Rum Jungle Aquatic Ecosystem Survey

Early Dry Season 2014

June 2016
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EXECUTIVE SUMMARY

Hydrobiology was commissioned by the Northern Territory Government (Department of Mines and Energy) to undertake an impact assessment and develop locally derived water quality guidelines for the former Rum Jungle mine site. This report covers an aquatic ecosystem survey conducted in May-June 2014 that was undertaken to provide input data to be used in that assessment. It was the first such survey since the 1990s, when post remediation surveys were first conducted after the initial mine site rehabilitation in the mid 1980s (see Jeffree and Twining 2000, Jeffree et al. 2001).

Specifically for this survey, the objectives were to:

- update the assessment of the status of the aquatic ecosystems downstream of the mine lease area since the surveys of the 1990s, with particular focus on where the patterns of aquatic ecosystem condition differed from those observed in the earlier assessments;
- provide contemporary aquatic ecosystem condition assessment and species distribution patterns that in combination with water and sediment quality monitoring data could be used to develop revised water quality objectives based on ecosystem response to contaminant concentrations; and
- investigate alternative sampling techniques that would potentially make future sampling more appropriate and/or cost effective.

Fishes, macrocrustaceans, general macroinvertebrates and benthic diatoms were sampled from 18 sites in the Finniss River upstream of Walker’s Ford, including the East Branch to upstream of the Rum Jungle mine lease area, between 18 May and 6 June 2014, where the sites still retained water at the time and were appropriate for each type of sampling. Where possible and appropriate at each site, sampling methods were designed to be comparable to methods that had been used historically, but other methods were trialled according to the third objective. This was the first such survey of the river system in relation to the Rum Jungle mine in over 20 years.

It was demonstrated that a combination of sampling with a reduced set of floating gill nets for an abbreviated set period of 1630-2030 in combination with fyke netting, electrofishing and bait trapping would capture the range of fish species collected in earlier sampling and be comparable, after adjustment for set period and net area, to the full set of floating and sinking gill nets set from dusk to dawn used in earlier sampling periods. This could be achieved with greatly reduced effort, and concomitant reduction of issues with field crew fatigue for an intensive sampling program and risk of enmeshing and drowning of Freshwater Crocodiles, the populations of which had increased strongly since the 1990s.

There were generally consistent findings for the four groups of aquatic organisms targeted. There were no indications of impact in the Finniss River downstream of the East Branch. This was consistent with the findings of surveys conducted in the 1990s, except indicting further recovery of mussel populations, and general recovery of the main Finniss River after
remediation of the mine site in the mid 1980s, but in contrast to the findings of surveys in the 1970s of impacts in the Finniss River as far downstream as Florence Creek.

There were also relatively consistent patterns of reductions in diversity and abundance of all four groups in the mine lease area (zone 2) and gradual improvement in diversity and abundance downstream of the mine lease to the Finniss River junction. Tissue metal concentrations in a number of species also indicated increased bioavailability of copper and zinc in the mine lease area, and cobalt and nickel either in the mine lease area or shortly downstream of it, and gradual reduction of bioaccumulation of those metals downstream through the East branch, with no evidence for increased bioaccumulation of them at any of the Finniss River sites. This is consistent with known inputs of acid drainage containing substantial quantities of those metals into the East Branch within the mine lease area.

The assemblages in the East Branch were improved for all three groups relative to what was found in the 1990s, despite no further remediation of the mine lease area. The reason for this is unclear, and may indicate:

i) there is a time dependency related to lag factors that are operating on the rates of recolonisation after the step reduction in contaminants loads that was measured in the 80’s and 90’s;

ii) annual contaminant loadings and/or their bioavailabilities have continued to reduce since the 90s allowing for more recolonisation, such as via reduction of sediment sources of contaminants over time; and/or

iii) there has been continued adaptation in the fish biota of the East Branch following their decades of exposure to contaminants, as demonstrated in the 90s for one species in the East Branch (Gale et al., 2003), although the patterns of bioaccumulation by that species in 2014 were not consistent with a high level of inhibition of copper uptake persisting for the East Branch population.

Exceptions were found to the general pattern of a gradient of impact in the East Branch stemming from the mine lease area and improving downstream, and the inference that this was caused by acid drainage:

- Site EBdsRB supported a diverse, abundant macroinvertebrate assemblage that was comparable to those of the Finniss River and upper East Branch control sites, despite being within the mid-reaches of zone 3 downstream of the mine lease area;
- The fish assemblage at the site upstream of EBdsRB, EB@GS327, was more speciose than for other zone 3 sites, and more comparable to the sites in zone 4, while the assemblage at EBdsRB was more comparable to the site in the mine lease area EB@GS200; and
- The diatom assemblage of the East Branch, while less diverse and abundant than the sites in the Finniss River system, was dominated by species that were classified as alkalophilic or preferring circumneutral pH waters. The metal tolerances of the dominant species were not known. The observed pH preferences of the dominant species were not consistent with an impact caused by acid drainage, and this was postulated to have resulted from altered grazing pressure caused by the absence of
fish and macrocrustacean algivorous species and reduced abundance of macroinvertebrate grazers. However, the absence of fish and macrocrustacean algivores was also not able to be explained, and may have resulted from either greater sensitivity to increase metal bioavailability of those species compared with other feeding guilds, or to reduced quality of their algal food sources due to the observed differences in algal assemblage composition.

It was acknowledged that the use of a single round of biological assessment over 20 years after previous sampling was not a strong basis for comparison, and also that the timing of the survey early in the dry season was not comparable to the later dry season sampling of the 1990s, particularly for the intermittent East Branch. Therefore it was recommended that:

- Repeat sampling in 2015 of the Finnis and East Branch using the recommended new suite of sampling methodologies, including a much reduced program of gill netting to improve the baseline of contemporary ecosystem condition for use for assessment of the success of further rehabilitation and be consistent with sets of multiple rounds of sampling used in the previous periods. It is recommended that this occur in the similar early dry season period as for the 2014 sampling because this will capture maximal spatial extent of fish species when access permits; and

- It was recommended that more effort be placed into understanding the current extent of recovery and its drivers in the East Branch by:
  - an additional sampling round later in the Dry of 2015 targeted at macroinvertebrate and diatom assemblages but with fish sampling of the East Branch only to provide a better comparison with sampling in the 90s; and
  - ii) comparison of the presence of biota along the pollution gradient of the East Branch with ecological risk predictions of the presence of different biota based on water quality alone, including geochemical modelling of bioavailable fractions, for comparison with similar 90s assessments.
# Rum Jungle Aquatic Ecosystem Survey

**Early Dry Season 2014**

**June 2016**

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1 INTRODUCTION

1.1 Background

Hydrobiology was commissioned by the Northern Territory Government (Department of Mines and Energy) to undertake an impact assessment and develop locally derived water quality guidelines for the former Rum Jungle mine site. This report covers an aquatic ecosystem survey conducted in May-June 2014 that was undertaken to provide input data to be used in that assessment. It was the first such survey since the 1990s, when post remediation surveys were first conducted after the initial mine site rehabilitation in the mid 1980s (see Jeffree and Twining 2000, Jeffree et al. 2001).

As described in the study Terms of Reference (ToR), the former Rum Jungle Mine site was mined in the 1950s-1970s then rehabilitated during the 1980s. Monitoring of landform stability and water quality has continued since that time. A current collaborative Northern Territory and Commonwealth Governments project (under a Partnership Agreement) aims to provide a more permanent reduction in environmental impacts from the site due to acid and metalliferous drainage (AMD) by adopting leading practice rehabilitation methods. A Conceptual Rehabilitation Plan was completed in May 2013 as the final output of Stage 1.

Already completed are some of the studies to apply the ANZECC (2000) water quality guidelines for rehabilitation planning at the Rum Jungle Mine site. The aim of these studies is to provide:

- a clear definition of environmental values, or uses;
- a good understanding of links between human activity, including indigenous uses, and environmental quality;
- unambiguous management goals;
- appropriate water quality objectives, or targets; and
- an effective management framework, including cooperative, regulatory, feedback and auditing mechanisms.

Two reports already completed (Hydrobiology, 2013a and 2013b) have identified and defined the receiving environment including the relevant environmental values of the receiving environment in accordance with ANZECC/ARMCANZ methodology including assessment of the aquatic ecosystems as well as fluvial sediments downstream of the mine site. Building on these previous two studies, the purpose of this project was to:

- undertake expanded environmental impact assessment monitoring to ensure a robust data set is compiled and interpreted (in parallel with ongoing monitoring by DME) and, based on this assessment, make recommendations in relation to any elevated levels of contaminants identified or measurable biological impairment; and
- develop locally derived water quality guidelines which can be applied to the process of developing detailed designs for rehabilitated landforms at Rum Jungle. These will be used as a basis for planning all existing and new data (gathered by DME and this project).
1.2 Objectives

Specifically for this survey, the objectives were to:

- update the assessment of the status of the aquatic ecosystems downstream of the mine lease area since the surveys of the 1990s, with particular focus on where the patterns of aquatic ecosystem condition differed from those observed in the earlier assessments; and
- provide contemporary aquatic ecosystem condition assessment and species distribution patterns that, in combination with water and sediment quality monitoring data, could be used to develop revised water quality objectives based on ecosystem response to contemporaneous contaminant concentrations.

This report provides a description of the survey that was undertaken and reviews the aquatic ecosystem condition data in the light of those objectives.

In the course of developing and undertaking the survey, it became apparent that some survey methodologies that had been used in the past were no longer regarded as good sampling practice, were more labour intensive than was practicable for a wider ranging survey being carried out within a limited timeframe, or were no longer appropriate due to changes in the aquatic ecosystems for reasons of concern for animal welfare, as is discussed in more detail in Section 3.1. The issues meant that an additional objective of the survey was to investigate alternative sampling techniques that would potentially make future sampling more appropriate and/or cost effective.

2 METHODOLOGY

2.1 Survey Timing and Sampling Sites

The survey was conducted between 18 May and 6 June 2014. It was conducted as a joint exercise between Hydrobiology and the Northern Territory Department of Mines and Energy (DME), including members of the Environmental Monitoring Unit of DME (EMU). Although it was attempted to include traditional owners in the sampling team, via liaison between DME and the Northern Land Council and some direct contact with traditional owners on the Rum Jungle Liaison Committee, unfortunately no traditional owners were able to volunteer to participate at the time of the survey.

The survey sites are listed in Table 2-1 and their locations are shown in Figure 2-1. Note that by convention in this report the east branch of the Finiss River is referred to simply as the East Branch. Also shown in the table and on the figure are the locations of river zones that were defined by Hydrobiology (2013a) for the purpose of setting water quality objectives. Those zones are used in this report to refer to groups of sites with differing levels of mine site-related inputs and dilution of them, because the zone boundaries are defined by sources of inputs and by major tributary junctions that will afford some dilution and geochemical alteration of waters from the mine lease area.
### Table 2-1  Sampling sites used for the 2014 survey and corresponding historical site codes.

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Figure 2-1 Sampling site locations
### 2.2 Field procedure

#### 2.2.1 Gill netting

As an objective of the survey was to compare 2014 fish catches with the historic datasets, it was important to ensure that the methods used were comparable with those used in previous rounds of sampling, whilst balancing that desire with the desire to trial less destructive sampling techniques and control the overall sampling effort. Table 2-2 shows the historic gill net set. Descriptions of the historic net set in previous publications had suggested that the mesh size referred to knot-to-knot measurements, but inquiry with the field sampling team from the 1990s indicated that the measurements were actually stretched-mesh or the maximum length of the mesh hole size if stretched to its maximum extent. By convention in this report, all nets are referred to by the knot-to-knot size in mm.

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<th>Drop (m)</th>
<th>Stretched Mesh</th>
<th>Knot to knot</th>
</tr>
</thead>
<tbody>
<tr>
<td>Float</td>
<td>12.5</td>
<td>2.4</td>
<td>0.5</td>
<td>12</td>
</tr>
<tr>
<td>Sink</td>
<td>12.5</td>
<td>2.4</td>
<td>0.5</td>
<td>12</td>
</tr>
<tr>
<td>Float</td>
<td>25</td>
<td>1.56</td>
<td>1</td>
<td>26</td>
</tr>
<tr>
<td>Sink</td>
<td>25</td>
<td>1.56</td>
<td>1</td>
<td>26</td>
</tr>
<tr>
<td>Float</td>
<td>25</td>
<td>1.88</td>
<td>1.5</td>
<td>40</td>
</tr>
<tr>
<td>Sink</td>
<td>25</td>
<td>1.88</td>
<td>1.5</td>
<td>40</td>
</tr>
<tr>
<td>Float</td>
<td>25</td>
<td>2.5</td>
<td>2</td>
<td>50</td>
</tr>
<tr>
<td>Sink</td>
<td>25</td>
<td>2.5</td>
<td>2</td>
<td>50</td>
</tr>
<tr>
<td>Float</td>
<td>25</td>
<td>3.75</td>
<td>3</td>
<td>75</td>
</tr>
<tr>
<td>Sink</td>
<td>25</td>
<td>3.75</td>
<td>3</td>
<td>75</td>
</tr>
</tbody>
</table>

A critical parameter for gill nets is the diameter of the monofilament that is used to construct the meshes. Thicker line is more robust, but tends to have reduced catch efficiency as the resulting net becomes less flexible and fish less likely to become enmeshed, particularly smaller individuals that would normally be caught by smaller meshed nets.

