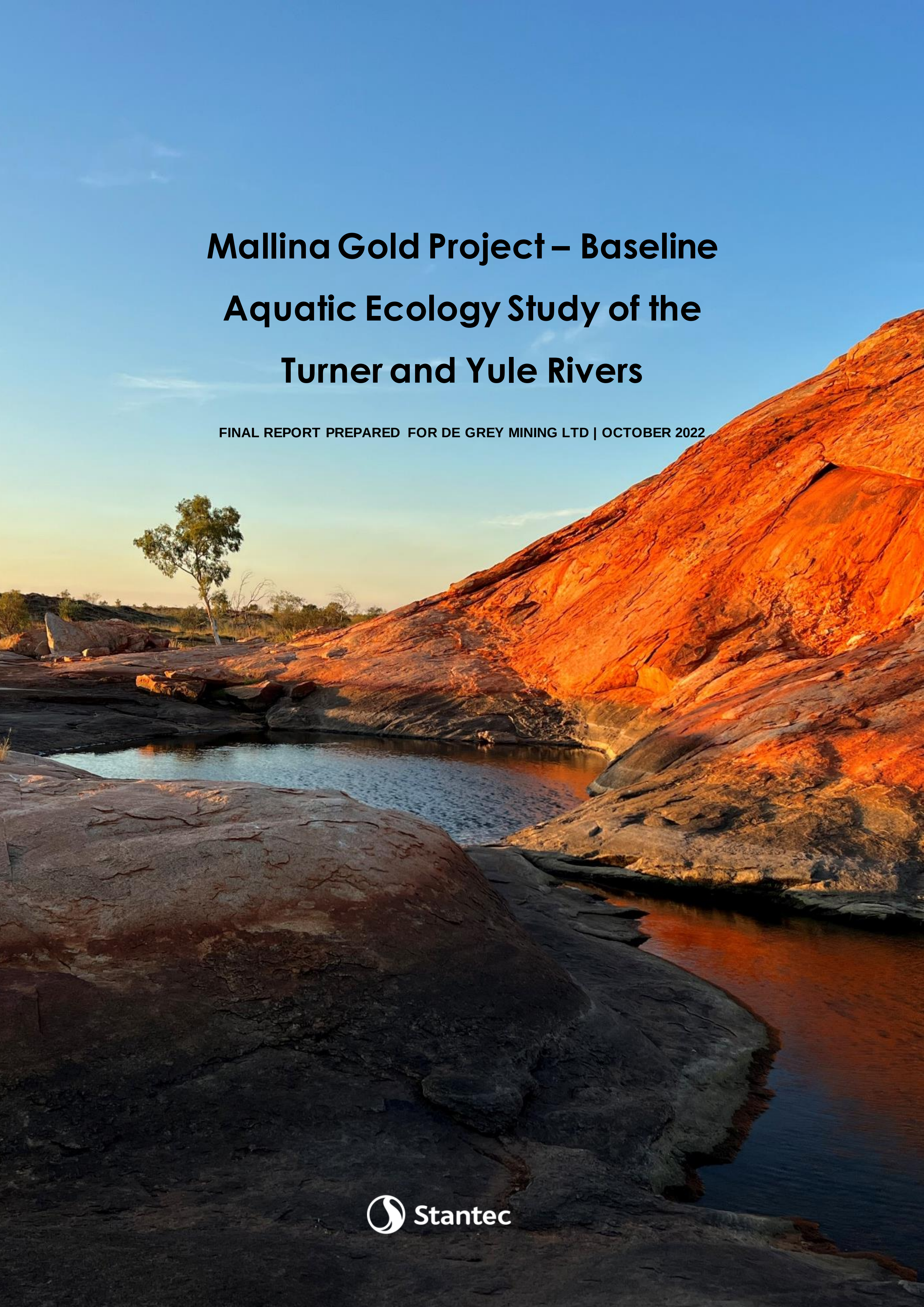
Mallina Gold Project – Baseline Aquatic Ecology Study of the Turner and Yule Rivers

FINAL REPORT PREPARED FOR DE GREY MINING LTD | OCTOBER 2022



Stantec

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Executive Summary

Background and Objective

De Grey Mining Limited (De Grey) are planning to develop the Mallina Gold Project (MGP), located approximately 85 km southwest of Port Hedland, in the Pilbara region of Western Australia. The MGP includes the Hemi Deposit, for which below water table mining will require dewatering, with proposed discharge of up to 40 to 45 ML/day of surplus water to the Turner River. Therefore, environmental impact assessment (EIA) will likely be assessed by the Environmental Protection Authority (EPA), under Part IV of the *Environmental Protection Act 1986* (EP Act) for the Inland Waters Factor.

Stantec Australia Ltd (Stantec) was commissioned to undertake a baseline study of the Turner and Yule Rivers (the Study). The objective of the baseline study was to develop a knowledge base to provide an understanding of the ecological values of the Turner and Yule Rivers in the vicinity of the MGP, to inform regulatory approval.

A total of 12 sites were sampled along the Turner (including Turner River East) and Yule Rivers during dual phase field surveys; completed in November 2021 (dry season) and May 2022 (wet season). While seasonal sampling occurred, dry conditions extended into the wet season survey of the Study. A range of ecological components were assessed, including water and sediment quality, aquatic macrophytes, phytoplankton, periphyton (diatoms), aquatic invertebrates, fish, waterbirds and other vertebrate fauna (reptiles and amphibians). As well as traditional sampling methods, water samples were also collected during the dry season for eDNA analysis, to detect potential significant fauna species.

Key Findings

The abiotic characteristics of the pools of the Turner and Yule Rivers were characterised as mostly freshwater (<5,000 µS/cm), although subject to nutrient enrichment from unrestricted livestock access. Increases in salinity were evident due to evapoconcentration, with natural mineralisation of surface waters (Al, As, B, Cu, Zn, and U) and sediments (Cr and Ni) also occurring over the course of the hydroperiod. However, water quality was generally considered favourable, supporting a diverse and abundant biological community in both river systems. In total, the number of taxa recorded comprised nine aquatic macrophytes, 73 phytoplankton, 54 diatoms, 182 aquatic invertebrates,14 fish, 13 waterbirds, and one reptile, one amphibian and one native mammal species, which were recorded from the Turner and Yule Rivers across both seasons.

Where present, macrophyte, algal, invertebrate and fish communities were typically comparable in both waterways, although the Yule River supported a higher species diversity and abundance of aquatic biota. This was associated with the larger, more permant pools, increasing habitat availability and contributing to habitat heterogeneity. In contrast the Turner River pools were typically smaller, with sandy substrates and turbid water. These pools were characterised by opportunistic, transient insect taxa, as well as hardy and adaptable fish species (*Melanotaenia australis* and *Leiopotherapon unicolor*). The majority of macrophyte, algal, invertebrate and vertebrate taxa recorded during the Study are known to have broader distributions throughout the Pilbara and northern-Australia.

Although *Liasis olivaceus barroni* (Pilbara Olive Python), listed as Vulnerable under both the BC Act and the EPBC Act was not recorded during this Study (including via eDNA analysis), the species has previously been observed along the Turner River. The listed vertebrate fauna species *Dasyurus hallucatus* (Northern Quoll) was also detected by eDNA analysis during the Study and is known to forage within the Turner River.

Aquatic Ecology Values and Significant Taxa

A summary of the conservation significant fauna records from the Study are provided in **Table ES1**. In the Turner River, this comprised the Pilbara endemic aquatic beetles; *Sternopriscus pilbaraensis*, *Tiporus tambreyi* and *Laccobius billi*, and in Turner River East, the damselfly *Eurysticta coolawanyah* (**Figure ES1**). These Pilbara endemics are not listed as threatened and are known to occur more broadly throughout the region. *Ephippiorhynchus asiaticus australis* (Black Stork) was recorded in the downstream reaches of the Turner River, approximately 20 km from the coast and the IUCN listed (Vulnerable).

Extended dry conditions into the wet season caused the pools of the Turner River to contract substantially over the course of the Study. This corresponded to reduced habitat availability and biodiversity, associated with poor water quality conditions (including increased salinity, turbidity, and nutrients), exacerbated by unrestricted livestock access. Based on the lack of conservation significant aquatic biota records (listed under State or Federal legislation), the highly seasonal, semi-permanent pools of the Turner River are considered to be of **low to moderate** ecological value within a regional context.

In comparison, the larger, permanent pools (likely groundwater fed) of the Yule River provided more favourable water quality and a diverse range of structurally complex habitats for aquatic biota. These pools supported the IUCN Vulnerable listed damselfly *Eurysticta coolawanyah* and dragonfly *Hemicordulia koomina* (**Figure ES1**), as well as the Pilbara endemic aquatic beetles *Tiporus tambreyi* and *Laccobius billi*, hemipteran back swimmer *Anisops nabillus* and the dragonfly *Ictinogomphus dobsoni*. The IUCN listed (Near Threatened) Indonesian short-finned eel, *Anguilla bicolor* (**Figure ES1**), was also recorded during the wet season of the Study and is only known from the Fortescue, De Grey and Yule Rivers in the Pilbara. As the Yule River provides permanent refuge for aquatic biota, due to the persistence of pools during extended dry periods, ecological values are considered to be **moderate to high** within a regional context.

Impact Assessment and Considerations

Pilbara river systems support aquatic habitats ranging from semi-permanent to permanent pools, with extensive reaches in between that can be subject to lengthy dry periods, only flowing only after substantial rainfall. The proposed discharge from the MGP to the Turner River will cause a shift from seasonal flows to a permanent hydrological regime, with the following modelled characteristics predicted:

- Downstream extent from the discharge outfall of approximately 45 km and typically 40 m wide (with a maximum of 150 m wide in some areas of the river);
- Depth mostly approximating 20 cm or less, although deeper areas (up to 1.3 m) may occur where water naturally pools; and
- Total surface area (predicted maximum) of approximately 225 ha.

The discharge is expected to create additional aquatic habitat that favours resident fauna or species adapted to perennial flows, resulting in a change in the dominant biological communities during the temporary discharge period (three years). However, it is considered highly unlikely that any species will be lost from the Turner River, given the broader distribution of the aquatic biota taxa recorded during the Study. These taxa are typically known to occur in waterbodies throughout the Pilbara region and have the ability to actively disperse and recolonise newly created flows or pools.

Additionally, the aquatic biota inhabiting these waterways are inherently resilient, due to the highly variable hydrological regimes and fluctuating water quality conditions that are typical of the Pilbara region. In the Turner River, this will enable aquatic biota to persist and adapt to any temporary perturbation from proposed discharge and/or drawdown associated with the development of the MGP. The artificial habitat created by the discharge is also relatively common throughout waterways in the Pilbara, associated with iron ore operations.

Based on the findings of this Study, the Yule River exhibits comparatively higher ecological values than the Turner River and was characterised by sizable groundwater fed, permanent pools that supported three IUCN listed aquatic biota taxa. In contrast, and in response to the dry conditions that extended into the wet season survey, the pools of the Turner River were smaller, isolated and more turbid, supporting a lower biodiversity (and no listed aquatic biota), which was of low to moderate ecological value.

A preliminary impact assessment and considerations for the management and mitigation of the MGP, specific to the Turner and Yule Rivers is as follows:

- Construction activities will not extend to the Yule River. Drawdown from dewatering and based on hydrogeological modelling, is also not expected to influence the Yule River or the permanent pools that it supports. Drawdown is likely to be constrained to the eastern and western boundaries of the resource and there are no predicted impacts (**negligible risk**) to the permanent pools of this system.
- It is likely that several options will be implemented to manage surplus water on site during development of the MGP, including aquifer re-injection, and re-use (where possible), in conjunction with a requirement for environmental discharge.
- The Turner River, based on hydrological modelling, has substantial storage capacity, and can accommodate the proposed volume and rates of discharge water over the temporary period. It is expected that a higher rate of discharge (up to 45 ML/day) will be required during the first three years, prior to the site becoming operational, after which surplus water will decrease substantially (up to 10 ML/day).
- Where required and prior to environmental discharge, water should be subject to pre-treatment, or allow for natural attenuation within retention ponds, to ensure water quality is within acceptable limits and does not pose a risk to aquatic biota. The discharge schedule from surficial and deeper bedrock aquifers may also require manipulation to ensure the standard of water quality discharge to the environment is maintained.
- The discharge outfall should be located within the main channel of the river that is typically subject to high velocity flows during the wet season. The outfall should also be designed and engineered to avoid erosion of riverbanks and beds, dissipating the energy of the flow within the channel.
- The discharge water should be adequately contained within the river channel, avoiding inundation of sensitive riparian vegetation communities that are not subject to a permanent hydrological regime.
- Due to the sensitivity of these communities to changing groundwater levels, a staged reduction in discharge may be required over a longer period, prior to complete cessation, allowing riparian vegetation to adapt.
- Development of an ongoing, robust ecological monitoring program to determine potential changes in ecological values associated with the proposed discharge should be implemented, with potential threshold and trigger criteria (following regulatory guidance), providing comparison to this Study during operations.

It is expected that after the completion of technical documents comprising the opportunistic flood study, hydrological modelling, and hydrogeological characterisation, Stantec will undertake a comprehensive discharge assessment, to determine the quantitative risk to sensitive biological receptors from proposed discharge and drawdown for the MGP. However, the results of this Study indicate that due to the temporary nature of potential impacts, inherent resilience of aquatic biota, and limited conservation significant records from the Turner River, with adequate mitigation and management, the **preliminary risk to aquatic biota from proposed discharge is low**.

Table ES1: Summary of characteristics and ecological values of the Turner and Yule Rivers from the Study (TR=Turner River, TRU=Turner River Upstream, TRD=Turner River Downstream, TRE=Turner River East, YR=Yule River, YRU=Yule River Upstream, YRD=Yule River Downstream).

River System	Hydrology / Habitat	Water Quality	Sediment Quality	Primary Producers	2nd and 3rd Order Consumers	Conservation Significant Taxa	Ecological Value
Turner River and Turner River East	• Semi-permanent pools influenced by rainfall, contracting or drying during low rainfall conditions (except for TR1 due to underlying bedrock). • Limited instream habitat, with smaller pools characterised by sandy substrate, absence of submerged macrophytes and turbid water.	• Moderately to strongly alkaline pH. • Freshwater (<5,000µS/cm) except for TR1 and TRD2 (>5,000µs/cm). • Elevated nutrients (TN & TP) due to unrestricted livestock access. • Generally low metals except for some minor exceedances of ANZG (2018) GV for Al, As, B, Cu, Zn, and U across sites. • Similar water quality results across seasons, due to low rainfall conditions.	• Circumneutral to strongly alkaline pH. • Generally low salinity, low nutrients and low metals. • Ni slightly above ANZG (2018) GV for TR1-A.	• 6 macrophyte taxa, 58 phytoplankton taxa and 42 diatom taxa. • All have a Pilbara wide, or more cosmopolitan distribution. • Limited primary productivity in receding pools of Turner River.	• 116 aquatic aquatic invertebrate taxa (including insects with high dispersal capabilities). • 10 fish species (5 new records; Banded Scat, Tarpon, Milkfish, Common Silverbiddy and Mangrove Jack). • 7 waterbird species (one from eDNA analysis). • 1 frog and 1 mammal species (from eDNA analysis). • Most species with a common and widespread distribution across the Pilbara and Northern Australia.	• **Pilbara Endemics:** ○ *Sternopriscus pilbaraensis* (aquatic beetle) (TRU1) ○ *Laccobius billi* (aquatic beetle) (TRE2, TRU1, TR1) ○ *Tiporus tambreyi* (aquatic beetle) (TRU1, TR1) • **BC Act/EPBC Act Endangered:** ○ *Dasyurus hallucatus* (Northern Quoll) (TR1; eDNA sampling) • **IUCN Red List Vulnerable:** ○ *Eurysticta coolawanyah* (damselfly) (Turner River East; TRE2) • **IUCN Red List Near Threatened:** ○ *Ephippiorhynchus asiaticus australis* (Black Stork) (TRD2)	**Low to Moderate** *Justification: small, isolated pools with less habitat complexity and no listed aquatic biota.*
Yule River	• Larger permanent, groundwater fed pools (except YRU1 and YRU2 that are semi-permanent). • Predominantly on substrate with minimal seasonal variation in pool size and depth (between wet and dry season). • Complex instream habitats (macrophytes, undercut banks, woody debris, detritus and overhanging trees), characterised by silt-clay substrate, dense macrophytes and increased water clarity.	• Circumneutral to strongly alkaline pH. • Freshwater (<5,000µS/cm) except for YRU1 (>8,000µs/cm). • Elevated nutrients (TN & TP) due to unrestricted livestock access. • Generally low metals except for some minor exceedances of ANZG (2018) GV for B, Cu, Zn, and U across sites. • Similar water quality across seasons, due to low rainfall conditions.	• Circumneutral to strongly alkaline pH. • Generally low salinity, nutrients and metals levels. • Cr slightly above ANZG (2018) GV for YR3. • Ni above ANZG (2018) GV for several sites and above GV-High for YR3	• 9 macrophyte taxa, 55 phytoplankton taxa, 45 diatom taxa • All have a Pilbara wide, or more cosmopolitan distribution. • *Cyperus vaginatus* only recorded from permanent pools on the Yule River. • Primary productivity generally higher and more diverse.	• 159 aquatic invertebrate taxa (including insects with high dispersal capabilities). • 12 fish species (high diversity due to large pools and 3 new records; Milkfish, Mangrove Jack and Threadfin Silverbiddy). • 9 waterbird species and one reptile species. • Most species with a common and widespread distribution across the Pilbara and Northern Australia.	• **Pilbara Endemics:** ○ *Tiporus tambreyi* (aquatic beetle) (YR3) ○ *Laccobius billi* (aquatic beetle) (YRU1-A) ○ *Anisops nabillus* (hemipteran back swimmer) (YR3, YRD1) ○ *Ictinogomphus dobsoni* (dragonfly) (YR2, YRD1) • **IUCN Red List Vulnerable:** ○ *Eurysticta coolawanyah* (damselfly) (YRU1-A, YRD1) ○ *Hemicordulia koomina* (dragonfly) (YR3) • **IUCN Red List Near Threatened:** • *Anguilla bicolor* (Indonesian short-finned eel) (YR1)	**Moderate to High** *Justification: large, groundwater fed permanent pools with structurally complex habitats supporting listed aquatic biota.*

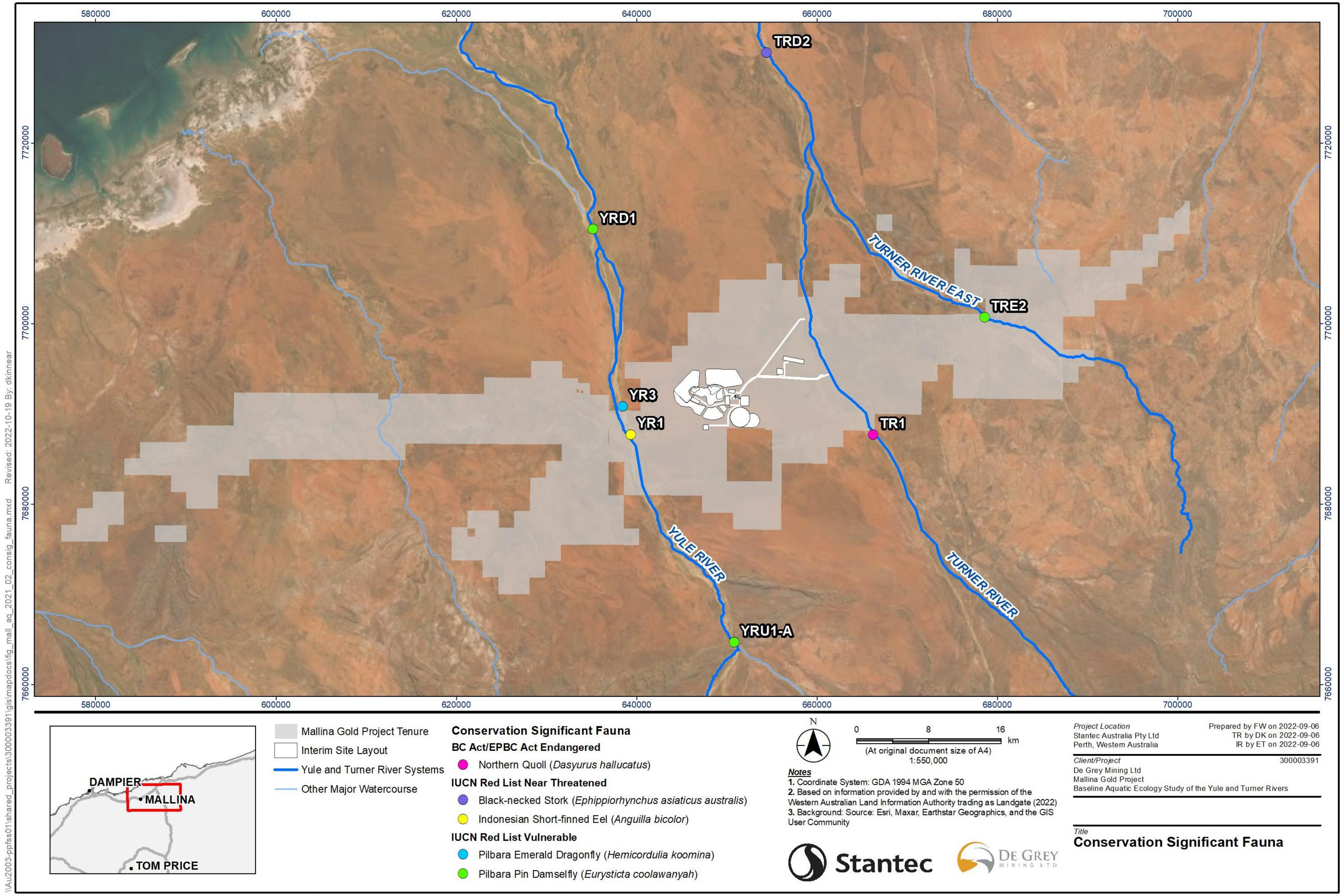

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Figure ES1: Listed conservation significant records for the Turner and Yule Rivers, based on the results of the Study.

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1 Introduction

1.1 Background and Objective

De Grey Mining Limited (De Grey) are planning to develop the Mallina Gold Project (MGP), located approximately 85 km southwest of Port Hedland, in the Pilbara region of Western Australia (**Figure 1-1**). A key component of the MGP comprises a large scale, high value, near surface Hemi Gold Deposit, situated between two major ephemeral river systems; the Turner River to the east, and the Yule River to the west (**Figure 1-1**). Below water table (BWT) mining will be required to access part of the Hemi resource, which will require dewatering discharge of up to 45 ML/day of surplus water to the Turner River. Additionally, due to the scale of the MGP, the Yule River may also be impacted by construction activities and/or groundwater drawdown.

Therefore, environmental impact assessment (EIA) of Inland Waters as a key factor, will be required as part of the approvals process by the Environmental Protection Authority (EPA), under Part IV of the *Environmental Protection Act 1986* (EP Act). The objective of the EPA's Inland Water Environmental Factor Guideline (EPA 2018) is "*to maintain the hydrological regimes and quality of groundwater and surface water so that environmental values are protected*" (EPA 2018). Guidance focuses on impacts to significant ecosystems such as springs and pools, particularly in arid areas, as well as their aquatic biota and ecological processes.

Stantec Australia Ltd (Stantec) was commissioned to undertake a desktop assessment and a dual phase baseline study of the Turner and Yule Rivers (the Study). The findings of the desktop assessment indicated there was limited information available on these river systems, with no studies undertaken in the last decade (Stantec 2021). The objective of the baseline study was to develop a knowledge base to provide an understanding of the ecological values of the Turner and Yule Rivers in the vicinity of the MGP, to inform regulatory approvals. The objective was addressed by completion of the following tasks:

- Undertaking dual phase (dry and wet season) field surveys of the rivers, with systematic sampling of water and sediment quality and aquatic biota;
- Identification of all aquatic biota to genus or species level, where possible;
- Assessment of the conservation status of species records;
- Spatial and temporal analysis of abiotic and biotic data to determine trends; and
- Discussion of ecological values within a local and regional context, considering the hydrological regime.

1.2 Existing Environment

1.2.1 Biogeographical Context

The Interim Biogeographic Regionalisation for Australia (IBRA) is a bioregional framework dividing Australia into 89 bioregions and 419 subregions based on climate, geology, landforms, soils, vegetation, flora and fauna, as well as land use (Thackway and Cresswall 1995). The MGP is primarily located within the Chichester subregion of the Pilbara bioregion, with its northern section also adjacent to the Roebourne subregion (**Figure 1-2**). The 9,044,560 ha Chichester subregion is the largest of four Pilbara subregions (McKenzie *et al.* 2009). The coastal Roebourne subregion covers an area of 2,008,983 ha (Kendrick and Stanley 2001) (**Figure 1-2**). Together, the two subregions comprise over 50% of the of the Pilbara bioregion (McKenzie *et al.* 2009) (**Figure 1-2**).

The Chichester subregion includes the northern section of the Pilbara Craton, an ancient and arid landscape characterised by undulating Archean granite and basalt plains with substantial areas of basalt ranges (Kendrick and McKenzie 2003). The basalt plains host a shrub steppe of *Acacia inaequilatera* over *Triodia* hummock grasslands, while tree steppes of *Eucalyptus leucophloia* occur on the ranges (Kendrick and McKenzie 2003). The Roebourne subregion comprise quaternary alluvial and older colluvial coastal plains hosting similar vegetation communities to the Chichester subregion, transitioning to samphire, *Sporobolus* and mangroves on the coastal marine alluvial flats and river deltas (Kendrick and Stanley 2001). Grazing is a key land use in the area, particularly along major river systems, although there is limited information on the impacts of these activities on aquatic systems (Kendrick and McKenzie 2003).

1.2.2 Climate

The Pilbara bioregion has an arid to semi-tropical climate, and hot, dry conditions prevail for most of the year (McKenzie *et al.* 2003). Rainfall in the region is highly seasonal, dependent on summer cyclones and storms, with most rainfall occurring between January and March (**Figure 1-3**), in response to tropical cyclone activity. However, annual rainfall is typically low; the long-term mean annual rainfall recorded at nearby Indee station (004016) is 338 mm (Bureau of Meteorology 2022). Maximum temperatures generally exceed 35°C from October to April (**Figure 1-3**), and high evaporation causes an extreme moisture deficit (Loomes and Braimbridge 2010).

Prior to the dry season survey of the Study (November 2021), no rainfall (0 mm) was recorded at Indee station in the preceding four months (June to October), considered typical conditions for the bioregion (**Figure 1-3**). Rainfall was also low in the wet season, with no rainfall recorded in November and December 2021, and below average rainfall recorded between January 2021 and April 2022 (**Figure 1-3**), prior to the wet season survey of the Study (May 2022).

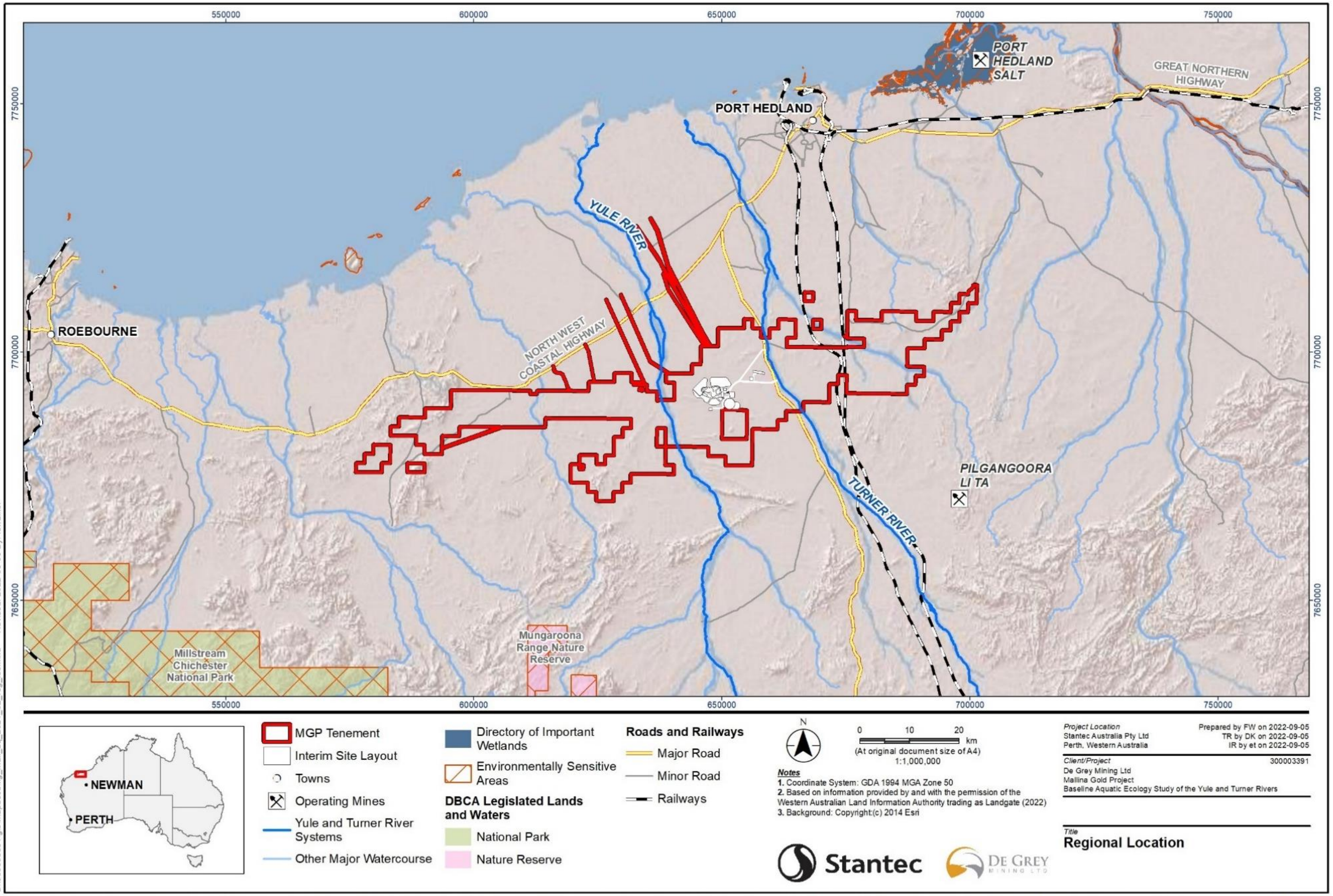

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Figure 1-1: Regional location of the MGP in the Pilbara region of Western Australia.

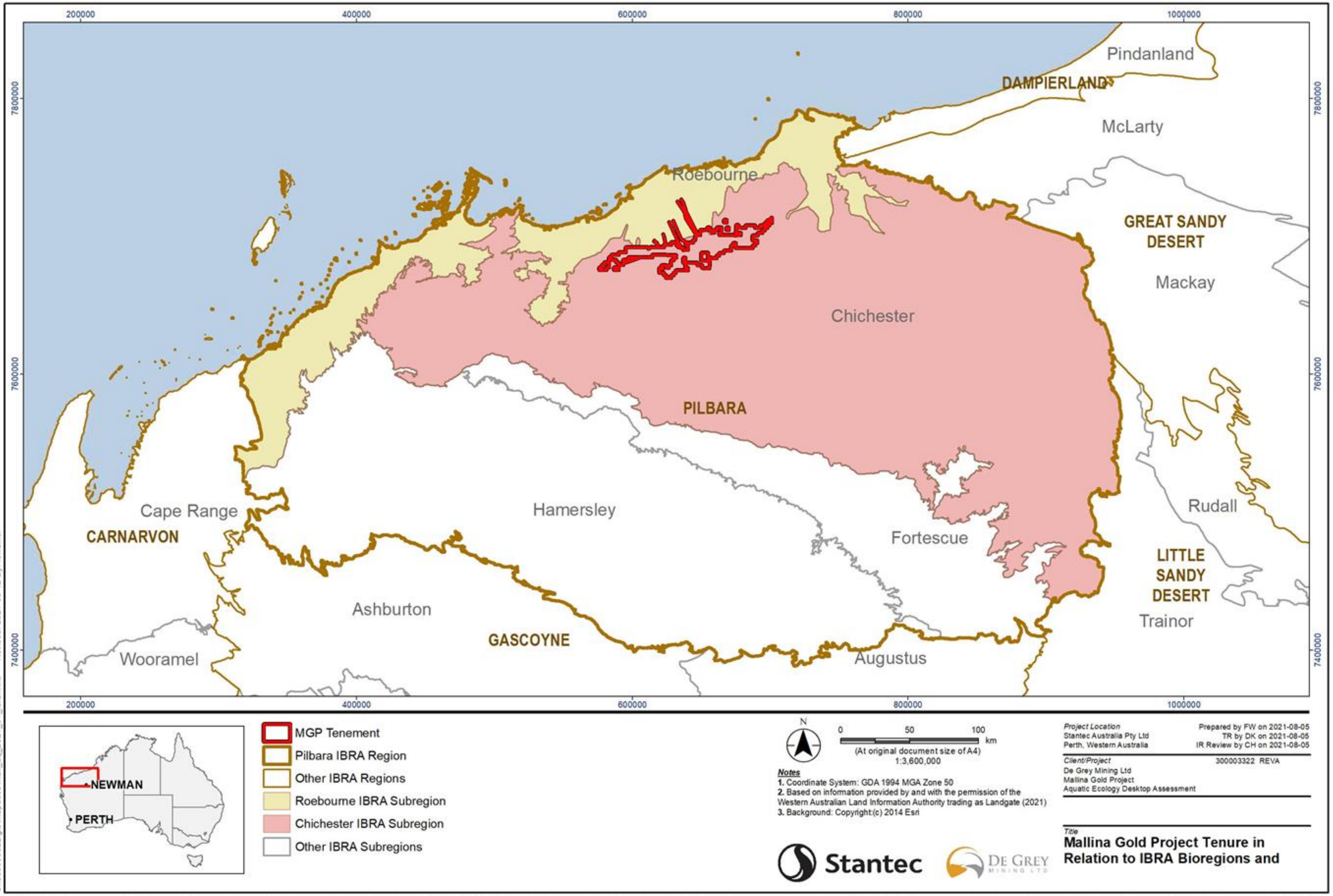

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Figure 1-2: Location of the MGP within the IBRA Chichester subregion.

