depth: Dry 2021: 2.2 m Wet 2022: 3.2 m.		

Site	Habitat	Description	Site Photo: Dry Season Survey	Site Photo: Wet Season Survey
WWS	**Spring**	Permanent spring comprising a series of pools and interconnecting riffles. Located within Rio Tinto's HD1 discharge area – surface flows maintained by discharge from spurs currently. Dry 2021: 100 m x 12 m Wet 2022: 100 m x 11 m Overstorey vegetation comprising *Melaleuca argentea* and *Eucalyptus camaldulensis* over a dense shrub layer. Emergent macrophyte comprising *Cyperus vaginatus,* and *Schoenoplectus subulatus*. Fringing *Stylidium weeliwolli* (P3) and *Lobelia arnhemiaca* present in the dry season. Algal bloom in the dry. WWS is a Priority 1 PEC. Substrate comprising primarily gravel, pebbles, sand, and cobbles, with the pool infilled with sediment in the Wet 22. Maximum water depth: Dry 2021: 1.2 m Wet 2022: 1.2 m.		
BENS	**Spring**	Series of creek pools. Dry 2021: 100 m x 10 m Wet 2022: 110 m x 15 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. Obvious impacts by cattle, with sedges grazed, and erosion of banks. Maximum water depth: Dry 2021: 1.2 m Wet 2022: 1.6 m.		

			Site Photo	
Site	**Habitat**	**Description**	**Dry Season Survey**	**Wet Season Survey**
MUNJS	**Permanent creek pools**	A series of long permanent pools, with numerous riffle sections Dry 2021: 400 m x 15 m Wet 2022: 400 m x 15 m. Riparian vegetation comprising *Eucalyptus camaldulensis* and *Melaleuca argentea*. Emergent macrophyte comprising *Typha domingensis, Cyperus vaginatus and Eleocharis geniculata*. *Chara* spp., *Vallisneria annua* and *Potamogeton tepperi* submerged macrophytes present in-stream. No fish. No obvious signs of disturbance. *Stylidium fluminense* present throughout in the dry. Mineral substrate almost exclusively bedrock overlain by silt and organics. Maximum water depth: Dry 2021: 3.4 m Wet 2022: 4.5 m.		
SS	**Spring**	Permanent spring flowing into a series of pools via a braided channel. Dry 2021: 200 m x 22 m Wet 2022: 250 m x 22 m Riparian vegetation comprising *Melaleuca argentea* and sedges (*Cyperus vaginatus* and *Eleocharis geniculata*). Submerged macrophyte comprising *Chara* '*globularis*' and *Potamogeton tepperi.* P2 Priority flora (ground creeper *Ipomoea racemigera*) present. Mineral substrate heterogenous, dominated by gravel, pebbles, and sand. Disturbances included cattle impacts and introduced vegetation (such as Mexican poppy *Argemone ochroleuca* subsp. *ochroleuca*). Maximum water depth: Dry 2021: 1.2 m Wet 2022: 1.2 m.		

4.2 Water Quality

All raw water quality data are provided in Appendix D.

4.2.1 In situ

Electrical conductivity (EC) within the Survey Area ranged from 630 µS/cm (YC4) to 677 µS/cm (YC3) in the Dry 2021, and 444 µS/cm (YC4) to 675 µS/cm (YC3) in the Wet 2022. Reference sites MUNJS, BENS and WWS all recorded higher EC than the Survey Area in at least one season (Figure 4.2). While all sites recorded EC in excess of the ANZG (2018) DGV (> 250 µS/cm), the DGV for EC is known to be conservative and not necessarily applicable to Pilbara waters, which are known to experience wide-ranging EC. All sites were classified as freshwater ecosystems (Mayer *et al.*, 2005)[3].

Two Survey Area sites held water in both seasons. Of these, there was no seasonal variation in EC at YC3, but YC4 recorded notably lower EC in the wet season (Figure 4.2). The elevated EC in the dry is common in Pilbara systems where there is large temporal and seasonal variability due to flushing in the wet season and waters receding in the dry resulting in evapoconcentration of ions. Similarly greater EC was recorded from reference sites in the dry season, including MUNJS, BENS and SS. No seasonal variation was recorded from WWS (Figure 4.2).

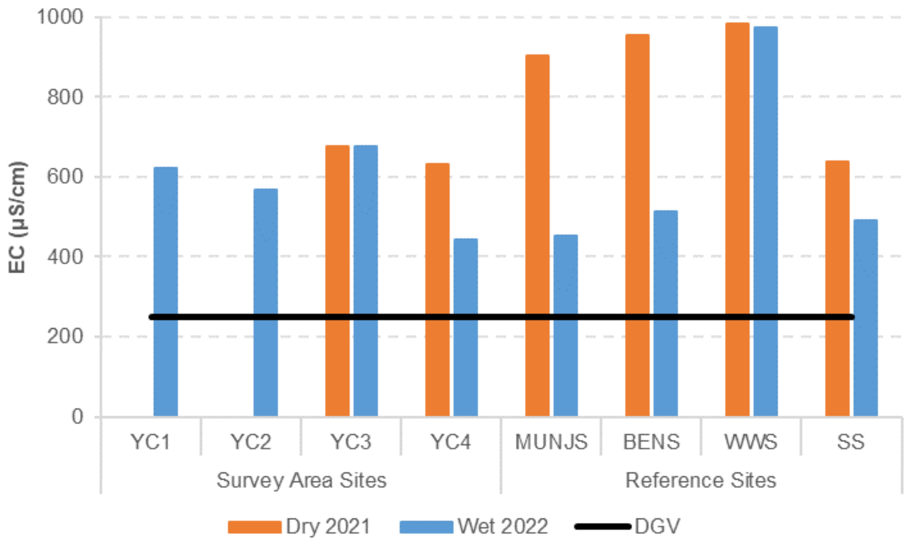


Figure 4.2: Electrical conductivity (EC; µS/cm) recorded from all sites, compared to the ANZG (2018) DGV.

Dissolved oxygen (DO) ranged from 29.6% (at YC3) to 88.2% (at MUNJS) in the Dry 2021, and 12.2% (YC3) to 88.8% (MUNJS) in the Wet 2022. DO concentrations within the Survey Area were low, with all sites recording saturation levels below the lower DGV in both seasons (Figure 4.3). Most reference

[3] Salinity categories are based on the Department of Water and Regulation (DWER) classification system, where fresh/marginal < 1,000 mg/L (~1,500 µS/cm), brackish = 1,000 mg/L – 2,000 mg/L (~1,500 µS/cm to 3,000 µS/cm), saline = 2,000 mg/L – 10,000 mg/L (~ 3,000 µS/cm – 15,000 µS/cm), and hypersaline > 10,000 mg/L (> 15,000 µS/cm).

sites also recorded similarly low DO in both seasons, with MUNJS being the only site to record DO saturation within the ANZG (2018) DGVs (Figure 4.3).

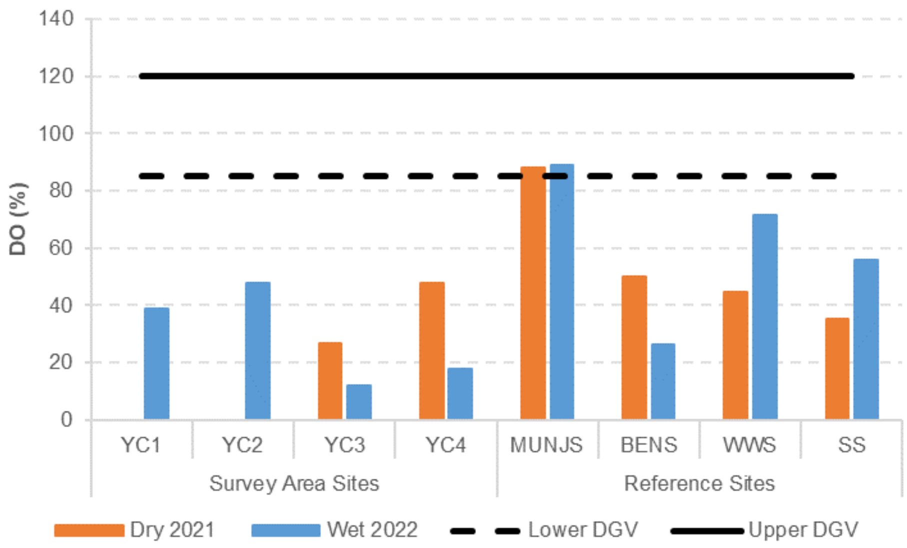


Figure 4.3: Dissolved oxygen (DO %) recorded from all sites, compared to the ANZG (2018) upper and lower DGVs.

Surface water pH within the Survey Area was neutral, with little variability between sites. Lowest pH was recorded at YC3 (7.03) in the wet season and the highest (7.67) was also recorded from YC3 in the dry season. Reference sites ranged from slightly acidic (6.2 at WWS in the Dry 2021) to basic (8.33 at SS in the Dry 2021). Only two sites exceeded the upper ANZG (2018) DGV, SS in the dry season (pH = 8.33) and MUNJS in both seasons (Dry: 8.07 and Wet: 8.04), however neither was of ecological concern.

4.2.2 Ionic composition

The ionic composition of all Survey Area and reference sites was dominated by bicarbonate (HCO_3) anions, in both seasons. Survey Area sites were exclusively dominated by calcium (Ca) cations in both seasons, as was reference site WWS. MUNJS was dominated by sodium (Na) cations in both seasons. BENS and SS showed some seasonal variation, with BENS dominated by magnesium (Mg) cations in the Dry 2021 and Ca cations in the Wet 2022. SS was dominated by Ca cations in the dry season and Na cations in the wet season.

4.2.3 Alkalinity

Alkalinity measures the capacity of the water to resist sudden changes in pH, i.e., it is the buffering capacity of the water. Alkalinity of less than 20 mg/L is considered low, and the system would have limited ability to buffer against rapid changes in pH. In this respect, surface waters within the Survey Area would be considered to be well buffered, with all sites recording alkalinity greater than 150 mg/L. Greatest alkalinity from the Survey Area was recorded from YC4 in the Dry 2021 (264 mg/L). Across the reference sites, alkalinity ranged from 93 mg/L at MUNJS in the Wet 2022 to 428 at BENS in the

Dry 2021. Therefore, surface waters at reference sites would also be considered to have good buffering capacity.

4.2.4 Nutrients

Nitrogen ammonia (N_NH_3) concentrations were low at all sites sampled. In both seasons all values were below the limit of detection (LOD; < 0.01 mg/L), and therefore all concentrations were below the 95% and 99% toxicity DGVs. Nitrogen nitrate (N_NO_3) concentrations were also low, ranging from values below the LOD (< 0.01 mg/L) to 0.22 mg/L (at reference site SS) in the Dry 2021, and from below LOD to 0.29 mg/L (again at SS) in the Wet 2022.No sites recorded nitrate concentrations above the ANZG (2018) DGV.

Nitrogen oxide (N_NOx) concentrations were variable within the Survey Area, ranging from concentrations below the LOD (at YC3 and YC4 in the Dry 2021, and YC2 in the Wet 2022) to 0.07 mg/L at YC1 in the Wet 2021 (Figure 4.4). This contrasts with a maximum concentration recorded from reference sites of 0.29 mg/L, almost 30 times greater than the ANZG (2018) DGV (from SS in the Wet 2022) (Figure 4.4). Exceedances of the N_NOx eutrophication DGV were recorded from all sites sampled except YC2 and BENS (Figure 4.4).

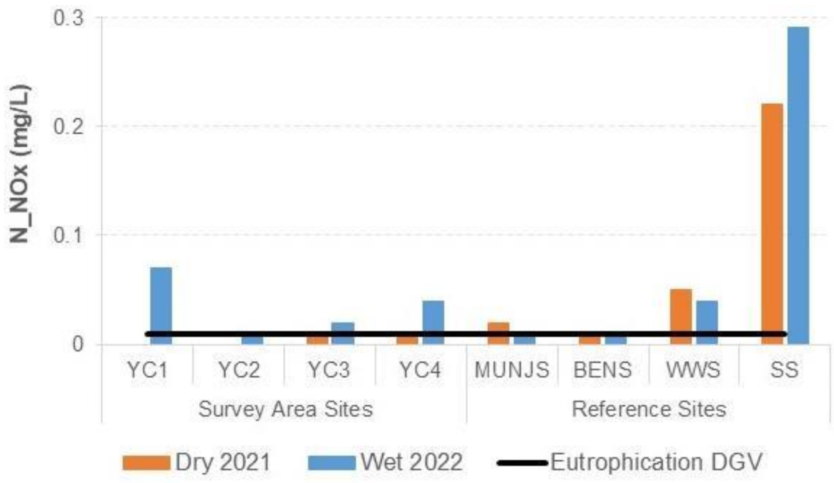


Figure 4.4: Nitrogen oxide (N_NOx; mg/L) recorded from all sites, compared to the ANZG (2018) eutrophication DGV.

Total nitrogen (Total N) concentrations recorded from the Survey Area were generally low, ranging from 0.15 mg/L (at YC3) to 0.32 mg/L (at YC4) in the Dry 2021, and from 0.12 mg/L (YC3) to 0.22 mg/L (YC1) in the Wet 2022 (Figure 4.5). This compares to a range of Total N between 0.03 mg/L (at WWS in the Wet 2022) and 0.34 mg/L (at SS in the Wet 2022) at reference sites (Figure 4.5). Although concentrations recorded from YC4 in the dry season, and SS in the wet, exceeded the eutrophication DGV for Total N, these exceedances were marginal.

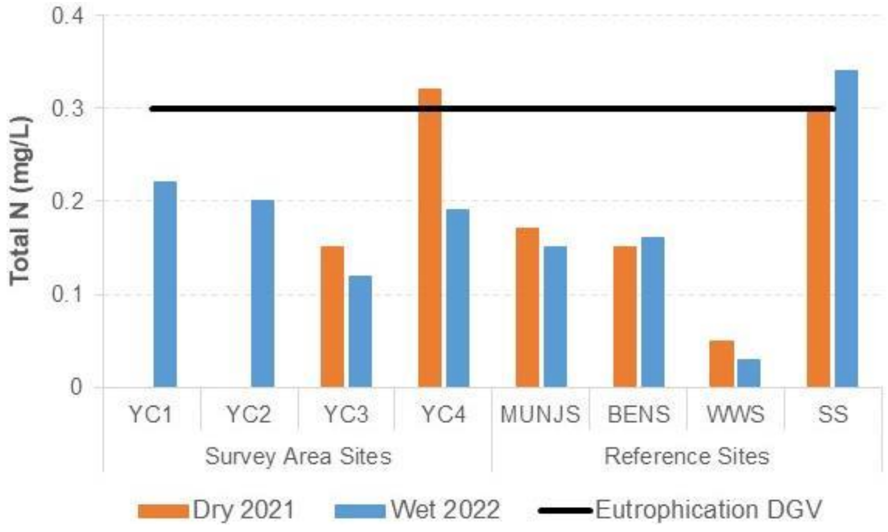


Figure 4.5: Total nitrogen (Total N; mg/L) recorded from all sites, compared to the ANZG (2018) eutrophication DGV.

Total phosphorous (total P) concentrations were high and in excess of the eutrophication DGV at all sites, both within the Survey Area and at reference sites, in both seasons (Figure 4.6). Within the Survey Area, concentrations ranged from 0.016 mg/L (at YC3 in the Wet 2022) to 0.053 mg/L (at YC4 in the Dry 2021). The concentration recorded from YC4 in the dry season was more than five times greater than the eutrophication DGV. Total P concentrations at reference sites ranged from 0.014 mg/L (at WWS in the Wet 2022) to 0.034 mg/L (at MUNJS in the Dry 2021) (Figure 4.6).

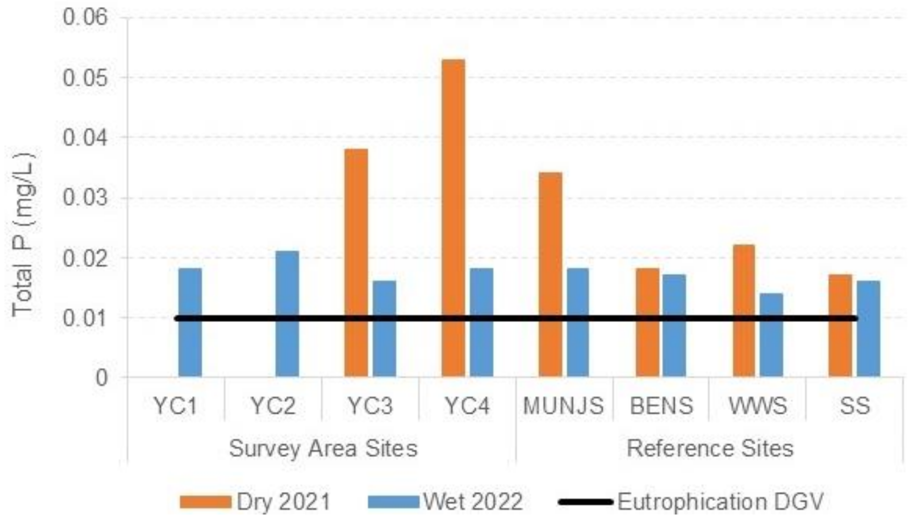


Figure 4.6: Total phosphorus (Total P; mg/L) recorded from all sites, compared to the ANZG (2018) eutrophication DGV.

4.2.5 Dissolved metals

Dissolved metal concentrations within Survey Area pools were low, with many analytes recording concentrations below LODs at all sites (i.e., cadmium, chromium, nickel, lead, selenium, and zinc). No dissolved metals were recorded in concentrations greater than the 95% toxicity DGV, and only one was in excess of the 99% toxicity DGV within the Survey Area. Dissolved boron (dB) concentrations exceeded the 99% DGV at all Survey Area sites, in both seasons (Figure 4.7). Exceedances of the 99% toxicity DGV for dB were also recorded from reference sites (MUNJS, BENS and WWS).

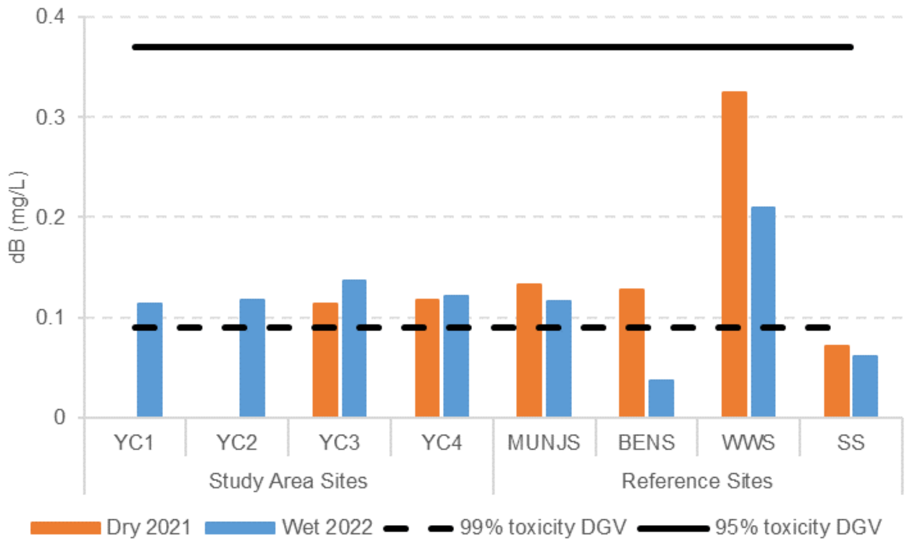


Figure 4.7: Dissolved boron (dB; mg/L) recorded from all sites, compared to the ANZG (2018) toxicity DGVs.

4.2.6 Water quality comparison with the previous surveys

Average EC recorded from surface waters within the Survey Area has remained relatively consistent over time, with no seasonal or temporal trends apparent (Figure 4.8). In contrast, reference site EC has undergone obvious seasonal change, with increases in the dry season and decreases in the wet (Figure 4.8). Although this pattern is common in Pilbara waterbodies, all reference sites are spring systems and generally experience little seasonal variation due to ongoing contributions by groundwater. Overall, there was no significant difference in EC between sampling event, but there was a significant difference between site type (Table 4.2). Reference sites recorded significantly greater EC than the Survey Area, i.e., surface waters within the Survey Area were fresher (Figure 4.8).

Average DO recorded from Survey Area pools decreased steadily between the Dry 2019 and Dry 2020, with an increase in the Wet 2021, followed by another steady decline to the Wet 2022. This pattern of change over time was similar at reference sites (Figure 4.8). While there was no significant difference in DO between sampling event, saturation was found to be significantly lower within the Survey Area in comparison to reference sites (Table 4.2, Figure 4.8).

While there has been some change in average pH over time within Survey Area pools, the difference between sampling events was marginal, and similar changes were also recorded at reference sites (Figure 4.8). Overall, there was no significant difference in pH between sampling events, although there was between site type. pH was significantly lower within Survey Area pools in comparison to reference sites (Table 4.2, Figure 4.8).

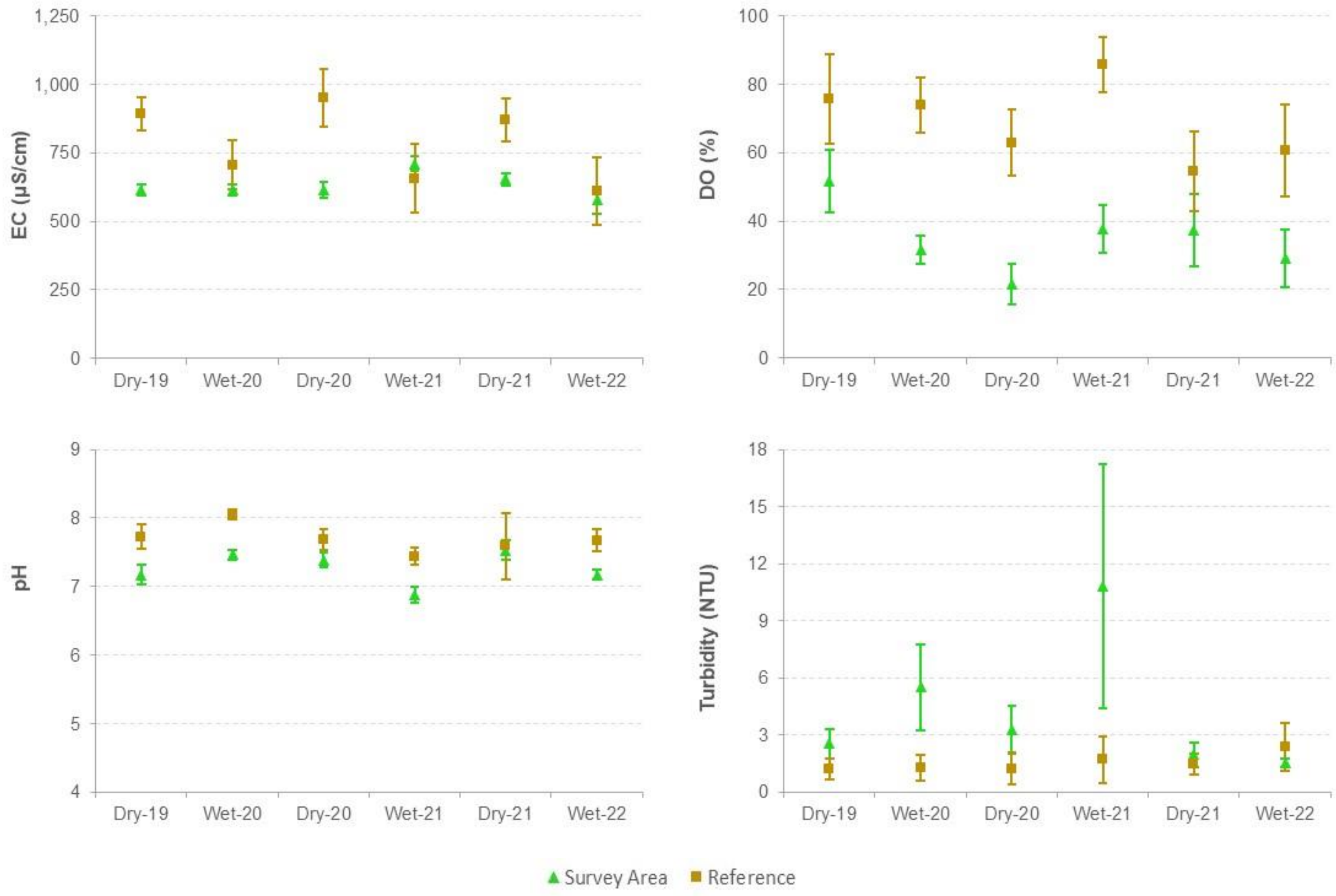


Figure 4.8: Comparison of *in situ* water quality analytes between sampling events(average ± standard error).

While average turbidity was relatively consistent over time within reference sites, there was notable variation within the Survey Area, both between and within sampling events (Figure 4.8). Higher turbidity has been recorded from the Survey Area in the wet season, in comparison to the dry, with the exception of the Wet 2022. This is not unexpected in Pilbara systems, with wet season flows and runoff from the surrounding catchment contributing suspended sediments to creeks. However, overall, there was no significant difference in turbidity between sampling events (Table 4.2). There was a significant difference between site type though, with significantly greater turbidity recorded from the Survey Area (Table 4.2, Figure 4.8).

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

Analyte	Source	df	F	*p*-value
Log EC	Sampling event	5	2.00	0.107
	Type	1	7.78	0.009
	Sampling event*type	5	2.06	0.095
	Corrected total	45		
DO	Sampling event	5	1.86	0.127
	Type	1	37.28	0.000
	Sampling event*type	5	0.71	0.620
	Corrected total	45		
pH	Sampling event	5	2.25	0.072
	Type	1	14.60	0.001
	Sampling event*type	5	0.50	0.777
	Corrected total	45		
Log Turbidity	Sampling event	5	0.20	0.961
	Type	1	6.43	0.016
	Sampling event*type	5	0.24	0.941
	Corrected total	45		

There was minimal change in average nitrogen nitrate concentrations within the Survey Area over time, with the greatest change being an increase of 0.03 mg/L (average) between the Dry 2021 (average N_NO_3 = 0.005 mg/L) in the Wet 2022 (average = 0.034 mg/L) (Figure 4.9). Overall, there was no significant difference in nitrogen nitrate concentrations between sampling events or between site type (Table 4.3).

There has been a similar pattern of change over time in both Survey Area and reference sites in terms of average total P concentrations, however, the increase in concentrations in the wet and dry seasons of 2021 was considerably more marked within the Survey Area (Figure 4.9). Average total P concentrations within the Survey Area dropped in the Wet 2022, to concentrations slightly lower than the Dry 2020 (prior to the increase) and similar to that recorded from reference sites in the Wet 2022 (Figure 4.9). Statistical analysis indicated that total P concentrations in the Wet 2022 and Dry 2020 were significantly lower than those recorded in the Dry 2019 and Wet 2020 (but statistically similar to the Wet 2021 and Dry 2021 (Table 4.3, Figure 4.9). There was also a significant difference in total P between site type, with significantly higher concentrations recorded from the Survey Area in comparison to reference sites (Table 4.3, Figure 4.9).

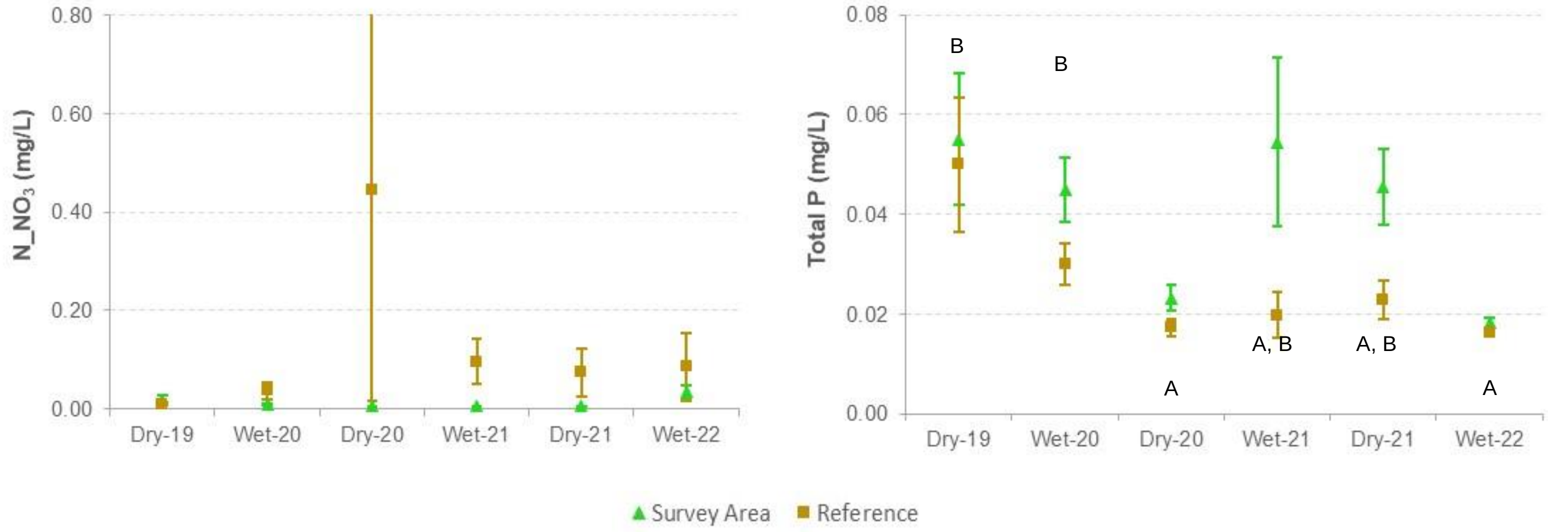


Figure 4.9: Comparison of selected nutrient analytes between sampling events(average ± standard error).

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

Analyte	Source	df	F	*p*-value
Nitrate	Sampling event	5	0.71	0.621
	Type	1	2.01	0.165
	Sampling event*type	5	0.78	0.569
	Corrected total	45		
Log Total P	Sampling event	5	8.42	0.000
	Type	1	14.80	0.001
	Sampling event*type	5	1.54	0.203
	Corrected total	45		

Average concentrations of dAs, dBa, dU and dV were all significantly greater at reference sites than pools within the Survey area (Table 4.4, Figure 4.10). Although concentrations of dCu and dMn were also generally higher at reference sites, the difference was not significant (Two-way ANOVA; df = 1, $p > 0.052$). One dissolved metal, dFe, was recorded in significantly higher concentration from surface waters within the Survey Area in comparison to reference sites (Table 4.4, Figure 4.10).