In the absence of certainty of this parameter, it was assumed that the monofilament threads used were those commonly used by Australian net manufacturers. There is a tendency of these manufacturers to err in favour of more robust nets, rather than catch efficiency, particularly for the smaller mesh sizes which are rarely used for commercial fishing purposes. While the more robust nets work well for commercial fishing for larger species, particularly in the tropics where crocodile damage to nets can be an operating cost burden, the tendency to favour robustness can lead to under-sampling of smaller fishes in the smaller meshed nets. Hydrobiology experience has indicated that this commonly leads to a net catch efficiency detriment for nets of 25 mm knot-to-knot measurement or less. Improved catch efficiency has been found for nets sourced from southeast Asia or Europe for these mesh sizes, as manufacturers in these countries tend to favour finer monofilament thread. Over the years the most reliable supplier of such nets has been found to be Oy Lindemen AB of
Finland, and this has resulted in these nets being commonly referred to within the company as Finnish nets. These nets use 0.2 to 0.25 mm diameter monofilament line. The comparable Australian nets used 0.37 or 0.42 mm diameter line.

Consequently, as Hydrobiology usually maintains a stock of Finnish nets, these were used as alternative/supplementary nets for the 13, 19 and 25 mm nets. Also, as the Finnish nets come in a standard 10 m long by 2.4 m drop configuration, they are often more readily employed in smaller waterholes and in snaggy areas than are the longer nets that were historically used can be difficult to set fully extended.

Also, it was decided to use non-destructive electrofishing and fyke netting techniques in the hope that they could at least in part replace the destructive gill net sampling that had been done in the past. Because these techniques favour capture of small-bodied species, it was decided to not include the 6 mm gill net that had been used in the past to target these smaller species.

Table 2-3 lists the full net set that was taken for use for this survey. Not all nets were able to be used at each site, depending on the available aquatic habitat and configuration/characteristics of the site. Further discussion of what nets were used at what sites and why is made in Section 3.1.1. Generally there was a tendency to favour the Finnish nets over the Australian nets where there was limited available space for nets.

Table 2-3 Gill nets used in 2014

<table>
<thead>
<tr>
<th>Weighting</th>
<th>Dimensions (length × drop) m</th>
<th>Source</th>
<th>Line diameter mm</th>
<th>Mesh mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Float</td>
<td>10 × 2.4</td>
<td>Finnish</td>
<td>0.2</td>
<td>13</td>
</tr>
<tr>
<td>Sink</td>
<td>10 × 2.4</td>
<td>Finnish</td>
<td>0.2</td>
<td>13</td>
</tr>
<tr>
<td>Float</td>
<td>10 × 2.4</td>
<td>Finnish</td>
<td>0.25</td>
<td>19</td>
</tr>
<tr>
<td>Sink</td>
<td>10 × 2.4</td>
<td>Finnish</td>
<td>0.25</td>
<td>19</td>
</tr>
<tr>
<td>Float</td>
<td>25 × 1.88</td>
<td>Australian</td>
<td>0.37</td>
<td>19</td>
</tr>
<tr>
<td>Sink</td>
<td>25 × 1.88</td>
<td>Australian</td>
<td>0.37</td>
<td>19</td>
</tr>
<tr>
<td>Float</td>
<td>10 × 2.4</td>
<td>Finnish</td>
<td>0.25</td>
<td>25</td>
</tr>
<tr>
<td>Sink</td>
<td>10 × 2.4</td>
<td>Finnish</td>
<td>0.25</td>
<td>25</td>
</tr>
<tr>
<td>Float</td>
<td>25 × 2.5</td>
<td>Australian</td>
<td>0.37</td>
<td>25</td>
</tr>
<tr>
<td>Sink</td>
<td>25 × 2.5</td>
<td>Australian</td>
<td>0.37</td>
<td>25</td>
</tr>
<tr>
<td>Float</td>
<td>25 × 3.75</td>
<td>Australian</td>
<td>0.42</td>
<td>39</td>
</tr>
<tr>
<td>Sink</td>
<td>25 × 3.75</td>
<td>Australian</td>
<td>0.42</td>
<td>39</td>
</tr>
</tbody>
</table>

The nets were set for variable time periods as discussed in Section 3.1.1. The default was from dusk to dawn with a net clearance (removal of enmeshed fishes) at midnight.

2.2.2 Electrofishing

Electrofishing was conducted using a Smith Root model LR20B backpack electrofisher. At most sites where it was used, rainbowfishes were readily evident in the sampling area, and
so the instrument settings were adjusted according to the electrical conductivity of the water and the responses of the rainbowfishes. If larger specimens, and particularly gudgeons were present, the output settings were adjusted according to the responses of those species when encountered. In particular, care was taken to avoid causing cervical muscle spasms in gudgeons and gobies, which can result in debilitating injuries, as these groups are more prone to this impact than other fishes. Generally, the instrument was initially set at 150 V, with a pulse frequency of 70 Hz and a duty cycle of 40%, and adjusted according to fish responses.

At each site a visual assessment was made of areas that could be safely waded. The electrofisher operator and assistant then waded upstream through the selected area, with one or more crocodile spotters on the stream high bank were judged appropriate, sampling in all available habitats within the safe sampling area or when more than 10 mins had transpired from the last new species collected, whichever occurred first. It was generally attempted to use at least 300 s of instrument on-time where possible. All captured specimens were kept alive in a sampling bucket, and identified to species and counted before return to the sampling site. Only one sample was taken per site using this device.

### 2.2.3 Fyke nets

Fyke nets of two sizes were used, depending on the availability of suitable setting locations and the water depth at those locations. The nets were:

- large fyke – 1 m diameter with wings 5 m long by 1 m deep with 4 mm woven mesh; and
- small fyke – 0.5 m diameter with wings 5 m long by 1 m deep with 4 mm woven mesh.

Fyke nets were set overnight (dusk to dawn) at the time of setting the gill nets at each site, after visual selection of suitable sites that were safe to wade, and were of suitable depth for each size net. Only two nets were set at each site, with the combination of sizes used dependent on the water depth at each site, with a bias toward using the 1 m diameter nets were possible. At EB@GS097 two large and two small nets were set to provide some basis for comparison between net sizes at a site.

The nets were set in a manner to ensure at least part of the final cod end was above water so that any air breathing species collected would not drown overnight. In the morning, the nets were retrieved and the catch was emptied into a bucket of water where the specimens were kept alive until identified to species and counted and returned alive to the sampling site. Any trapped reptiles (turtles and crocodiles were captured during the survey) were removed from the net immediately on retrieval of the net, identified and counted before release at the site of capture. Turtles were measured for carapace length and photographed prior to release.
2.2.4 Bait traps
Standard recreational bait traps 43 cm × 25 cm × 25 cm, with 2 mm mesh and funnels on each end were baited with cat biscuits and set in backwaters, snags and bank overhangs from dawn to dusk. A total of five traps was set at each site where they were used. When retrieved, captured specimens were identified to species, counted and returned to the water.

2.2.5 Cast netting
A nylon monofilament cast net with 12 mm knot to knot mesh and 1.86 m drop was used opportunistically to catch fish where time and habitat suitability permitted. It was only used to supplement the species list for sites, and was not used in a quantitative manner.

2.2.6 Seine netting
A seine net with 4 mm stretched mesh of woven multifilament which was 10 m long and with a 2 m drop and central cod end built into the bag of the net was used only occasionally where time and habitat (shallow areas with few snags and a shallow sloping bank profile for the final stages of the net haul) permitted. It caught few fishes and did not add to the species list for any site, and so the seine net catches were not used in the data analyse in the Results section.

2.2.7 Macroinvertebrate sampling
Macroinvertebrate sampling used a reconstruction of the submersible pumped water sampler used by Edwards (2002). The sampler consists of a 250 mm internal diameter cylindrical sampling head unit that is connected by a sampling hose and return water hose to a second unit that encloses the sample collection mesh and a pump unit. The pump is used to circulate water from the head unit through the collection mesh and back to the head unit, trapping entrained macroinvertebrates. Samples were collected only from bed sands that could be safely accessed by wading. Agitation of the sands enclosed by the head unit to a depth of 100 mm by use of mild steel probe allowed collection of macroinvertebrates on the sand surface and to a depth of 100 mm within the sand. Three replicate samples were collected at each site, with each replicate selected randomly from the selected sampling area.

The mesh used was 500 μm mesh, on the recommendation of C. Edwards based on knowledge of the macroinvertebrate assemblages from previous sampling in the 1990s. The collected specimens and associated debris retained by the collection mesh were preserved in 70% ethanol in plastic jars and labelled. The preserved samples were sent to Alistair Cameron Consulting for sample sorting and specimen identification, generally to the Family level of identification used by Edwards (2002), and enumeration.

2.2.8 Diatom sampling
Diatom samples were collected by using a small plastic spatula to collect sediment surface film from backwater/depositional areas that were safely accessible at each site. Each sample consisted of sediment surface scrapes from at least three areas, and two replicate samples were collected at each site. The samples were put into plastic vials, and preserved with
Lugol’s solution. The preserved samples were sent to the Geography, Environment and Population Department at Adelaide University for identification and enumeration (based on standard microscope fields of view).

2.2.9 Tissue metal concentration samples

Tissue samples of the following tissue types and species were collected at each site depending on availability from the sampling conducted at each site:

- Bony bream *Nematalosa erebi* flesh (dorsal muscle) samples;
- Hyrtl’s tandan *Neosilurus hyrtlii* flesh samples;
- Northern trout gudgeon *Mogurnda mogurnda* hind body samples;
- Black-banded rainbowfish *Melanotaenia nigrans* whole body samples; and
- *Macrobrachium bullatum* purged (in site water for at least 48 h until faecal pellets were no longer visible in the gut) cephalothorax samples.

Specimens for tissue metal concentration analysis were frozen until they could be dissected on return to the EMU laboratories in Darwin. Dissections were performed on fresh polyethylene sheets using instruments that had been washed in a solution of 10% analytical grade nitric acid in demineralised water. Precautions were taken during dissection to prevent contamination of tissues by changing scalpel blades between fish batches from each site and species, having the dissector and assistants wear vinyl surgical gloves, and washing all tissues and dissecting equipment with distilled/deionised water before and after each dissection. After dissection each tissue sample was thoroughly washed with deionised water and placed in a separate sample bag and labelled. This bag was then placed in a second bag, also labelled. Samples were then frozen in readiness for shipping.

The frozen samples were then transported back to Brisbane on ice where they were on-forwarded to Advanced Analytical Australia in Brisbane for tissue metal concentration analysis by ICP-MS.

Samples of fish flesh for radionuclide activity analysis were also dissected on fresh polyethylene sheets using instruments that had been washed in a solution of 10% analytical grade nitric acid in demineralised water. At least 250 g of flesh tissue was taken per sample. After dissection each tissue sample was thoroughly washed with deionised water and placed in a separate sample bag and labelled. This bag was then placed in a second bag, also labelled. Samples were then frozen in readiness for shipping.

The frozen samples were then transported back to Brisbane on ice were they were on-forwarded to The National Centre for Radiation Science of ESR (Institute of Environmental Science and Research Ltd) in Christchurch, New Zealand for analysis for $^{210}\text{Pb}$, $^{210}\text{Po}$, $^{226}\text{Ra}$ and $^{228}\text{Ra}$.

Mussel *Velesunia angasi* samples were collected by hand at each selected site where they occurred. Up to 50 specimens were collected at each site, and kept alive in site water until they could be delivered to the Environmental Research Institute of the Supervising Scientist (ERISS) for analysis for $^{210}\text{Pb}$, $^{210}\text{Po}$, $^{226}\text{Ra}$ and $^{228}\text{Ra}$.
2.3 Data Analysis

Univariate statistical analyses were performed using the Tibco Spotfire S+ 8.2 statistical analysis package. Multivariate analyses were performed using the Primer-E Ltd, Primer 6.1 analysis package.

Electrofishing samples were standardised by scaling to 400 s of instrument on-time for abundance data, but not for species richness. Samples from individual gill nets were scaled to the net dimensions of the historical dataset for abundance measurements, but not for species richness. Fyke net and bait trap samples were not scaled.

The tissue metal concentrations were log transformed prior to analysis, as metals may accumulate with age, and length is related to age by a growth curve, usually of the form:

\[ \text{Length} = \text{Length}_{\text{max}} - \left( \text{Length}_{\text{max}} - \text{Length}_{0, \text{age, class}} \right) e^{-Kt} \]

Where \( t \) is age and \( K \) is the instantaneous growth rate. Thus, where metal concentration is linearly correlated with age, it would be log-correlated with length. Therefore, length was included as a covariate in the analyses with log transformed metal as the dependent variable. The assumptions of traditional ANCOVA, equality of variance and normality of the residual variance, were checked by examination of graphs of the residuals against the model values, and normal probability plots of the residuals. A manual stepwise analysis procedure with term inclusion/exclusion threshold of \( P=0.10 \) used. Where more than one term had a \( P \) value above the threshold in a step, the interaction term and then the covariate were preferentially removed from the model in that sequence.

The metal concentrations were compared with the Food Standards Australia New Zealand (FSANZ 2013) standards where appropriate.

3 RESULTS

3.1 Fish and Macro-crustaceans

3.1.1 Assessment of Sampling Methods

3.1.1.1 Non Gill Net Methods

Electrofishing and fyke netting were trialled in 2014 as replacements of the 13 mm gill net used in previous rounds of sampling primarily to assess the possibility of using non-destructive sampling methods as a replacement of gill netting. They were also used as replacements of seine netting, because they do not have the same restricting requirements for areas with few obstructions to minimise snagging of the net and a good beach area for the final stage of hauling the seine net. Essentially, the two devices were able to be used in a wider variety of habitat types than the combination of 13 mm gill net and seine net and had the added advantage of being non-destructive sampling methods.
Backpack electrofishing is a widely used method of non-destructive sampling of fishes, but because of the need for the operator and assistant(s) to wade in the water and the relatively low power output compared with larger, generator powered units, the technique will have had the following limitations in the context of sampling in the Finnis River system:

- is generally restricted to waters of wadable depth, typically less than 1 m;
- in waters with resident crocodiles will be further restricted to habitats and stream sections that are safe for people to wade, with good access for rapid egress, and absence of or good visibility into potential crocodile habitat;
- effectively can only be used during the day when visibility increases the effectiveness of the device and when crocodile risks can be minimised; and
- will tend to be biased towards macrocrustaceans and small bodied fishes due to the ability of larger specimens to avoid or clear the effective capture zone around the anode except when habitat configurations prevent that.