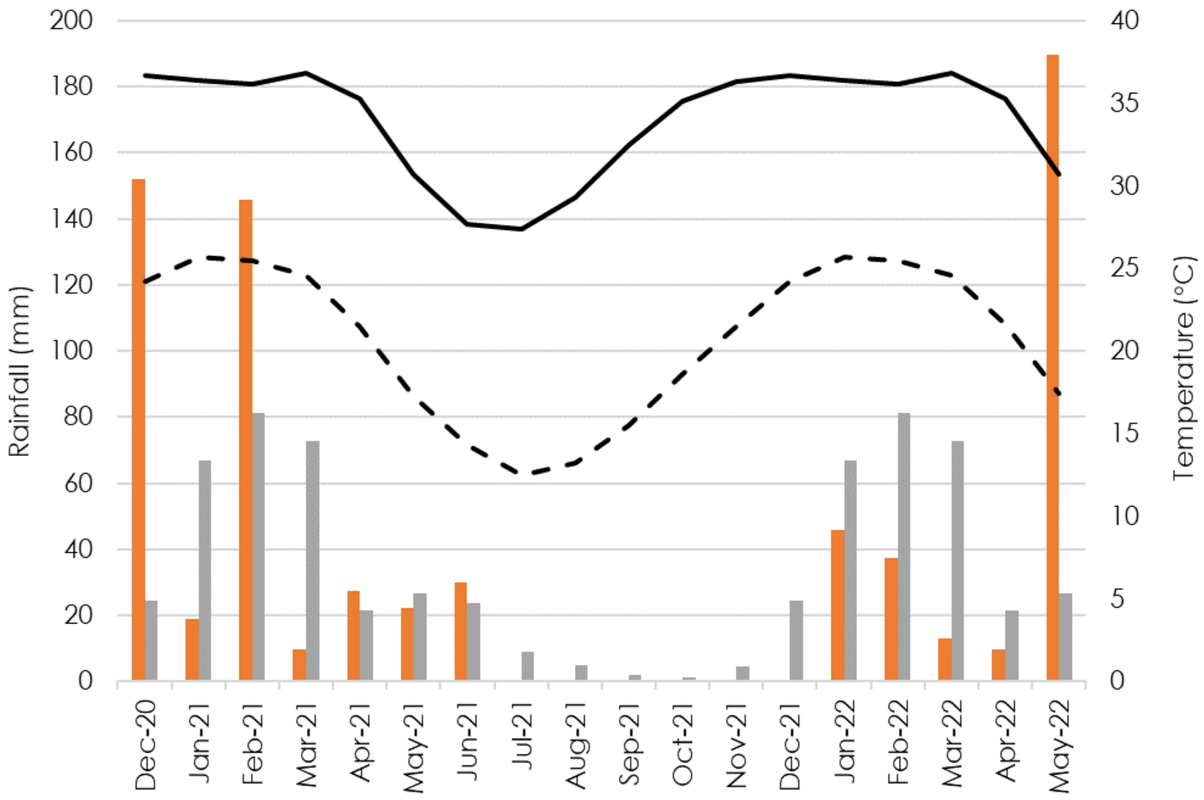

Figure 1-3: Monthly rainfall from December 2020 to May 2022 (■), compared to the mean monthly rainfall (■) and mean minimum (- - -) and maximum (—) temperatures (1909 to 2022) for Indee station 004016 (Bureau of Meteorology 2022).

1.2.3 Hydrology and Hydrogeology

Due to the arid to semi-tropical climate, unique geography and geomorphology, and the presence of extensive alluvial aquifers, inland waterbodies of the Pilbara are diverse, comprising claypans, salt marshes, rockpools, springs and rivers. While the majority of these waterbodies are ephemeral, semi-permanent/permanent pools are also known to occur providing important areas of refugia for aquatic biota (Pinder *et al.* 2010).

The MGP intersects two major inland watercourses; the Turner and Yule Rivers, as well as the smaller Peawah River to the west, and a series of small, converging ephemeral tributaries (**Figure 1-4**). The Turner River flows parallel to the Yule River (approximately 20 km to the west), with a catchment area of 4,802 km^2, and a total length of 116 km (WorleyParsons 2012). Approximately 40 km inland from the coast, the Turner River is bisected by a minor tributary to the east (Turner River East), which extends for another 40 km from the confluence and is separate to the main channel. Both waterways are ephemeral, with intermittent flows occurring during the wet season and extended periods of no flow over the dry season (WorleyParsons 2012). Monitoring data from the Pincunah Gauging Station (1985 to 2011) show flows typically only occur on 51 days each year, with a mean annual flow volume of 33,250 ML (WorleyParsons 2012).

The majority of the Turner River overlies an alluvial aquifer with a thickness of approximately 43 m, and a saturated thickness of 6 to 7 m (Department of Water 2011). A weathered bedrock aquifer lies beneath the alluvial aquifer, with some secondary calcrete development, and connectivity between both aquifers (Department of Water 2011). Several permanent pools have also been identified along the Turner River, which similar to the Yule, are surface expressions of the underlying alluvial aquifer where groundwater meets the river channel (Department of Water 2011; WorleyParsons 2012).

The Yule is a major river system with a catchment area of approximately 12,000 km^2 (Braimbridge 2010; Braimbridge and Loomes 2013). It flows in a north-easterly direction, from the Chichester and Mungaroona ranges to the coast, with a total length of 217 km (Braimbridge 2010). It is an ephemeral system, typically with little or no flow during the dry season (May to November), and periodic high flows during the wet season (December to April) dependent on rainfall (Braimbridge 2010). The mean annual flow volume at Jelliabidina Gauging Station (1973 to 2010) is 331,000 ML/year.

The lower reaches of the Yule River (downstream of the North West Coastal Highway) overlie a semi-confined alluvial aquifer (maximum thickness 50 m), primarily comprising sands and gravels with small sections of calcrete (Braimbridge 2010). Between flows, the system is reduced to a series of semi-permanent/permanent pools, supported by groundwater where the underlying aquifer intersects the river channel (Braimbridge and Loomes 2013).

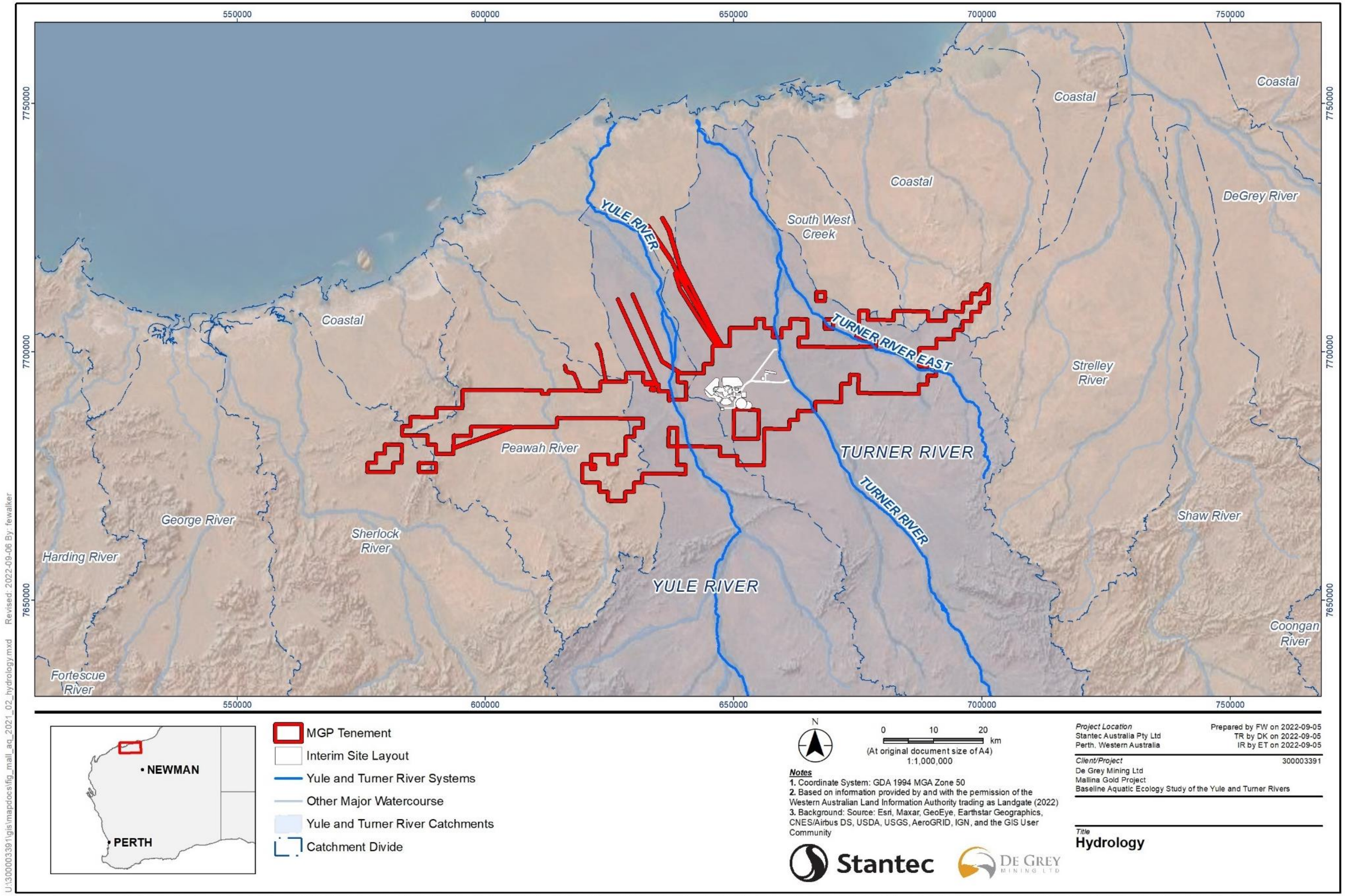

Figure 1-4: Hydrology and catchments in relation to the MGP.

2 Methods

2.1 Survey Rationale

The EPA has not developed prescriptive technical guidance for surveying Inland Waters in Western Australia. However, the National Water Quality Management Strategy (NWQMS) provides a framework for the management of water quality in Australia and New Zealand; the Water Quality Management Framework (WQMF) (ANZG 2018; Australian Government 2018). To protect the environmental values of waterways, the WQMF applies a weight of evidence approach to collect, analyse and evaluate qualitative, semi-quantitative or quantitative environmental and biological lines of evidence (LoE), typically comprising a range of ecological components across multiple trophic levels, to enable overall assessment (Australian Government 2018). The following LoE were sampled from each site during this Study, to characterise and assess ecosystem condition:

- water and sediment quality;
- aquatic macrophytes (aquatic plants);
- phytoplankton (algae);
- periphyton (diatoms);
- aquatic invertebrates (zooplankton and macroinvertebrates);
- fish; and
- other vertebrate fauna (Pilbara olive python, frogs, reptiles and water birds).

At each site during the Study, habitat characterisation was undertaken, to document the key hydrological, geological, and biological attributes of the waterway. Photographs were also captured to provide a record of site conditions at the time of each survey.

2.2 Survey Design and Team

The Study was undertaken by suitably qualified aquatic Stantec Scientists, led by Dr Fiona Taukulis (**Table 2-1**). The dry season survey was undertaken from the 4th to the 10th of November 2021, and the wet season survey took place between 12th and 18th May 2022. No rainfall occurred in the four months preceding the dry season survey (June to October 2021), and rainfall was below average prior to the wet season survey. As a result, the surface waters of the Turner and Yule Rivers during both surveys comprised a series of isolated remnant waterbodies, with water levels receding substantially between the dry and wet seasons.

Sites were selected based on the review of satellite imagery and known (named) pools, with locations ground-truthed in the field for accessibility and the presence of surface water. Subsequently, 10 sites were sampled during the dry season survey; four sites within the Turner River (including one site in Turner River East) and six sites in the Yule River. During the wet season, 12 sites were sampled; repeat sampling of 10 dry season sites with an additional two sites sampled (one each on the Turner and Yule Rivers). Reconnaissance of several additional sites was also undertaken during the Study; however, these sites were dry and were excluded from the sampling program. A summary of the sites sampled, and survey design is provided in **Table 2-2**, with locations shown in **Figure** 2-1.

The dry and wet season field surveys were led by Stantec Principal Aquatic Scientist Chris Hofmeester, assisted by Principal Scientist Dr Ruchira Somaweera (dry season survey) and Graduate Scientist Charlotte Boehm (wet season survey). Theda Morrissey (De Grey Site Environmental Advisor) also provided field assistance during both surveys. Sampling was conducted under Department of Biodiversity, Conservation and Attractions (DBCA) Regulation 27 Fauna Taking (Biological Assessment) Licence BA27000526, and Department of Primary Industries and Regional Development (DPIRD) Fisheries Exemption 3587 (dry season) and 251002222 (wet season). A range of abiotic and biotic components were assessed at each site, with the sampling regime summarised in **Table 2-3**.

In the laboratory, identification of aquatic biota was undertaken by relevant Stantec specialists. This included Dr Fiona Taukulis and Dr Erin Thomas for taxonomic resolution of algae (including diatoms) and macrophytes. Aquatic invertebrate identification was completed by taxonomists Chris Hofmeester, Emma Thillainath and Dr Erin Thomas. For some groups of microinvertebrates, additional taxonomic verification was required, outlined in more detail in the methods below (**Section 2.8**). Technical reporting was completed by Chris Hofmeester, Emma Thillainath and Dr Fiona Taukulis of Stantec.

Table 2-1: Summary of Stantec personnel showing their qualifications and experience.

Name	Qualifications and Experience
Dr Fiona Taukulis	BSc (Hons) Environmental Biology; PhD, >20 years' experience
Dr Erin Thomas	BSC (Hons) Environmental Biology; PhD >20 years' experience
Dr Ruchira Somaweera	BSc (Hons) Zoology; PhD, 15 years' experience
Chris Hofmeester	BSc (Hons) Environmental Biology, 10 years' experience
Emma Thillainath	BSc (Hons) Coastal and Marine Science, 8 years' experience
Charlotte Boehm	BSc Animal Ecology, 1 years' experience

Table 2-2: Sites sampled during the wet and dry seasons at the Turner and Yule River for the Study (NV = site not visited, grey text indicates site was dry and excluded from sampling program).

	Site	Easting	Northing	Dry Season (Nov 2021)	Wet Season (May 2022)	Location in relation to MGP
Turner River	TRE1	674304	7702949	DRY	DRY	Immediately downstream (northwest) of the MGP tenement in Turner River East
	TRE2	678598	7700634	✓	✓	Within MGP tenement in Turner River East, ~5 km upstream of the TRE1
	TRU1	678264	7663877	✓	✓	~30 km upstream (south) of the MGP tenement and proposed discharge
	TRU2	676593	7667382	NV	DRY	~26 km upstream (south) of the MGP tenement and proposed discharge
	TR1	666235	7687633	✓	✓	Within the MGP tenement (southernmost border), upstream of proposed discharge. Also known as Red Rock
	TR1-A	663748	7691197	NV	✓	Within the MGP tenement, ~1 km downstream (north) of TR1, upstream of proposed discharge
	TR2	658514	7704152	DRY	DRY	Immediately downstream (north) of the MGP tenement, likely within the extent of the proposed discharge
	TRD2	654441	7729971	✓	✓	~40 km south of the MGP tenement and likely downstream of the extent of the proposed discharge
Yule River	YRU1	651405	7664437	✓	✓	~20 km upstream (south) of the MGP tenement
	YRU1-A	650848	7664643	NV	✓	~18 km upstream of the MGP tenement
	YRU2	647661	7672527	✓	✓	~10 km upstream of the MGP tenement
	YR1	639367	7687647	✓	✓	Within MGP tenement, adjacent approximately 7.5 km from proposed site infrastructure
	YR2	640477	7683293	✓	✓	Within MGP tenement, ~5 km upstream of YR1
	YR3	638479	7690790	✓	✓	Within MGP tenement (northernmost boundary), ~3 km downstream of YR1. Also known as Jelliabidina Pool.
	YRD1	635191	7710393	✓	✓	~15 km downstream (north) of the MGP tenement; pool beneath the NW Coastal Highway bridge
	YRD3	637386	7701013	NV	DRY	~10 km downstream of the MGP tenement
Total Sites Sampled Turner River				**4**	**5**	
Total Sites Sampled Yule River				**6**	**7**	
Total Sites Sampled/Season				**10**	**12**	

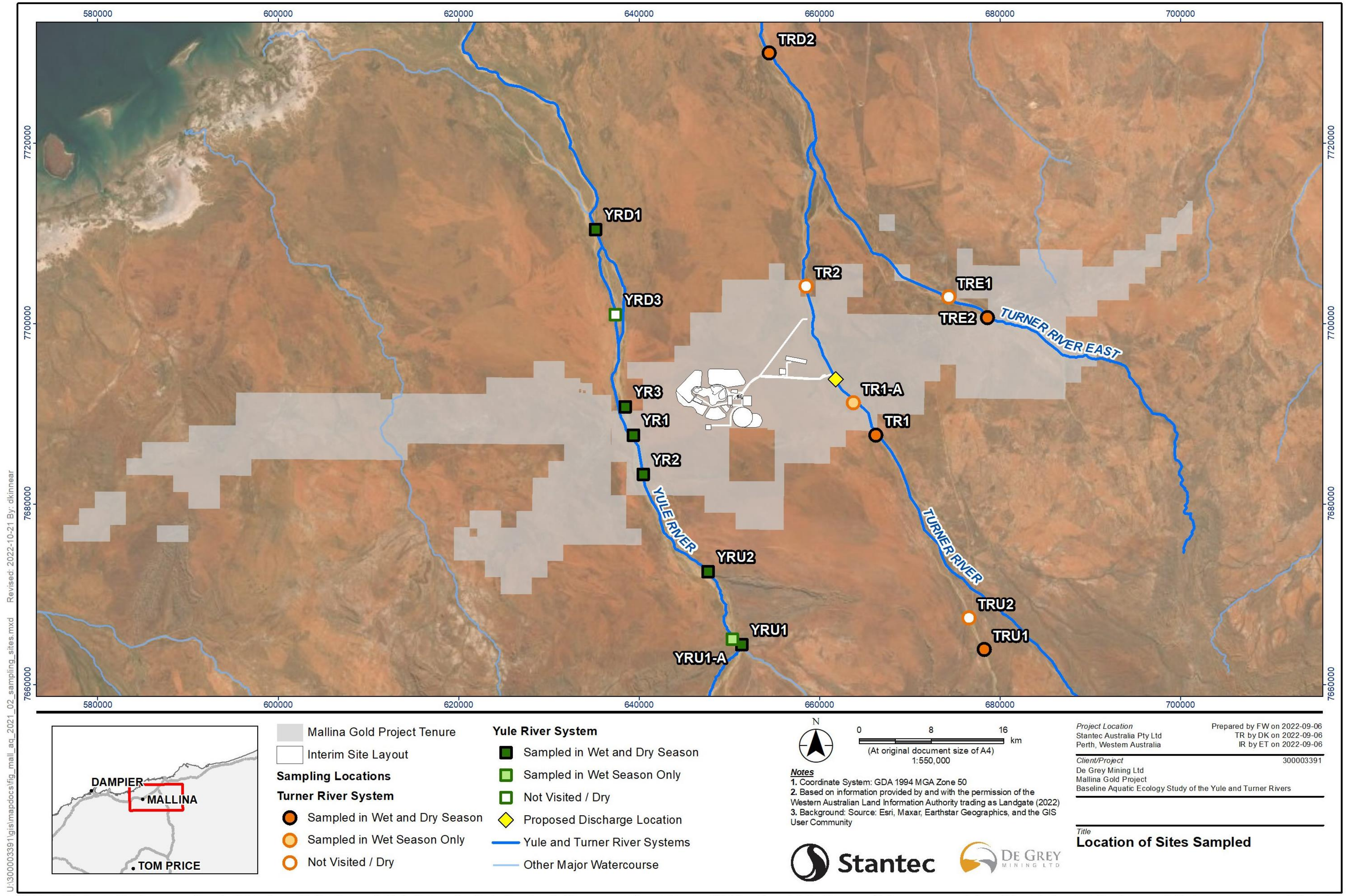

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Figure 2-1: Location of Turner and River sites in relation to the MGP and Hemi deposit.

Table 2-3: Summary of the sampling regime employed at each site during the Study.

Site		Water Quality	Sediment Quality	Macrophytes	Phytoplankton and Diatoms	Aquatic Invertebrates	Fish	eDNA Sampling (Filtered)	eDNA Sampling (Passive)	Other Vertebrates (Opportunistic Observation)
Turner River / Turner River East	TRE2	✓	✓	✓	✓	✓	✓	-	-	✓
	TRU1	✓	✓	✓	✓	✓	✓	✓DSO	-	✓
	TR1	✓	✓	✓	✓	✓	✓	✓DSO	✓DSO	✓
	TR1-A	✓WSO	✓WSO	✓WSO	✓*WSO	✓WSO	✓WSO	-	-	✓WSO
	TRD2	✓	✓	✓	✓	✓	✓	-	-	✓
Yule River	YRU1	✓	✓	✓	✓	✓	✓	-	-	✓
	YRU1-A	✓WSO	✓WSO	✓WSO	✓WSO	✓WSO	✓WSO	-	-	✓WSO
	YRU2	✓	✓	✓	✓	✓	✓	✓DSO	-	✓
	YR1	✓	✓	✓	✓*	✓	✓	-	-	✓
	YR2	✓	✓	✓	✓*	✓	✓	-	-	✓
	YR3	✓	✓	✓	✓*	✓	✓	-	-	✓
	YRD1	✓	✓	✓	✓	✓	✓	-	-	✓

Note: WSO = Wet Season Only; DSO = Dry Season Only; * indicates phytoplankton sample results not available; - indicates sample not collected.

2.3 Water Quality

During the Study, at each site, *in situ* readings of pH, salinity (electrical conductivity; EC), dissolved oxygen and water temperature were recorded using a YSI Pro-Plus portable water quality meter. Additionally, water samples were collected from the water column for the analysis of nutrients, ionic composition, and dissolved metals (**Table 2-4**), using sterilised bottles provided by the NATA-accredited Australian Laboratory Services (ALS), containing preservative where required. Water samples collected for metals analysis were filtered through a 0.45 µm Millipore filter, with samplers wearing nitrile gloves to avoid contamination. Bottles were sealed and kept cool prior to being couriered to ALS (Wangara) for the analysis.

Table 2-4: Analytical suite for water samples collected during the Study.

Basic Parameters and Nutrients	Anions and Cations	Dissolved Metals	
pH	Chloride (Cl)	Aluminium (Al)	Iron (Fe)
Electrical Conductivity (EC)	Bicarbonate (HCO_3)	Arsenic (As)	Mercury (Hg)
Total Dissolved Solids (TDS)	Carbonate (CO)	Barium (Ba)	Manganese (Mn)
Turbidity	Sulphate (SO_4)	Boron (B)	Molybdenum (Mo)
Suspended Solids (SS)	Sodium (Na)	Cadmium (Cd)	Nickel (Ni)
Nitrite + Nitrate (NO_x)	Magnesium (Mg)	Chromium (Cr)	Selenium (Se)
Total Kjeldahl Nitrogen (TKN)	Calcium (Ca)	Cobalt (Co)	Uranium (U)
Total Nitrogen (TN)	Potassium (K)	Copper (Cu)	Vanadium (V)
Total Phosphorus (TP)		Lead (Pb)	Zinc (Zn)

Surface water pH was classified according to the system developed by Foged (1978), comprising acidic (4.5 to 6.5), circumneutral (6.5 to 7.5), and alkaline (>7.5) conditions, while salinity levels were categorised according to Hammer (1986), as freshwater (>5,000 µS/cm) and hyposaline (>5,000 µS/cm to 30,000 S/cm). Analytical water quality results were compared to the Australian and New Zealand (ANZG 2018) Default Guideline Values (DGVs) for freshwaters. Basic parameters and nutrients were compared against stressor DGVs for slightly-moderately disturbed ecosystems in tropical northern Australia, while dissolved metals were compared against toxicant DGVs at the level of 95% species protection (except for some potentially bioaccumulating metals, whereby 99% species DGVs were applied).

2.4 Sediment Quality

Sediment samples were collected from each site during the Study from along the margins of the watercourses using sterilised glass jars (provided by ALS), with samplers wearing nitrile gloves to prevent incidental contamination. All sediment samples were sealed and kept cool for the duration of the field survey, and then couriered to ALS in Wangara for the analysis of a range of parameters including ionic composition, nutrients, and metals (**Table 2-5**).

Table 2-5: Analytical suite for sediment samples collected during the Study.

Basic Parameters and Nutrients	Anions and Cations	Metals	
pH	Chloride (Cl)	Aluminium (Al)	Iron (Fe)
Electrical Conductivity (EC)	Bicarbonate (HCO_3)	Arsenic (As)	Mercury (Hg)
Total Soluble Salts (TSS)	Carbonate (CO)	Barium (Ba)	Manganese (Mn)
Moisture Content	Sulphate (SO_4)	Boron (B)	Molybdenum (Mo)
Total Organic Carbon (TOC)	Sodium (Na)	Cadmium (Cd)	Nickel (Ni)
Nitrite + Nitrate (NO_x)	Magnesium (Mg)	Chromium (Cr)	Selenium (Se)
Total Kjeldahl Nitrogen (TKN)	Calcium (Ca)	Cobalt (Co)	Uranium (U)
Total Nitrogen (TN)	Potassium (K)	Copper (Cu)	Vanadium (V)
Total Phosphorus (TP)		Lead (Pb)	Zinc (Zn)

Sediment pH was also classified according to Hazelton and Murphy (2007), ranging from very strongly acidic (<5.0) to very strongly alkaline (>9.0). Analytical sediment quality results were compared to the ANZG (2018) Guideline Values (GVs) including GV-High concentrations; levels that are potentially toxic to aquatic biota.

2.5 Macrophytes (Aquatic Plants)

Macrophytes (emergent and submerged forms) were opportunistically photographed and collected during the Study, where observed at sites. Macrophyte samples were examined under a dissecting microscope in the laboratory and identified to genus or species level (where possible) based on morphological and reproductive features, using relevant literature and keys.

2.6 Phytoplankton

Phytoplankton was collected with a 20 µm mesh net during the Study, towed through the water column (rinsed between sites to prevent cross-contamination), over an approximate 30 m reach at each site. The resultant samples were transferred into a 70 mL vial and kept cool to preserve algal structure. In the laboratory, three representative slides from each sample were mounted on glass microscopy slides and examined under a compound microscope at 40x magnification. The relative abundance of algal taxa from the phytoplankton samples was recorded, and was calculated per cell, colony, or filament, dependent on morphological form. Taxa were identified to genus and species level by Stantec's experienced algal taxonomists, using appropriate taxonomic literature.

2.7 Periphyton (Diatoms)

Periphyton (diatoms) were collected in the form of twigs, sediments, rocks, debris and macrophytes from the shallow waters of each site during the Study. Samples were placed in 50 mL polycarbonate containers and kept cool for preservation. In the laboratory, diatoms were treated in 70% nitric acid to remove organic material, and permanent slides were prepared. Three replicate slides were made from each sample, with enumeration and identification carried out at 100x magnification under a compound microscope. A maximum of 100 diatoms were counted from each site, to provide a representation of community structure. Taxa were identified to species level, with verification provided by Stantec's experienced diatom taxonomists, using relevant taxonomic guides.

2.8 Aquatic Invertebrates

Microinvertebrates (zooplankton) were sampled using a 53 µm plankton net swept through the water column over a standardised (50 m) longitudinal reach at each site during the Study. Samples were placed into 250 ml polycarbonate containers and preserved in 100% ethanol. Aquatic macroinvertebrates were sampled at each site using a 250 µm D-frame dip net using a kick/sweep motion over approximately 50 m, targeting all available habitat types including riffles, detritus, woody debris, open water column, benthic sediments and submerged and emergent macrophytes (**Plate 2-1A**). Material retained in the D-frame net was emptied into 1.5 L polycarbonate containers and preserved in 100% ethanol.

Micro and macroinvertebrate samples were processed under a dissecting microscope, with specimens separated into their broad taxonomic groups (family level). Following this, specimens were identified to the lowest taxonomic rank possible (typically species-level) using dissecting or compound microscopes by Stantec specialists. For several microcrustacean groups, specialist identification was also required (**Table 2-6)**.

Table 2-6: Aquatic invertebrate taxonomy specialists utilised during the Study.

Group	Personnel	Affiliation
Ostracoda	Dr Stuart Halse	Bennelongia Environmental Consultants
Copepoda and Cladocera	Jane McRae	Bennelongia Environmental Consultants
Ostracoda, Copepoda and Cladocera	Dr Russel Shiel	Benham Laboratories

2.9 Fish

Fish were sampled using several integrated methods during the Study, consisting of beach seine, gill netting (where deemed safe and appropriate to do so), fyke netting and visual observation. Gill nets of 10 mm, 13 mm, 19 mm and 25 mm mesh were deployed for a set time of 20 minutes at each site, with nets constantly checked and cleared to ensure fish are not placed under undue stress. Two beach seine hauls were conducted at each site to target smaller bodied/juvenile species (**Plate** 2-1**B**). Two fyke nets (comprising a single hooped funnel and 5 m "wings"; mesh size 6 mm) were also deployed overnight at select sites (YRU1-A and YR1) during the wet season survey. All captured fish were placed in a 20 L container, identified, measured for standard length (from the tip of the snout to the posterior end of the last vertebra) and released back into the waterway. Fish nomenclature followed that of Allen *et al.* (2002).

Plate 2-1: (A) Macroinvertebrate ‘kick-sweep’ sampling method at Yule River site YR1, and (B) seine net haul targeting fish fauna at Yule River site YRD1.

2.10 Other Vertebrate Fauna

2.10.1 Field Observations

Opportunistic observations of other vertebrate fauna (frogs, freshwater turtles and waterbirds) utilising the waterways at were recorded during the Study. These fauna were identified to species level, where possible in the field, by Stantec specialists.

2.10.2 eDNA Sampling and Analysis

Environmental DNA (eDNA) sampling was undertaken during the dry season survey, using a metabarcoding approach (multi-species). However, the primary target of the analysis was to detect the Pilbara Olive Python (POP); *Liasis olivaceus barroni*. This species is listed as Vulnerable under the Western Australian *Biodiversity Conservation Act 2016* (BC Act) and Federal *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). Sites were selected for eDNA sampling based on presence of suitable POP habitat in the surrounding environment, typically comprising rocky outcrops and gorges near waterways.

Three sites met the selection criteria, from which, three replicate eDNA water samples were taken at each location (TR1 River Pools, TRU1 and YRU2). Three additional replicate water samples were taken from the rockpools at TR1 (Red Rock Rockpools), where the POP had been observed in the months prior to the dry season survey (Sarah Thomas, De Grey, pers. comm. 2022).

Water samples were collected in sterile, 1 L containers provided by eDNA Frontiers (Curtin University) and were filtered on-site through 0.45 µm mixed cellulose ester (MCE) membrane filters using a peristaltic Sentino pump to capture eDNA present in the water. Additionally, three passive samples were taken from TR1 (Red Rock Rockpools), comprising deployment of three 0.45 µm MCE membrane filters in the water column (within sterile mesh bait bags) for a period of 24 hours. Two negative control samples were also taken, comprising clean bleach solution from the filtering process, as per eDNA sampling standard procedures. Throughout the collection and filtering process, samplers wore nitrile gloves, with all sampling equipment sterilised in a bleach solution between sampling sites to avoid cross-contamination. Samples (MCE membrane filters) were then frozen and transported to the eDNA Frontiers laboratory for DNA extraction.

Samples were analysed at eDNA Frontiers for the presence of DNA from the POP and other vertebrate fauna using a metabarcoding assay targeting the mtDNA 16s gene of the species for taxon assignment (where there is an existing reference library). This process involved:

- Extraction of eDNA from half of each filter paper using a Qiagen DNeasy blood and tissue kit. Each sample was assigned an individual combination of index tags and amplified by polymerase chain reaction (PCR) using a 16S assay that detects reptiles. Laboratory extraction and PCR controls were included to test for contamination, which returned negative results.
- Bioinformatic tools were used to analyse raw sequence data generated from the metabarcoding. Sequences were then dereplicated and unique sequences were transformed into zero radius operational taxonomic units (ZOTUs) to provide sensitive taxonomic resolution.
- Following stringent quality control filtering, generated ZOTUs were queried against the nucleotide database from the National Centre for Biotechnology Information (NCBI; GenBank) and assigned to a species, where possible.

It should be noted that while sequences recovered were converted to the lowest possible taxon based on similarities and differences to a DNA database (NCBI’s GenBank), this database, and the underlying taxonomic framework may contain errors. Accordingly, the DNA taxon identifications should be interpreted as the best available assignment, based on available information and may be considered erroneous in some instances.

2.11 Statistical Analysis

A range of multivariate statistical analyses were employed to interrogate the data collected during the Study performed in the statistical package PRIMER, Version 7.0. Principal components analysis (PCA) was used to investigate patterns in abiotic parameters (water and sediment quality) across both seasons. Prior to analysis, data values below the level of analytical detection were halved, while parameters with more than 50% of values below detection were removed from the dataset. Selected parameters were transformed to reduce skewness (ensuring the data was normally distributed) and collinear variables (those with a linear relationship) were removed during pre-treatment of the data. The results of the PCA are shown in the form of a plot, on which sites that are similar are located closer together. Vectors radiate from the centre of the plot, representing the influence of each parameter. Higher concentrations of a parameter tend to occur near the end point of the vector. The percentage variance is used to explain the strength of the PCA; presented over the first two axes of the plot. A value of more than 60% is considered a useful interpretation of the results (Clarke and Warwick 2001).