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

Analyte	Source	df	F	*p*-value
Dissolved arsenic	Sampling event	5	0.80	0.559
	Type	1	14.71	0.001
	Sampling event*type	5	1.17	0.343
	Corrected total	45		
Log dissolved boron	Sampling event	5	1.56	0.197
	Type	1	0.00	0.951
	Sampling event*type	5	1.09	0.382
	Corrected total	45		
Dissolved barium	Sampling event	5	0.27	0.925
	Type	1	5.89	0.021
	Sampling event*type	5	0.34	0.886
	Corrected total	45		
Dissolved iron	Sampling event	5	0.76	0.584
	Type	1	4.43	0.043
	Sampling event*type	5	0.52	0.757
	Corrected total	45		
Dissolved uranium	Sampling event	5	0.97	0.451
	Type	1	14.90	0.000
	Sampling event*type	5	1.15	0.355
	Corrected total	45		
Dissolved vanadium	Sampling event	5	0.25	0.939
	Type	1	7.30	0.011
	Sampling event*type	5	1.13	0.362
	Corrected total	45		

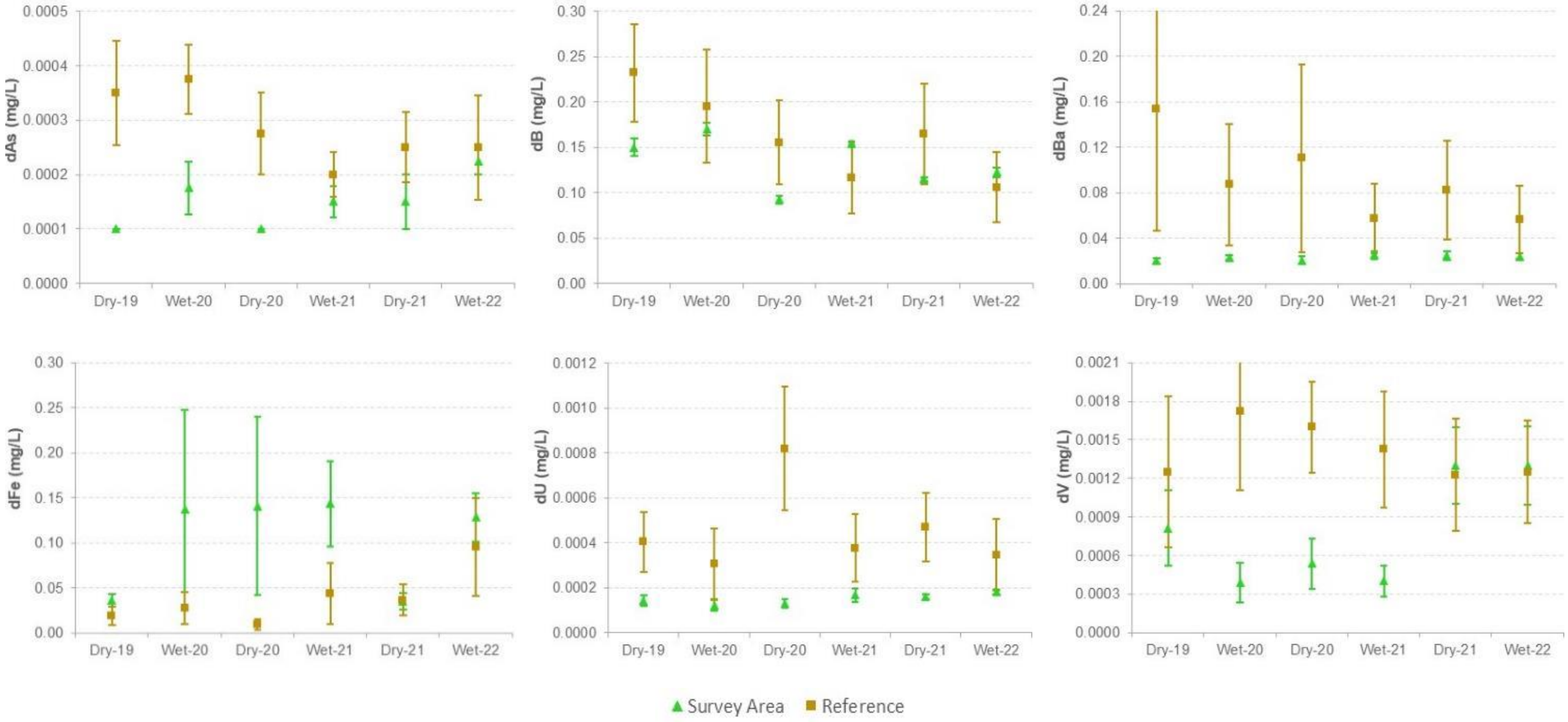


Figure 4.10: Comparison of selected dissolved metal analytes between sampling events (average ± standard error).

No dissolved metals recorded significantly different concentrations between sampling events (Table 4.4). However, there were some general trends over time, some of which were similar between reference and Survey Area sites, and some of which were unique to the Survey Area. For example, dB concentrations generally decreased over time at reference sites, with the exception of the Dry 2021, whilst in the Survey Area, concentrations increased in the wet and decreased in the dry (Figure 4.10). Concentrations of dBa and dU remained relatively consistent over time at Survey Area sites, but at reference sites a seasonal pattern of change was evident, with greater concentrations recorded in the dry season (Figure 4.10). Notably high average dU was recorded from reference sites in the Dry 2020, but this was largely due to a high concentration recorded from just one site (RW). Concentrations of dFe within reference sites remained relatively consistent over time, until the Wet 2022 when there was a notable increase (Figure 4.10). In contrast, dFe concentrations have been highly variable over time, with a large increase in the Wet 2020 (Figure 4.10). Variation amongst sites was greatest within reference sites (as evidenced by the large standard error bars) in comparison to the Survey Area. This is not surprising given all sites within the Survey Area are located within the same creekline, in close proximity, while reference sites are more broadly distributed, and may occur in different geological landscapes.

4.3 Macrophytes

4.3.1 Taxa composition and richness

Seven macrophytes were recorded from the Survey Area, comprising five emergent macrophytes and two submerged macrophytes (Table 4.5). An additional three emergent and three submerged macrophytes were recorded from reference sites (Table 4.5). 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 (i.e., *Acacia coriacea* var. *pendens, Pluchea rubelliflora*, *Stemodia grossa, Vigna lanceolata* var. *lanceolata*) (Table 4.5).

Emergent macrophytes recorded from the Survey Area included *Cyperus vaginatus, Eleocharis geniculata, Schoenoplectus subulatus, Fimbristylis sieberiana*, and *Typha domingensis* (Table 4.5). *Cyperus vaginatus* and *Typha domingensis* were present at all Survey Area sites, while *Eleocharis geniculata* and *Schoenoplectus subulatus* were present at YC3 and YC4, and *Fimbristylis sieberiana* at YC4 only (Table 4.5). *Machaerina juncea, Schoenus falcatus,* and *Imperata cylindrica* were present at reference site MUNJS (Table 4.5). *Imperata cylindrica* is also known to occur in Yandicoogina Creek (Biologic, 2020a), but not in direct association with any of the aquatic sampling sites, and therefore is not included in the taxa list here.

Submerged macrophytes recorded from the Survey Area comprised *Vallisneria nana* (from YC4) and *Chara `fibrosa`* (from YC3). Additional submerged macrophytes recorded from reference sites included *Chara `globularis`* and *Potamogeton tepperi*, both recorded from SS and MUNJS (Table 4.5).

Table 4.5: Flora recorded during the current study.

Class/Order	Family	Lowest taxon	Survey Area Sites				Reference Sites			
			YC1	YC2	YC3	YC4	WWS	BENS	SS	MUNJS
CHLOROPHYTA										
CHAROPHYCEAE										
Charales	Characeae	*Chara* spp.↓								
		Chara `*fibrosa*`			X					X
		Chara `*globularis*`							X	X
PLANTAE										
MAGNOLIOPSIDA										
Asterales	Asteraceae	*Pluchea rubelliflora*^^		X	X			X	X	
		?Rhodanthe margarethae								X
		**Tridax procumbens*				X				
	Campanulaceae	*Lobelia arnhemiaca*^					X		X	X
	Stylidiaceae	*Stylidium fluminense*^								X
		Stylidium weeliwolli^ (P3)					X	X		
Brassicales	Capparaceae	*Capparis spinosa* subsp. *nummularia*								X
	Cleomaceae	*Arivela viscosa*							X	
Fabales	Fabaceae	*Acacia colei* var. *colei*	X							
		Acacia coriacea subsp. *pendens*^		X	X			X	X	X
		Acacia ?hamersleyensis								X
		Acacia pyrifolia var. *pyrifolia*			X					
		Acacia tumida var. *pilbarensis*		X	X	X				
		Crotalaria medicaginea var. *neglecta*						X		
		Cullen leucanthum							X	
		Glycine canescens						X		
		Indigofera monophylla				X				
		Petalostylis labicheoides			X			X	X	
		Rhynchosia minima						X		
		**Vachellia farnesiana*				X				
		Vigna lanceolata var. *lanceolata*^							X	
		Vigna sp. Hamersley Clay (A.A. Mitchell PRP 113)						X		
Lamiales	Lamiaceae	*Clerodendrum floribundum* var. *angustifolium*	X							
	Plantaginaceae	*Stemodia grossa*			X				X	X
		Stemodia sp.					X	X		
Laurales	Lauraceae	*Cassytha filiformis*					X			
Malpighiales	Phyllanthaceae	*Nellica maderaspatensis*						X	X	
	Violaceae	*Afrohybanthus aurantiacus*				X				
Malvales	Malvaceae	*Corchorus lasiocarpus*			X					
		Gossypium robinsonii	X		X	X		X		
		Gossypium sturtianum var. *sturtianum*						X		
		Waltheria indica				X				

			Survey Area Sites				Reference Sites			
Class/Order	**Family**	**Lowest taxon**	**YC1**	**YC2**	**YC3**	**YC4**	**WWS**	**BENS**	**SS**	**MUNJS**
Myrtales	**Lythraceae**	*Ammannia multiflora*^							X	
	Myrtaceae	*Eucalyptus camaldulensis*^	X	X	X	X	X	X		X
		Melaleuca argentea^	X	X	X	X	X	X	X	X
Ranunculales	**Papaveraceae**	**Argemone ochroleuca* subsp. *ochroleuca*							X	
Rosales	**Moraceae**	*Ficus brachypoda*								X
		Ficus sp.	X							
Santalales	**Santalaceae**	*Santalum lanceolatum*								
Sapindales	**Sapindaceae**	*Atalaya hemiglauca*								X
		Dodonaea viscosa subsp. *mucronata*						X		
		Dodonaea pachyneura								X
Solanales	**Convolvulaceae**	*Ipomoea plebeia*						X		
		Ipomoea racemigera (P2)							X	
LILIOPSIDA										
Alismatales	**Hydrocharitaceae**	*Vallisneria annua*↓						X		X
		Vallisneria nana↓				X				
		Vallisneria sp.↓	R	R						
	Potamogetonaceae	*Potamogeton tepperi*↓							X	X
Poales	**Cyperaceae**	*Cyperus cunninghamii* subsp. *cunninghamii*								X
		Cyperus vaginatus^	X	X	X	X	X	X	X	X
		Eleocharis geniculata^			X	X			X	X
		Fimbristylis sieberiana				X				
		Machaerina juncea^								X
		Schoenoplectus subulatus^			X	X	X	X	X	
		Schoenus falcatus^								X
	Poaceae	**Cenchrus ciliaris*			X				X	
		Cymbopogon ambiguus	X	X	X					X
		Eriachne mucronata								X
		Eulalia aurea	X	X						
		Imperata cylindrica^								X
		Sorghum plumosum		X		X				
		Themeda triandra	X							
	Typhaceae	*Typha domingensis*^	X	X	X	X	X		X	X
		Taxa richness	**13**	**12**	**18**	**17**	**10**	**20**	**21**	**26**

* Introduced species. (P2) Priority Flora Species. ^ Associated with creeks and/or sub-perennial surface water. ^^ Seasonal wet areas, claypans and rivers. ↓ submerged macrophyte. R from rehydrates

4.3.2 Conservation significant flora

Three species of conservation significant flora were recorded in the current study, one of which was recorded within the Survey Area. *Fimbristylis sieberiana* is a P3 species (DBCA, 2022), and was recorded from YC4 (Plate 4.1). It is described as a shortly rhizomatous tufted perennial sedge which flowers between May and June. It occurs along drainage lines (WAH, 1998-). As part of the Yandicoogina Gorge flora and vegetation surveys, Biologic (2020a) noted that *F. sieberiana* individuals were generally recorded adjacent to perennially wet portions of the creek that supported a high diversity and cover of sedge and hydrophytic/ mesophytic flora species.

Plate 4.1: The priority sedge, *Fimbristylis sieberiana* (P3), recorded from YC4 (Biologic ©).

The remaining priority species were both annual herbs and included *Ipomoea racemigera* and *Stylidium weeliwolli*. Both are listed as DBCA Priority Species, P2 and P3, respectively (DBCA, 2022). The former was recorded from SS and the latter from WWS. *Stylidium weeliwolli* is considered to be an indicator of soil moisture or semi-permanent to permanent surface water availability (Rio Tinto, 2020).

4.3.3 Introduced flora

Three introduced species, buffel grass (**Cenchrus ciliaris*), mimosa bush (**Vachellia farnesiana*), and the herb coatbuttons (**Tridax procumbens*), were recorded from the Survey Area. One additional introduced species, Mexican poppy (**Argemone ochroleuca* subsp. o*chroleuca*) was collected from reference site SS. None of these species are listed as Weeds of National Significance (WoNS). However, **Cenchrus ciliaris*, **Vachellia farnesiana,* and **Argemone ochroleuca* subsp. o*chroleuca,* are all considered to be highly invasive and able to establish and spread rapidly (DBCA, 2013).

4.3.4 Flora comparison with previous studies

In comparison to the PBS sites sampled previously, macrophyte richness from all Yandicoogina Creek sites was greater than or comparable to Homestead Creek, but lower than Kalgan Pool and WWS-PBS (Figure 4.11). There was a notable reduction in wetland flora richness at WWS between the PBS and current survey. However, this area is currently impacted by dewatering and discharge operations from HD1, as well as more recently being affected by the introduction of the invasive redclaw (*Cherax quadricarinatus*), which feed on submerged macrophytes, as well as detritus and zooplankton (DPIRD, 2020; Haubrock *et al.*, 2021; Marufu *et al.*, 2018). It should also be noted that the Weeli Wolli Spring site location differed slightly between surveys, with the PBS site being located approximately 660 m downstream of the WWS site sampled during the current survey.

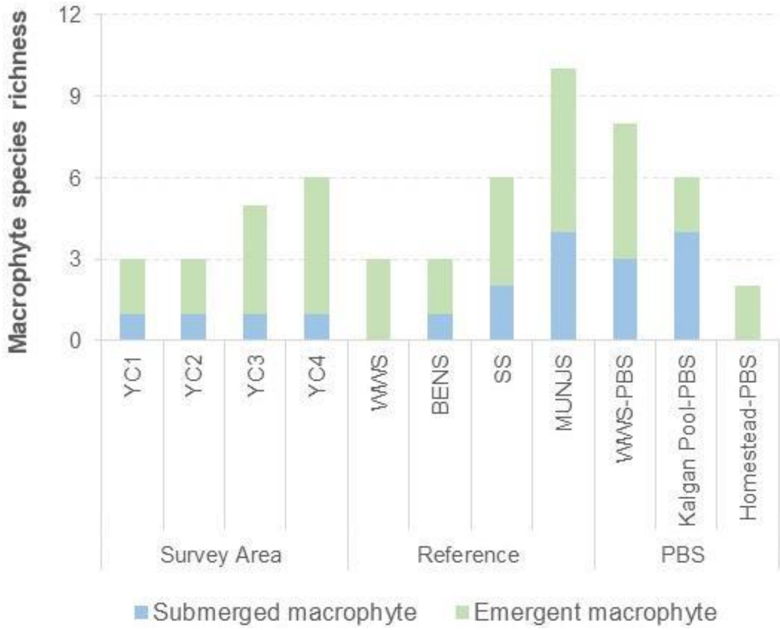


Figure 4.11: Macrophyte (emergent and submerged) richness recorded in the current study (dry and wet seasons combined), in comparison to the PBS from Homestead Creek headwaters (January 2006), Kalgan Pool (September 2004 and April 2005) and Weeli Wolli Spring (September 2003 and May 2005; Mike Lyons, unpub. data).

4.4 Zooplankton

4.4.1 Taxa composition and richness

Zooplankton samples were successfully collected from all sites except YC1 and YC2 in the Dry 2021, which were both dry at the time of sampling. A total of 55 zooplankton taxa[4] were recorded from the Survey Area, comprising:

- Protista (protists; five taxa),
- Rotifera (rotifers; 21 taxa),
- Maxillopoda (Copepoda; nine taxa),
- Cladocera (water fleas; four taxa), and

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

- Ostracoda (seed shrimp; 16 taxa; see Appendix E for full taxa list).

In the Dry 2021, zooplankton richness ranged from five taxa (at WWS) to 27 (at SS), and in the Wet 2022 ranged from eight taxa (at YC1) to 21 (at YC3; Figure 4.12). Generally, richness recorded from the Survey Area was comparable to reference sites, although richness was low at YC3 in the Dry 2021 and YC1 in the Wet 2022. At sites within the Survey Area that were successfully sampled in both seasons, high seasonal variability was evident, with site YC3 recording low taxa richness in the dry (nine taxa), but the highest richness of all sites sampled in the wet (including references). Meanwhile, richness at YC4 was relatively high in the dry season (24 taxa) but decreased in the wet (12 taxa). Reference sites generally recorded lower richness in the Wet 2022 compared to the Dry 2021, except WWS, which recorded higher richness in the wet season (Figure 4.12). Seasonal and spatial variability in zooplankton is well known throughout the world.

Zooplankton composition was generally dominated by Rotifera and Maxillopoda (Figure 4.12). Richness of rotifers at YC3 in the wet was notably high (ten taxa). The diversity of Cladocera and Ostracoda was generally low at all sites, with some sites recording no individuals from these groups. In the Wet 2022, no Cladocera were recorded at any site (Figure 4.12).

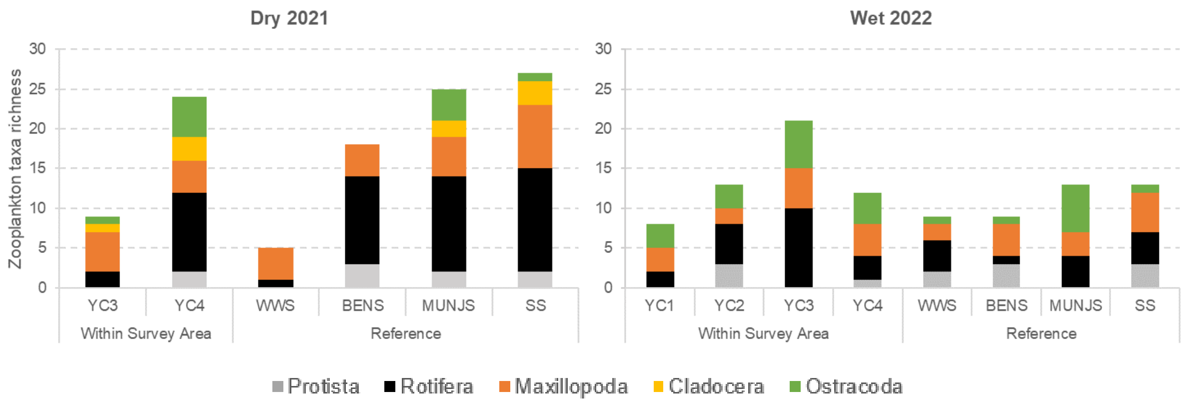


Figure 4.12: Zooplankton taxa richness recorded from each site in the Dry 2021 (left) and Wet 2022 (right).

Ostracod molecular results

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

Molecular analysis indicated that none of the ostracods recorded from surface waters within the Survey Area have restricted ranges, are unique to the Survey Area, or would be considered SREs (Biologic, 2022c). *Cypridopsis* `sp. Biologic-OSTR011` (recorded from YC4 in the Dry 21 and YC3 in the Wet 22), Cyprididae `sp. Biologic-OSTR021` (YC1 and YC2 in the Wet 22), and *Cypretta* `sp. Biologic-OSTR029` (YC4 in the Dry 21) are all known from systems outside the Survey Area, with the furthest record being 310 km to the west. A fourth OTU, *Ilyodromus* `sp. Biologic-OSTR014` was recorded from reference site MUNJS in the wet season. This taxon is also widespread and has a linear range of over 300 km (Biologic, 2022c).

4.4.2 Conservation significant zooplankton taxa

Most zooplankton taxa recorded from the Survey Area are widely distributed across northern Australia or the world (cosmopolitan species). However, one ostracod species, *Vestalenula marmonieri*, recorded from YC4 in the Dry 2021 is a Pilbara endemic. This species is known to occur in surface waters and hyporheic zones across the Pilbara.

In addition, molecular analysis of ostracod specimens collected from Survey Area site YC3 in the Wet 2022 formed a unique OTU, *Meridiescandona* `sp. Biologic-OSTR074`. These specimens were more than 9% divergent from other sequences included in the analysis (Biologic, 2022c). This study denotes the first record of this OTU, with all current known specimens only recorded from within the Survey Area. Biologic believe this OTU may represent the described species, *Meridiescandona marillanae* based on morphology and distribution, although this cannot be stated with certainty currently. *M. marillanae* is known from shallow groundwaters of the nearby Marillana Creek.

<u>Other species of interest</u>

Other species of interest were recorded from reference sites only and were not found to be present in the Survey Area (i.e., the ostracods *Cypretta* `sp. Biologic-OSTR076`, Cyprididae `sp. Biologic-OSTR049` and Cyprididae `sp. Biologic-OSTR075`. Both *Cypretta* `sp. Biologic-OSTR076` and Cyprididae `sp. Biologic-OSTR075` were recorded from surface waters of MUNJS in the wet season, denoting the first records of these OTUs. Cyprididae `sp. Biologic-OSTR049` was recorded from reference site BENS in the Wet 2022. This denotes the first record of this OTU, which is presently only known from BENS, as well as one site downstream of the discharge on Weeli Wolli Creek (Biologic, 2023).

4.4.3 Zooplankton comparison with previous surveys

Average zooplankton richness has generally been greater in the dry season in comparison to the wet, in both the Survey Area and reference sites (Figure 4.13). The only exception to this was in the Survey Area in the Wet-20, when average zooplankton was marginally greater than the preceding dry season. Overall, there was no significant difference in zooplankton taxa richness between sampling events (Two-way ANOVA; df = 5, p = 0.230), nor between site type (df = 1, p = 0.377).

Figure 4.13: Average zooplankton taxa richness (± standard error) in the Survey Area and Reference sites recorded during each sampling event since the Dry 2019.

4.4.4 Zooplankton comparison with other studies

Zooplankton richness from the Survey Area was compared with previous studies detailed in section 3.4.3 above, for those studies which sampled more than one replicate site within a creek system. Weeli Wolli Creek sites were split into Weeli Wolli Spring (recorded from the historic spring area) and Weeli Wolli Creek (upper Weeli Wolli Creek river pools), to reflect differences in water permanence and hydrology between these two areas; factors which would influence zooplankton assemblages. Two sites could not be included in this analysis due to a lack of replication (MACREF2 and BENS). As detailed in the methods, the dataset was amalgamated, and taxonomy aligned, prior to analysis to ensure any differences in taxonomic knowledge between samplers and years was accounted for.

The Survey Area generally recorded average zooplankton richness comparable to nearby creek systems, including Marillana Creek, Weeli Wolli Creek (and Spring), Munjina Creek and the Davis River (Figure 4.14). However, within-season variation, as well as variation between seasons, was much lower in the Survey Area in comparison to most other creeklines included in the analysis, especially Munjina Spring and the Davis River. Overall, there was no significant difference in average zooplankton between season (Two-way ANOVA; df = 1, F = 0.25, p = 0.616), nor between creeks (df = 6, F = 0.98, p = 0.446).

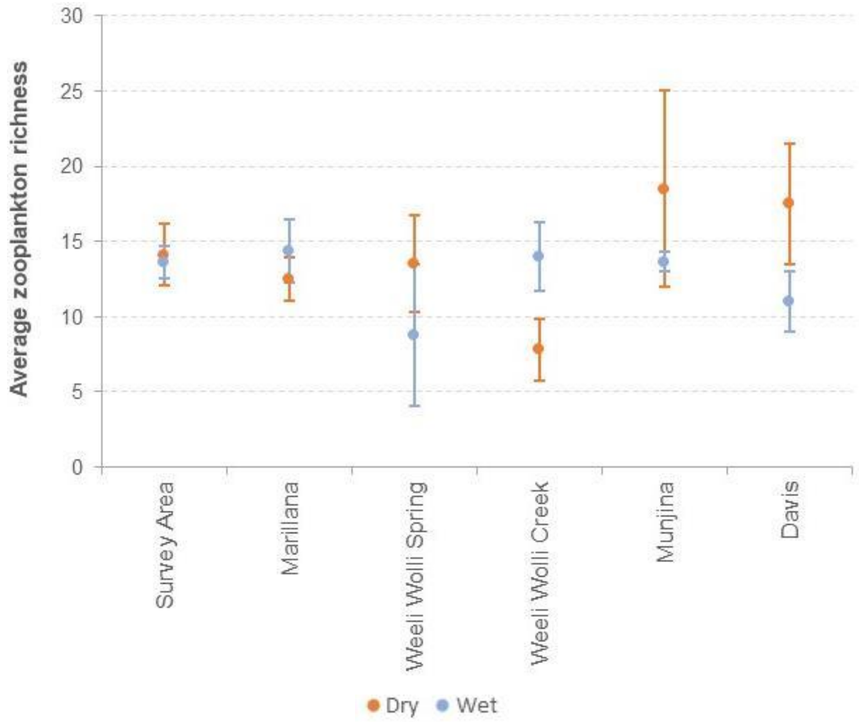


Figure 4.14: Average zooplankton taxa richness (± se) recorded from the Survey Area, in comparison to other studies and nearby creek systems, in both seasons.

4.5 Hyporheos Fauna

4.5.1 Taxa composition and richness

Hyporheic samples were successfully collected from all sites except YC1 and YC2 in the Dry 2021, which were both dry. As mentioned in section 3.3, an additional five hyporheic samples (YC5H to YC9H) were collected in the Wet 2022. A total of 98 taxa were recorded from hyporheic zones along Yandicoogina Creek (see Appendix F for full taxa list). The taxa included specimens from 21 higher taxonomic orders including:

- Rotifera (one taxon)
- Cnidaria (freshwater polyp; one taxon)
- Nematoda (roundworm; one taxon)
- Platyhelminthes (flatworm; one taxon)
- Mollusca (freshwater snail; one taxon)
- Oligochaeta (aquatic segmented worm; ten taxa)
- Acarina (water mites; nine taxa)
- Ostracoda (seed shrimp; seven taxa)
- Copepoda (eight taxa)
- Amphipoda (side swimmers; three taxa)
- Isopoda (one taxon)
- Syncarida (two taxa)

- Collembola (springtails; three taxa)
- Coleoptera (beetles; 16 taxa)
- Diptera (two-winged flies; 27 taxa)
- Thysanoptera (thrips; one taxon)
- Odonata (dragonflies and damselflies; two taxa)
- Diplura (diplurans; one taxon)
- Pauropoda (pauropods; one taxon)
- Pseudoscorpiones (false scorpions; one taxon)
- Symphyla (pseudocentipedes; one taxon).

More than half of the taxa recorded from the Survey Area were stygoxene (60%) and do not have specialised adaptations for groundwater habitats (Figure 4.15). Troglofauna comprised 3% of the taxa collected, and though terrestrial, were considered of interest and reported here due to the lack of information on troglofauna within the Survey Area more generally (see section 4.5.3 below for further information). Hyporheos fauna, comprising stygobites, permanent hyporheos stygophiles, occasional hyporheos stygophiles and possible hyporheic taxa, made up the remaining taxa collected (i.e., 37%). A total of 19% of the taxa recorded from hyporheic zones of the Survey Area are directly dependant on groundwater for their persistence (stygobites and permanent hyporheos stygophiles).

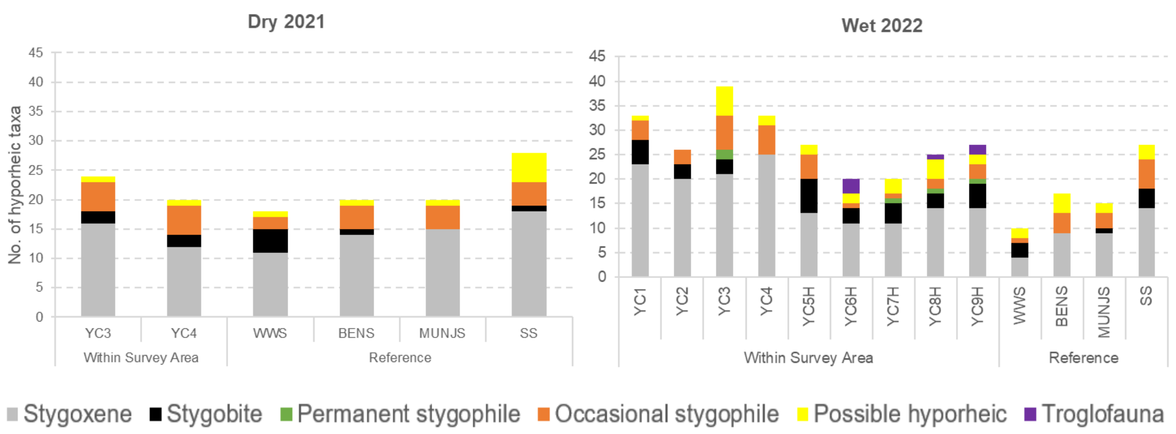


Figure 4.15: Hyporheic taxa richness recorded from each site in the Dry 2021 (left) and Wet 2022 (right).

Hyporheos fauna recorded from the Survey Area included:

Occasional hyporheos stygophiles

- ostracod *Candonopsis* cf. *tenuis* (*Candonopsis* `sp. Biologic-OSTR009`);
- copepod *Microcyclops varicans*;
- oligochaetes *Dero nivea*, *Nais variabilis*, *Pristina aequiseta* and *Pristina longiseta*; and
- beetles Hydraenidae sp. (L), *Hydraena* sp., *Limbodessus occidentalis* and Scirtidae sp. (L)

Permanent stygophiles

- water mites *Guineaxonopsis* sp., *Rutacarus* sp. and *Wandesia* sp.

Stygobites

- ostracods *Gomphodella* sp., *Gomphodella* `sp. Biologic-OSTR077`, *Meridiescandona* `sp. Biologic-OSTR074`, *Vestalenula marmonieri* and *Vestalenula matildae*;
- copepods *Diacyclops* nr. *humphreysi*, *Dussartcyclops* sp., *Elaphoidella* sp., *Parastenocaris* `sp. Biologic-HARP022`[5], and *Pescecyclops* sp.;
- syncarids *Atopobathynella* `sp. Biologic-PBAT042` and Bathynellidae `sp. Biologic-BATH019`;
- amphipods Paramelitidae sp., *Chydaekata* sp. E and Paramelitidae `sp. Biologic-AMPH023`; and
- isopod *Pygolabis* `sp. Biologic-ISOP035`.

Possible hyporheic taxa recorded included higher-level identifications for which taxa may have belonged to a stygal or hyporheos species, and the Chironomidae (non-biting midge larvae) ?*Australopelopia* sp. This undescribed species is commonly found in hyporheic zones in the Pilbara, and has a reduced eye typical of fauna that are adapted to interstitial environments.

4.5.2 Conservation significant hyporheos taxa

While most of the taxa recorded within the Survey Area are generally common and ubiquitous across the Pilbara, a number are of conservation significance (14 taxa) and are either locally restricted or rarely collected. Further information regarding these taxa is provided below.