This combination of limitations meant that it was anticipated that the electrofisher would overlap with the 13 mm gill net and seine net in terms of fish species targeted, but would sample habitats that were not able to be sampled by either (e.g. shallow snaggy sections), and would overlap in terms of habitats sampled by the seine net (i.e. shallow sandy areas), but would not sample deeper areas sampled by the 13 mm gill net. It was considered to have sampled a similar range of habitats to those sampled by rotenone sampling in the 1970s.

Fyke nets are also non-destructive sampling devices that are widely used and come in a wide variety of configurations, and have been selected as a standard sampling method for fishes in Western Australia (WADOW 2009). They work best at night, when electrofishing is not possible, from previous experience of Hydrobiology are known to be effective at collecting a wide variety of fish species, and will also safely capture a range of aquatic tetrapods, particularly turtles, which can provide supplementary information for targeted sampling of that group of organisms. The size of the fyke net limits the depth of water that it can be set in, because to be effective the “wings” and opening of the net should reach from the water surface to the bottom. For this round of sampling two different sizes of fyke net were used, as described in the Methods section, so that the nets targeted different ranges of depths. The larger of the nets was anticipated to have overlapped with the water depths typically targeted in the past by the 13 mm gill net.

An advantage of both sampling methods is that they do not require the fish to become enmeshed in order to be captured, as do gill nets, and so are also able to capture fishes that are not readily caught in gill nets, such as eels, flatfishes and rays.

Other non-destructive methods that were trialled in 2014 included the use of collapsible bait traps, a standard recreational bait capture method that uses bait to collect a range of fishes and crustaceans, and seine netting. Bait traps were able to be used at most sites, but with limited success, whereas seine netting was time consuming in an already busy field schedule, and was restricted to use in areas where the net could be hauled without snagging.
and with a good beach or low-slope bank area where the net can be hauled ashore without substantial loss of captured specimens. In 2014 it was not used widely because of these restrictions, and the widespread use of other methods.

Table 3-1 shows a comparison of the fish species caught by the combination of sampling equipment used to target smaller fishes in the single round of sampling in May-June 2014 compared with fish species caught by seine netting and the 13 mm gill net in all past sampling rounds. Only three species collected in the 1990s by the 13 mm/seine were not caught by the methods used in 2014, and only one of those, *Acanthropagrus berda* was not caught by other gill nets in 2014. That species is a marine vagrant species that was not collected by any method in 2014, most probably due to low abundance in fresh water at that time. However, the suite of methods used in 2014 captured 11 fish species, 5 crustacean species and a crocodile species that were not captured in the 1990s by the combination of the 13 mm gill net and seine netting (the latter only used in the East Branch in 1990s sampling). Therefore, the suite of methods used in 2014 was much more comprehensive than the two devices used to target smaller species in the 1990s, particularly the combination of electrofishing and fyke netting, which captured all species captured by the full suite.
Table 3-1  Species caught by 13 mm gill net and seine netting in 1990s sampling and by methods targeting smaller species used in 2014. Light shading indicates not caught in 1990s. Dark shading indicates not caught in 2014.

<table>
<thead>
<tr>
<th>Column1</th>
<th>1990's</th>
<th>2014</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>13 mm Gill</td>
<td>Other Gill</td>
</tr>
<tr>
<td>Acanthopagrus australis</td>
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<td>X</td>
</tr>
<tr>
<td>Ambassius macleayi</td>
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<td>X</td>
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<td>Amniataba percoides</td>
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<tr>
<td>Craterocephalus stercusmuscarum</td>
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<tr>
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<td>Dytiscid sp 2 (Medium)</td>
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</tr>
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</tr>
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<td>X</td>
</tr>
<tr>
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</tr>
<tr>
<td>Lates calcarifer</td>
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</tr>
<tr>
<td>Leiopotherapon unicolor</td>
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<td>X</td>
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<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Melanotaenia nigrans</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Melanotaenia splendidida inornata</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Mogurnda mogurnda</td>
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</tr>
<tr>
<td>Nematalosa erebi</td>
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</tr>
<tr>
<td>Neosilurus ater</td>
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</tr>
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<tr>
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</tr>
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</tr>
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</tr>
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</tr>
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</tr>
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<td>X</td>
</tr>
<tr>
<td>Macrobrachium handschini</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Crocodylus johnstoni</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grand Total</td>
<td>8</td>
<td>11</td>
</tr>
</tbody>
</table>

3.1.1.2 Comparison of Gill Net Set Times

In the 1970s and 1990s, sampling with gill nets involved setting the nets before sunset (nominally completed by 18:00) with the nets checked and cleared at midnight and after dawn (nominally 06:00). This worked well, with only rare instances of crocodiles becoming enmeshed or damaging the gill nets (R. Jeffree pers. obs.). Before the start of sampling for this survey, it was acknowledged that the crocodile populations had increased in density.
substantially since the 1990s, and that the chance of crocodiles becoming enmeshed had increased concomitantly, particularly *C. johnstoni*. Therefore, in addition to the midnight and dawn net checks, net checking for crocodiles only (i.e. not including removal of fishes) at 2 h intervals was instigated for this survey to mitigate that risk.

Unfortunately, that system failed to prevent incident. Two *C. johnstoni* became enmeshed and drowned in gill nets at the first site sampled, FRdsMB, despite the use of 2 h net check intervals. At the second sampled site, FRusMB there were no incidents with 2 h net checks. After that the sampling schedule moved to sites in the upper East Branch, where gill nets were not used. This was because there had been no historic use of gill nets in the East Branch, and the upstream sites had only shallow water that could be effectively sampled by other means. The next site for which gill nets were used was EBusHS. At this site, only a subset of gill nets could be used due to the limited extent of deeper habitats, and despite the first net check being within 1.5 h of dusk, a specimen of *C. johnstoni* had drowned at that time. It was decided then that the nets would be removed at 20:30 because a similarly limited pre-dusk to ~20:30 set time had proven to be an effective strategy to minimise *C. johnstoni* capture while still collecting most fish species in other project work. Hydrobiology had conducted in the southern Gulf of Carpentaria. This strategy was also employed at site EBdsHS, with the additional of hourly net checks for crocodiles. The nets were set slightly earlier in the afternoon (16:30) to ensure the full peak period of fish movement around dusk was included. Note that these sites had never been sampled using gill nets in the past, and hence there were no historic data available for comparison. Although upstream of EBdsHS, EB@GS327 was the next site sampled. This site included an extensive waterhole and so a set of four gill nets was able to be deployed from 16:30 to 20:30 with hourly checks for crocodiles.

At the next site, EBusFR, where the sampling site was in a large waterhole more comparable to those in the Finniss River, it was decided that the sampling would revert to the full dusk to dawn sampling period to enable comparison of catches at that site with the Finniss River sites and the historic sampling in the Finniss River. However, it was apparent that there would be benefit in future if the shorter 16:30 to 20:30 set time were able to be used as:

- it would reduce field crew fatigue by limiting the period requiring hourly net checks;
- it would assist with minimising the risk of enmeshing and drowning or harming *C. johnstoni*; and
- if it resulted in effective sampling of fishes it would reduce the amount of mortality to fishes as well.

Therefore, for EBusFR and the remaining Finniss River sites, the nets were:

- set each afternoon at 16:30;
- checked each hour until dawn;
- checked and cleared of fishes at 20:30;
- checked and cleared of fishes at 24:00; and
• checked, cleared of fishes and removed at 06:30

Each time the nets were cleared of fishes, the catch was recorded as a separate event to enable comparison of the effectiveness of each period at collecting a representative sample of fishes. Table 3-2 shows that the majority of species collected at each of the sites where the 20:30 net check was used were collected in that initial period. While additional species were collected in subsequent checks they represented a small proportion of the total number of species collected at each site. Similarly, Table 3-3 shows that on average almost three quarters of the total number of fish caught by midnight and half of the fish caught in total overnight were collected in the first period. The standard errors of the mean proportions caught for each period were small, indicating that a reliable estimate of the catch in terms of number of species and number of fish at the midnight and dawn checks could be obtained by extrapolation from the 20:30 check.

**Table 3-2** Cumulative number of species collected in gill net set with each net check and proportion of species collected in the 20:30 check of the cumulative total at 24:00 and 06:30

<table>
<thead>
<tr>
<th>Site</th>
<th>20:30 check</th>
<th>24:00 check</th>
<th>06:30 check</th>
<th>%20:30/24:00</th>
<th>%20:30/06:30</th>
</tr>
</thead>
<tbody>
<tr>
<td>EBUSFR</td>
<td>8</td>
<td>1</td>
<td>1</td>
<td>89%</td>
<td>80%</td>
</tr>
<tr>
<td>FR@GS204</td>
<td>11</td>
<td>1</td>
<td>0</td>
<td>92%</td>
<td>92%</td>
</tr>
<tr>
<td>FR3</td>
<td>11</td>
<td>0</td>
<td>0</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>FRDSFC</td>
<td>10</td>
<td>1</td>
<td>3</td>
<td>91%</td>
<td>71%</td>
</tr>
<tr>
<td>FRUSFC</td>
<td>10</td>
<td>0</td>
<td>2</td>
<td>100%</td>
<td>83%</td>
</tr>
<tr>
<td>FRUSMB</td>
<td>11</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FRDSMB</td>
<td>8</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Mean                  94%     85%
SE                    2.4%   4.9%

**Table 3-3** Cumulative abundance of fishes collected in gill net set with each net check and proportion of specimens collected in the 20:30 check of the cumulative total at 24:00 and 06:30

<table>
<thead>
<tr>
<th>Site</th>
<th>20:30 check</th>
<th>24:00 check</th>
<th>06:30 check</th>
<th>%20:30/24:00</th>
<th>%20:30/06:30</th>
</tr>
</thead>
<tbody>
<tr>
<td>EBUSFR</td>
<td>16</td>
<td>10</td>
<td>11</td>
<td>62%</td>
<td>43%</td>
</tr>
<tr>
<td>FR@GS204</td>
<td>25</td>
<td>8</td>
<td>8</td>
<td>76%</td>
<td>61%</td>
</tr>
<tr>
<td>FR3</td>
<td>36</td>
<td>11</td>
<td>23</td>
<td>77%</td>
<td>51%</td>
</tr>
<tr>
<td>FRDSFC</td>
<td>27</td>
<td>14</td>
<td>23</td>
<td>66%</td>
<td>42%</td>
</tr>
<tr>
<td>FRUSFC</td>
<td>34</td>
<td>12</td>
<td>24</td>
<td>74%</td>
<td>49%</td>
</tr>
<tr>
<td>FRUSMB</td>
<td>37</td>
<td>29</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FRDSMB</td>
<td>36</td>
<td>36</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Mean                  71%     49%
SE                    3.0%   3.4%
Table 3-4 shows the species that were caught in each check period across all sites. Only *Liza vaigiensis* would not have been caught by a combination of the 20:30 check and the non-gill net sampling used in 2014, and that species was only represented by a single specimen caught at FRdsMB. The species is primarily active at dawn, dusk and during the day, and so the capture of a single specimen in the morning net check at one site is indicative only that it was rare in the system, not that it would only be likely to be captured in a particular net check period.

**Table 3-4** Species caught in each net check period and by other methods in 2014 sampling

<table>
<thead>
<tr>
<th>All Species</th>
<th>8:30</th>
<th>Midnight</th>
<th>Morning</th>
<th>Other Sampling</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Ambassis macleayi</em></td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td><em>Amniaataba percoïdes</em></td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td><em>Glossamia aprion</em></td>
<td>X</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td><em>Glossogobius sp. 2.</em></td>
<td>X</td>
<td>X</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td><em>Gunter sp.</em></td>
<td>✓</td>
<td>X</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td><em>Hephaestus fuliginosus</em></td>
<td>✓</td>
<td>X</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td><em>Lates calcarifer</em></td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td><em>Leiopotherapon unicolor</em></td>
<td>✓</td>
<td>X</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td><em>Liza vaigiensis</em></td>
<td>X</td>
<td>X</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td><em>Megalops cyprinoides</em></td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td><em>Melanotaenia splendida inornata</em></td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td><em>Nematalosa erebi</em></td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td><em>Neoarius bernyi</em></td>
<td>✓</td>
<td>X</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td><em>Neosilurus ater</em></td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td><em>Neosilurus hyrtlii</em></td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td><em>Oxyeleotris lineolata</em></td>
<td>✓</td>
<td>✓</td>
<td>X</td>
<td>✓</td>
</tr>
<tr>
<td><em>Oxyeleotris selhemi</em></td>
<td>X</td>
<td>✓</td>
<td>X</td>
<td>✓</td>
</tr>
<tr>
<td><em>Neoarius graeffei</em></td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td><em>Strongylura kreftii</em></td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td><em>Syncomistes butleri</em></td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td><em>Toxotes chatareus</em></td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td><em>Toxotes lorentzi</em></td>
<td>✓</td>
<td>X</td>
<td>X</td>
<td>✓</td>
</tr>
</tbody>
</table>

Using only the 16:30 to 20:30 set period would provide adequate compatibility with historic sampling while minimising the risk of enmeshing crocodiles and allowing much improved management of field team fatigue.

