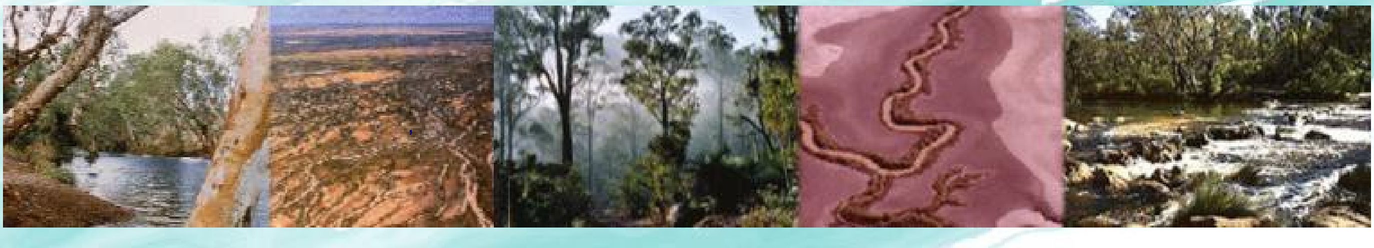

A member of the Rio Tinto Group

River Pool Ecosystem Study
April 2017

Report ST5/2017

Streamtec Pty Ltd

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1. SUMMARY

An annual biophysical/ ecological survey of the Robe River (the Pilbara region of north-western Australia) was conducted in April 2017, as on-going commitment to assess environmental impacts of mine development at Mesa J on the adjacent and downstream aquatic ecosystem of the river (largely the permanent, 'refugial' pools). The aquatic monitoring program was undertaken by *Streamtec Pty Ltd* and commissioned by Rio Tinto (RTIO). This assessment has been conducted annually since 1991 (*i.e.* before mining at Mesa J). This sampling addresses specific commitments made under the (then) Western Australian Minister for the Environment (see Conditions, 7.2.3, 7.2.4, 7.2.5 and 7.2.7) and later under *Ministerial Statement MS208* (see Conditions 3, 4 and 5).

The long-term biophysical/ ecological surveys of the Robe River are an integrated , long-term assessment of environmental parameters including aquatic fauna (*i.e.* aquatic macroinvertebrates and fish), channel/pool morphology, riparian/bank condition, weeds, water flows and water quality.

The significant value of this program is in its long-term commitment to assess impacts, if any, of mining and evaluate these in the context of extreme natural events which typically have a long-term return frequency (*e.g.* prolonged dry-spells, tropical cyclones). The study is an upstream-downstream design, where upstream sites (those from Mesa J) serve as controls for 'impact' sites occurring in the pools downstream from Mesa J. This study has been nominated as a Global Long Term Ecological Research (LTER) site[1] where sampling design/methodology have been consistent over the near-thirty year duration of the program.

The current survey conducted April 2017 is consistent with the framework outlined by previous findings that changes in ecological conditions of the pools, are primarily the result of seasonal and annual variation in rainfall and subsequent river flows with extreme natural events (and dry spells) providing the overarching ecological 'framing' context. The April 2017 sampling was conducted following the 'wet season'. In this survey, although water levels were elevated and 13 pools were located. Additional pools were located with assistance of two local Indigenous Elders accompanying the sampling trip.

In April 2017, the pools sampled were: Martangkuna ('Permanent Pool'), Pulari Nyunangka ('Duck Pool'), Japanese Pool, Medawandy Waters, Pannawonica Hill Pool, Thintuoona[2], 'Cams Pool', Pirathalu, Gungaree[2], Ngalooin ('Mussel Pool'), Yarramudda, Gnieraoora ('Yeera Bluff') and Robe Pool[2]. Although pool water levels were low, there were measurable flows at Pannawonica Hill, Pulari Nyunangka, Yarramudda, Gungaree, Martangkuna, Cams Pool and Medawandy Waters. However, the rate of these flows was low generally at between 0.25m^3/s and 1m^3/s.

Fixed station underwater cameras were trialed for the fish surveys and found to be largely unsuitable due to the inherent high turbidity of the water. Acoustic cameras will be further tested as a technique suitable for highly turbid water (note, these camera can record at night). Additional techniques to be trialed include assessing the value of environmental DNA (e-DNA) and the required genetic 'fingerprinting' of fish. If this technique proves suitable, it will only require a pool-water sample to determine the fish present.

Detailed statistical (*e.g.* aquatic fauna) and qualitative analyses (*e.g.* of riparian condition) of April 2017 data showed there have been no statistically significant or qualitatively detectable changes to the aquatic ecology/ environmental conditions of the Robe River pools adjacent and downstream to Mesa J that could be attributable to mining and its attendant operations alone. This annual assessment is consistent with previous analyses (1991-2017) where extreme natural events (*e.g.* tropical cyclones and extended dry spells) determine the structure of pool morphology, riparian condition and consequently the pool ecological assemblages.

1. The Long Term Ecological Research (LTER) Network was created by the US National Science Foundation in 1980.
2. Signifies a newly-sampled pool in 2017. Robe Pool was visited, but not sampled due to cultural sensitivities.

Field sampling the focal Robe River pools emphasised the prior influence of wet periods on pool biodiversity; with most of the fish observed being juvenile presumably as the pools were re-colonised following hydrological re-connection. The number of aquatic macroinvertebrate species collected during April 2016 (67 taxa= 'species') was low when compared across the long-term data record. At the individual pool level, macroinvertebrate species diversity ranged from 33 species at Pannawonica Hill Pool to 40 species at Pirathalu. A total of seven species of fish were observed (Spangled Perch, Barred Grunter, Bony Bream, Fortescue Grunter, Rainbowfish, Eel-tailed Catfish and Freshwater Mullet). The dominant species observed were Bony Bream (*Nematalosa erebi*), Rainbowfish (*Melanotaenia splendida australis*) and a highly-regional endemic, the Fortescue Grunter (*Leiopotherapon aheneus*).

The water chemistry of the pools was of high biological quality with the exceedances of ANZECC (2002) Trigger Levels limited to turbidity and a small elevation of total phosphorus (0.02mg/L *vs.* ANZECC/ARMCANZ Trigger Value 0.01mg/L) at Pirathalu. This small increase over the trigger values for nutrients is considered a consequence of unrestricted livestock access to the pool. Dissolved oxygen levels were low; a consequence of high water temperatures (29-31^{O}C). Salinity/conductivity showed a gradient of increasing concentration downstream (*e.g.* 571µs/cm at Ngalooin to 996µs/cm at Thintuoona; near the railway crossing). This gradient is considered a function of the underlying geology. Pool turbidity was highly variable ranging from 2.7NTU at Martangkuna to approaching 30NTU at Gnieraoora.

Vegetation condition of the riparian zones was good and the riparian weed Mexican Poppy which, in the past, has been common was recorded at low levels of infestation in 2017, both upstream and downstream of Mesa J. The emergent aquatic weed (Indian Fern) was observed at some sites (*e.g.* Yarramudda where it occupied a small area of ~2.5m^2). Both weeds can be spread directly by human activities. The bulrush *Typha* was common at many sites and dominated the shorelines at Yarramudda.

The re-sampling of the pools in April 2017 followed significant rainfall and river flows during December 2016/ January 2017. Consequently, the ecological condition of the pools has shown a level of recovery reflecting the ability of fauna, particularly fish, to re-colonise the previously dry reaches of the river. Therefore, any artificial barriers to migration (*e.g.* badly-placed culverts) have the potential to limit upstream fish movement; however during high flows most culverts are generally 'drowned-out' (*e.g.* the low level crossing at Mesa J) and not considered to represent a significant obstacle to migration.

TABLE OF CONTENTS

1. **SUMMARY** ... 3
TABLE OF CONTENTS ... 5
2. **STUDY CONTEXT** ... 6
3. **INTRODUCTION** ... 8
4. **METHODS** ... 9
4.1 SAMPLING PERIOD ... 9
4.2 STUDY AREA ... 9
4.3 STUDY SITES ... 11
4.4 HYDROLOGY - RAINFALL AND RIVER DISCHARGE ... 11
4.5 PHYSICO-CHEMISTRY - MORPHOLOGY AND WATER QUALITY ... 11
4.6 MACROINVERTEBRATE FAUNA ... 12
4.7 FISH FAUNA ... 12
4.8 RIPARIAN VEGETATION AND WEEDS ... 12
4.9 STATISTICAL ANALYSES ... 12
5. **RESULTS AND DISCUSSION** ... 13
5.1 HYDROLOGY - RAINFALL AND RIVER DISCHARGE ... 13
5.2 CLIMATE ... 14
5.3 SUMMARY OF FLOW CONDITIONS ... 17
5.4 PHYSICO-CHEMISTRY ... 19
5.5 MINE DEWATERING ... 19
5.6 POOL MORPHOLOGY AND SEDIMENTATION ... 19
5.7 TURBIDITY ... 24
5.8 SALINITY ... 24
5.9 DISSOLVED OXYGEN ... 24
5.10 WATER TEMPERATURE ... 25
5.11 NUTRIENTS ... 25
5.12 MACROINVERTEBRATE FAUNA ... 25
5.13 TEMPORAL VARIATION ... 27
5.16 FISH FAUNA ... 28
5.17 RIPARIAN VEGETATION ... 31
5.18 REGIONAL ASSESSMENT ... 31
6. **CONCLUSIONS** ... 31
7. **REFERENCES** ... 32
8. **APPENDICES** ... 35
APPENDIX 1. POSITION OF STUDY SITES SAMPLED IN THE ROBE RIVER ... 36
APPENDIX 2. SAMPLING METHODS (BASED ON ANZECC 2000 GUIDELINES ... 38
WATER QUALITY ... 38
CHANNEL MORPHOLOGY ... 39
VEHICLE DISTURBANCE ... 39
STATISTICAL ANALYSES: PRIMER ... 40
APPENDIX 3. ANZECC/ARMCANZ (2002) GUIDELINES ... 41

2. STUDY CONTEXT

This study addresses important Ministerial Requirements and environmental commitments related to management of mining and associated activities of RTIO largely at Mesa J.

The initial Mesa J- Environmental Management Program outlined in a Consultative Environmental Review (CER) (Robe River Iron Assoc. 1992). Section 5.1 outlined a requirement for a monitoring program of key permanent river pools adjacent to Mesa J (see Streamtec 1991) both upstream and downstream of operations at Mesa J. In this design, the upstream sites serve as controls. The parameters measured in these pools by Streamtec (1992), (turbidity, salinity/ conductivity, depth, pH, dissolved oxygen, nutrients, water temperature and aquatic fauna) formed the basis of all subsequent monitoring and environmental assessments. The sampling from 1992 (Streamtec 1991-2016) addressed the following Environmental Commitments of the CER:

7.1.1 Develop and implement environmental monitoring and management programs for the mining operation and associated activities in the course of the project implementation.

7.1.4 Minimise as far as practicable, recognising the requirements of the mining and ore transfer, direct and indirect alteration of the physical environment for the duration of the project.