Acari

The water mites *Guineaxonopsis* `sp. Biologic-ACAR011` and *Guineaxonopsis* `sp. Biologic-ACAR013` was recorded from the hyporheos of YC7H in the wet season. The *Guineaxonopsis* genus is not commonly recorded and is poorly understood, with only one species currently described from Tasmania. Two previous morphotypes are known from the Pilbara; *Guineaxonopsis* sp. S1 and *Guineaxonopsis* sp. P1. The former was recorded from Cangan Pool within the Yule catchment (approximately 136 km from the Survey Area) during the PBS and several bores during the Pilbara Stygofauna Survey (PSS), including bores from the Robe and Fortescue River basins, Port Hedland coast and Great Sandy Desert. *Guineaxonopsis* sp. P1 was recorded from Minigarra Creek pools at Woodie Woodie (approximately 258 km from the Survey Area) during the PBS, but was not recorded during the PSS. One additional taxa of *Guineaxonopsis* were recently identified through molecular analysis; *Guineaxonopsis* `sp. Biologic-ACAR012` (from Western Creek) (Biologic, 2022e). *Guineaxonopsis* specimens recorded from the Survey Area have been recorded elsewhere. For instance, *Guineaxonopsis* `sp. Biologic-ACAR011` has been recorded from the hyporheic zone of the Upper

[5] This identification was made following morphological and molecular analysis, and given it matched an already known OTU with a linear distribution of over 300 km it has not been discussed further here or in section 4.5.2. It does appear to have a disjunct distribution based on current records.

Fortescue River, Western Creek (Biologic, 2022e) and Weeli Wolli Spring (Biologic, 2022d), while *Guineaxonopsis* `sp. Biologic-ACAR013` has been recorded by the authors from Marillana Creek (Biologic, 2022a).

Rutacarus sp. was recorded from the hyporheos of Survey Area site YC3 in the Wet 2022. This genus is poorly known from Western Australia, with only two described species from river interstices in eastern Australia. *Rutacarus* sp. was previously recorded during the PBS from a single sampling occasion at Bamboo Spring, approximately 91 km north of the Survey Area. It is not possible to determine whether the Bamboo Spring *Rutacarus* is the same as one of the species recorded from the Survey Area. However, recent molecular analyses undertaken by the authors found three distinct OTUs formed from *Rutacarus* specimens, from the nearby Marillana Creek and BENS on Weeli Wolli Creek (*Rutacarus* `sp. Biologic-ACAR007`), and Weeli Wolli Creek (*Rutacarus* `sp. Biologic-ACAR005` and *Rutacarus* `sp. Biologic-ACAR006`).

The water mite *Wandesia* `sp. Biologic-ACAR009` recorded from the hyporheos of YC3 within the Survey Area is a permanent stygophile. The taxonomy of this 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 species, *Wandesia* sp. P1 (nr *glareosa*), was recorded during the PBS from river pools and springs (Pinder *et al.*, 2010). It is not known whether *Wandesia* sp. recorded from the current study is the same as the known morphotype from the PBS, as specimens from the PBS are unavailable for comparison. Specimens of this OTU have previously been recorded from Marillana Creek (Biologic, 2022a), Kalamina Gorge (Karijini National Park), and Weeli Wolli Creek (Biologic, 2022d).

Ostracoda

Meridiescandona `sp. Biologic-OSTR074` was collected from the hyporheos of YC3 and YC5H within the Survey Area, during the Wet 2022. This is a stygal ostracod and was also recorded from surface waters of YC3. The OTU is currently only known from within the Survey Area, though it may represent the known, described species *Meridiescandona marillanae*. Further morphological and molecular work is required to confirm this.

Specimens collected from the hyporheos of YC7H formed a new OTU, *Gomphodella* `sp. Biologic-OSTR077`. This stygal ostracod was more than 12% divergent from other sequences in the analysis (Biologic, 2022c). The current study denotes the first record of this OTU and based on current information, is only known from within the Survey Area, though this may change with additional work elsewhere.

Amphipoda

Molecular analyses of specimens found two stygal amphipods *Chydaekata* `sp. E` and Paramelitidae `sp. Biologic-AMPH023`, which have previously been recorded from the Survey Area (Biologic, 2020b, 2022b). *Chydaekata* `sp. E` is an undescribed morphotype that belongs to a previously published OTU (Finston *et al.*, 2007). While previously only known from Marillana and Weeli Wolli Creeks (Finston *et al.*, 2007), additional records of *Chydaekata* `sp. E` indicates this species is restricted to Marillana, Weeli Wolli and Yandicoogina Creeks (Figure 4.16). In the current study, *Chydaekata* `sp. E` was recorded from the hyporheos of YC3 in both seasons in the Survey Area, and reference sites BENS and WWS in the Dry 2021, both of which are located on Weeli Wolli Creek.

Paramelitidae `sp. Biologic-AMPH023` is known from Marillana, Weeli Wolli and Yandicoogina Creeks (Biologic, 2020b, 2022b). The current study recorded Paramelitidae `sp. Biologic-AMPH023` from the hyporheos of Survey Area site YC3 in the Wet 2022 (Figure 4.16).

Isopoda

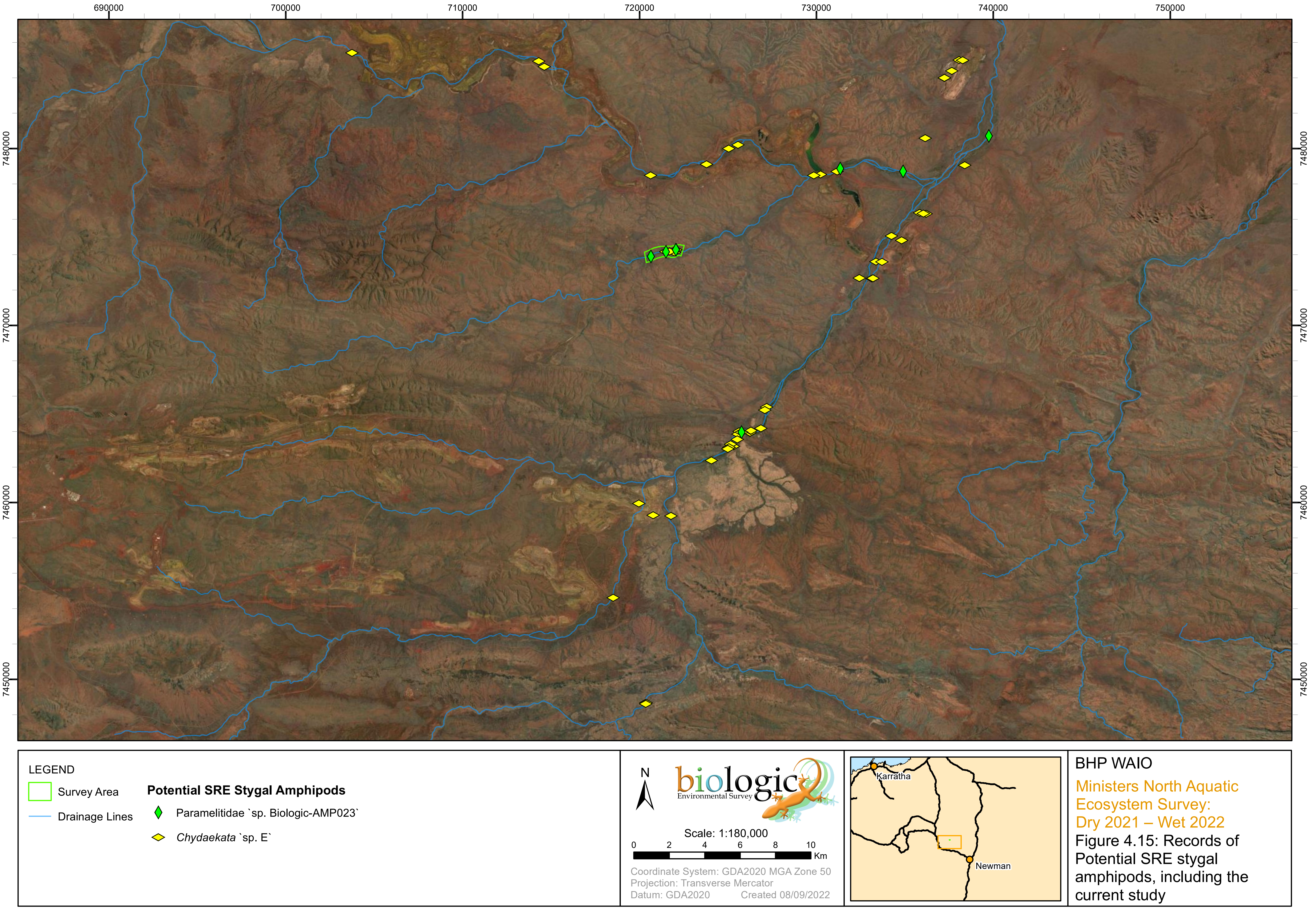
Isopod specimens collected from the Survey Area were successfully sequenced and matched a previously recorded OTU (Biologic, 2022b), *Pygolabis* `sp. Biologic-ISOP035`. In the current survey, *Pygolabis* `sp. Biologic-ISOP035` was recorded from the hyporheos of YC5H, YC8H and YC9H, all located within the Survey Area (Figure 4.17). Current information indicates *Pygolabis* `sp. Biologic-ISOP035` is restricted to the Survey Area. It is more than 16% divergent from the known, described species *Pygolabis weeliwolli* which occurs nearby (Figure 4.17).

Syncarida

Molecular analyses of syncarid specimens from the Survey Area formed two new OTUs: *Atopobathynella* `sp. Biologic-PBAT042` and Bathynellidae `sp. Biologic-BATH019`. These OTUs were more than 12% divergent from all other sequences in the analysis, including an OTU previously recorded from Yandicoogina Creek, Bathynellidae `sp. Biologic-BATH008` (Biologic, 2020b, 2022c). Both *Atopobathynella* `sp. Biologic-PBAT042` and Bathynellidae `sp. Biologic-BATH019` were recorded from the hyporheos of YC1 during the Wet 2022 (Figure 4.18).

Other species of interest

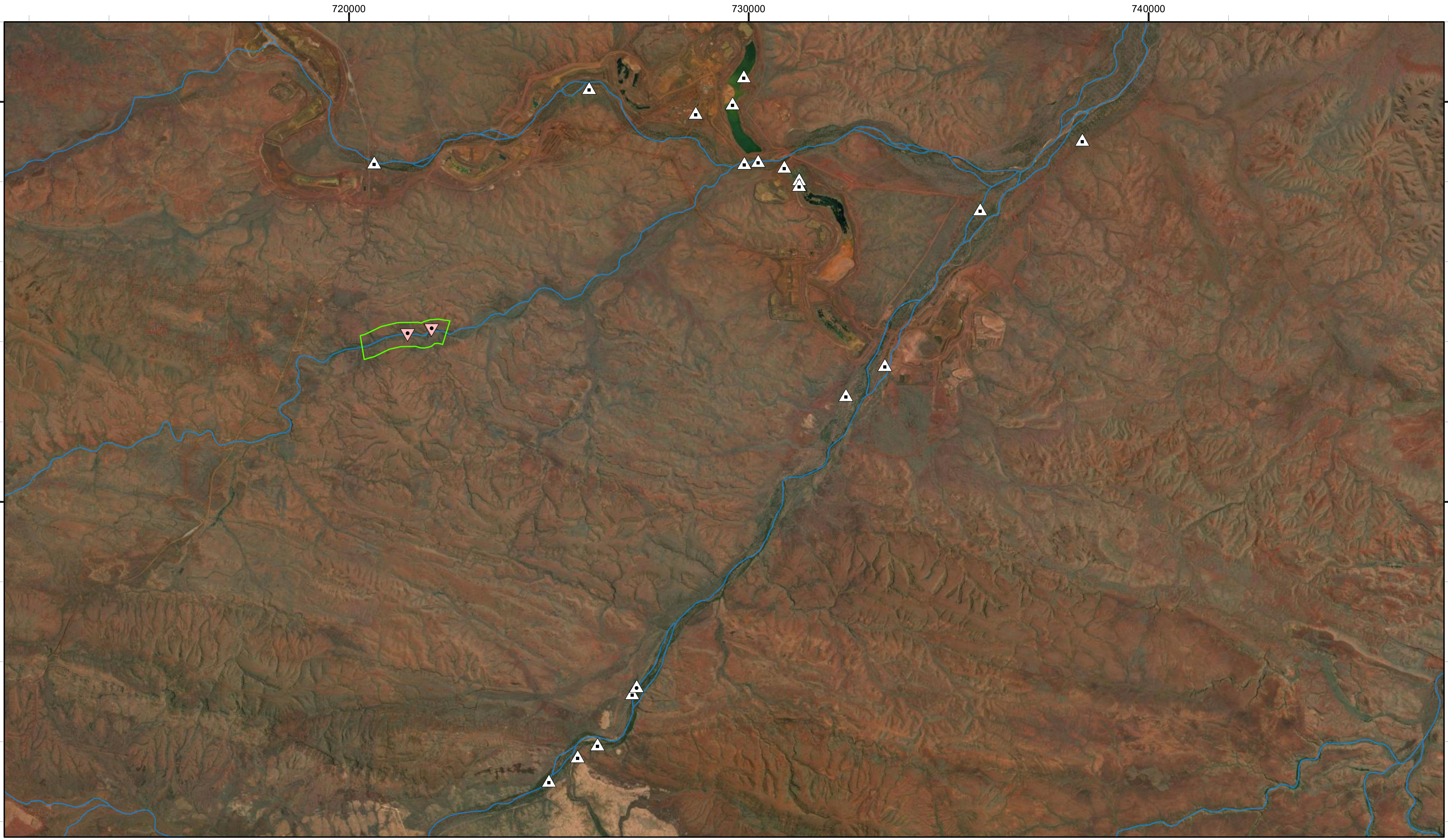
Other species of interest were recorded from reference sites only and were not found to be present in the Survey Area (i.e., two amphipods Paramelitidae `sp. Biologic-AMPH024` and Paramelitidae `sp. Biologic-AMPH049`, one syncarid *Atopobathynella* `sp. Biologic-PBAT043`, one isopod *Pygolabis* `sp. Biologic-ISOP079`, and three ostracods *Gomphodella* `sp. Biologic-OSTR078`, *Notacandona boultoni* and *Meridiescandona facies*). Paramelitidae `sp. Biologic-AMPH024` is a known OTU recorded from WWS in both seasons, and appears to be restricted to Weeli Wolli Creek, while Paramelitidae `sp. Biologic-AMPH049` was recorded from the hyporheos of reference site SS in both seasons. *Atopobathynella* `sp. Biologic-PBAT043` and *Pygolabis* `sp. Biologic-ISOP079` were both recorded from SS in the Wet 2022, and represents the first record of these OTUs. Ostracod specimens from WWS in the Wet 2022 formed a new OTU, *Gomphodella* `sp. Biologic-OSTR078`. The ostracods *Notacandona boultoni* (WWS, both seasons) and *Meridiescandona facies* (BENS, Dry 2021) were also recorded.



BHP WAIO

Ministers North Aquatic Ecosystem Survey: Dry 2021 – Wet 2022

Figure 4.15: Records of Potential SRE stygal amphipods, including the current study



LEGEND

Survey Area

Drainage Lines

Potential SRE Stygal Isopods

Pygolabis `sp. Biologic-ISOP035`

Pygolabis weeliwolli

N

biologic Environmental Survey

Scale: 1:90,000

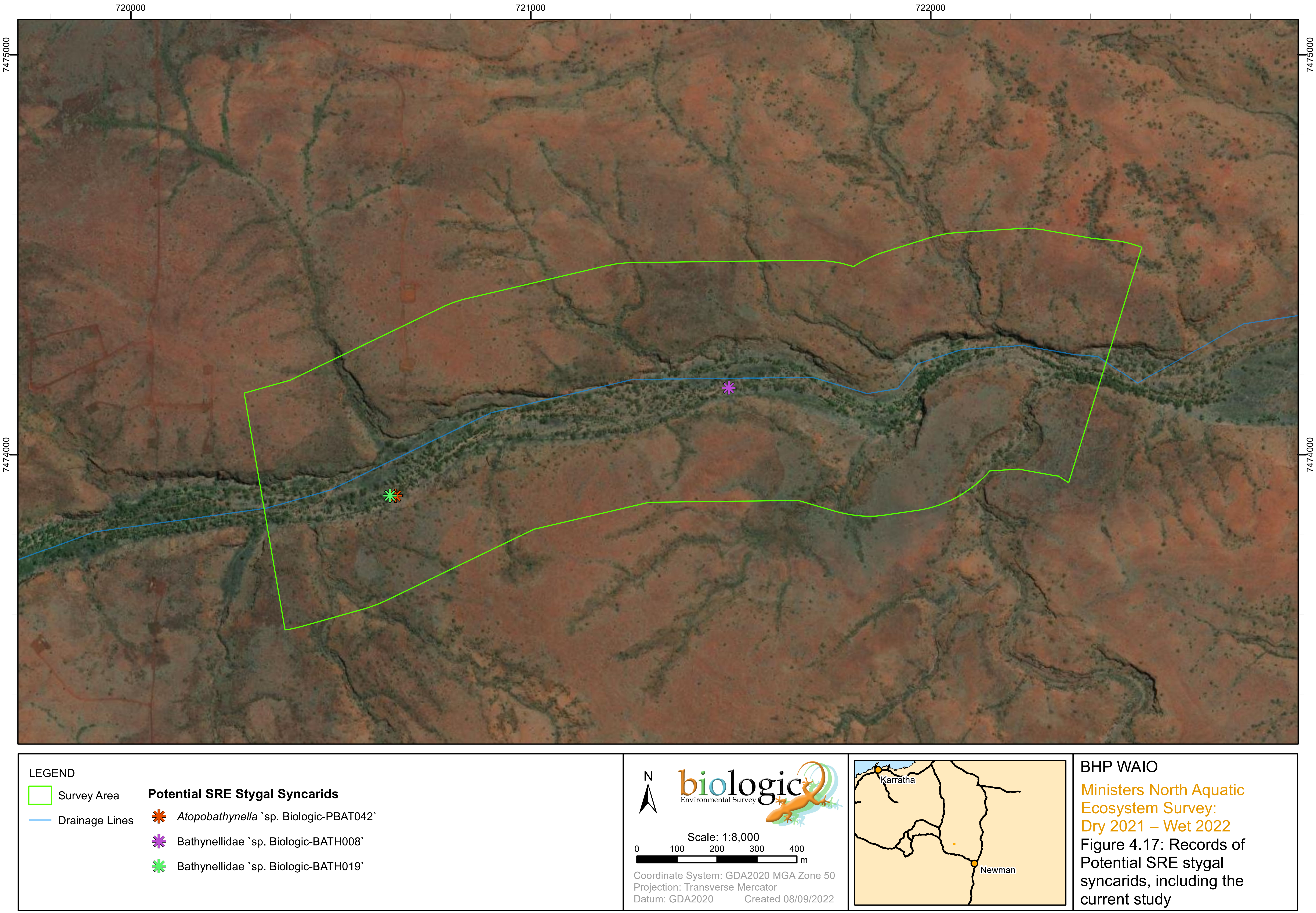
0 1 2 3 4 5 Km

Coordinate System: GDA2020 MGA Zone 50
Projection: Transverse Mercator
Datum: GDA2020 Created 08/09/2022

BHP WAIO

Ministers North Aquatic Ecosystem Survey: Dry 2021 – Wet 2022

Figure 4.16: Records of Potential SRE stygal isopods, including the current study



BHP WAIO

Ministers North Aquatic Ecosystem Survey: Dry 2021 – Wet 2022

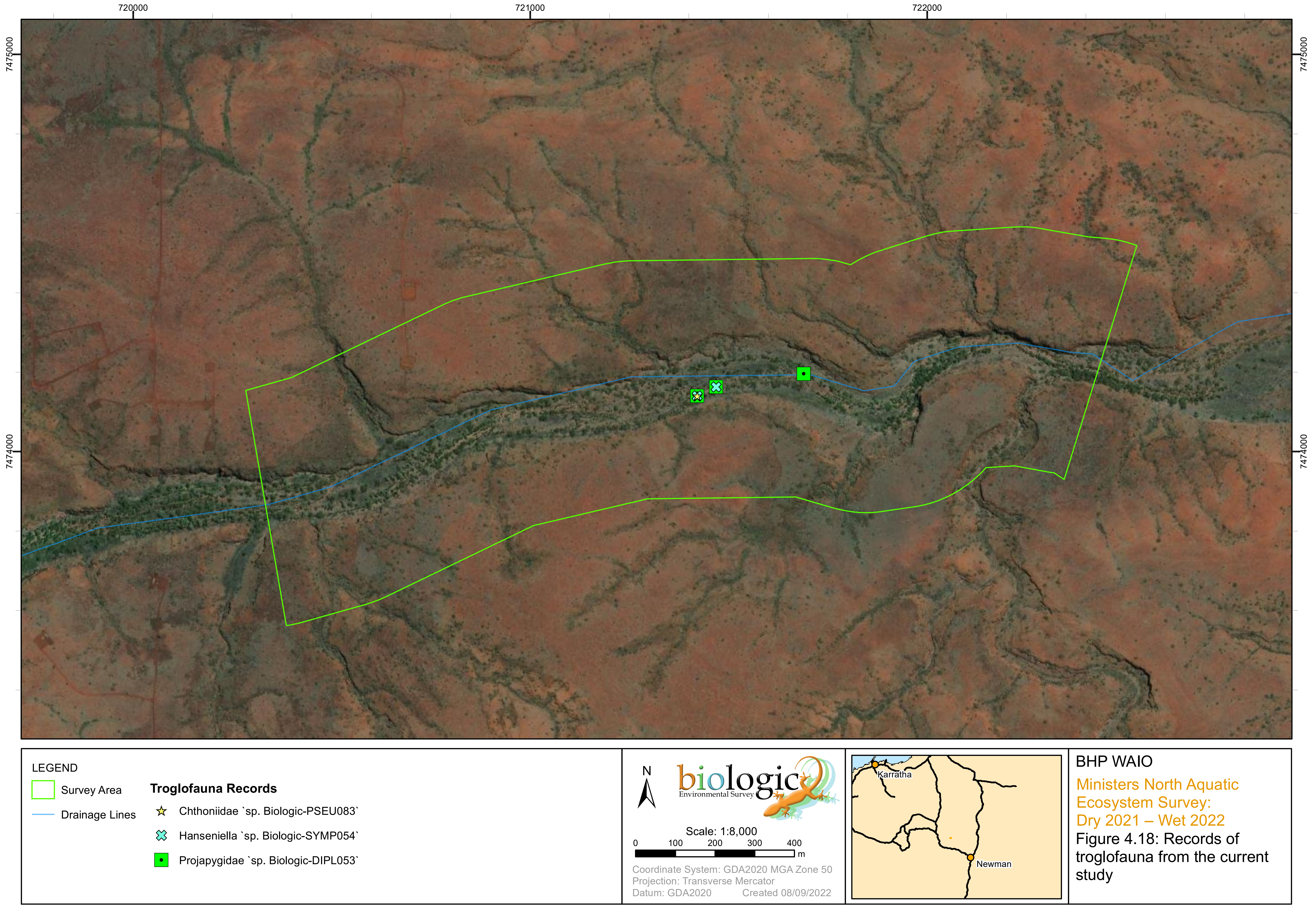
Figure 4.17: Records of Potential SRE stygal syncarids, including the current study

4.5.3 Troglofauna

Three taxa which represent troglofauna were collected from hyporheic samples within Yandicoogina Creek in the wet season. These taxa were morphologically identified as belonging to the groups Pseudoscorpiones, Diplura and Symphyla. Given that limited troglofauna surveys have been undertaken within the Survey Area, representative specimens of these groups were submitted for molecular analysis to provide further clarity on their identity and provide information on the species present in this habitat within the creek. The pseudoscorpion was placed within a new OTU, Chthoniidae `sp. Biologic-PSEU083`, which was found to be 17% divergent from all other available sequences in the genetic database (Biologic, 2022c). Chthoniidae `sp. Biologic-PSEU083` was recorded from YC6H in the wet season (Figure 4.19). It is possible this species represents a Potential SRE, however, this cannot be stated with certainty and additional survey work may increase its currently known distribution.

Dipluran specimens collected from YC6H, YC8H and YC9H all formed a single OTU, Projapygidae `sp. Biologic-DIPL053`. This OTU was found to be 14% divergent from all other sequences used in the molecular analysis (Biologic, 2022c). Based on current information, Projapygidae `sp. Biologic-DIPL053` is known only from within the Survey Area, though this may change with additional surveys elsewhere (Figure 4.19). Specimens of Projapygidae may represent soil fauna, or alternatively, they may represent a potentially restricted species of troglofauna, however, given the limited sampling of soil fauna in the Pilbara this is difficult to determine currently.

Symphyla specimens collected from the Survey Area formed a single OTU, *Hanseniella* `sp. Biologic-SYMP054`. This OTU was recorded from YC6H and YC9H (Figure 4.19). This survey also represents the first record of this taxon. Given all taxa within the *Hanseniella* genus are considered troglobites and have small ranges less than 50 km (Bennelongia, 2013, 2015, 2016), it is considered likely that *Hanseniella* `sp. Biologic-SYMP054` represents a Potential SRE (Data Deficient). Many *Hanseniella* species have known linear ranges of < 5 km (Bennelongia, 2016).



BHP WAIO

Ministers North Aquatic Ecosystem Survey: Dry 2021 – Wet 2022

Figure 4.18: Records of troglofauna from the current study

4.5.4 Hyporheos fauna comparison with previous surveys

Hyporheos fauna taxa richness at reference sites was generally higher in the dry season and lower in the wet (Figure 4.20). This seasonal pattern was not evident in the Survey Area, with hyporheos fauna taxa richness remaining relatively consistent between the Dry 2019 and Wet 2020, followed by an increase in the Dry 2020. Hyporheos fauna richness within the Survey Area then decreased between the Dry 2020 to the Dry 2021, followed by an increase in Wet 2022 (Figure 4.20). Within-season variability was relatively high in both the Survey Area and at reference sites.

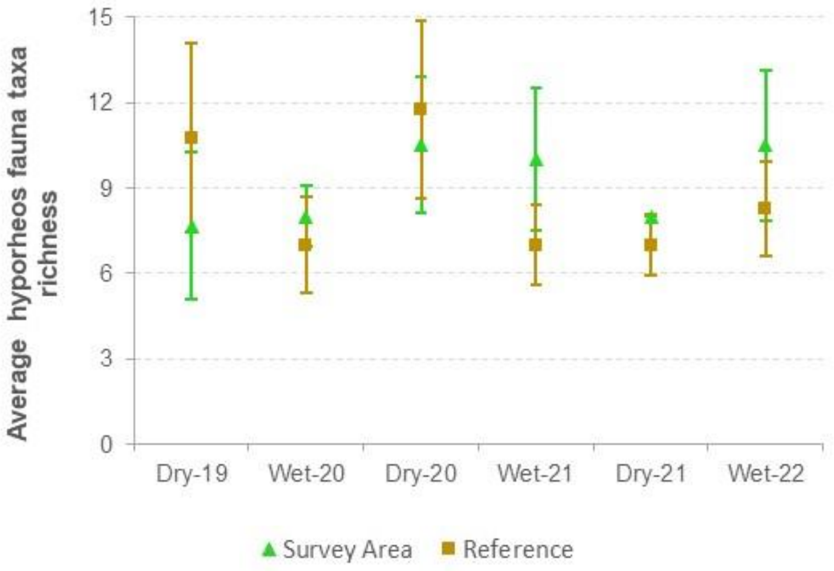


Figure 4.20: Average hyporheos fauna taxa richness (± standard error) in the Survey Area and Reference sites recorded during each sampling event since the dry 2019.

The average number of occasional hyporheos taxa recorded from the Survey Area generally showed a seasonal pattern of change over time in the first three sampling events, with greater richness in the wet season and lower in the dry (Figure 4.21). However, since the Dry 2020, richness of occasional hyporheos taxa has shown a relatively steady increase over time within the Survey Area. This increase has not been apparent at reference sites, where there was a notable decline in average occasional hyporheos fauna richness since the Dry 2020. The increase in richness within the Survey Area over the last 18 months or so may be due to lowering surface water levels (see section 4.1.1), with an increased number of surface taxa taking refuge in the hyporheic zone. However, if groundwater levels decline further, the extent and availability of this habitat will also reduce.

In terms of stygobites, average richness recorded from Survey Area hyporheic zone increased slightly between the Dry 2019 to the Dry 2020, followed by a decrease in the Wet 2021. Since this time, stygobitic taxa richness has been steadily increasing (Figure 4.21). This pattern of change over time was not apparent at reference sites, where a generally seasonal trend has been recorded (generally higher stygobite richness in the dry season). There was a decline in stygobite richness between the Dry 2020 and Wet 2021 at both Survey Area and reference sites, although the decrease within the Survey

Area was more marked. High within-sampling event variation was recorded in both Survey Area sites and within reference sites (as evidenced by the large standard error bars) (Figure 4.21).

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

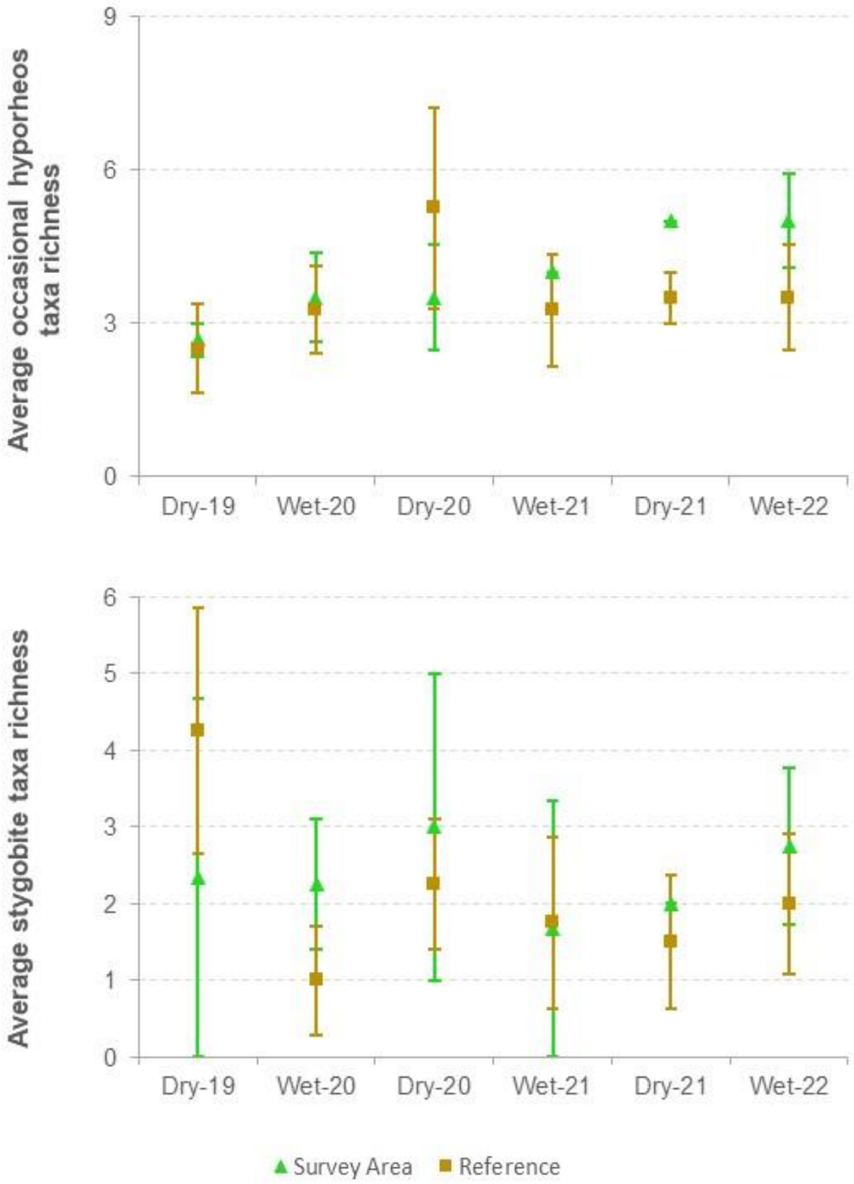


Figure 4.21: Average occasional hyporheos fauna taxa richness (± standard error) (top) and stygobite taxa richness (bottom) (± standard error) in the Survey Area and Reference sites recorded during each sampling event since the Dry 2019.