Biological data were investigated using hierarchical classification and non-multidimensional scaling (nMDS) analyses, performed on the algal, diatom and aquatic invertebrate data to determine similarities and significant differences in community structure between sites. Prior to analyses, data was transformed (square root abundance) where required, to reduce skewness. For hierarchical classification, the Bray-Curtis index was used to calculate coefficient similarities between sites, with classification based on the group-average linking algorithm. The results are presented in the form of a dendrogram (link-tree), showing the percentage similarity between sites, based on biological community structure (Clarke and Warwick 2001). The nMDS ordination is represented as a two-dimensional plot, grouping sites with similar composition together. The strength of the analyses is indicated by a stress value, with <0.2 providing an adequate explanation of the data (Clarke and Warwick 2001). The SIMPROF routine was also run to determine statistical significance between site groupings, the results of which are overlain as circles on the associated nMDS plot (Clarke and Warwick 2001).

2.12 Conservation Significant Species

The key findings of the Study were summarised and the status of listed conservation significant taxa were collated for each river system, according to bioregion, State or Federal legislation and global listings (where information was available). A summary of these listings and their definitions is provided in **Table 2-7**.

Table 2-7: Conservation significant aquatic invertebrate and vertebrate fauna listings, specific to this Study.

Legislation / Reference	Listing Status / Code	Definition
Pinder *et al.* 2010 (Bioregion)	Pilbara endemic	Aquatic invertebrates currently only known from the Pilbara bioregion
BC Act (State)	Endangered (En)	Taxa rare or likely to become extinct, as endangered taxa
EPBC Act (Federal)	Endangered (En)	Taxa considered to be facing a very high risk of extinction in the wild in the near future
IUCN Red List (Global)	Vulnerable (Vu)	Best available evidence indicates it meets the Vulnerable criteria and is facing a high risk of extinction in the wild
	Near Threatened (NT)	Evaluated against criteria and does not qualify for critically endangered, endangered or vulnerable, but likely to qualify for a threatened category in the near future

3 Results and Discussion

3.1 Habitat Characterisation

Habitat characterisation of sites sampled during the Study, including a description of their geomorphological, hydrological, and biological features is provided in **Table 3-1**. A total of 12 sites were sampled over the two seasons comprising five sites within the Turner River and seven in the Yule River.

The majority of sites on the Turner River were semi-permanent pools influenced by rainfall, that were more sizable during the dry season and receded to smaller, shallower waterbodies in the wet season, due to the extended dry conditions (**Table 3-1**). The exception was TR1 (Red Rock), with surface water extent remaining relatively similar between seasons, likely due to underlying bedrock limiting infiltration (**Table 3-1**), while most sites comprised a sandy/silt base. There was also evidence of livestock across a number of pools, especially during the wet season, where cattle were likely frequenting these waterbodies.

In comparison, most of the Yule River sites were larger permanent or semi-permanent, groundwater-fed pools, perched on silty-clay, with limited variation evident in pool size or depth between seasons (**Table 3-1**). The exception was YRU2, which contracted substantially to a series of small, isolated pools during the wet season, due to the prolonged dry conditions.

Complex instream habitat, such as large beds of macrophytes, undercut banks, large woody debris, and detritus, as well as dense riparian vegetation (providing habitat including overhanging vegetation and tree roots), characterised the larger, more permanent pools of the Yule River (YRU1-A, YR1, YR2 and YR3) (**Table 3-1**). In comparison, habitat tended to be limited and was more homogenous in the smaller semi-permanent pools of the Turner River, which typically lacked macrophytes and were turbid (**Table 3-1**). These pools provide important refugia for both aquatic and terrestrial biota in an otherwise arid landscape in the Pilbara (Pinder *et al.* 2010).

Table 3-1: Habitat characterisation and photographs of sites sampled during the Study.

Site	Dry Season – November 2021	Wet Season – May 2022	Description
Turner River			
TRE2			During the dry season, surface waters comprised a large (100 m length, 30 m width), deep (>1.5 m) relatively turbid pool located at the base of a rocky gorge in Turner River East. Instream habitat was complex and comprised large woody debris, submerged and emergent macrophytes, detritus, and overhanging vegetation. During the wet season the water body had contracted substantially, to a pool approximately 30 m long and 10 m wide, with a maximum depth of 1.2 m, with instream habitat more limited. During both seasons, riparian vegetation was healthy but scattered, primarily comprising *Melaleuca argentea* and flooded gum. Substrate primarily comprising coarse sand, with some silty clay on the pool's margins.
TRU1			During the dry season, the site comprised a large (100 m length, 20 m width), deep (>1.5 m) relatively turbid pool located in the centre of the Turner River main channel. Instream habitat was complex and comprised large woody debris, submerged and emergent macrophytes, detritus, and overhanging vegetation. Substrate primarily comprised coarse sand, with some silty clay on the pool's margins. During the wet season, surface waters had reduced to a series of very small (1 m x 1 m, <0.2 m deep) pools, which were heavily impacted by cattle. Subsequently, substrates were dominated by anoxic, silty clay. During both seasons, riparian vegetation was healthy but scattered, primarily comprising *Melaleuca argentea* and flooded gum.
TR1			A series of small (3 x 3 m, 0.2 cm deep) to moderately sized (20 x 10 m, 1 m deep) turbid rockpools located at the centre of the Turner River main channel. Instream habitat very limited, with some submerged macrophytes (charophytes) present. Riparian vegetation absent. Substrate comprising sand overlying bedrock. Pool size and depth had only reduced slightly between the dry and wet seasons, due to surface waters likely being perched atop the bedrock base, with limited infiltration. Also known as Red Rock.

Site	Dry Season – November 2021	Wet Season – May 2022	Description
TR1-A	NOT VISITED		A series of relatively large (100 m x 25 m, 1.8 m depth), open turbid rockpools located on the western edge of the Turner River main channel. Instream habitat relatively limited, with some submerged macrophytes and small patches of emergent macrophyte (*Typha*) present, along with some large woody debris and detritus around the pool margins. Riparian zone also limited, with some scattered *Melaleuca argentea*. Substrate comprising silty clay and sand overlying bedrock. Not visited during the dry season survey.
TRD2			During the dry season, surface waters comprised a broad (>100 m length, 30 m width), relatively shallow (0.5 m) clear pool situated beneath the Great Northern Highway bridge. Surface waters had contracted substantially during the wet season, with only a small (15 m x 5 m), shallow (0.4 m) pool remaining, with waters turbid from and blooming algae/cyanobacteria and fouled with deceased fish. In both seasons, instream habitat was limited to a few scattered boulders, with no aquatic macrophytes present and riparian vegetation absent. Substrate comprised primarily sand, with silty clay at the pool's margins, which was anoxic during the wet season survey.
Yule River			
YRU1			Relatively small (10 m long, 10 m wide), shallow (0.4 m deep), turbid pool, situated on the eastern edge of the Yule River, at the base of a rocky ridge. Benthic substrates consisted primarily of clay and silt, with a few scattered boulders. In-stream habitat was minimal and primarily comprised organic detritus, with no aquatic macrophytes (plants) present. Fringed by dense *Melaleuca argentea* suggesting at least semi-permanence of surface and/or groundwater. Sediments comprised mostly anoxic silt overlying sand and large boulders. Limited instream habitat. Due to groundwater influence and/or clay substrate (on which surface waters may have been perched), there was minimal change in pool size and depth between dry and wet season sampling. Evidence of heavy cattle usage in both seasons, likely mobilising fine sediments leading to turbid water.

Site	Dry Season – November 2021	Wet Season – May 2022	Description
YRU1-A	NOT VISITED		Moderately long (30 m), narrow (5 m) clear permanent pool located in the centre of the Yule River main channel, fed by a small upwelling on the southern side. Pool located up against relatively steep bank, approximately 3-4 m high, with dense riparian vegetation (*Melaleuca argentea*) on the eastern side of the pool (no vegetation was present on the western side). Complex in-stream habitat included dense aquatic macrophyte and algal growth, overhanging (draping) vegetation, tree roots, undercut banks, large woody debris and detritus. Benthic substrates exclusively comprising coarse sand which is prominent throughout the Yule River main channel. Not visited during the dry season survey.
YRU2			During the dry season, surface waters comprised a narrow (<10 m width), shallow (<0.5 m), clear meandering creek extending over 500 m; likely groundwater fed. During the wet season, surface waters had reduced to a series of very small (2 m x 2 m, <0.5 m deep) pools (although were still clear) likely reflecting a reduction in groundwater levels due to prevailing dry conditions. Fringed with a narrow zone of dense *Melaleuca argentea* and flooded gums, indicating groundwaters are typically close to the surface, although the riparian zone is scattered with distance from the creek. Sediments comprised mostly sand with some scattered gravel and cobbles. Variety of instream habitat types including algal mats, sparse aquatic macrophytes, root mats, detritus and riffle zones (dry season only).
YR1			Large (>250 m length, 10 m width), deep (>1.5 m) permanent pool situated on the eastern edge of the Yule River main channel. Water relatively turbid. Steep, incised banks with sediments comprising silty clay, gravel and cobbles on the edges, with a bedrock base. Dense aquatic macrophyte growth suggesting high productivity, including emergent *Typha domingensis* and *Schoenoplectus subulatus* beds throughout the pool. Highly complex instream habitat included the macrophyte beds, as well as overhanging (draping) vegetation, tree roots, large woody debris, boulders and detritus. Fringed with a narrow zone of dense *Melaleuca argentea* and flooded gums (particularly on the western edge) indicative of water permanency. Limited change in pool size or depth between the dry and wet seasons.
YR2			Very large (>500 m length, >30 m wide), deep (>1.5 m), clear permanent pool situated on the eastern edge of the Yule River main channel. Steep banks with dense submerged and emergent macrophyte growth; sediments comprised silty clay with some overlying gravel on the edges, and sand through the centre of the pool. Instream habitat was complex, particularly on the pool's edges, and included broad macrophyte beds, overhanging (draping) vegetation, undercuts, tree roots, large woody debris, boulders and detritus. Relatively wide (20 to 40 m) and healthy riparian zone comprising dense *Melaleuca argentea*, *Eucalyptus* spp. and scattered *Sesbania formosa*. Limited change in pool size or depth between the dry and wet seasons.

Site	Dry Season – November 2021	Wet Season – May 2022	Description
YR3			Large (>250 m length, >30 m wide), deep (>1.5 m) turbid permanent pool situated on the eastern edge of the Yule River main channel. Steep banks with dense algal, submerged, and emergent macrophyte growth; heavily cattle impacted with much of the emergent macrophytes trampled or eaten away. Complex habitat favouring waterbirds, including large areas of open water, shallow banks and sandbars where birds were observed wading, aquatic plant growth and overhanging trees for perching. Sediments comprising silty clay with some overlying gravel. Sparse to moderately dense riparian zone primarily comprising *Melaleuca argentea* and flooded gum. Limited change in pool size or depth between the dry and wet seasons. Also known as Jelliabidina Pool.
YRD1			A moderately sized (50 x 20 m), relatively deep (>1 m) and slightly turbid permanent pool, situated on the eastern edge of the Yule River main channel beneath the NW Coastal Highway bridge. Complex instream habitat including large woody debris, detritus, aquatic macrophytes and boulders present at the pool's margins, with relatively open habitat in the centre of the pool. Benthic substrates exclusively comprised coarse sand. Sparse to moderately dense (pool fringes) riparian zone primarily comprising *Melaleuca argentea* and flooded gum. Pool size receded slightly between the dry and wet season surveys.

3.2 Water Quality

The chemical and physical properties of temporary inland waters are primarily influenced by the filling and drying cycles, driven by rainfall, surface runoff and groundwater interaction (Young and Kingsford 2006). Although the underlying processes and interactions in these waterbodies are similar to permanent systems, they tend to show more variation due to evapoconcentration (Boulton and Brock 1999). The hydroperiod of river systems in the arid zone of Western Australia fluctuates from highly fragmented to strongly connected, which contributes to habitat heterogeneity (Kingsford and Thompson 2006; McGregor *et al.* 2006). In dry periods, temporary river systems in the Pilbara are typically reduced to a series of isolated pools, which constitute important refugia for aquatic and terrestrial fauna (Beesley and Prince 2010; Department of Western Australia 2004; Dobbs and Davies 2009; Loomes and Braimbridge 2010; Morgan *et al.* 2009).

The surface water pH of Turner River during the Study was moderately to strongly alkaline (Foged 1978), ranging from 8.25 (TRE2; Turner River East) to 9.05 (TRD2) during the dry season, and from 8.36 (TRU1) to 9.5 (TR1) during the wet season (**Table 3-2**, **Figure 3-1**). In the Yule River, pH was circumneutral-alkaline to strongly alkaline (Foged 1978) , ranging from 7.59 (YRU2) to 8.8 (YRU1) in the dry season, and from 7.61 (YRU2) to 8.71 (YR3) during the wet season (**Table 3-3, Figure 3-1**). Surface water pH was above the upper ANZG (2018) DGV (8.0) in all Turner River sites, and in several Yule River sites in both seasons (**Table 3-2**, **Table 3-3, Figure** 3-1**A**). This is considered typical for semi-permanent river pools and spring fed pools of the Pilbara (Pinder *et al.* 2010). Previous surveys of Turner and Yule and Rivers recorded similar results, with Turner River pH typically ranging between 8.5 and 9.2, and Yule River pH ranging between 7.6 and 8.9 (Masini 1988; Masini and Walker 1989; Pinder and Leung 2009; Morgan *et al.* 2009).

Salinity, measured as EC, was classified as freshwater (<5,000 µs/cm) during the Study (Hammer 1986) in the majority of Turner and Yule River sites. Exceptions included Turner River sites TR1 (5,400 µs/cm) and TRD2 (7,090 µs/cm) during the wet season and Yule River site YRU1 during the dry season (8,460 µs/cm) (**Table 3-2**, **Table 3-3**). Each of these pools were relatively small and shallow, with TR1 and in particular, TRD2, contracting in size and depth between the surveys, with increasing salinity likely driven by evapoconcentration towards the end of the hydroperiod (Boulton and Brock 1999). Salinity in the remaining Yule River pools ranged from 380 µs/cm (YRU2; dry season) to 3,410 µs/cm (YR3; wet season), while in the Turner River ranged from 234 (TRE2; Turner River East; wet season) to 3,830 µs/cm (TR1; dry season) (**Table 3-2**, **Table 3-3**). During previous studies, EC at Yule River pools ranged from 297 µs/cm to 2,695 µS/cm, with lower salinity recorded at the Turner River (5 µs/cm to 375 µS/cm) (Masini 1988; Masini and Walker 1989; Morgan *et al.* 2009; Pinder and Leung 2009). Higher salinities recorded during this Study were likely due to the dry conditions preceding both seasonal surveys. In addition, although salinity exceeded the ANZG (2018) DGV of 250 µs/cm at the majority of sites (**Table 3-2**, **Table 3-3, Figure 3-1B**), this is considered typical of Pilbara pools (Pinder *et al.* 2010), and aquatic biota strongly adapted to rapidly changing conditions over the course of the hydroperiod (Dunlop *et al.* 2005).

During the dry season, the composition of cations at all Turner and Yule River sites was dominated by Na, with Mg/Ca sub-dominance interchangeable, followed by K (the exception being the shallow, receding pool of YRU1, where K was more dominant than Ca) during the Study (**Table 3-2**, **Table 3-3**). Cations generally followed a similar pattern during the wet season, however, Ca was the dominant cation at Turner River TRE2 (Turner River East) and TR1-A; sites where salinity was markedly low (<271 µS/cm) (**Table 3-2**, **Table 3-3**). In contrast, the dominance of anions was interchangeable in both seasons, with HCO_3 or Cl>CO_3 or SO_4 being common at most sites (**Table 3-2**, **Table 3-3**). The ionic composition of waterbodies in the Pilbara can vary considerably throughout the hydroperiod (Pinder *et al.* 2010), and is typically influenced by factors such as catchment geology, the influence of groundwater and evapoconcentration (Hart and McKelvie 1986).

The concentration of DO (% saturation) was highly variable across sites during both seasons, although typically represented well oxygenated surface waters. Low levels of DO (<25% saturation) is associated with anoxia, and can be critically limiting to aquatic biota (Williams 1998), leading to the release of nutrients and metals bound in sediments (Connell 2005). Concentrations recorded during the Study were above this level; Turner River DO ranged from 25.4% in TRU1 (wet season) to 125% in TR1 (wet season), while Yule River DO ranged from 30% in YR1 (wet season) to 120% in YR3 (dry season) (**Table 3-2**, **Table 3-3, Figure** 3-1**C**). Although mostly below the lower ANZG (2018) DGV of 90% (**Figure** 3-1**C**), DO exhibits substantial diurnal variation in response to biological and physical processes (primarily photosynthesis and respiration by aquatic organisms), with the majority of aquatic biota of arid zone systems strongly adapted to these fluctuations (Boulton and Brock 1999; Reddy and DeLaune 2008).

Surface waters were generally clear during the Study, with turbidity below the ANZG (2018) DGV (15 NTU) in all sites, except for YRU1 (36 NTU) and YR1 (17 NTU) during the dry season, and TRD2 (130 NTU) during the wet season (**Table 3-2**, **Table 3-3, Figure** 3-1**D**). The comparatively higher turbidity in YRU1 and YR1 during the dry season was likely related to the suspension of fine sediments in these pools from livestock. The markedly higher turbidity in TRD2 during the wet season also appeared to be attributed to the mobilisation of fine sediments, as well as the high concentration of phytoplankton (green algae) within this pool, driven by elevated nutrient concentrations. During previous surveys, turbidity within Yule River pools ranged from very clear (1.9 NTU) to slightly turbid (22.5 NTU) (Masini 1988; Masini and Walker 1989). However, these values are considered relatively low in the context of Pilbara riverine pools, with turbidity over 150 NTU frequently recorded, typically during the wet season (Pinder *et al.* 2010).

The TN concentrations within the Turner River sites ranged from 0.7 mg/L (TRE2; Turner River East and TRU1) to 2.8 mg/L (TR1) during the dry season, and from 0.6 mg/L (TR1-A) to 15.6 mg/L (TRD2) during the wet season. Yule River sites ranged from 0.2 mg/L (YRU2) to 4.7 mg/L (YRU1) for TN during the dry season, and from below the limit of reporting (LOR; 0.1 mg/L) in YRU1-A, to 1.5 mg/L in YRU1 (**Table 3-2**, **Table 3-3**, **Figure 3-2A**). TN exceeded the ANZG (2018) stressor (eutrophication) DGV (0.3 mg/L) in all sites except for YRU2 (dry and wet seasons), and YRU1-A (wet season) (**Table 3-2**, **Table 3-3**, **Figure 3-2A**). TKN (sum of organic nitrogen, ammonia, and ammonium) was equivalent to TN at all sites, suggesting that cattle waste was likely the main contributor to nitrogen in these rivers. The TP concentrations also exceeded the ANZG (2018) stressor (eutrophication) DGV (0.01 mg/L) in all sites other than YRU2 (dry season), and YRU1-A (wet season) (**Figure 3-2B**).

However, TP was largely comparable across sites and rivers, typically ranging between 0.01 mg/L and 0.09 mg/L during the Study (**Table 3-2**, **Table 3-3**, **Figure 3-2B**). Exceptions were YRU1 during the dry season, and TRD2 during the wet season, where TP was more than 21x and 55x higher than the ANZG (2018) DGV, respectively (**Figure 3-2B**). Elevated concentrations of TP (and TN) in TRD2 during the wet season was likely due to evapoconcentration of nutrients within the small, shallow pool, which was also characterised by a high abundance of phytoplankton and deceased fish. Nutrient enrichment is common in Pilbara riverine pools, reflecting a the influence of groundwaters and widespread pastoralism (Boulton and Brock 1999; Jakowyna *et al.* 2000). Waterbodies subject to eutrophication often experiencing algal blooms and prolific macrophyte growth (Shaw *et al.* 2003), which may also affect the composition of aquatic invertebrate communities (Pinder and Leung 2009).

The concentrations of the majority of dissolved metals were recorded at levels below respective analytical limits of reporting (LOR) during the Study (**Table 3-2**, **Table 3-3**). Where metals were detected, there were no clear trends evident between the two river systems or seasons. There were a minor number of exceedances of ANZG (2018) DGVs (**Table 3-2**, **Table 3-3**), comprising:

- Al, which slightly exceeded the 95% DGV (0.055 mg/L) in Turner River site TRD2 during the dry season (0.06 mg/L) (**Figure 3-3A**);
- As, which slightly exceeded the 95% DGV (0.024 mg/L) in TRD2 during the wet season (0.028 mg/L);
- B, which exceeded the 95% DGV (0.94 mg/L) in Yule River site YRU1 during the dry season (2.79 mg/L), and TR1 (1.06 mg/L), TRD2 (1.45 mg/L) and YR3 (0.99 mg/L) during the wet season (**Figure 3-3B**);
- Cu, which exceeded the 95% DGV (0.0014 mg/L) in Turner River sites TR1 (0.002 mg/L), TRE2 (Turner River East; 0.002 mg/L) and TRU1 (0.013 mg/L), and Yule River sites YRU1 (0.002 mg/L) and YRU2 (0.011 mg/L) during the dry season (**Figure 3-3C**); and
- Zn, which exceeded the 95% DGV (0.008 mg/L) in Turner River site TR1 (0.045 mg/L) and Yule River site YRU2 (0.02 mg/L) during the dry season (**Figure 3-3D**).
- Numerous sites in both river systems the dry and wet seasons also exceeded the ANZG (2018) freshwater low reliability trigger value for U, which is considered indicative only (**Table 3-2**, **Table 3-3**).

Naturally elevated dissolved metal concentrations, compared to ANZG (2018) DGVs, and particularly B, Cu and Zn are commonly associated with surface waters in the Pilbara, attributed to local geology and the weathering of sedimentary rocks (WRM 2009;2015;2017). Elevated concentrations of Al are also a characteristic of inland waters in the region due to colloidal clays in silicates (G. Clarke pers. comm. 2015). Based on the results of this Study, the Turner and Yule Rivers may also exhibit natural U enrichment.

There was some degree of variation evident in surface water quality across sites and river systems during the Study, reflected in the PCA (**Figure 3-4**). This was mainly driven by differences in salinity, nutrients and metals within individual sites. For example, sites including TR1 (both seasons), YR1 (dry season), YR3 (wet season) and YRU1 (dry season) were distinct due to elevated salinity (>2000 µS/cm) and nutrients including TN and TP (**Figure 3-4**). In contrast, sites such as TRE2 (Turner River East) and TRU1 (wet season) were separated due to elevated concentrations of Al and Ba, respectively, while YRD1 (dry season) and TRU1 (wet season) had comparatively higher Mn and Ba, respectively (**Figure 3-4**). There were limited differences observed between seasons, with a high degree of sites overlapping, which was likely attributed to the ongoing dry conditions experienced throughout the region.

Table 3-2: Water quality from the Turner and Yule Rivers during the dry season (November 2021), compared to ANZG (2018) DGVs.

	Water Quality Parameters	LOR	Turner River				Yule River						ANZG (2018)	
			TRE2	TRU1	TR1	TRD2	YRU1	YRU2	YR1	YR2	YR3	YRD1	Stressor DGV	Toxicant DGV
Basic	pH (unit)		8.25	8.35	9.01	9.05	9	7.59	8.8	7.97	7.69	8.16	6.5 - 8.0	-
	Total Dissolved Solids	10	490	1,190	2,490	670	5,500	247	1,830	332	858	298	-	-
	Dissolved Oxygen		7.12	5.37	6.11	7.87	4.23	4.38	-	4.69	8.86	4.13	-	-
	Dissolved Oxygen (%)		97.2	67.7	76.4	113.7	57.3	59.7	-	68.8	120	52.8	90 - 120	
	Electrical Conductivity (µS/cm)	1	754	1,830	3,830	1,030	8,460	380	2,820	510	1,320	459	250	-
	Total Suspended Solids	5	17	<5	15	19	62	<5	28	<5	<5	7	-	-
	Turbidity (NTU)	0.1	11	3.1	6	9.7	36	0.6	17	1.9	3.8	2.8	15	-
Ions	Sodium	1	98	243	679	158	1530	50	514	65	212	56	-	-
	Magnesium	1	18	65	77	38	235	10	68	14	35	13	-	-
	Calcium	1	43	46	19	16	22	22	24	30	38	31	-	-
	Potassium	1	4	7	17	9	26	2	7	2	5	3	-	-
	Chloride	1	145	410	988	216	2,200	41	605	55	225	43	-	-
	Sulphate	1	4	93	56	6	202	4	34	4	<1	2	-	-
	Bicarbonate	1	182	312	356	200	1030	141	524	194	421	180	-	-
	Carbonate	1	4	21	140	55	552	<1	149	2	<1	<1	-	-
Nutrients	Total Nitrogen	0.1	0.7	0.7	2.8	2	4.7	0.2	1.6	0.4	1.1	0.6	0.3	-
	Total Phosphorus	0.01	0.03	0.02	0.09	0.02	0.22	0.01	0.08	0.02	0.07	0.02	0.01	-
	Total Kjeldahl Nitrogen	0.1	0.7	0.7	2.8	2	4.7	0.2	1.6	0.4	1.1	0.6	-	-
	Nitrite + Nitrate	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.05	<0.01	<0.01	<0.01	0.02	0.7^{E}	2.1^{T}
Metals & Trace Elements	Aluminium	0.01	0.03	<0.01	<0.01	0.06	0.02	0.01	0.04	<0.01	0.01	<0.01	-	0.055
	Arsenic	0.001	0.001	0.002	0.005	0.005	0.008	<0.001	0.004	<0.001	<0.001	<0.001	-	0.024
	Barium	0.001	0.086	0.169	0.09	0.049	0.235	0.064	0.074	0.086	0.125	0.205	-	-
	Boron	0.05	0.14	0.4	0.77	0.25	2.79	0.18	0.83	0.14	0.31	0.12	-	0.94
	Cadmium	0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	-	0.002
	Chromium	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-	0.00031
	Cobalt	0.001	<0.001	<0.001	<0.001	<0.001	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	-	-
	Copper	0.001	0.002	0.002	0.013	0.001	0.002	0.011	0.001	<0.001	<0.001	<0.001	-	0.0014
	Iron	0.05	0.07	0.16	<0.05	0.06	<0.05	0.13	0.07	<0.05	0.22	0.14	-	0.7
	Lead	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-	0.0034
	Manganese	0.001	0.035	0.091	0.017	0.02	0.003	0.1	0.018	0.061	0.184	1.11	-	1.9
	Molybdenum	0.001	<0.001	0.001	0.004	0.002	0.007	<0.001	0.002	<0.001	<0.001	<0.001	-	-
	Mercury	0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	-	0.00006
	Nickel	0.001	0.001	0.001	0.006	0.001	0.009	0.001	0.001	<0.001	<0.001	<0.001	-	0.011
	Selenium	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	-	0.008
	Uranium	**0.001**	**0.002**	**0.005**	**0.016**	**0.003**	**0.058**	<0.001	**0.013**	**0.002**	<0.001	<0.001	-	-
	Vanadium	0.01	<0.01	<0.01	<0.01	<0.01	0.03	<0.01	0.01	<0.01	<0.01	<0.01	-	-
	Zinc	0.005	<0.005	0.005	0.045	<0.005	<0.005	0.02	<0.005	<0.005	<0.005	<0.005	-	0.008

*Note: Red shading indicates exceedance of ANZG (2018) DGVs, while bold text indicates exceedance of low reliability freshwater trigger value. ^{E} = Eutrophication DGV. ^{T} = Toxicity DGV. * indicates low reliability freshwater trigger value only of 0.0005 mg/L (considered indicative only).*

Table 3-3: Water quality from the Turner and Yule Rivers during the wet season (May 2022), compared to ANZG (2018) DGVs.

Water Quality Parameters		LOR	Turner River					Yule River							ANZG (2018)	
			TRE2	TRU1	TR1	TR1-A	TRD2	YRU1	YRU1-A	YRU2	YR1	YR2	YR3	YRD1	Stressor DGV	Toxicant DGV
Basic	pH (unit)		8.42	8.36	9.5	8.44	8.92	8.17	7.86	7.61	7.86	8.13	8.71	8.48	6.5 - 8.0	-
	Total Dissolved Solids	1	152	2,400	3,510	176	4,610	533	314	352	1,190	320	2,220	300	-	-
	Dissolved Oxygen		5.1	2.09	10.43	5.59	4.1	8.23	4.86	6.4	2.71	7.66	5.21	6.22	-	-
	Dissolved Oxygen (%)		58.4	25.4	125	63	48.6	102.5	60.6	71.5	30	89.1	63.4	74	90	120
	Electrical Conductivity (µS/cm)	1	234	3,690	5,400	270	7,090	820	483	541	1,830	492	3,410	462	250	-
	Total Suspended Solids	5	12	6	26	8	163	13	<5	<5	8	<5	18	12	-	-
	Turbidity (NTU)	0.1	15	2.9	5.7	3.6	130	8.8	1	3.8	5.5	0.5	12	11	15	-
Ions	Sodium	1	19	537	1,010	14	1,280	79	57	56	308	63	602	50	-	-
	Magnesium	1	5	116	58	8	126	34	10	15	35	12	68	10	-	-
	Calcium	1	23	37	14	30	13	55	28	37	43	25	24	35	-	-
	Potassium	1	3	20	21	4	46	9	2	3	7	2	9	3	-	-
	Chloride	1	18	912	1,480	12	1,880	58	46	50	340	55	704	41	-	-
	Sulphate	1	3	101	136	2	18	<1	11	8	<1	8	44	6	-	-
	Bicarbonate	1	94	537	176	126	833	358	178	205	507	172	624	176	-	-
	Carbonate	1	<1	30	208	2	142	24	<1	<1	26	3	207	5	-	-
Nutrients	Total Nitrogen	0.1	1	3.8	2.7	0.6	15.6	1.5	<0.1	0.2	1.1	0.3	1.2	0.6	0.3	-
	Total Phosphorus	0.01	0.07	0.08	0.07	0.04	0.56	0.1	<0.01	0.03	0.04	0.02	0.08	0.05	0.01	-
	Total Kjeldahl Nitrogen	0.1	1	3.8	2.7	0.6	15.6	1.5	<0.1	0.2	1.1	0.3	1.2	0.6	-	-
	Nitrite + Nitrate	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.7^{E}	2.1^{T}
Metals & Trace Elements	Aluminium	0.01	0.04	<0.01	<0.01	0.02	<0.01	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	0.02	-	0.055
	Arsenic	0.001	0.001	0.005	0.005	<0.001	0.028	0.001	<0.001	<0.001	0.002	<0.001	0.006	<0.001	-	0.024
	Barium	0.001	0.034	0.159	0.068	0.064	0.057	0.095	0.089	0.075	0.151	0.081	0.077	0.071	-	-
	Boron	0.05	0.06	0.64	1.06	0.08	1.45	0.38	0.11	0.1	0.46	0.11	0.99	0.09	-	0.94
	Cadmium	0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	-	0.002
	Chromium	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-	0.00031
	Cobalt	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-	-
	Copper	0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-	0.0014
	Iron	0.05	<0.05	0.08	<0.05	<0.05	<0.05	0.07	0.16	0.07	0.14	<0.05	<0.05	<0.05	-	0.7
	Lead	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-	0.0034
	Manganese	0.001	0.002	0.41	0.002	0.004	0.005	0.225	0.561	0.059	0.044	0.006	0.008	0.002	-	1.9
	Molybdenum	0.001	<0.001	0.001	0.006	<0.001	0.015	0.001	0.001	<0.001	<0.001	<0.001	0.004	<0.001	-	-
	Mercury	0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	-	0.00006
	Nickel	0.001	<0.001	<0.001	0.002	0.002	0.007	0.002	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	-	0.011
	Selenium	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	-	0.008
	Uranium	**0.001**	**0.003**	**0.002**	**0.006**	**0.002**	**0.014**	**0.007**	<0.001	<0.001	<0.001	**0.002**	**0.018**	**0.001**	-	-
	Vanadium	0.01	<0.01	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	-	-
	Zinc	0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	-	0.008

*Note: Red shading indicates exceedance of ANZG (2018) DGVs, while bold text indicates exceedance of low reliability freshwater trigger value. ^{E} = Eutrophication DGV. ^{T} = Toxicity DGV. * indicates low reliability freshwater trigger value only of 0.0005 mg/L (considered indicative only).*

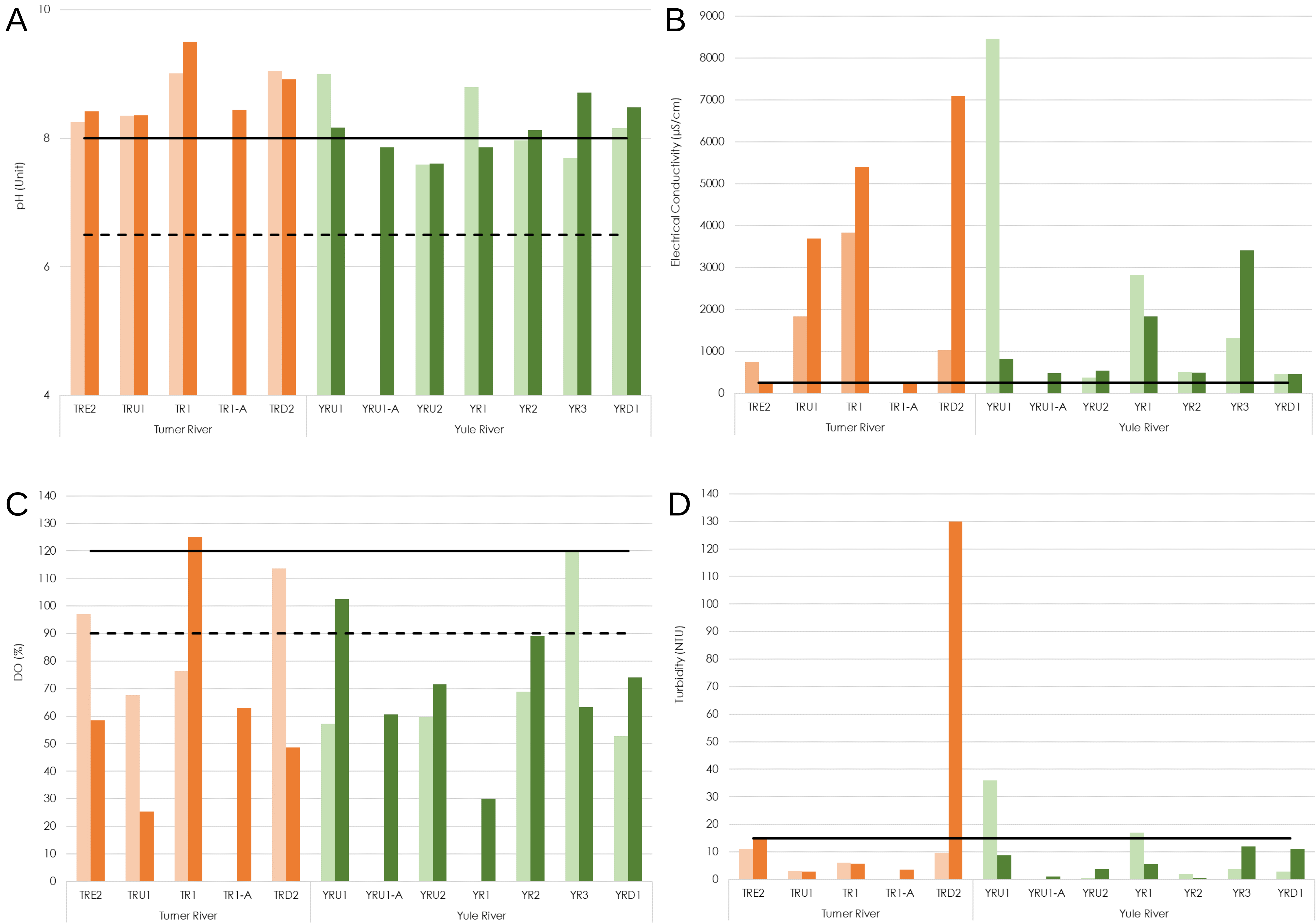


Figure 3-1: Water quality of the Turner and Yule Rivers (■■ = dry season, ■■ = wet season) during the Study, compared to ANZG (2018) lower (---) and upper (—) stressor DGVs; (A) pH, (B) salinity (EC), (C) DO, and (D) turbidity.