7.1.7 Monitor and manage dewatering of the mining area, and discharge of excess water to adjacent watercourses.

7.1.8 Take appropriate steps to protect and manage hydrology and vegetation within the adjacent riverine environment.

7.1.9 Monitor and manage any scour or siltation in the Robe River and Jimmawurrada Creek adjacent to the project.

Following the acceptance of the CER (Robe River Iron Assoc. 1992), the conditions set by the (then) Minister for the Environment were addressed by the monitoring program (Streamtec 1991-2016) where:

7.2.3 Environmentally Significant Areas: "The Robe River- Jimmawurrada Creek environment, its vegetation, water levels and water quality, and particularly the permanent pools of the Robe River, are to be protected from unacceptable direct and indirect impacts of this project during the life of the project, recognising the requirements of mining and ore transport."

7.2.4 Drainage Management: "The Robe River- Jimmawurrada Creek system needs to be protected from pollution and unacceptable sedimentation, recognising the requirements of mining and ore transport".

7.2.5 Dewatering Management: "The permanent pools and vegetation of the Robe River- Jimmawurrada Creek system are to be protected from unacceptable environmental impacts, recognising the requirements of mining and ore transport".

7.2.7 Environmental Management Programme: "A comprehensive management programme should be prepared to integrate the various components in conditions" (e.g. 7.2.3, 7.2.4, 7.2.5).

Key Project Approvals addressed by this monitoring program are under Part IV of the Environmental Protection Act 1986: Mesa J- Ministerial Statement 208.

Rio Tinto produced an Operations Environmental Management Plan (RTIO-HSE 0162720:2012). Sections 4.1 and 4.2 relate to water abstraction and discharge. Appendix 1 of that document outlines the comprehensive monitoring program developed for the Robe River.

The Rio Tinto "*Robe Valley Mesa J&K Surface Water Management Plan*" (RTIO-PDE-0068650, see http://iodms/iodms/wdk/theme/documentum/images/space.gif) outlines a framework for effective water management. The potential environmental impacts of climate change in the Pilbara were also identified as a potential risk. The long-term Streamtec study, by providing an extensive time-series (1991-2017), is clearly well-placed to assess impacts to surface water ecosystems, from both mining, natural and larger-scale anthropogenic influences (*e.g.* climate change). In addition, by including control sites (*i.e.* upstream of Mesa J in the program), any changes to ecological baselines, in the absence of mining, can be determined and consequently better-managed.

3. INTRODUCTION

The current program outlined in this report (conducted during April 2017) was commissioned by Rio Tinto (RTIO) to assess impacts, if any, from their mining activities on Robe River pools as per relevant Western Australian Ministerial Statements (see previous). This on-ground program incorporates an annual aquatic ecosystem survey of Robe River pools as part of an on-going commitment to assess any environmental impacts of mine development on the adjacent and downstream aquatic ecosystem (see ecologia/Streamtec 1992, Streamtec 1992 –2017).

The Robe River is situated in the Pilbara bioregion of Western Australia. Rivers and streams in this region are typically episodic with flow occurring following significant rainfall events. The Pilbara has an extreme and highly variable climate changing due to both natural and more recently, through global anthropogenic influences.

In the Pilbara, rainfall has recently been steadily increasing from the northeast and evaporation rates exceed rainfall by a factor of more than 10x. Following rainfall, generally there is only limited run-off and an even smaller fraction recharges groundwater. Despite this, groundwater recharge is required to maintain pool water levels during extensive dry periods. In the Pilbara, it is estimated that about 200GL of (high quality) de-watering is discharged into rivers each year (McFarlane 2015).

During the dry season, rivers are usually restricted to a series of permanent pools; providing an important refuge for both terrestrial and aquatic fauna. The faunal assemblages essentially 'contract' to these pools during dry periods, to re-invade other regions of the riverine system following significant river flow.

Research on the freshwater fauna of Australia's dryland river systems has been largely ad hoc. These systems are typically less disturbed than their counterparts in more populous regions, yet despite recognition of the importance of water-bodies in the Pilbara; there has been only short-term, generally limited scope ecological research.

The current sampling regime was initiated in 1991 offering an important set of data on an arid system within the Pilbara region. The annual assessment is important in providing knowledge of temporal and spatial variability in biological parameters. In addition to providing a better understanding of impacts, if any, associated with mining operations, long-term ecological monitoring improves our understanding of the natural variability (e.g. extended dry spells, tropical cyclones) within the Robe River catchment. This long-term assessment of the aquatic environment of the Robe River has shown natural events have an overriding influence.

To date there have been no detectable changes to aquatic fauna, water levels, water quality and riparian vegetation that could be attributed to direct mining operations at Mesa J. In addition, there have been no detectable impacts to the Robe River/Jimmawurrada Creek system from pollution, unacceptable sedimentation and unacceptable environmental impacts that could be attributed to direct mining operations at Mesa J.

Differences in ecological parameters of pools, is primarily influenced by seasonal climatic influences, with a major determinant factor of variability in both aquatic fauna biodiversity and water quality being pool morphology and permanence (*e.g.* Streamtec 1992-2015). This existing baseline data, combined with continued monitoring of the Robe River, will allow informed solutions to be made on current and future environmental issues and catchment-scale activities.

PROJECT OBJECTIVES

- The completion of an aquatic biomonitoring program (*e.g.* macroinvertebrates, fish, water quality, flows, pool morphology and riparian condition) of significant pools located on the Robe River. Sample sites included thirteen permanent pools (see Appendix 1).
- In order to gain a better understanding of broad-scale ecosystem resilience of the pools, a survey of the Robe River was conducted to identify additional permanent pools (both upstream and downstream from Mesa J).
- Document and interpret the ecological significance of patterns or differences in pools both upstream and downstream of Mesa J.
- Compare biological data collected in 2017 with the previous record and assess any observed changes to natural events in or mining activities.

4. METHODS

Since the commencement of this sampling program (1991), sampling design and methodology have been standardised (with the same operators) and consistent among surveys. This enables valid comparisons to be made across the long-term monitoring period. Consequently the strength of this sampling program is its long- term nature. A summary and general description of the standard sampling protocol is given below. Detailed information on sampling in Appendix 2 and outlined in previous reports (see Streamtec 1991- 2015).

4.1 SAMPLING PERIOD

The present survey taken in April 2017 represents an "early wet" sampling; a period of reduced environmental 'stress' for resident aquatic biota. During this period, aquatic fauna is restricted to refugial pools after flows in December 2016. Previous monitoring has also been conducted following the 'dry season and other high rainfall events, providing a database across a wide range of flow and weather conditions.

4.2 STUDY AREA

The Robe River lies in the Pilbara biogeographic region of Western Australia. For the majority of its course, the Robe River is ephemeral in flow with wide, shallow floodplains. Localised flows and pools are maintained where highly permeable underground aquifers intersect surface river channels; forming isolated ecological 'refugia' (see Figure 1).

The climate of this region is typified by high temperatures, low rainfall (~ 400mm p/a), evaporation rates about 10x rainfall and largely unpredictable cyclonic activity. Rainfall occurs largely between December and June with maximum monthly falls typically recorded between December and April. Mining is near to the rivers course, at the Mesa J deposit, in the Eastern Deepdale region to the south-west of Pannawonica.

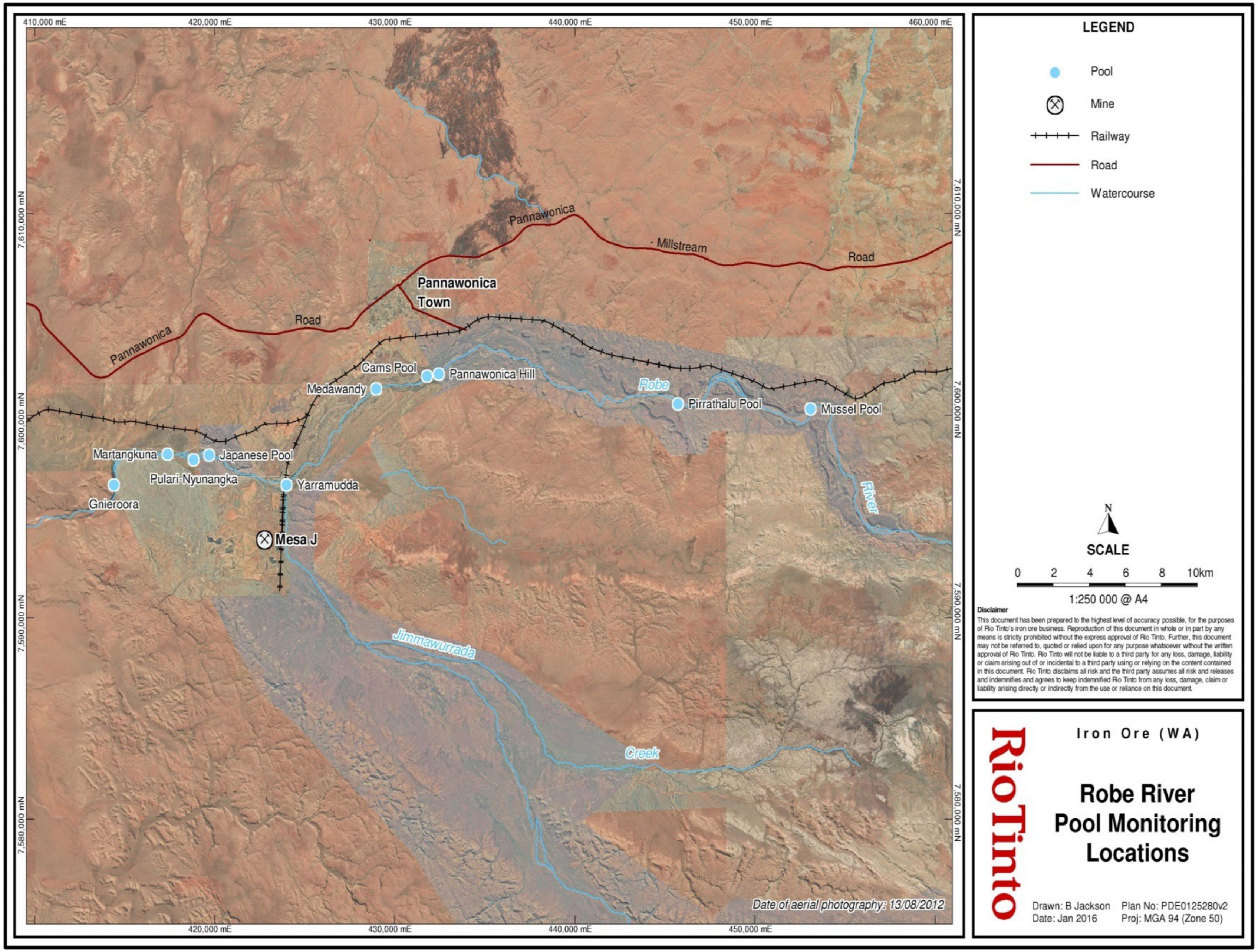


Figure 1. Position of the survey pools in the Robe River (note alternative spellings for Yeera Bluff Pool; Gnieraoora and Gnieroora). Note, Robe Pool, Thintuoona and Gungaree are off the scale of this map being further downstream (west) of these sites (see Appendix 1 for site details and coordinates).