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

Analyte	Source	df	F	*p*-value
Overall hyporheos fauna taxa richness	Sampling event	5	0.739	0.600
	Type	1	0.133	0.718
	Sampling event*type	5	0.489	0.782
	Corrected total	43		
Occasional hyporheos taxa richness	Sampling event	5	.852	.524
	Type	1	.428	.518
	Sampling event*type	5	.679	.642
	Corrected total	43		
Stygobite taxa richness	Sampling event	5	.490	.781
	Type	1	.074	.788
	Sampling event*type	5	.366	.868
	Corrected total	43		

4.6 Macroinvertebrates

4.6.1 Taxa composition and richness

A total of 160 macroinvertebrate taxa was recorded from Yandicoogina Creek in the Survey Area (see Appendix G for the full taxonomic list). The macroinvertebrate fauna of the Survey Area comprised:

- Cnidaria (freshwater hydra; one taxon),
- Gastropoda (freshwater snails; three taxa),
- Oligochaeta (aquatic segmented worms; 10 taxa),
- Acarina (water mites; 12 taxa),
- Crustacea (amphipods or side swimmer; two taxa),
- Collembolla (spring tails; three taxa),
- Coleoptera (beetles; 47 taxa), Diptera (two winged flies; 40 taxa),
- Ephemeroptera (mayflies; six taxa),
- Hemiptera (true bugs; 16 taxa),
- Odonata (dragonflies and damselflies; 14 taxa) and
- Trichoptera (caddisflies; six taxa).

Of the 160 taxa recorded from the Survey Area, 72 were singletons and recorded from one sample only (i.e., one site in one season). More common taxa, recorded from five or more samples, included the beetles *Hydaena* sp. and larval Scirtidae sp., the soldier fly larvae Stratiomyidae sp., the horse fly larvae Tabanidae, the biting midge larvae Ceratopogoninae sp., non-biting midge larvae *Tanytarsus* sp. and *Larsia ?albiceps*, the mosquito larvae *Culex* sp., the mayfly larvae Baetidae sp., and the dragonfly larvae Anisoptera sp.

Within-site macroinvertebrate richness ranged from 38 (at reference site WWS) to 83 (at reference site BENS) in the Dry 2021, and from 35 (at reference site WWS) to 74 (at reference site BENS) in the Wet 2022 (Figure 4.22). Notably high macroinvertebrate richness was also recorded in the Survey Area, from YC4 in the Dry 2021 (73 taxa) and YC3 in the Wet 2022 (71 taxa). The high richness recorded from YC4 was not evident in the Wet 2022, with only 41 taxa recorded from this site at that time. This was influenced by a reduction in the number of Coleoptera, Ephemeroptera, Hemiptera and Odonata, as well as a complete absence of Trichoptera from YC4 in the wet. Yandicoogina Creek was in flood at the time of sampling in the wet season, and it is likely this influenced the low richness, with invertebrates likely flushed downstream and/or taking refuge in the deeper, less accessible parts of the pool. Surface water was observed to be flowing into the pool at the time of sampling, with riffle sequences present. However, the survey was within days of a high rainfall event, and it is therefore unlikely there was sufficient time for invertebrates to colonise these flowing areas of creekline.

Most sites were dominated by slow flow and relatively tolerant taxa, i.e., Coleoptera and Diptera. Dominance of Diptera within aquatic macroinvertebrate assemblages of the Pilbara is common (Pinder *et al.*, 2010). Taxa which require faster flows, such as Lepidoptera, leptophlebiid mayflies, Simulidae (Diptera), *Cheumatopysche* and *Chimarra* caddisflies (Trichoptera) were generally restricted to the flowing reference sites, including Weeli Wolli Spring, Munjina Spring and Skull Springs (Figure 4.22). Yandicoogina Creek generally recorded a low richness of Trichoptera in comparison to reference sites, with the exception of YC4 (Figure 4.22).

4.6.2 Conservation significant macroinvertebrate taxa

The vast majority of aquatic macroinvertebrates recorded from the Survey Area were common, ubiquitous species. Excluding taxa which could not be assigned a distribution status due to insufficient information or taxonomy (juveniles/damaged specimens), most remaining taxa had distributions extending across Australia (38%), Northern Australia (17%), or the Australasian region (9%). A total of 19% were cosmopolitan, 2% endemic to Western Australia, and 1% found across northern Western Australia. Taxa restricted to the Pilbara region accounted for 14% of the taxa from the Survey Area (of those with known distributions).

Pilbara endemic taxa were recorded from all sites sampled, including reference sites (Figure 4.23). The greatest number of Pilbara endemic taxa was recorded from YC4 in the Dry 2021 and BENS in both seasons (both sites with five taxa; Figure 4.23). This was closely followed by reference site SS which recorded four Pilbara endemic taxa in the Wet 2022. Survey Area sites YC2 and YC3 recorded one Pilbara endemic taxon (Figure 4.23).

Within the Pilbara endemic fauna were six taxa of further interest which represented either conservation significant species currently listed on the IUCN Red List of Threatened Species (*Hemicordulia koomina*, *Eurysticta coolawanyah* and *Ictinogomphus dobsoni*), short-range endemics (*Chydaekata* `sp. E` and Paramelitidae `sp. Biologic-AMPH023`) and a potentially uncommon and/or restricted species (*Wandesia* sp.). Further detail on these taxa is provided below.

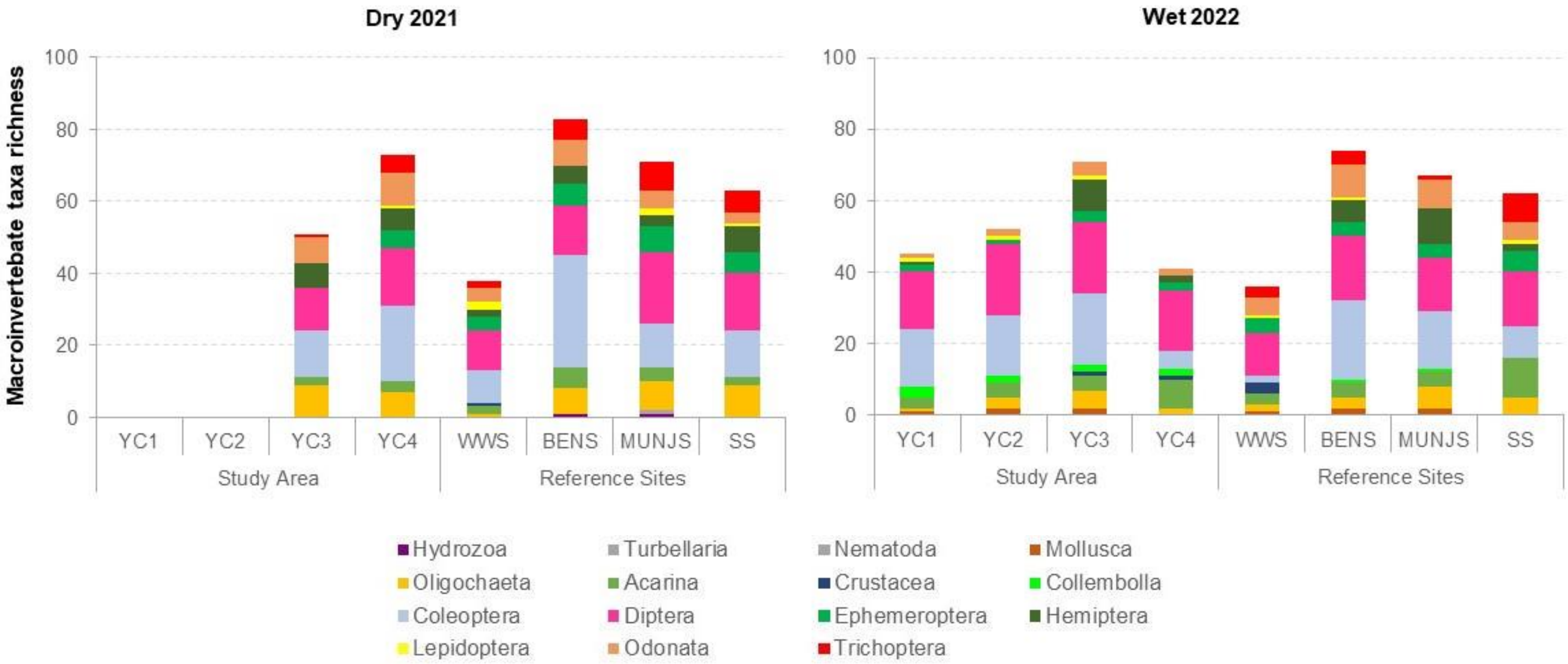


Figure 4.22: Macroinvertebrate taxa richness recorded from each site in each season.

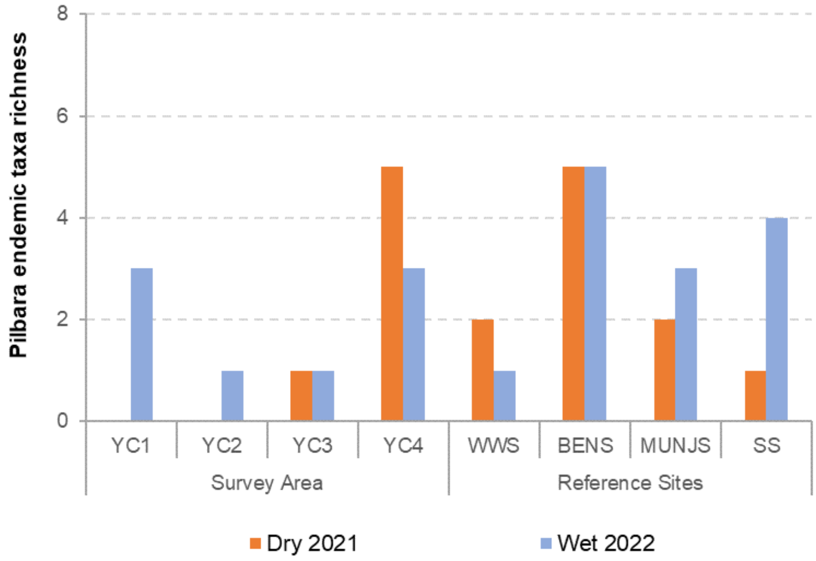


Figure 4.23: Number of Pilbara endemic macroinvertebrate taxa recorded from each site in each season.

Odonata

The Pilbara emerald, *Hemicordulia koomina*, is currently listed on the IUCN (2022) as Vulnerable (see Appendix A for IUCN classification definitions). Its listing was based on it being known from only five sites in the Pilbara (Millstream station, Koomina Pools on Tanberry Creek, Palm Pool south of Karratha, Fortescue Crossing, and Millstream Spring). The IUCN listing for *H. koomina* was updated in 2016, but the update did not appear to take into account grey literature records or those recorded during baseline surveys for developments. Including known locations reported in Pinder *et al.,* (2010) and sites known by the authors, *H. koomina* likely occurs at more than 15 sites across the Pilbara. The IUCN listing did indicate that its maximum known extent of occurrence was 6,504 km^2 (Dow, 2019b) however, Bush *et al.* (2014) provided an estimate of the current extent of suitable habitat as 119,416 km^2. This species is still considered rare and is infrequently collected and rarely recorded. It was recorded from YC4, BENS and SS during the current survey, and is previously known from YC1, YC3, and YC4 (Biologic, 2020c, 2022b). Lowering water levels from groundwater abstraction and climate change have been highlighted as a considerable threat to this species, as well as its severely fragmented distribution (IUCN, 2022).

The Pilbara pin damselfly, *Eurysticta coolawanyah* is currently listed as Vulnerable (IUCN, 2022). This listing was based on its collection from less than five locations. Like the Pilbara emerald, the listing was for *E. coolawanyah* was revised in 2016, but did not take into account grey literature records. Its extent of occurrence, based on a polygon around the known occupied areas (four locations listed in the IUCN listing), is 7,937 km^2 (Dow, 2019a); however, Bush *et al.* (2014) provide an estimate of the current extent of suitable habitat as 298,177 km^2. Including the PBS and grey literature records (sampling programs undertaken by the authors and others), the species has now been recorded from numerous locations in the Pilbara, albeit in low numbers and with a disjunct distribution (Pinder *et al.,* 2010, Jess Delaney, unpub. data). During the current study, *E. coolawanyah* was recorded from the Survey Area (at YC4) and one reference site (BENS). It was previously recorded from YC4 (Biologic, 2020c).

The Pilbara tiger *Ictinogomphus dobsoni* is endemic to the Pilbara region and is currently listed on the IUCN Red List as Near Threatened (IUCN, 2022). The listing was updated in 2016 and was based on its record from less than ten locations. This is despite the fact that during the PBS undertaken between 2003 and 2006, *I. dobsoni* was recorded from 16 locations across the Pilbara (Pinder *et al.*, 2010). The Pilbara tiger is thought to 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 BENS. It is also previously known from Survey Area site YC3.

Amphipoda

The amphipods recorded from Yandicoogina Creek surface waters during the current study were stygal and are known to belong to the same species recorded from the hyporheic zone, *Chydaekata* \`sp. E\` and Paramelitidae \`sp. Biologic-AMPH023\`. *Chydaekata* \`sp. E\` was recorded from surface waters at YC4 in the Dry 2021, as well as reference site WWS. It has previously been recorded from surface waters at YC3 (Biologic, 2022b) and YC4 (Dry 2019) (Biologic, 2020c). As discussed above in section 4.5.2, *Chydaekata* \`sp. E\` is a Potential SRE (sub-category data deficient) known only from Yandicoogina Creek, Marillana Creek, and upper Weeli Wolli Creek. Paramelitidae \`sp. Biologic-AMPH023\` was recorded from surface waters at YC3 in the Dry 2021. It was previously recorded from this site in the Wet 2021 (Biologic, 2022b).

Acarina

The water mite *Wandesia* sp. was recorded from surface waters of YC1 in the Wet 2022. This is likely to be the same species occurring within the hyporheic zone of YC3 detailed above in section 4.5.2. Further molecular work is being undertaken to confirm this, and provide information which can be used to assess its likely distribution status.

4.6.3 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 = 0.92) between macroinvertebrate assemblages and four predictor variables was produced (Table 4.7). The environmental variables were temperature, turbidity, concentration of dissolved aluminium, and maximum depth. Together, these environmental variables explained more than one third of the variation amongst the Yandicoogina Creek macroinvertebrate assemblages (36.59%).

Table 4.7: DistLM results examining correlations between Yandicoogina Creek macroinvertebrate assemblages and environmental data (water quality and habitat).

Variable	r	Pseudo-F	*p*-value	% variance explained
Temperature	0.34	2.62	<0.0001	11.59
Turbidity	0.46	2.30	0.0017	9.56
Dissolved aluminium	0.59	2.19	0.0038	8.47
Maximum depth	0.77	2.07	0.0186	6.98
		Total % variation explained		**36.59%**

4.6.4 Macroinvertebrate comparison with previous studies

A seasonal pattern of change in average macroinvertebrate taxa richness has been evident over time, within both the Survey Area and in reference sites, with greater richness recorded in the dry season and lower in the wet (Figure 4.24). There was a notable increase in average macroinvertebrate richness in the Survey Area between the Wet 2021 and Dry 2021. Despite the flooding event in the most recent sampling event, average richness recorded in the Wet 2022 was greater than all other preceding events with the exception of the notably high richness recorded in the Dry 2021. While there was also an increase in average richness within reference sites between the Wet 2021 and Dry 2021, this increase was not as marked as that within the Survey Area (Figure 4.24). Overall, there was no significant difference in macroinvertebrate richness between sampling event (Table 4.8). There was however, a significant difference between site type, with significantly higher average macroinvertebrate richness recorded from reference sites. The lower richness within the Survey Area was primarily due to the low richness recorded consistently from YC2. Sampling of this site was hampered by the abundant *Typha* growth and difficulty manoeuvring the dip net to undertake kick sweep sampling effectively.

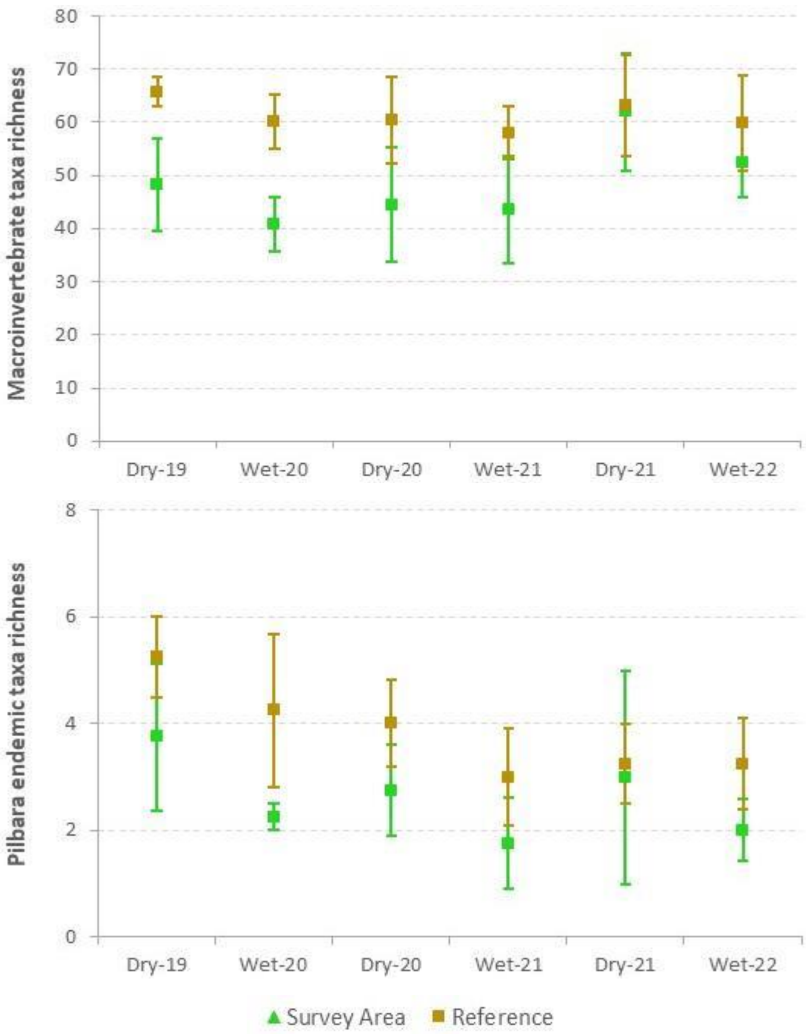


Figure 4.24: Average macroinvertebrate taxa richness (± standard error) (top) and Pilbara endemic taxa richness (bottom) (± standard error) from the Survey Area and Reference sites in each sampling event since the Dry 2019.

The average number of Pilbara endemic taxa recorded from both Survey Area and reference sites decreased between the Dry 2019 and the Wet 2021, followed by an increase in the Dry 2021 (Figure 4.24). Although there was a decrease in Pilbara endemic taxa richness in the Wet 2022 within the Survey Area, richness in reference sites remained consistent with the previous sampling event. Overall, there was no significant difference in average Pilbara endemic taxa richness between sampling event, but there was a significant difference between site type (Table 4.8). Like overall macroinvertebrate richness, Pilbara endemic taxa richness was significantly higher within reference sites (Figure 4.24). Again, this was likely due to the low number of endemics recorded from YC2 primarily.

Table 4.8: Two-way ANOVA results, comparing macroinvertebrate taxa richness between sampling events and site type (Survey Area vs reference). Significant *p*-values are shown in red.

Analyte	Source	df	F	*p*-value
Macroinvertebrate taxa richness	Sampling event	5	0.58	0.711
	Type	1	7.47	0.010
	Sampling event*type	5	0.33	0.889
	Corrected total	43		
Pilbara endemic taxa richness	Sampling event	5	1.26	0.303
	Type	1	4.99	0.032
	Sampling event*type	5	0.15	0.980
	Corrected total	43		

4.6.5 Macroinvertebrate comparison with other studies

Macroinvertebrate richness was compared to the other aquatic studies undertaken in the area for those studies which sampled more than one replicate site within a creek system (details provided in section 3.4.3 above). As with the zooplankton data, Weeli Wolli Creek sites were split into Weeli Wolli Spring and Weeli Wolli Creek, and some reference sites were removed due to a lack of replication within a sampling event (i.e., BENS, MUNJS and MACREF1). The macroinvertebrate dataset was amalgamated, and taxonomy aligned, prior to analysis to ensure any differences in taxonomic knowledge between samplers and years was accounted for.

Yandicoogina Creek generally recorded similar average richness to nearby Marillana Creek, with slightly higher average richness than Weeli Wolli Creek (not including the Weeli Wolli Spring PEC), but lower richness than Davis Creek (Figure 4.25). Overall, these differences in average macroinvertebrate richness were found to be significant (Two-way ANOVA; df = 5, F = 6.02, p < 0.001). The Tukey' post-hoc test indicated that average richness from Yandicoogina Creek was statistically similar to Weeli Wolli Creek, Marillana Creek, Marillana Creek Downstream and Weeli Wolli Spring, but significantly lower than the Davis River (Figure 4.25). There was no significant difference in macroinvertebrate richness between season (df = 1, F = 0.11, p = 0.747; Figure 4.25).

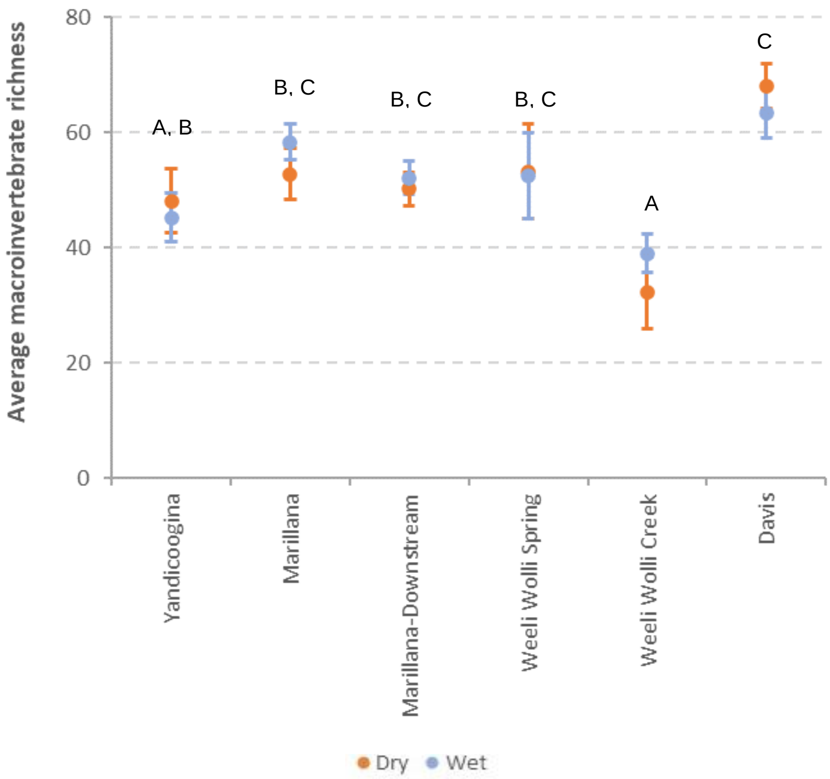


Figure 4.25: Average macroinvertebrate taxa richness (± se) recorded from Yandicoogina Creek, in comparison to other studies and nearby creek systems, in both seasons.

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

Macroinvertebrate assemblages of Yandicoogina Creek formed a relatively tight cluster, with the exception of the YC2 samples from the Dry 2020 and Wet 2021, and the YC1 sample from the Wet 2021 (Figure 4.26). Macroinvertebrate richness within these samples was considerably lower than all other Survey Area samples, likely leading to this separation in ordination space. Generally, the Survey Area samples sat closest in the ordination to the Yandicoogina Creek Reference site, which is perhaps unsurprising, but were also similar to Munjina Spring samples, and some BENS (WWS2) and Marillana Creek samples (upper Marillana Creek as sampled by Biologic in the Dry 2020 and Wet 2021 for MAC4) (Figure 4.26). There was considerable separation between Survey Area samples and those from non-spring sites on Weeli Wolli Creek and Marillana Creek-Downstream.

Overall, there was a significant difference in macroinvertebrate assemblages between creeks (Two-way ANOSIM; R = 0.42, $p < 0.001$), and between season (R = 0.09, $p = 0.02$; Figure 4.27). Pairwise post-hoc results indicated that macroinvertebrate assemblages of the Survey Area were most similar to assemblages of Munjina Spring, WWS2 (BENS), and the reference site on Yandicoogina Creek (sampled for MAC4, i.e., MACREF1; Table 4.9).

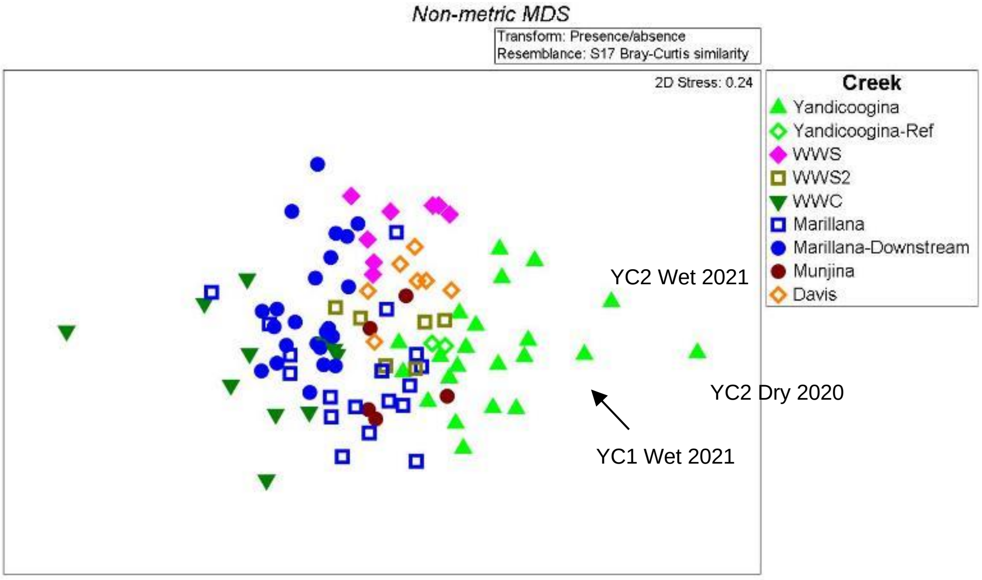


Figure 4.26: nMDS of macroinvertebrate assemblages recorded during the current study, with data from previous studies included. Samples are identified by creek.

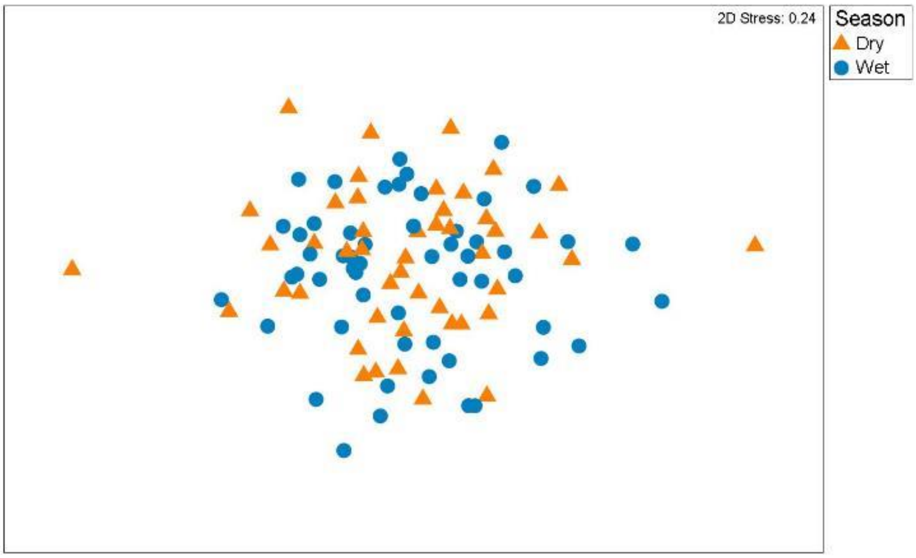


Figure 4.27: nMDS ordination of macroinvertebrate assemblages as above, but with samples identified by season.

Table 4.9: Post-hoc pairwise results comparing macroinvertebrate assemblages between creeks/reaches. NB: significant separations are indicated by red font).

Creek/reach	R	*p*-value
Yandicoogina-Ref	-0.36	0.993
WWS (BENS)	0.56	<0.0001
WWS2	0.12	0.052
WWC	0.62	<0.0001
Marillana	0.47	<0.0001
Marillana-Down	0.71	<0.0001
Munjina	0.36	0.064
Davis	0.33	0.001

4.6.6 Introduced macroinvertebrate taxa

No introduced invertebrate taxa were recorded from the Survey Area. However, one introduced species was recorded from reference site WWS. This was the freshwater crayfish *Cherax quadricarinatus*, commonly known as redclaw. Over the course of the study, a total of 25 redclaw were removed from WWS, with four individuals removed in the Dry 2021 and 21 in the Wet 2022 (Figure 4.28). The sex ratio was in favour of females in the Dry 2021 (2:1), and males in the Wet 2022 (1.2:1) (Figure 4.28).

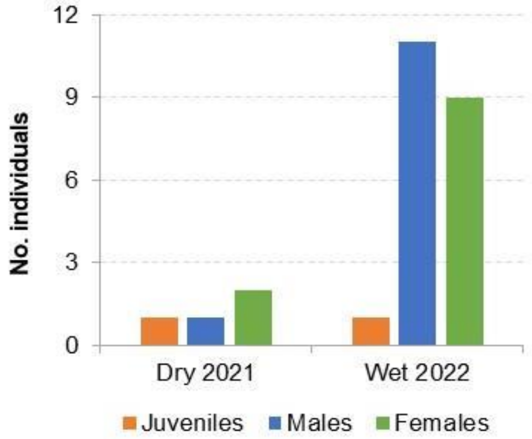


Figure 4.28: Number of redclaw recorded from WWS in each sampling event.

As few individuals were recorded in the Dry 2021, age-class structures were only examined for the Wet 2022 specimens (Figure 4.29). Carapace length ranged from 29 to 57 mm in females, 22 to 54 in males, and one 21 mm juvenile (Figure 4.29). The highest abundance of individuals was within the 40 -50 mm size class, which accounted for 33% of the total population removed. Two berried females were removed from WWS in the Dry 2021 (Plate 4.2).