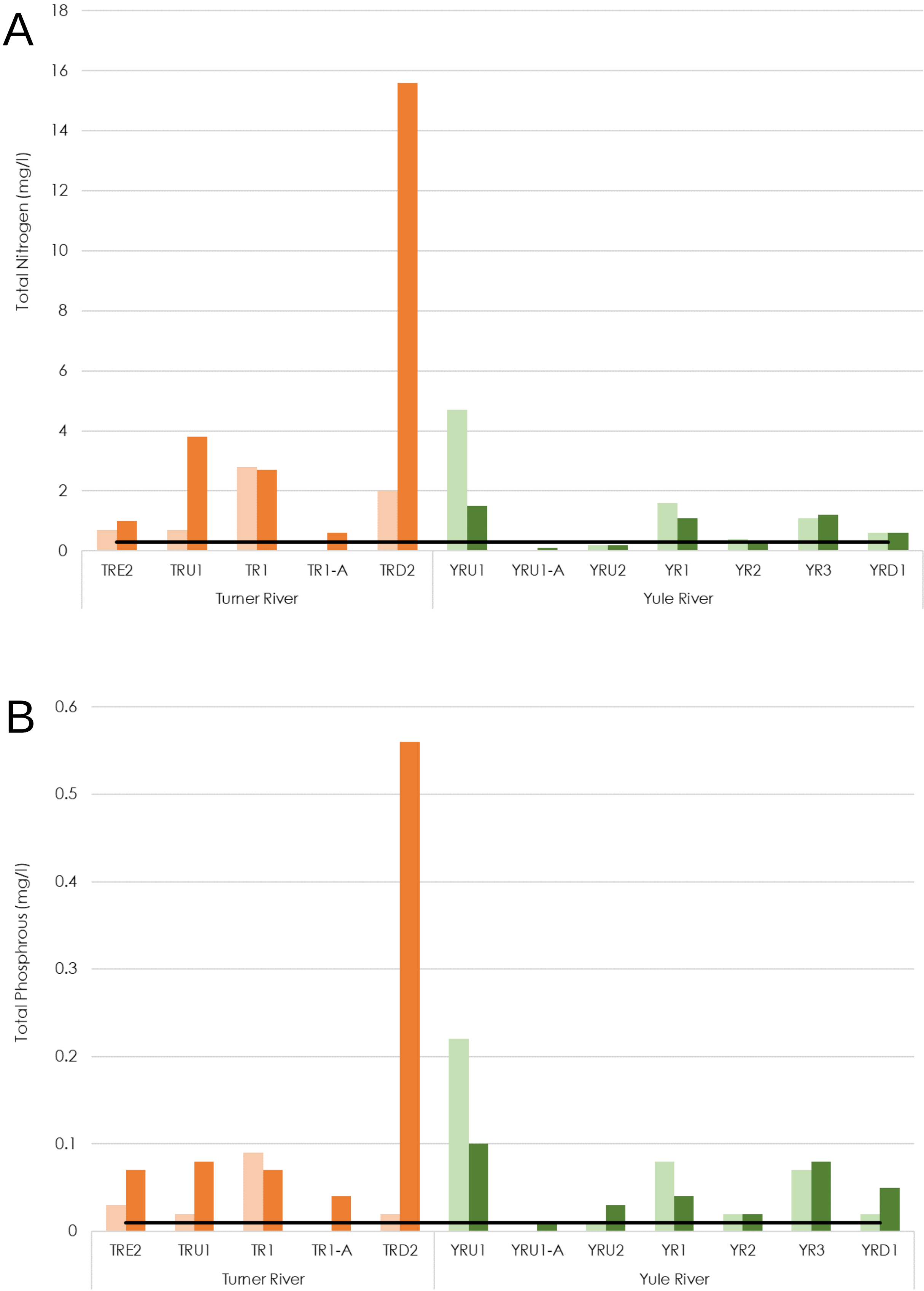


Figure 3-2: Water quality (nutrients) of the Turner and Yule Rivers (■■ = dry season, ■■ = wet season) during the Study compared to ANZG (2018) DGVs (—); (A) Total Nitrogen and (B) Total Phosphorus.

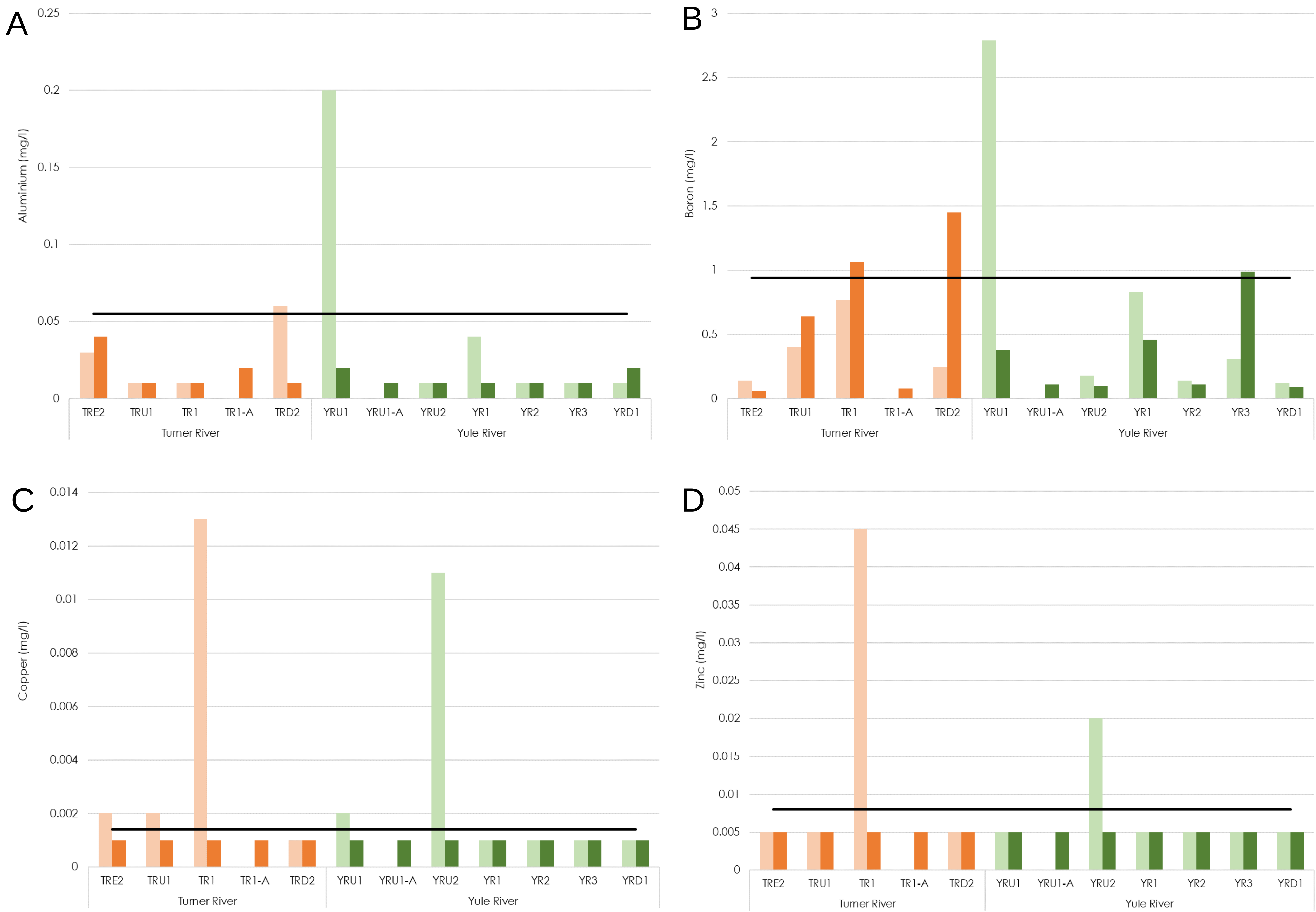


Figure 3-3: Water quality of Turner and Yule Rivers (■■ = dry season, ■■ = wet season) during the Study, compared to ANZG (2018) DGVs for 95% species protection; (A) aluminium, (B) boron, (C) copper, and (D) zinc.

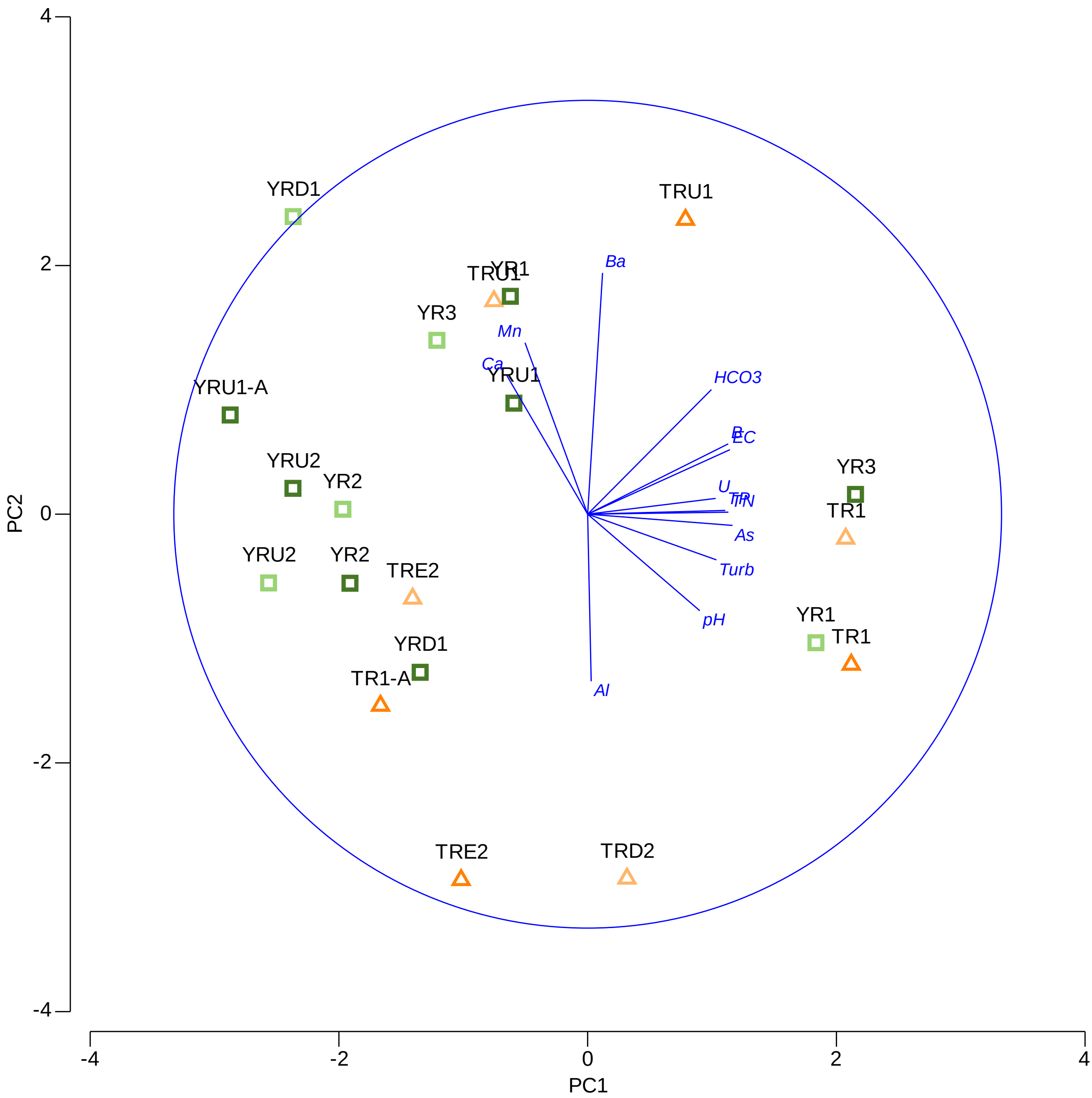


Figure 3-4: PCA of water quality of the Turner and Yule Rivers during the Study (△ = Turner River wet season, △ = Turner River dry season, □ = Yule River wet season, □ = Yule River dry season). A total of 73.9% variation in the data is explained by the first two axes.

3.3 Sediment Quality

Sediments form an important component of aquatic ecosystems and support a wide range of benthic organisms (McKenzie *et al.* 2004; Pulford and Flowers 2006). However, they can also serve as a sink for any contaminants (Simpson *et al.* 2005), which may influence aquatic biota. The sediments of lakes and rivers in the arid zone of Western Australia often exhibit high spatial heterogeneity (Simpson *et al.* 2005), similar to surface waters, associated with alternate wetting and drying cycles, and the effects of dilution from rainfall and subsequent evapoconcentration (Boulton and Brock 1999; McComb and Qui 1998).

The pH of Turner River sediment during the Study ranged from 7.8 (TRE2; Turner River East) to 9.2 (TR1) during the dry season, and from 7.4 (TR1-A) to 9.7 (TRD2) during the wet season (**Table 3-4**, **Table 3-5, Figure 3-5A**), classified as neutral to very strongly alkaline (Hazelton and Murphy 2007). Yule River pH was also neutral to very strongly alkaline (Hazelton and Murphy 2007) during the dry season, ranging from 7.2 (YRU2) to 9.2 (YRU1), and from 7.7 (YRD1) to 9.6 (YR3) during the wet season (**Table 3-4**, **Table 3-5, Figure 3-5A**). Sediment pH was generally comparable across seasons for the Turner and Yule Rivers, with the alkaline conditions reflecting surface waters, and considered typical of inland waters in Western Australia (Gregory 2008). Sediment pH is strongly influenced by changes in the hydroperiod, redox reactions and fluctuations in the concentration of carbonates and organic matter (Connell 2005; Reddy and DeLaune 2008).

Sediment salinity (measured as total soluble salts, TSS) of Turner River during the Study ranged from 187 mg/kg in TRE2 (Turner River East) to 877 mg/kg in TR1 during the dry season, and from 375 mg/kg in TRE2 to 1870 mg/kg in TRD2 during the wet season (**Table 3-4**, **Table 3-5, Figure 3-5B**). The salinity of the Yule River ranged from 296 mg/kg in YRD1 to 10,600 mg/kg in YRU1 during the dry season, and from 199 mg/kg in YRU2 to 2,250 mg/kg in YR3 during the wet season (**Table 3-4**, **Table 3-5, Figure 3-5B**). The relatively high sediment salinity in YRU1 during the dry season was consistent with elevated surface water salinity at this site, likely associated with evapoconcentration. Sediment salinity of wetlands and rivers in arid regions of Western Australia can display a high spatial heterogeneity (Simpson *et al.* 2005), associated with alternate wetting and drying cycles (Boulton and Brock 1999; McComb and Qui 1998).

Ionic composition in the sediments generally followed trends in water quality, with Na typically being the dominant cation across all sites (except for TRE2, TR1-A, YRU1-A, YRU2 and YRD1 during the wet season). The dominance of minor cations (K, Mg and Ca) was interchangeable between seasons and sites. The dominance of anions typically followed $HCO_3 > Cl > SO_4 > CO_3$, however there was a high degree of variation between seasons, particularly during the wet season. Spatial and temporal variation in the ionic balance is common in the Pilbara region, and is considered typical of inland waterbodies in Western Australia (Gregory 2008; Hart and McKelvie 1986). Changes in ionic dominance within the sediments are likely a result of local geology and evapoconcentration over the course of the hydroperiod (Chakrapani 2002; Gorham 1961).

The concentration of TN was highly variable between sites within the two rivers, with the highest levels recorded from Yule River during the dry season, and notably YR3 (4,830 mg/kg), YR1 (3,730 mg/kg) and YRU1 (1,150 mg/kg). During the wet season, Turner River site TR1-A had the highest TN concentration of all sites (1,140 mg/kg) (**Table 3-5, Figure 3-5C**). In the dry season, TP was more homogenous although was also highest in Yule River sites YR3 (385 mg/kg), YR1 (280 mg/kg) and YRU1 (182 mg/kg) (**Table 3-4**, **Table 3-5, Figure 3-5D**). More broadly, the Yule River had higher nutrient levels in the sediments, predominantly during the dry season and was likely associated with animal waste from unrestricted livestock access. Fluctuating nutrient concentrations in arid zone river systems can also be influenced by the breakdown of organic matter by microbes and sediment mineral composition (Reddy and DeLaune 2008).

The concentrations of most metals were below analytical detection limits or ANZG (2018) GVs/GV-high within the Turner and Yule River sediments during the Study, except for the following:

- Cr, which was slightly above the ANZG (2018) GV (80 mg/kg) in YR3 (97 mg/kg) (**Figure 3-6B**) during the dry season;
- Ni, which was above the ANZG (2018) GV (21 mg/kg) in several Yule River sites across both seasons, and in YR3 slightly exceeded the GV-High (52 mg/kg), with a concentration of 58 mg/kg during the dry season (**Table 3-4**, **Table 3-5, Figure 3-7A**); and
- Ni, which slightly exceeded the ANZG (2018) GV (21 mg/kg) in Turner River site TR1-A (24 mg/kg) during the wet season (**Figure 3-7A**).

It is likely that elevated Cr and Ni concentrations in the sediments of the Yule River sites reflect natural mineralisation within the catchment and is characteristic of inland waterbodies throughout Western Australia, attributed to natural mineralisation (Förstner 1977; Gregory 2008). However, exceedances compared to the ANZG (2018) GV identified during this Study were considered relatively minor.

The sediment quality PCA, similar to water quality showed limited seasonal differences across sites (**Figure 3-8**). Instead, variation was evident at individual sites and was primarily attributed to elevated salinity, nutrients or metals. For example, there were comparatively higher concentrations of TN and metals (Ni, U and Zn) in the sediment of YR1 (dry season) and YRU1 (wet season), while YRU1 exhibited high sediment salinity (>10,000 mg/L) in the dry season and were distinct in the analysis (**Figure 3-8**). However, numerous sites in both seasons were clustered together due to lower concentrations of these metals.

Table 3-4: Sediment quality recorded from the Turner and Yule and Rivers during the dry season (November 2021), compared to ANZG (2018) DGVs.

Sediment Quality Parameters		LOR	Turner River				Yule River						ANZG (2018)	
			TRE2	TRU1	TR1	TRD2	YRU1	YRU2	YR1	YR2	YR3	YRD1	GV	GV-High
Basic	pH (unit)		7.8	8.6	9.2	8.9	9.2	7.2	8.5	7.7	8	8.6		
	Electrical Conductivity (µS/cm)	1	55	167	258	64	3,110	112	581	270	655	87	-	-
	Total Soluble Salts	5	187	568	877	217	10,600	380	1,980	918	2,230	296		
	Moisture Content (%)	1	16.8	24.4	22.3	15.7	46.9	19.3	57.8	32.7	76.3	24.8	-	-
	Total Organic Carbon (%)	0.5	<0.5	<0.5	<0.5	<0.5	5.5	<0.5	6.6	0.9	12.5	<0.5	-	-
Cations and Anions	Sodium	10	100	100	230	20	4490	50	970	210	1670	20	-	-
	Magnesium	10	20	40	40	10	160	<10	160	30	220	10	-	-
	Calcium	10	20	40	30	<10	20	30	80	110	270	60	-	-
	Potassium	10	<10	<10	20	<10	120	<10	50	30	130	<10	-	-
	Chloride	10	30	110	250	20	6,370	20	790	120	1780	10	-	-
	Sulfate	10	70	100	20	<10	1,020	20	340	70	490	20	-	-
	Bicarbonate	5	51	239	277	80	962	153	870	519	788	162	-	-
	Carbonate	5	<5	<5	<5	<5	176	<5	23	<5	<5	<5	-	-
Nutrients	Total Nitrogen	20	40	80	30	20	1,150	270	3,730	980	4,830	220	-	-
	Total Phosphorus	2	22	22	22	14	132	54	280	86	385	46	-	-
	Total Kjeldahl Nitrogen	20	40	80	30	20	1,150	270	3,730	980	4,830	220	-	-
	Nitrite + Nitrate	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	1.6	<0.1	-	-
Metals and Trace Elements	Aluminium	50	570	630	740	540	8,900	2,510	9,870	4,850	16,800	1,630	-	-
	Arsenic	5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	20	70
	Barium	10	<10	<10	<10	<10	70	30	240	50	160	20	-	-
	Boron	50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	-	-
	Cadmium	1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	2	10
	Chromium	2	5	4	20	24	66	14	48	22	97	8	80	370
	Cobalt	2	<2	<2	<2	<2	10	4	10	7	18	2	-	-
	Copper	5	<5	<5	<5	<5	18	<5	22	10	34	<5	65	270
	Iron	50	1,760	3,830	4,620	4,510	24,300	10,300	26,800	16,500	41,200	6,210		
	Lead	5	<5	<5	<5	<5	5	<5	6	<5	10	<5	50	220
	Manganese	5	19	118	33	14	332	289	691	344	421	70	-	-
	Mercury	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.15	1
	Molybdenum	2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	-	-
	Nickel	2	<2	<2	6	3	32	9	29	18	58	5	21	52
	Selenium	5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	-	-
	Uranium	0.1	0.2	0.4	0.4	0.2	4.8	0.4	5.9	1.2	4.4	0.1	-	-
	Vanadium	5	<5	<5	7	6	35	13	37	23	63	9	-	-
	Zinc	5	<5	<5	<5	<5	24	8	27	16	48	5	200	410

Note: Red shading indicates exceedance of ANZG (2018) DGVs.

Table 3-5: Sediment quality from the Turner and Yule Rivers during the wet season (May 2022), compared to ANZG (2018) DGVs.

Sediment Quality Parameters		LOR	Turner River					Yule River							ANZG (2018)	
			TRE2	TRU1	TR1	TR1-A	TRD2	YRU1	YRU1-A	YRU2	YR1	YR2	YR3	YRD1	GV	GV-High
Basic	pH (unit)	0.1	8.4	8.9	9.2	7.4	9.7	8.5	8.6	7.8	8.8	8.3	9.6	7.7		
	Electrical Conductivity (µS/cm)	1	110	463	277	136	551	179	111	58	258	183	663	298	-	-
	Total Soluble Salts	5	375	1,570	942	462	1,870	609	378	199	877	622	2,250	1,010		
	Moisture Content (%)	1	18.4	24.6	16.6	36.3	29.8	29.3	25.3	20	34.9	31.8	18.9	36	-	-
	Total Organic Carbon (%)	0.5	<0.5	0.6	<0.5	3.1	1	2	<0.5	<0.5	2.9	0.6	<0.5	3	-	-
Cations and Anions	Sodium	10	20	390	350	30	910	160	50	20	450	110	630	110	-	-
	Magnesium	10	10	110	30	20	40	40	20	<10	50	30	30	40	-	-
	Calcium	10	50	50	20	60	20	70	60	30	60	50	10	180	-	-
	Potassium	10	10	40	20	30	120	40	10	<10	40	20	40	30	-	-
	Chloride	10	10	490	310	<10	1,050	70	30	10	260	50	460	50	-	-
	Sulfate	10	10	120	50	30	150	100	60	20	60	20	540	160	-	-
	Bicarbonate	5	245	342	165	186	382	395	159	104	462	352	321	445	-	-
	Carbonate	5	<5	66	42	<5	267	<5	<5	<5	27	5	178	<5	-	-
Nutrients	Total Nitrogen	20	180	490	80	1140	700	620	310	110	910	710	300	820	-	-
	Total Phosphorus	2	38	68	31	98	77	100	70	45	103	78	69	100	-	-
	Total Kjeldahl Nitrogen	20	180	490	80	1140	700	620	310	110	910	710	300	820	-	-
	Nitrite + Nitrate	0.1	0.7	<0.1	<0.1	0.4	0.1	0.2	0.3	<0.1	0.5	1.9	0.3	2.2	-	-
Metals and Trace Elements	Aluminium	50	860	800	770	5,240	3,310	9,180	4,680	1,450	4,210	3,820	3,200	7,070	-	-
	Arsenic	5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	20	70
	Barium	10	<10	30	<10	50	40	80	40	10	70	50	30	60	-	-
	Boron	50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	-	-
	Cadmium	1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	2	10
	Chromium	2	7	5	12	51	40	64	18	10	38	17	19	37	80	370
	Cobalt	2	<2	<2	<2	7	4	10	6	2	6	5	4	9	-	-
	Copper	5	<5	<5	<5	11	7	20	9	<5	11	7	7	16	65	270
	Iron	50	2,560	4,180	4,620	19,900	14,200	23,700	15,900	6,080	14,700	13,600	10,500	23,900		
	Lead	5	<5	<5	<5	7	<5	6	<5	<5	<5	<5	<5	<5	50	220
	Manganese	5	33	258	47	234	181	306	237	46	305	132	106	230	-	-
	Mercury	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.15	1
	Molybdenum	2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	-	-
	Nickel	2	2	<2	7	24	16	33	18	6	22	14	13	26	21	52
	Selenium	5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	-	-
	Uranium	0.1	0.5	0.5	0.5	1.8	1	3.6	1.2	0.3	0.7	0.6	1	1.8	-	-
	Vanadium	5	<5	<5	6	26	21	34	22	9	19	17	15	31	-	-
	Zinc	5	<5	<5	<5	19	8	26	16	5	13	13	10	24	200	410

Note: Red shading indicates exceedance of ANZG (2018) DGVs

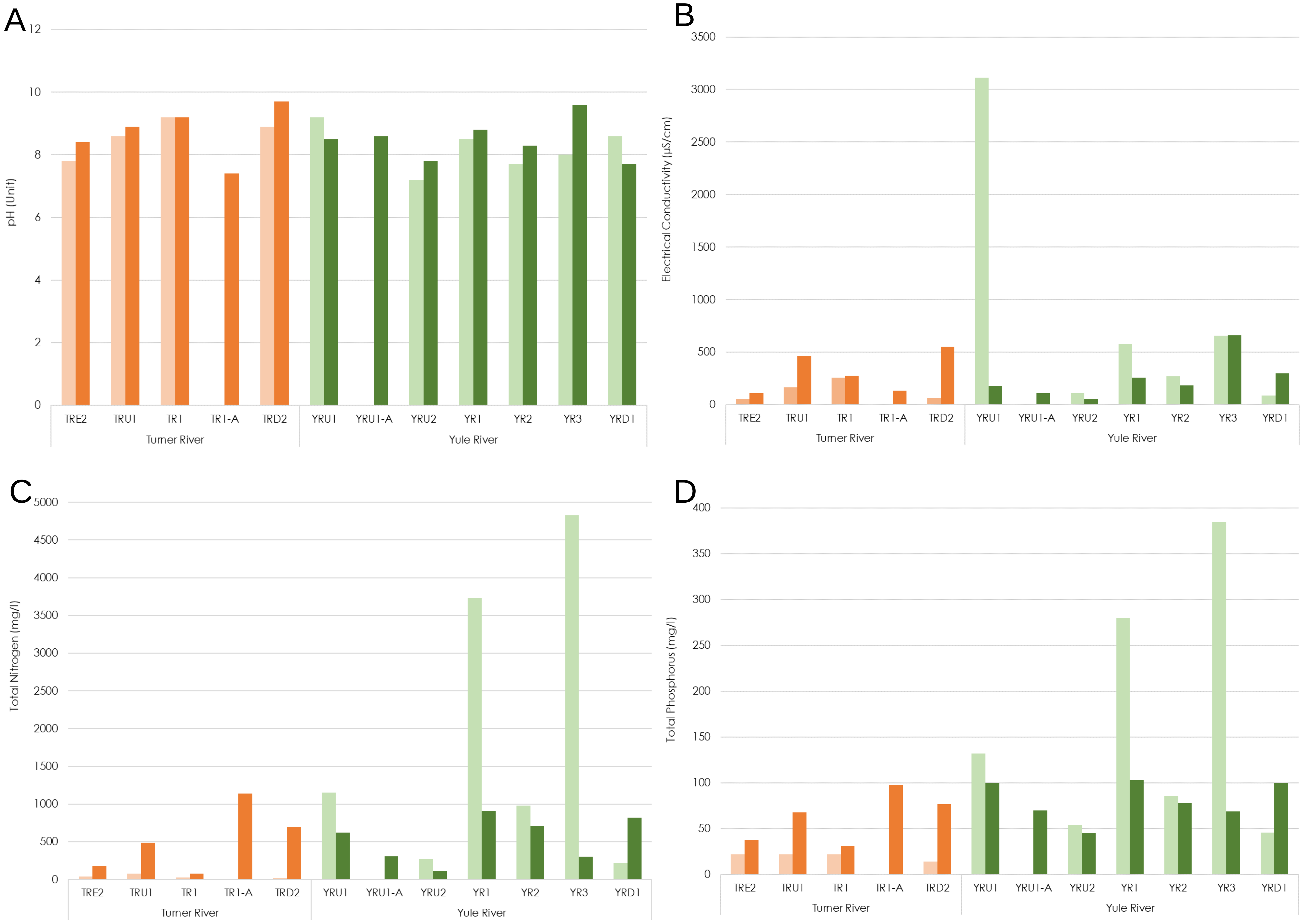


Figure 3-5: Sediment quality of the Turner and Yule Rivers (■■ = dry season, ■■ = wet season) during the Study; (A) pH, (B) salinity (EC), (C) Total Nitrogen, and (D) Total Phosphorus.

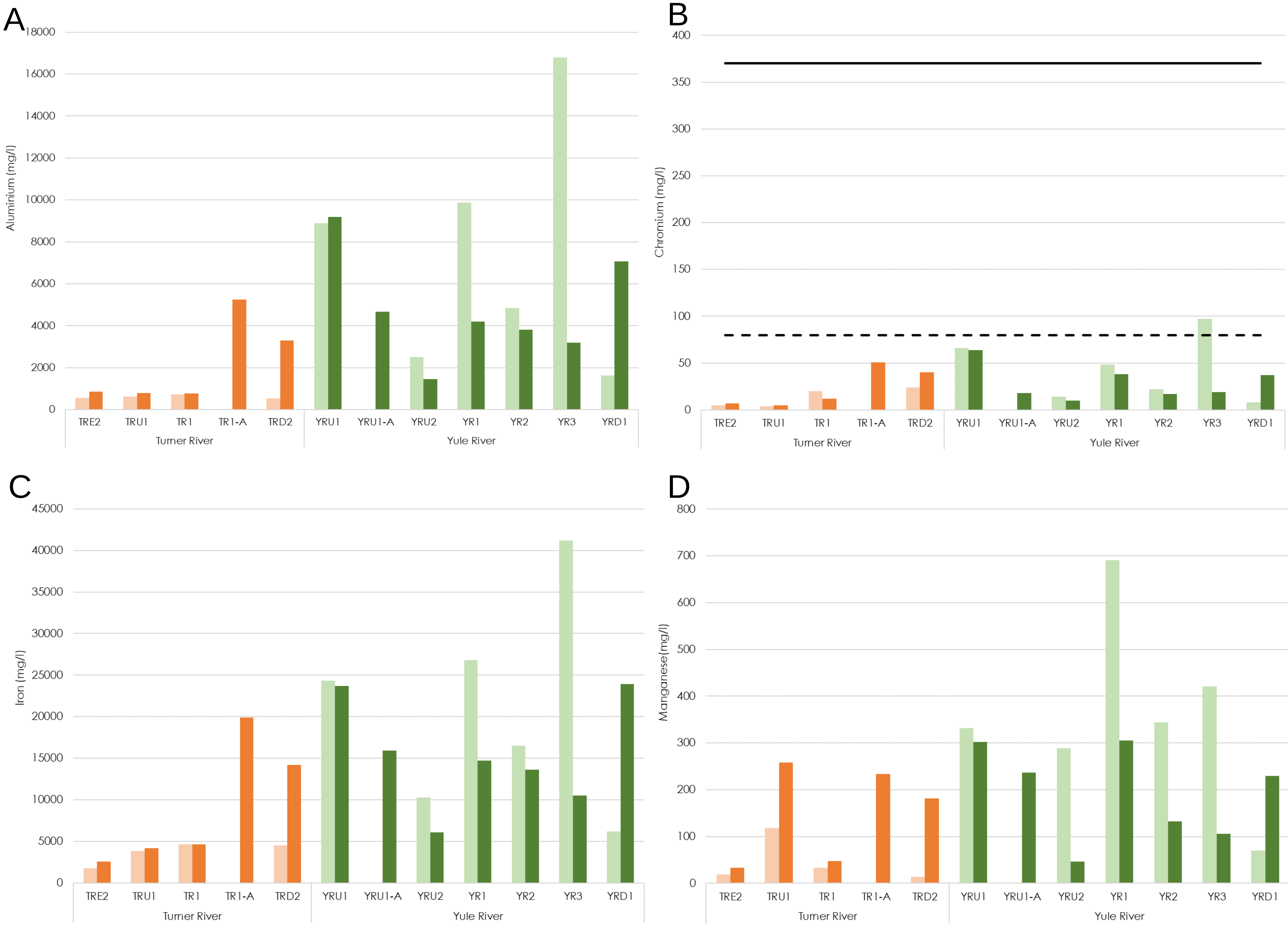


Figure 3-6: Sediment quality of the Turner and Yule Rivers (= dry season, = wet season) during the Study, with ANZG (2018) lower (---) and upper (—) stressor DGVs; (A) Al, (B) Cr, (C) Fe, and (D) Mn.