In order to complete the full night of sampling for this survey the team was split into two groups. One set the nets and checked them for crocodiles until midnight, including doing the 20:30 and 24:00 clearances and catch processing. The second team checked the nets for crocodiles from 01:00 until the final clearance and removal at 06:30. While this allowed each team to get some sleep each night, managing accumulated fatigue over sequential nights of sampling, with daytime sampling activities included, was difficult. The reduction of the set
time to a 4 h period would greatly reduce this burden while collecting around 85% of the fish species and 50% of the fish catch that would be obtained from the full set period.

3.1.1.3 Comparison of Sinking and Floating Gill Nets

Historically, gill nets of the same mesh size had been set at each site to either hang from the water surface (floating nets) or remain in contact with the bottom of the water hole (sinking nets), based on the concept that fishes of more demersal habits would tend to be more effectively captured by the sinking nets, while more pelagic and surface-dwelling species would be more efficiently captured by the floating nets. However, it was noted in the 2014 sampling that many sites had water column depths within or only slightly more than the net drop length and that those that were substantially deeper than the net drop tended to have many snags at depth. The sinking nets did not appear to have collected a substantially different fish catch, but were found to be markedly more prone to snagging and being damaged during the course of the survey. If indeed there was no substantial advantage to the use of sinking nets, future sampling could be greatly simplified, and incur less equipment costs, if sinking nets were not used.

A comparison of the abundance of fishes captured in sinking and floating nets for sites which had matched sets of floating and sinking nets, after taking differences between sites and between net mesh sizes (ANOVA, with net type (sinking or floating), and site as main factors and net mesh size nested within site) found that there was no significant difference between catches in floating and sinking nets (p>0.05) but there were differences between sites and net mesh sizes (p<<0.05). This is illustrated in Figure 3-1.

Similarly, there was no difference in species richness between sinking and floating nets (p>0.05), but there was also no difference between sites (p>0.05) or between mesh sizes (p=0.06) (see Figure 3-2).

A cluster analysis of the species caught in each gill net across all sites in 2014 and in 1992 is illustrated in Figure 3-3. In the figure, nets connected by dashed lines were not significantly different by Simprof analysis (P>0.05). Floating and sinking nets of most net sizes formed a single cluster, with floating and sinking nets of each mesh size paired within subgroups. The 2014 13 mm nets formed a separate cluster, in part because this size mesh tends to target rainbowfishes and other small-bodied species and because the nets of this mesh size used in 2014 had finer monofilament line used to construct the meshes, increasing the efficiency of the net. The two 13 mm nets used in 1992 were distinct from all other nets, most probably due to catch inefficiency of the coarser monofilament used previously.

Therefore, overall for the 1992 and 2014 sampling, there does not appear to have been any substantial difference in the amount or type of fishes caught by sinking and floating nets, after accounting for mesh size and sampling site.
Figure 3-1 Abundance of fishes in each sinking or floating gill net at each site.

Figure 3-2 Species richness in each sinking or floating gill net at each site.
3.1.2 Finniss River Site Gill Net Catches Over Time

In Figure 3-4 is shown a comparison of the average total abundances of fishes for the three sites immediately downstream of the junction with the EB compared to those for the control sites that occur upstream of the East Branch junction and downstream of the Florence Creek junction. These data were based on those fishes caught in a standardised set of gill nets which was consistent throughout all sampling periods and on the suite of species reported by Jeffree and Twining (2000) for consistency with the historical datasets. All the sampling periods, beginning in the 1970s, were included in this comparison which indicated the following:

i) the fish abundances measured in 2014 at both control and impacted sites showed comparable mean values relative to those measured in both 1992 and 1995;

ii) mean abundances were actually higher at the impacted than the control sites on average for each of the three post remediation sampling periods; and

iii) fish abundances at control sites in 2014 were similar to those determined in both 1992 and 1995, but about a factor of three greater than those measured at control sites during 1974.
Figure 3-4. Abundances of seven species captured in a standardised set of gill nets

Figure 3-5 shows a comparison of the mean number of fish species at impacted versus control sites for 2014, and with all those for the previous sampling periods, pre- and post-remediation at Rum Jungle in the 1980s. For 2014 more species were caught at impacted sites than control sites, a result similar to that for the sampling rounds in 1992 and 1995, although more species in total were caught at both control and impacted sites in 2014 compared with these earlier sampling periods. Numbers of species found at control sites were quite similar among all the six sampling periods.
3.1.2.1 Discussion of results

The results for 2014, 1995 and 1992 showed remarkable consistencies in both the abundances and diversity of fishes over a sampling period which spanned two decades, after remedial activities at the Rum Jungle mine site in the 1980s. These consistencies were present in groups of sites, both unexposed and exposed to contaminants from Rum Jungle. Such consistencies suggested that any reductions in contaminant loadings or water concentrations due to Rum Jungle effluents since the 1990s have had no appreciable additional benefit for fishes in the main Finnisss River sampling sites. Moreover, constancy at the control sites in their fish diversity and abundances over this long period suggests that trends in other environmental factors have been and currently are also of little significance for the viability of these fish communities.

The low abundances at control sites during the three samplings in 1974 relative to the post-remedial samplings may provide an indication of the potential extent of natural variation over a period of 40 years that can exist in fish populations in this region of the Finnisss River. However, it is not known why the control site abundances were so relatively low in 1974. It is possible that precedent climatic conditions or other controlling factors played a role. Note that among other potential influencing patterns, the population density of the piscivorous Freshwater Crocodile Crocodylus johnstoni and partly piscivorous Saltwater Crocodiles C. porosus were at their lowest for all of the sampling rounds in 1974, as commercial hunting of them ceased in 1964 and 1974 respectively and the populations have been recovering since that time. Therefore, high levels of predation from crocodiles would not have been a factor in the low control site fish abundances in 1974.

The greater constancy in the diversity of fish species at control sites over the 40 year sampling period suggests it may be a more reliable and useful measure of environmental quality in the impacted region of the Finnisss, than fish abundances alone.

The results of the fish sampling in 2014 also indicated the following:

a) There was no negative impact on fish diversity and abundances of the current levels of contaminants being delivered to the Finnisss River; this conclusion is particularly supported by heightened numbers of species and total abundances at impacted sites compared with controls,

b) The comparison of results among the three post-remedial sampling programs suggested an increase over time in fish diversity at the impacted but not control sites, but this trend would require a further sampling round for verification.

3.1.3 2014 Finnisss River versus East Branch Comparisons

3.1.3.1 All Methods

The use of a broad suite of methods of sampling at each site was designed to ensure the majority of resident fish and macro-crustacean species present at each site were recorded for each sampling location. Table 3-5 provides a complete list of all species collected in 2014 and the sites where they were collected. It is clear that there was a progressive increase in the
The number of fish species occurring at sites in the East Branch from the mine lease area downstream except for a relatively high species richness at EB@GS327, where a large waterhole was present offering relatively more habitat opportunities compared with the other East Branch sites immediately upstream and downstream of it.

### Table 3-5: Species recorded at each site in 2014. Blue shading highlights diadromous species.

<table>
<thead>
<tr>
<th>Species</th>
<th>FC@LB</th>
<th>EB@IB</th>
<th>EB@GS200</th>
<th>EB@GS327</th>
<th>EBdsRB EB5</th>
<th>EB@GS097</th>
<th>EBdsHS (EB3)</th>
<th>EBdsHS (EB2)</th>
<th>EBusFR (EB1)</th>
<th>FRusMB</th>
<th>FRdsMB</th>
<th>FR@GS204</th>
<th>FR3</th>
<th>FRusFC (FR2)</th>
<th>FRdsFC (FR1)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fishes</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ambassis macleayi</td>
<td>X X X</td>
<td>X X X</td>
<td>X X X</td>
<td>X X X</td>
<td></td>
<td>X X X</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Melanotaenia nigrans</td>
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<td>X X X</td>
<td>X X X</td>
<td>X X X</td>
<td></td>
<td>X X X</td>
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<td>X X X X</td>
<td>X X X X</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Melanotaenia splendidina inornata</td>
<td>X X X</td>
<td>X X X</td>
<td>X X X</td>
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<td></td>
<td>X X X</td>
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<td>X X X X</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Mogurnda mogurnda</td>
<td>X X X</td>
<td>X X X</td>
<td>X X X</td>
<td>X X X</td>
<td></td>
<td>X X X</td>
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<td></td>
</tr>
<tr>
<td>Neosilurus ater</td>
<td>X</td>
<td>X</td>
<td>X X X</td>
<td>X X X</td>
<td></td>
<td>X X X</td>
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</tr>
<tr>
<td>Glossamia aprion</td>
<td>X</td>
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<td>X X X</td>
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<td></td>
<td>X X X</td>
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<td>Neosilurus hystlii</td>
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</tr>
<tr>
<td>Oxyeleotris selhemi</td>
<td>X</td>
<td>X</td>
<td>X X X</td>
<td>X X X</td>
<td></td>
<td>X X X</td>
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</tr>
<tr>
<td><strong>Glossogobius sp. 2.</strong></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<td></td>
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<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Megalops cyprinoides</td>
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<td>X</td>
<td>X X X</td>
<td>X X X</td>
<td></td>
<td>X X X</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Leioptotherapon unicolor</td>
<td>X</td>
<td>X</td>
<td>X X X</td>
<td>X X X</td>
<td></td>
<td>X X X</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Craterocephalus stercusmuscarum</td>
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<td></td>
</tr>
<tr>
<td>Oxyeleotris lineolata</td>
<td>X</td>
<td>X</td>
<td>X X X</td>
<td>X X X</td>
<td></td>
<td>X X X</td>
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<td></td>
</tr>
<tr>
<td>Lates calcarifer</td>
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<td>X X X</td>
<td>X X X</td>
<td></td>
<td>X X X</td>
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<td></td>
</tr>
<tr>
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<td>X</td>
<td>X X X</td>
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<td></td>
<td>X X X</td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Amniataba percoides</td>
<td>X</td>
<td>X</td>
<td>X X X</td>
<td>X X X</td>
<td></td>
<td>X X X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Strongylura krefftii</td>
<td>X</td>
<td>X</td>
<td>X X X</td>
<td>X X X</td>
<td></td>
<td>X X X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Hephaestus fuliginosus</td>
<td>X</td>
<td>X</td>
<td>X X X</td>
<td>X X X</td>
<td></td>
<td>X X X</td>
<td></td>
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<td>Neoarius berneyi</td>
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<td><strong>Glossogobius giurus</strong></td>
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<td>Nematalosa erebi</td>
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<td>Toxotes lorentzi</td>
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<tr>
<td>Caridina gracilirostrus</td>
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<td>Caridina typus</td>
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The two sites upstream of the mine had comparable numbers of species to the sites within the lease area, but with the addition of one species, *Neosilurus ater*, that is known to migrate upstream into intermittent streams to spawn (Orr and Milward 1984). Only young of the year specimens of that species were collected from this upstream site, but they were in high abundance, indicating successful spawning in the upper reaches of the East Branch.

Crustaceans were well represented in the East Branch, with the exception of *Cherax quadricarinatus* upstream of gauging station 097, and the complete absence of Atyidae shrimp. That Family was well represented by three species of the genus *Caridina* in the main Finniss sites. Species of this Family are generally regarded as being metal sensitive, and as algal grazers, require food sources that are also sensitive to increased metal bioavailability.

Notably, three diadromous¹ species were recorded from the East Branch. Two catadromous² species (Barramundi *Lates calcarifer*, and Tarpon *Megalops cyprinoides*) and one amphidromous³ species (Munro’s Goby *Glossogobius* sp. 2) were found. The amphidromous Flathead Goby *Glossogobius gigus* and the marine vagrant¹ Diamond-scale Mullet *Liza vaigiensis* were collected from the Finniss River upstream of the East Branch and the other three migratory species were found at all Finniss River sites or all sites downstream of the East Branch for Munro’s Goby. This indicates that the water quality of the East Branch did not prevent these species from migrating into or past the East Branch. As noted above, at least one potamodromous⁵ species, the Black Catfish *Neosilurus ater*, was able to make a spawning migration through the mine lease area to spawn in the headwaters of the East Branch.

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¹ Diadromous = migrates between fresh and marine waters  
² Catadromous = Resident in fresh water but spawns in marine environments  
³ Amphidromous = Resident in fresh water and spawns in fresh water but has an obligatory marine larval stage  
⁴ Marine vagrant = primarily resident and spawning in marine waters but may enter fresh waters  
⁵ Potamodromous = has obligatory migrations within freshwaters for feeding or spawning purposes. Term is not generally applied to the need to retreat to refugia during the dry season and disperse from refugia in the wet season for fishes in intermittent/ephemeral systems.
The fishes that were not recorded from the East Branch included two algivorous species, Bony Bream *Nematalosa erebi* and Butler’s Grunter *Syncomites butleri*, both Ariidae species, Berney’s Catfish *Neoarius berneyi* and Lesser Salmon Catfish *Neoarius graeffei*, both Toxotidae species, the Seven-spot Archerfish *Toxotes chatareus* and the Primitive Archerfish *Toxotes lorentzi*, the above mentioned Flathead Goby and Diamond-scale Mullet, and the Swamp Eel *Ophisternon gutturale*. The Swamp Eel catches were the first records of this species from the Finniss River system, although the related One-gilled Eel *O. bengalense* was collected in 1975 by rotenone sampling in Florence Creek and FR6(FRusMB). Note that as the taxonomy of this group is uncertain, it is possible that the earlier record was of the same species.