Plate 4.2: Two berried females collected from WWS.

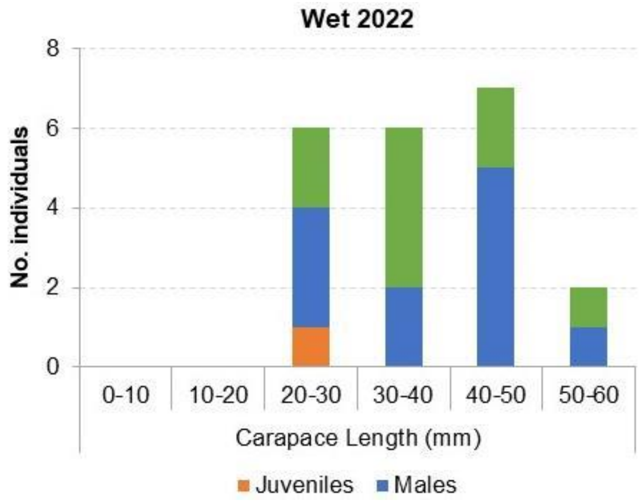


Figure 4.29: Carapace length (mm) for redclaw recorded from WWS in the Wet 2022.

4.7 Rehydration Emergence Trials

Water quality recorded from rehydrate tanks was generally conducive to emergence of fauna and germination of flora, although DO and temperature did become temporarily low in some tanks on a limited number of occasions. DO ranged from 40% (in the YC2 tank in the Dry 2021 Phase 2 trial) to 96.2% (YC1 in the Dry 2021 Phase 1 trial) (Table 4.10). Water temperatures in trial tanks ranged from 17.9 °C (YC1 in the Dry 2021 Phase 1 trial) to 26.8 °C (YC2 in the Dry 2021 Phase 2 trial). This is generally similar to the average water temperatures recorded from pools within the Survey Area during the Dry 2021 (24.6 °C), although the lowest temperature recorded from trial tanks was somewhat lower than surface water pools (21.5 °C). Overall, the temperatures in the rehydrate tanks were considered sufficient to allow emergence to occur.

pH was slightly more basic in the rehydration tanks than recorded from inundated pools within the Survey Area. For example, average pH recorded from the Dry 2021 tanks during the trials ranged from 7.7 in YC2 during Phase 1, to 9 in YC1 during Phase 2 (Table 4.10). This contrasts with a pH range of 7.39 (YC4) to 7.67 (YC3) recorded from inundated pools on Yandicoogina Creek in the Dry 2021. However, the pH recorded within the inundated trial tanks was well within the range experienced in Pilbara pools. Therefore, pH was considered unlikely to adversely affect hatching success in the trials.

EC was notably higher within the Dry 2021 rehydration tanks than that recorded from inundated Yandicoogina sites. For example, EC was 677 µS/cm at YC3 and 630 µS/cm at YC4 during the Dry 2021, in comparison to an average of 2264.4 µS/cm (Phase 1) and 871.4 µS/cm (Phase 2) from YC1 sediments during rehydration trials, and an average of 4178.4 µS/cm (Phase 1) and 1613.2 µS/cm (Phase 2) from Dry 2021 YC2 sediments (Table 4.10). The EC values recorded during the rehydration trials were indicative of saline waters (i.e., > 1500 µS/cm) and, therefore, may have exceeded the tolerance of the egg bank and ultimately led to low productivity.

During phase 1, the YC1 tank was particularly cloudy from day 15 onwards. However, no algal blooms were observed over the course of the trials in either YC1 or YC2 tanks. Therefore, water clarity was considered unlikely to have adversely affected emergences.

Table 4.10: Summary of water quality recorded during the Dry 2021 rehydration trials.

Highlighted cells refer to values which are in excess of; ■ > the ANZG 95% DGV, and ■ > point of ecological stress.

		Temp °C		pH		EC (µs/cm)		DO %	
Dry 2021		**Phase 1**	**Phase 2**	**Phase 1**	**Phase 2**	**Phase 1**	**Phase 2**	**Phase 1**	**Phase 2**
ANZG DGV				**6-8**		**250**		**85-120**	
YC1	**min**	17.9	20.8	7.8	8.0	1554.0	542.0	41.8	47.5
	max	25.6	26.7	8.9	9.0	2832.0	1002.0	78.6	96.2
	mean	22.1	23.0	8.2	8.5	2264.4	871.4	57.8	79.8
	se	0.7	0.6	0.1	0.1	145.9	40.9	5.5	4.3
YC2	**min**	18.1	21.0	7.7	8.0	3210.0	752.0	40.0	48.2
	max	25.3	26.8	8.9	8.8	5399.0	1942.0	84.5	94.9
	mean	22.0	23.4	8.2	8.5	4178.4	1613.2	65.9	78.7
	se	0.7	0.6	0.1	0.1	324.9	110.6	5.5	4.4

4.7.1 Taxonomic composition and species richness

Given the high salinity in rehydration tanks, the trials were relatively unproductive, yielding a total of seven invertebrate taxa and one submerged macrophyte (Table 4.11). Over 2,000 specimens emerged from the two trial tanks. While few rehydration studies are publicly available, and reported results are highly variable, the current study recorded lower invertebrate taxa richness than has been recorded for Pilbara sediments previously (i.e., ten invertebrate taxa recorded from Coolibah wetlands, 20 taxa from Warramboo, and 36 taxa from creeks near Paraburdoo) (WRM, 2016).

Invertebrate taxa which emerged from the Yandicoogina Creek sediments included Turbellaria (flat worms; one taxon), Rotifera (rotifers; one taxon[6]), Acarina (aquatic mite; one taxon), Cladocera (water fleas; one taxon), Ostracoda (seed shrimp; 2 taxa), and Diptera (two-winged flies; one taxon). One submerged macrophyte (*Vallisneria* sp.) was recorded at both YC1 and YC2 during the rehydration trials. All invertebrate taxa recorded during rehydration trials are known from the creek and were recorded during the current study from invertebrate samples collected from inundated pools. The submerged macrophyte, however, adds to the known records of macrophytes as *Vallisneria* has not been previously recorded from YC1 and YC2 when inundated.

Both YC1 and YC2 rehydration tanks yielded a total of five taxa, including macrophytes (Table 4.11). Crustacea was the richest group, of which Ostracoda was the most diverse and found to emerge from both sediments collected from sites. Rotifers and crustaceans typically make up a large proportion of the invertebrate assemblage in temporary waters due to their ability to produce desiccation resistant

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

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.

Table 4.11: Taxa recorded from rehydration trials.

Phylum/Class/Order	Family	Lowest taxon	YC1	YC2
ANIMALIA				
PLATYHELMINTHES		Turbellaria sp.	3	
ROTIFERA		Rotifera sp.	5	5
ARTHROPODA				
CHELICERATA				
Sarcoptiformes		Oribatida sp.		1
CRUSTACEA				
Branchiopoda				
Diplostraca	**Chydoridae**	Chydoridae sp.	2	
Ostracoda	**Darwinulidae**	Darwinulidae sp.		1
	Diaptomidae	*Eodiaptomus lumholtzi*		1
HEXAPODA				
Insecta				
Diptera	**Psychodidae**	Psychodidae sp.	2	
PLANTAE				
LILIOPSIDA				
Alismatales	**Hydrocharitaceae**	*Vallisneria* sp.	3	3
		Taxa richness	**5**	**5**

Note: Values are log10 abundance categories, where 1 = 1, 2 = 2-10, 3 = 11-100, and so on.

4.7.2 Conservation significance of emergent fauna

None of the taxa which emerged from Survey Area sediments are listed as being of conservation significance. None represent additional records to the known richness within Yandicoogina Creek.

4.8 Fish

4.8.1 Species composition and richness

Four freshwater fish species were recorded in 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, only spangled perch, western rainbowfish, and Pilbara tandan were recorded within the Survey Area.

4.8.2 Abundance

A total of 1,102 individual fish was recorded in the current study, with 582 recorded in the Dry 2021 (84 from the Survey Area and 498 from reference sites), and 520 in the Wet 2022 (130 from the Survey Area and 390 from reference sites) (Table 4.12). Within the Survey Area, the greatest abundance of

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[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.

fish was recorded from YC4 in both the Dry 2021 and the Wet 2022 (74 and 114 individuals, respectively). This compares to a maximum of 248 individuals recorded from a reference site in the Dry 2021 (WWS), and 109 in the Wet 2022 (SS). Of all sites successfully sampled, YC3 recorded the lowest abundance of fish in the Dry 2021, and YC2 in the Wet 2022 (10 and 16 individuals, respectively) (Table 4.12). Within the Survey Area, only YC4 held sufficient water in both seasons to allow fish to be sampled.

Spangled perch, western rainbowfish, and Pilbara tandan were recorded in the Survey Area, in at least one site and one season (Table 4.12). Lowest fish diversity was recorded from YC2 and YC3 within the Survey Area (one species). Highest fish diversity was recorded from reference site SS, with all four fish species recorded (spangled perch, western rainbowfish, Pilbara tandan and Pilbara bony bream). Western rainbowfish was the most widespread species overall, being recorded at all Survey Area sites that held sufficient water (YC2, YC3 and YC4), and reference sites WWS, BENS and SS. Although, spangled perch was also widely distributed, it was not recorded from YC2 or YC3 (Table 4.12).

Western rainbowfish was the most abundant fish in the Survey Area, with 59 individuals recorded during the Dry 2021 and 97 during Wet 2022. Spangled perch was the next most abundant species in the Survey Area, with 25 individuals recorded in the Dry 2021 and 31 individuals in the Wet 2022. Only two individual Pilbara tandan were recorded in the Survey Area (YC4 in Wet 2022). Western rainbowfish was also the most abundant fish at the reference sites, with 300 individuals recorded during the Dry 2021, and 183 during Wet 2022. Pilbara tandan was recorded in high numbers at reference sites WWS, BENS and MUNJS (30 individuals in Dry 2021, and 62 individuals in Wet 2022). The Pilbara bony bream was only recorded at one reference site (SS), with three individuals recorded in the Dry 2021, and 38 during Wet 2022 (Table 4.12).

4.8.3 Conservation significant fish species

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

4.8.4 Length-frequency analysis

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 which were recorded within the Survey Area in sufficient abundance (spangled perch, western rainbowfish, and Pilbara tandan).

Table 4.12: Abundance of each freshwater fish species recorded from each site.

Type	Site	*Leiopotherapon unicolor* Spangled perch		*Melanotaenia australis* Western rainbowfish		*Neosilurus* sp. Pilbara tandan		*Nematolosa* sp. Pilbara bony bream		Abundance		Diversity	
		D	W	D	W	D	W	D	W	D	W	D	W
Survey Area	YC1	-	-	-	-	-	-	-	-	-	-	-	-
	YC2	-	0	-	16	-	0	-	0	-	16	-	1
	YC3	0	-	10	-	0	-	0	-	10	-	1	-
	YC4	25	31	49	81	0	2	0	0	74	114	2	3
Reference	WWS	0	1	248	32	8	12	0	0	256	45	2	3
	BENS	32	66	11	42	3	26	0	0	46	134	3	3
	MUNJS	-	-	-	-	-	-	-	-	-	-	-	-
	SS	133	42	41	109	19	22	3	38	196	211	4	4
	Abundance	190	140	359	280	30	62	3	38	582	520		
										1102			

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 2021 and Wet 2022 (94% and 76%, respectively) (Figure 4.30). No new recruits or juveniles were recorded in the Survey Area during the current study. Adults constituted the greatest proportion of spangled perch at reference sites during Dry 2021 (74%), while juveniles made up the greatest proportion in Wet 2022 (55%).

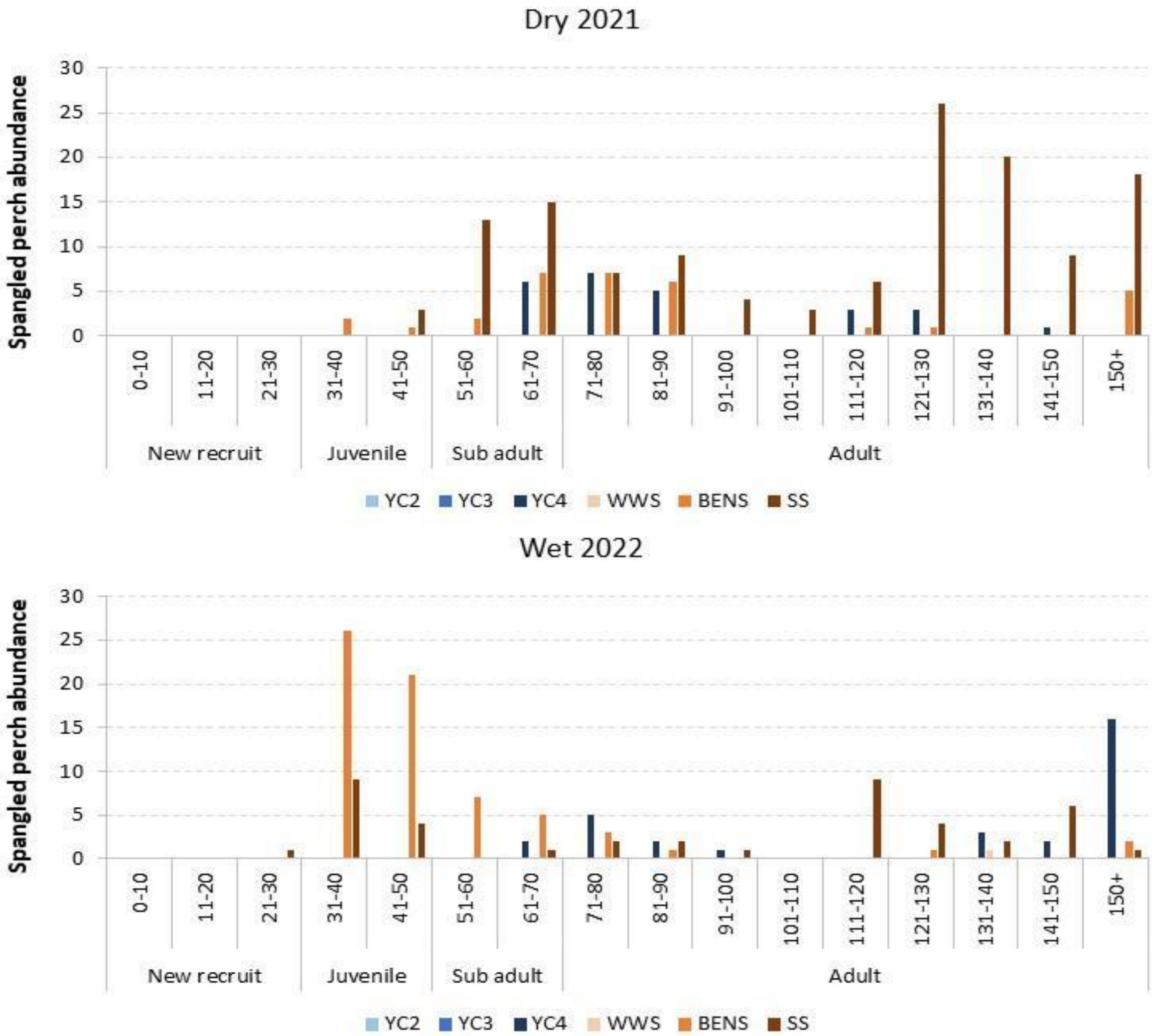

Figure 4.30: Length frequency analysis for spangled perch in the Dry 2021 (top) and the Wet 2022 (bottom).

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

Western rainbowfish

Western rainbowfish have multiple spawning events throughout the year which take advantage of the intermittent rainfall and streamflow characteristic 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.

In the Survey Area, adults constituted the greatest proportion of western rainbowfish recorded in both the Dry 2021 and the Wet 2022 (98% and 59%, respectively) (Figure 4.31). No new recruits were recorded in the Survey Area during the Dry 2021, with a very small proportion recorded in the Wet 2022 (1%). In the Dry 2021, adults made up the greatest proportion of western rainbowfish at reference sites (87%), with very few new recruits and juveniles recorded (<1% and 4%, respectively). During the Wet 2022 however, juveniles comprised the greatest proportion (40%), followed by sub-adults and adults (22% and 29%, respectively).

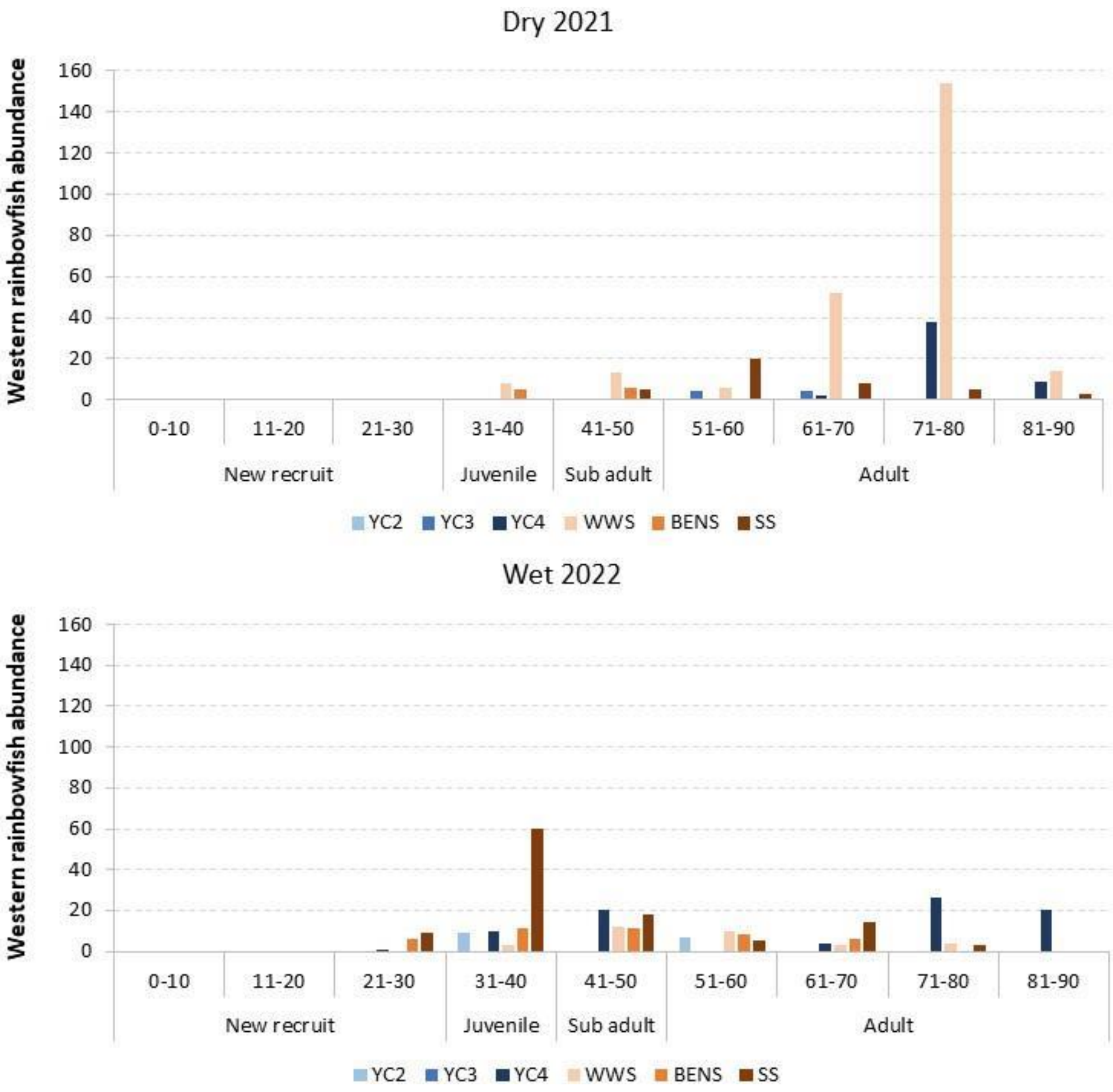

Figure 4.31: Length frequency analysis for western rainbowfish in the Dry 2021 (top) and the Wet 2022 (bottom).

Pilbara tandan

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

Only two adult Pilbara tandan were recorded from the Survey Area during the current study (Figure 4.32). Adults comprised the main proportion of Pilbara tandan recorded from the reference sites during both the Dry 2021, and Wet 2022 (77% and 95%, respectively). No new recruits or juveniles were recorded from the Survey Area or reference sites during the current study, which indicate no recent breeding or recruitment (Figure 4.32). Interpretations regarding population structure of Pilbara tandan in the area are complicated by the low numbers of fish recorded as a result of their cryptic nature.

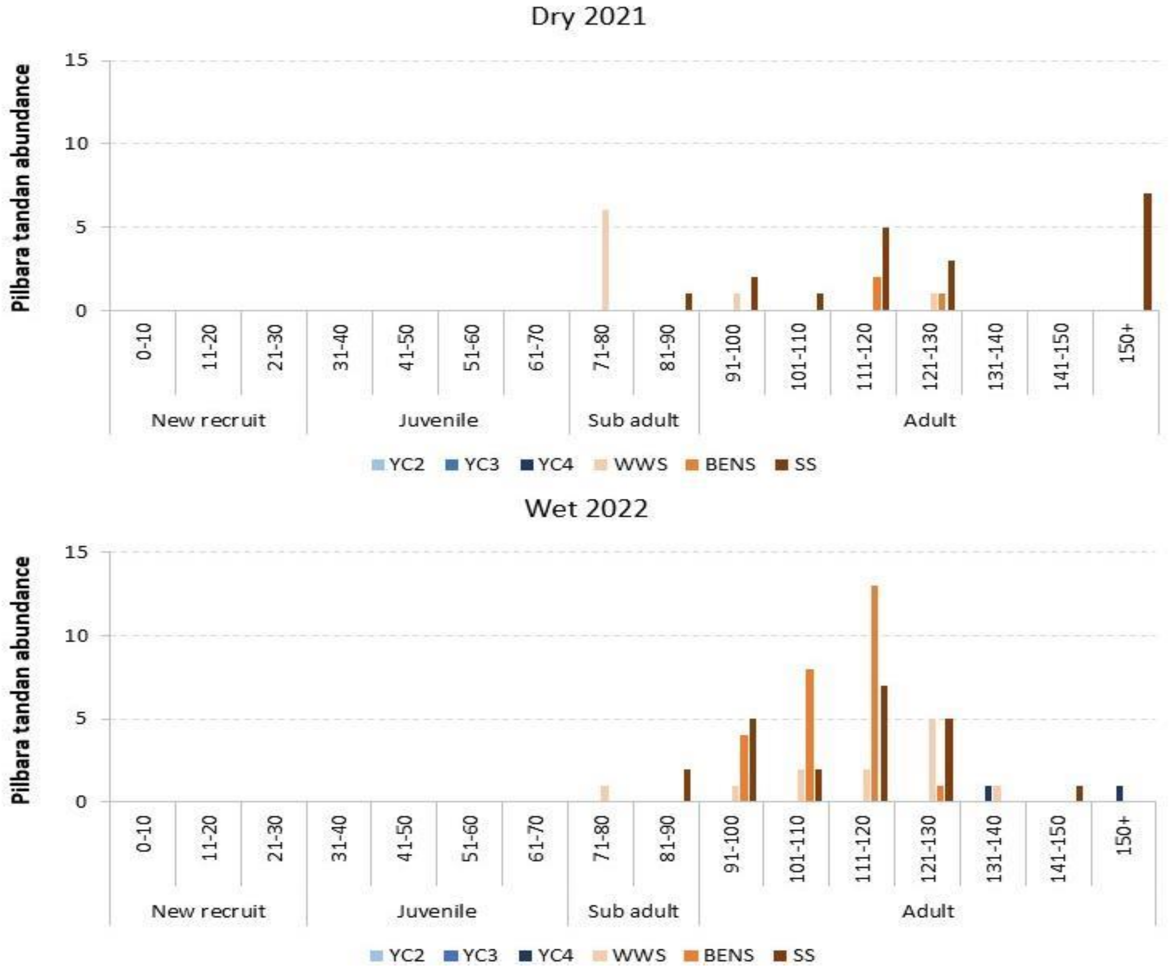

Figure 4.32: Length frequency analysis for Pilbara tandan in the Dry 2021 (top) and the Wet 2022 (bottom).

4.8.5 Fish change over time

For the two most common and abundant species, spangled perch and western rainbowfish, differences in abundances recorded between sampling events and site type was investigated. Similar patterns in change over time were apparent between the Survey Area and reference sites, for both species (Figure 4.33). With respect to the abundance of spangled perch, changes appeared to be seasonal, with generally greater abundances recorded in the wet season. This was also observed for western rainbowfish, but with greatest average abundance recorded during the Dry 2021, in both the Survey Area and reference sites (Figure 4.33). There was a high degree of variability in fish abundance within a sampling event, for both Survey Area and reference sites, as evidenced by the large standard error bars. This was particularly pronounced in reference sites (Figure 4.33). Overall, there was no significant difference in fish abundance between sampling event for either species (Two-way ANOVA; df = 5, p > 0.750), but significantly greater abundances were recorded from reference sites in comparison to the Survey Area (df = 1, p < 0.05; Table 4.13).

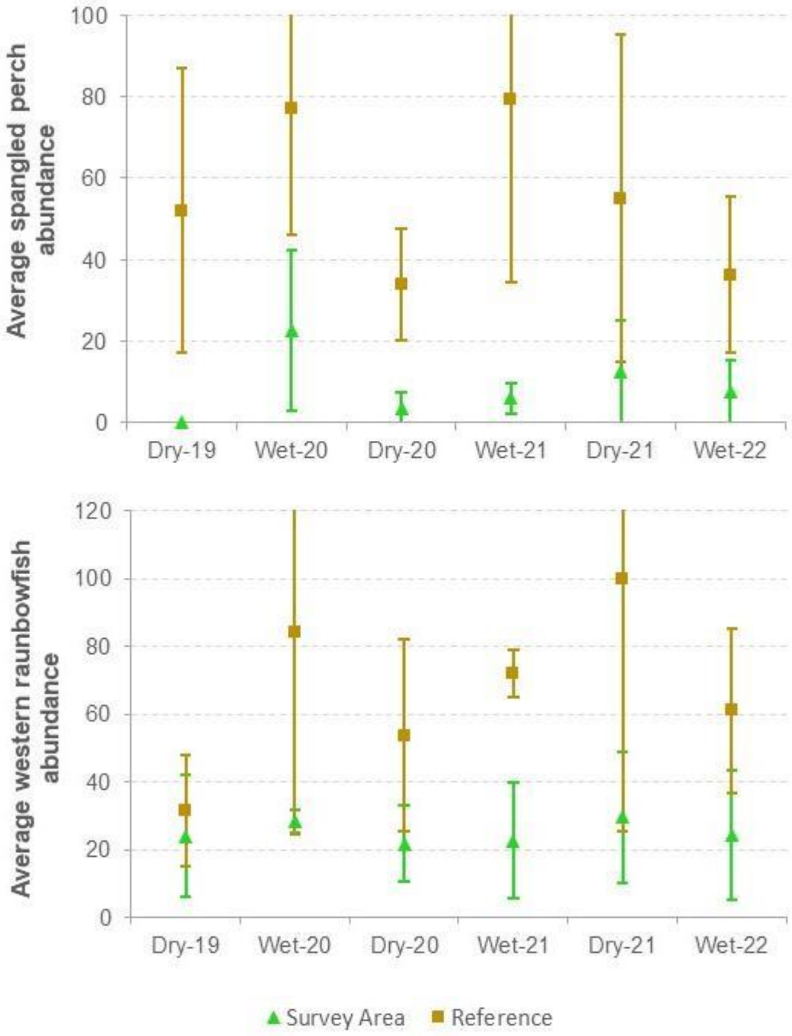

Figure 4.33: Average fish abundance (± standard error) from the Survey Area and Reference sites in each sampling event since the Dry 2019, showing abundances for spangled perch (top) and western rainbowfish (bottom).

Table 4.13: Two-way ANOVA results, comparing fish abundance between sampling events and site type (Survey Area vs reference). Significant *p*-values are shown in red.

Analyte	Source	df	F	*p*-value
Spangled perch abundance	Sampling event	5	0.52	0.757
	Type	1	10.66	0.003
	Sampling event*type	5	0.25	0.936
	Corrected total	35		
Western rainbowfish abundance	Sampling event	5	0.275	0.922
	Type	1	4.665	0.041
	Sampling event*type	5	0.184	0.966
	Corrected total	35		

4.9 Other Vertebrate Fauna

4.9.1 Frogs

The desert tree frog, *Litoria rubella*, was recorded from the Survey Area at YC2 during the Wet 2022. Tadpoles were also observed at SS during the Dry 2021, and at MUNJS in the Wet 2022. The tadpoles recorded were most likely one of three species known to inhabit the Survey Area: desert tree frog (*Litoria rubella*); Pilbara toadlet (*Uperoleia saxatilis*); and Mains frog (*Cyclorana maini*) (Biologic, 2020c, 2022b).

5 DISCUSSION

5.1 Habitat Assessment

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

Surface water levels in permanent pools of the Survey Area continue to decrease over time, which effectively reduces aquatic habitat (Table 5.1). This was the first survey in which some sites were dry at the time of sampling, i.e., YC1 and YC2 in the Dry 2021. Although both sites held water for the Wet 2022 survey, it is likely these pools had recently been inundated following the high rainfall event in late March, immediately prior to the survey. While it is not known how long these pools persisted, it was likely short-lived, with both sites being completely dry by late July 2022. Surface water within Yandicoogina Creek, which is a known spring, appears to be draining quickly, rather than being maintained by groundwater intersecting the surface. The reduction in pool depth over time observed in the Survey Area was not mirrored at reference sites. Elsewhere, seasonal change was evident in pool depths, with greater maximum depth recorded in the wet season, following rainfall and flooding, and lower depths in the dry season, as would be expected for Pilbara waterbodies. While the change in maximum water depth between sampling events was not statistically significant, this was likely due to the large variation in depth within a sampling event, particularly within the Survey Area. YC1 and YC2, for example, were shallow or dry, while YC4 recorded a maximum depth of up to 5 m.

The lowering water levels have been accompanied by adverse changes to vegetation condition and in-stream habitat. Notably, *Typha domingensis* was in poor condition, with signs of senescence, particularly at YC2. Reductions in surface water and groundwater levels in the Survey Area also result in reduced habitat availability and extent of hyporheos habitat. The cause of the declining water levels should be investigated.

Table 5.1: Water level changes at YC1 between the Dry 2019 and Wet 2022.

Dry 2019	Wet 2020	Dry 2020	Wet 2021	Dry 2021	Wet 2022
					
Max depth: 0.40 m	Max depth: 0.60 m	Max depth: 0.40 m	Max depth: 0.15 m	Max depth: Dry	Max depth: 1.2 m

5.2 Water Quality

As previously reported, water quality at Yandicoogina Creek was good and characterised by fresh, clear waters, with low dissolved oxygen saturation, neutral pH, and generally low nitrogen nutrient and dissolved metals concentrations. While all sites within Yandicoogina Creek recorded EC in excess of the ANZG (2018) DGV, none were considered to pose a threat to aquatic life, 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). Seasonal variation was difficult to ascertain this study, given two sites were dry in the Dry 2021. Previously, there has been little seasonal variation in EC within the Survey Area, due to the connection to groundwaters and lack of evapoconcentration in the dry season. There was no significant difference in EC between sampling events, but reference sites recorded significantly greater EC than the Survey Area.