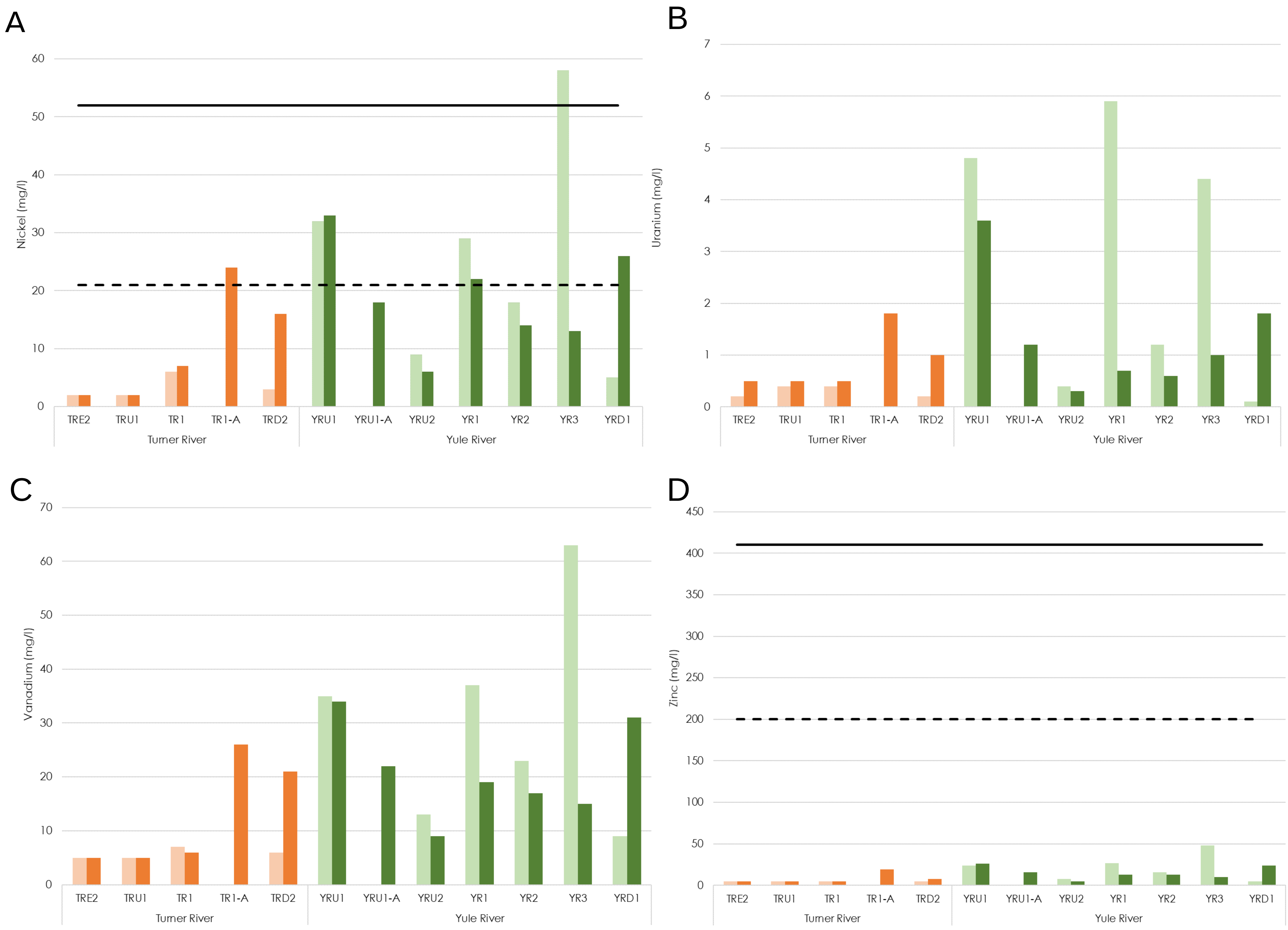


Figure 3-7: Sediment quality of Turner and Yule Rivers (■■ = dry season, ■■ = wet season) during the Study, with ANZG (2018) lower (---) and upper (—) stressor DGVs; (A) Ni, (B) U, (C) V, and (D) Zn.

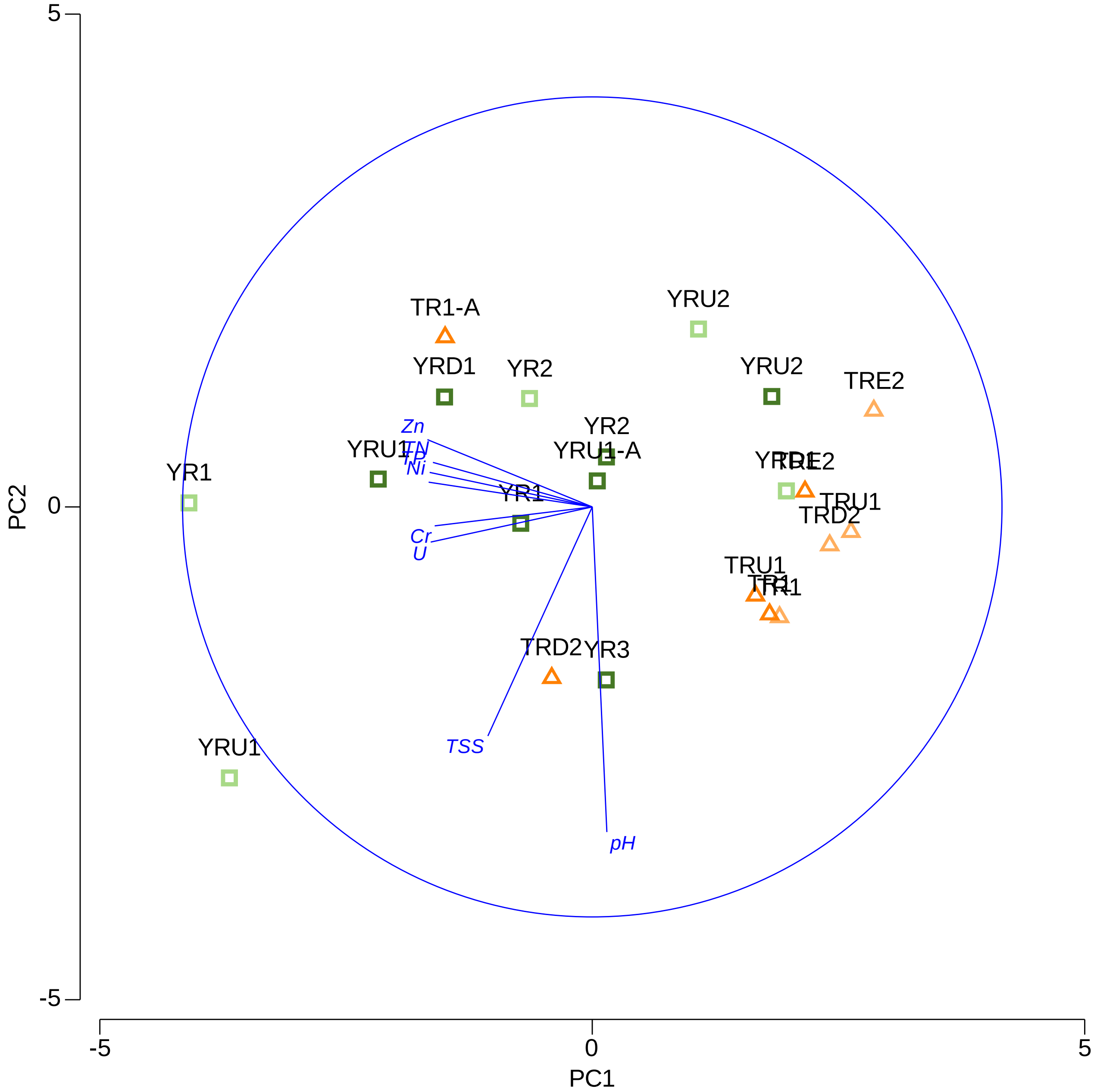


Figure 3-8: PCA of sediment quality of the Turner and Yule Rivers (△ = Turner River wet season, △ = Turner River dry season, □ = Yule River wet season, □ = Yule River dry season). A total of 88.3% of variation in the data is explained by the first two axes.

3.4 Aquatic Macrophytes

Macrophytes are aquatic plants that can survive at least some period of inundation. In arid climates submerged, free-floating and emergent species occur, which are of considerable ecological importance (Williams 1983). Macrophytes have a vital role in nutrient cycling within aquatic systems, as well as providing diverse structural habitats and shelter for invertebrates and fish (Bunn *et al.* 2006; Sainty and Jacobs 2003). Many aquatic plants also produce desiccation resistant seeds, an adaptation to lengthy dry periods, and germinate in favourable conditions to aid in the recovery of temporary wetlands during the onset of flooding (Brock *et al.* 2006).

During the Study, a total of nine aquatic macrophyte taxa belonging to six different families were recorded, comprising both submerged and emergent forms (**Table 3-6**). Among the submerged macrophytes, Hydrocharitaceae was the most well represented family (three taxa), with the remaining families (Characeae, Potamogetonaceae and Ruppiaceae) comprising one taxon each (**Table 3-6**). Emergent macrophyte families included Cyperaceae (two taxa) and Typhaceae (one taxa) (**Table 3-6**).

Diversity was higher in the Yule River, with all nine taxa recorded, while only six macrophyte taxa were recorded during the Study. *Typha domingensis* (**Plate 3-1A**) was the most widespread emergent macrophyte, identified in two Turner River sites, and four Yule River sites (**Table 3-6**). This species typically dominates the emergent vegetation of rivers and creeklines in the Pilbara, forming dense stands along banks and shallower areas (Lyons 2015; Pinder *et al.* 2010). Comparatively, *Cyperus vaginatus* is more commonly associated with permanent pools and springs (Pinder *et al.* 2010), consistent with its distribution in permanent pools from the Yule River in sites YR1, YR2. YR3 and YRD1 (**Table 3-6**). Emergent macrophytes are important oviposition (egg-laying) habitat in the water column for insects with mobile adult stages, such as dragonfly larvae (Gooderham and Tsyrlin 2002; Pinder and Leung 2009), as well as foraging and nesting habitat for waterbirds (Sainty and Jacobs 2003).

Among the submerged macrophytes, *Najas marina* (**Plate 3-1B**) was the most common species, recorded in eight sites; two Turner River sites and six Yule River sites during the Study (**Table 3-6**). This cosmopolitan taxon is prevalent throughout the Pilbara (Lyons 2015; Pinder *et al.* 2010), and is known to inhabit fresh and saline waterbodies of alkaline pH, often occupying a range of depths (Sainty and Jacobs 2003). *Vallisnaria annua* and *Potamogeton tepperi* were also relatively widespread, recorded in seven and six sites, respectively. *Vallisnaria annua* is an annual species common in shallow running waters and ephemeral pools across northern Australia, while *Potamogeton tepperi* is known from tropical regions, including warm, permanent pools of the Pilbara region (Lyons 2015; Pinder *et al.* 2010).

The highest macrophyte site diversity occurred in YR2 from Yule River (seven taxa during both the dry and wet seasons), followed by Yule River sites YR1 and YR3 (six taxa in both seasons) (**Table 3-6**). Diversity in these sites was associated with water permanency and morphological heterogeneity, with deep pools, shallow backwaters, and areas of flow providing variable habitat for submerged and emergent macrophytes (Lyons 2015) (**Plate 3-1A**). In comparison, macrophytes were considered depauperate or absent within semi-permanent pools including Turner River sites TRU1 and TRD2, and Yule River sites YRU1 and YRU2 (**Table 3-6, Plate 3-1D**). The seasonal nature of these sites, which are subject to high flows during the wet season, followed by a recessional phase and drying, are considered unfavourable conditions for the establishment and persistence of macrophytes (Lyons 2015).

Between the wet and dry seasons, there was limited variation evident in macrophyte diversity and abundance in Turner River site TR1 and in Yule River sites (YR1, YR2, YR3, YRD1) (**Table 3-6**), reflecting the relative permanence of water in these pools. Comparatively, there was a reduction in macrophyte diversity between the dry and wet seasons as pools continued to recede at sites TRE2, TRU1 and YRU2 (**Table 3-6**), with declining water levels and reduced habitat availability, due to ongoing low rainfall conditions.

The aquatic macrophytes of the Turner and Yule Rivers comprised common, ubiquitous taxa, previously identified from these systems and/or known from the Pilbara bioregion more broadly (Loomes and Braimbridge 2010; Masini and Walker 1989; Pinder and Leung 2009; van Dam *et al.* 2005). Macrophyte diversity was higher in the Yule River, attributed to the presence of larger, permanent pools and favourable habitat, with limited change in diversity between seasons, and likely improved water clarity. Where present, submerged macrophytes in both the Turner and Yule Rivers likely provide important habitat in the water column for a range of trophic levels including periphytic algae, zooplankton, macroinvertebrates with aquatic larval stages (such as dragonfly larvae) and juvenile fish (Gooderham and Tsyrlin 2002; Pinder and Leung 2009), while emergent macrophytes provide foraging and nesting habitat for waterbirds (Sainty and Jacobs 2003).

Table 3-6: Diversity of aquatic macrophytes recorded from Turner and Yule Rivers during the Study.

Macrophyte Taxa	Dry Season – November 2021										Wet Season – May 2022											
	Turner River				Yule River						Turner River					Yule River						
	TRE2	TRU1	TR1	TRD2	YRU1	YRU2	YR1	YR2	YR3	YRD1	TRE2	TRU1	TR1	TR1-A	TRD2	YRU1	YRU1-A	YRU2	YR1	YR2	YR3	YRD1
Submerged Macrophytes																						
Characaceae																						
Chara sp. (nr. *vulgaris*)			✓			✓		✓					✓				✓			✓		
Potamogetonaceae																						
Potamogeton tepperi	✓						✓	✓	✓		✓			✓			✓		✓	✓	✓	
Hydrocharitaceae																						
Vallisnaria annua						✓	✓	✓		✓			✓	✓			✓		✓	✓		
Najas marina	✓		✓			✓	✓	✓	✓	✓			✓				✓		✓	✓	✓	✓
Najas tenufolia	✓	✓						✓						✓						✓		
Ruppiacae																						
Ruppia sp.							✓		✓										✓		✓	
Emergent Macrophytes																						
Typhaceae																						
Typha domingensis	✓						✓	✓	✓	✓	✓			✓					✓	✓	✓	✓
Cyperaceae																						
Schoenoplectus subulatus									✓												✓	
Cyperus vaginatus							✓	✓	✓	✓									✓	✓	✓	✓
Diversity	**4**	**1**	**2**	**0**	**0**	**3**	**6**	**7**	**6**	**4**	**2**	**0**	**3**	**4**	**0**	**0**	**4**	**0**	**6**	**7**	**6**	**3**
Total Diversity	**5**				**9**						**6**					**9**						

Plate 3-1: (A) Emergent and submerged macrophytes in Yule River site YR1 (permanent pool), (B) a bed of *Najas marina* in YR3, (C) submerged habit of *Najas tenufolia* at TRU1, and (D) absence of aquatic macrophytes at TRD2.

3.5 Phytoplankton

Algae can occur as either free-floating planktonic or benthic organisms (Bellinger and Sigee 2010). Planktonic algae are referred to as phytoplankton and have several important roles within aquatic ecosystems. This includes primary production through photosynthesis and nutrient cycling, and in the provision of food resources, supporting higher order consumers such as aquatic invertebrates and small fish (Bunn 1995; Porter *et al.* 2007; Sainty and Jacobs 2003). Phytoplankton in temporary waters also demonstrate seasonal succession of species, depending on trophic status and nutrient availability (Bellinger and Sigee 2010).

A total of 73 planktonic algae were recorded during the Study, representing five different phyla (**Table 3-7**). Bacillariophyta (diatoms) was the most prevalent phyla in both the dry and wet seasons, comprising 40 taxa in total, followed by Cyanophyta (blue-green algae; 15 taxa) and Chlorophyta (green algae; 13 taxa), while Euglenophyta (euglenoids; three taxa) and Dinophyta (dinoflagellates; two taxa) had limited representation. While the composition of phytoplankton varied across seasons (**Figure 3-9A-C**), the taxa identified were considered common and ubiquitous and are known from river systems throughout Australia and globally (Entwisle *et al.* 1997; Bellinger and Sigee 2010).

Diversity during the Study was higher in the dry season (52 taxa) compared to the wet season (42 taxa), and was dominated by Bacillariophyta, with 32 and 16 taxa, respectively (**Figure 3-9A-C**). In contrast, Chlorophyta were more diverse in the wet season (12 taxa), compared to the dry season (6 taxa), while Cyanophyta numbers were stable (10 taxa in both seasons) (**Figure 3-9A-C**). The diversity of Dinophyta and Euglenophyta was consistently low in both seasons, with three or less taxa recorded in each season (**Figure 3-9A-C**).

Site diversity was variable, with more than 20 taxa recorded at three sites in Turner River (TRE2; Turner River East, TRU1 and TR1) during the dry season (**Figure 3-10A**). More broadly, site diversity ranged from 10 to 19 taxa in the Yule River during the dry season and from 10 to 14 taxa during the wet season, while in the Turner River ranged from 16 to 23 taxa during the dry season and nine to 13 taxa during the wet season (**Figure 3-10A**). A reduction in diversity between seasons of the Study was likely driven by a decrease in surface water extent and reduced water quality within receding pools during the wet season, resulting in less phytoplankton productivity (Cooper 1996).

The abundance of phytoplankton was also higher during the dry season of the Study, which was characterised by the dinoflagellate *Peridinium* sp. recorded from nine of the ten sites and was prevalent in Turner River (**Table 3-7**, **Figure 3-9E**). This single-celled alga is characteristic of freshwaters high in nutrients and is also known to form blooms (Bellinger and Sigee 2010; Entwisle *et al.* 1997). This taxon was most dominant at site TRU1 (>25,000 cells), likely reflecting elevated TN and TP concentrations. Several freshwater green algae were also relatively widespread throughout the dry season including *Staurastrum*, *Scenedesmus* and *Cosmarium* species (**Table 3-7**), collectively referred to as desmids (Bellinger and Sigee 2010; Entwisle *et al.* 1997). In the dry season, Turner River site TRU1 also supported an abundance of the freshwater diatom (John 2000) *Navicula cryptocephala* (>3,000 cells) and the filamentous cyanobacterium *Oscillatoria* sp. (480 filaments) (**Table 3-7**). Compared to Turner River, Yule River sites typically had lower phytoplankton abundance (**Figure 3-10B**), which may reflect higher primary productivity within dense macrophyte communities.

During the wet season of the Study, the abundance of phytoplankton generally decreased in both river systems (**Figure 3-10B**). However, taxa such as the motile bi-flagellated green alga *Chlamydomonas* sp.,a well-known freshwater genus (Entwisle *et al.* 1997), dominated site TRD2 (1482 cells) (**Table 3-7**, **Figure 3-9F**). While in TR1, the blue-green alga *Chroococcus* sp. was also recorded in high abundance (1,215 cells). Cyanobacteria are known to form blooms in response to nutrient enrichment (Bellinger and Sigee 2010) and in this instance, was likely attributed to elevated nutrients from cattle frequenting the area. The remainder of the sites in the Turner and Yule River comprised a low abundance of taxa representing a range of phyla (**Table 3-7**).

Hierarchical classification and nMDS (and SIMPROF analysis) highlighted the differences in the community structure of phytoplankton according to season and river systems during the Study (**Figure 3-11A,B**). While three groups were evident based on the SIMPROF analysis, there was a high degree of overlap (**Figure 3-11B**) reflecting broad similarities in algal composition. In the dry season, sites in the Turner and Yule Rivers displayed close to 30% similarity (**Figure 3-11A**). The Yule River sites in the wet season were statistically similar and overlapped with sites TRU1, TRD2 and TR1 in the Turner River during the wet season (**Figure 3-11B**). Of these sites, YRU1 and YRU2 were the most comparable, with >50% similarity in community structure (**Figure 3-11A**). Shifts in phytoplankton community structure between the dry and wet seasons were likely due to water quality changes (specifically nutrients) and habitat availability, key factors known to influence algae in temporary waterbodies (Bellinger and Sigee 2010).

Table 3-7: Phytoplankton diversity and abundance recorded at Turner River and Yule River sites during the Study.

Phytoplankton Taxa	Dry Season – November 2021										Wet Season – May 2022							
	Turner River				Yule River						Turner River				Yule River			
	TRE2	TRU1	TR1	TRD2	YRU1	YRU2	YR1	YR2	YR3	YRD1	TRE2	TRU1	TR1	TRD2	YRU1	YRU1-A	YRU2	YRD1
Bacillariophyta																		
Achnanthidium exiguum		36																
Achnanthidium minutissimum	19						1											
Amphora subturgida												2		4		1		
Chaetoceros muelleri					4								130	12				
Cocconeis placentula																15		
Cyclotella stelligera	2	54			20		2						3	2	148		2	
Cymbella aspera		15																
Cymbella sp. aff. *cymbiformis*	2	15	12	12														
Cymbella turgida													6	2				1
Diploneis subovalis	1	60						1										
Encyonema minutum			9					3								1		
Fragilaria spp.												2				16	3	1
Gomphonema undulatum	1					3	5			2								
Gyrosigma balticum	13	30					8									1	1	
Hantzschia amphioxys		15	3															
Hantzschia distinctepunctata						1												
Hantzschia sp.															10	2	3	2
Hantzschia sp. aff. *baltica*	1																	
Luticola mutica																2		
Mastogloia elliptica		57	60	28			1	1									1	
Mastogloia smithii		165		10			2											
Navicula cryptocephala		3180	15	2											12	7		9
Navicula radiosa									8									
Navicula viridula							5			1								
Nitzschia sigma			9		7													
Nitzschia sp.			60															
Nitzschia closterium	1				1		3											
Nitzschia fasciculata					8													
Nitzschia linearis		15	6															
Nitzschia palea			105		69		9	6		132					10	23	3	128
Pinnularia gibba		45																
Pinnularia microstauron			18	2			8											
Rhopalodia gibberula		30	9	26	1			1										
Rhopalodia musculus	1		33			8	1	5	1									

Phytoplankton Taxa	Dry Season – November 2021										Wet Season – May 2022							
	Turner River				Yule River						Turner River				Yule River			
	TRE2	TRU1	TR1	TRD2	YRU1	YRU2	YR1	YR2	YR3	YRD1	TRE2	TRU1	TR1	TRD2	YRU1	YRU1-A	YRU2	YRD1
Sellaphora pupula	3					1			1		1							
Synedra ulna	14	15				2	2		1									
Tabellaria flocculosa																1		
Tabularia fasciculata	5	69	15			4		5		21								
Triceratium sp.														8				
Tryblionella calida					1		2											
Chlorophyta																		
Ankistrodesmus sp.		45						5										
Botryococcus sp.													21	6	1			
Chlamydomonas sp.												50		1482				
Closterium sp.				1	7				1				3				31	
Coelastrum sp.															12		5	
Cosmarium sp.	1	15	255	5	3	2	1	2		18	2		2					
Dunaliella sp.																2		
Elakatothrix sp.											142							12
Oedogonium sp.													6				4	
Pediastrum sp.	1		12		10	1	2	396	1					2				121
Pseudosphaerocystis sp.															4			
Scenedesmus sp.	34	150	9		3		13	3			1	2		2		1	1	10
Staurastrum sp.	16	75	354	2				57		3	6	7						10
Cyanophyta																		
Anabaena sp.				7			3		2	3								
Aphanocapsa sp.				2							85							
Aphanothece sp.	1		18										24					
Aphoococcus sp.			30	4														
Chroococcus sp.	16		69	7		10			1	168		6	1215					
Cyanothece sp.				1														
Merismopedia sp.	3	315	9		3		1	16	1	12		3	54	6				
Microcystis sp.												11						
Nostoc sp.									44									
Oscillatoria sp.		480		10					17			1				3		1
Phormidium sp.													5					
Phormidium sp.																	1	
Pseudoanabaena sp.																		3
Spirulina sp.												3	2			27		
Synechocystis sp.	5																	

Phytoplankton Taxa	Dry Season – November 2021										Wet Season – May 2022							
	Turner River				Yule River						Turner River				Yule River			
	TRE2	TRU1	TR1	TRD2	YRU1	YRU2	YR1	YR2	YR3	YRD1	TRE2	TRU1	TR1	TRD2	YRU1	YRU1-A	YRU2	YRD1
Dinophyta																		
Gymnodinium sp.											1							
Peridinium sp.	53	45	25200	73	144	8		13	15	3	1		45		24		9	
Euglenophyta																		
Euglena sp.								3						2	5		1	
Phacus sp.		30			3		1	4	5		1			2	45		45	1
Trachelomonas sp.						2		1	10									
Diversity	**21**	**23**	**22**	**16**	**15**	**11**	**19**	**17**	**14**	**10**	**9**	**10**	**13**	**12**	**10**	**14**	**14**	**12**
Abundance	**193**	**4956**	**26310**	**192**	**284**	**42**	**70**	**522**	**108**	**363**	**240**	**87**	**1516**	**1530**	**271**	**102**	**110**	**299**

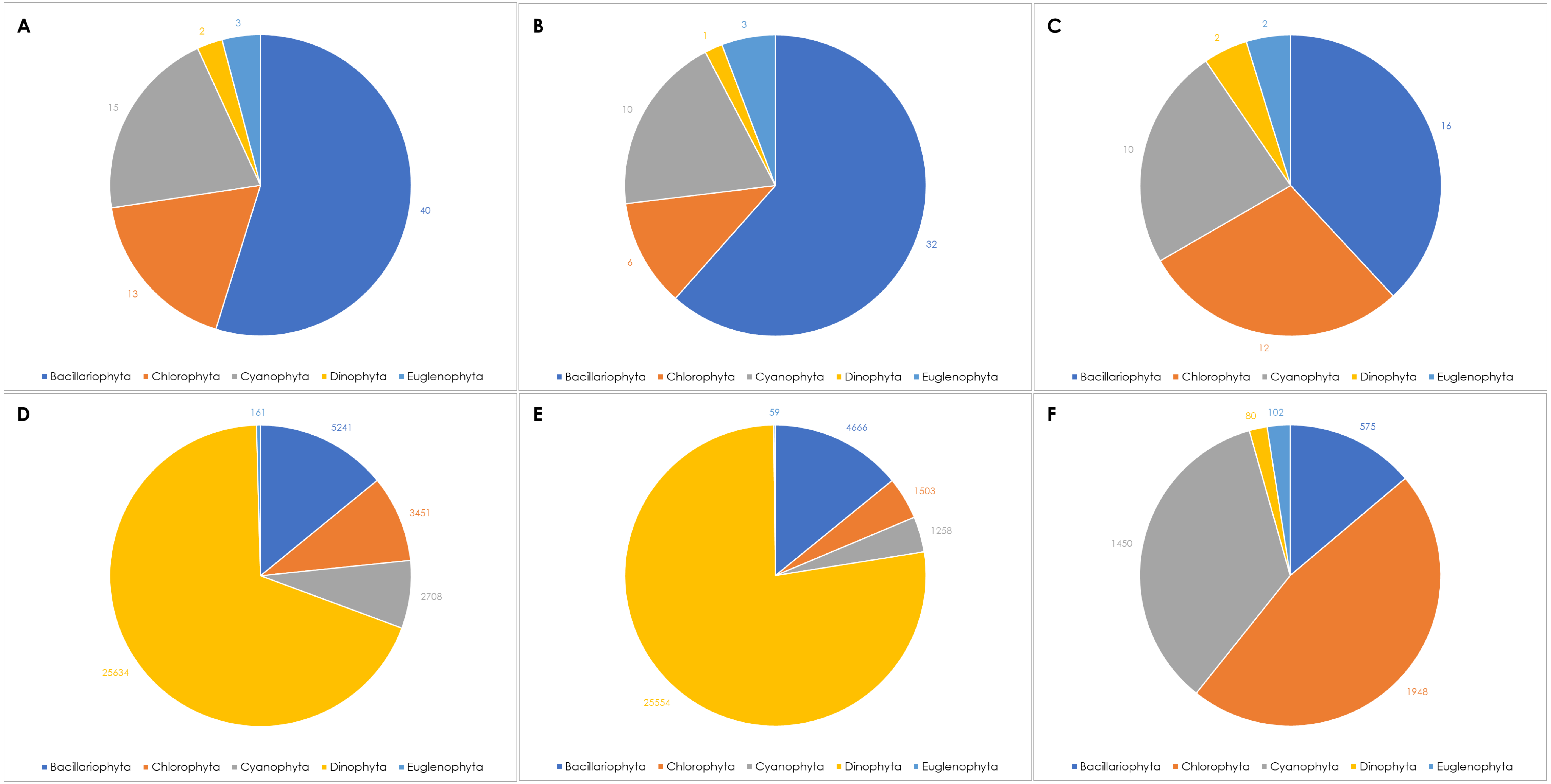


Figure 3-9: Summary of phytoplankton; (A) total diversity, (B) dry season diversity, (C) wet season diversity, (D) total abundance, (E) dry season abundance, and (F) wet season abundance, recorded during the Study.

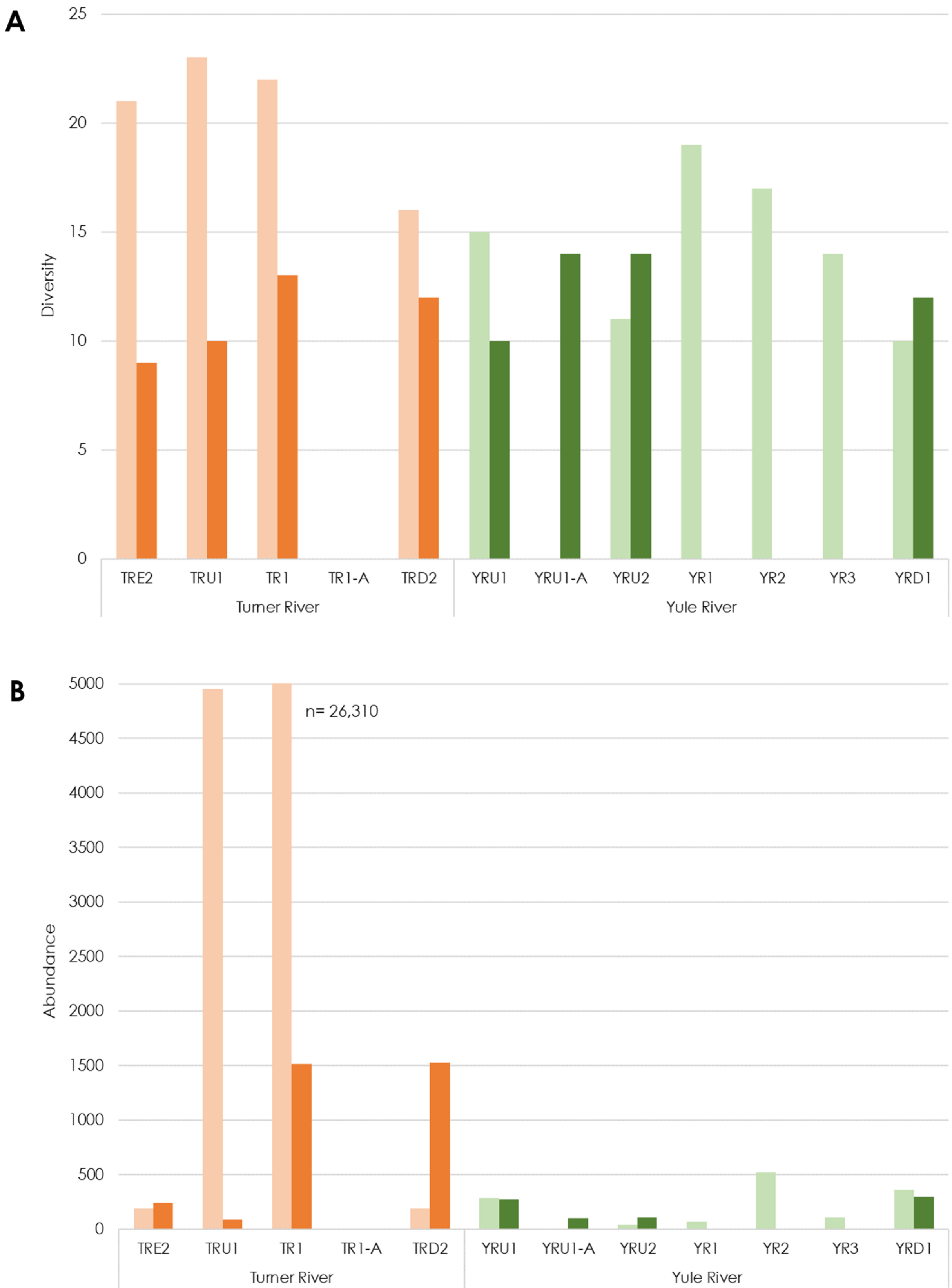
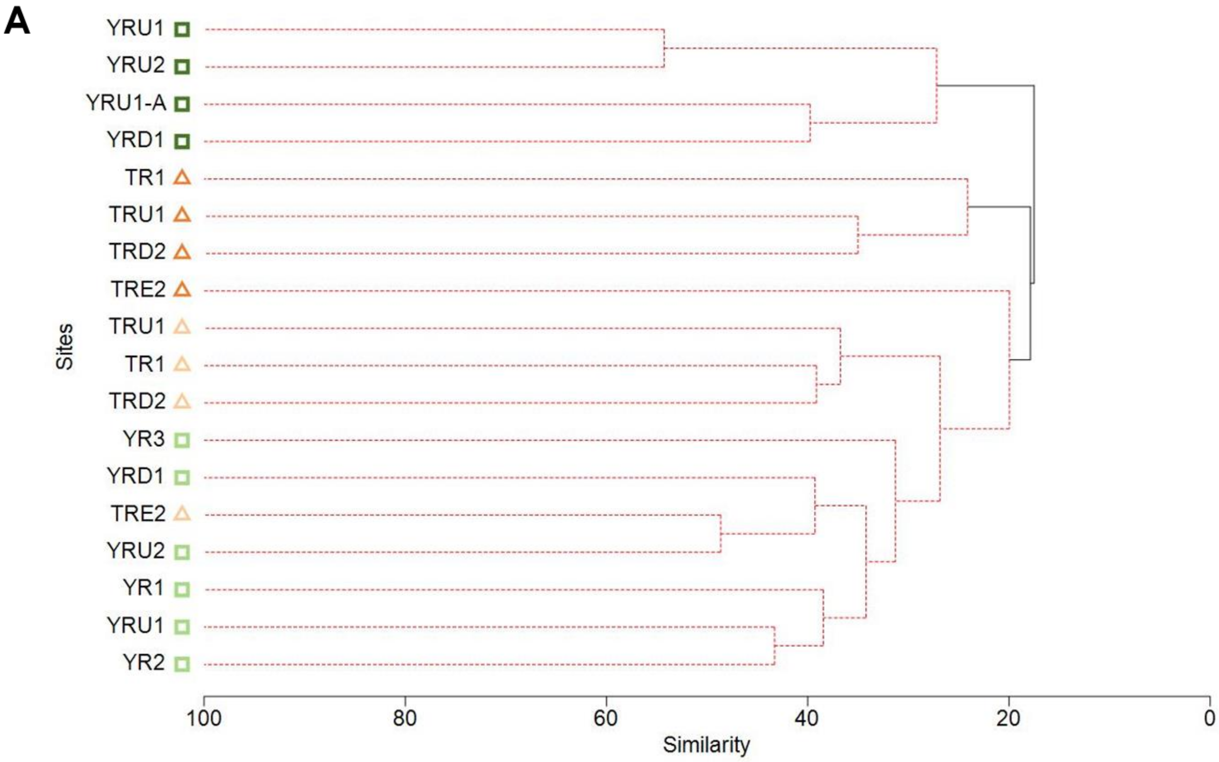


Figure 3-10: Aquatic invertebrate diversity (A) and abundance (B) of Turner and Yule River sites (■■ = dry season, ■■ = wet season) during the Study.



