Hydrobiology

Bioaccumulation of heavy metals in McArthur River and tributaries

Investigation and assessment of potential impacts

January 2016

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EXECUTIVE SUMMARY

Environmental monitoring undertaken by McArthur River Mine (MRM) has reported elevated concentrations of some metals in aquatic organisms within the mine lease, but also in limited samples from adjacent catchments. The Northern Territory Government (Department of Health, Department of Mines and Energy, Department of Primary Industries and Fisheries) determined that an independent review of the MRM monitoring program and its results was required. This review aims to assess potential heavy metal contamination emanating from MRM, as well as determining background levels in the broader region based on existing data. The focus is on potential effects on human health from consumption of affected aquatic species.

Based on the data reviewed and people consulted for this study, the risk to human health posed by consumption of fish from the McArthur River system was considered to be low. This was particularly true when the likely consumption patterns from our early consultation works across the study area were taken into account. Certainly, the calculations of theoretical maximum daily consumption rates indicated that even the most ardent local fisherperson would not to breach the tolerable intake of any particular contaminant in the study area.

However, we identified several knowledge gaps that, when addressed, may warrant reassessment. Principal among these gaps were:

- Insufficient representation of reference sites in the dataset from outside the McArthur River catchment. The DPIF sampling went some way to addressing this, but future sampling should incorporate reference data collected at the same time as those from the area of interest in each round of sampling.
- The monitoring program does not match the species favoured by people that fish in the area. Again, recent efforts by DPIF and MRM have attempted to address this but there still remains some mismatch between species that are consumed and those tested. Prime examples include turtles and the guts of barramundi (and turtles).
- The sampling design needs to take into account the high mobility of fishes in the MacArthur River, via use of appropriate analyses and interpretation, such as via considerations of gradients of exposure.

Overall, given that only a small proportion of the tissue samples of the parts of fishes and other organisms collected from outside the mine area had tissue metal concentrations that were above health-based food standards, and that the people of the study area are at most comparable to average aquatic food consumers in the general Australian population, the assessment of low risk is appropriate.

It is acknowledged that the results of this study, based largely on historical data primarily collected for environmental purposes, may do little to alleviate the perceived concerns already present in the local community. Where there is a desire to enact a program that may assist in alleviating these concerns, and confirming this preliminary risk assessment, then it is recommended that any future monitoring incorporate the modifications (or augmentations) identified under the Gap Analysis undertaken for this study.

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1 INTRODUCTION

Environmental monitoring undertaken by McArthur River Mine (MRM) has reported elevated concentrations of some metals in aquatic organisms within the mine lease, but also in limited samples from adjacent catchments. The NT Government (Department of Health, Department of Mines and Energy, Department of Primary Industries and Fisheries) determined that an independent review of the MRM monitoring program and its results was required. The review (this study) aims to assess potential heavy metal contamination emanating from MRM, as well as determining background levels in the broader region based on existing data. The focus is on potential effects on human health from consumption of affected aquatic species.

This assessment is based around answering three primary questions:

1. *What is the nature and magnitude of risk to human health posed by contaminants in the tissue of aquatic fauna?*
2. *What is the likelihood that contamination in aquatic fauna is attributable to the presence of the McArthur River mine (MRM)?*
3. *What is the rigour of the existing monitoring regime instigated by MRM in detecting contamination of aquatic fauna at levels of concern to human health?*

We address these questions through review of existing information provided by the NT Government, liaison with knowledgeable stakeholders and through consultation with potentially affected people living in the study area (Figure 1-1).

1.1 Background

The McArthur, Wearyan and Limmen Bight Rivers are located in the Gulf of Carpentaria in the Northern Territory approximately 700 km southeast of Darwin. The McArthur River Mine is situated within this region on the McArthur River, approximately 45 km southwest of Borroloola (Figure 1-1).

The mineral deposit was originally discovered in the 1950s. Large-scale mining commenced in 1995 as an underground zinc/lead/silver mine and converted to an open pit mine in 2007 which included the diversion of the McArthur River. Concentrate is transported to Bing Bong Port via the highway and transferred by a purpose-built bulk carrier to offshore ships. Mineral exploration activities continue in the surrounding area, and there is recent interest in the unconventional gas reserves of the greater McArthur and Georgina basins[1].

[1] *Northern Territory shale gas potential more than just hot air*, ABC News 18 March 2015, http://www.abc.net.au/news/2015-03-18/northern-territory-shale-gas-potential/6329952