Dissolved oxygen (DO) concentrations within the Survey Area were low, with all sites recording DO below the lower ANZG (2018) DGV, in both seasons. Additionally, some sites (YC3 in both seasons and YC4 in the Wet 2022) recorded DO below the point of ecological stress (~30%). Although oxygen needs of aquatic biota differ between species and life history stage, Butler and Burrows (2007) reported acute toxicity between 25% and 30% for six tropical, northern Australian freshwater species. Such low DO has been reported from the Survey Area previously (Biologic, 2020c, 2022b). Aquatic biota may be adversely affected by low DO, especially since these levels appear to be sustained over relatively long periods. DO saturation recorded from these sites was likely related to the decay of algae and organic matter surrounding the *Typha* beds, with bacteria consuming oxygen in the water as part of this process. Several reference sites also recorded low DO, in at least one season. Reference sites recorded significantly greater DO saturation than the Survey Area, however, overall, there was no significant difference in DO between sampling events.

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

Nutrient concentrations within Yandicoogina Creek were low and below toxicity DGVs. However, eutrophication DGVs were exceeded for N_NOx (at all sites sampled except YC2 and BENS), total N (at YC2 and SS), and total P (at all sites). The eutrophication DGV is designed to protect aquatic ecosystems from the effects of nuisance algal and macrophyte growth. Excessive plant growth can physically smother aquatic invertebrates, as well as deplete oxygen in the water, due to increased biological oxygen demand as plants decay and are decomposed by bacteria. The relationship between nitrate-enrichment and enhanced algal growth in freshwaters is well documented, often resulting in very high density/ abundance, but low species richness (Camargo & Alonso, 2006; Wagenhoff *et al.*, 2011). While the idea that phosphorus (as FRP or total P) is the primary limiting factor for algal growth in freshwaters has been challenged as too simplistic (Beck & Hall, 2018; Elser *et al.*, 2007; Muhid & Burford, 2012), the fact that N_NOx and total P are enriched in surface waters of Yandicoogina Creek, suggests that any additional nutrient inputs to the Survey Area (such as from cattle or inputs from groundwater discharge) could increase the risk of eutrophication. In the current survey, exceedances of total N were marginal and unlikely to cause ecological harm or lead to eutrophic conditions on their own (i.e., without taking into account the elevated total P).

While there was no significant difference in nitrogen nutrients between sampling events, change over time in total P concentrations resulted in a significant difference between events. Concentrations of total P recorded in the Wet 2022 and Dry 2020 were found to be significantly lower than those recorded in the Dry 2019 and Wet 2020 (but statistically similar to the Wet 2021 and Dry 2021). Total P within the Survey Area was also significantly higher than that recorded from reference sites.

Dissolved metal concentrations were generally low within the Survey Area. However, dB exceeded the 99% toxicity DGV at all Survey Area sites, as well as some reference sites. The seemingly high dB concentrations recorded in the current study are not atypical for Pilbara surface waters, with many pools and springs commonly recording values in the range seen here. The ANZG (2018) DGVs for dB are perhaps too conservative for freshwater ecosystems of the region. There was no significant difference in dB concentrations between the Survey and reference sites, nor between sampling events.

Although there were previous exceedances of the ANZG (2018) interim working level at some Survey Area sites for dFe (Biologic, 2020c, 2022b), all concentration in the current study were low and within guidelines. Overall, there was no significant difference in dFe concentration between sampling events, but concentrations recorded from the Survey Area were found to be significantly higher than reference sites.

5.3 Wetland Flora

As noted previously (Biologic, 2020c, 2022b), the Survey Area classifies as a highly significant groundwater dependent ecosystem (GDE), being comprised of numerous high level key mesophytic/ hydrophytic indicator species, such as *Melaleuca argentea*, *Eucalyptus camaldulensis, Imperata cylindrica* and *Fimbristylis sieberiana*, as well as moderate-level indicator species *Cyperus vaginatus* (highly abundant), *Schoenoplectus subulatus* and *Eleocharis geniculata*. In places, this groundwater dependent vegetation (GDV) was dense. In-stream, *Vallisneria nana* (YC4) and C*hara fibrosa* (YC3) were present. Including previous surveys, a total of three submerged macrophyte taxa are known, with *Ruppia* sp. previously recorded from YC4. Given taxonomic limitations with *Chara* and *Ruppia*, the list of known submerged macrophyte species from the Survey Area likely represents numerous additional species. Of the aforementioned macrophytes, *Vallisneria nana* indicates water permanence as it is known only from perennial creeks and rivers (Rea *et al.*, 2002; Rio Tinto, 2020).

GDVs within the Survey Area are showing obvious signs of the lowering groundwater levels. For example, there has been decline in the crown of some trees, notably in *Melaleuca argentea* (Clinton van den Bergh, Biologic, pers. comm.). In addition, juvenile *M. argentea* along the northern gorge wall have recently been observed to be dead or dying (Clinton van den Bergh, Biologic, pers. comm.). This indicates groundwater is lowering beyond the depth of their root zone, and at a rapid rate. Detrimental impacts to the tree health of *Melaleuca argentea* trees have been recorded to occur with as little as a 0.5 m decrease in groundwater levels (McLean, 2014).

5.4 Zooplankton

A total of 55 zooplankton taxa was recorded from the Survey Area, including protists, rotifers, copepods, Cladocera and ostracods. As is common with zooplankton across the Pilbara, and more broadly across the world (Klais *et al.*, 2016; Zhang *et al.*, 2019), richness was highly spatially and temporally variable within the Survey Area. Within the Survey Area, YC3 recorded a higher richness in the Wet 2022 compared to the Dry 2021, while wet season richness was lower at YC4 compared to the dry season. In general, zooplankton richness from Yandicoogina Creek was comparable to reference sites. Seasonal variation was high, in both the Survey Area and at reference sites, with lower zooplankton richness generally recorded following floods. Being planktonic, zooplankton are highly responsive to increases in flow and flooding events, with high flows likely flushing zooplankton taxa sites, with the population yet to fully re-establish.

Zooplankton richness recorded during the current study was also compared to previous surveys undertaken in nearby creek systems. Similar to previous results, the Survey Area was found to exhibit comparable average zooplankton richness to nearby creek systems, including Marillana Creek, Weeli Wolli Creek (and Spring), Munjina Creek and the Davis River. Overall, there was no significant difference in zooplankton richness between creeks or seasons. While there was high variability in zooplankton richness, within a creek system within a season, variability in the Survey Area was much lower than most other creeklines included in the analysis, especially Munjina Spring and the Davis River. This is likely due to the permanent nature of the pools within Yandicoogina Creek, coupled with the slower flows and reduced impacts of flooding in this system compared to others such as the Davis River and Weeli Wolli Spring, and therefore greater zooplankton residence time and persistence of habitat. However, if surface water levels continue to decline, persistence and security of habitat for zooplankton will be reduced, likely leading to increased variability and a decline in richness.

One taxon recorded during the current study, *Meridiescandona* `sp. Biologic-OSTR074`, was of conservation significance. This study denotes the first record of this OTU, with all current known specimens only recorded from within the Survey Area. Morphological characteristics were similar to that of the described species *Meridiescandona marillanae*, although current information is not sufficient to confirm this. Further morphological and molecular work may enable this OTU to be aligned with the described species in future. *Meridiescandona marillanae* is only known from shallow groundwaters of Marillana Creek, and the species is considered likely to have a small range.

5.5 Hyporheos Fauna

A total of 98 invertebrate taxa was recorded from hyporheic zones within the Survey Area. Of these, a total of 19% are directly dependant on groundwater for persistence (i.e., stygobites and permanent hyporheos stygophiles). The percentage of stygobitic taxa recorded from the Survey Area was found to be notably high in comparison to that reported previously for Pilbara hyporheic zones (i.e., 5% stygobitic fauna recorded in Halse *et al*. 2002). As identified previously (Biologic, 2020c, 2022b), the high proportion of stygobitic taxa reflects the strong groundwater connection within this reach of Yandicoogina Creek. Troglofauna comprised 3% of the taxa collected, and though terrestrial, were considered of interest and reported here due to the lack of information on troglofauna within the Survey Area. All troglofauna taxa were recorded in the Wet 2022 from the additional hyporheic sampling sites which do not always have an inundated hyporheic zone (i.e., YC6H, YC8H and YC9H). It is perhaps unsurprising that these were the sites where troglofauna were recorded, given they would likely represent a humid, subterranean environment, that is not often inundated in comparison to the other sites sampled for hyporheos fauna in Yandicoogina Creek where shallow groundwater would be much more persistent. The three troglofauna taxa recorded all constituted first records (Chthoniidae `sp. Biologic-PSEU083`, Projapygidae `sp. Biologic-DIPL053`, and *Hanseniella* `sp. Biologic-SYMP054`).

In the Dry 2021, the Survey Area generally recorded low hyporheic richness. This was influenced by the declining water levels and fact that two routine sampling sites were dry at the time of the Dry 2021 survey, and none of the additional hyporheic sites had available hyporheic habitat (no water present). However, during the Wet 2022 several sites recorded high richness of stygobionts including, YC1 (five taxa), YC5H (seven taxa) and YC9H (five taxa). This suggests that hyporheic habitat must have been maintained at some locations beneath the creekbed, in close proximity to these sampling sites, and that the habitat was not entirely lost between the dry season and the Wet 2022.

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

- the ostracod *Meridiescandona* `sp. Biologic-OSTR074` (YC3 and YC5H) - the OTU is currently only known from within the Survey Area. Though it may represent the known, described species *Meridiescandona marillanae*, that species is also known from a small range. Further morphological and molecular work is required to confirm the alignment of the OTU with the described species.
- the ostracod *Gomphodella* `sp. Biologic-OSTR077` (YC7H) – identified through a combination of morphology and molecular analysis. The current study denotes the first record of this OTU and based on current information, is only known from within the Survey Area, though this may change with additional work elsewhere.
- the amphipod *Chydaekata* `sp. E` (YC3) - restricted to Marillana, Upper Weeli Wolli and Yandicoogina Creeks (previously also recorded from the Survey Area at sites YC3, YC4, YC5H, YC7H and YC9H).
- the amphipod Paramelitidae `sp. Biologic-AMPH023` (YC3) - known only from Yandicoogina Creek, Marillana Creek and lower Weeli Wolli Creek (downstream of the confluence with Marillana). Previously also recorded from the Survey Area at sites YC1, YC3, YC5H and YC9H.
- the syncarid *Atopobathynella* `sp. Biologic-PBAT042` (YC1) – this study represents the first record of this OTU and given parabathynellids are known to have restricted ranges, this taxon should be considered a Potential SRE (Data Deficient).
- the syncarid Bathynellidae `sp. Biologic-BATH019` (YC1) – this is the first record of this OTU and it is likely to represent a Potential SRE (Data Deficient).

- The isopod *Pygolabis* `sp. Biologic-ISOP035` (YC5H, YC8H and YC9H) – current information indicates this species is restricted to within the Survey Area. Previously recorded at YC3.

The richness of occasional hyporheos taxa recorded from the Survey Area has generally increased over time, since surveys in the creek began in 2019. This continued increase in occasional hyporheos taxa recorded within Survey Area hyporheic zones may be due to lowering surface water levels, with an increased number of surface taxa taking refuge in the hyporheic zone. Overall, this change was not significant and there was no significant difference in hyporheos fauna, occasional hyporheos taxa or stygobitic taxa richness between sampling events. This result was influenced by the large variation within sampling events, both in the Survey Area and at reference sites.

5.6 Macroinvertebrates

A total of 160 macroinvertebrate taxa was recorded from the Survey Area during the current study. The composition of macroinvertebrate fauna within the Survey Area was similar to most Pilbara pools and was dominated by slow flow and relatively tolerant taxa, i.e., Coleoptera and Diptera. Richness within the Survey Area was variable, and while YC3 and YC4 continued to record relatively high richness, there was notable seasonal variation. There was a large reduction in macroinvertebrate richness at YC4 in the Wet 2022 which was likely due to flooding following the high rainfall event in late March, immediately prior to the survey. Invertebrates had likely been flushed downstream and/or were taking refuge in the deeper, less accessible parts of the YC4 pool. Surface water was observed to be flowing into the pool at the time of sampling, with riffle sequences present. However, the survey was within days of the rainfall event, and it is therefore unlikely there was sufficient time for invertebrates to re-colonise these flowing areas of creekline. While hydrological processes, including the timing, frequency and extent of flows, flooding and inundation are known to be important natural drivers for aquatic ecosystems in arid zones (Boulton, 1999; Walker *et al.*, 1995), flooding results in increased scouring, transport, and redistribution of sediments and organic matter, which effectively flushes the benthic community downstream (Herbst *et al.*, 2018). Sampling too soon following a flood event can led to reduced invertebrate richness due to this scouring and flushing, with insufficient time for fauna to recolonise and stabilise. Difficulties with field planning and preparation meant that sampling in the Wet 2022 was inadvertently undertaken too soon after the March rainfall event. Studies have shown that within a month of flooding, Pilbara pool assemblages recorded similar richness as they did prior to flooding, as well as similar richness to pools that did not experience floods (Pinder *et al.*, 2010).

The impacts of flooding were not as apparent at YC3, with no flows or riffles present at the time of sampling in the Wet 2022. YC3 is located downstream of YC4, and it is likely the large pool at YC4 located against the bedrock cliff and on a meander, reduced flood velocities for downstream areas. It is well known that river morphology influences the impact of flooding, with more sinuous rivers exhibiting lower flood peaks and water velocities, while having an increased ability to attenuate flow by slowing and storing flood water than straight rivers (Arthington, 2012; Schumm, 1985). The reduced impact of flooding at YC3 was reflected in the macroinvertebrate richness, where greater richness was recorded in the Wet 2022. In fact, richness recorded from YC3 in the wet season was similar to the highest richness recorded during the current study (from reference sites BENS) and was greater than that recorded from SS on the Davis River. Interestingly, macroinvertebrate richness at YC1 and YC2 have always been low due to sampling difficulties associated with low water depths and the abundance of *Typha* at these sites. However, in the Wet 2022, richness at YC1 and YC2 was relatively high, and greater than reference site WWS. The increased depth and habitat availability recorded in the Wet 2022 led to the higher taxa richness. Overall, macroinvertebrate richness recorded from the Survey Area was significantly lower than that recorded from reference sites in the current study.

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

Multivariate analyses on the same dataset of current and previous surveys indicated that macroinvertebrate assemblages of the Survey Area were statistically similar to assemblages of Munjina Spring, Bens Oasis (second occurrence of the Weeli Wolli Spring Priority 1 PEC) and the reference site on Yandicoogina Creek (sampled for MAC4, i.e., MACREF1). Survey Area assemblages were notably different to the non-spring sites on Weeli Wolli Creek and Marillana Creek-Downstream. This is perhaps unsurprising given several Pilbara studies have shown that significantly higher biological richness occurs in permanent waters, in particular groundwater fed, spring systems (Kay *et al.*, 1999; Masini, 1988; Pinder *et al.*, 2010). In fact, Pinder *et al.,* (2010) found aquatic invertebrate assemblage composition was strongly associated with water permanence, flow, water chemistry, the diversity and abundance of macrophytes and sediment type.

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

- the Pilbara emerald, *Hemicordulia koomina* (YC4, as well as reference site BENS and SS) - Vulnerable on the IUCN Red List.
- the Pilbara pin, *Eurysticta coolawanyah* ((YC4, as well as reference site BENS) - Vulnerable on the IUCN Redlist.
- The Pilbara tiger, *Ictinogomphus dobsoni* (YC4 and reference site BENS) – Near Threatened on the IUCN Red List.
- the stygal Potential SRE amphipod *Chydaekata* \`sp. E\` (surface waters of YC4, and reference site WWS) - known only from Yandicoogina Creek, Marillana Creek, and Upper Weeli Wolli Creek.
- The stygal Potential SRE amphipod Paramelitidae \`sp. Biologic-AMPH023\` (surface waters of YC3) – known only from Yandicoogina Creek, Marillana Creek, and Lower Weeli Wolli Creek.
- The water mite *Wandesia* sp. (surface waters of YC1), likely the same species which occurred in the hyporheic zone of YC3.

Analysis of the macroinvertebrate assemblages of Yandicoogina Creek (across all sampling events) showed a strong and significant correlation with four environmental variables, including water temperature, turbidity, concentration of dissolved aluminium, and maximum depth. Given there does not appear to be a significant decline in macroinvertebrate richness over time (accompanying the lowering water levels), the relationship between richness and water depth was further investigated using linear regression. Macroinvertebrate richness was found to be significantly correlated with maximum depth in pools ($R = 0.52$, $p = 0.013$), with greater richness recorded from deeper pools (Figure 5.1). This suggests that although the richness of macroinvertebrate richness does not show a decline over time currently, macroinvertebrates (richness and assemblages) are responding to the lowering water levels. Reduced flows from aquifers to surface water pools can compromise pool ecosystems in a number of ways, including reductions to pool size, longevity, connectivity between pools, and linkages between pools and riparian zones (i.e., where pools contract away from the river bank) (Boulton & Hancock, 2006). Indirect effects resulting from such changes include declines in water quality, increasing water temperature, altered patterns of submerged and emergent macrophyte growth, increased intensity of disturbance by cattle, reduced habitat diversity and altered community interactions (i.e., changes to predatory fish populations) (Boulton & Hancock, 2006; Pinder & Leung, 2009). The changes in GDVs create a more open understorey, allowing cattle to move further into the Yandicoogina Gorge and creek, which will led to adverse impacts to pools associated with increased nitrogen nutrient concentrations, trampling, erosion, weed dispersal, and increased total suspended solids in-stream. While cattle faeces have been observed at the most downstream end of the Survey Area previously, around YC3, during the tree health monitoring survey in July 2022, a cow was found encroaching further upstream near YC2.

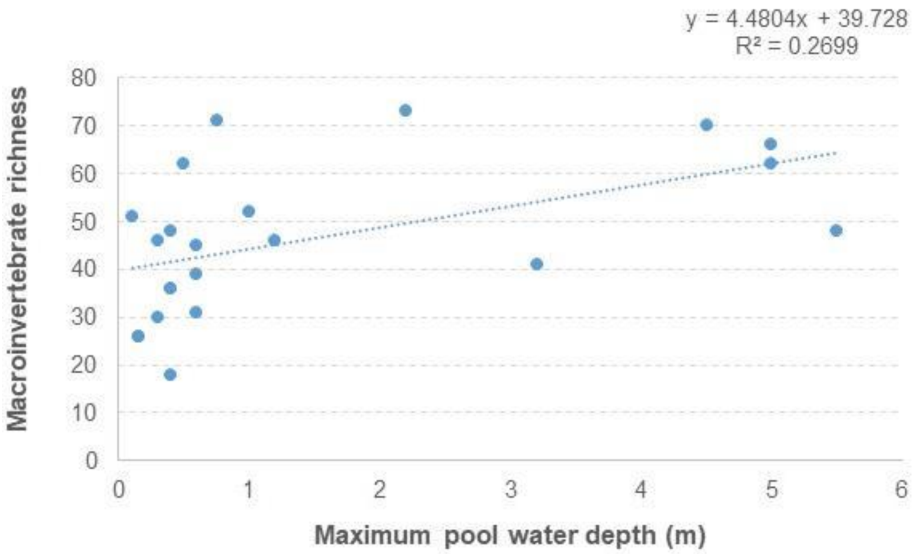

Figure 5.1: Linear regression plot examining the relationship between macroinvertebrate richness and maximum water depth in Yandicoogina Creek pools.

Seasonal drying, or reduced flows and water levels associated with the natural and regular hydrological cycle, is well tolerated by aquatic biota, especially in arid environments such as the Pilbara (Pinder & Leung, 2009). Aquatic biota have both high resistance (populations can survive in situ) and resilience (populations are able to re-establish quickly following drought) to seasonal drying. In comparison, drying which occurs outside the predictable timing and duration of the natural hydrological regime, sometimes referred to as supra-seasonal drought, is more difficult for aquatic biota to overcome. In this way, reduced groundwater inputs to Pilbara pools associated with supra-seasonal drying may exacerbate the ecological effects of natural, seasonal change. Drying is known to have adverse impacts on invertebrate diversity in desert rivers (Boulton & Hancock, 2006; Lake, 2003; Pinder & Leung, 2009), but the effect on fauna of individual pools depends on whether the pool dries completely or reduce to a level which causes conditions to cross the threshold of ecological harm (i.e., evapoconcentration leading to salinity, and/or reductions in DO leading to anoxia) (Lake, 2003). For a river reach such as that within the Survey Area, the impact to the overall reach is related to the proportion of pools negatively affected and whether pools which can act as refugia remain (Boulton & Hancock, 2006). Although macroinvertebrate assemblages within the Survey Area were correlated with water temperature and maximum depth, showing response to lowering water levels, current richness within the Survey Area is still high, and species of conservation significance still present within pools. The large, deep pool at YC4 likely acts as a refuge, with reduced impacts from lowering groundwater levels, providing a source for re-colonisation of nearby pools following re-inundation in the wet season.

5.7 Rehydrates

The rehydration emergence trials were relatively unproductive, yielding a total of seven invertebrate taxa and one submerged macrophyte. This low productivity was likely due to the high salinity recorded within the trial tanks, likely limiting the emergence of freshwater biota. The high salinities experienced in the tanks reflect concentrations of stored salts within the sediments, but in the natural system these likely get flushed with the ‘first flush’ following high rainfall events, which effectively dilutes concentrations within surface waters (EC at the time of sampling in the Dry 2021 was 677 µs/cm at YC3 and 630 µs/cm at YC4).

None of the taxa which emerged from Survey Area sediments are listed as being of conservation significance or represent additional records to the known diversity within Yandicoogina Creek.

5.8 Fish

All freshwater fish species likely to populate the Survey Area were recorded. Although the diversity of fish might be considered low, the results are not surprising given the low diversity of fish across the Pilbara generally, likely due to the region’s aridity (Allen *et al.*, 2002; Masini, 1988; Morgan *et al.*, 2014). Greatest freshwater fish diversity in the region is reported from relatively clear, permanent, and semi-permanent pools. Although the Pilbara tandan is endemic to the region, none of the four species recorded are listed or of conservation significance. All are common and ubiquitous across the Pilbara.

Spangled perch recruitment in the Survey Area likely occurred earlier in the wet season, with individuals growing to the size of juveniles by the time of the Wet 2022 survey. The low abundance of new recruits and juvenile western rainbowfish within the Survey Area suggest low levels of breeding and recruitment. Pilbara bony bream were the least abundant and widespread species recorded during the current study, only found at reference site SS. 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).

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, fishing within the Survey Area is impeded by access, the overgrown *Typha* (particularly at YC2), and inability to utilise the electrofisher due to helicopter access to the gorge. The deep pool at YC4 is also difficult to sample adequately, as the steep sides make it difficult to seine effectively. The difficulties with sampling may have resulted in the significantly lower abundances of spangled perch and western rainbowfish recorded from the Survey Area, in comparison to reference sites. 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 for re-colonisation of other pools following wet season rains.

5.9 Other Vertebrate Fauna

The desert tree frog, *Litoria rubella*, was the only other vertebrate fauna observed in the Survey Area. This is also the only species of frog previously recorded from Yandicoogina Creek during aquatic surveys, however, at least two other species are considered likely to occur, based on database search results and the authors experience in and around the Survey Area. These include the Pilbara toadlet (*Uperoleia saxatilis*) and Mains frog (*Cyclorana maini*). None of these frog species are restricted or listed for conservation significance. All are relatively widespread along creeklines in the Pilbara region.

Other aquatic vertebrates considered likely to occur within the Survey Area included the flat-shelled, or dinner plate turtle (*Chelodina steindachneri*) and the Pilbara olive python (*Liasis olivaceus barroni*). The last shelled turtle is endemic to Western Australia, being 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). They have been recorded from systems that dry for more than two years. *Chelodina steindachneri* is not currently listed on any conservation lists.

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. 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 high significance GDE. Several phreatophytes and mesophytic/ hydrophytic indicator species were present throughout the Survey Area, including *Melaleuca argentea*, *Eucalyptus camaldulensis*, *Imperata cylindrica* (recorded by the Biologic flora team near YC4; (Biologic, 2020a), *Cyperus vaginatus* (highly abundant), *Fimbristylis sieberiana* (P3), and *Schoenoplectus subulatus*. The presence of submerged macrophytes indicative of water permanence (i.e., *Vallisneria nana*) at YC4 further highlights the persistence of surface water. The lowering surface water and groundwater levels are of concern and should be investigated further. Although invertebrate richness has not showed a significant difference between sampling events (i.e., no decline), macroinvertebrate assemblages were shown to be responding to changing water levels. If the decline continues adverse impacts may begin to appear to the aquatic fauna of the Survey Area. Currently, impacts are being noted to GDVs.

While most of the taxa recorded from the Survey Area are generally common and ubiquitous across the Pilbara, a number are of conservation significance, and are either locally restricted or rarely collected (Table 6.1).

6.2 Final remarks

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

The fact that groundwater in the area appears to be declining over time is a concern, and the cause for the decline should be investigated further. The 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 previously persistent/permanent pools completely dried in the Dry 2021 is of concern.

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

Type	Species	Sites Recorded			Conservation significance / Distribution
		Within Survey Area	Reference Sites	Previous surveys (Biologic, 2020c)	
Stygal ostracods	*Meridiescandona facies*		BENS (hyporheos)	YC1 (hyporheos) YC9H (hyporheos)	Known from Weeli Wolli Creek and the central and eastern Fortescue (and more recently Yandicoogina Creek)
	Meridiescandona \`sp. Biologic-OSTR074\`	YC3 (hyporheos & surface waters) YC4 (hyporheos) YC5H (hyporheos)			The OTU is currently only known from within the Survey Area, though it may represent the known, described species *Meridiescandona marillanae*. Further morphological and molecular work is required to confirm this.
	Notacandona boultoni	YC3 (hyporheos)	WWS (hyporheos)		SRE; Known from Weeli Wolli Creek, and now Yandicoogina Creek.
	Candonopsis \`sp. Biologic-OSTR025\`			YC1 (hyporheos)	First record of this OTU (but likely to be more widespread)
	Gomphodella yandii			YC7H (hyporheos)	SRE; known only from Weeli Wolli Creek, Marillana Creek and now Yandicoogina Creek.
	Gomphodella alexanderi			YC3 (hyporheos)	SRE; known only from Marillana Creek and now Yandicoogina Creek, as well as groundwater bores at Yandi.
	Gomphodella \`sp. Biologic-OSTR077\`	YC7H (hyporheos)			Potential SRE, first record. Currently known only from Yandicoogina Creek. Distribution may widen in the future with additional sampling.
Harpacticoid	Canthocamptidae sp. B01			YC3 (hyporheos)	SRE; previously known only from bores within the Yandi area.
Syncarida	Bathynelllidae \`sp. Biologic-BATH008\`			YC9H (hyporheos)	New genus. Not previously known. More than 18% divergent from all other sequences in the genetic analysis (Biologic, 2022c).
	Bathynellidae \`sp. Biologic-BATH019\`	YC1 (hyporheos)			Potential SRE, first record of this OTU. 12% divergent from Bathynelllidae \`sp. Biologic-BATH008\`. Currently only known from Yandicoogina Creek.
	Atopobathynella \`sp. Biologic-PBAT042\`	YC1 (hyporheos)			Potential SRE, first record of this OTU. Currently only known from Yandicoogina Creek.
Stygal amphipods	*Chydaekata* sp. \`E\`	YC3 (hyporheos) YC4 (surface waters)	WWS (hyporheos & surface waters) BENS (hyporheos)	YC3 (hyporheos & surface waters) YC4 (surface waters) YC5H (hyporheos) YC7H (hyporheos) YC9H (hyporheos)	SRE; known only from Marillana Creek and Upper Weeli Wolli Creek.
	Paramelitidae 'sp. Biologic-AMPH023'	YC3 (hyporheos & surface waters)		YC1 (hyporheos) YC3 (hyporheos) YC5H (hyporheos) YC9H (hyporheos)	SRE; known only from Yandicoogina Creek, Marillana Creek and lower Weeli Wolli Creek (downstream of the confluence with Marillana).
Stygal isopod	*Pygolabis* \`sp. Biologic-ISOP035\`	YC5H (hyporheos) YC8H (hyporheos) YC9H (hyporheos)		YC3 (hyporheos)* YC4 (hyporheos)* YC5H (hyporheos*) YC7H (hyporheos)* YC9H (hyporheos)*	Potential SRE, first record. Currently known only from Yandicoogina Creek.
Water mites	*Austraturus* sp. P2			YC4 (surface waters)	Undescribed Species. Morphotype with a disjunct distribution in the Pilbara. Appears to be restricted to permanent pools of good ecological condition.
	Wandesia sp.	YC1 (surface waters) YC3 (hyporheos)		YC3 (hyporheos) YC6H (hyporheos)	Species identification unknown, may be uncommon, with a disjunct distribution in the Pilbara

Type	Species	Sites Recorded			Conservation significance / Distribution
		Within Survey Area	**Reference Sites**	**Previous surveys (Biologic, 2020c)**	
Damselfly	*Eurysticta coolawanyah*	YC4 (surface waters)	BENS (surface waters)	YC4 (surface waters)	Vulnerable IUCN Red List
Dragonflies	*Hemicordulia koomina*	YC4 (surface waters)	BENS (surface waters)	YC1 (surface waters) YC3 (surface waters) YC4 (surface waters)	Vulnerable IUCN Red List
	Ictinogomphus dobsoni	YC4 (surface waters)	BENS (surface waters)	YC3 (surface waters)	Near Threatened IUCN Red List

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

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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 Attractions Priority codes

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

Appendix B: Default 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). Data derived from trigger values supplied by Australian states and territories, for the Northern Territory and regions north of Carnarvon in the west and Rockhampton in the east (ANZECC & ARMCANZ, 2000).

Aquatic Ecosystem	Analyte TP mg/L	FRP mg/L	TN mg/L	NOx mg/L	NH_4^+ mg/L	DO % saturation[f]	pH
Upland River[e]	0.01	0.005	0.15	0.03	0.006	90-120	6.0-7.5
Lowland River[e]	0.01	0.004	0.2-0.3[h]	0.01[b]	0.01	85-120	6.0-8.0
Lakes	0.01	0.005	0.35[c]	0.01[b]	0.01	90-120	6.0-8.0
Wetlands[3]	0.01-0.05[g]	0.05-0.025[g]	0.35-1.2[g]	0.01	0.01	90[b]-120 [b]	6.0-8.0

b = Northern Territory values are 0.005mg/L for NO_x, and < 80 (lower limit) and >110% saturation (upper limit) for DO;

c = this value represents turbid lakes only. Clear lakes have much lower values;

e = no data available for tropical WA estuaries or rivers. A precautionary approach should be adopted when applying default trigger values to these systems;

f = dissolved oxygen values were derived from daytime measurements. Dissolved oxygen concentrations may vary diurnally and with depth. Monitoring programs should assess this potential variability;

g = higher values are indicative of tropical WA river pools;

h = lower values from rivers draining rainforest catchments.