4.3 STUDY SITES

The location of current study sites and their position relative to the Mesa J mine are shown in Figure 1. A total of thirteen focal pools were surveyed in 2017; Martangkuna ('Permanent Pool'), Pulari Nyunangka ('Duck Pool'), Japanese Pool, Medawandy Waters, Pannawonica Hill Pool, Thintuoona*, 'Cams Pool', Pirathalu, Gungaree*, Ngalooin ('Mussel Pool'), Yarramudda, Gnieraoora ('Yeera Bluff'), Robe Pool*. Although pool water levels were low, there were measurable flows at Pannawonica Hill, Pulari Nyunangka, Yarramudda, Gungaree, Martangkuna, Cams Pool and Medawandy Waters. (See Appendix 1, * represents a previously un-sampled pool).

The program's design is based on a BACI model (Before and After Control Impact) where sites upstream of Mesa J serve as control sites for downstream (potential impact) pools. The "before" sampling is represented by baseline surveys conducted in 1991, prior to significant mining operations at Mesa J.

Neither 'before' nor 'control' sites however, should be considered completely representative of pre-mine conditions as mining was initially conducted at Middle Robe between 1972 and 1982 and from Deepdale between 1972-1985.

4.4 HYDROLOGY - RAINFALL AND RIVER DISCHARGE

Patterns in rainfall river discharge were analysed to determine the relationship between hydrological indices and associated changes to pool morphology and permanence. Long-term rainfall data for Pannawonica (Station 5069) was provided by Climate Services, Bureau of Meteorology (Perth). Rainfall and temperature records for the Pannawonica were provided by RTIO.

4.5 PHYSICO-CHEMISTRY - MORPHOLOGY AND WATER QUALITY

Measurements of pool morphology and selected water quality parameters were made in conjunction with the aquatic fauna sampling at each focal pool. Water temperature, dissolved oxygen, salinity/ conductivity, turbidity, redox and pH were measured in situ (0.5 depth) using a YEO-KAL (YK-611) water quality analyser. Water samples were also taken for analysis of nutrients as both total nitrogen (TN) and total phosphorus (TP).

River pool morphology was determined with depth measurements (graduated pole) and pool width and length were qualitative measurements. Levels of fine inorganic sediment and areas of deeper water in each pool were qualitatively assessed and coded by rank (0-4), this was conducted during the fish surveys. The sediment category was assessed as the extent of deposited sediment cover over the natural shale-base of pools on an ordinal rank of 0-4; where 0=no sediment evident, 1=25% coverage, 2=50% coverage, 3=75% and 4=total streambed coverage.

4.6 MACROINVERTEBRATE FAUNA

The pool macroinvertebrate fauna was sampled at all sites (aside from Robe Pool where, due to cultural sensitivities, all sampling was conducted from the bank). Methodologies for collecting fauna were designed to sample the major aquatic habitats and maximise the number of species recorded at each site (see Appendix 2 for details). Quantitative sampling was conducted using a heel-kick (*sensu* Davies 1998) or sweep method (depending on habitat), compatible with the methodology of NRHP (National River Health Program) sampling protocols. Samples, containing sediment, detritus and aquatic macroinvertebrate fauna, were preserved on site.

In the laboratory, macroinvertebrates were removed from the samples under a binocular microscope and identified to the lowest taxon possible either by use of keys or by matching specimens to an existing voucher collection developed exclusively for the Robe River. The existence of rare, restricted or endemic species was determined by cross-referencing taxa lists for each site/habitat with a long-established database. Conclusions on the rarity of any macroinvertebrate species cannot be made with complete surety due to the inherent taxonomic uncertainties associated with this region.

4.7 FISH FAUNA

Fish were recorded by direct observation using a mask and snorkel (a two-assessment transect across 100m reach). A list of presence/absence for each species was constructed for each of the pools. Details of field methods are detailed in Appendix 2. Fish were identified to species based on taxonomy described in Allen (1989) and later in Allen *et al.* (2002). During the previous sampling trip, GoPro underwater cameras were trialed to 'de-risk' the sampling methodology. However, due to naturally high turbidity, the cameras were of limited value and in April 2017, the sampling reverted to direct observation. In the future, acoustic cameras will be trialed; these can operate in highly turbid water (including able to be operated at night).

4.8 RIPARIAN VEGETATION AND WEEDS

An assessment of local riparian vegetation condition was made on the basis of dominant plant species and relative degree of disturbance assessed as weed invasion, livestock damage and fire. Assessments were broadly based on the rapid assessment methodology outlined in Pen and Scott (1995) and WRC (1999). At each site, two 50m transects from the waters' edge upslope were made and the following parameters recorded: slope (in degrees), % leaf litter covering the soil, weeds (in area), livestock disturbance (low, medium, high), and over-story condition: 1= dead, 2= much leaf loss, many dead branches, 3= some dead branches, 4= pristine). Methods are presented in Appendix 2. Opportunistic, qualitative surveys were also made of the noxious aquatic weed Indian Water Fern, *Ceratopteris thalictroides* and the riparian weed Mexican Poppy.

4.9 STATISTICAL ANALYSES

Statistical analyses using ANOVA (analysis of variance) were used to compare spatial and temporal variations in water quality data. PRIMER (Plymouth Routines in Multivariate Ecological Research) computer package was used to describe multivariate (spatial and temporal) patterns in macroinvertebrate community structure and relate these patterns to changes in measured environmental parameters (*e.g.* water chemistry, pool morphology, riparian condition). Analyses were conducted on both species-level presence/ absence and macroinvertebrate abundance data. The relationship between community structure and the pools was analysed using a sub-set of the physico-chemical parameters measured. In summary, similarity matrices (between pools) were calculated based on macroinvertebrate assemblages. These similarity values were then represented graphically using hierarchical clustering (CLUSTER) and multidimensional scaling (MDS) to determine how similar pools were to each other in terms of aquatic fauna. Principal Components Analysis (PCA) was also used to summarise underlying patterns in environmental data.

5. RESULTS AND DISCUSSION

The sampling was conducted in the immediate post-wet period (April 2017). Previous sampling has typically been conducted during the late dry; a period of elevated environmental 'stress' to the resident aquatic fauna of the permanent pools.

5.1 HYDROLOGY - RAINFALL AND RIVER DISCHARGE

The Pilbara biogeographical region of Western Australia is characterised by low and unreliable annual rainfall and, when coupled with high annual evapo-transpiration rates (*e.g.* >10x annual rainfall), results in spatially-restricted aquatic ecosystems (pools). Rainfall is highly unpredictable with significant variation in annual rainfall. The coefficient of variation (CV) for rainfall for the Pilbara ranges 0.4 to 0.7 ('high') in comparison for south-west Western Australia CV is 0.2 ('low') and the Kimberley CV is 0.3 (see Figure 2).

Pannawonica receives the majority of its rainfall over summer in association with cyclonic events. Peaks in rainfall typically occur during January-March with months of lowest rainfall occurring in September and October (Figure 2). Natural flows in the Robe River, both upstream and downstream of Mesa J are tightly linked to annual rainfall patterns. Following trends in rainfall data, maximum flows are typically recorded following peak rainfall (Figure 2). Pool water levels during the dry period are maintained by groundwater (*i.e.* they are groundwater-dependent-ecosystems).

The Pilbara region has >3m evaporation per annum and as most permanent pools are considerably less than this depth, they are maintained by groundwater. Annual rainfall recharges levels and flows are linked to rainfall events. For analysis, these two seasons are referred to as "wet" and "dry". Long term analysis also identified two transitional seasons, the "ramp down" period where rainfall and hence flow declines following the wet and the "the ramp up period" when increasing rainfall and flow following the dry season (Figure 2).

5.2 CLIMATE

The climatic condition in the (approx.) 12 months period prior to the sampling is shown in Figures 3-4. The pattern of temperature and rainfall are considered typical for the region (10-45^{O}C). As previously discussed, heavy rainfall events and peak discharges are generally associated with tropical cyclones or monsoons. In the past, the highest category cyclones that have impacted the Pilbara coastline are listed by the Bureau of Meteorology and include TC Orson in April 1989, TC John in December 1999, TC Monty in March 2004, TC Clare in Jan 2006, and TC Glenda in March 2006.

These cyclones resulted in peak discharges and a number of significant flow events have been recorded in years following above average rainfall in consecutive months (*i.e.* January 1997). The large Robe River floods of September 1993 and January 2000 were also associated with monsoon lows. Flooding is often enhanced if flows follow rainfall that has already saturated the profile leading to elevated water levels.

These data suggest that significant flow events in the Robe River pools are either 'pulse' events that occur through peaks in monthly rainfall or when the extensive duration of rainfall is sufficient to maintain high water levels in the river.

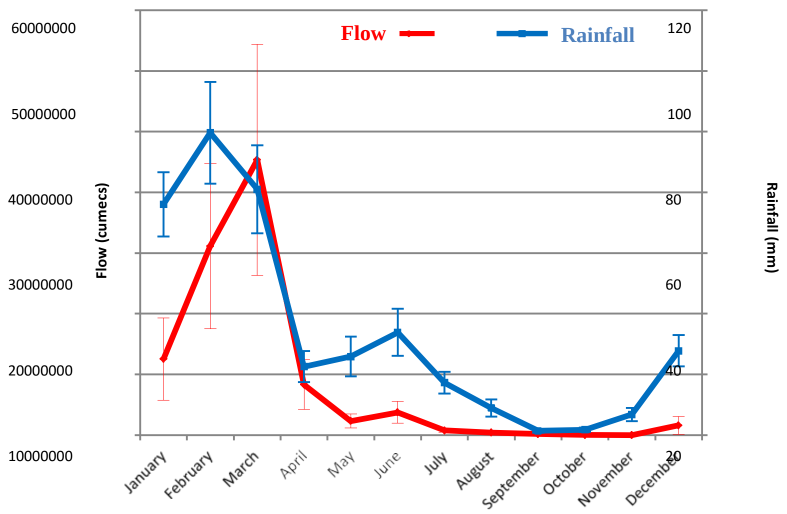


Figure 2. Average monthly flow and rainfall (+ SE).
Rainfall measured at Pannawonica and flows at Yarraloola.