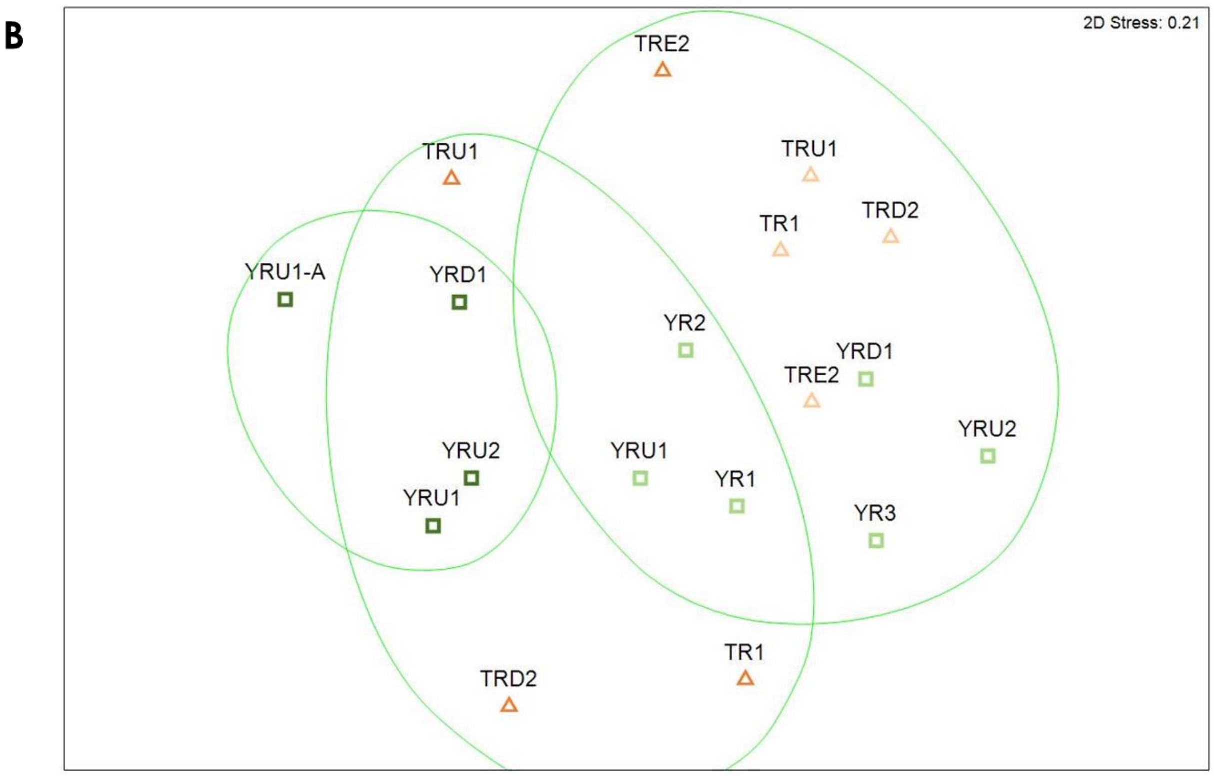


Figure 3-11: (A) Dendrogram and, (B) nMDS (green circles denote significant difference from SIMPROF) analysis, of phytoplankton community structure in the Turner and Yule Rivers during the Study (△ = Turner River wet season, △ = Turner River dry season, □ = Yule River wet season, □ = Yule River dry season).

3.6 Periphyton (Diatoms)

Diatoms are a unicellular, microalgae that are characterised by their siliceous cell wall (termed a frustule) (John 2000), occupying a range of free floating (planktonic) and attached (periphytic) habitats, including the sediments of lakes and streams (Blinn 1995; Campagna 2007; John 1998; Taukulis 2007). They are important primary producers, as well as often forming the basis of the food chain, providing a food source for aquatic invertebrates (John 1998). They also have well-documented water quality tolerance limits and habitat preferences, meaning they are useful biological indicators of their wider environment and habitat (John 2000).

A total of 54 diatom taxa were identified from periphyton during the Study, representing 28 genera (**Table 3-8**). There were 41 species recorded in the dry season and 46 taxa in the wet season and were abundant in both river systems (**Table 3-8**). The most speciose genera were common to both surveys, comprising *Navicula* and *Nitzschia* representatives (**Table 3-8**), consistent with the diatom assemblage known from inland waters throughout WA (John 1998; Taukulis 2007). Species composition was considered typical of freshwater streams and rivers in WA (John 1998; 2000), and more broadly throughout Australia and globally.

Site diversity during the Study generally varied from seven to 15 taxa, with a maximum of 16 taxa recorded from sites TRU1, TR1 and YR3 during the wet season (**Figure 3-12**). Diversity tended to be higher in the Yule River sites during both seasons, likely reflecting greater habitat and substrate heterogeneity within these larger pools. In contrast, the smaller, more homogenous pools of the Turner River had lower diatom diversity, notably in site TRD2 during the dry season (five taxa) (**Figure 3-12**). Sites with lower diatom diversity (including TRD2) were mostly characterised by a substate of sand and gravel over hard bedrock, providing limited attachment sites for diatom colonisation (Krejci and Lowe 1986).

In the dry season, *Nitzschia palea*, *Achnanthidium exiguum*, *Mastogloia elliptica*, *Navicula radiosa* and *Synedra ulna* were relatively abundant and widespread throughout the Turner and Yule and Rivers, with *Nitzschia palea* being recorded in nine of the 10 sites (**Table 3-8**). All are common freshwater taxa widespread in urban and regional rivers throughout WA (John 1998 1983; Taukulis 2007). In addition, *Nitzschia palea* is also associated with nutrient rich environments (John 1998), consistent with the water quality results of the Study, while genera such as *Achnanthidium and Mastogloia are* closely associated with epiphytic growth on macrophytes (John 2000).

During the wet season, *Nitzschia microcephala*, *Nitzschia palea*, *Achnanthidium exiguum*, *Anomoeoneis sphaerophora* and *Gomphonema undulatum* were the most abundant and widespread diatom species recorded in the Turner and Yule Rivers (**Table 3-8**). Similar to the dry season, *Nitzschia palea* and *Achnanthidium exiguum* were common, occurring in 11 and eight sites, respectively. However, taxa including *Nitzschia microcephala*, *Anomoeoneis sphaerophora and Gomphonema undulatum* were more dominant in the wet season of the Study. These taxa are all considered discriminating freshwater diatom taxa in lakes and streams throughout inland areas of WA (Taukulis 2007).

The hierarchical classification indicated that most sites had some degree of similarity (>30%) in diatom community structure (**Figure 3-13A**), which was represented by most sites clustering together on the nMDS (**Figure 3-13B**). Sites YRU1 during the wet and dry season and TR1-A during the wet season were significantly different, likely due to the prevalence of the eutrophic species *Nitzschia palea*, while sites TR1 and TRU1 during the wet season were also distinct and were characterised by sandy substrates supporting comparable diatom assemblages (**Figure 3-13A, B**). Site TRD2 during the dry season was also significantly different (**Figure 3-13A, B**), due to low species diversity and the dominance of *Amphora ovalis* var. *affinis*, a widely distributed freshwater and estuarine taxon (John 1983). During the wet season, the Yule River sites YRU1-A and YRU2 had the highest similarity in diatom community structure (>60%) (**Figure 3-13A**), dominated by freshwater diatoms including *Achnanthidium exiguum* and *Nitzschia palea*, colonising to homogenous habitat present at both sites driving this similarity. More broadly, the key environmental factors influencing the diatom assemblages in these river systems appear to be habitat type and availability, including macrophytes and substrate composition, as well as water quality parameters and such as salinity and nutrient concentrations (Townsend & Gell 2005; Taukulis 2007; John 1998).

Table 3-8: Summary of benthic diatoms (relative abundance; maximum 100 frustules) recorded at Turner River and Yule River sites during the Study.

Diatom Taxa	Dry Season – November 2021										Wet Season – May 2022											
	Turner River				Yule River						Turner River					Yule River						
	TRE2	TRU1	TR1	TRD2	YRU1	YRU2	YR1	YR2	YR3	YRD1	TRE2	TRU1	TR1	TR1-A	TRD2	YRU1	YRU1-A	YRU2	YR1	YR2	YR3	YRD1
Achnanthidium exiguum	1	11	2			47	13	6	4	20	3		2		23		25	33	5		21	6
Achnanthidium minutissimum	26					3		38	29		1						2			77		1
Amphora mexicana													20									
Amphora ovalis												3	9									
Amphora ovalis var. *affinis*	1			87																		
Amphora subturgida							2						47								1	
Anomoeoneis sphaerophora												2	4		5	2	4		3		4	1
Cocconeis placentula		1					1															
Craticula cuspidata							3							6								
Cyclotella meneghiniana								1	1		2					25						
Cyclotella stelligera	15	3					18	5			2					7						1
Cyclotella striata																			2		6	
Cymbella aspera		1				4												1				
Cymbella sp. aff. *cymbiformis*			5	5									2									
Cymbella turgida											1	25	2	7	2			3				
Diploneis ovalis			4									2	1									
Diploneis subovalis		1				3						1		6		7	2	1			5	
Encyonema minutum		3	4					2	1				3	2					1	1		
Epithemia sp. aff. *reichelti*													3									
Eunotia bilunaris	1								4												1	
Eunotia pectinalis																					1	
Fallacia tenera					6																	
Frustulia rhomboides					20																	
Gomphonema parvulum			3			2		3	2		2						13	30	28	1		40
Gomphonema undulatum			1				2			25	5			18			4	1	20	2	15	4
Gyrosigma balticum		2													12			1	1			
Hantzschia amphioxys	1										3		1			1						
Hantzschia baltica		1	4																			
Hantzschia distinctepunctata												1			2			1				
Hantzschia virgata							2															
Luticola mutica					2						1	1				1						
Mastogloia elliptica		16	34	4		10	2	3		3		24	6		7			1	1		12	
Mastogloia smithii		6	7				3		5						1					1	3	
Navicula cryptocephala	3												6		7				15	8	5	
Navicula radiosa	20	39		3		5	1	8	11													
Navicula sp. aff. *rhynchocephala*	5		6								14	2	6		1	8	7	8				

Diatom Taxa	Dry Season – November 2021										Wet Season – May 2022											
	Turner River				Yule River						Turner River					Yule River						
	TRE2	TRU1	TR1	TRD2	YRU1	YRU2	YR1	YR2	YR3	YRD1	TRE2	TRU1	TR1	TR1-A	TRD2	YRU1	YRU1-A	YRU2	YR1	YR2	YR3	YRD1
Navicula sp. aff. *recens*																3	2					
Navicula viridula						4	6			3						2						9
Neidium productum												1										
Nitzschia amphibia			1				4										2		7			
Nitzschia closterium																1						
Nitzschia linearis					1	1										1			2		5	
Nitzschia microcephala					4		14		9		2	1	6	1	15	18	8	1	5		7	1
Nitzschia palea	23	7	23		63	14	28	5	19	44	53	2	2	35	25	3	15	2	8		5	33
Nitzschia sigma																					6	
Pinnularia gibba		2		1								5		1								
Pinnularia microstauron						1								7								
Pleurosigma elongatum									9									1				
Rhopalodia gibberula												23		2								2
Rhopalodia musculus			4							1		5										1
Sellaphora pupula						1					10			7		8	8	5				1
Synedra ulna	3	7	2			3		29	6	4	1	2					8	11	2	10		
Tabularia fasciculata						2																
Tryblionella calida	1				4		1							8		13					3	
Abundance	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**120**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**
Diversity	**12**	**14**	**14**	**5**	**7**	**14**	**15**	**10**	**12**	**7**	**14**	**16**	**16**	**12**	**11**	**15**	**13**	**15**	**14**	**7**	**16**	**12**

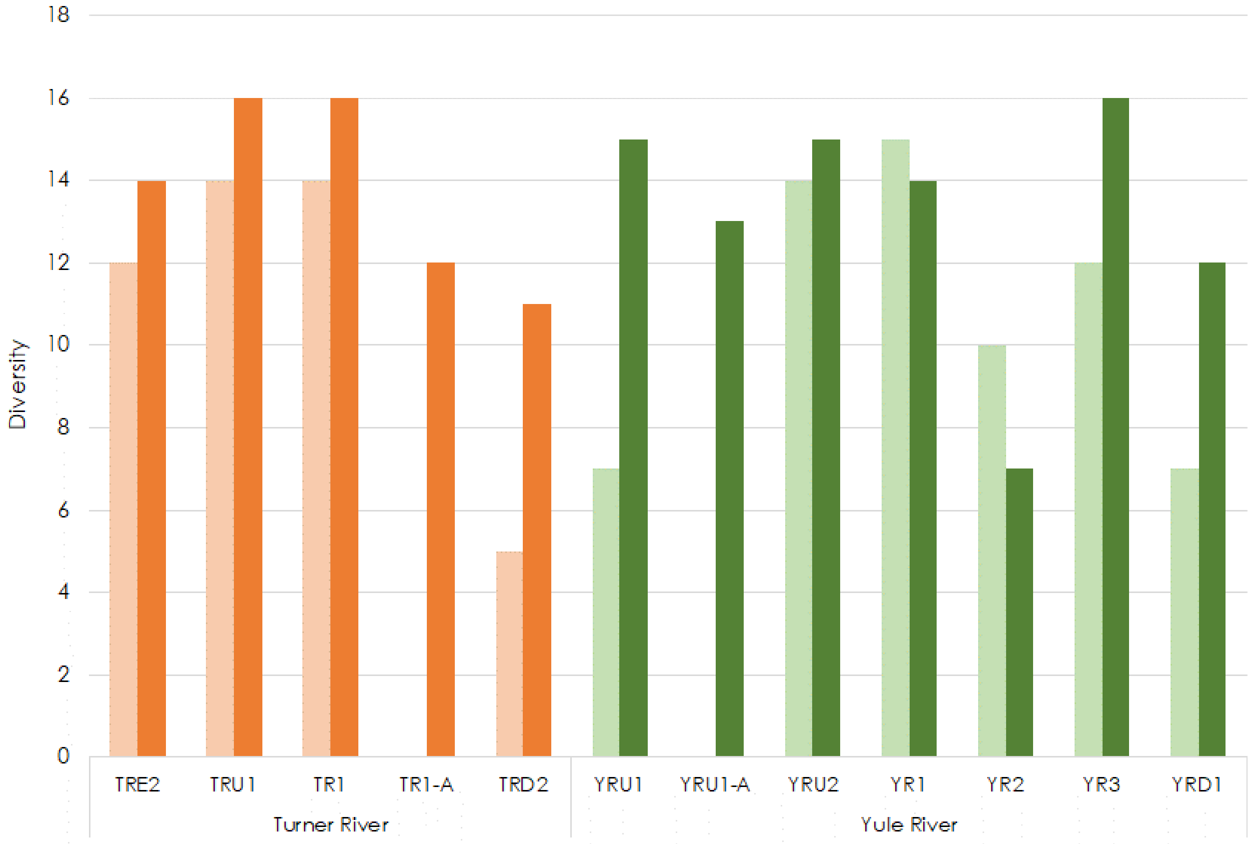


Figure 3-12: Benthic diatom diversity of Turner and Yule River sites (■■ = dry season, ■■ = wet season) during the Study.

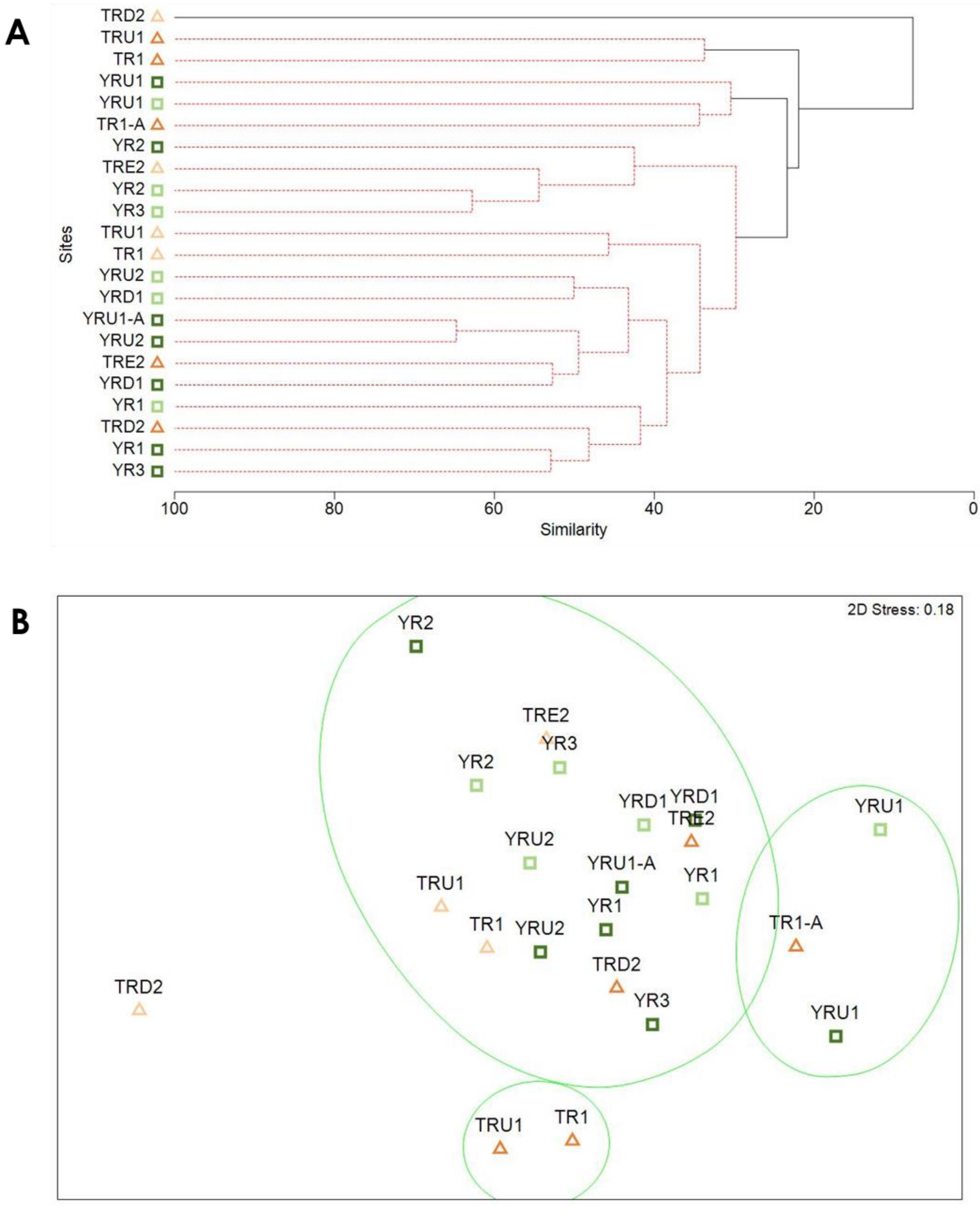


Figure 3-13: (A) Dendrogram and, (B) nMDS (green circles denote significant difference from SIMPROF) analysis, of diatom community structure in the Turner and Yule Rivers during the Study (△ = Turner River wet season, △ = Turner River dry season, □ = Yule River wet season, □ = Yule River dry season).

3.7 Aquatic Invertebrates

Aquatic invertebrates inhabit a range of environments from freshwater streams to inland lakes and wetlands. They belong to several trophic groups, including consumers and decomposers, and play an integral role in ecosystem function (Gooderham and Tsyrlin 2002). They comprise a diverse range of groups that are sensitive to changes in water quality and can therefore be used as biological monitors to detect changes in physical and chemical parameters such as salinity, nutrients, and metals (Cairns Jnr. and Pratt 1993; Dills and Rogers Jnr 1974; Hellawell 1986).

A total of 4,208 aquatic invertebrate specimens representing 182 taxa from ten higher order groups were recorded during the Study (**Table 3-9**). These included Insecta (insects), Gastropoda (aquatic snails and limpets), Bivalvia (freshwater clams and mussels), Arachnida (aquatic mites), Oligochaeta (aquatic worms), Nematoda (round worms), Monogononta (rotifers) and the crustacean groups Branchiopoda (comprising Cladocera; water fleas), Maxillopoda (comprising copepods) and Ostracoda (seed shrimp) (**Table 3-9**, **Figure 3-14A-F**). Of these, insects were the dominant group, comprising 3,032 specimens and 130 taxa, followed by the Maxillopoda, with 604 specimens and 16 taxa, all of which were copepods (**Table 3-9**, **Figure 3-14A-F**). Aquatic mites were also relatively diverse (14 taxa, 131 specimens), while the remaining groups typically comprised less than 200 specimens and eight taxa each (**Table 3-9**, **Figure 3-14A-F**).

The aquatic invertebrate community during this Study was generally consistent with previous studies of river systems in the Pilbara, where insects are prevalent (Pinder and Leung 2009; Pinder et al. 2010; WRM 2009;2015;2017). A total of seven insect groups were recorded during the Study, including Diptera (true flies), Coleoptera (aquatic beetles), Ephemeroptera (mayflies), Hemiptera (true bugs), Lepidoptera (aquatic caterpillars), Odonata (dragonflies and damselflies) and Trichoptera (caddisflies) (**Table 3-9**). Of these, Diptera and Coleoptera were dominant, accounting for >60% of all insect taxa and >70% of all specimens recorded. All insect groups recorded were considered transient or opportunistic taxa, comprising mobile winged adult stages, which allow them to readily disperse and rapidly colonise newly created habitats (Gooderham and Tsyrlin 2002).

The diversity and abundance of aquatic invertebrates varied between seasons, with 123 taxa and 2,209 specimens recorded during the dry season, and 152 taxa and 1,999 specimens recorded during the wet season (**Table 3-9**). The increased diversity during the wet season may reflect greater habitat availability and overall higher biological productivity in the smaller pools sampled during May 2022 (wet season). With low rainfall conditions during both seasons of the Study, and most semi-permanent/permanent pools reducing in size, aquatic invertebrates were likely seeking refuge and habitat in remaining waterbodies. Regardless, invertebrate composition was relatively similar between the seasons, with insects dominant and Maxillopoda (copepods) and Arachnida (aquatic mites) also prevalent (**Figure 3-14A-F**).

The abundance of aquatic invertebrates was generally higher during the dry season of the Study, except for insects (**Figure 3-14B, E**), likely driven by the presence of larger pools and increased habitat availability. Higher abundances of Gastropoda, Cladocera, Arachnida, Rotifers and Copepods were recorded in the dry season (**Figure 3-14E**), with these groups typically preferring slow-flowing or lentic conditions and unable to disperse (Szlauer-Lukaszewska and Pesic 2020; Tina Liu and Resh 1997). However, aquatic invertebrates belonging to the class Insecta were more abundant and diverse during the wet season, likely due to their dispersal mechanisms, which allow them to find available habitat and actively seek refugia (**Figure 3-14C, F**). Aquatic mites (Arachnida) were also more diverse during the wet season (**Figure 3-14C**). Aquatic mites are often abundant in temporary waterbodies, despite not showing specialised adaptations to desiccation. Instead, dispersal is facilitated by their larvae which parasitise on adult insects, which colonise newly inundated pools (Bird *et al.* 2019).

The majority of aquatic invertebrate taxa recorded were common, ubiquitous species with distributions spanning the Pilbara, northern Australia or the Oceania region. The most widespread taxon comprised the chironomid (non-biting midge) *Procladius* spp. and the biting midge larvae Ceratopogoninae spp., recorded in 21 of the 22 sites across both seasons of the Study (**Table 3-9**). The most abundant taxa were the chironomid *Tanytarsus* spp. (446 specimens), the chironomid *Procladius* spp. (254 specimens) and the copepod *Eodiaptomus lumholtzi* (191 specimens) (**Table 3-9**). Chironomids often constitute the most common and abundant invertebrate taxa in freshwaters worldwide, due to their tolerance to a range of environmental conditions, including low oxygen, high temperatures, high salinity and nutrients and desiccation (Cornette *et al.* 2015). Their presence in this Study may reflect nutrient enrichment associated with unrestricted livestock access to the pools of these river systems.

Eodiaptomus lumholtzi is a common and broadly distributed species across the Pilbara region (Pinder *et al.* 2010), having been previously recorded from the Fortescue River, Coondiner Creek, Kalgan Creek, Gudai-Darri Spring, Cane River and from Papua New Guinea, with a pan tropical distribution (Vlaardingerbroek 1989, WRM 2020). This species is listed as Vulnerable on the IUCN Red List of Threatened Species (Reid 1996). However, its status requires updating, with the species having been recorded widely across Northern Australia since its IUCN listing in 1996. *Eodiaptomus lumholtzi* was found in >40% of sites during both seasons, tending to be more abundant in Turner River (**Table 3-9**).

During the dry season of the Study, aquatic invertebrate diversity was highest in Yule River sites YR3 (50 taxa) and YR2 (43 taxa) (**Figure 3-15A**). The lowest diversity was recorded in Yule River site YRU1 during the dry season (11 taxa), followed by Turner River site TRD2 (18 taxa). During the wet season, diversity was highest in Yule River site YRD1 (56 taxa) and Turner River East site TRE2 (50 taxa) (**Figure 3-15A**), while the lowest diversity occurred in Turner River site TRD2 (18 taxa) (**Figure 3-15A**). The range of taxa recorded in Turner River sites (18 to 50 taxa) was comparable to Yule River sites (11 to 56 taxa), although diversity in the former was higher in the wet season (**Figure 3-15A**), likely reflecting the prevalence of insects and their dispersal mechanisms (Bunn *et al.* 2006).

Aquatic invertebrate abundance was more variable between sites and seasons during the Study. In the Turner River, abundance ranged from 96 (TRD2 in the dry season) to 371 specimens (TRU1 in the wet season), while in the Yule River, abundance ranged from 43 specimens (YRU1 in the dry season) to 444 specimens (YRD1 in the dry season) (**Figure 3-15B**). In contrast to diversity, taxa abundance was generally higher in the dry season, likely attributed to greater habitat availability.

Seven taxa endemic to the Pilbara region were recorded during the Study, including the aquatic beetles *Sternopriscus pilbaraensis*, *Tiporus tambreyi* and *Laccobius billi*, the hemipteran back swimmer *Anisops nabillus*, the dragonflies *Hemicordulia koomina* and *Ictinogomphus dobsoni*, and the damselfly *Eurysticta coolawanyah* (**Table 3-10**). Of these, both *Hemicordulia koomina* and *Eurysticta coolawanyah* are also listed as Vulnerable on the IUCN Red List of Threatened Species (Dow 2019a, b) and are known from only a small range (extent of occurrence of less than 20,000 km^2 for *E. coolawanyah*, and less than 6,000 km^2 for *H. koomina*). They inhabit streams, rivers and riverine pools in the Pilbara, with key threats to persistence including habitat alteration (declining water levels) due to development and climate change (Dow 2019a, b). However, *H. koomina has been recorded* from over 40 locations in the Pilbara, while *E. coolawanyah* has been recorded from over 15 locations (Pinder *et al.* 2010), suggesting both species are more broadly distributed than proposed by the IUCN. During this Study, *Eurysticta coolawanyah* was recorded in site TRE2 (Turner River East) and in sites YRU1-A and YRD1 (Yule River) during the wet season (**Table 3-10**), while *Hemicordulia koomina* was only recorded from site YR3 (Yule River) in the dry season.

The hierarchical classification of aquatic invertebrates indicated a relatively low level of similarity (approximately 20%) in community structure across all sites and seasons (**Figure 3-16A**). This reflects differences in site characteristics and available habitat and changes in pool size between seasons. There was also a high diversity albeit low number of insect taxa (including Coleoptera, Diptera and Hemiptera) that contributed to the variability between sites. However, according to the nMDS (and SIMPROF analysis), many of the sites also clustered together, with close to 30% similarity in composition (**Figure 3-16A, B**), due to the dominance of several common, ubiquitous insect taxa such as chironomid representatives (**Table 3-9**). In the Yule River, YR2 (wet season) had a significantly different composition, attributed to low diversity of insect taxa (**Figure 3-16B**). Two other groups were distinct comprising TRD2 in Turner River and YRU1 in Yule River during the wet season, with a high degree of similarity and an invertebrate assemblage (>65%) (**Figure 3-16A, B**), comprising micronectids (water boatmen) and notonectids (backswimmers). Yule River sites YR3 (wet season) and YR1 (dry season) were also similar to a lesser extent (approximately 40% similarity) due to lentic taxa, including the gastropod *Gyraulus* spp.,.hemipterans including *Paraplea brunni* and the backswimmer (notonectid) *Anisops hackeri*. These sites were characterised by perennial flows and stable habitat and water quality, reflected in their invertebrate assemblages.

Table 3-9: Summary aquatic invertebrates (total abundance) recorded at Turner River and Yule River sites during the Study.