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

Salinity	(µs/cm)	Comments
Aquatic Ecosystem		
Upland & lowland rivers	20-250	Conductivity in upland streams will vary depending on catchment geology. The first flush may result in temporarily high values
Lakes, reservoirs & wetlands	90-900	Higher conductivities will occur during summer when water levels are reduced due to evaporation
Turbidity	**(NTU)**	
Aquatic Ecosystem		
Upland & lowland rivers	2-15	Can depend on degree of catchment modification and seasonal rainfall runoff
Lakes, reservoirs & wetlands	2-200	Most deep lakes have low turbidity. However, shallow lakes have higher turbidity naturally due to wind-induced re-suspension of sediments. Wetlands vary greatly in turbidity depending on the general condition of the catchment, recent flow events and the water level in the wetland.

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

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

Notes:

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

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

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

B = Chemicals for which possible bioaccumulation and secondary poisoning effects should be considered (Section 8.3.3.4)

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

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

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

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

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

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

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

Appendix C: Habitat results

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

Dry season 2021

		Bedrock	Boulders	Cobbles	Pebbles	Gravel	Sand	Silt	Clay
Yandicoogina Creek	YC3	0	0	18	37	35	8	2	0
	YC4	2	4	3	14	23	20	12	22
References	WWS	2	1	12	32	42	8	3	0
	BENS	2	4	2	21	36	32	2	1
	MUNJS	91	1	0	3	2	1	2	0
	SS	3	0	9	27	39	18	3	1

Wet season 2022

		Bedrock	Boulders	Cobbles	Pebbles	Gravel	Sand	Silt	Clay
Yandicoogina Creek	YC1	2	1	24	26	20	7	15	5
	YC2	1	1	10	18	26	22	16	6
	YC3	0	0	18	35	31	8	8	0
	YC4	2	4	3	17	23	20	16	15
References	WWS	6	1	9	30	28	18	8	0
	BENS	2	4	2	21	31	27	12	1
	MUNJS	89	1	0	3	2	1	4	0
	SS	1	0	9	25	34	18	10	3

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

Dry season 2021

		Inorganic seds	Sub. mac.	Emerg. mac.	Algae	LWD	Detritus	Roots	Trailing veg.	Habitat types
Yandicoogina Creek	YC3	4	5	34	40	0	5	0	12	6
	YC4	40	9	10	2	15	18	4	2	8
References	WWS	54	0	1	32	4	2	6	1	7
	BENS	47	1	1	1	12	22	11	5	8
	MUNJS	51	12	10	10	8	3	3	3	8
	SS	7	2	2	48	4	24	12	1	8

Wet 2022

		Inorganic seds	Sub. mac.	Emerg. mac.	Algae	LWD	Detritus	Roots	Trailing veg.	Habitat types
Yandicoogina Creek	YC1	50	0	25	6	4	8	4	3	6
	YC2	2	0	62	5	6	8	9	8	8
	YC3	45	0	25	11	1	5	0	13	7
	YC4	44	1	9	2	15	18	6	5	8
References	WWS	76	0	2	2	2	4	12	2	8
	BENS	38	0	1	11	12	22	11	5	8
	MUNJS	50	10	9	10	8	6	3	4	0
	SS	36	3	2	10	6	25	15	3	0

Appendix D: Water quality data

Dry season 2021

		ANZG DGV		Within Survey Area		Reference Sites			
Analyte	**Units**	**99% DGV**	**95% DGV**	**YC3**	**YC4**	**MUNJS**	**BENS**	**WWS**	**SS**
Temperature	ºC			24.5	21.5	22.8	24.2	26	22.5
Conductivity (EC)	µS/cm		250	677	630	902	954	984	639
pH	pH units		6-8	7.67	7.39	8.07	7.76	6.2	8.33
Redox	mV			36.9	88.6	75.2	36.5	108.5	72
DO	%		85-120	26.9	47.8	88.2	50.1	44.5	35.2
Turbidity	NTU		15	1.3	2.6	2.7	2.1	0.5	0.6
TSS	mg/L			7	5	1	2	<1	2
Alkalinity	mg/L			264	256	232	428	355	257
Hardness	mg/L			238	245	275	419	402	248
Na	mg/L			41.3	43.7	72.2	25.4	43.2	37.8
Ca	mg/L			47.2	47.8	38.2	61.9	69.9	48.2
Mg	mg/L			29.2	30.6	43.6	64.2	55.2	30.9
K	mg/L			10.4	11	9.5	4.9	9	4.6
HCO_3	mg/L			264	256	232	428	355	257
Cl	mg/L			41	44	173	58	80	45
S_SO_4	mg/L			10.50	10.20	1.50	10.00	20.60	7.10
CO_3	mg/L			<1	<1	<1	<1	<1	<1
dAl	mg/L	0.027	0.055	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
dAs	mg/L	0.001	0.024	<0.0002	0.0002	0.0002	0.0004	0.0003	<0.0002
dB	mg/L	0.09	0.37	0.113	0.117	0.133	0.128	0.325	0.072
dBa	mg/L			0.0288	0.0205	0.0609	0.0515	0.0089	0.2080
dCd	mg/L	0.00006	0.0002	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005
dCo	mg/L			<0.0001	<0.0001	<0.0001	0.0003	<0.0001	<0.0001
dCr	mg/L	0.00001	0.001	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002
dCu	mg/L	0.001	0.0014	0.00007	0.00006	<0.00005	0.00028	<0.00005	0.00008
dFe	mg/L	0.300*		0.044	0.026	0.084	0.018	0.006	0.038
dMn	mg/L	1.2	1.9	0.0021	0.0028	0.0130	0.0802	<0.0005	0.1310
dMo	mg/L			0.0001	0.0002	<0.0001	0.0002	0.0002	0.0002
dNi	mg/L	0.008	0.011	<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
dS	mg/L			11.20	10.10	1.39	10.90	20.40	7.13
dSe	mg/L	0.005	0.011	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	0.0003
dU	mg/L			0.00015	0.00017	<0.00005	0.00051	0.00069	0.00065
dV	mg/L			0.0010	0.0016	0.0002	0.0010	0.0023	0.0014
dZn	mg/L	0.0024	0.008	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
N_NH_3	mg/L	0.32	0.90	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
N_NO_3	mg/L	1.00	2.40	<0.01	<0.01	0.02	<0.01	0.05	0.22
N_NOx	mg/L		0.01	<0.01	<0.01	0.02	<0.01	0.05	0.22
Total N	mg/L		0.30	0.15	0.32	0.17	0.15	0.05	0.30
Total P	mg/L		0.01	0.038	0.053	0.034	0.018	0.022	0.017

Wet season 2022

		ANZG DGV		Within Survey Area				Reference Sites			
Analyte	Units	99% DGV	95% DGV	YC1	YC2	YC3	YC4	MUNJS	BENS	WWS	SS
Temperature	°C			28.6	28	27.2	27	24.3	26.7	25.7	28.1
Conductivity (EC)	µS/cm		250	623	569	675	444	452	514	975	492
pH	pH units		6-8	7.09	7.36	7.03	7.19	8.04	7.4	7.42	7.84
Redox	mV			20	-1.8	-63.6	-53.5	-21.4	0.9	124.7	-23.1
DO	%		85-120	38.7	47.8	12.2	17.6	88.8	26.2	71.7	55.8
Turbidity	NTU		15	1.6	2.1	1.5	1.0	1.1	2.5	<0.1	5.8
TSS	mg/L			<1	3	1	<1	<1	2	<1	8
Alkalinity	mg/L			221	198	230	157	93	213	303	199
Hardness	mg/L			230	218	250	161	132	224	382	186
Na	mg/L			33	32.6	37.9	24.1	36.1	10.4	41.4	29.6
Ca	mg/L			46.1	43.3	48.4	32.9	18.6	40.2	68.4	37.4
Mg	mg/L			28	26.6	31.4	19.2	20.7	30.0	51.2	22.4
K	mg/L			10.8	10.7	12.7	8.7	7.6	3.4	8.9	4.7
HCO_3	mg/L			221	198	230	157	93	213	303	199
Cl	mg/L			30	30	36	24	79	16	83	30
S_SO_4	mg/L			20.2	19.5	20.8	14.40	9.40	3.80	20.00	5.20
CO_3	mg/L			<1	<1	<1	<1	<1	<1	<1	<1
dAl	mg/L	0.027	0.055	0.015	0.013	<0.005	<0.005	0.006	0.016	<0.005	0.017
dAs	mg/L	0.001	0.024	0.0002	0.0002	0.0003	0.0002	<0.0002	0.0005	0.0003	<0.0002
dB	mg/L	0.09	0.37	0.113	0.118	0.137	0.121	0.116	0.037	0.210	0.061
dBa	mg/L			0.0212	0.0204	0.0315	0.0223	0.0388	0.0335	0.0106	0.1440
dCd	mg/L	0.00006	0.0002	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005
dCo	mg/L			0.0002	0.0002	0.0002	0.0003	<0.0001	0.0004	<0.0001	<0.0001
dCr	mg/L	0.00001	0.001	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002
dCu	mg/L	0.001	0.0014	0.00040	0.00028	0.00016	0.00026	0.00012	0.00055	0.00017	0.00038
dFe	mg/L	0.300*		0.077	0.088	0.176	0.172	0.246	0.099	<0.002	0.034
dMn	mg/L	1.2	1.9	0.0259	0.028	0.0348	0.0343	0.0244	0.5060	<0.0005	0.0558
dMo	mg/L			0.0002	0.0002	0.0002	0.0002	<0.0001	0.0002	0.0002	0.0002
dNi	mg/L	0.008	0.011	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
dPb	mg/L	0.001	0.0034	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
dS	mg/L			20.40	18.60	20.30	14.70	9.27	3.87	19.60	5.27
dSe	mg/L	0.005	0.011	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	0.0002	0.0003
dU	mg/L			0.00021	0.00016	0.00018	0.00018	<0.00005	0.00020	0.00076	0.00040
dV	mg/L			0.0019	0.0016	0.0005	0.0012	0.0003	0.0009	0.0018	0.0020
dZn	mg/L	0.0024	0.008	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
N_NH_3	mg/L	0.32	0.90	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
N_NO_3	mg/L	1.00	2.40	0.07	<0.01	0.02	0.04	<0.01	<0.01	0.04	0.29
N_NOx	mg/L		0.01	0.07	<0.01	0.02	0.04	<0.01	<0.01	0.04	0.29
Total N	mg/L		0.30	0.22	0.2	0.12	0.19	0.15	0.16	0.03	0.34
Total P	mg/L		0.01	0.018	0.021	0.016	0.018	0.018	0.017	0.014	0.016

Appendix E: Zooplankton taxonomic list

Dry season 2021

			Survey Area		Reference			
Phylum/Class/Order	**Family**	**Lowest taxon**	**YC3**	**YC4**	**WWS**	**BENS**	**MUNJS**	**SS**
PROTISTA								
SARCOMASTIGOPHORA		Sarcomastigophora sp.	0	3	0	1	1	2
CILIOPHORA		Ciliophora sp.	0	2	0	2	1	2
Prostomatea								
Prorodontida	**Colepidae**	*Coleps* sp.	0	0	0	2	0	0
ROTIFERA		Rotifera sp.	0	1	0	2	2	1
Bdelloidea		Bdelloidea sp.	0	2	1	2	2	1
Philodinida	**Habrotrochidae**	*Habrotrocha* sp.	0	0	0	0	1	0
Monogononta								
Flosculariaceae	**Hexarthridae**	cf. *Hexarthra* sp.	0	0	0	1	0	0
	Testudinellidae	*Testudinella* sp.	0	0	0	2	0	2
Ploima	**Brachionidae**	*Keratella procurva*	0	0	0	1	0	0
	Euchlanidae	*Euchlanis* sp.	0	0	0	0	2	0
	Lecanidae	*Lecane* sp.	1	2	0	0	1	1
		Lecane bulla	0	0	0	1	0	0
		Lecane cf. *batillifer*	0	0	0	0	0	1
		Lecane cf. *bulla*	0	0	0	0	2	0
		Lecane cf. *hamata*	2	0	0	0	0	0
		Lecane cf. *opias*	0	0	0	0	0	2
	Lepadellidae	*Lepadella* (*Lepadella*) sp.	0	1	0	0	2	1
		Colurella sp.	0	2	0	0	0	0
		Colurella cf. *uncinata*	0	2	0	0	0	2
		Lepadella (*Lepadella*) cf. *benjamini*	0	0	0	0	3	0
		Lepadella (*Lepadella*) cf. *patella*	0	0	0	0	4	2
	Mytilinidae	*Mytilina* cf. *ventralis*	0	0	0	0	2	0
	Notommatidae	*Cephalodella* sp.	0	0	0	3	0	0
	Synchaetidae	*Polyarthra* sp.	0	2	0	1	0	0
		Polyarthra vulgaris	0	0	0	0	0	2
	Tetrasiphonidae	*Tetrasiphon* sp.	0	0	0	1	0	0
	Trichocercidae	*Trichocerca* sp.	0	2	0	3	1	1
		Trichocerca cf. *intermedia*	0	2	0	0	0	0
		Trichocerca similis	0	3	0	4	2	2
	Trichotriidae	*Macrochaetus* cf. *subquadratus*	0	0	0	0	0	1

Phylum/Class/Order	Family	Lowest taxon	Survey Area YC3	YC4	Reference WWS	BENS	MUNJS	SS
ARTHROPODA								
CRUSTACEA								
Branchiopoda								
Diplostraca	**Chydoridae**	*Alona* sp.	0	3	0	0	1	2
		Alona cf. *rigidicaudis*	0	0	0	0	0	3
		Chydorus sp.	0	4	0	0	0	0
		Ephemeroporus cf. *barroisi*	1	0	0	0	1	0
	Daphniidae	*Ceriodaphnia* sp.	0	3	0	0	0	2
Ostracoda		Ostracoda sp. (juv. Indet.)	0	0	0	0	1	0
Podocopida	**Candonidae**	*Candonopsis* cf. *tenuis*	0	2	0	0	0	0
	Cyprididae	*Bennelongia tirigie*	0	0	0	0	4	0
		Cypretta `sp. Biologic-OSTR029`	0	2	0	0	0	0
		Cypridopsis `sp. Biologic-OSTR011`	0	2	0	0	0	0
		Ilyodromus sp.	0	0	0	0	2	1
	Darwinulidae	Darwinulidae sp.	1	0	0	0	0	0
		Vestalenula sp.	0	2	0	0	0	0
		Vestalenula marmonieri	0	2	0	0	0	0
	Notodromadidae	*Newnhamia fenestrata*	0	0	0	0	3	0
Maxillopoda		Copepoda sp. (nauplii)	1	4	2	0	0	0
Calanoida		Calanoida sp. (juv. Indet.)	0	0	2	0	0	2
Cyclopoida		Cyclopoida sp. (juv. Indet.)	2	0	0	0	3	3
	Cyclopidae	Cyclopidae sp.	0	0	1	0	0	0
		Eucyclops australiensis	0	0	1	0	0	3
		Mesocyclops brooksi	0	4	0	5	2	0
		Mesocyclops darwini	2	0	0	3	2	3
		Mesocyclops notius	0	4	0	0	0	0
		Microcyclops varicans	3	0	0	0	0	3
		Paracyclops cf. *fimbriatus*	0	0	0	0	1	0
		Thermocyclops cf. *decipiens*	0	0	0	4	0	2
		Tropocyclops cf. *prasinus*	0	0	0	5	0	0
		Tropocyclops confinus confinus	2	5	0	0	5	2
Poecilostomatoida	**Ergasilidae**	cf. *Ergasilus* sp.	0	0	0	0	0	2
		Taxa richness	**9**	**24**	**5**	**18**	**25**	**27**

Wet season 2022

			Survey Area				Reference			
Phylum/Class/Order	**Family**	**Lowest taxon**	**YC1**	**YC2**	**YC3**	**YC4**	**WWS**	**BENS**	**MUNJS**	**SS**
PROTISTA		Testate Amoeba	0	2	0	0	2	1	0	0
AMOEBOZOA		Testate Amoeba cf. Hyalospheniformis sp.	0	0	0	0	0	1	0	0
Tubulinea		Tubulinea sp.	0	2	0	0	0	0	0	0
cf. Arcellinida		cf. Arcellinida sp.	0	0	0	0	0	0	0	2
CILIOPHORA		Ciliate sp. indet.	0	2	0	1	1	0	0	1
Prostomatea										
Prorodontida	**Colepidae**	cf. *Coleps* sp.	0	0	0	0	0	0	0	2
GASTROTRICHA		Gastrotricha sp.	0	0	0	0	0	2	0	0
ROTIFERA		Rotifera sp.	2	2	0	0	0	1	0	0
Bdelloidea		Bdelloidea sp.	0	0	2	1	0	0	1	1
Monogononta										
Ploima	**Brachionidae**	*Platyias quadricornis*	0	0	1	0	0	0	0	0
	Branchionidae	*Keratella* sp.	0	0	0	0	0	0	2	0
	Euchlanidae	*Euchlanis* cf. *dilatata*	2	0	0	0	0	0	0	0
	Lecanidae	*Lecane* sp.	0	1	2	0	0	0	0	1
		cf. *Lecane* sp.	0	0	1	0	0	0	0	0
		Lecane arcuata	0	0	0	1	0	0	0	0
		Lecane cf. *bulla*	0	0	2	0	0	0	0	1
		Lecane cf. *decipiens*	0	0	2	0	0	0	0	0
		Lecane cf. *grandis*	0	1	0	0	0	0	0	0
		Lecane cf. *opias*	0	1	2	1	0	0	0	0
		Lecane cf. *rhenana*	0	2	0	0	0	0	0	0
		Lecane hastata	0	0	0	0	0	0	1	0
	Lepadellidae	*Colurella* cf. *obtusa*	0	0	0	0	0	0	1	0
		Colurella cf. *uncinata*	0	0	2	0	1	0	0	0
		Lepadella sp.	0	0	2	0	1	0	0	0
		Lepadella cf. *patella*	0	0	2	0	2	0	0	1
	Trichocercidae	*Trichocera* sp.	0	0	0	0	1	0	0	0
ARTHROPODA										
CRUSTACEA										
Ostracoda		Ostracoda sp. (juv. Indet.)	0	0	0	2	0	0	0	0

			Survey Area				Reference			
Phylum/Class/Order	**Family**	**Lowest taxon**	**YC1**	**YC2**	**YC3**	**YC4**	**WWS**	**BENS**	**MUNJS**	**SS**
Podocopida										
	Candonidae	*Candonopsis* cf. *tenuis*	0	0	2	3	0	0	0	0
		Meridiescandona `sp. Biologic-OSTR074`	0	0	2	0	0	0	0	0
	Cyprididae	*Bennelongia strellyensis*	0	0	0	0	0	0	4	0
		Cypretta sp.	0	0	3	0	0	0	0	0
		Cypretta `sp. Biologic-OSTR076`	0	0	0	0	0	0	2	0
		Cyprididae sp.	0	0	0	2	0	0	0	0
		Cyprididae `sp. Biologic-OSTR021`	4	5	0	0	0	0	0	0
		Cyprididae `sp. Biologic-OSTR049`	0	0	0	0	0	1	0	0
		Cyprididae `sp. Biologic-OSTR075`	0	0	0	0	0	0	2	0
		Cypridopsis `sp. Biologic-OSTR011`	0	0	3	0	2	0	0	0
		Ilyodromus `sp. Biologic-OSTR014`	0	0	0	0	0	0	2	0
		Riocypris fitzroyi	0	0	2	0	0	0	0	0
		Stenocypris major	0	0	2	0	0	0	2	1
	Darwinulidae	*Darwinula* sp.	2	2	0	1	0	0	0	0
	Notodromadidae	*Newnhamia fenestrata*	3	3	0	0	0	0	4	0
Maxillopoda		Copepoda sp. (nauplii)	0	0	0	0	1	0	0	0
Cyclopoida		Cyclopoida sp. (juv. Indet.)	2	2	3	3	2	3	3	3
	Cyclopidae	*Ectocyclops phaleratus*	0	0	1	0	0	1	0	0
		Mesocyclops brooksi	0	0	0	0	0	0	0	3
		Mesocyclops darwini	0	0	2	7	0	0	2	2
		Mesocyclops notius	2	0	1	0	0	2	2	2
		Microcyclops varicans	2	1	3	4	0	1	0	2
		Thermocyclops cf. *decipiens*	0	0	0	3	0	0	0	0
		Taxa richness	**8**	**13**	**21**	**12**	**9**	**9**	**13**	**13**

Appendix F: Hyporheic fauna taxonomic list

Dry season 2021

Phylum/Class/Order	Family	Lowest taxon	Survey Area YC3	Survey Area YC4	Reference WWS	Reference BENS	Reference MUNJS	Reference SS
CNIDARIA								
Hydrozoa								
Anthoathecata	**Hydridae**	*Hydra* sp.	2	0	0	0	0	0
NEMATODA		Nematoda sp.	0	0	1	0	0	0
MOLLUSCA								
Gastropoda								
Hygrophila	**Lymnaeidae**	*Bullastra vinosa*	0	0	0	0	0	1
ANNELIDA								
Oligochaeta								
Tubificida	**Enchytraeidae**	Enchytraeidae sp.	0	0	0	0	0	1
	Naididae	Naidinae sp. (imm./dam.)	4	2	1	2	0	0
		Dero sp. (imm./dam.)	0	0	0	0	0	1
		Dero furcata	0	0	0	2	0	0
		Dero nivea	0	2	0	0	0	0
		Nais communis	0	2	0	0	0	0
		Nais variabilis	0	2	0	0	0	0
		Pristina aequiseta	3	2	0	0	3	0
		Pristina leidyi	3	1	0	0	0	2
		Pristina longiseta	3	2	1	0	0	0
		Pristina sima	0	0	0	0	0	1
	Phreodrilidae	Phreodrilidae sp.	0	0	0	0	3	1
ARTHROPODA								
ARACHNIDA								
Mesostigmata		Mesostigmata sp.	1	1	0	3	0	1
Sarcoptiformes		Oribatida sp.	1	0	0	0	0	0
		Trombidioidea sp.	0	0	0	0	0	2
Trombidiformes	**Halacaridae**	Halacaridae sp.	1	0	0	2	0	0
	Pezidae	Pezidae sp.	0	0	0	1	0	0

			Survey Area		Reference			
Phylum/Class/Order	**Family**	**Lowest taxon**	**YC3**	**YC4**	**WWS**	**BENS**	**MUNJS**	**SS**
CRUSTACEA								
Maxillopoda								
Cyclopoida	**Cyclopidae**	*Ectocyclops phaleratus*	0	0	1	0	3	1
		Microcyclops varicans	3	2	3	2	0	1
		Paracyclops cf. *fimbriatus*	0	0	0	0	3	0
Ostracoda								
Podocopida	**Candonidae**	*Notacandona boultoni*	0	0	3	0	0	0
		Meridiescandona facies	0	0	0	3	0	0
		Meridiescandona `sp. Biologic-OSTR074`	0	2	0	0	0	0
	Darwinulidae	*Vestalenula marmonieri*	2	0	0	0	0	0
Malacostraca								
Amphipoda	**Paramelitidae**	*Chydaekata* sp. E	2	0	2	1	0	0
		Maarrka weeliwolli	0	0	1	0	0	0
		Paramelitidae sp. indet.	0	2	0	0	0	0
		Paramelitidae `sp. Biologic-AMPH024`	0	0	3	0	0	0
		Paramelitidae `sp. Biologic-AMPH049`	0	0	0	0	0	1
COLLEMBOLA								
Entomobryomorpha		Entomobryoidea sp.	0	0	1	3	1	2
INSECTA								
Coleoptera	**Carabidae**	Carabidae sp. (L)	0	0	1	1	0	0
	Dytiscidae	Dytiscidae sp. (L)	0	0	0	1	0	0
		Bidessini sp. (L)	2	0	0	0	1	0
		Copelatus irregularis	0	0	0	0	2	0
		Copelatus nigrolineatus	0	0	0	0	2	0
		Hydroglyphus godeffroyi	1	0	0	0	0	0
		Limbodessus compactus	0	0	0	0	2	0
	Georissidae	*Georissus* sp.	0	0	0	0	0	2
	Hydraenidae	Hydraenidae sp. (L)	0	0	0	0	0	2
		Hydraena sp.	3	0	0	0	2	0
	Hydrochidae	*Hydrochus obscuroaeneus*	0	0	0	0	1	0
	Hydrophilidae	Hydrophilidae sp. (L)	0	0	0	0	0	2
		Chaetarthria nigerrima (L)	0	0	2	0	0	2
		Chaetarthria nigerrima	0	0	0	0	0	1
		Enochrus sp. (L)	0	0	1	0	0	3
		Sternolophus sp. (L)	0	0	0	0	1	0

Phylum/Class/Order	Family	Lowest taxon	Survey Area YC3	Survey Area YC4	Reference WWS	Reference BENS	Reference MUNJS	Reference SS
	Ptiliidae	Ptiliidae sp.	0	0	0	3	0	0
	Scirtidae	Scirtidae sp. (L)	3	0	0	2	3	0
	Staphylinidae	Staphylinidae sp.	0	0	0	2	0	0
Diptera	**Cecidomyiidae**	Cecidomyiidae sp.	0	0	0	2	0	0
	Ceratopogonidae	Ceratopogonidae sp. (P)	0	2	0	0	0	1
		Ceratopogoninae sp.	3	3	2	2	3	3
		Dasyhelea sp.	0	2	3	1	1	2
	Chironomidae							
	Chironominae	Chironominae sp. (imm./dam.)	0	2	0	0	0	2
	Chironomini	*Chironomus* aff. *alternans*	2	0	0	0	0	0
		Polypedilum (*Pentapedilum*) *leei*	0	1	0	0	0	0
		Polypedilum sp.	2	0	0	0	0	0
		Polypedilum sp. K1	0	0	0	0	2	0
	Tanytarsini	*Cladotanytarsus* sp.	0	0	0	0	0	2
		Tanytarsus sp.	2	0	0	0	0	0
	Orthocladiinae	nr. *Gymnometriocnemus* sp.	0	0	0	0	2	0
		Parametriocnemus sp.	0	0	0	0	1	0
	Tanypodinae	*Ablabesmyia hilli*	0	0	1	0	0	0
		?*Australopelopia* sp.	0	0	0	0	0	2
		Larsia ?albiceps	2	0	0	0	0	0
		Paramerina sp. 1	0	0	3	0	0	0
		Paramerina sp. 2	0	0	0	2	0	2
		Procladius sp.	1	0	0	0	0	0
	Culicidae	*Aedes* sp.	0	0	0	0	1	0
		Culex sp.	0	0	0	0	0	1
	Dolichopodidae	Dolichopodidae sp.	0	2	0	0	0	0
	Ephydridae	Ephydridae sp.	2	2	0	0	0	0
	Muscidae	Muscidae sp.	0	2	0	0	0	1
	Stratiomyidae	Stratiomyidae sp.	0	0	0	1	0	0
	Thaumaleidae	Thaumaleidae sp.	0	0	1	0	0	0
	Tipulidae	Tipulidae sp.	0	1	0	0	2	0
Ephemeroptera	**Baetidae**	Baetidae sp. (imm./dam.)	0	0	0	0	0	2
Lepidoptera	**Crambidae**	Acentropinae sp. (imm./dam.)	0	0	0	2	0	0
Odonata		Anisoptera sp. (imm./dam.)	2	0	0	0	0	0
		Zygoptera sp. (imm./dam.)	1	0	0	0	0	0
		Taxa richness	**24**	**20**	**18**	**20**	**20**	**28**

Wet season 2022

			Survey Area									Reference			
Phylum/Class/Order	**Family**	**Lowest taxon**	**YC1**	**YC2**	**YC3**	**YC4**	**YC5H**	**YC6H**	**YC7H**	**YC8H**	**YC9H**	**WWS**	**BENS**	**MUNJS**	**SS**
CNIDARIA															
Hydrozoa															
Anthoathecata	**Hydridae**	*Hydra* sp.	0	0	0	0	0	0	0	0	0	0	1	0	1
PLATYHELMINTHES		Turbellaria sp.	0	0	2	0	0	0	0	0	0	0	0	0	0
ROTIFERA		Rotifera sp.	0	2	0	0	0	0	0	0	0	0	0	0	0
NEMATODA		Nematoda sp.	3	3	1	3	2	3	2	2	3	0	0	2	0
MOLLUSCA															
Gastropoda															
Hygrophila	**Lymnaeidae**	Lymnaeidae sp.	0	1	0	0	0	0	0	0	0	0	0	0	0
ANNELIDA															
Oligochaeta		Oligochaeta sp. (earthworm)	0	0	0	0	2	0	0	0	0	0	0	0	0
Tubificida	**Enchytraeidae**	Enchytraeidae sp.	0	1	0	0	0	2	0	0	0	0	0	0	0
	Naididae	Naidinae sp.	0	0	0	0	0	2	0	0	0	0	3	2	2
		Allonais ranauana	0	0	0	0	0	0	0	0	0	0	0	2	0
		Dero furcata	0	0	0	0	0	0	0	0	0	0	3	0	0
		Dero nivea	0	0	0	0	0	0	0	0	0	0	4	0	0
		Pristina aequiseta	4	0	4	4	2	0	0	0	0	0	3	0	2
		Pristina longiseta	2	0	4	4	1	0	0	0	3	0	0	0	3
	Phreodrilidae	Phreodrilidae sp.	6	0	3	3	3	0	0	3	0	0	0	0	1
ARTHROPODA															
ARACHNIDA		Acari sp.	0	0	2	4	1	2	2	3	3	2	1	4	0
Mesostigmata		Mesostigmata sp.	2	1	0	3	2	2	2	2	2	0	0	2	2
Trombidiformes		Trombidioidea sp.	1	0	2	2	0	0	0	0	0	0	0	0	2
	Anisitsiellidae	*Rutacarus* sp.	0	0	1	0	0	0	0	0	0	0	0	0	0
	Halacaridae	Halacaridae sp.	0	0	3	3	2	2	0	0	3	0	0	0	0
	Hydryphantidae	*Wandesia* sp.	0	0	2	0	0	0	0	0	0	0	0	0	0
	Mideopsidae	*Guineaxonopsis* sp.	0	0	0	0	0	0	2	2	1	0	0	0	0
	Pezidae	Pezidae sp.	2	0	2	0	0	0	0	0	0	0	0	0	0
Sarcoptiformes		Oribatida sp.	3	2	2	2	1	3	1	2	2	0	0	0	1
Pseudoscorpiones	**Chthoniidae**	Chthoniidae `sp. Biologic-PSEU083`	0	0	0	0	0	2	0	0	0	0	0	0	0
CRUSTACEA															
Branchiopoda															
Diplostraca	**Chydoridae**	*Alona* sp.	0	0	0	0	0	0	0	0	0	0	0	0	1
Maxillopoda															
Cyclopoida	**Cyclopidae**	*Diacyclops* nr. *humphreysi*	0	1	0	0	2	0	0	1	0	0	0	0	0
		Dussartcyclops sp.	2	2	0	0	0	0	0	0	2	0	0	0	0
		Microcyclops varicans	2	2	3	2	2	2	0	4	2	0	0	2	2
		Paracyclops sp.	0	0	1	0	0	0	0	0	0	0	0	0	0
		Pescecyclops sp.	0	0	0	0	0	2	3	3	2	0	0	1	0
		Thermocyclops sp.	0	0	1	0	0	0	1	1	1	0	4	0	0
Harpacticoida	**Canthocamptidae**	*Elaphoidella* sp.	0	0	0	0	0	0	1	0	2	0	0	0	0
	Parastenocarididae	*Parastenocaris* `sp. Biologic-HARP022`	1	2	0	0	1	0	1	0	2	0	0	0	0
Ostracoda															
Podocopida	**Candonidae**	*Candonopsis* cf. *tenuis*	0	0	3	3	0	0	0	0	2	0	0	2	0
		Meridiescandona `sp. Biologic-OSTR074`	0	0	2	0	1	0	0	0	0	0	0	0	0
		Notacandona boultoni	0	0	0	0	0	0	0	0	0	1	0	0	0
	Cyprididae	Cyprididae sp.	0	0	0	0	0	0	0	0	0	0	0	1	0
		Cyprididae `sp. Biologic-OSTR021`	3	0	0	0	0	0	0	0	0	0	0	0	0
	Darwinulidae	*Vestalenula marmonieri*	0	0	0	0	3	0	0	0	0	0	0	0	1
		Vestalenula matildae	0	0	0	0	2	0	0	0	0	0	0	0	0