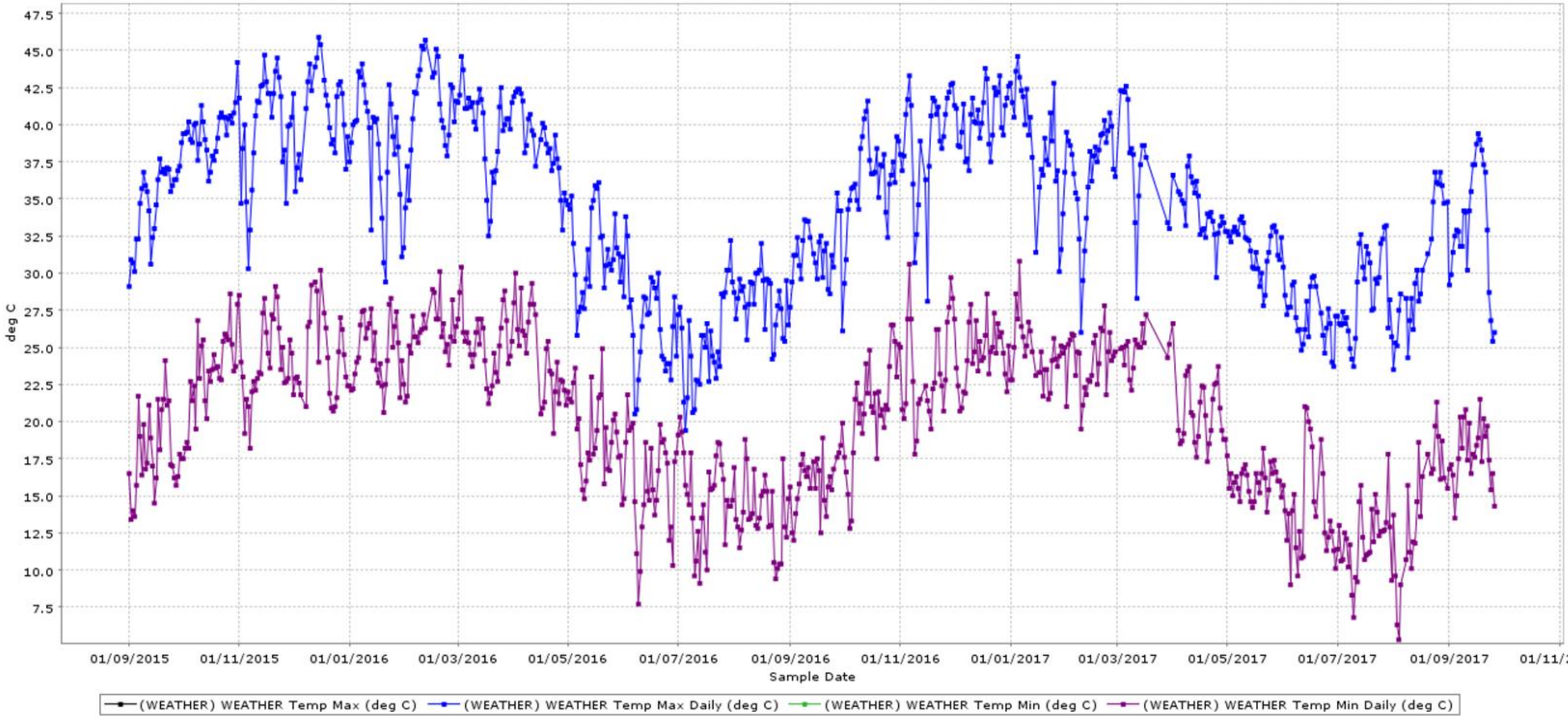


Figure 3. Maximum and minimum daily temperatures (ºC) at Pannawonica townsite September 2015 to September 2017.

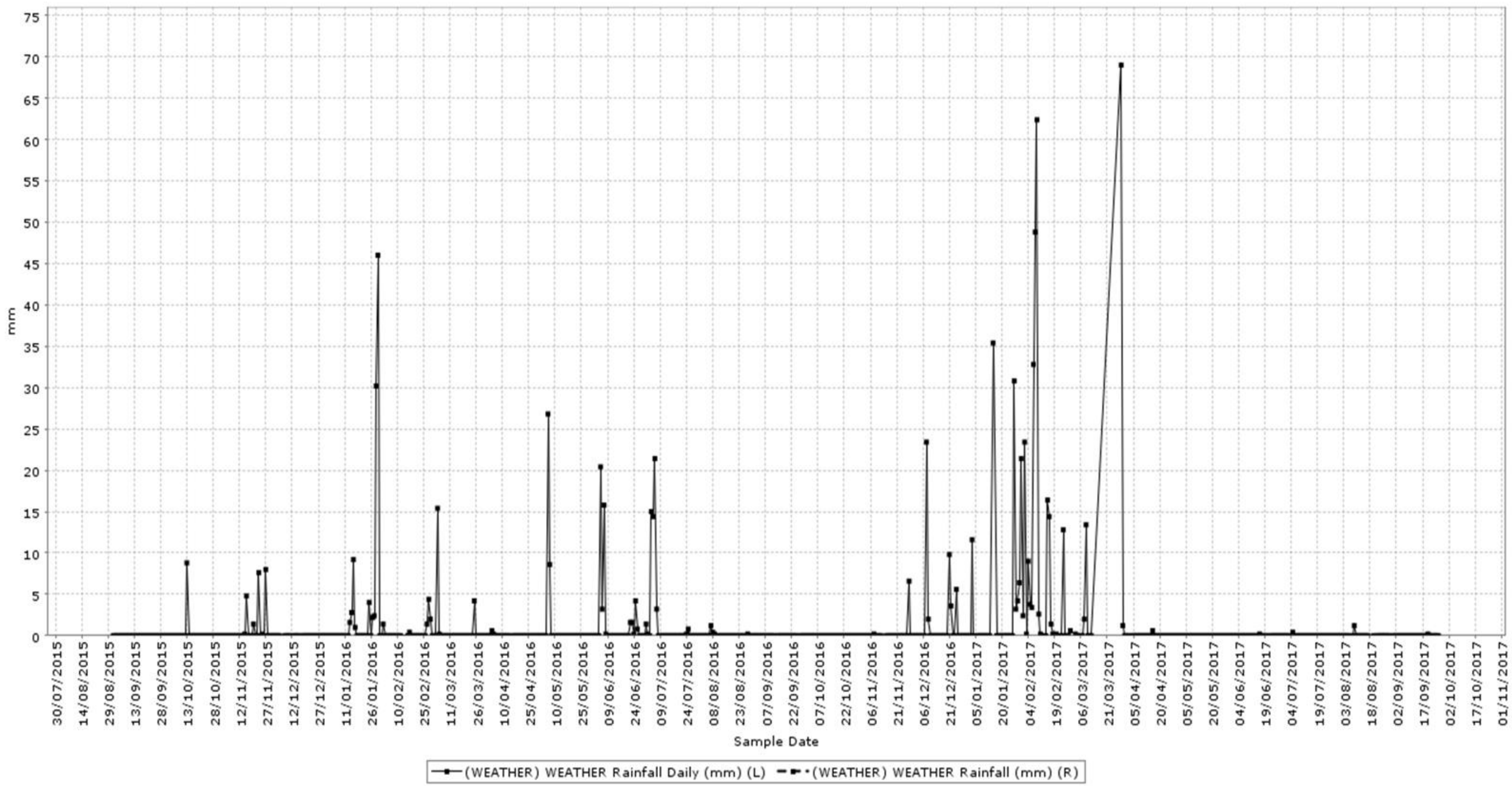


Figure 4. Daily rainfall (in mm) at Pannawonica townsite July 2015 to April 2017.

5.3 SUMMARY OF FLOW CONDITIONS

Since the establishment of the initial biomonitoring in 1991, considerable variance in rainfall and associated flow conditions have been observed within the Robe River. The timing of Robe River aquatic sampling in April 2017 followed significant rainfall in December 2016 and follow-up in 23rd March 2017 (~68mm; see Figure 4). The pool levels were high and presumably pools had been connected following the previous high- rainfall conditions.

Initial surveys in 1991 were conducted following a series of low-flow years. In September 1993, rainfall resulted in a flow event which at the time was the highest peak discharge on record. In subsequent years, relatively high water levels were maintained in pools by a number of high rainfall events. Then, from January 2001, three consecutive years' of lower than average rainfall (January 2001 to May 2003) resulted in significantly lower total annual streamflow being recorded at Yarraloola. In contrast, during March 2004, rainfall contributed from TC Monty to an above- average rainfall for the wet season (September and March). The delivery of this rain was constant over consecutive days and although significant flow was recorded at Yarraloola, there was no extensive flooding associated with this cyclone. At this time, the Yarraloola gauging station recorded the highest monthly discharge since 1972 (596611 ML), and total annual flows for 2004 were the highest on record. High flows were also observed during the sampling in 2014.

Significant rainfall events from tropical cyclones (*e.g.* Glenda and Clare) during 'summer' 2006 resulted in significant total monthly flows being recorded. Three consecutive months of higher than average rainfall resulted in high levels of discharge being maintained during January to March 2006. Following the October 2006, monthly rainfall was below average an in 2007 zero-flow was again recorded at Yarraloola. On the west coast of Western Australia a TC occurred each month from November 2007 to April 2008, resulting in higher than average rainfall recorded. The April 2017 sampling followed significant rainfall in the preceding months (*e.g.* 24mm 6th December 2016, 36mm in 20th January 2017, 63mm in February 2017 and 68mm in March 2017. Long term annual rainfall for Pannawonica is 427mm (Figure 5). There has been a trend, across the >40 year rainfall record, for increasing annual rainfall. This is consistent with some of the predictions for climate change in the Pilbara and Kimberley regions of Western Australia.

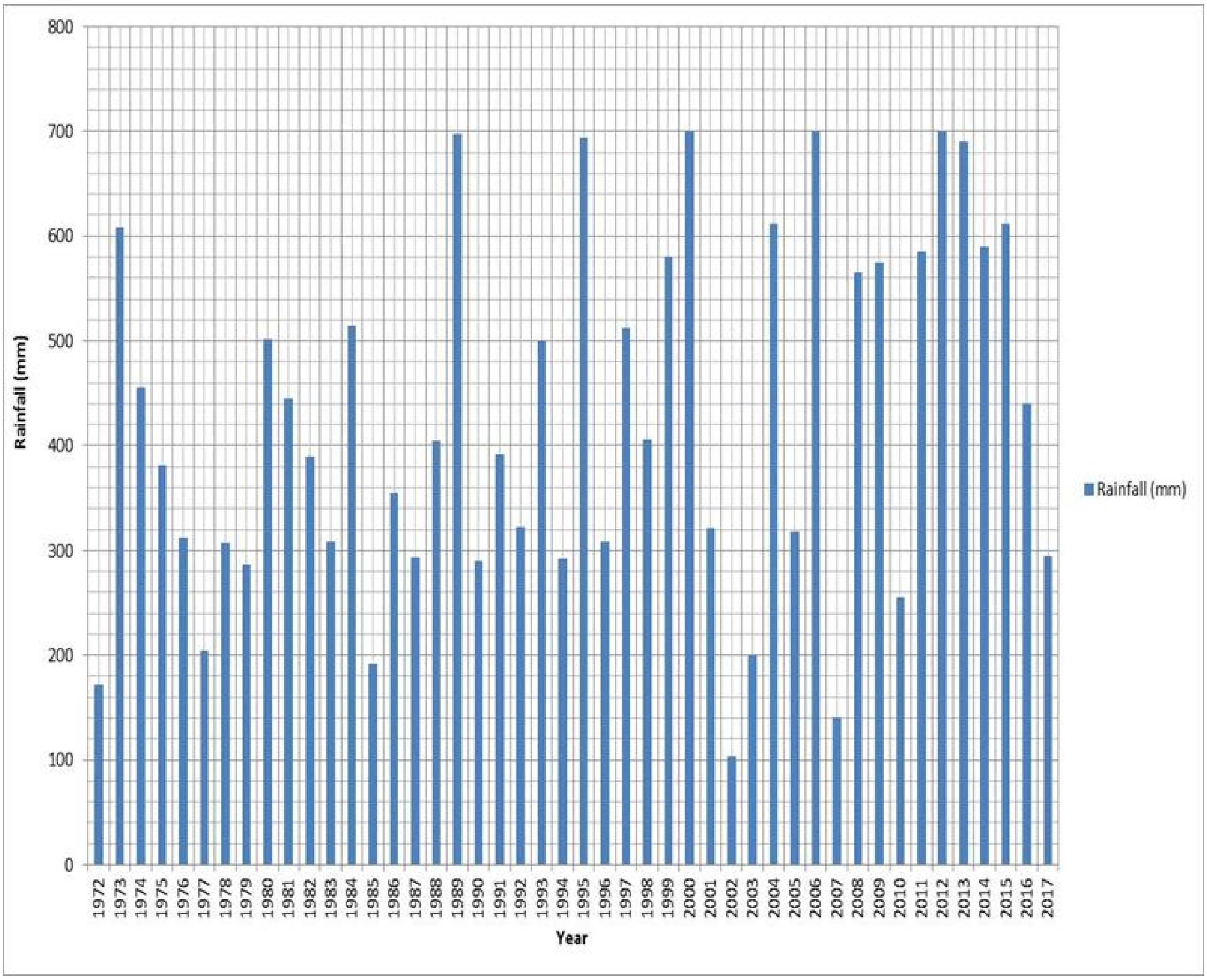


Figure 5. Total annual rainfall for Pannawonica (Station 5069). Note, the 2017 rainfall data are up to the sampling period (April). The long-term annual average is 427mm.