Aquatic Invertebrate Taxa	Dry Season - November 2021										Wet Season - May 2022											
	Turner River				Yule River						Turner River					Yule River						
	TRE2	TRU1	TR1	TRD2	YRU1	YRU2	YR1	YR2	YR3	YRD1	TRE2	TRU1	TR1	TR1-A	TRD2	YRU1	YRU1-A	YRU2	YR1	YR2	YR3	YRD1
Arachnida																						
Trombidiformes																						
Arrenuridae spp.						2							6							1		
Eylaidae spp.																						2
Halacaridae sp.																				1		
Hydrachinidae spp.									1	1									1			
Hydrodroma sp.																		1				
Hydryphantidae spp.		1												3								
Hygrobatidae spp.	1			1		1						1						1				
Limnesiidae spp.	2	9		1		3		1		2			1									2
Mesostigmata spp.									1													
Oribatida spp.																				2		
Oxidae spp.		1				6				14			1					1				
Pionidae spp.		1												3								
Trombidioidea sp.																1						
Unionicoliidae spp.	12	17	1			1	1	2	1	3		2	4	9				1				
Bivalvia																						
Cyrenidae																						
Corbicula sp.								1		3							1			6		2
Hyriidae																						
Velesunio wilsoni										1												
Branchiopoda																						
Diplostraca																						
Chydoridae																						
Armatalona macrocopa			1																			
Daphniidae																						
Ceriodaphnia cornuta	1		13	1																		
Simocephalus heilongjiangensis								4														
Macrothricidae																						
Macrothrix breviseta	14		14		1			1		4		21										
Moinidae																						
Moina micrura s.l.																						48
Sididae																						
Diaphanosoma excisum																						1
Diaphanosoma unguiculatum									25													
Latonopsis australis				1				1	25	3												
Clitellata																						
Oligochaeta																						
Oligochaeta spp.			1			2			2			4	3				1					1
Gastropoda																						
Lymnaeidae																						
Bullastra vinosa	5	17	2						1	25				3			4					
Planorbidae																						

Aquatic Invertebrate Taxa	Dry Season - November 2021										Wet Season - May 2022											
	Turner River				Yule River						Turner River					Yule River						
	TRE2	TRU1	TR1	TRD2	YRU1	YRU2	YR1	YR2	YR3	YRD1	TRE2	TRU1	TR1	TR1-A	TRD2	YRU1	YRU1-A	YRU2	YR1	YR2	YR3	YRD1
Amerianna spp.									4										1			
Gyraulus spp.	1	16				1	35		11	35	1	5							7		2	
Insecta																						
Coleoptera																						
Dytiscidae																						
Allodessus bistrigatus											1	1			1	2						
Cybister spp. (L)											1										2	
Cybister tripunctatus		1		1	1	2			2	1	1	5				2		1				
Copelatus nigrolineatus																1	2					3
Eretes australis															5	3			1			
Hydaticus consanguineus									2										1			
Hydroglyphus grammopterus											12	5	1		14	8	3					
Hydroglyphus leai			1			1		9		2												
Hydroglyphus orthogrammus											3	5	1			3	6	9				2
Hydrovatus sp. (L)								1	2								1			4		
Hydrovatus weiri												1										
Hyphydrus lyratus						1	1	2		1		1	1	1						1		3
Laccophilus sp. (L)																						1
Laccophilus sharpi									1													
Neobidessodes denticulatus																				1		10
Onychohydrus atratus																		1				
Rhantaticus congestus																1			1			
Sternopriscus pilbaraensis		1																				
Sternopriscus spp. (female)			2																			
Tiporus tambreyi			5						3			1	1									
Gyrinidae																						
Dineutus australis																1						
Hydraenidae																						
Hydraena spp.									1		1						1					2
Hydrochidae																						
Hydrochus sp.			1			1			2	1	2	2										2
Hydrophilidae																						
Berosus spp. (L)												2		1	2	1						
Berosus australiae							1															
Berosus dallasae			1								2	2			5	1	4	1	1			1
Berosus gibbae						1				2												
Berosus munitipennis															1		2					
Berosus nutans																					1	
Berosus pulchellus						1					2	7			13	9						
Enochrus deserticola						1		1	12		3											8
Enochrus elongatulus																						1
Helochares sp. (L)						2			1			1										
Helochares tatei													2									1
Laccobius billi											4	1	4				1					

Aquatic Invertebrate Taxa	Dry Season - November 2021										Wet Season - May 2022											
	Turner River				Yule River						Turner River					Yule River						
	TRE2	TRU1	TR1	TRD2	YRU1	YRU2	YR1	YR2	YR3	YRD1	TRE2	TRU1	TR1	TR1-A	TRD2	YRU1	YRU1-A	YRU2	YR1	YR2	YR3	YRD1
Paracymus spenceri									2		1											6
Sternolophus marginicollis																		1				
Regimbartia attenuata						2			2													3
Scirtidae																						
Scirtidae spp. (L)									3													
Diptera																						
Ceratopogonidae																						
Ceratopogonidae sp. (pupae)	1																1					
Ceratopogoninae spp.	6	2	3	1	4	3	35	8	2	15	4	5	2	6	6	2	1	8	1	1		1
Dasyheleinae spp.								2		2										2		
Chaoboridae																						
Chaoboridae sp.																1						
Chironomidae																						
Chironomidae spp. (imm./dam./pupae)	9	2	2	2		2	7	2	2		2	1	4	5	13	4			2			2
Tanypodinae spp. (imm./dam.)		1		2				6														
Ablabesmyia hilli	1							5					1				12	1	7	6		
Chironomus spp.											1	15				3	13	1	8			1
Cladotanytarsus spp.	3	55	7	1	8			11	2		4			10		4						5
Cladopelma curtivalva													1									1
Clinotanypus crux																						10
Coelopymia pruinosa					6		2				2			3							1	2
Cricotopus spp.	2	1					2	1														
Cryptochironomus griseidorsum			14								3			2				4	5	9		
Dicrotendipes spp.	1	24	45	5	2	11				6	9	10	1		1		14			6	1	1
Larsia albiceps	3	2	28	1		2	9	5	15	4	3		5	2			3	1	2	6		23
Microchironomus spp.					3							2		4		5		1				
Nanocladius spp.																				2		1
Parachironomus spp.											1											2
Paracladopelma 'M3'			7		1									1						1		
Parakiefferiella spp.		1									1									1		1
Paramerina spp.	1								11		7		1					1		3	1	
Paratanytarsus spp.		50		19				1		6							1					
Paratendipes sp. 'K1'	1		5				1															
Paratendipes sp.											3											
Polypedilum leei	1	25						4	1		7										35	19
Polypedilum nr *watsoni*	1		5	3	2						12	10	1	6	40	29	1		5		2	
Polypedilum nubifer			5				3															
Procladius spp.	5	6	5		14	7	30	4	5	6	9	6	33	36	24	27	4	13	3	4	10	3
Rheocricotopus spp.								1														
Rheotanytarsus spp.	2	10				11		1	1		2	2		1						1		3
Stenochironomus watsoni								1										1		1		1
Tanytarsus spp.	2	5		24		128	3	4	4	209	8	1		18			6	34				
Thienemanniella spp.		2																				
Culicidae																						

Aquatic Invertebrate Taxa	Dry Season - November 2021										Wet Season - May 2022											
	Turner River				Yule River						Turner River					Yule River						
	TRE2	TRU1	TR1	TRD2	YRU1	YRU2	YR1	YR2	YR3	YRD1	TRE2	TRU1	TR1	TR1-A	TRD2	YRU1	YRU1-A	YRU2	YR1	YR2	YR3	YRD1
Culicidae spp. (pupae)		1						8									4		4			
Aedes spp.				1				11									1					
Anopheles sp.																				1		
Culex spp.									5								11		5	14		
Stratiomyidae																						
Stratiomyidae spp.								3	1										2			
Tabanidae																						
Tabanidae spp.								5	4								1					
Ephemeroptera																						
Baetidae																						
Baetidae spp. (imm./dam.)		2					4				2								1		17	1
Cloeon sp. Red Stripe		2					12		1		2		1			3		3	7	14	15	2
Caenidae																						
Caenidae spp. (imm./dam.)			8			1	3		1				8	1			1					4
Tasmanocoenis sp. M			3														2					
Tasmanocoenis sp. P/*arcuata*			4						1		3		12	1								6
Hemiptera																						
Belostomatidae																						
Diplonychus eques						1	2	5	2	4		4					1	4	13		1	
Gerridae																						
Gerridae spp. (imm./dam.)						1											1					1
Limnogonus fossarum gilguy		1									3											
Mesoveliidae																						
Mesovelia vittigera																	1					
Micronectidae																						
Micronectidae spp. (imm./fem.)		4	2					1		5	2	7	7		17	9			1		2	
Austronecta spp.											2											
Austronecta micra		8	2					1			3											
Micronecta adelaidae											2	3	11		6	6						
Micronecta annae													1			1						
Micronecta virgata										3						3						
Nepidae																						
Ranatra diminuta	4	3			1				1	1									6	2		
Notonectidae																						
Notonectidae spp. (imm./dam.)																					6	
Anisops spp. (imm./fem.)							7		2	3					3	12			1		7	
Anisops nr *canaliculatus*										1					1							
Anisops hackeri							12									6					1	
Anisops nabillus										2											3	
Anisops nasutus															2							
Anisops stali															1							
Anisops thienemanni							1															
Pleidae																						
Paraplea brunni	3	3				1	20	9	11	65	2	6					3	1	11		40	11

Aquatic Invertebrate Taxa	Dry Season - November 2021										Wet Season - May 2022											
	Turner River				Yule River						Turner River					Yule River						
	TRE2	TRU1	TR1	TRD2	YRU1	YRU2	YR1	YR2	YR3	YRD1	TRE2	TRU1	TR1	TR1-A	TRD2	YRU1	YRU1-A	YRU2	YR1	YR2	YR3	YRD1
Lepidoptera																						
Crambidae																						
Parapoynx sp.	3	1						3						2			1		1			
Odonata																						
Epiprocta spp. (imm./dam.)						1		1	1				2				4			2	3	
Zygoptera spp. (imm./dam.)	1						3	3	1		2		1				1				7	3
Aeshnidae																						
Hemianax papuensis											3						1		2			6
Coenagrionidae																						
Agriocnemis spp.													1							1		
Argiocnemis rubescens								3			1								5		11	4
Ischnura aurora	1						10			5	1									1		2
Ischnura heterosticta							3														3	
Pseudagrion aureofrons							5			2										1	4	1
Corduliidae																						
Hemicordulia koomina									1													
Gomphidae																						
Austrogomphus gordoni			1									1					1					
Isostictidae																						
Eurysticta coolawanyah											1						2					10
Lindeniidae																						
Ictinogomphus dobsoni																				1		4
Libellulidae																						
Diplacodes bipunctata								1										1			1	
Diplacodes haematodes																	1					
Macrodiplax cora										1												
Orthetrum caledonicum							2					1	1	1			1	4				9
Rhodothemis lieftinki								1														
Zyxomma elgneri													1				1					2
Trichoptera																						
Ecnomidae																						
Ecnomus sp.		1						3			1		14	8			1			1	1	8
Hydroptilidae																						
Hellyethira sp.									1								1					
Orthotrichia sp.		2																		1		
Leptoceridae																						
Leptoceridae sp. (imm./dam.)									1											8		
Leptocerus atsou									1											2		
Oecetis sp.		1	1						4				4	1			1					1
Triplectides ciuskus seductus		1																				
Maxillopoda																						
Calanoida																						
Diaptomidae																						
Eodiaptomus lumholtzi	43	2		23							21	20		32						5	3	42

Aquatic Invertebrate Taxa	Dry Season - November 2021										Wet Season - May 2022											
	Turner River				Yule River						Turner River					Yule River						
	TRE2	TRU1	TR1	TRD2	YRU1	YRU2	YR1	YR2	YR3	YRD1	TRE2	TRU1	TR1	TR1-A	TRD2	YRU1	YRU1-A	YRU2	YR1	YR2	YR3	YRD1
Calanoid copepodites											4	2										4
Calanoid nauplii												1										
Cyclopoida																						
Cyclopidae																						
Australoeucyclops karaytugi						13																
Mesocyclops spp.	7												16									
Mesocyclops brooksi																1						3
Mesocyclops darwini							1		8	1								10				
Mesocyclops notius			50	7		1		29			1							2				
Microcyclops sp. P1 (PSW)							44		32													
Microcyclops varicans												7										
Paracyclops sp. 8 (PSW)				2				1														
Thermocyclops decipiens		48					5		10		7								17			
Cyclopoid copepodites											9	12		13			4	15	7			8
Cyclopoid nauplii												5							3			
Harpacticoida																						
Canthocamptidae																						
Cletocamptus deitersi												2										
Canthocamptid copepodite												1										
Monogononta																						
Ploima																						
Brachionidae																						
Brachionus angularis		40																				
Brachionus dichotomus								1														
Brachionus falcatus		1																				
Flosculariaceae																						
Hexarthridae																						
Hexarthra mira														1								
Nematoda																						
Nematoda spp.												1										
Ostracoda																						
Podocopida																						
Cyprididae																						
indet. cyprididae																1						
Stenocypris major										5							1		5			
Darwinulidae																						
Vestalenula marmonieri																	2					
Diversity	**29**	**40**	**30**	**18**	**11**	**30**	**29**	**43**	**50**	**35**	**50**	**42**	**34**	**27**	**18**	**29**	**46**	**27**	**32**	**34**	**26**	**56**
Abundance	**137**	**371**	**239**	**96**	**43**	**211**	**264**	**168**	**236**	**444**	**184**	**192**	**154**	**174**	**155**	**150**	**131**	**122**	**137**	**113**	**180**	**309**

Table 3-10: Pilbara endemic aquatic invertebrate species recorded at Turner and Yule River sites during the Study.

Aquatic Invertebrate Taxa	Dry Season - November 2021										Wet Season - May 2022											
	Turner River				Yule River						Turner River					Yule River						
	TRE2	TRU1	TR1	TRD2	YRU1	YRU2	YR1	YR2	YR3	YRD1	TRE2	TRU1	TR1	TR1-A	TRD2	YRU1	YRU1-A	YRU2	YR1	YR2	YR3	YRD1
Insecta																						
Coleoptera																						
Dytiscidae																						
Sternopriscus pilbaraensis		✓																				
Tiporus tambreyi			✓						✓			✓	✓									
Hydrophilidae																						
Laccobius billi											✓	✓	✓				✓					
Hemiptera																						
Anisops nabillus										✓											✓	
Odonata																						
Corduliidae																						
Hemicordulia koomina									✓													
Isostictidae																						
Eurysticta coolawanyah											✓						✓					✓
Lindeniidae																						
Ictinogomphus dobsoni																				✓		✓
Diversity	**0**	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**2**	**1**	**2**	**2**	**2**	**0**	**0**	**0**	**2**	**0**	**0**	**1**	**1**	**2**

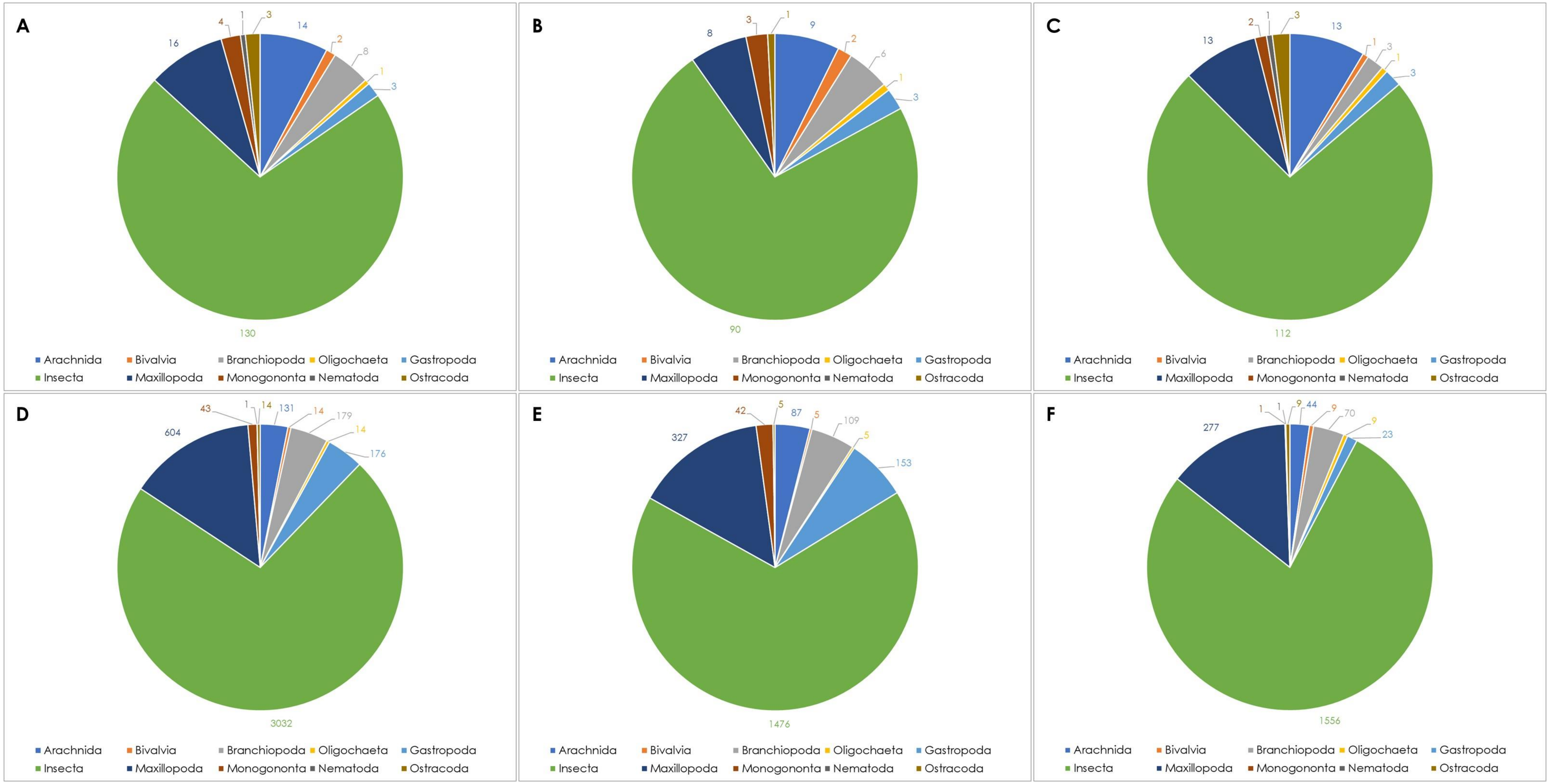


Figure 3-14: Summary of aquatic invertebrates; (A) overall diversity, (B) dry season diversity, (C) wet season diversity, and (D) overall abundance, (E) dry season abundance and (F) wet season abundance, recorded during the Study

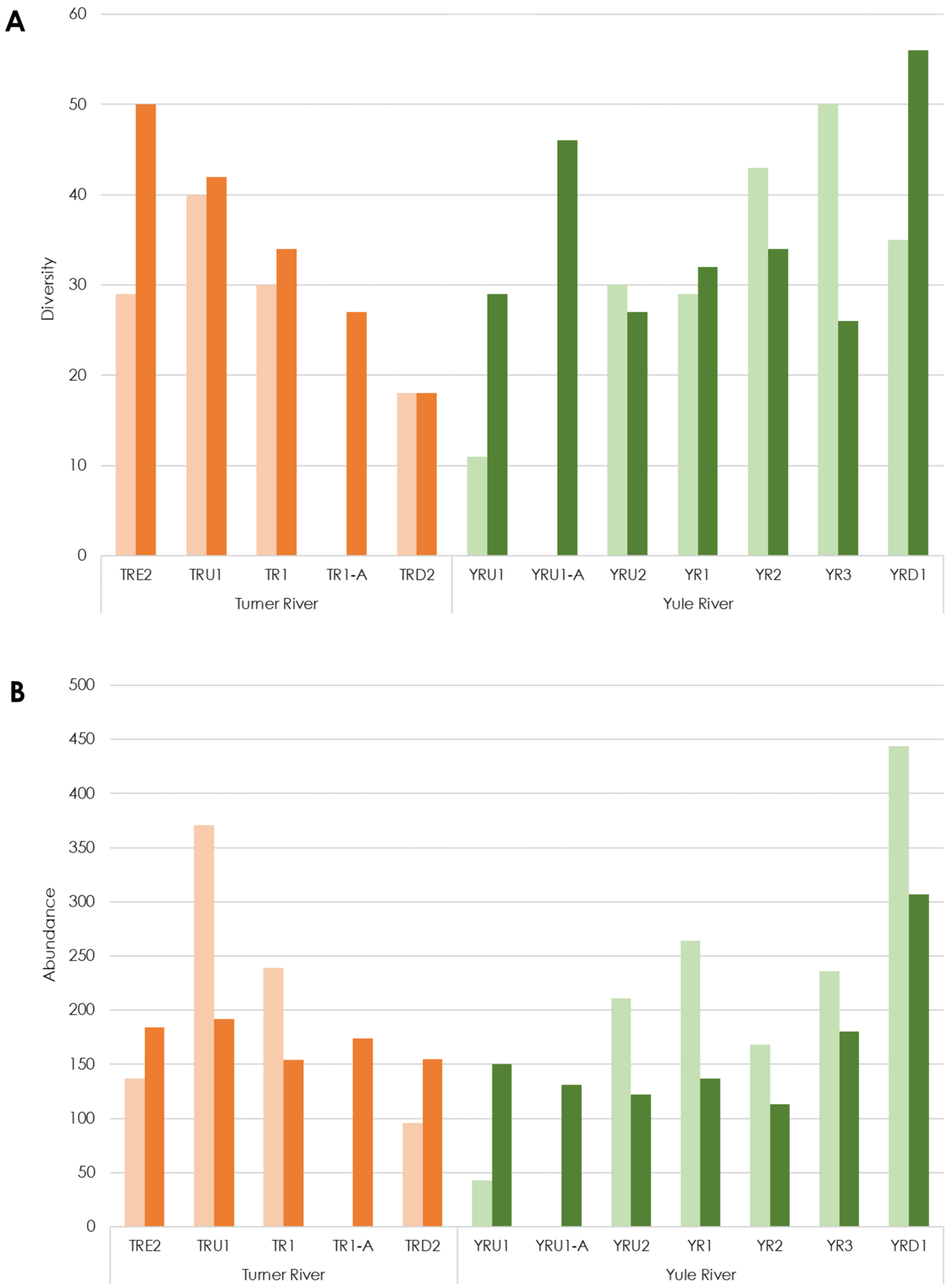


Figure 3-15: Aquatic invertebrate diversity (A) and abundance (B) of Turner and Yule River sites (■■ = dry season, ■■ = wet season) during the Study.

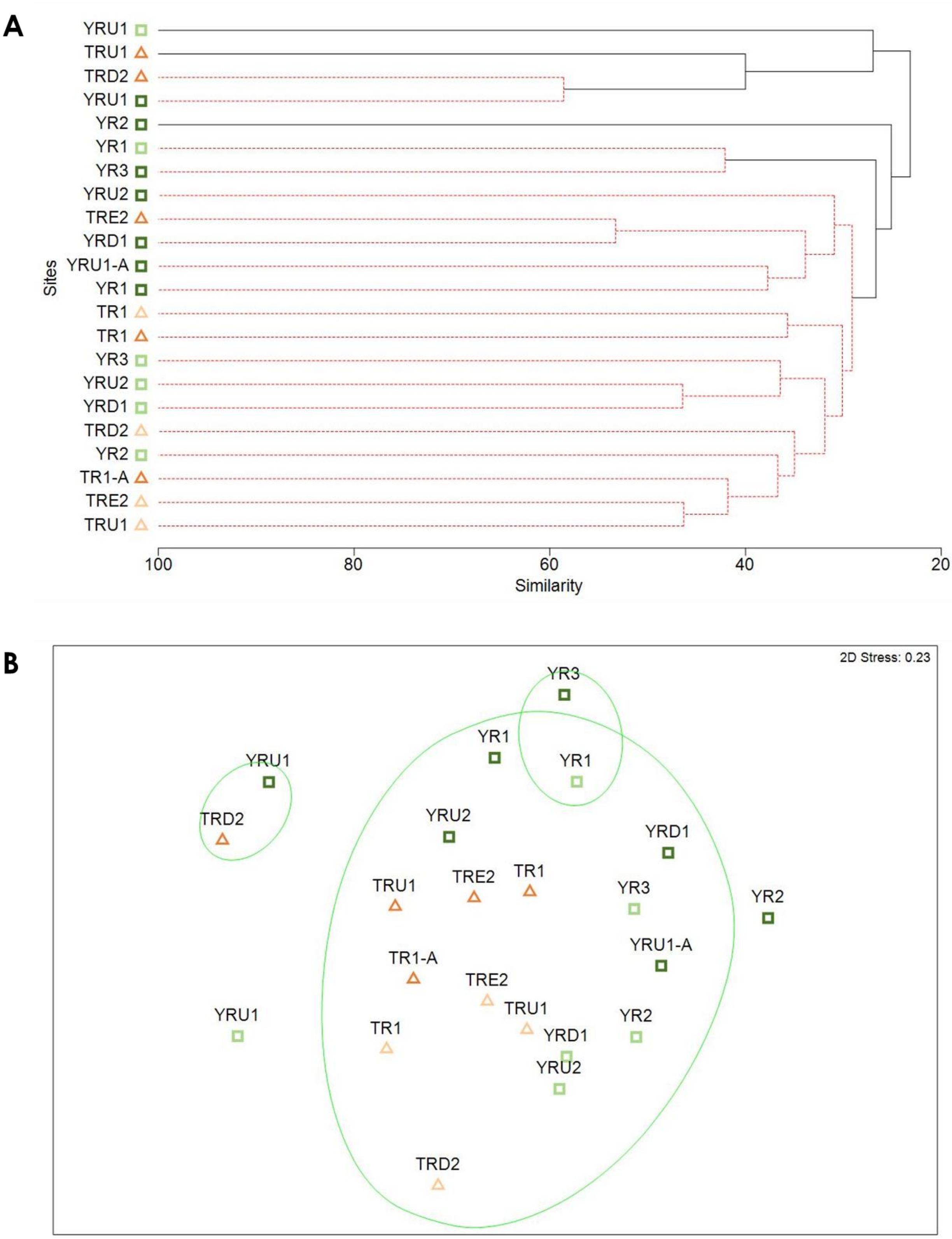


Figure 3-16: (A) Dendrogram and, (B) nMDS (green circles denote significant difference from SIMPROF) analysis, of aquatic invertebrate community structure in the Turner and Yule Rivers during the Study (△ = Turner River wet season, △ = Turner River dry season, □ = Yule River wet season, □ = Yule River dry season).

3.8 Fish

Australia has a relatively depauperate freshwater fish fauna, particularly given its size, likely a reflection of the mostly arid conditions (Allen *et al.* 2002). However, there is a high degree of endemism, particularly in Western Australia (Allen *et al.* 2002; Morgan *et al.* 2014a; Morgan *et al.* 2014b). Some species occur exclusively in freshwater habitats, and others inhabit estuarine or marine environments, while still requiring freshwater for some stage of their life cycle (Allen *et al.* 2002). The importance of permanent pools, particularly with shallow and deep areas, which provide refugia for freshwater and estuarine species in the Pilbara is well known (Beesley and Prince 2010; Braimbridge 2010; Dobbs and Davies 2009; Morgan *et al.* 2009). The influence of groundwater has been identified as a key factor that provides buffering from adverse temperature, salinity and dissolved oxygen levels within these pools (Morgan *et al.* 2009).

A total of 1,090 fish specimens were captured, identified, and released during the Study, representing 14 species. Of these, seven are considered obligate freshwater species, including the Western Rainbowfish (*Melanotaenia australis*), Spangled Perch (*Leiopotherapon unicolor*), Barred Grunter (*Amniataba percoides*), Hyrtll's Tandan (*Neosilurus hyrtlii*), Bony Bream (*Nematalosa erebi*), Empire Gudgeon (*Hypseleotris compressa*) and Indonesian Short-finned Eel (*Anguilla bicolor*) (**Table 3-11**). The remaining seven species, including Banded Scat (*Selenotoca multifasciata*), Tarpon (*Megalops cyprinoides*), Milkfish (*Chanos chanos*), Threadfin Silverbiddy (*Gerres filamentosus*), Common Silverbiddy (*Gerres subfasciatus*), Mangrove Jack (*Lutjanus argentimaculatus*) and Sea Mullet (*Mugil cephalus*) are estuarine/marine (**Table 3-11**). The juveniles of these taxa utilise the freshwater reaches of coastal rivers, before migrating to the ocean to complete their life cycle (Allen *et al.* 2002; Morgan and Gill 2004).

An additional five fish taxa were detected from laboratory analysis of eDNA samples collected during the dry season survey; Crimson Spotted Rainbowfish (*Melanotaenia duboulayi*), Fortescue Grunter (*Leiopotherapon aheneus*), Spangled Perch, Tarpon and Bony Bream (**Appendix A**). Of these taxa, the Crimson Spotted Rainbowfish does not occur in the Pilbara region (Allen *et al.* 2002; Morgan and Gill 2004), with the DNA detected most likely belonging to the closely related Western Rainbowfish *Melanotaenia australis*, which was recorded at all Turner and Yule River sites using traditional sampling methods. Similarly, the Fortescue Grunter, although occurring in the Pilbara region, does not occur in the Turner and Yule River systems (Allen *et al.* 2002; Morgan and Gill 2004). Instead, this species is restricted to the Robe, Fortescue and Ashburton Rivers (Allen *et al.* 2002; Morgan and Gill 2004), with its detection most likely representing DNA of the closely related Spangled Perch (*Leiopotherapon unicolor*). The remaining three species detected (Bony Bream, Spangled Perch and Tarpon) (**Appendix A**), were recorded from both river systems using traditional sampling methods during the Study.

During the Study, fish diversity was variable between sites and seasons, ranging from two (TR1-A in the wet season) to nine (YRD1 in the dry season) species, while no fish were recorded from several sites across both river systems in the wet season (**Table 3-11, Figure 3-17**). Site YRD1 is a permanent, deep waterbody that exhibits habitat heterogeneity (including submerged and emergent macrophytes, large woody debris and overhanging branches and vegetation), and is relatively close to the coast, providing refugia for both freshwater and marine/estuarine vagrant fish species. In contrast, TR1-A was a small shallow pool located further inland with limited in-stream habitat, reflected in the low diversity of fish. In addition, the sites that did not support fish communities (TRU1, YRU1 and YRU2 in the wet season) comprised the smallest pools that had almost completed dried. There was also a notable decline in diversity between the dry and wet seasons, likely due to the prevailing dry conditions and recession of pools, limiting habitat and food availability.

The fish species recorded during the Study mostly comprised common, ubiquitous species with broader distributions throughout the Pilbara and beyond (Allen *et al.* 2002; Morgan *et al.* 2014a; Morgan and Gill 2004; Morgan *et al.* 2014b). The Western Rainbowfish (**Plate 3-2B**) (recorded from all 12 sites), Spangled Perch (**Plate 3-2A**) (11 sites) and Bony Bream (**Plate 3-2C**) (seven sites) are ubiquitous in the region, and are known from all major river systems (Morgan *et al.* 2014a; Morgan *et al.* 2009; Morgan and Gill 2004). The Spangled Perch and Bony Bream are also two of Australia's most widespread fish species, and occur throughout drainages within the Kimberley, Northern Territory, Queensland, Murray-Darling basin and Lake Eyre (Morgan *et al.* 2014b). This is due to their ability to withstand extreme variations in water quality, and their high fecundity, with protracted spawning periods that extend over many months (Allen *et al.* 2002; Morgan and Gill 2004).

Tarpon was the most frequently recorded estuarine fish species during the Study, occurring at all sites except Turner River site TR1-A and Yule River sites YR1 and YR3 (**Table 3-11**). This species is a common inhabitant of large riverine pools in the Pilbara, including the Turner and Yule Rivers, which it utilises as nursery habitat. However, adults of this species are also known to spend lengthy periods in the freshwater reaches of waterways throughout the region (Morgan and Gill 2004).

There was one fish species of conservation significance identified during the Study; the Indonesian short-finned eel, *Anguilla bicolor* (**Plate 3-2D**), recorded from Yule River site YR1 in the wet season (**Table 3-11**). This species is the only representative of the family Anguillidae (freshwater eels) known from Western Australia, and is only known from the Fortescue, De Grey and Yule Rivers in the Pilbara, including a single location upstream of MGP tenure near site YRU1-A (Morgan and Gill 2004). This species has a catadromous life cycle, spending most of its life (typically 20 years or more) in freshwaters, before migrating to the ocean to spawn, dying shortly thereafter (Morgan and Gill 2004). It has a widespread distribution across coastal rivers of the Indo-Pacific region, however, it is listed as Near Threatened on the IUCN Red List of Threatened Species, as it is targeted widely for human consumption and leather products across Asia (Pike *et al.* 2020) Given its broad range, and the limited harvesting of this species locally, *Anguilla bicolor* is considered to be of minor conservation risk in Australia (Shelley *et al.* 2018).

A total of 12 fish species were recorded from the Yule River, which included three species not previously known from the system; Milkfish, Mangrove Jack and Threadfin Silverbiddy (Masini 1988; Morgan *et al.* 2009; Morgan and Gill 2004). In comparison, ten fish species were recorded from the Turner River, comprising five new records for this waterway; Banded Scat, Tarpon, Milkfish, Common Silverbiddy and Mangrove Jack (Masini 1988; Morgan *et al.* 2009; Morgan and Gill 2004). This corresponds to previous surveys of the area, with 13 species known from the Yule River, and six species known from the Turner River (Masini 1988; Morgan *et al.* 2009; Morgan and Gill 2004). Based on this Study, the smaller, shallower pools that have limited habitat within the Turner River support fewer fish species, compared to the more permanent pools of the Yule River, which have a greater diversity of habitat and increased coastal connectivity (**Figure 3-17**; **Table 3-11**).

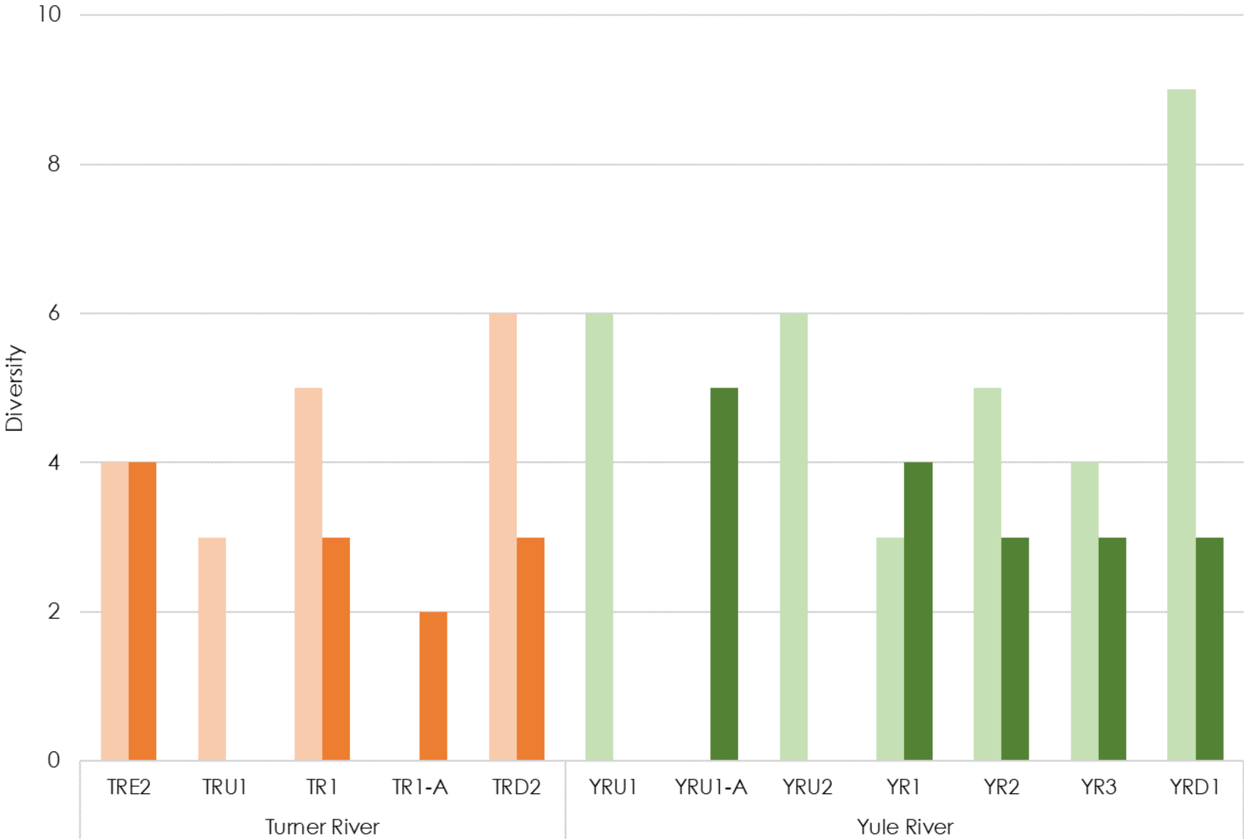


Figure 3-17: Diversity of fish recorded from the Turner and Yule Rivers (■■ = dry season, ■■ = wet season) during the Study.