The absence of the Atyidae Family of algivorous shrimp, and the two algivorous fish species from the East Branch may be indicative of a water quality impact on the quality of algal food sources in that branch. Note that the assessment of benthic diatoms highlighted differences in taxonomic composition of that group of single-celled algae in the East Branch, but the connection to water quality was not obvious (see Section 3.2). It is also possible that all the algivorous fishes and Atyidae were themselves particularly metal intolerant. It should be noted that Atyidae are widely used for ecotoxicity testing in Australia and are generally regarded as being relatively metal sensitive for macrocrustaceans, and the only known test of copper tolerance of a species of the same genus as Bony Bream, *Nematalosa papuensis*, indicated that it was relatively sensitive to copper for mature fishes (Hydrobiology 2006), with a 3 h LC₅₀ that was mid-range for published 96 h LC₅₀ values for fishes.

The number of species collected from the East Branch was substantially greater than for previous sampling (Table 3-6). No doubt that was at least in part due to the additional sampling methods used (see Section 3.1.1.1), and also potentially time of sampling in an intermittent stream relative to the end of the wet season, but it did show a clear increase in the abundance and diversity of fishes and crustaceans compared with sampling in either the 1970s or 1990s. Sampling in the 1990s was primarily based on seine netting in the East Branch, but again effort was put into collecting all the resident species that could be collected. Also, it should be noted that sampling in the previous decades involved more than one round of sampling and hence a greater likelihood of collecting rare species. Therefore, the large increase in the number of species collected from a single survey in 2014, and in particular the collection of fishes and crustaceans from the mine lease area (zone 2), indicated substantial improvement in the aquatic ecosystem of the East Branch since the 1990s.
### Table 3-6  Species collected from sites in the East Branch sub-catchment by period of sampling

<table>
<thead>
<tr>
<th>Species</th>
<th>1973-74</th>
<th>1990's</th>
<th>2014</th>
</tr>
</thead>
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<tr>
<td><em>Ambassis macleayi</em></td>
<td>X X</td>
<td>X X X X X X X X X X</td>
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<tr>
<td><em>Amniataba percoides</em></td>
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<td>X X</td>
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<tr>
<td><em>Craterocephalus stercusmuscarum</em></td>
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<tr>
<td><em>Craterocephalus stramineus</em></td>
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<td>X X</td>
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<tr>
<td><em>Glossamia aprion</em></td>
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<tr>
<td><em>Glossogobius sp. 2.</em></td>
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<td><em>Hephaestus fuliginosus</em></td>
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<tr>
<td><em>Lates calcarifer</em></td>
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<td><em>Leiopotherapon unicolor</em></td>
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<tr>
<td><em>Melanotaenia cyprinoides</em></td>
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<td><em>Melanotaenia nigra</em></td>
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<tr>
<td><em>Melanotaenia splendida inornata</em></td>
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<tr>
<td><em>Mogurnda mogurnda</em></td>
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<tr>
<td><em>Neosilurus ater</em></td>
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<td><em>Neosilurus hyrtlii</em></td>
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<td><em>Oxyeleotris lineolata</em></td>
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<td><em>Oxyeleotris selhemi</em></td>
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<td>X X</td>
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<tr>
<td><em>Strongylura kreffti</em></td>
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<tr>
<td><em>Caridina gracilirostris</em></td>
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<tr>
<td><em>Caridina sp. 1</em></td>
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<tr>
<td><em>Cherax quadricarinatus</em></td>
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<tr>
<td><em>Austrothelphusa transversa</em></td>
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<tr>
<td><em>Macrobrachium bullatum</em></td>
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<tr>
<td><em>Macrobrachium handschini</em></td>
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**KEY**
- Zone 4
- Zone 3
- Zone 2
- Zone 1

**Diadromous Species**

A cluster analysis of the presence/absence data reflected the observed incremental addition of species down the East Branch. The first cluster included the East Branch sites from upstream of the mine lease area and within the mine lease area (zones 1 and 2) as well as site EBdsRB in the upper reaches of zone 3. EB@GS327, which had unusually high species richness for its position in the catchment, formed its own cluster, but was most similar to a group containing the remaining East Branch sites (zones 3 and 4). The sites from the upper Finniss River in zone 5 formed a distinct cluster that was most similar to a group containing the remaining sites in the Finniss River from zones 6 and 7. The lower East Branch site clusters were more similar to the Finniss River clusters than to the upper East Branch cluster.
3.1.3.2 Electrofishing

Electrofishing was unreplicated at each site, because the main emphasis of the use of the technique was capture of a wide range of species of small-bodied fishes and macrocrustaceans. Crocodile risk also meant that it was difficult to find sufficient safe areas to electrofish for replicated sampling and minimisation of the time spent wading. Hence a single unreplicated sample was judged to be best for risk management.

Therefore, while parametric analyses could be performed by grouping sites within river zones, the resulting analyses had little discriminatory power. Although there were significant differences between zones for electrofisher abundance and species richness per site (ANOVA, p<0.05) the only pair-wise difference that could be discerned by multiple range test was that the abundance for sites in zone 2 was less than for sites in zone 6.

Multivariate analyses were made, with similar grouping of sites resulting from non-metric multidimensional scaling and by group average agglomerative hierarchical clustering. The latter was selected for simplicity and is shown in Figure 3-7. Solid lines in the figure indicate significant groupings. The upper most and lower most sites in the East Branch, EB@LB and EBusFR, formed a significant grouping, which Simper analysis indicated was most strongly linked to the abundances of Northern Trout Gudgeon *Mogurnda mogurnda*, and *Macrobrachium bullatum* but also with good catches of *M. handschini*. This group was most similar to a group containing the other two upper East Branch sites, FC@LB and EB@GS200, which was characterised by the abundance of Northern Trout Gudgeon and *M. bullatum* with the absence of *M. handschini*. The remaining East Branch sites formed a distinct grouping characterised again by the abundances of Northern Trout Gudgeon and *M. bullatum*. The Finniss River sites formed the final cluster consisting of two groups of sites closer to (FR@GS204, FR3) and further from (FRusFC, FRdsFC) the East Branch junction characterised by the abundance of a group of crustaceans (*Caridina gracilirostris, M. bullatum,* etc.).
M. handschini and C. typus) at the upstream sites and the same species with C. longirostris at the downstream sites.

Therefore, overall the electrofishing data indicated that the East Branch differed from the Finniss River in terms of the composition of the assemblage of small-bodied species targeted by that sampling method, particularly the crustaceans. The reason for the grouping of the lowermost and uppermost sites in the East Branch on the basis of Northern Trout Gudgeon and crustacean catches is not readily apparent although five of the seven taxa caught by electrofishing at EBusFR were caught at EB@LB.

![Figure 3-7](image)

**Figure 3-7** Group average agglomerative hierarchical cluster dendrogram for electrofisher catches by site.

### 3.1.3.3 Fyke Netting

Fyke netting was the most widely used sampling method, which enabled comparison across all river zones except zone 7. Using each fyke net as a replicate at each site nested within each zone, on the assumption that small and large fyke nets were equivalent because they sampled similarly in waters of different depths, nested ANOVA designs were used to assess whether catches differed between zones. For species richness there was a significant difference between zones (p<0.05) with both zones 1 and 4 having greater richness than zone 6, but no significant site effect. For abundance, there was also a significant difference between zones (p<0.05) but not sites within zone (p>0.05). The geometric mean of abundance for zone 1 was greater than for all other zones, with zones 2, 3 and 4 in the East Branch having greater abundance in turn than for the Finniss River zones 5 and 6. This reflects the high catches of Black Catfish from the EB@LB in zone 1, and probably also the fact that at the Finniss River sites the fyke nets had to be set in shallow areas between water holes due to crocodile risk, whereas fish were most abundant in the deeper waterholes at the Finniss River sites. At the East Branch sites there were usually more extensive areas of shallower habitat suitable for fyke netting, and they represented a larger proportion of the available habitat at each site. This may have contributed to the relatively better catches in fyke nets at the East Branch sites.

Cluster analysis of the fyke netting data (Figure 3-8) was generally consistent with the ANOVA analyses, but provided more detail on differences between sites and samples in catch composition. Reading the dendrogram from right to left, there was a cluster of mostly
samples from sites in zones 3 and 4 in the lower East Branch, but also including one sample from the upper Finniss in zone 5. The next major group, although including sub-groupings was primarily samples from sites in the upper East Branch in zones 1, 2 and 3, but also one of the replicates from EBusFR in zone 4. These two primarily East Branch groups were more similar to each other than to any other groups. The next cluster was an unusual grouping of one replicate from EBusHS in the lower reach of zone 3 and one replicate from FRusMB in zone 5. The next group contained a replicate each from two zone 6 sites, FR@GS204 and FRusFC. This group was more similar to the remaining two groups than to any other clusters. The next two groups included the remaining zone 6 replicates with one samples from FRusFC significantly different from the other zone 6 replicates. The final group was the two FRdsMB samples, which were distinct from all other sites.

Overall this cluster analysis highlighted the differences in the catches between Finniss River and East Branch sites, with a secondary distinction between upper and lower East Branch sites, but it also highlighted that very local influences on the catch efficiency and selectivity of fyke nets caused substantial variability between replicates at some sites.

**Figure 3-8** Group average agglomerative hierarchical cluster dendrogram for fyke net catches by site.

### 3.1.3.4 Gill Netting

As discussed above, the use of gill nets varied between sites in response to the sometimes conflicting requirements to:

- As far as practical provide backwards compatibility with historic sampling;
- Minimise the likelihood of enmeshing freshwater crocodiles;
- Manage fatigue levels in the sampling team; and
- Deploy only as many nets as could be effectively used in the available water holes at each sampling site without the nets interfering with catches in neighbouring nets.
The resulting differences in the suite of nets used at each site and the durations over which they were set meant that it was not possible to compare gill net catches across a wide range of sites. However, in the next section some net subsets were used to make comparisons of catches across subsets of sites.

3.1.3.5 Combined Methods Most Widely Used

Because the methods varied between sites depending on the aquatic habitat characteristics of each site, it was difficult to identify a suite of methods that was both used widely across sites and collected the majority of fish species. In particular, gill nets were not used at most East Branch sites, and where used, different subsets of the full gill net suite were used at each site depending on the available volume of water that could be sampled. The following sections examine spatial patterns using suites of sampling methods that best provided coverage of sampling sites and zones and the types of sampling conducted.

Electrofishing, Fyke Netting and Bait Trapping Combined

The suite that was most widely used included electrofishing, fyke nets and bait traps. Figure 3-9 shows a cluster dendrogram for the catches for each site for the combined methods suite. It indicated that the catch at FRusMB was different from that at any other site, possibly due to the restricted areas available at that site for fyke nets and electrofishing. FR@GS204 and FR3 formed a distinct grouping of those two adjacent sites in zone 6, while the only other Finniss River site that was included in the analysis, FRusFC was more similar to a grouping of East Branch sites in zones 3 and 4 than to the other Finniss River sites. This might have been because that site had a reach of braided, shallow flowing habitats where these methods were used that was heavily vegetated and snaggy but afforded habitat diversity that was more akin to that found at the East Branch sites than were the shallower areas available at the other Finniss River sites. The remaining group included the sites in the upper East Branch that did not include deepwater habitat.
Figure 3-9  Group average agglomerative hierarchical cluster dendrogram for combined electrofishing, fyke netting and bait trapping catches by site.

Gill Net Subsets

A suite of 13, 19, 25 and 40 mm floating gill nets was set between late afternoon and 20:30 at sites FR@GS204, FR3, FRusFC and FRdsFC in the Finniss River and at sites EB@GS327 and EBusFR in the East Branch. Cluster analysis (Figure 3-10) showed that catches from the two river branches were distinct. Simper analysis indicated that the distinction between groups was influenced by the abundances of Tarpon *Megalops cyprinoides*, Hyrtl’s Tandan *Neosilurus hyrtlii*, and Black Catfish *N. ater* at the East Branch sites and of Bony Bream *Nematalosa erebi*, Tarpon, Seven-spot Archerfish *Toxotes chatareus*, Black Catfish and Longtom *Strongylura krefftii* at the Finniss River sites. The absence of Bony Bream and Archerfish from the East Branch has already been noted.
A suite of floating 13, 19, 25 and 40 mm gill nets and a sinking 13 mm net was set from dusk to dawn at all Finniss River sites and EBusFR. Cluster analysis of those catches (Figure 3-11) demonstrated that the East Branch catch was distinct from all Finniss River site catches. The Finniss River catches were all more similar to each other than to the EBusFR catch but there were some significant differences between sites. These distinctions were not related to proximity to the East Branch, but more probably were related to the size of the water hole sampled at each site. Sites not significantly distinct from each other included FR@GS204 in zone 6 and FRusMB in zone 5, and FR3 in zone 6 and FRdsFC in zone 7. FRdsMB and FRusFC were distinct from the other Finniss River sites.
The full suite of sinking and floating 13, 19, 25 and 40 mm gill nets set from dusk to dawn was used only at sites FRusMB, FRdsMB, FR3, FRusFC and FRdsFC. Cluster analysis of those catches found no significant distinctions between sites, indicating comparability of gill net catches from Finniss River sites in zones 5, 6 and 7.

### 3.2 Diatoms

Diatom species richness was lower for zone 2 than for zones 6 and 1, while abundance was lower for zone 2 than for all other zones except 7 (ANOVA, p<0.05). The samples for FRdsFC in zone 7 were collected from the only available shallow water habitat that could be safely waded, which was a high flow area with few backwater areas, and where it would be expected that the diatom assemblage would have been scoured to some extent in all accessible collection locations. Figure 3-12 and Figure 3-13 clearly show the reduced diatom assemblage in zone 2, and recovery of the assemblage through zones 3 and 4 in the East Branch. Note the high variability in abundance in Zone 6, especially for FR3 and FRusFC, which reflected the difficulty of finding safe sites for sampling that were not in high current areas and not heavily shaded.