			Survey Area									Reference			
Phylum/Class/Order	**Family**	**Lowest taxon**	**YC1**	**YC2**	**YC3**	**YC4**	**YC5H**	**YC6H**	**YC7H**	**YC8H**	**YC9H**	**WWS**	**BENS**	**MUNJS**	**SS**
	Limnocytheridae	*Gomphodella* sp.	0	0	0	0	0	1	0	0	0	0	0	0	0
		Gomphodella \`sp. Biologic-OSTR077\`	0	0	0	0	0	0	2	0	0	0	0	0	0
		Gomphodella \`sp. Biologic-OSTR078\`	0	0	0	0	0	0	0	0	0	1	0	0	0
Malacostraca															
Bathynellacea	**Bathynellidae**	Bathynellidae \`sp. Biologic-BATH019\`	2	0	0	0	0	0	0	0	0	0	0	0	0
	Parabathynellidae	*Atopobathynella* \`sp. Biologic-PBAT042\`	2	0	0	0	0	0	0	0	0	0	0	0	0
		Atopobathynella \`sp. Biologic-PBAT043\`	0	0	0	0	0	0	0	0	0	0	0	0	2
Amphipoda	**Paramelitidae**	*Chydaekata* sp. E	0	0	2	0	0	0	0	0	0	0	0	0	0
		Paramelitidae \`sp. Biologic-AMPH023\`	0	0	3	0	0	0	0	0	0	0	0	0	0
		Paramelitidae \`sp. Biologic-AMPH024\`	0	0	0	0	0	0	0	0	0	2	0	0	0
		Paramelitidae \`sp. Biologic-AMPH049\`	0	0	0	0	0	0	0	0	0	0	0	0	1
		Paramelitidae sp. indet	1	0	0	0	3	2	0	0	0	0	0	0	0
Isopoda	**Tainisopidae**	*Pygolabis* \`sp. Biologic-ISOP035\`	0	0	0	0	2	0	0	2	2	0	0	0	0
		Pygolabis \`sp. Biologic-ISOP079\`	0	0	0	0	0	0	0	0	0	0	0	0	1
COLLEMBOLA															
Entomobryomorpha		Entomobryoidea sp.	0	3	0	1	3	0	2	2	1	0	0	0	0
Poduromorpha		Poduroidea sp.	3	0	3	3	0	3	3	3	4	0	1	3	1
Symphypleona		Symphypleona sp.	4	3	3	3	2	2	3	4	4	0	1	3	1
ENTOGNATHA															
Diplura	**Projapygidae**	Projapygidae \`sp. Biologic-DIPL053\`	0	0	0	0	0	2	0	1	2	0	0	0	0
INSECTA															
Coleoptera		Coleoptera sp. (L)	0	0	1	2	0	0	0	0	0	0	0	0	0
	Carabidae	Carabidae sp.	0	0	1	0	0	0	0	0	0	0	0	0	0
		Carabidae sp. (L)	2	0	1	1	2	1	0	0	2	0	0	0	0
	Dytiscidae	Bidessini sp. (L)	0	0	2	1	0	0	0	0	0	0	0	0	0
		Dytiscidae sp. (L)	0	0	0	1	0	0	0	0	0	0	0	0	0
		Laccophilus sp. (L)	0	0	0	0	0	0	0	0	0	0	0	0	2
		Limbodessus compactus	0	0	0	1	0	0	0	0	0	0	0	0	0
		Limbodessus occidentalis	0	0	1	0	0	0	0	0	0	0	0	0	0
	Hydraenidae	Hydraenidae sp. (L)	0	0	0	0	1	0	0	0	0	2	0	0	2
		Hydraena sp.	1	1	3	1	1	0	0	1	0	0	0	0	0
		Limnebius sp.	0	0	0	0	0	0	0	0	0	0	0	0	2
	Hydrophilidae	Hydrophilidae sp. (L)	0	0	2	0	0	0	0	0	0	2	0	0	2
		Chaetarthria nigerrima (L)	0	0	0	0	0	0	0	0	0	1	0	0	2
		nr. *Anacaena* sp.	0	0	0	1	0	0	0	0	0	0	0	0	0
	Noteridae	*Neohydrocoptus subfasciatus*	1	0	0	1	0	0	0	0	0	0	0	0	0
	Ptiliidae	Ptiliidae sp.	0	0	0	1	0	0	0	0	0	0	0	0	0
	Scirtidae	Scirtidae sp. (L)	0	1	2	2	0	0	2	0	0	0	3	0	0
	Staphylinidae	Staphylinidae sp.	0	0	1	0	0	0	0	0	0	0	0	0	0
Diptera	**Cecidomyiidae**	Cecidomyiidae sp.	1	1	0	2	0	0	0	0	0	0	1	0	0
	Ceratopogonidae	Ceratopogonidae sp. (P)	2	0	0	2	0	1	0	2	0	0	0	0	3
		Ceratopogoninae sp.	3	2	2	3	3	2	2	2	2	0	2	2	2
		Dasyhelea sp.	0	0	0	0	0	0	0	0	0	0	0	0	1
		Forcipomyiinae sp.	0	0	0	0	0	0	0	0	0	1	0	0	0
	Chironomidae	Chironomidae sp. (P)	2	2	0	2	0	0	0	0	0	0	0	0	0
	Chironominae														
	Chironomini	*Chironomus* aff. *alternans*	1	0	0	0	0	0	0	0	0	0	0	0	0
		Dicrotendipes sp. \`CA1\`	1	1	0	0	0	0	0	0	0	0	0	0	0
		Polypedilum sp.	0	0	1	0	0	0	0	0	0	0	0	1	0
		Polypedilum (Pentapedilum) leei	0	2	0	0	0	0	0	0	0	0	0	0	0
		Polypedilum nubifer	2	0	0	0	0	0	0	0	0	0	0	0	0
		Polypedilum sp. K1	3	2	2	3	0	0	2	2	2	0	0	1	0
	Tanytarsini	*Tanytarsus* sp.	2	0	0	0	0	0	1	0	0	2	0	0	0
	Orthocladiinae	Orthocladiinae sp. BES12662	0	0	0	0	2	0	0	0	0	0	0	0	0
		nr. *Gymnometriocnemus* sp.	3	0	3	2	0	0	0	2	0	0	3	0	0
	Tanypodinae	Tanypodinae sp. BES10593	0	2	0	0	2	0	0	0	3	0	0	0	2

			Survey Area									Reference			
Phylum/Class/Order	**Family**	**Lowest taxon**	**YC1**	**YC2**	**YC3**	**YC4**	**YC5H**	**YC6H**	**YC7H**	**YC8H**	**YC9H**	**WWS**	**BENS**	**MUNJS**	**SS**
		?*Australopelopia* sp.	0	0	2	0	0	0	2	3	0	0	2	0	0
		Larsia ?albiceps	2	2	1	3	0	0	3	2	3	0	0	0	0
		Paramerina sp. 1	0	0	2	0	2	0	3	0	0	2	2	0	0
		Paramerina sp. 2	0	0	0	3	0	0	0	0	0	0	3	0	0
		Procladius sp.	0	0	0	0	0	0	0	1	0	0	0	0	0
	Dolichopodidae	Dolichopodidae sp.	0	1	0	0	0	0	0	0	0	0	0	0	0
	Scatopsidae	Scatopsidae sp.	0	0	0	0	0	0	0	0	0	0	2	0	0
	Sciaridae	Sciaridae sp.	1	1	0	0	0	0	0	0	0	0	0	0	0
	Stratiomyidae	Stratiomyidae sp.	0	0	1	0	0	0	0	0	0	0	0	0	0
	Tipulidae	Tipulidae sp.	0	2	0	0	0	0	0	0	0	0	0	0	0
Ephemeroptera	**Baetidae**	*Cloeon* sp. Red Stripe	0	0	0	0	0	0	0	0	0	0	0	0	1
Hemiptera	**Gelastocoridae**	*Nerthra* sp.	0	0	0	0	0	0	0	0	0	0	0	0	1
Thysanoptera		Thysanoptera sp.	0	0	0	0	0	0	0	1	1	0	0	0	0
MYRIAOPODA															
Pauropoda		Pauropoda sp.	2	2	2	2	3	3	0	2	3	0	0	2	0
Symphyla															
Cephalostigmata	**Scutigerellidae**	*Hanseniella* `sp. Biologic-SYMP054`	0	0	0	0	0	2	0	0	1	0	0	0	0
		Taxa richness	**33**	**26**	**39**	**33**	**27**	**20**	**20**	**25**	**27**	**10**	**17**	**15**	**27**

Appendix G: Macroinvertebrate fauna taxonomic list

Dry season 2021

			Within Survey Area		Reference			
Phylum/Class/Order	**Family**	**Lowest taxon**	**YC3**	**YC4**	**WWS**	**BENS**	**MUNJS**	**SS**
CNIDARIA								
Hydrozoa	**Hydridae**	*Hydra* sp.	0	0	0	3	1	0
MOLLUSCA								
Gastropoda								
Hygrophila	**Lymnaeidae**	*Bullastra vinosa*	0	2	0	0	1	3
	Planorbidae	*Ferrissia petterdi*	2	2	2	2	0	2
		Gyraulus sp.	2	3	0	3	2	0
PLATYHELMINTHES		Turbellaria sp.	0	0	0	0	2	0
ANNELIDA								
Oligochaeta								
Tubificida	**Naididae**	*Allonais pectinata*	0	0	0	0	2	0
		Dero furcata	0	0	0	2	0	0
		Dero nivea	0	0	0	3	0	0
		Dero sp.	1	0	0	1	0	0
		Naidinae sp.	2	2	0	2	2	3
		Nais communis	1	0	0	0	0	2
		Pristina aequiseta	1	1	0	0	2	3
		Pristina leidyi	2	0	0	0	2	4
		Pristina longiseta	2	0	0	2	2	3
		Pristina osborni	1	1	0	0	0	0
		Pristina sp.	0	0	0	0	2	0
	Phreodrilidae	Phreodrilidae sp.	0	1	0	0	0	3
ARTHROPODA								
CHELICERATA								
Arachnida		Acari sp.	0	0	0	0	1	1
Sarcoptiformes		Oribatida sp.	0	0	2	0	1	0
Trombidiformes	**Aturidae**	*Austraturus* sp.	0	1	0	2	0	0
	Eylaidae	*Eylais* sp.	0	0	0	2	0	0
	Hygrobatidae	*Australiobates* sp.	0	0	1	0	0	0
	Hygrobatidae	*Coaustraliobates minor*	0	0	0	2	1	0
	Limnesiidae	*Limnesia parasolida*	0	0	0	2	0	0
	Limnesiidae	*Limnesia* sp. \`solida group\`	2	3	0	3	3	1

Phylum/Class/Order	Family	Lowest taxon	Within Survey Area YC3	Within Survey Area YC4	Reference WWS	Reference BENS	Reference MUNJS	Reference SS
	Unionicolidae	*Neumania* sp.	2	2	0	2	0	0
CRUSTACEA								
Malacostraca								
Amphipoda	**Paramelitidae**	*Chydaekata* sp. E	0	0	2	0	0	0
HEXAPODA								
Insecta								
Coleoptera	**Carabidae**	Carabidae sp.				1		
	Curculionidae	Curculionidae sp. (L)			2			
	Dytiscidae	*Allodessus bistrigatus*		2	1	2		
		Austrodytes plateni				2		
		Cybister sp. (L)				1	2	
		Hydaticus consanguineus	2	2				
		Hydaticus daemeli	2	2		2		
		Hydroglyphus daemeli		1				
		Hydroglyphus grammopterus				3		3
		Hydroglyphus leai	2	2				
		Hydroglyphus orthogrammus		3		3		3
		Hydrovatus opacus	3					1
		Hydrovatus sp. (L)		2		2		1
		Hyphydrus elegans				2	2	
		Hyphydrus lyratus		3	1	2	2	2
		Laccophilus sharpi		3	1	2	1	
		Limbodessus compactus				2		
		Necterosoma regulare				1		
		Necterosoma undecimlineatum		2				
		Neobidessodes denticulatus		2				
		Platynectes decempunctatus var. decempunctatus				2		
		Rhantaticus congestus	1	1				
	Elmidae	*Austrolimnius* sp. (L)						3
	Gyrinidae	*Dineutus australis*			2		3	
		Gyrinidae sp.					3	
		Macrogyrus paradoxus			1			
	Hydraenidae	*Hydraena* sp.	2	3		3	1	
		Limnebius sp.				1		1
		Ochthebius sp.				1		
	Hydrochidae	*Hydrochus burdekinensis*				2		

Phylum/Class/Order	Family	Lowest taxon	Within Survey Area YC3	YC4	Reference WWS	BENS	MUNJS	SS
		Hydrochus eurypleuron				2		
		Hydrochus interioris		1		2		
		Hydrochus obscuroaeneus		2		2	1	
		Hydrochus sp. P1				2		1
	Hydrophilidae	*Anacaena horni*			1	2		
		Berosus dallasae					1	3
		Berosus sp. (L)						3
		Chaetarthria nigerrima						1
		Coelostoma fabricii				1		1
		Enochrus deserticola	2			3	1	
		Helochares sp. (L)				2		3
		nr. *Anacaena* sp.		2				
		Paracymus spenceri	2	1		2	1	
		Regimbartia attenuata	2	2	1	3	1	
		Sternolophus australis	3	3				
		Sternolophus marginicollis	3	3		2		
		Sternolophus sp. (L)				2		
	Limnichidae	Limnichidae sp.	1					
	Scirtidae	Scirtidae sp. (L)	2	3	2	3		
Diptera	**Ceratopogonidae**	Ceratopogonidae sp. (P)	3				2	2
		Ceratopogoninae sp.	2	2	2	1	4	4
		Dasyhelea sp.	4		2		4	4
		Forcipomyiinae sp.	1					
	Chironomidae	*Ablabesmyia hilli*			1	1	4	
		Ablabesmyia notabilis		2				
		Chironomidae sp. (P)			2		2	3
		Chironomus aff. alternans	3	2		2		
		Cladotanytarsus sp.					4	4
		Cricotopus sp. 2			1		3	
		Dicrotendipes jobetus				2		
		Dicrotendipes sp. `CA1`			1		4	4
		Dicrotendipes sp. P4					4	
		Kiefferulus intertinctus	2	2		1		
		Larsia ?albiceps	1	3		2	4	4
		Nanocladius sp.					4	
		Parachironomus sp.				1		
		Paramerina sp. 1	1	2	2	1	4	4
		Parametriocnemus sp.					4	

			Within Survey Area		Reference			
Phylum/Class/Order	**Family**	**Lowest taxon**	**YC3**	**YC4**	**WWS**	**BENS**	**MUNJS**	**SS**
		Paratanytarsus sp.		2				
		Polypedilum leei		2				
		Polypedilum nubifer		2		1	3	
		Polypedilum sp.						3
		Procladius sp.		2		3	3	
		Rheocricotopus sp.						5
		Tanytarsus sp.	2	3	3	3	4	4
		Thienemanniella sp.			2			
	Culicidae	*Aedes* sp.					2	
		Anopheles sp.		2				2
		Culex sp.		1				3
		Culicidae sp.				1		
		Culicidae sp. (P)						1
	Dolichopodidae	Dolichopodidae sp.		1				4
	Simuliidae	Simuliidae sp.			1		4	
	Stratiomyidae	Stratiomyidae sp.	2	2	1	3	2	1
	Tabanidae	Tabanidae sp.	2	2		3	2	
	Tipulidae	Tipulidae sp.	1					
Ephemeroptera	**Baetidae**	Baetidae sp.		3	3	2	3	4
		Cloeon fluviatile		2		2		
		Cloeon sp. Red Stripe		2	3	2	3	4
		Offadens G1 sp. WA2			3		1	4
	Caenidae	*Tasmanocoenis* sp.		2	2	3	2	4
		Tasmanocoenis sp. M				1		4
		Tasmanocoenis sp. P/*arcuata*		1		2	2	4
	Leptophlebiidae	*Atalophlebia* sp. AV17					4	
		Leptophlebiidae sp.					4	
Hemiptera	**Belostomatidae**	*Diplonychus eques*	2	1			2	2
	Gelastocoridae	*Nerthra* sp.						1
	Gerridae	Gerridae sp.	1	1		1		3
		Limnogonus fossarum gilguy	1					
		Limnogonus luctuosus	2	1				
		Limnogonus sp.			2			3
	Hebridae	*Hebrus axillaris*				2		
	Micronectidae	*Austronecta bartzarum*		1				
	Nepidae	*Laccotrephes tristis*		2			1	
	Notonectidae	Notonectidae sp.					2	
	Pleidae	*Paraplea* sp.		2		2		1

Phylum/Class/Order	Family	Lowest taxon	Within Survey Area YC3	YC4	Reference WWS	BENS	MUNJS	SS
	Veliidae	*Nesidovelia peramoena*	2			2		
		Nesidovelia sp.	2		1			
		Veliidae sp.	2			3		1
Lepidoptera	**Crambidae**	*Margarosticha* sp. 3			2		2	1
		Parapoynx sp.		1				
		Tetrernia sp.			1			
		Acentropinae sp.					1	
Odonata	**Aeshnidae**	Aeshnidae sp.	1					
	Coenagrionidae	*Argiocnemis rubescens*	2	3		2	2	
		Ischnura aurora		2			2	
		Pseudagrion aureofrons		2	3	2		
	Corduliidae	*Hemicordulia koomina*		1		2		2
	Isostictidae	*Eurysticta coolawanyah*		1		2		
	Libellulidae	*Diplacodes haematodes*	2	3			2	
		Nannophlebia injibandi	2		2			
		Orthetrum caledonicum	2			2		2
		Zyxomma elgneri		2				
	Lindeniidae	*Ictinogomphus dobsoni*		1				
		Anisoptera sp.	3	2	2	3	4	3
		Zygoptera sp.	2		2	3	3	
Trichoptera	**Ecnomidae**	Ecnomidae sp.		1				
		Ecnomina sp. F group					3	
		Ecnomus pilbarensis		2		2	2	2
	Hydropsychidae	*Cheumatopsyche wellsae*			2		2	2
	Hydroptilidae	*Hellyethira* sp.				3	2	
		Orthotrichia sp.			2	2		
	Leptoceridae	Leptoceridae *sp.*		2		2	2	2
		Oecetis sp. Pilbara 4				2		2
		Triaenodes sp.		1			1	
		Triplectides australis	1					
		Triplectides ciuskus seductus		3		3	2	2
	Philopotamidae	*Chimarra* sp. AV17					2	1
		Taxa richness	**51**	**73**	**38**	**83**	**71**	**61**

Wet season 2022

Phylum/Class/Order	Family	Lowest taxon	Survey Area YC1	YC2	YC3	YC4	Reference WWS	BENS	MUNJS	SS
CNIDARIA										
Hydrozoa	**Hydridae**	*Hydra* sp.	0	0	0	0	0	3	0	2
MOLLUSCA										
Gastropoda										
Hygrophila	**Lymnaeidae**	*Bullastra vinosa*	2	3	0	0	0	0	3	0
	Planorbidae	*Ferrissia petterdi*	0	0	2	0	1	1	0	0
		Gyraulus sp.	0	2	3	0	0	4	3	0
PLATYHELMINTHES		Turbellaria sp.	1	0	0	0	0	0	0	0
ANNELIDA										
Oligochaeta		Oligochaeta sp.	0	1	0	0	0	0	0	0
Tubificida	**Naididae**	*Allonais pectinata*	0	0	0	0	0	0	2	0
		Allonais ranauana	0	0	0	0	0	0	2	2
		Dero furcata	0	0	2	1	0	0	0	0
		Dero nivea	0	0	0	0	0	0	2	0
		Naidinae sp.	0	0	2	0	0	2	0	3
		Nais communis	0	0	0	0	0	0	2	0
		Pristina aequiseta	0	0	2	0	0	0	2	2
		Pristina leidyi	0	0	0	0	1	0	0	0
		Pristina longiseta	1	2	2	0	1	2	2	3
	Phreodrilidae	Phreodrilidae sp.	0	1	2	2	0	2	0	3
ARTHROPODA										
CHELICERATA										
Arachnida		Acari sp.	0	4	2	0	0	0	0	3
Mesostigmata		Mesostigmata sp.	3	4	0	3	0	0	0	0
Sarcoptiformes		Oribatida sp.	0	3	0	3	3	0	0	3
Trombidiformes		Trombidioidea sp.	2	4	0	3	0	0	0	0
	Arrenuridae	*Arrenurus* (*Truncaturus*) sp.	0	0	1	0	0	0	2	0
		Arrenurus sp.	0	0	0	0	0	0	0	3
	Aturidae	*Albia* sp.	0	0	0	0	0	3	0	0
		Austraturus sp.	0	0	0	0	0	3	0	0
	Hydrodromidae	*Hydrodroma* sp.	0	0	0	0	0	0	1	3
	Hydryphantidae	*Diplodontus* sp.	0	0	0	0	0	0	2	0
		Wandesia sp.	1	0	0	0	0	0	0	0
	Hygrobatidae	*Australiobates* sp.	0	0	0	0	0	0	0	3
		Procorticacarus sp.	0	0	0	0	2	0	0	3
	Limnesiidae	*Limnesia parasolida*	0	0	0	0	0	0	0	4
		Limnesia sp. `solida group`	0	0	3	3	0	4	3	3
	Mideopsidae	*Gretacarus* sp.	0	0	0	0	0	0	0	3
	Oxidae	*Oxus* sp.	0	0	2	2	1	0	0	0
	Unionicolidae	*Neumania* sp.	0	0	0	2	0	4	0	3
		Recifella sp.	0	0	0	2	0	0	0	3
		Unionicolidae sp.	0	0	0	3	0	0	0	0
CRUSTACEA										
Malacostraca										
Amphipoda	**Paramelitidae**	*Chydaekata* sp. E	0	0	0	1	2	0	0	0
		Paramelitidae `sp. Biologic-AMPH023`	0	0	2	0	0	0	0	0
Decapoda	**Parastacidae**	*Cherax quadricarinatus*	0	0	0	0	1	0	0	0
Entognatha										
Entomobryomorpha		Entomobryoidea sp.	1	2	2	1	0	2	1	0
Poduromorpha		Poduroidea sp.	2	0	0	0	0	0	0	0
Symphypleona		Symphypleona sp.	3	3	2	1	0	0	0	0

			Survey Area				Reference			
Phylum/Class/Order	**Family**	**Lowest taxon**	**YC1**	**YC2**	**YC3**	**YC4**	**WWS**	**BENS**	**MUNJS**	**SS**
Insecta										
Coleoptera		Coleoptera sp. (L)	2	2	2					
	Carabidae	Carabidae sp. (L)	1	2	1	1		1		
	Dytiscidae	*Allodessus bistrigatus*		1						
		Austrodytes sp. (L)							2	
		Bidessini sp. (L)	2	2	2			3		
		Copelatus irregularis				1		1		
		Copelatus sp. (L)	2	1		1				
		Cybister sp. (L)			2					
		Hydaticus daemeli							1	
		Hydaticus sp. (L)			2					
		Hydroglyphus grammopterus			2			2		
		Hydroglyphus orthogrammus	1		3			3	2	
		Hydrovatus opacus		1					1	1
		Hydrovatus sp. (L)		2				2	2	
		Hyphydrus elegans	1	1				1		
		Laccophilus sharpi		1						
		Limbodessus compactus		2	2			1		1
		Neobidessodes denticulatus				2				
		Platynectes decempunctatus var. *decempunctatus*							2	
		Tiporus tambreyi						1		2
	Elmidae	*Austrolimnius* sp.								2
		Austrolimnius sp. (L)					1			2
	Gyrinidae	*Dineutus australis*	1	1					2	
		Macrogyrus gibbosus							1	
	Heteroceridae	Heteroceridae sp. (L)	1	1						
	Hydraenidae	*Hydraena* sp.	2	2	3			3	1	
		Hydraenidae sp. (L)			1					
	Hydrochidae	*Hydrochus eurypleuron*						1		
		Hydrochus interioris						2		
		Hydrochus obscuroaeneus		2	3			3		2
		Hydrochus macroaquilonius						2		
		Hydrochus sp. P1						1		
	Hydrophilidae	Hydrophiloidea sp.	1							1
		Agraphydrus coomani						1		
		Anacaena horni			2			2	2	
		Berosus dallasae	1							
		Enochrus deserticola						1	1	
		Helochares sp. (L)			1			2	2	
		nr. *Anacaena* sp.				2				
		Paracymus sp. (L)		1	1					
		Paracymus spenceri			1				1	
		Regimbartia attenuata			2			2		
		Regimbartia sp. (L)		1						
		Sternolophus australis	2						1	
		Sternolophus immarginatus	1		1					
		Sternolophus marginicollis							2	2
		Sternolophus sp. (L)			1			2		
	Limnichidae	Limnichidae sp. C							1	
	Ptiliidae	Ptiliidae sp.	1							
	Scirtidae	Scirtidae sp. (L)	3	5	2		2	3		2
	Staphylinidae	Staphylinidae sp.	1		1					
Diptera	**Cecidomyiidae**	Cecidomyiidae sp.		3	2			1		
	Ceratopogonidae	Ceratopogonidae sp. (P)	2	3	3		2	1		
		Ceratopogoninae sp.	3	3	3	2	1	2	2	3
		Dasyhelea sp.			3	3		1	3	2
		Forcipomyiinae sp.		1	3		2	1		

Phylum/Class/Order	Family	Lowest taxon	Survey Area YC1	YC2	YC3	YC4	Reference WWS	BENS	MUNJS	SS
	Chironomidae	*Ablabesmyia hilli*	3	3				2		
		Chironomidae sp. (P)	3	5	2	2	2	3	2	3
		Chironomus aff. *alternans*			4	2		3		3
		Cladotanytarsus sp.			2	2			1	2
		Corynoneura sp.					1			
		Cricotopus albitarsis					2		2	
		Cryptochironomus griseidorsum							1	
		Dicrotendipes jobetus							2	
		Dicrotendipes sp. \`CA1\`	2				2	2	2	3
		Dicrotendipes sp. P4	2						1	
		Kiefferulus intertinctus				2		3		
		Larsia ?albiceps	4	4		1	2	2	3	3
		nr. *Gymnometriocnemus* sp.				1				
		Orthocladiinae sp.				1				
		Parachironomus sp.			2					
		Paramerina sp. 1			4	2	2	4	3	3
		Polypedilum leei				2				
		Polypedilum nubifer			2				2	
		Polypedilum sp.	2							
		Polypedilum sp. K1	4	5		2				2
		Procladius sp.	3	3		2		2		3
		Rheocricotopus sp.								3
		Tanypodinae sp.		1						
		Tanytarsus sp.	2		3	2	1	3	3	3
		Thienemanniella sp.							2	
	Culicidae	*Aedes* sp.		2	1					
		Anopheles sp.			2			2		
		Culex sp.	3	2	3	1		3		
	Dolichopodidae	Dolichopodidae sp.		2		2		1		2
	Empididae	Empididae sp.		1						
	Ephydridae	Ephydridae sp.			2					
	Psychodidae	Psychodidae sp.		2			1			
	Scatopsidae	Scatopsidae sp.						2		
	Sciaridae	Sciaridae sp.	1	3	2					
	Simuliidae	Simuliidae sp.							3	2
		Simuliidae sp. (P)								1
	Stratiomyidae	Stratiomyidae sp.	2	4	2		1			
	Syrphidae	Syrphidae sp.		3	2					
	Tabanidae	Tabanidae sp.	2	2	2					
	Tipulidae	Tipulidae sp.	2	3		1				
Ephemeroptera	**Baetidae**	Baetidae sp.	3	2	3	2	4	3	3	3
		Cloeon fluviatile				3				2
		Cloeon sp. Red Stripe	1		2			2	3	
		Pseudocloeon hypodelum					3			3
	Caenidae	Caenidae sp.			1		3	3		3
		Tasmanocoenis sp.							2	
		Tasmanocoenis sp. M								2
		Tasmanocoenis sp. P/*arcuata*					1	2	2	2
Hemiptera	**Belostomatidae**	Belostomatidae sp.							2	
		Diplonychus eques				1			2	
	Gerridae	Gerridae sp.			2					2
		Limnogonus fossarum gilguy							2	
		Limnogonus luctuosus				1		2	2	2
		Rhagadotarsus anomalus						2		
	Hebridae	*Hebrus axillaris*						1		
	Mesoveliidae	*Mesovelia vittigera*			2					
		Mesoveliidae sp.			2					
	Notonectidae	*Anisops hackeri*			1				1	

			Survey Area				Reference			
Phylum/Class/Order	**Family**	**Lowest taxon**	**YC1**	**YC2**	**YC3**	**YC4**	**WWS**	**BENS**	**MUNJS**	**SS**
		Anisops nabillus							1	
		Anisops sp.							1	
		Enithares sp.							1	
		Enithares woodwardi			2					
		Notonectidae sp.							1	
	Pleidae	*Paraplea brunni*						3	2	
	Veliidae	*Microvelia oceanica*			2					
		Nesidovelia peramoena			2			2		
		Nesidovelia sp.	1		2			3		
		Veliidae sp.			3					
Lepidoptera	**Crambidae**	Acentropinae sp.	2	1	2		1	2		
		Margarosticha sp.								1
Odonata	**Aeshnidae**	Aeshnidae sp.			3		1	2		
		Hemianax papuensis			2				3	
	Coenagrionidae	*Argiocnemis rubescens*				2		2	2	2
		Pseudagrion aureofrons					2	1		2
	Corduliidae	*Hemicordulia tau*						1		
	Isostictidae	*Eurysticta coolawanyah*						2		
	Libellulidae	*Diplacodes haematodes*					2		2	2
		Orthetrum migratum							2	
		Tramea sp.							2	
		Zyxomma elgneri						2		
	Lindeniidae	*Ictinogomphus dobsoni*						2	1	
		Anisoptera sp.	2	2	3	2	1	3	3	2
		Zygoptera sp.		2	3		3	3	2	2
Trichoptera	**Ecnomidae**	*Ecnomus pilbarensis*						2		2
	Hydropsychidae	*Cheumatopsyche wellsae*					3			4
	Leptoceridae	Leptoceridae sp.						1		2
		Leptocerus sp. AV2								1
		Oecetis sp. Pilbara 4						2		1
		Triplectides australicus						1		
		Triplectides ciuskus seductus							1	2
	Philopotamidae	*Chimarra* sp. AV17								4
		Philopotamidae sp.					1			3
		Taxa richness	**46**	**52**	**71**	**41**	**34**	**75**	**67**	**63**