Table 3-11: Fish species recorded from the Turner and Yule Rivers during the Study, according to freshwater and estuarine/marine ecological preferences.

Fish Species		Dry Season – November 2021										Wet Season - May 2022											
Common Name	Common Name	Turner River				Yule River						Turner River					Yule River						
		TRE2	TRU1	TR1	TRD2	YRU1	YRU2	YR1	YR2	YR3	YRD1	TRE2	TRU1	TR1	TR1-A	TRD2	YRU1	YRU1-A	YRU2	YR1	YR2	YR3	YRD1
Freshwater Species																							
Western Rainbowfish	*Melanotaenia australis*	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			✓	✓			✓		✓		✓	
Spangled Perch	*Leiopotherapon unicolor*	✓	✓	✓		✓	✓		✓	✓	✓	✓		✓	✓			✓		✓	✓		
Barred Grunter	*Amniataba percoides*					✓	✓	✓	✓	✓	✓							✓			✓	✓	
Hyrtl's Tandan (Eel-tailed Catfish)	*Neosilurus hyrtlii*					✓												✓					
Bony Bream	*Nematalosa erebi*	✓		✓	✓	✓		✓	✓		✓	✓									✓	✓	✓
Empire Gudgeon	*Hypseleotris compressa*									✓										✓			✓
Indonesian Short-finned Eel	*Anguilla bicolor*																			✓			
Estuarine/Marine Species																							
Banded Scat	*Selenotoca multifasciata*				✓						✓												
Tarpon	*Megalops cyprinoides*	✓	✓	✓	✓	✓	✓		✓		✓	✓		✓				✓					✓
Milkfish	*Chanos chanos*						✓				✓					✓							
Common Silver-Biddy	*Gerres subfasciatus*				✓																		
Threadfin Silverbiddy	*Gerres filamentosus*			✓	✓		✓				✓												
Mangrove Jack	*Lutjanus argentimaculatus*										✓	✓				✓							
Sea Mullet	*Mugil cephalus*															✓							
	Diversity	**4**	**3**	**5**	**6**	**6**	**6**	**3**	**5**	**4**	**9**	**4**	**0**	**3**	**2**	**3**	**0**	**5**	**0**	**4**	**3**	**3**	**3**

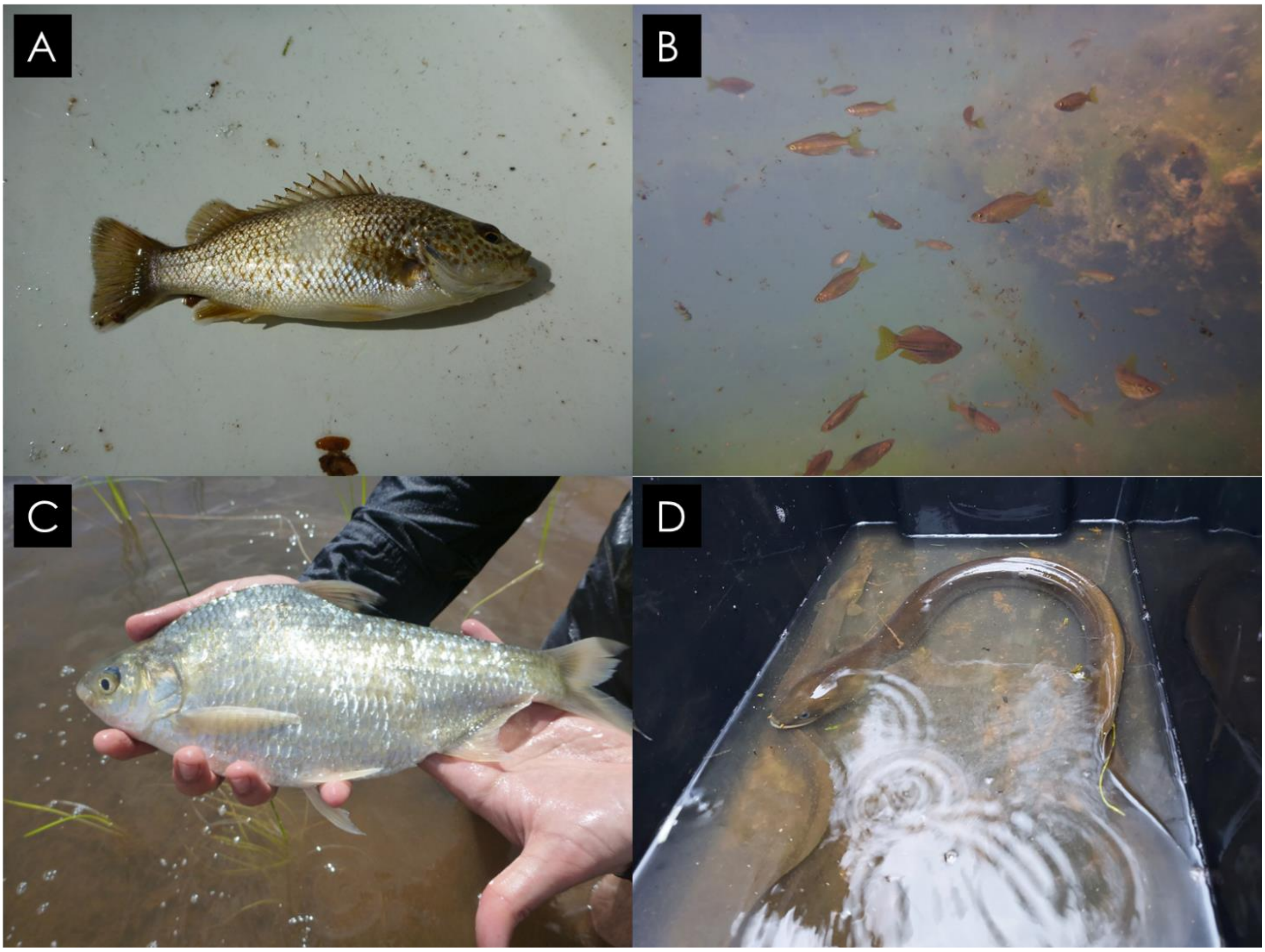


Plate 3-2: Fish species recorded during the Study including (A) Spangled Perch (*Leiopotherapon unicolor*), (B) Western Rainbowfish (*Melanotaenia australis*), (C) Bony Bream (*Nematalosa erebi*), and (D) Indonesian Shortfin Eel (*Anguilla bicolor*).

3.9 Other Vertebrate Fauna

Permanent and semi-permanent pools, which support macrophytes and riparian vegetation, and are influenced by groundwater, are recognised as important habitats for waterbirds, amphibians and reptiles, for foraging, breeding or reproduction, or need a water source for part of their life history stages (Johnstone *et al.* 2013). During the wet season in the arid zone of Western Australia, these vertebrate fauna are often more widely dispersed (Masini 1988), while in the dry season they utilise the remaining isolated as refugia (Masini 1988). These pools can also provide important foraging habitat for mammals, during prolonged dry conditions.

3.9.1 Waterbirds

A total of 13 waterbird species were recorded from the Turner and Yule Rivers during the Study (**Table 3-12**). The majority (12) of these species were recorded via field observations. However, one taxon was detected from eDNA during the dry season; the Black-crowned Night Heron (*Nycticorax nycticorax*), recorded from Turner River site TR1 (**Table 3-12**). Although this species is not known from the Australasian region, the closely related Nankeen Night Heron (*Nycticorax caledonicus*) occurs in the Pilbara region, where it frequents permanent waterbodies and preys on invertebrates, fish, frogs and lizards (Johnstone *et al.* 2013).

The highest diversity of waterbirds was recorded from Yule River site YR3 (five taxa in the dry season, and six taxa in the wet season) (**Table 3-12**). This large permanent pool contained favourable habitat comprising an open area for swimming and diving, shallow areas for wading and foraging, a range of emergent and submerged macrophytes and *Eucalyptus* trees. The remaining sites on both river systems were typically smaller in size or contained fewer habitats, and generally recorded two or less species in both seasons.

The most common and widespread species recorded during the Study was the Black-fronted Dotterel (*Charadrius melanops*), which was observed at three sites in the Turner River (TRU1, TR1 and TR1-A), and three sites in the Yule River (YRU1-A, YR3 and YRD1) (**Table 3-12**). The Black-fronted Dotterel is an ubiquitous species in the Pilbara region, known from lentic and lotic waterbodies including artificial habitats (Bell *et al.* 2014). They are usually seen small numbers (consistent with this Study) or occasionally in small flocks (Storr 1984).

The Black-necked Stork (*Ephippiorhynchus asiaticus australis*), listed as Near Threatened on the IUCN Red List, was from TRD2 during the wet season of the Study (**Table 3-12**, **Plate 3-3A**). This species was formerly rare in the Pilbara and was likely only a vagrant from the Kimberley (Storr 1984). However, in the last 50 years, this species has gradually increased in numbers throughout the region, although records are still largely restricted to the northern and eastern regions of the Pilbara (Johnstone *et al.* 2013). The remaining waterbird species recorded (Eastern Great Egret, White-faced Heron, White-necked Heron, Pacific Black Duck, Australasian Grebe, Wood Duck, Little Pied Cormorant, Australian Pelican and Australasian Darter) are common and widespread, having been previously recorded from the Turner and Yule Rivers (Masini 1988) or more broadly (Johnstone *et al.* 2013).

3.9.2 Reptiles

One species of freshwater turtle was recorded during the Study; the Dinner Plate Turtle *Chelodina steindachneri* (**Plate 3-3B**). This species was recorded exclusively in the Yule River, from sites YRU1 (wet and dry seasons), YRU1-A (wet season) and YR1 (wet season) (**Table 3-12**). This is the only freshwater turtle species known from the Pilbara region, where it is widespread (its distribution also extends to the Gascoyne region), and is not listed as conservation significant (Kuchling 1988). As an arid zone specialist, *Chelodina steindachneri* can survive periods of drought by aestivating for up to three years in moist riverbed sediments (Kuchling 1988). *Chelodina steindachneri* are commonly found within ephemeral creeklines, due to their ability to withstand dry conditions, however, the species also utilises semi-permanent and permanent pools, where they prey on fish, invertebrates and frogs (Kuchling 1988).

The Pilbara Olive Python, *Liasis olivaceus barroni*, is listed as Vulnerable under both the BC Act and the EPBC Act, and has a strong affinity to rocky escarpments and gorges, and is often along watercourses (Wilson and Swan 2010), where they are known to ambush prey such as kangaroos and wallabies (Tutt *et al.* 2004; Tutt *et al.* 2002). While not observed during the Study (or detected from eDNA), this species has previously been observed from several locations along the Turner River (Stantec 2021), including site TR1 (Sarah Thomas, De Grey, pers. comm. 2022). It is also likely that this species utilises the semi-permanent and permanent pools of the Yule River. As the Pilbara Olive Python is primarily nocturnal, its absence during the Study may reflect survey timing and the cryptic nature of the species.

3.9.3 Amphibians

One species of frog was recorded during the Study; the Desert Tree Frog *Litoria rubella* (**Plate 3-3C**), from Turner River site TR1 (**Table 3-12**), which is common and widespread across the arid regions of Australia (Tyler and Doughty 2010). A total of 12 species of frog from two families (Hylidae and Myobatrachidae) are known from the Pilbara region (Tyler and Doughty 2010). However, as the majority of frog species are primarily nocturnal, their absence during the Study is also likely due to survey timing, as well as the prolonged dry conditions.

3.9.4 Mammals

The eDNA results from the dry season of the Study detected the Northern Quoll, *Dasyurus hallucatus*, from Turner River site TR1 (**Table 3-12**). This species is listed as Endangered under both the BC Act and the EPBC Act. In the Pilbara region, the Northern Quoll shows a close association with rocky habitats such as ironstone ridges, basalt mesas, granite outcrops and gorges (DAWE 2017). Additionally, waterholes, such as the rockpools at TR1, provide important foraging habitat (DAWE 2017). Terrestrial fauna surveys associated with the MGP have also recorded Northern Quolls visiting and foraging within the Turner River (Western Wildlife, pers. comm. 2022). The DNA of a second mammalian species; domestic cattle *Bos taurus,* which is ubiquitous across the Pilbara region, was also detected across several pools (**Appendix A**).

Plate 3-3: Vertebrate fauna recorded during the Study including (A) black-necked stork (*Ephippiorhynchus asiaticus australis*) (B), dinner plate turtle (*Chelodina steindachneri*), and (C) desert tree frog (*Litoria rubella*).

Table 3-12: Diversity of reptile, amphibian, waterbird and mammals recorded at Turner and Yule River sites during the Study.

Species		Dry Season - November 2021										Wet Season - May 2022											
Common Name	Scientific Name	Turner River				Yule River						Turner River					Yule River						
		TRE2	TRU1	TR1	TRD2	YRU1	YRU2	YR1	YR2	YR3	YRD1	TRE2	TRU1	TR1	TR1-A	TRD2	YRU1	YRU1-A	YRU2	YR1	YR2	YR3	YRD1
Reptiles																							
Dinner Plate Turtle	*Chelodina steindachneri*					✓											✓	✓		✓			
Frogs																							
Desert Tree Frog	*Litoria rubella*			✓																			
Waterbirds																							
Australasian Darter	*Anhinga melanogaster novaehollandiae*																					✓	
Eastern Great Egret	*Ardea modesta*									✓												✓	✓
White-faced Heron	*Ardea novaeholandiae*												✓	✓				✓		✓		✓	
White-necked Heron	*Ardea pacifica*	✓																					
Pacific Black Duck	*Anas superciliosa*							✓		✓										✓		✓	
Black-fronted Dotterel	*Charadrius melanops*		✓	✓						✓					✓			✓					✓
Wood Duck	*Chenonetta jubata*				✓																		
Black-necked Stork	*Ephippiorhynchus asiaticus australis* NR															✓							
Night Heron	*Nycticorax nycticorax*			✓**																			
Australian Pelican	*Pelecanus conspicillatus*															✓						✓	
Little Pied Cormorant	*Phalacrocorax melanoleucos*									✓													
Australasian Grebe	*Tachybaptus novaehollandiae*																					✓	
Straw-necked Ibis	*Threskiornis spinicollis*									✓													
Mammals																							
Northern Quoll	*Dasyurus hallucatus* END			✓**																			
	Diversity	**1**	**1**	**4**	**1**	**1**	**0**	**1**	**0**	**5**	**0**	**0**	**1**	**1**	**1**	**2**	**1**	**3**	**0**	**3**	**0**	**6**	**2**

Note: NR = Listed as Near Threatened on the IUCN Red List; END = Listed as Endangered under the BC Act and the EPBC Act; ** indicates species was detected from eDNA analysis.

4 Summary

4.1 Key Findings

A summary of the abiotic and biotic characteristics and ecological values of the Turner and Yule Rivers based on the findings of this Study are provided in **Table 4-1**. At the local and regional scale, the larger, more permanent groundwater-fed pools of the Yule River are important within the arid-zone of the Pilbara (Howe and Pritchard 2007). Maintenance of pool size and depth by groundwater limits diurnal and seasonal fluctuations in water quality, buffering aquatic biota from changes in water temperature, dissolved oxygen, and salinity (Loomes and Braimbridge 2010). Water permanency within groundwater-fed pools also provides refuge and migratory routes for fauna, including fish populations that may require freshwater and coastal habitat to complete their life cycles (Morgan et al. 2009).

While the region experienced prolonged dry conditions into the wet season during the Study, typically, these pools would increase in size after rainfall, with rivers flowing and connecting inland freshwater habitat to coastal environments. Increased surface water results in greater habitat availability and favourable water quality, which enhance primary productivity (macrophytes and algae), which support higher order consumers including aquatic invertebrates and vertebrates. While these trends were not observed during this Study due to the prolonged dry conditions, an opportunistic flood study was recently undertaken by Stantec in July 2022 following above average rainfall, the results of which are pending and will be subsequently appended to this technical report.

During this Study, the abiotic characteristics of the pools of the Turner and Yule Rivers were characterised as mostly freshwater (<5,000 µS/cm), although subject to nutrient enrichment from unrestricted livestock access. Increases in salinity were evident due to evapoconcentration, with natural mineralisation of surface waters (Al, As, B, Cu, Zn, and U) and sediments (Cr and Ni) also occurring over the course of the hydroperiod. However, water quality was generally considered favourable, supporting a diverse and abundant biological community in both river systems. In total, the number of taxa recorded comprised nine aquatic macrophytes, 73 phytoplankton, 54 diatoms, 182 aquatic invertebrates,14 fish, 13 waterbirds, and one reptile, one amphibian and one native mammal species, which were recorded from the Turner and Yule Rivers across both seasons.

Where present, macrophyte, algal, invertebrate and fish communities were typically comparable in both waterways, although the Yule River supported a higher species diversity and abundance of aquatic biota. This was associated with the larger, more permant pools, increasing habitat availability and contributing to habitat heterogeneity. In contrast the Turner River pools were typically smaller, with sandy substrates and turbid water. These pools were characterised by opportunistic, transient insect taxa, as well as hardy and adaptable fish species (*Melanotaenia australis* and *Leiopotherapon unicolor*). The majority of macrophyte, algal, invertebrate and vertebrate taxa recorded during the Study are known to have broader distributions throughout the Pilbara and northern-Australia.

Although *Liasis olivaceus barroni* (Pilbara Olive Python), listed as Vulnerable under both the BC Act and the EPBC Act was not recorded during this Study (including via eDNA analysis), the species has previously been observed along the Turner River. The listed vertebrate fauna species *Dasyurus hallucatus* (Northern Quoll) was also detected by eDNA analysis during the Study and is known to forage within the Turner River.

4.2 Aquatic Ecology Values

A summary of the conservation significant fauna records from the Study are provided in **Table 4-1**. In the Turner River, this comprised the Pilbara endemic aquatic beetles; *Sternopriscus pilbaraensis*, *Tiporus tambreyi* and *Laccobius billi*, and in Turner River East, the damselfly *Eurysticta coolawanyah* (**Figure 4-1**). These Pilbara endemics are not listed as threatened and are known to occur more broadly throughout the region. *Ephippiorhynchus asiaticus australis* (Black Stork) was recorded in the downstream reaches of the Turner River, approximately 20 km from the coast and the IUCN listed (Vulnerable).

Extended dry conditions into the wet season caused the pools of the Turner River to contract substantially over the course of the Study. This corresponded to reduced habitat availability and biodiversity, associated with poor water quality conditions (including increased salinity, turbidity, and nutrients), exacerbated by unrestricted livestock access. Based on the lack of conservation significant aquatic biota records (listed under State or Federal legislation), the highly seasonal, semi-permanent pools of the Turner River are considered to be of **low to moderate** ecological value within a regional context.

In comparison, the larger, permanent pools (likely groundwater fed) of the Yule River provided more favourable water quality and a diverse range of structurally complex habitats for aquatic biota. These pools supported the IUCN Vulnerable listed damselfly *Eurysticta coolawanyah* and dragonfly *Hemicordulia koomina* (**Figure 4-1**), as well as the Pilbara endemic aquatic beetles *Tiporus tambreyi* and *Laccobius billi*, hemipteran back swimmer *Anisops nabillus* and the dragonfly *Ictinogomphus dobsoni*. The IUCN listed (Near Threatened) Indonesian short-finned eel, *Anguilla bicolor* (**Figure 4-1**), was also recorded during the wet season of the Study and is only known from the Fortescue, De Grey and Yule Rivers in the Pilbara. As the Yule River provides permanent refuge for aquatic biota, due to the persistence of pools during extended dry periods, ecological values are considered to be **moderate to high** within a regional context.

Table 4-1: Summary of characteristics and ecological values of the Turner and Yule Rivers from the Study (TR=Turner River, TRU=Turner River Upstream, TRD=Turner River Downstream, TRE=Turner River East, YR=Yule River, YRU=Yule River Upstream, YRD=Yule River Downstream).

River System	Hydrology / Habitat	Water Quality	Sediment Quality	Primary Producers	2nd and 3rd Order Consumers	Conservation Significant Taxa	Ecological Value
Turner River and Turner River East	• Semi-permanent pools influenced by rainfall, contracting or drying during low rainfall conditions (except for TR1 due to underlying bedrock). • Limited instream habitat, with smaller pools characterised by sandy substrate, absence of submerged macrophytes and turbid water.	• Moderately to strongly alkaline pH. • Freshwater (<5,000µS/cm) except for TR1 and TRD2 (>5,000µs/cm). • Elevated nutrients (TN & TP) due to unrestricted livestock access. • Generally low metals except for some minor exceedances of ANZG (2018) GV for Al, As, B, Cu, Zn, and U across sites. • Similar water quality results across seasons, due to low rainfall conditions.	• Circumneutral to strongly alkaline pH. • Generally low salinity, low nutrients and low metals. • Ni slightly above ANZG (2018) GV for TR1-A.	• 6 macrophyte taxa, 58 phytoplankton taxa and 42 diatom taxa. • All have a Pilbara wide, or more cosmopolitan distribution. • Limited primary productivity in receding pools of Turner River.	• 116 aquatic aquatic invertebrate taxa (including insects with high dispersal capabilities). • 10 fish species (5 new records; Banded Scat, Tarpon, Milkfish, Common Silverbiddy and Mangrove Jack). • 7 waterbird species (one from eDNA analysis). • 1 frog and 1 mammal species (from eDNA analysis). • Most species with a common and widespread distribution across the Pilbara and Northern Australia.	• **Pilbara Endemics:** o *Sternopriscus pilbaraensis* (aquatic beetle) (TRU1) o *Laccobius billi* (aquatic beetle) (TRE2, TRU1, TR1) o *Tiporus tambreyi* (aquatic beetle) (TRU1, TR1) • **BC Act/EPBC Act Endangered:** o *Dasyurus hallucatus* (Northern Quoll) (TR1; eDNA sampling) • **IUCN Red List Vulnerable:** o *Eurysticta coolawanyah* (damselfly) (Turner River East; TRE2) • **IUCN Red List Near Threatened:** o *Ephippiorhynchus asiaticus australis* (Black Stork) (TRD2)	**Low to Moderate** *Justification: small, isolated pools with less habitat complexity and no listed aquatic biota.*
Yule River	• Larger permanent, groundwater fed pools (except YRU1 and YRU2 that are semi-permanent). • Predominantly on substrate with minimal seasonal variation in pool size and depth (between wet and dry season). • Complex instream habitats (macrophytes, undercut banks, woody debris, detritus and overhanging trees), characterised by silt-clay substrate, dense macrophytes and increased water clarity.	• Circumneutral to strongly alkaline pH. • Freshwater (<5,000µS/cm) except for YRU1 (>8,000µs/cm). • Elevated nutrients (TN & TP) due to unrestricted livestock access. • Generally low metals except for some minor exceedances of ANZG (2018) GV for B, Cu, Zn, and U across sites. • Similar water quality across seasons, due to low rainfall conditions.	• Circumneutral to strongly alkaline pH. • Generally low salinity, nutrients and metals levels. • Cr slightly above ANZG (2018) GV for YR3. • Ni above ANZG (2018) GV for several sites and above GV-High for YR3	• 9 macrophyte taxa, 55 phytoplankton taxa, 45 diatom taxa • All have a Pilbara wide, or more cosmopolitan distribution. • *Cyperus vaginatus* only recorded from permanent pools on the Yule River. • Primary productivity generally higher and more diverse.	• 159 aquatic invertebrate taxa (including insects with high dispersal capabilities). • 12 fish species (high diversity due to large pools and 3 new records; Milkfish, Mangrove Jack and Threadfin Silverbiddy). • 9 waterbird species and one reptile species. • Most species with a common and widespread distribution across the Pilbara and Northern Australia.	• **Pilbara Endemics:** o *Tiporus tambreyi* (aquatic beetle) (YR3) o *Laccobius billi* (aquatic beetle) (YRU1-A) o *Anisops nabillus* (hemipteran back swimmer) (YR3, YRD1) o *Ictinogomphus dobsoni* (dragonfly) (YR2, YRD1) • **IUCN Red List Vulnerable:** o *Eurysticta coolawanyah* (damselfly) (YRU1-A, YRD1) o *Hemicordulia koomina* (dragonfly) (YR3) • **IUCN Red List Near Threatened:** • *Anguilla bicolor* (Indonesian short-finned eel) (YR1)	**Moderate to High** *Justification: large, groundwater fed permanent pools with structurally complex habitats supporting listed aquatic biota.*

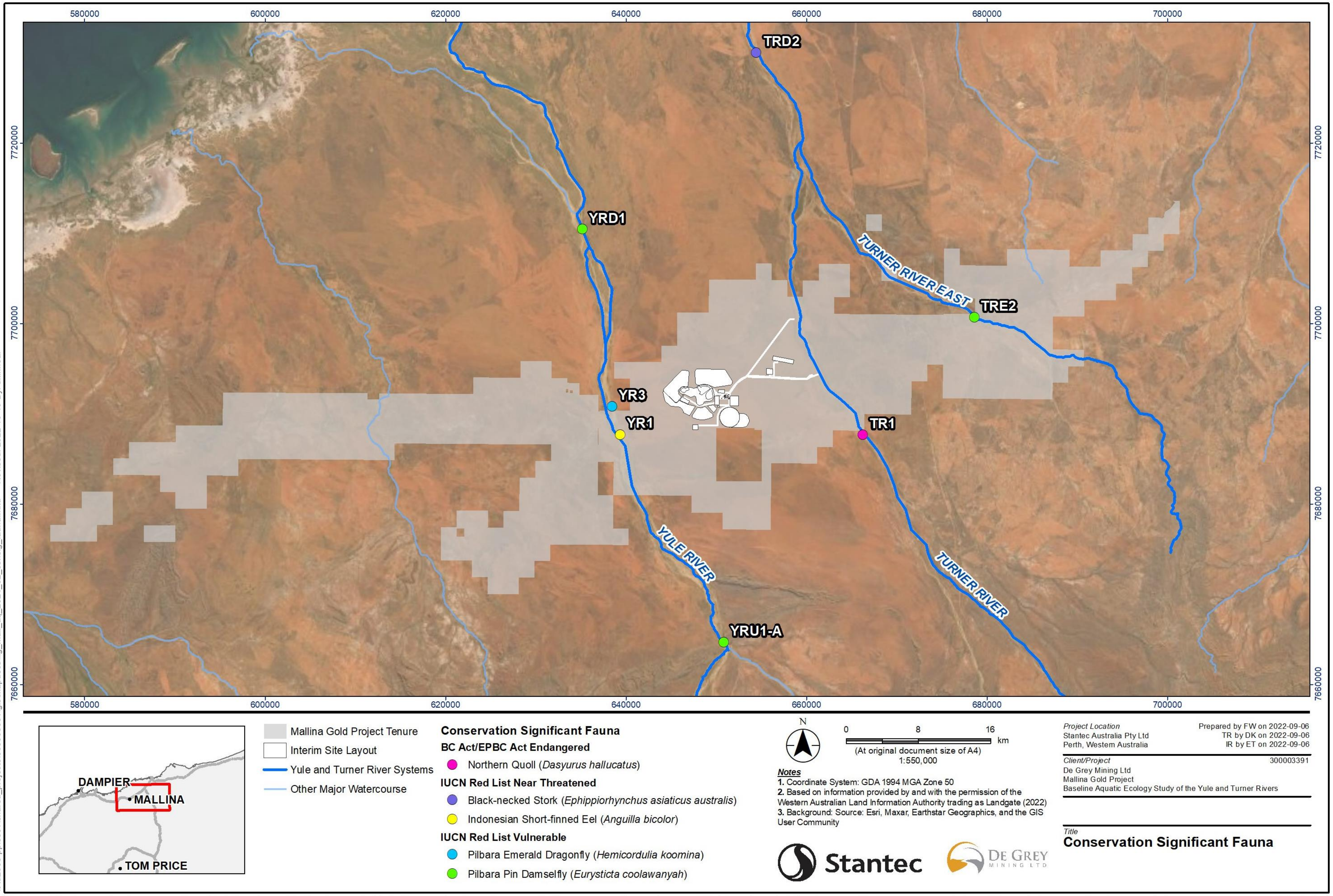


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Figure 4-1: Listed conservation significant records for the Turner and Yule Rivers, based on the results of the Study.

5 Impact Assessment and Considerations

Pilbara river systems support aquatic habitats ranging from semi-permanent to permanent pools, with extensive reaches in between that can be subject to lengthy dry periods, only flowing only after substantial rainfall. The proposed discharge from the MGP to the Turner River will cause a shift from seasonal flows to a permanent hydrological regime, with the following modelled characteristics predicted:

- Downstream extent from the discharge outfall of approximately 45 km and typically 40 m wide (with a maximum of 150 m wide in some areas of the river);
- Depth mostly approximating 20 cm or less, although deeper areas (up to 1.3 m) may occur where water naturally pools; and
- Total surface area (predicted maximum) of approximately 225 ha.

The discharge is expected to create additional aquatic habitat that favours resident fauna or species adapted to perennial flows, resulting in a change in the dominant biological communities during the temporary discharge period (three years). However, it is considered highly unlikely that any species will be lost from the Turner River, given the broader distribution of the aquatic biota taxa recorded during the Study. These taxa are typically known to occur in waterbodies throughout the Pilbara region and have the ability to actively disperse and recolonise newly created flows or pools.

Additionally, the aquatic biota inhabiting these waterways are inherently resilient, due to the highly variable hydrological regimes and fluctuating water quality conditions that are typical of the Pilbara region. In the Turner River, this will enable aquatic biota to persist and adapt to any temporary perturbation from proposed discharge and/or drawdown associated with the development of the MGP. The artificial habitat created by the discharge is also relatively common throughout waterways in the Pilbara, associated with iron ore operations.

Based on the findings of this Study, the Yule River exhibits comparatively higher ecological values than the Turner River and was characterised by sizable, groundwater fed, permanent pools that supported three IUCN listed aquatic biota taxa. In contrast, and in response to the dry conditions that extended into the wet season survey, the pools of the Turner River were smaller, isolated and more turbid, supporting a lower biodiversity (and no listed aquatic biota), which was of low to moderate ecological value.

A preliminary impact assessment and considerations for the management and mitigation of the MGP, specific to the Turner and Yule Rivers is as follows:

- Construction activities will not extend to the Yule River. Drawdown from dewatering and based on hydrogeological modelling, is also not expected to influence the Yule River or the permanent pools that it supports. Drawdown is likely to be constrained to the eastern and western boundaries of the resource and there are no predicted impacts (**negligible risk**) to the permanent pools of this system.
- It is likely that several options will be implemented to manage surplus water on site during development of the MGP, including aquifer re-injection, and re-use (where possible), in conjunction with a requirement for environmental discharge.
- The Turner River, based on hydrological modelling, has substantial storage capacity, and can accommodate the proposed volume and rates of discharge water over the temporary period. It is expected that a higher rate of discharge (up to 45 ML/day) will be required during the first three years, prior to the site becoming operational, after which surplus water will decrease substantially (up to 10 ML/day).
- Where required and prior to environmental discharge, water should be subject to pre-treatment, or allow for natural attenuation within retention ponds, to ensure water quality is within acceptable limits and does not pose a risk to aquatic biota. The discharge schedule from surficial and deeper bedrock aquifers may also require manipulation to ensure the standard of water quality discharge to the environment is maintained.
- The discharge outfall should be located within the main channel of the river that is typically subject to high velocity flows during the wet season. The outfall should also be designed and engineered to avoid erosion of riverbanks and beds, dissipating the energy of the flow within the channel.
- The discharge water should be adequately contained within the river channel, avoiding inundation of sensitive riparian vegetation communities that are not subject to a permanent hydrological regime.
- Due to the sensitivity of these communities to changing groundwater levels, a staged reduction in discharge may be required over a longer period, prior to complete cessation, allowing riparian vegetation to adapt.
- Development of an ongoing, robust ecological monitoring program to determine potential changes in ecological values associated with the proposed discharge should be implemented, with potential threshold and trigger criteria (following regulatory guidance), providing comparison to this Study during operations.

It is expected that after the completion of technical documents comprising the opportunistic flood study, hydrological modelling, and hydrogeological characterisation, Stantec will undertake a comprehensive discharge assessment, to determine the quantitative risk to sensitive biological receptors from proposed discharge and drawdown for the MGP. However, the results of this Study indicate that due to the temporary nature of potential impacts, inherent resilience of aquatic biota, and limited conservation significant records from the Turner River, with adequate mitigation and management, the **preliminary risk to aquatic biota from proposed discharge is low**.

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Appendices

We design with community in mind

Appendix A eDNA Analysis Results

Species	Common Name	TR1 (Red Rock Rockpool)		TR1 (River Pools)	TRU1	YRU2
		Filtered	Passive	Filtered	Filtered	Filtered
Fish						
*Melanotaenia dubouIayi**	Rainbowfish			✓	✓	✓
*Leiopotherapon aheneus**	Fortescue Grunter					✓
Leiopotherapon unicolor	Spangled Perch	✓		✓	✓	✓
Nematolosa erebi	Bony Bream			✓		
Megalops cyprinoides	Tarpon				✓	
Birds						
*Nycticorax nycticorax**	Night Heron			✓		
Eolophus roseicapilla	Galah				✓	
Mammals						
Bos taurus	Domestic Cattle			✓		✓
Dasyurus hallucatus ENDANGERED	Northern Quoll		✓			

Note: *indicates taxa not known to occur in the local area; these records likely represent closely related species which are known to occur in the region.

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