Total annual rainfall was above average for the three years prior to the 2017 sampling (see Figure 5). Monthly records revealed that the majority of rainfall occurred in the month of December-April (Figure 4). Peak rainfall coincided with a weak low that approached the far west Pilbara coast which then combined with a mid- latitude upper trough. Previously this low has resulted in heavy rainfall and substantial flooding in both the Robe and adjacent Fortescue rivers (BOM, 2008).

5.4 PHYSICO-CHEMISTRY

The physico-chemistry of the river system is largely dependent on local geology and riparian conditions. Large flow events can lead to increased turbidity which is transported downstream.

Pool water quality in the Robe River pools was fresh, slightly alkaline, with moderate levels of turbidity. Generally, the water chemistry of the pools was of high biological quality with the exceedances of ANZECC (2002) Trigger Levels limited to turbidity and a small elevation of total phosphorus (0.02mg/L *vs.* ANZECC/ARMCANZ Trigger Value of 0.01 mg/L) at Pirathalu. This small increase over the trigger values for nutrients is considered a consequence of unrestricted livestock access to pools. Dissolved oxygen (DO) levels were low; a consequence of high water temperatures (29-31^{O}C). Salinity/conductivity showed a slight gradient of increasing concentration downstream (*e.g.* 571µs/cm at Ngalooin to 996µs/cm at Thintuoona). This gradient is considered a function of the underlying geology rather than any anthropogenic influences; although dewatering may connect pools (see Table 1). Pool turbidity was highly variable ranging from 2.7NTU at Martangkuna to almost 30NTU at Gnieraoora (Yeera Bluff). Low levels were recorded at Pannawonica Hill Pool (Figure 6).

Long-term monitoring has revealed that water chemistry of pools show predictable levels largely associated with the sampling season (Dobbs and Davies, 2009). To date, there have been no statistically significant changes in the water quality of the Robe River that could be directly attributable to mining operations. Rainfall and river flows have been identified as having the greatest influence on pool morphology and water chemistry (Streamtec 2001-2016). A summary of the April 2017 physico-chemical parameters measured in conjunction with the aquatic survey is presented in Table 2.

5.5 MINE DEWATERING

A series of pools in Jimmawurrada Creek and in the Robe River downstream from discharge points were previously sampled for pH, DO, temperature, salinity/ conductivity, turbidity, total nitrogen and total phosphorus. Previously, the values showed considerable similarities with water in the Robe River; due to the permeability of the Robe pisolite and water being essentially 'recycled' from the mine to and from the river. The de-watering volumes into Jimmawurrada were low at point B (200kL) in March and ranged from 66-191ML in June 2017 (Table 1, Figure 7).

Table 1. Monthly discharge into Jimmawurrada Creek (points 5, 6) and the Robe River (point B) (volumes in kL).

Discharge Point	Monthly Discharge Volume (kL)							
	Jan-17	**Feb-17**	**Mar-17**	**Apr-17**	**May-17**	**Jun-17**	**Jul-17**	**Aug-17**
5	9522	285984	140248	51665	822	249	37100	0
6	5226	26045	42310	28955	17568	22555	30674	17627
B	66082	129691	192617	119042	34882	191358	14399	1490

5.6 POOL MORPHOLOGY AND SEDIMENTATION

Turbidity and sedimentation levels are generally a function of the interaction of river hydrology and underlying geomorphology. Water levels in the permanent pools have showed a trend upstream and downstream of Mesa J; *i.e.* dropping slightly over the winter dry season and rising again following summer rainfall events. At some sites turbidity exceeded ANZECC guidelines (mean values ~20NTU). These high values were measured both upstream and downstream from Mesa J (Table 1) and were considered a consequence of local pool geology.

Table 2. Physico-chemical parameters measured in conjunction with aquatic fauna surveys of the Robe River, April 2017. Shading indicates exceedance of ANZECC/ARMCANZ guidelines (2000). Blue-shaded; new pool sampled only in 2017.

* Areas of deeper water in each pool were coded by rank where: 1 = no areas > 2.5 m in depth, 2 = some areas > 2.5 m in depth, 3 = many areas > 2.5 m in depth, 4 = substantial areas > 2.5 m in depth. Cont=continuous.

Site Codes; Mart. = Martangkuna; Gnier. = Gnieraoora; Yarra. = Yarramudda; Jap. = Japanese Pool; Meda. = Medawandy Waters; Panna. = Pannawonica Hill Pool; Ngal. = Ngalooin Pool (Mussel Pool).

				Downstream						Adjacent	Upstream				
	Parameters	**Units**	**ANZECC Trigger Levels**	Thintuoona	Gungaree	Gnier.	Mart.	Pulari.	Jap.	Yarr.	Meda.	Panna.	Cams Pool	Pirathalu	Ngal.
Water Quality	Dissolved Oxygen (DO)	%		16.7	2.01	20.2	55.4	38.8	75.3	80.4	56.2	96.4	24.5	109.0	71.7
	Conductivity (EC)	υs/cm	>2500	996	822	883	805	718	764	743	782	671	692	682	571
	Salinity	ppt		0.41	0.42	0.42	0.41	0.39	0.41	0.30	0.32	0.32	0.32	0.30	0.32
	pH	pH units	6-8	6.8	7.7	7.8	8.0	7.3	7.6	6.7	7.7	7.2	7.1	8.76	7.1
	Temperature	Celsius	-	29.3	28.4	29.9	28.7	27.3	29.7	30.5	29.8	29.2	30.5	25.0	29.4
	Turbidity	NTU	<2-15	12.7	4.8	4.8	4.09	2.7	6.7	30.4	7.9	9.2	20.2	14.3	6.8
	Total Nitrogen	mg/L	0.2-0.3	0.10	0.16	0.26	0.12	0.10	0.16	0.11	0.15	0.30	0.25	0.25	0.10
	Total Phosphorous	mg/L	0.01	<0,01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	0.02	0.01
Pool Morphology	Length of main Pool	m		>1000	>1000	>1000	>1000	>1000	>1000	>1000	>1000	>1000	>1000	>1000	>1000
	Average Width	m		50	20	32	40	50	120	180	120	40	55	30	35
	Average Depth	m		2.5	0.3	1.8	0.25	0.3	0.4	2.5	2.2	1.5	2.5	1.1	2.6
	Flow	m^3/sec		0	0.28	0	0	1	0	0.5	0.5	0	0	0	0
	Area Code	1-4		2	2	4	1	2	2	4	3	3	4	3	4
	Sediment Code	1-4		2	2	1	2	1	2	3	2	3	4	3	4
Fauna	Macroinvertebrates	# taxa		37	29	39	36	34	34	37	35	33	36	40	38
	Fish	# species		5	4	6	6	6	6	7	7	6	6	6	6
	Livestock adjacent	#'s		0	0	0	0	0	0	0	0	0	0	0	0
Flora	Riparian condition	1-4		4	4	4	4	4	4	4	4	4	4	4	4
	Indian Fern	m^3		0	0	0	0	0	0	5	0	0	0	0	0
	Mexican Poppy	m^3		0	0	0	0	0	0	0	1	1	0	0	1
Catchment	Slope	%		4	4	4	4	3	4	4	4	3	4	4	4
	Riparian Width	m		cont	cont	cont	cont	cont	cont	cont	cont	cont	cont	cont	cont
	Leave Cover	%		50	40	40	25	40	35	25	20	15	20	25	45
	Vehicle Disturbance	1-4		0	0	2	1	1	2	0	1	3	3		1

Figure 6. Pannawonica Hill Pool during April 2017.

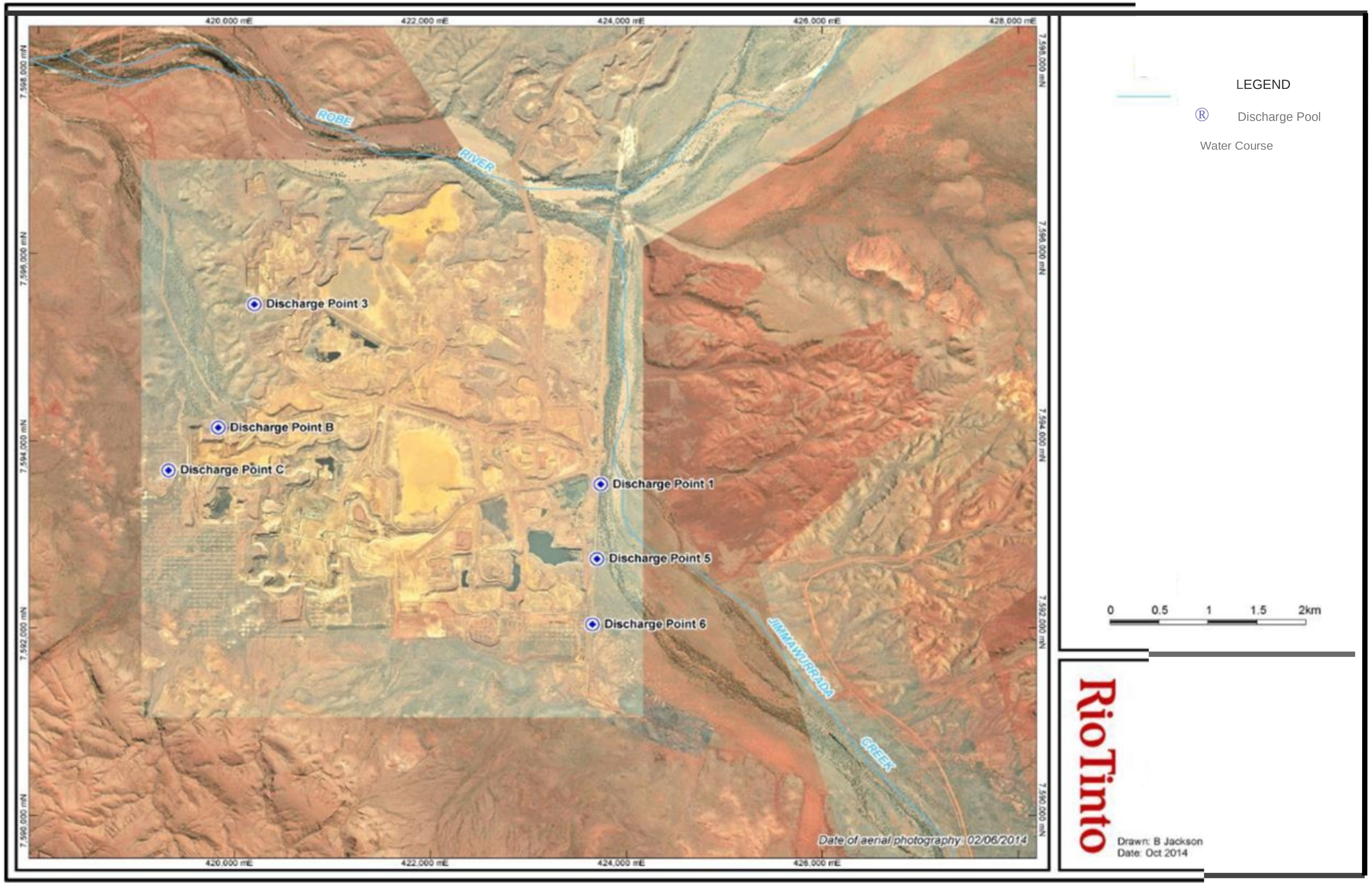


Figure 7. Dewatering points on Jimmawurrada Creek (discharge points 1, 5, and 6) and the Robe River (discharge points 3, B and C), adjacent to Mesa J.