![Figure 3-12 Diatom species richness by site and zone](image-url)
A cluster analysis of the diatom samples was also conducted (Figure 3-14). This did not differentiate the zone 2 sites from the remainder of the East Branch sites as strongly as the univariate analyses indicated, suggesting that while zone 2 had reduced abundance and species richness, the diatom assemblages nonetheless remained compositionally similar to those of the other East Branch Sites. The diatom assemblages of the zone 1 sites were more comparable to each other and one of the replicates from the zone 7 site FRdsFC than to the other East Branch sites, but all other East Branch samples were grouped into one cluster. The zone 1 sample cluster was more similar to the Finniss River groupings, which included a grouping of the samples from FRusFC and the remaining sample from FRdsFC, and another grouping of most Finniss River samples from zones 5 and 6. A single replicate from FD@GS204 was distinct from all other samples, but the reason for this was unclear. It did have around five times the abundance of *Navicula menisculoides* of any other site.

The diatom species that primarily contributed to the separation of sample groups in the cluster analysis did not have known water quality sensitivities that were relevant to the known water qualities of the zones. The species primarily associated with the group containing all East Branch sites downstream of zone 1 according to Simper analysis were *Acanthidium minutissimum, Nitschia palea, Rhopalodia musculus* and *Nitzschia paleaceae*. Of those, little is known of the tolerances of the first other than that it is classified as slightly-motile, the second is understood to prefer waters of circum-neutral pH, while the third and fourth are alkaliphilous, which was not expected for key species for the East Branch. The key species contributing to the difference between the zone 1 and zones 2, 3 and 4 sites was *Acanthidium minutissimum*, which did not elucidate what water or sediment quality
characteristics might have contributed to the differences in the assemblages. None of the key contributing taxa have known metal sensitivities, but it may be relevant that the marine species *Nitzschia closterium* is widely used in ecotoxicity testing and is known to be very sensitive to metals. The Finniss River sample groupings were characterised by a number of species, including several in the genus *Navicula* including *N. radiosafallax*, *N. menisculus*, *N. veneta* and *N. schreoterii*. The key contributing species with known pH affinities were all either alkaliphilous or preferring circum-neutral waters.

Therefore, while the diatom assemblages clearly identified a region of detriment in zone 2 with recovery down the East Branch, and indicated closer affinity of samples from the upper East Branch with samples from the Finniss River than to the other East Branch zones, the observed assemblage differences were not readily associated with key water or sediment quality characteristics. However, it may be pertinent that the fish fauna of the East Branch was found to be devoid of algivorous species and the algal grazing shrimp Family *Atyidae* were also absent from the East Branch, and so the differences in the diatom assemblages between zones may have reflected differences in grazing pressure rather than water or sediment quality. Conversely, the differences in algal assemblages represented by the differences in diatom assemblages may had been the cause of the absence of algivorous taxa from the East Branch, if this resulted in reduced quality of the algal food sources.

The results of this survey of the diatom assemblages were generally very consistent with the limited data and interpretation provided in the only previous assessment of the sand-associated benthic diatom flora of the East Branch by Ferris *et al.* (2002) which found a gradient of improving condition of the flora from the mine lease area downstream through the East Branch, a distinct difference in assemblage composition between reference sites in the upper East Branch and the upper Finniss River, and a range of “a few to 23 species” per site in the East Branch compared with 3 to 20 species found per sample per site in the East Branch in this survey (see Figure 3-12).
Figure 3-14 Group average agglomerative hierarchical cluster dendrogram for diatom samples by site
3.3 Macroinvertebrates

Macroinvertebrate samples taken during the May/June 2014 sampling round in the Rum Jungle study area were identified and analysed and the results are presented below. Available macroinvertebrate data from surveys conducted by Cyrus Edwards as part of his MSc in 1995 were incorporated to allow a historical comparison of data.

3.3.1 Macroinvertebrates 2014

Initial analysis was performed on the 2014 macroinvertebrate data set to determine the current state of populations and identify if any differences existed in macroinvertebrate composition between sites.

3.3.1.1 Abundance

Average macroinvertebrate abundance was calculated for each site surveyed in 2014 and the results were graphed (See Figure 3-15).

![Figure 3-15: Average macroinvertebrate abundance at sites sampled during 2014](image)

As Figure 3-15 indicated that there may exist significant differences in abundances between sites, an ANOVA analysis was performed on the data to determine site comparisons were significant. The test revealed that there was an overall significant difference in abundance between sites (P<0.001).
The data were analysed using a Multiple Range Analysis in S+ to determine which sites were significantly different from each other. The resultant groupings are presented in Table 3-7.

Table 3-7: Results from Multiple Range Test on Abundance data

<table>
<thead>
<tr>
<th>Multiple Range Test result</th>
</tr>
</thead>
</table>

The Multiple Range test grouped sites EB@GS200 (Zone 2), EB@GS327 (Zone 3), EB@GS097 (Zone 3) & EBusHS (Zone 3) together indicating that no significant differences occurred between those sites. Mean abundance ranged from four (EB@GS200) to 12 (EB@GS097) specimens per site. Site EB@GS200 had significantly lower abundance than all other sites with the exception of those three sites.

Sites EB@GS327, EB@GS097 and EBusHS were also found not to be significantly different from sites FRusMB (Zone 5), EDbdsHS (Zone 4) & EBusFR (Zone 4), although they differed significantly from all other sites except EB@GS200. The inclusion of site FRusMB in this grouping was due to the low abundances observed at this site, despite it having been selected as a control site. This was most likely due to the limited area suitable for sampling at that site, with sampling having to be done adjacent to a road crossing.

Furthermore, sites FRusMB, EDbdsHS & EBusFR were grouped with sites EB@LB (Zone 1), FRusFC (Zone 6), FRdsMB (Zone 5), FRdsFC (Zone 7) & EDbdsRB (Zone 3), which were not significantly different from each other but were significantly different from sites FC@LB (Zone 1), FR0 (Zone 7), FR3 (Zone 6) & EB@GS204 (Zone 6). The grouping of the two Zone 4 sites (EDbdsHS & EBusFR) and the Zone 5 site (FRusMB) with the Zone 1, 5, 6 & 7 sites shows that these sites these lower East Branch sites were comparable in abundance to a number of Finniss River sites, including control sites. Although site EDbdsRB was located in Zone 3, this site exhibited high abundances which were similar to abundances seen in Zones 1, 5, 6 and 7.

With the exception of site FRusMB, all the Finniss River and upper East Branch control sites were not significantly different, indicating no impact to macroinvertebrate abundances downstream of the East Branch junction.

Overall the Multiple Range Test analysis indicated that significant differences existed between sites from zones 2 and 3 and sites from zones 1, 5, 6 and 7, with the exceptions of FRusMB, which had unusually low abundances for a Finniss River site, and EDbdsRB, which had unusually high abundance for a zone 3 site.
3.3.1.2 Richness

Taxa richness for the 2014 data set was also calculated and is presented graphically in Figure 3-16.

![Figure 3-16: Taxa Richness of macroinvertebrates at sites sampled in 2014](image)

Taxa richness data was analysed using an ANOVA to determine if any significant differences in taxa richness occurred between sites. The test revealed that there was a significant overall difference in richness between sites (P<0.001).

The data were analysed using a Multiple Range Analysis in S Plus to determine which sites were significantly different from each other. The resultant groupings are presented Table 3-8.

Table 3-8: Multiple Range Test result for Richness data
The Multiple range test revealed that site EB@GS200 (Zone 2) was significantly different from all other sites sampled. This site exhibited the lowest taxa richness value of any site.

The analysis grouped sites FRusMB (zone 5), EB@GS327 (zone 3), EBusHS (zone 3), EB@GS097 (zone 3), EBusFR (zone 4), EB@LB (zone 1) and EBdsHS (zone 4) together as they were not significantly different from each other in taxa richness. Again we can see that sites from Zones 3 and 4 were grouped together although sites FRusMB and EB@LB were also grouped with the sites from these zones. Figure 3-15 shows that these two sites had abundances lower than other sites in their respective Zones, although the reason for this is not known.

Several of the sites in the above grouping (sites EBusHS, EB@GS097, EBusFR, EB@LB and EBdsHS which had richnesses ranging from 10-12 taxa) also grouped with sites FRusFC (zone 6), FRdsFC (zone 7), FRdsMB (zone 5), EBdsRB (zone 3), EB@GS204 (zone 6) and FC@LB (zone 1), sites which had richness ranging between 17 and 21 taxa. The grouping of these Zone 1, 5, 6 & 7 sites (as well as the anomalous site, EBdsRB from Zone 3) with the Zone 3, 4 and 1 sites listed suggests that, as the taxa richnesses at these sites were not significantly different, some overlap occurred, indicating that conditions in Zones 3 and 4 were becoming more similar to conditions in Zones 1, 5, 6 & 7.

The log average richness for EB@GS200 was significantly lower than for all other sites.

### 3.3.2 Multivariate Analysis

To determine whether significant differences in macroinvertebrate composition occurred between sites and zones, cluster analysis and non-metric multi-dimensional scaling were carried out. These highlighted possible differences in macroinvertebrate composition between zones although few obvious differences in sites within zones were apparent.

Only the cluster analysis results are presented in Figure 3-18 because the MDS ordinations produced similar groupings. The samples from EB@GS200 were distinct from the samples collected from all other sites. The next cluster consisted of the majority of East Branch samples from zones 3 and 4, with the exception of the samples from EBdsRB, but also included two of three samples from EB@LB in zone 1, the three samples from FRusMB in zone 5, and one of three samples from FRdsFC. The remaining samples were grouped together, but that group contained some significant sub-groups. One sample from FRusFC was distinct from the other Finniss River samples. The next cluster contained the remaining samples from zone 1, while the next group contained samples from Finniss River sites in zones 5, 6 and 7, but also two of three samples from EBdsRB. This was followed by a group of the samples from FR@GS204 in zone 6, and then a final group containing samples from zones 5 and 6 and the remaining sample from EBdsRB.
Overall, the cluster analysis demonstrated that the only site in zone 2 was distinct from all other sites, the East Branch sites from downstream of the mine lease area were distinct from most Finniss River and upper East Branch sites, except for individual relatively depauperate samples and the samples from FRusMB, which has been noted to have potentially been impacted by proximity of a road crossing to the only available sampling area. EBdsRB, which was found to have unusual abundance and richness of macroinvertebrates for an East Branch site, was more similar to Finniss River sites than to the other East Branch sites in composition too. It is not known why this site supported such a relatively intact macroinvertebrate assemblage.

Figure 3-17: Dendrogram showing differences in macroinvertebrate composition by zone

### 3.3.2.1 Functional Feeding Guild

Functional Feeding Guild (FFG) composition for each site was calculated and then graphed (see Figure 3-18).

#### Table 3-9: Key to Functional Feeding Guild abbreviations

<table>
<thead>
<tr>
<th>Functional Feed Guild Key</th>
<th>Abbreviation</th>
<th>Guild Descriptor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fco</td>
<td>Filtering Collector</td>
<td></td>
</tr>
<tr>
<td>Gco</td>
<td>Gathering Collector</td>
<td></td>
</tr>
<tr>
<td>Sc</td>
<td>Scraper</td>
<td></td>
</tr>
<tr>
<td>P</td>
<td>Predator</td>
<td></td>
</tr>
<tr>
<td>Sh</td>
<td>Shredder</td>
<td></td>
</tr>
<tr>
<td>U</td>
<td>Undetermined</td>
<td></td>
</tr>
</tbody>
</table>
Figure 3-18: Functional Feeding Guild compositions at sites sampled in 2014

As can be seen from Figure 3 above, the majority of sites in the Rum Jungle study area were dominated by Gathering Collector and Filtering Collector guilds. The only exception to this is site EBushHS which had a dominant Predator guild present. Predators were generally most abundant in the East Branch sites although they did occur in the control sites upstream of the lease boundary and the Finnis River sites. However, there was a larger proportion of scrapers at the majority of the Finnis River sites compared with the East Branch sites.

### 3.3.2.2 PET Taxa

Presence of PET (Plecoptera, Ephemeroptera and Trichoptera) taxa in samples was calculated to determine the proportion of macroinvertebrate populations that these taxa constituted. The results are presented in Figure 3-19.
As can be seen from Figure 3-19, proportions of PET taxa at all sites were relatively low, with the lowest numbers of PET taxa occurring primarily at the East Branch sites (again site EBdsRB seems to have been an exception to this). Sites FRusMB and EB@GS200 did not have any PET taxa at all present. Site EB@GS200 was located in the mine lease area and the lack of PET taxa at this site is indicative of disturbance. It is interesting to note that PET taxa increased from Zone 2 into upper Zone 3 and Zone 4, which is consistent with gradual improvement in water quality downstream. The highest number of PET taxa occurred at site FR@GS204, with the second highest occurring at sites FR3 and FRdsFC.

### 3.3.2.3 Grazers & Non-Grazers

During the 2014 survey round Diatom samples were taken as another indicator organism to be used to determine the state of the waters in the study area. It was observed in the results of the diatom analysis that abundance and richness of diatoms were suppressed in zone 2 but recovered through zones 3 and 4 and that the diatom assemblage composition of the East Branch sites differed from those of the other zones. Whether differences in the abundance and diversity of grazers (macroinvertebrates which primarily feed on algal matter) and non-grazers (those macroinvertebrates that feed on other sources of food) might explain the differences in diatom assemblage composition was examined.
Figure 3-20: Prevalence of Grazer and Non-Grazer macroinvertebrates from 2014 samples

Figure 3-20 shows proportions of grazers which appeared similar across all sites. It is important to note that the abundances of macroinvertebrates at the East Branch sites was significantly lower than other sites, therefore less grazer specimens were present at those sites than at other sites in the study area.