Figure 8. Pirathalu upstream of Mesa J on the Robe River (left). Medawandy Waters (right).

5.7 WATER TURBIDITY

Natural turbidity and sedimentation are dependent on the hydrology, geomorphology and the suspended load from upstream. Turbidity levels in the Robe River have fluctuated both annually and seasonally, with elevated turbidity (70NTU; see Dobbs and Davies 2009) typically recorded immediately following flood events. Previous surveys of Robe pools have shown consistently low levels of turbidity in the dry season. Several pools, notably Yarramudda, have consistently shown elevated levels of turbidity.

5.8 SALINITY

In 2017, salinity levels within all pools were categorised as fresh[3]. The low salinity of water in the north-west of Western Australia has been attributed to long-term geochemical processes and geological history (Williams & Buckney 1976). A salinity gradient was evident in April 2017 and considered a consequence of local geomorphology. This gradient was evident prior to commencement of mining at Mesa J and not considered the direct result of mining activities.

5.9 DISSOLVED OXYGEN

Dissolved oxygen (DO) in survey pools showed significant spatial and temporal variation (Dobbs and Davies 2009). Previous spot measurements of DO, coupled with information from data- loggers have revealed concentrations ranging from overnight lows close to zero to supersaturated levels after midday. Dissolved oxygen levels of 70 – 120% (*i.e.* typically >2 mg/L) are generally considered suitable for resident aquatic fauna.

DO levels less than 2.0mg/L are considered the critical threshold at which respiration becomes difficult for many fish (ANZECC/ARMCANZ 2000). Daytime dissolved oxygen (DO) levels well-above threshold values both upstream and downstream of the mine (see Table 1). The DO of the pools reflects time of day with low levels in the morning (following night-time respiration of both plants and animals) to rise during the day due to photosynthesis by both macrophytes and algae.

[3] Fresh defined as <2,700 µS/cm; brackish/moderately saline 2,700 – 9,000 µS/cm; saline 9,000 – 55,000 µS/cm. Dept. of Agriculture, Government of Western Australia, 2002.

5.10 WATER TEMPERATURE

Long-term monitoring has highlighted the correlation between pool temperatures and ambient air temperatures both upstream and downstream from Mesa J (Figure 3). Temperature levels in 2017 were consistent with the long term averages for the month of April and generally varied between 29 and 32^{0}C.

5.11 NUTRIENTS

In long-term monitoring of the Robe River (Dobbs and Davies 2009), nutrient levels have sometimes exceeded Trigger Value guidelines. Previous high levels (see Streamtec 2001, 2015) of nitrogen and phosphorous have thought to be influenced by livestock access to the pools.

It should be noted that ANZECC guideline limits were developed primarily for water bodies other than those in the arid and semi-arid tropics of the Pilbara. The acceptable or 'normal' nutrient concentrations common to water bodies of this region remains poorly-understood and long-term monitoring of the Robe River suggest that guidelines are not directly transferable.

5.12 MACROINVERTEBRATE FAUNA

A total of 67 macroinvertebrate taxa[4] ('species') were collected and identified from the study sites in April 2017. Biodiversity of individual sites is shown in Table 2. The macroinvertebrate biodiversity recorded in 2017 approximated the 'average' when compared to the longer-term dataset (Dobbs and Davies 2009).

In 2017, the macroinvertebrate fauna was characterised by several regional endemic with no species considered rare or locally restricted. As with previous sampling, macroinvertebrate assemblages were dominated by larval stages of non-biting and biting midges (chironomids and ceratopogonids), freshwater prawns (Caridines), polychaetes (oligochaetes) and snails (gastropods). In the long-term data set 'low- occurrence' taxa (*i.e.* taxa recorded at <20% of sites) accounted for approximately 65% of all species recorded in 2017. This was similar to macroinvertebrate distributions in 2010 and 2014. Kay *et al.* (1999) conducted the first comprehensive study of aquatic macroinvertebrate distribution patterns in northern Western Australian and also found that ~25% of species occurred at most sites, while the remainder had widespread, but with a very heterogeneous spatial distribution.

The distribution of species in pools suggests that major differences are de-coupled from mining operations. Biodiversity of individual pools in 2017 ranged from 33 species at Pannawonica Hill Pool to 40 species at Pirathalu (Table 2, Figure 8). When comparing individual species, about 21% of species were exclusive to upstream sites compared to 24% of species found only in downstream sites. There was no statistically significant difference in species richness between upstream and downstream sites (one-way ANOVA, $p>0.05$; all cases). The multi-dimensional spatial patterns in macroinvertebrate community structure were investigated using multivariate classification and ordination techniques. Interpretation of the ordination (MDS) is reasonably straightforward, with sites clustering closer together representing samples that are similar in species composition and sites further apart having more different community structures.

Multi-dimensional ordination and multivariate analysis using ANOSIM revealed that there was no statistically significant difference in community structure/ clustering between sites upstream and downstream of Mesa J (Table 2).

Analysis of the long-term dataset revealed a broad separation of pools largely based on a simple measurement of pool morphology (depth and habitat) (see Figure 9, Figure 11). Highly episodic events such cyclones are important determinants of pool structure and habitat and consequently aquatic community structure (Streamtec 1991- 2017). Initially, there was a strong predictive model between simple measurements of pool size and macroinvertebrate community structure (Streamtec 1992). This indicated a structured, deterministic relationship. Following significant cyclones and extended dry periods, this model has shown less predictive success as recolonisation of species can be opportunistic and largely unpredictable. The biodiversity of pools is highly linked to pool morphology both upstream and downstream of Mesa J.

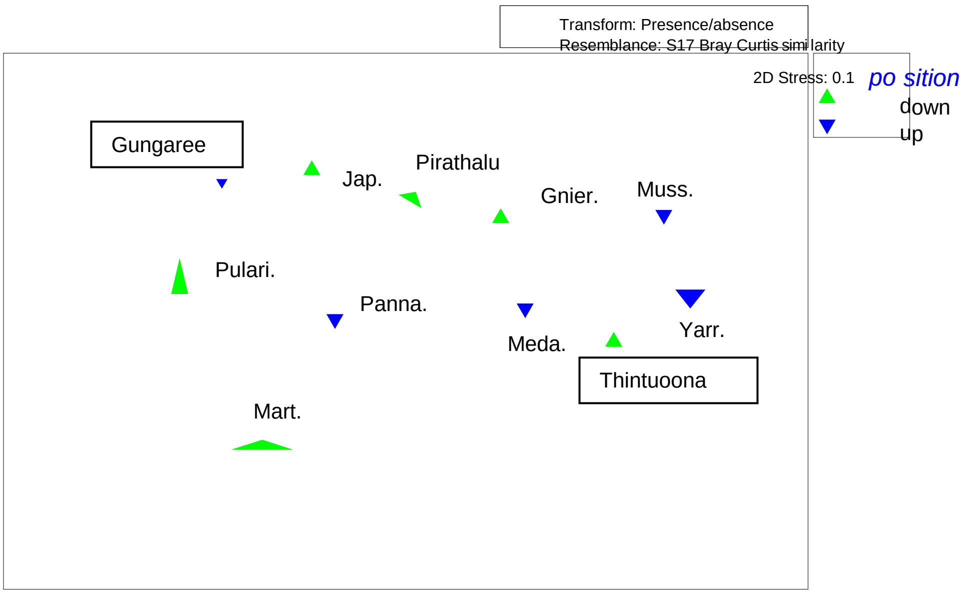


Figure 9. MDS ordination of 2017 macroinvertebrate presence/absence data set showing separation of sites (NB position of pools in relation to Mesa J has been overlaid showing no pattern in community structure based on this parameter).

5.13 TEMPORAL VARIATION

In the Pilbara bioregion, highly episodic and events with an extended return-period (*i.e.* cyclones) are important determinants of freshwater habitat and consequently aquatic community structure. A comparison of community structure across the long-term dataset shows significant rainfall and flow events the overriding determinants of ecological patterns. However, following high flow events, changes to macroinvertebrate community structure does not occur in a predictable manner with stochastic differences/shifts in species, recovery time and response (see Figure 9, Figure 11).

Changes to the macroinvertebrate community structure in April 2017 include an increase in juvenile species when compared to the previous sampling occasions. The macroinvertebrate community assemblages have shown significant resilience across the data record.

Figure 10. Measuring flow using cross sectional measurement methodologies.

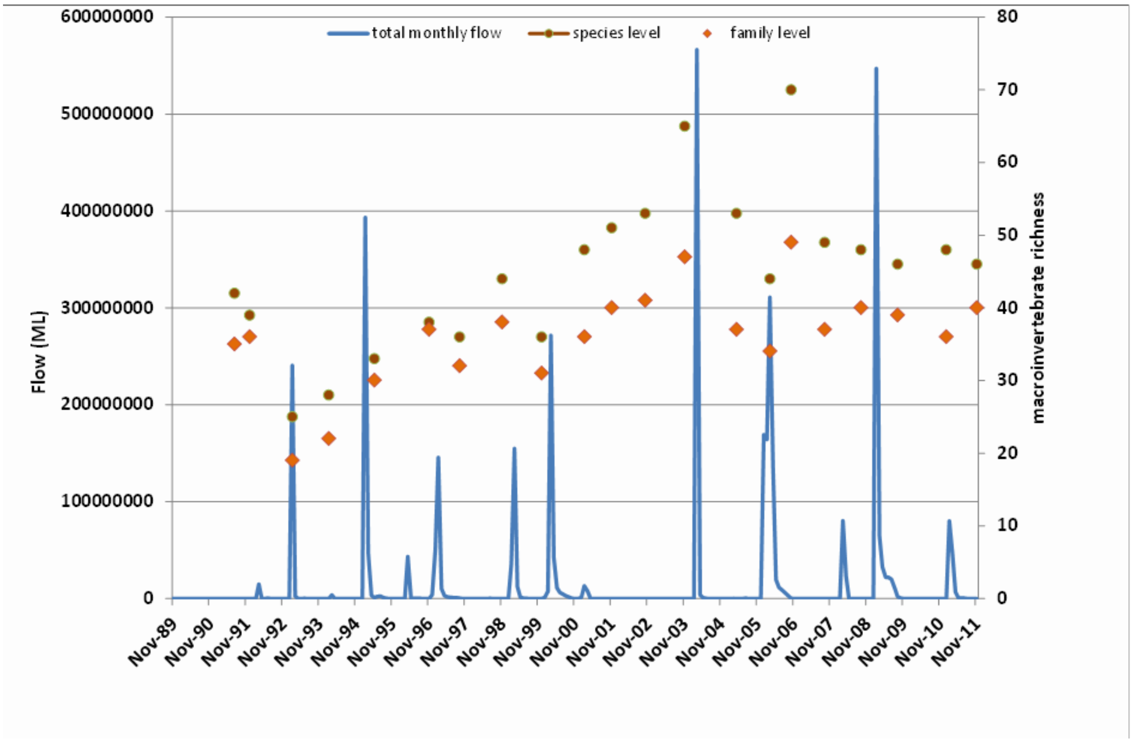


Figure 11. Species richness of macroinvertebrates as a function of flow (note, using previous data).

5.16 FISH FAUNA

A history of isolation of river systems of the north-west results in a low biodiversity of freshwater fish with few fish being recorded from the Pilbara (12 species) (Allen *et al,* 2002). A total of ten species have been recorded in the Robe River during aquatic surveys since 1991. Six of these species are classified by Allen *et al* (2002) as freshwater and the remaining four as freshwater/estuarine species (Table 3). To date, no introduced species have been recorded.

Seven species of fish were recorded in April 2017. Previously, patterns in fish biodiversity and distribution were consistent with the importance of habitat as per the long-term monitoring of pools, showing that biodiversity was linked to pool water levels, habitat and previous hydrological connectivity. All the seven fish species were recorded in both upstream and downstream sites. Mangrove jack, the striped butterfish and other estuarine species, previously observed in small downstream pools were absent in 2017 Patterns of fish species diversity and distribution were not related to the position of sites in relation to Mesa J.

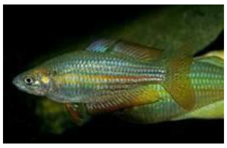
In April 2017, fish were again numerically dominated by freshwater species from the Tetrapontidae (Grunters) group particularly species of Rainbowfish (*Melanotaenia splendida australis*) (Table 2). The patterns of fish species distribution were unrelated to the position of sites in relation to Mesa J (*e.g.* similar patterns upstream and downstream). The distribution of fish species along the length of the river showed that all seven species were recorded both upstream and downstream of Mesa J. Previously, variations in fish diversity and distribution between upstream and downstream sites were correlated to pool depth and volume (see Figure 12). These patterns in species distribution are consistent with long-term trends and consistent with current knowledge of tropical fish (see Warfe *et al.* 2011). Freshwater/estuarine species, have exhibited the greatest variations temporally across surveys. Mangrove Jack, absent in early 2011, were sampled during September 2015 and again absent in 2017. The April 2017 sampling was characterised by high numbers of juvenile species of fish, presumably recently recolonising pools after the recent flows of December 2016 to March 2017. There has been anecdotal information about freshwater mullet being present in some pools (*e.g.* Cams Pool); however this is yet to be verified.

Table 3. Fish species recorded in the Robe River pools in all surveys.

	FRESHWATER SPECIES	
CLUPEIDAE - HERRINGS	*Nematalosa erebi* GUNTHER	Bony Bream
PLOTOSIDAE - EEL-TAILED CATFISH	*Neosilurus hyrtlii* STEINDACHNER	Eel-tailed Catfish
MELANOTAENIIDAE - RAINBOWFISH	*Melanotaenia splendida australis* PETERS	Western-Rainbow Fish
TERAPONTIDAE - GRUNTERS	*Amniataba percoides* GUNTHER	Barred Grunter
	Leiopotherapon aheneus MEES	Fortescue Grunter
	Leiopotherapon unicolor GUNTHER	Spangled Perch
	ESTUARINE SPECIES	
MEGALOPIDAE - TARPONS	*Megalops cyprinoides* BROUSSONET	Ox-eye Herring
SCATOPHAGIDAE-SCATS	*Selenotoca multifasciata* RICHARDSON	Striped Butterfish
GERREIDAE - SILVER BIDDIES	*Gerres filamentosus* CUVIER	Threadfin Silver-biddy
LUTJANIDAE-SNAPPERS	*Lutjanus argentimaculatus* FORSSKAL	Mangrove Jack

Freshwater and Estuarine Species present in the Robe Pools

(Photos courtesy of Allen G, 2002).



Western Rainbowfish

Spangled Perch

Barred Grunter

Fortescue Grunter

Eel-tailed Catfish

Bony Bream

Ox-eye Herring

Striped Butterfish

Mangrove Jack

Silver biddy

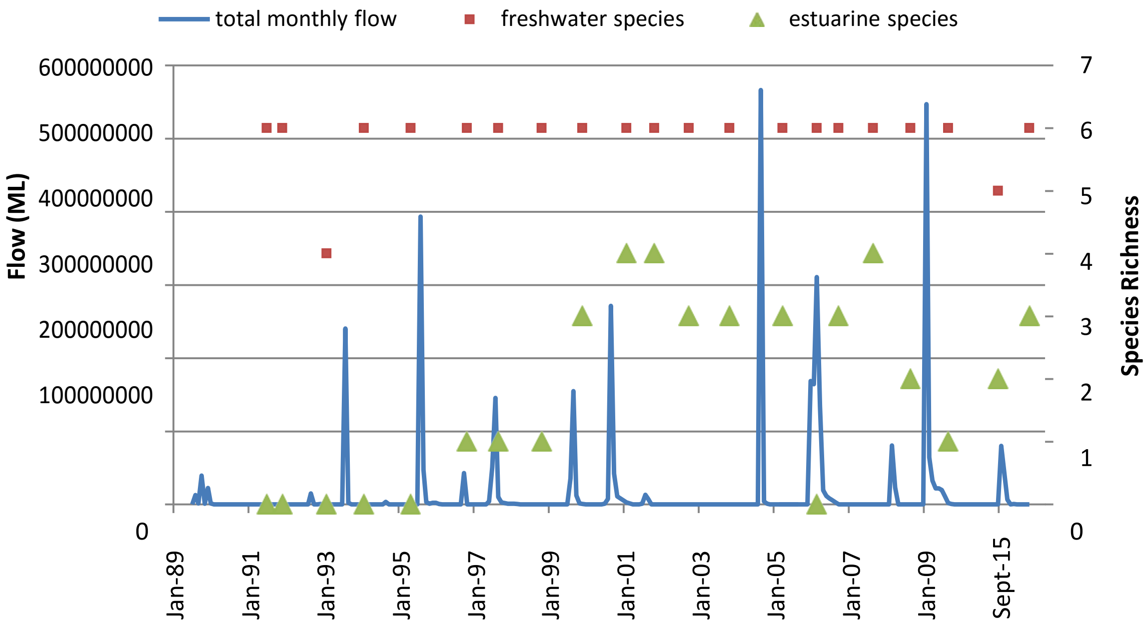


Figure 12. Comparison of fish species richness and total monthly flow at Yarraloola on the Robe River.

5.17 RIPARIAN VEGETATION

The Robe River riparian zone is dominated by moderately-dense to dense mixed woodland of Cadjeput *Melaleuca leucadendra*, River Gum *Eucalyptus camaldulensis* and Coolibah *E. microtheca.* In all cases, the riparian vegetation was in excellent condition.

The open understory of tall shrubs is dominated by *Petalostylis labicheoides*, with scattered *Sesbania formosa* and *Gossypium robinsonii* over sedges and mixed herbs. Filamentous green algae are common in the waterways, together with emergent macrophytes, such as *Potamogeton* and *Vallisneria* species, and fringing rushes, such as *Eleocharis* sp. The bulrush *Typha* was dominant on the shorelines of some pools, particularly Yarramudda.

The introduced Indian Fern (*Ceratopteris thalictroides*), common in previous surveys, was extremely restricted in 2017. The riparian weed, Mexican Poppy, was largely absent in April 2017. Vegetation condition was similar upstream and downstream of Mesa J (*e.g.* over story tree health was good with no significant difference upstream to downstream; ANOVA $p>0.05$; all cases).

5.18 REGIONAL ASSESSMENT

Broader scale and longer-term multivariate analyses of the structure of freshwater fauna in a range of sites in the Pilbara (including Turner Creek, Yule Brook, Fortescue River, Ashburton River) showed the Robe River sites, both upstream and downstream of Mesa J, "grouped" on a gradient of sites largely based on pool size, habitat and water permanence (see Vorosmarty *et al.* 2010). The larger permanent pools in the Fortescue River were the most diverse of the sites (due to presence of v- tailed catfish and freshwater turtles; absent in the Robe River) and the least diverse were the smaller, more ephemeral pools in the Turner River and Yule Brook. Sites in the Robe were transitory between these extremes and grouped with similar sized pools in the Ashburton River.

6. CONCLUSIONS

In April 2017, there were no statistically significant changes to the ecology of river pools from the long-term envelope. The long term database that exists from these Robe surveys allows informed analysis and interpretation of these changes. The current survey supports previous findings that difference in environmental characteristics of pools are primarily a result of overriding climatic influences determining pool permanence and local morphology (see Davies 2010, Catford *et al.* 2013).

These findings support previous analysis showing that rainfall and river flows have had influence on pool morphology, water chemistry and the resulting aquatic fauna (Streamtec 2001-2016). Highly episodic and extreme events such as cyclones appear to be an important determinant of aquatic biodiversity and fundamental ecological processes.

To date, there have been no detectable changes in the aquatic ecology of the Robe River that could be attributed to mining operations alone. Long Term Ecological Research (LTER) is an important global initiative providing extensive data bases of temporal and spatial variability in biological parameters. The current sampling regime was initiated in 1991 and offers a unique dataset on an arid system in the Pilbara region (see Pettit *et al.* 2011, Jardine *et al.* 2012). In addition to providing a better understanding of impacts, if any, associated with mining operations, long-term ecological monitoring improves our understanding of the natural variability within the Robe River catchment. The support of RTIO for this LTER is gratefully acknowledged.

The continued investigation of new pools greatly increases the knowledge of the larger scale distribution of refugial habitat. A 2-D model of the hydrology of the Robe River *(e.g.* map when flows connect pools and the required antecedent conditions (rainfall) leading to pool connectivity will assist modelling dewatering movement and pool condition.

The use of Indigenous locals in the sampling program has been valuable (particularly for developing 'stories' about the pools, historic names and traditional ecological knowledge). This emphasises the important link between ecological condition and community 'health' (see Speldewinde *et al.* 2009).

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8. APPENDICES

APPENDIX 1. POSITION OF STUDY SITES SAMPLED IN THE ROBE RIVER (also see Figure 1).

A pool name in inverted commas indicates a provisional naming. Grid references in MGA94. Highlighted= sampled in 2017.