### 3.3.3 Historical Comparison

When the findings of the 2014 survey round are compared to the analysis carried out by Cyrus Edwards in 1995 for his Master’s thesis some similarities were noted between data sets. The 1995 findings showed that there was a marked difference in abundance and richness and species composition between sites EBdsRB, EB@LB, FC@LB, FRusMB, FRdsMB and sites EBusFR, EBdsHS, EBusHS and EB@GS327. This same difference occurred in the 2014 data set (see Figure 3-15 and Figure 3-16).

The 1995 thesis also indicated that the most common taxa present in samples were the Ceratopogonidae, Chironominae and Tanypodinae, although abundances of these taxa were low in samples taken from the East Branch sites at the time, whereas sites upstream of the lease boundary and the Finniss River had substantial amounts of these taxa present. Additionally the East Branch sites had very few or no Caenidae present whereas sites on the Finnis River and upstream of the lease boundary had them present in notable numbers. A similar scenario occurred in the 2014 samples in regards to distribution of the above mentioned taxa, and their abundances at each site.
Furthermore, the presence of Ecnomidae, Baetidae, Nematoda and Orthocladiinae in significant numbers in the 1995 data set, set the sites in the Finniss River and upstream from the lease boundary apart from the sites affected by mine processes in the East Branch.

A difference between the 1995 data set and the 2014 data set was that, in 1995 sites on the Finniss River held large numbers of Dytiscidae beetles whereas the 2014 data set recovered very few of these from any site sampled.

The 1995 data set revealed that no Acarina, Chironomidae, Nematoda, Ecnomidae or Baetidae occurred at sites in the East Branch but all occurred in the Finniss River and sites upstream of the lease boundary. This result differed from the findings of the 2014 survey as these taxa were found at several sites in the East Branch, albeit in very low numbers.

Results from ANOSIM analysis of the 1995 data performed by Cyrus Edwards showed that sites EB@LB and FC@LB differed from the other sites on the East Branch (i.e. sites EBusFR, EBdsHS, EBusHS, EBdsRB & EB@GS327) significantly, which was also found for the 2014 data.

Although results from the 2014 data set were generally similar to those found during 1995, there was an indication that an improvement in macroinvertebrate assemblage condition in the East Branch had occurred. The occurrence of macroinvertebrate taxa previously not recorded in the East Branch as well as a trend of increasing PET taxa abundance downstream from site EB@GS200 indicated that the assemblages had improved. However, macroinvertebrate abundance levels at the East Branch sites were not yet as high as those in the Finniss River and upstream of the lease boundary, although taxa richness levels were more similar.

There was one marked improvement to the geographic range of a group of macroinvertebrates that was noted during field sampling that while not quantitatively measured was noteworthy. Markich et al. (2002) reported that mussels were absent from the Finniss River for 10 km downstream of the East Branch junction. However in the 2014 sampling mussels were collected from FR@GS204 for radionuclide analysis, while it was not possible to collect them from any site in the East Branch downstream of the upstream boundary of the mine lease area. Mussels were not otherwise specifically targeted for sampling, but they were observed at all Finniss River sites downstream of FR@GS204. This indicates that there had been substantial recovery of the mussel populations since the 1990s.

3.4 Tissue Metal Concentrations

3.4.1 Comparison with Food Standards

The tissue metal concentration analyses are provided in Appendix X as the analysis laboratory report, a tabulated summary including specimen information and graphed in comparison with the relevant FASANZ (2013) food standards. No metal concentrations were found to be above any human health standard.
3.4.2 Spatial comparisons

The concentrations of metals in each tissue type were examined for spatial (between zone and site) differences, either for increased bioaccumulation at sites near the mine or for suppressed bioaccumulation at potentially impacts sites as was found previously by Jeffree et al. (2014). Only metals and metalloids for which the majority of analyses at least at some sites were above the analytical detection limit were considered for statistical analysis for each tissue type.

3.4.2.1 *Macrobrachium bullatum* purged cephalothorax samples

This species was only collected for tissue metal analysis from zones, 3, 4, 6 and 7. Table 3-10 summarises the findings of the spatial analyses. Significant differences between sites were found for cadmium, cobalt, lead, nickel and zinc. The multiple range tests generally found few significant differences between sites. For cadmium, the log-average for EBusFR was greater than for FR3, but no other significant differences were found. Similarly for cobalt, EBusHS was greater than for FRdsFC but no other differences were significant. For nickel, EB@GS327 was greater than for FRdsFC. The greatest numbers of between-site differences were for lead and zinc. For lead EBusHS was greater than for all Finniss River sites except FR3 and also greater than EBusFR. Figure 3-21 shows that the measured values at this site were generally higher than at any other site, but that some replicates from EB@GS327 and EBusFR had similar concentrations. For zinc, EB@GS327 was higher than for all Finniss sites except FRusFC, and also the two zone 4 sites in the East Branch. FRusFC was also higher than was FR3.

Figure 3-21 Shows that there were general gradients of higher and more variable concentrations of cobalt, nickel and zinc in the East Branch closer to the mine, in zone 3, than at the zone 4 sites in the lower East Branch and zone 6 and 7 sites in the Finniss River. This is consistent with a source of increased bioavailability of those elements at the mine lease area, and generally declining bioavailability after mixing with the tributaries that form the zone boundaries. The increased variability for specimens closer to the source is consistent with variable residence time of individuals that have to migrate upstream to access aquatic habitat in this intermittent stream. There was no indication of suppressed bioaccumulation for specimens with greater exposure to elevated metals.
<table>
<thead>
<tr>
<th>Element</th>
<th>Site</th>
<th>Length</th>
<th>Multiple Range Test result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminium</td>
<td>NS</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Arsenic</td>
<td>NS</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Cadmium</td>
<td>P&lt;0.018</td>
<td>-</td>
<td>FR3 FR@GS204 FRdsFC EBusHS FRusFC EBdsHS EB@GS327 EBusFR</td>
</tr>
<tr>
<td>Cobalt</td>
<td>P&lt;0.041</td>
<td>-</td>
<td>FRdsFC FR@GS204 FR3 FRusFC EBusFR EB@GS327 EBdsHS EBusHS</td>
</tr>
<tr>
<td>Copper</td>
<td>NS</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Lead</td>
<td>P&lt;0.037</td>
<td>Int. p&lt;0.05</td>
<td>FR@GS204 FRusFC EBusFR FRdsFC FR3 EBdsHS EB@GS327 EBdsHS</td>
</tr>
<tr>
<td>Manganese</td>
<td>NS</td>
<td>-</td>
<td>Single high concentration sample for FRusFC caused significant site effect</td>
</tr>
<tr>
<td>Nickel</td>
<td>P&lt;0.009</td>
<td>-</td>
<td>FRdsFC FR@GS204 FR3 EBusFR EBdsHS EBusHS FRusFC EB@GS327</td>
</tr>
<tr>
<td>Zinc</td>
<td>P&lt;0.001</td>
<td>-</td>
<td>FR3 FRdsFC FR@GS204 EBusFR EBdsHS EBusHS FRusFC EB@GS327</td>
</tr>
</tbody>
</table>
Figure 3-21 Concentrations of selected metals in *M. bullatum* cephalothorax samples by site and zone and length where significant in the statistical analyses

3.4.2.2 Black-banded Rainbowfish *Melanotaenia nigrans* whole body samples

This species was collected for tissue analysis from all zones except zone 5, the Finniss River above the East Branch. Because of the small size of this species, specimens were analysed whole, and without purging because of a lack of facilities to purge gut contents from more
than one species per site. The East Branch population of this species had been the subject of a study of bioaccumulation of copper after exposure to the acid drainage from the Rum Jungle site in comparison with reference site populations by Gale et al. (2003) and found to have relatively reduced uptake of copper compared with the non-exposed populations.

Table 3-11 shows the results of the step-wise ANCOVA analyses, while Figure 3-22 illustrates the significant relationships. For cobalt, copper nickel and zinc there were differences between sites and trends through the East Branch sites that were consistent with a source of increased bioavailability of each metal within the mine lease area, and reducing bioaccumulation with distance and after the tributary junctions that mark the zone boundaries. Note that variability of bioaccumulation also decreased with distance from zone 2. For zinc this was complicated by a significantly negative overall relationship between zinc concentration and body length. Note that for all those metals the average concentrations and variability were lower for zone 1 than for any other East Branch zone.

Importantly, the pattern of bioaccumulation of copper was not consistent with greatly reduced capacity for or suppressed bioaccumulation for the specimens from the East Branch, with much lower bioaccumulation for the Finniss River sites and somewhat higher and more variable bioaccumulation for the zone 1 specimens compared with the zone 6 and 7 specimens, consistent with having had to pass through the other East Branch zones to reach zone 1.

For the other metals with significant between-site differences, the patterns were less clearly related to a source in the mine lease area. For aluminium and lead the highest average and greatest variability was for EBusFR, with the other East Branch sites not being significantly different from the control sites. For arsenic, most analyses were at the detection limit and measured concentrations were only found for zones 1, 2, 3 and 4, and with no sites being significantly different from all relevant control sites. For manganese, FC@LB was unusually low compared with the other sites, but the samples from zones 2, 3 and 4 were not significantly different from any other control sites.
Table 3-11  Between-site ANOVA analyses for metal concentrations in _M. nigrans_ whole body samples.

<table>
<thead>
<tr>
<th>Element</th>
<th>Site</th>
<th>Length</th>
<th>Multiple Range Test result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminium</td>
<td>P=0.002</td>
<td>P=0.018</td>
<td>EBeLB EBeRS LB FCcLB EBeGS097 FRdsFC EBeGS327 EBeGS200 FRUsFC EBeH5 EBeFR</td>
</tr>
<tr>
<td>Arsenic</td>
<td>P=0.030</td>
<td>NS</td>
<td>FCoLB FRsFC EBeH5 EBeLB EBeRS RB FRUsFC EBeGS097 EBeGS200 EBeFR EBeGS327</td>
</tr>
<tr>
<td>Cobalt</td>
<td>P=0.001</td>
<td>-</td>
<td>EBeLB FCcLB FRdsFC FRusFC EBeRB EBeGS097 EBeGS327 EBeH5 EBeFR EBeGS200</td>
</tr>
<tr>
<td>Copper</td>
<td>P=0.001</td>
<td>-</td>
<td>FRusFC FRsFC FCcLB EBeLB EBeRS RB EBeGS097 EBeGS200 FCcLB EBeH5 EBeFR EBeGS327</td>
</tr>
<tr>
<td>Lead</td>
<td>P=0.033</td>
<td>-</td>
<td>EBeLB EBeRS RB FRdsFC FRusFC EBeGS327 EBeGS200 FCcLB EBeH5 EBeGS097 EBeFR</td>
</tr>
<tr>
<td>Manganese</td>
<td>P=0.001</td>
<td>-</td>
<td>FCoLB FRsFC EBeGS200 FRdsFC EBeGS097 EBeRB EBeFR EBeRS RB EBeGS327</td>
</tr>
<tr>
<td>Nickel</td>
<td>P=0.001</td>
<td>-</td>
<td>EBeLB FCcLB FRdsFC FRusFC EBeRS RB EBeGS097 EBeH5 EBeFR EBeGS200 EBeFR EBeGS327</td>
</tr>
<tr>
<td>Zinc</td>
<td>P=0.001</td>
<td>P=0.017</td>
<td>ECoLB EBeH5 EBeGS097 EBeGS200 EBeRS RB FRUsFC FRdsFC EBeGS327 EBeGS200</td>
</tr>
</tbody>
</table>

NS = not significant. – not included in final model. Int. = interaction term
3.4.2.3 Northern Trout Gudgeon *Mogurnda mogurnda* hind body samples

Tissue samples for this species were collected from zones 1, 2, 3, 4 and 6. Significant between site differences were found only for cobalt, manganese, nickel and zinc (Table 3-12). For cobalt the highest log average concentrations were found for the samples from EBdsRB and EBusFR, but the three samples collected from FR@GS204 were very variable, and the log average concentrations for EB@GS327 and EB@GS200 were also relatively high compared with at least one control site. The pattern of observed bioaccumulation would be consistent with a source of increased bioavailability in the mine area if residence times of the specimens collected from EB@GS200 were relatively short, but would also be consistent with a source of cobalt downstream of that site.

For manganese, the pattern of bioaccumulation was not consistent with the Rum Jungle mine lease being a source of increased bioavailability, as the log average concentrations for EB@GS200 and FC@LB were significantly lower than for all other sites except EBdsHS, and relatively high concentrations were found for FR@GS204 and EB@LB.
The pattern for nickel was comparable to that for cobalt, with the highest concentrations found for the zone 3 sites EBdsRB and EB@GS327. For zinc the only site that differed from any others was FR@GS204, which was higher than a combination of East Branch and Finniss River sites.

Table 3-12  Between-site ANOVA analyses for metal concentrations in *M. mogurnda* hind body samples.
NS=not significant. – not included in final model. Int.=interaction term

<table>
<thead>
<tr>
<th>Element</th>
<th>Site</th>
<th>Length</th>
<th>Multiple Range Test result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arsenic</td>
<td>N5</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Cobalt</td>
<td>P&lt;0.001 P=0.010</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Copper</td>
<td>NS</td>
<td>P=0.019</td>
<td></td>
</tr>
<tr>
<td>Lead</td>
<td>NS</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Manganese</td>
<td>P=0.043 P=0.032</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nickel</td>
<td>P=0.006</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Zinc</td>
<td>P=0.009 NS</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Figure 3-23 Concentrations of selected metals in *M. mogurnda* hind body samples by site and zone

### 3.4.2.4 Hyrtl’s Tandan *Neosilurus hyrtlii* flesh samples

Samples of this species were collected from zones 3, 4, 6 and 7.