Pool	Easting	Northing
Cameron's Pool	431800	7602021
Pannawonica Hill	432444	7602133
Medawandy	428965	7601388
Yarramudda	424044	7596692
Japanese Pool	419714	7598110
Duck Pool	418837	7597875
Martangkuna	417396	7598134
Pirathalu	445718	7600650
Yeera Bluff	414408	7596619
Mussel Pool	453089	7600382
Ooranah Pool	392656	7603524
Gungaree	400726	7594557
Thintuoona	399920	7594475

Description	Position relative to Mesa 'J'	Northing Zone 50	Easting Zone 50
Most upstream site surveyed. Upstream from A1.	upstream	7600396.71	453906.68
Upstream, adjacent to Water Corporation gauging station (flying fox)	upstream	7600650.05	445718.12
Adjacent to Pannawonica Hill.	upstream	7602138.34	433354.72
3km downstream of Pannawonica Hill.	upstream	7600894.25	430026.59
2km downstream of Pannawonica Hill.	upstream	7601451.43	430886.25
Downstream of confluence with Jimmawurrada Creek.	adjacent	7596946.50	420850.66
Adjacent to Mesa J.	downstream	7597951.51	418920.71
Adjacent to Mesa J & upstream of Japanese Pool.	downstream	7597650.40	420186.37
2km upstream of Deepdale.	downstream	7597949.17	418461.02
Adjacent to Yeera Bluff; downstream of Deepdale homestead.	downstream	7595961.06	414592.93

'Mesa C'	Furthest downstream site, new large pool sampled in 2011	downstream	7593929.71	414230.39
Additional Sites				
Site 10	Left Turnoff just before Rocky Creek	upstream	7600836.501	550573.993
Site 11	Turnoff at Hollow Log, and straight towards Mesa	upstream	7601641.977	551562.173
Site 12	Turnoff at Mesa near the white drum	upstream	7600428.612	554026.502
Site 13 Mesa C	Near Railway Bridge (on left)	downstream	7603493.646	607325.702
Site 14 Mesa C	Turnoff right into river bed towards Railway Bridge	downstream	7603859.150	607388.508
Thintuoona Pool	Adjacent (to the north) of Robe Pool	downstream	7594475.522	399920.422
Gungaree Pool	Adjacent (to the north) of Robe Pool	downstream	7594556.710	400726.350

APPENDIX 2. SAMPLING METHODS (BASED ON ANZECC 2000 GUIDELINES AND THE NATIONAL RIVER HEALTH MONITORING PROGRAM (SEE DAVIES 1998).

WATER QUALITY

Water samples were collected using clean 250ml polyethylene bottle; one per site. Bottles washed thoroughly three times with site water (with lid attached).

Undisturbed water collected at 0.5 depth for laboratory analyses of total nitrogen and total phosphorus (analysed by Natural Resources Chemistry Laboratory, Chemistry Centre (WA)). Both the bottle and lid labelled.

Sample kept cool in esky on ice or stored at 4^0C where possible. Measured dissolved oxygen, temperature, salinity, electrical conductivity and pH *in situ*.

MACROINVERTEBRATES – Qualitative – D-net sampling

Sampled all habitats with 250µm D-net (heel-kick with opening of net facing into flow). Standardised protocol (see below). Fixed composite sample in ethanol in plastic bag with label.

Qualitative sampling was conducted using a 'heel-kick' or sweep method (depending on habitat) compatible with the methodology of NRHP/MRHI (National River Health Program and Monitoring River Health Initiative) protocols. 'Heel-kick' and sweep sampling was conducted with a dip net with 250µm mesh, a 350 x 250mm opening, 50-75cm depth and a 1-1.5m handle. The net was washed thoroughly after sampling each site to remove any adhering animals left from previous sampling. For channel and riffle habitats, the substratum was vigorously disturbed whilst holding the net downstream with its mouth facing the disturbed area and into the stream-flow.

Cobbles were picked-up, turned over and rubbed by hand to dislodge attached organisms into the net. This process continued upstream over a total distance of about 50m, covering both the fastest and slowest flowing sections of the specific habitat. Macrophytes were sampled by vigorously sweeping the net within the aquatic vegetation over a length of about 10m. All sweep samples, containing sediment, detritus and macroinvertebrate fauna, were preserved in 80% ethanol in sealed plastic bags. In the laboratory, samples were washed in a flume-hood to remove formalin.

Organic sediments, including macroinvertebrates, were then separated from the inorganic material by water elutriation. The organic sediments were then washed through 3mm, 500µm and 250µm mesh sieves to partition the sample into 'large' and 'small' fractions. The small fractions were sorted under a binocular microscope and collected macroinvertebrates transferred to 100% ethanol. For each sample, the entire 3mm and 500µm fractions were sorted, while 250µm fractions were sub-sampled by one fifth. All animals were identified to the lowest practicable taxonomic level.

FISH

Standardised the time/effort (see Methods). Fish identified to species by direct observation. For most sites, direct observation proved the most efficient method for surveying species presence.

CHANNEL MORPHOLOGY

The channel morphology was measured as pool length, width and depth. This was measured using a range-finder.

To estimate water discharge, a narrow segment of stream of uniform shape was selected and velocity measured, at 0.1m intervals across the segment. Bank-full widths were interpreted from debris zones and high-water marks on banks and riparian trees. River bed materials were qualitatively assessed (e.g. sand, gravels, cobbles, organics *etc*). Measured velocity (Marsh-McBirney Model 201M meter) across channel at 0.6 maximum depth (*sensu* Newbury & Gaboury 1993). Depth measured average depth (graduated pole or metal tape measure).

Sedimentation, as pool aggradation, was assessed as the relative amount of fine inorganic material covering the typical bed substrate. This was completed as a visual assessment by a single operator using mask/snorkel across a 50m transect, where 0= no sediment, 1 = present (0-25%) covering of the pool bed by sediment, 2= common (25-50%), 3= dominant (50-75%) of the pool bed covered by sediment, 4= total covering (100%) of pool bed by sediment.

Areas of deeper water are considered a strong surrogate of habitat complexity. Typically in Robe River pools, areas of deeper water formed around tree roots and large woody debris (LWD). Qualitative measurements of deeper water were made by a single operator using a mask/snorkel across a 50m ('zig-zag') transect, where = 0 areas of water deeper than 2.5m, 1= areas of deeper water (>2.5m) between 0 and 25% of the total pool bed area, 3= areas of deeper water (>2.5m) between 25 and 50% of the total pool bed area, 4= areas of deeper water (>2.5m) greater than 50% of the total pool bed area.

RIPARIAN VEGETATION CONDITION

This is a qualitative assessment of riparian condition with a note of dominant species. At each site, two 50m transects from the waters' edge upslope were made and the following parameters recorded: slope (in degrees), % leaf litter covering the soil, weeds (in area), livestock disturbance (low, medium, high), and over-story condition: 1= dead, 2= much leaf loss, many dead branches, 3= some dead branches, 4= pristine). Opportunistic, qualitative surveys were also made of the noxious aquatic weed Indian Water Fern, *Ceratopteris thalictroides* and the weed Mexican Poppy.

Assessments were broadly based on the rapid assessment methodology outlined in Pen and Scott (1995) and WRC (1999). At each site, two 100m transects from the waters' edge upslope were made and the following parameters recorded: slope (in degrees), % leaf litter covering the soil, weeds (in area), and livestock disturbance (*e.g.* low, medium, and high).

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WRC (1999). Planning and Management: Foreshore Condition Assessment in Urban and Semi-rural Areas of South-west Western Australia. Water and Rivers Commission River Restoration Report No. RR2. ISBN 0-7309-7443-X. October 1999.

VEHICLE DISTURBANCE

Multi-year sampling of the Robe River pools has been associated increasing levels of recreational 4WD vehicle use (particularly around some important pools, Pannawonica Hill and Gnieraoora). Consequently a qualitative coding was developed based on a visual assessment of the level of car tracks across two 100m vertical transect from the waterline, where 0= no tracks, 1= 1-5 tracks ('tracks' were coded as one per vehicle, so two tracks is one 4WD), 2= 5-10 tracks, 3= 10-20 tracks and 4= > 20 tracks.

STATISTICAL ANALYSES: PRIMER

To identify spatial (between sites) and temporal (between-sampling occasions) differences in water quality and macroinvertebrate community structure, data was classified and ordinated using PRIMER (Plymouth Routines in Multivariate Ecological Research) software (Clarke and Gorley, 2001). PRIMER performs multivariate analyses on data sets commonly recorded in biological monitoring of environmental impacts and is widely used for interpretation of community patterns.

Analyses of macroinvertebrates were conducted on presence/absence and abundance data. Similarity matrices were calculated using the Bray Curtis association measure which is appropriate for ecological data in freshwater systems. Sites were classified using hierarchical clustering (CLUSTER) which produces a dendrogram in which samples are grouped according to the similarity of their water quality or macroinvertebrate community composition. Hierarchical clustering is designed to provide ecological information on the occurrence of an assemblage of species from a number of sites - members of each division or group in the dendrogram have a more similar community structure and therefore more similar ecology.

Analysis of Variance (ANOVA)-type tests were then performed to determine if there was a significant separation between groups. This was done by ANOSIM, which compares the mean within-group similarity to the mean between-group similarity. Data were then ordinated using non-metric multi-dimensional scaling MDS. The ordination represents the samples as points in low-dimensional space where sites closest together have more in common than those further apart. Groups identified in the CLUSTER analysis are then overlaid onto the ordination. Species contribution to similarity of groups was calculated using the SIMPER routine. By looking at the overall percentage of contribution each species makes to the average dissimilarity between groups, species can be listed in decreasing order of their importance in discriminating the two groups.

In order to link environmental variables with patterns seen in community structure, physico- chemical data was analysed separately and then its multivariate pattern was compared to that of species data. Ordination of environmental data utilised Principal Components Analysis (PCA). The BIOENV routine was then used to examine whether a particular environmental variable or groups of variables distinguished sites in the as that of community structure.

APPENDIX 3. ANZECC/ARMCANZ (2002) WATER GUIDELINES

Default trigger values for nutrients, dissolved oxygen and pH for protection of aquatic ecosystems for tropical Australia for slightly disturbed ecosystems (from ANZECC/ARMCANZ 2002).

Trigger values are used to assess risk of adverse effects due to nutrients, biodegradable organic matter and pH in various ecosystem types. Data derived from trigger values supplied by Australian states and territories, for the Northern Territory and regions north of Carnarvon in the west and Rockhampton in the east.

TP = total phosphorus, FRP = filterable reactive phosphate, TN = total nitrogen, NOx = oxides of nitrogen, NH4+ = ammonium, DO = dissolved oxygen.

Ecosystem type	TP (mg/L)	FRP (mg/L)	TN (mg/L)	NOx (mg/L)	NH4+ (mg/L)	DO[2] (%)	pH
Upland River[1]	0.01	0.005	0.15	0.03	0.06	90-120	6.0-7.5
Lowland River[1]	0.01	0.004	0.2-0.3[4]	0.01[b]	0.01	85-120	6.0-8.0
Freshwater lakes & reservoirs	0.01	0.005	0.35	0.01	0.01	90-120	6.0-8.0
Wetlands	0.01-0.05[3]	0.005-0.025[3]	0.35-1.2[3]	0.01	0.01	90-120	6.0-8.0

1 = no data available for tropical WA estuaries or rivers. A precautionary approach should be adopted when applying default trigger values to these systems;
2 = percent saturation dissolved oxygen values were derived from daytime measurements. Dissolved oxygen concentrations may vary diurnally and with depth. Monitoring programs should assess this potential variability;
3 = higher values are indicative of tropical WA river pools;
4 = lower values from rivers draining rainforest catchments.