Significant differences were found only for cobalt, copper and zinc (see Table 3-13 and Figure 3-24). For all three metals the samples from the East Branch zone 3 sites were higher on average (after adjustment for length for cobalt) than for the Finiss River sites in zones 6 and 7 and the lower zone 4 site, EBusFR. The other zone 4 site, EBdsHS, was not significantly different from the zone 3 sites for any metal, but was also not significantly different from the downstream sites for zinc. These results are consistent with a source of elevated bioavailability of these metals in the East Branch at or above zone 3. There was no indication of inhibited bioaccumulation of metals by specimens of this species from the more impacted sites, as was reported by Jeffree et al. (2014).
Table 3-13 Between-site ANOVA analyses for metal concentrations in *N. hyrtlii* flesh samples. NS=not significant. – not included in final model. Int.=interaction term

<table>
<thead>
<tr>
<th>Element</th>
<th>Site</th>
<th>Length</th>
<th>Multiple Range Test result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arsenic</td>
<td>NS</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Cobalt</td>
<td>P&lt;0.001</td>
<td>P=0.019</td>
<td>EBusFR FRdsFC FRusFC &lt; EBusHS EBdsHS EB@GS327</td>
</tr>
<tr>
<td>Copper</td>
<td>P&lt;0.001</td>
<td>-</td>
<td>FRusFC FRdsFC EBusFR &lt; EB@GS327 EBdsHS EBusHS</td>
</tr>
<tr>
<td>Manganese</td>
<td>NS</td>
<td>P=0.005</td>
<td></td>
</tr>
<tr>
<td>Nickel</td>
<td>NS</td>
<td>P=0.002</td>
<td>P=0.040</td>
</tr>
<tr>
<td>Zinc</td>
<td>P=0.002</td>
<td>P=0.040</td>
<td>EBusFR FRusFC FRdsFC EBdsHS EB@GS327 EBusHS</td>
</tr>
</tbody>
</table>

Figure 3-24 Concentrations of selected metals in *N. hyrtlii* flesh samples by site and zone

3.4.2.5 Bony Bream *Nematalosa erebi* flesh samples

Bony Bream were not caught at any East Branch site, but this species had been used for assessment of metal bioaccumulation previously (Jeffree *et al.* 2014). Flesh samples were collected from all Finniss River sites in this survey, but between site differences were only found for arsenic and manganese Table 3-14. Importantly, no significant differences were
found for cobalt, copper, lead, nickel, uranium or zinc, in contrast to the findings of Jeffree et al. (2014). For arsenic, the highest log average concentration was found for FRusMB, the upstream control site. For manganese the log average concentration for FRusFC was greater than for FRusMB, but Figure 3-25 shows that this analysis was influenced by a relatively high concentration found for a single specimen from FRdsFC. Without that specimen in the analysis, the log average concentration for FRusFC remained significantly greater than for FRusMB but was also significantly greater than for FRdsMB, and FR3, FRdsFC and FR@GS204 were all significantly greater than FRusMB but not FRdsMB.

The observed differences between sites in arsenic and manganese bioaccumulation in this species were not consistent with a source of either enhanced or reduced bioaccumulation of those metalloids from the East Branch, but rather reflected differences between the upper Finniss River and sites near Florence Creek. As both elements can be relatively more soluble in ground waters, this might reflect localised differences in relative inflows of ground water.

Table 3-14 Between-site ANOVA analyses for metal concentrations in N. erebi flesh samples. NS=not significant. – not included in final model. Int.=interaction term

<table>
<thead>
<tr>
<th>Element</th>
<th>Site</th>
<th>Length</th>
<th>Multiple Range Test result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arsenic</td>
<td>P=0.001</td>
<td>-</td>
<td>FRusFC FRdsFC FR3 FRdsMB FR@GS204 FRusMB</td>
</tr>
<tr>
<td>Copper</td>
<td>NS</td>
<td>-</td>
<td>FRusMB FRdsMB FR@GS204 FR3 FRdsFC FRusFC</td>
</tr>
<tr>
<td>Manganese</td>
<td>P=0.001</td>
<td>-</td>
<td>FRusMB FRdsMB FR@GS204 FR3 FRdsFC FRusFC</td>
</tr>
<tr>
<td>Zinc</td>
<td>NS</td>
<td>-</td>
<td>FR3 FR@GS204 FRdsFC FRdsMB FRusFC</td>
</tr>
</tbody>
</table>

Figure 3-25 Concentrations of selected metals in N. erebi flesh samples by site and zone

3.5 Radionuclide analyses

At the time of writing, no results had been received from any laboratory for radionuclide activity concentrations in aquatic organism samples collected during the survey. Those results will be reported separately when they become available.
4 SUMMARY AND DISCUSSION

This first investigation in 20 years of the ecological status of the Finniss River and its East Branch had the following broad range of objectives:

i) To give an intensive ‘snapshot’ indication of the aquatic ecosystem diversity and abundances based predominantly on samples of fishes obtained from gill-netting and other supplementary methods, for comparison with those results from replicated sampling programs undertaken in the 90’s, when their recovery in the Finniss River proper was such that no impacts due to the presence of contaminants could be statistically discerned (Jeffree and Twining 2000), compared with unexposed regions;

ii) To initiate the definition of a benchmark of contemporary detriment to freshwater biotas so that any future changes may be discerned as a consequence of further remedial activities at Rum Jungle, as well as their temporal sequence;

iii) To expand the range of biotic measures that could be used system-wide in order to determine environmental quality, including the use of measures of macroinvertebrate and benthic diatom diversity, abundance and assemblage composition;

iv) Use sampling methodologies for fishes and larger macroinvertebrates that could permit modifications to those used historically in order to minimise adverse impacts on target and non-target biota, and reducing sampling effort but still retain scientific validity and comparability with historic datasets;

v) Discern any improvements in environmental quality compared with the 90s; particularly for the East Branch where there was still detriment to fishes and macroinvertebrates at that time;

vi) Expand the geographical scale of the assessment for the first time to include evaluation of effluents from the Mount Burton mine site;

vii) Provide the first data for the development of a subsequent cost-effective monitoring program;

viii) Provide further refinement in the status of the aquatic biota based on contemporary developments in their taxonomic resolution; and

ix) Provide a dataset that could be used to refine the water quality objectives developed for the mine site rehabilitation plan based on comparison of aquatic ecosystem status and measured water and sediment quality.

With regard to fishes the results indicated that in the main Finniss River there was no adverse impact on fish diversity and abundances due to their continuing exposures to effluents from Rum Jungle or Mount Burton mine. These results were thus comparable to those obtained from replicated sampling campaigns in the 90s that had shown recovery of sites downstream of the East Branch to levels that showed no significant differences from unexposed sites (Jeffree and Twining 2000). Such a result would be expected if there was no appreciable increases since the 90s in the contaminant loads being delivered to the main Finniss. This consistency in their recovery may also be attributed in part to the
adaptation of the fish biota, based on recent findings for 90s data (Jeffree et al., 2014), although those findings were not overtly supported by the 2014 sampling results.

In comparison with the 90s data for fishes at sites in the East Branch the results showed appreciable improvements in both the assemblage diversity as well as the geographical distributions of species, although there was a still a marked degree of reduction immediately downstream of the region of inflow of Rum Jungle contaminants in the East Branch. This appreciable recovery that has taken place over the last 20 years despite the absence of any further remedial efforts at the Rum Jungle mine site to further reduce the annual contaminant loadings. There are a number of possible explanations that are not mutually exclusive, viz.:

iv) There is a time dependency related to lag factors that are operating on the rates of recolonization after the step reduction in contaminants loads that was measured in the 80s and 90s;

v) Annual contaminant loadings and/or their bioavailabilities have continued to reduce since the 90s permitting further degrees of recolonisation, such as via reduction of sediment sources of contaminants over time; and

vi) There has been continued adaption in the fish biota of the East Branch following their decades of exposure to contaminants, as demonstrated in the 90s for one species in the East Branch (Gale et al. 2003), although the patterns of bioaccumulation of metals by that species were not consistent with continuance of a high level of inhibition of metal uptake for that species.

These explanations of continued recovery would suggest that there is a considerable degree of dynamism in the relationships between current contaminant levels and the recolonising capacities of the fish communities. This snapshot of continued recovery is probably also enhanced by the period in the annual cycle within which these current studies were undertaken, relative to the 90s investigations (very early Dry compared to later Dry in an intermittent system), as well as a more intensive sampling effort in 2014. Continued recolonisation of the riparian vegetation would also improve the aquatic habitats of East Branch.

In the context of the establishment of a contemporary benchmark against which to assess the environmental benefits of further remediation at Rum Jungle for the Finnis River the East Branch is where such improvements will be most clearly observed, as recovery in fish diversity in the main Finnis is already complete, or at least not discernibly different from unexposed sites, according to this current snapshot.

Given that the biological status of the intermittent East Branch will be a function of both the contaminant loads from Rum Jungle as well as water flows, both factors need to be taken into account when developing a monitoring program with the validity to demonstrate ecological improvements that can be attributed to further mine site remediation.
With respect to the adoption of new sampling methods and reductions in the duration and intensity of gill netting the results are supportive of an objective of the reduction of adverse impacts of a routine monitoring program. Reductions in both the period over which gill nets are set and also their number, in combination with electro-fishing, fyke netting and trapping, are indicated to be adequate to evaluate the biodiversity of these biota, but with greatly reduced mortalities of these target organisms as well as Freshwater Crocodiles.

Although recolonisation of the intermittent East Branch by fishes each year is necessarily by upstream movement from the Finnis River, for the majority of macroinvertebrates and diatoms recolonisation can be aerially or via aestivating life stages in situ in the East Branch. Establishment of assemblages for these groups will therefore be less contingent on connectivity with and sources of recruits from downstream reaches. This is evidenced by the assemblages of both groups at sites in the very intermittent upper East Branch catchment in zone 1 having been generally comparable to the assemblages in the upper Finnis River, whereas those sites supported depauparate fish and macrocrustacean assemblages.

Nonetheless, these ecosystem components indicated broadly similar patterns of assemblage condition across sites to those observed for fishes. The most impacted sites were those in zone 2, with generally recovery through zones 3 and 4, and with no indication of impact at the Finnis River sites. Site EBdsRB was anomalous in terms of its macroinvertebrate assemblage, being comparable to Finnis River sites rather than other East branch sites. This was not the case for the fish or diatom assemblages at that site. For fishes, the adjacent site EB@GS327 had unusually high species richness for its location in the East Branch, which was attributed to greater habitat diversity, but EBdsRB had richness indicative of its position in zone 3. The reason for this difference in macroinvertebrate assemblage health at this site is not clear, but as it was a shallow, somewhat isolated site, it may have reflected improved water quality at this site due to local runoff inflows.

Despite the anomaly of the macroinvertebrate assemblages of EBdsRB, the consistency of the general pattern of reduced biodiversity at East Branch sites in zone 2 with gradual improvement through zones 3 and 4 for all three groups of aquatic organisms suggests that this pattern was driven by a gradient of contaminant concentrations rather than limitation of recolonisation of an intermittent stream from downstream sources.

Mussels are not able to disperse aerially, but are able to disperse upstream via fish hosts carrying their glochidium larval stage as temporary parasites on gill and other external surfaces. Therefore, while requiring aquatic connectivity to colonise new areas, the movement of fishes into the East Branch would afford opportunities for this to occur. That they have fully recovered their geographic range in the Finnis River since the 90s, in the absence of further remediation of the mine lease area, is notable, as is their continued absence from the East Branch downstream of zone 1.
The tissue metal results were consistent with sources of increased bioavailability of cobalt, copper, nickel and zinc within or near the mine lease area, or zone 2. For cobalt and nickel, the results for Northern Trout Gudgeon were suggesting that the source might be just downstream of the mine lease area, in the upper reaches of zone 3, which is where water discharges from the moth-balled Brown’s Oxide polymetal mining operation had occurred in 2014. Other tissue types were indicative that at least copper and zinc had a primary source of elevated bioavailability in zone 2, and that the source of elevated cobalt and nickel bioavailability could also be in zone 2. These results were therefore also consistent with a potential driver of the observed patterns of impacts to the diatom, macroinvertebrate and fish assemblages being elevated bioavailable concentrations of those metals from within or near zone 2. Given the known continuation of loading of acid rock drainage into the East Branch from sources in the mine lease area, this finding was to be expected.

5 RECOMMENDATIONS

- Repeat sampling in 2015 of the Finnis and East Branch using the recommended new suite of sampling methodologies, including a much reduced program of gill netting to improve the baseline of contemporary ecosystem condition for use for assessment of the success of further rehabilitation and be consistent with sets of multiple rounds of sampling used in the previous periods. It is recommended that this occur in the similar early dry season period as for the 2014 sampling because this will capture maximal spatial extent of fish species when access permits; and
- It was recommended that more effort be placed into understanding the current extent of recovery and its drivers in the East Branch by:
  - an additional sampling round later in the Dry of 2015 targeted at macroinvertebrate and diatom assemblages but with fish sampling of the East Branch only to provide a better comparison with sampling in the 90s; and
  - ii) comparison of the presence of biota along the pollution gradient of the East Branch with ecological risk predictions of the presence of different biota based on water quality alone, including geochemical modelling of bioavailable fractions, for comparison with similar 90s assessments.

6 ACKNOWLEDGEMENTS

We would like to thank Cyrus Edwards and the EMU team members including Amanda Schaarschmidt, Grant Robinson and ??? for their invaluable assistance with the field work, particularly when the burden of increased frequency of net checks through the night became apparent. Overall support was provided by the DME Rum Jungle Project team, particularly Mitchell Rider and Tania Laurencont.

7 REFERENCES

ANZECC/ARMCANZ (Australia and New Zealand Environment and Conservation Council)/(Agriculture and Resource Management Council of Australia and New Zealand)