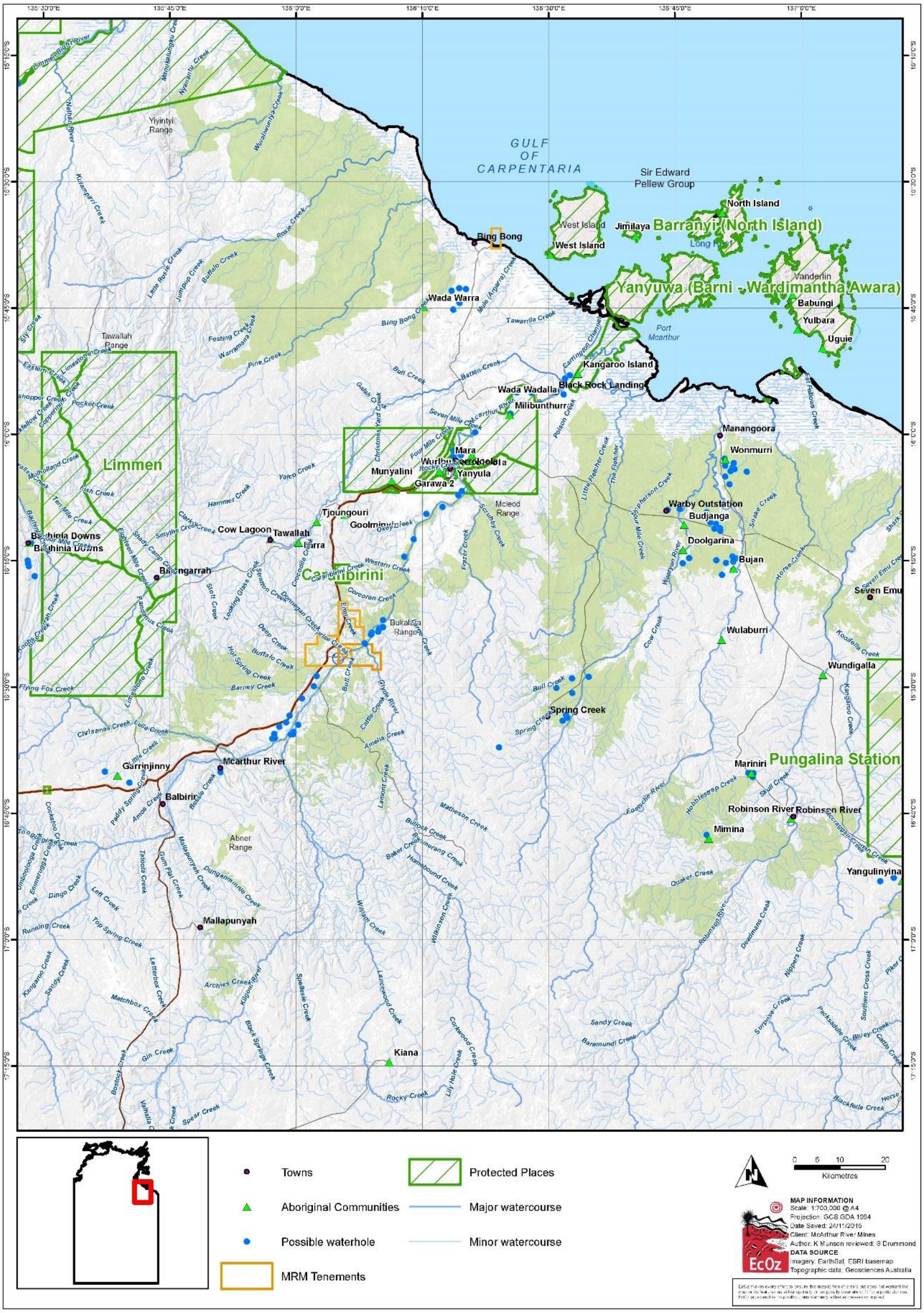

Figure 1-1 Study Area

1.2 Approach

Our approach was designed to address the study's three primary questions using the following:

1. *What is the nature and magnitude of risk to human health posed by contaminants in the tissue of aquatic fauna?*
    - A critical review of available data sources specific to this project;
    - Screening of available tissue metal data against Australian and international food standards;
    - Consultation with potentially affected people to gain an initial understanding of their consumption of fish caught in the study area; and
    - Undertaking of a risk assessment.
2. *What is the likelihood that contamination in aquatic fauna is attributable to the presence of the McArthur River mine (MRM)?*
    - Assessment of whether existing data were sufficient to determine a source and extent.
3. *What is the rigour of the existing monitoring regime instigated by MRM in detecting contamination of aquatic fauna at levels of concern to human health?*
    - Review of monitoring program components including geographic scope, species suitability, sample selection and processing, replication and analysis;
    - Conducting a gap analysis of information required to inform any future human health risk assessment; and
    - Recommending, if required, a statistically rigorous program that addresses perceived human health risks.

This report presents our findings for each task.

2 NATURE AND MAGNITUDE OF RISK TO HUMAN HEALTH

2.1 Review of available data sources

The NT Government made available several data sources to inform this study (Table 2-1). There also exists a large body of information on the broader area, which was briefly reviewed in the context of this study, such as:

- Independent Monitor review of MRM environmental performance (ERIAS 2014)
- EIS documentation produced by MRM in 2012 (the "Phase 3 Draft EIS"; Xstrata/MetServe 2012), 2005 (Xstrata/URS 2005) and 1992 (only the assessment of the EIS was reviewed, NT EPU 1992)
- Broadscale fish biodiversity surveys including: North Australian Freshwater Fish Atlas (NCTWR 2015), and associated literature review (Burrows 2008)
- Recreational fishing data (West et al. 2012).

Table 2-1 Available data sources, hereafter referred to by their descriptor

Reference	Descriptor	Description of data/information
DPIF (2014a, 2014b)	DPIF monitoring	Monitoring conducted by DPIF officers over two occasions in the dry season 2014. Included tissue-metal concentrations of a range of fish species, mud crabs (purchased from professional fishermen) and mussels collected in July/Aug 2014. Geographic scale included in the mine surrounds, downstream within McArthur River, and in neighbouring Limmen Bight and Foelsch rivers.
ToxConsult (2014)	ToxConsult	Specific Pb and Mn analysis of mussels that were collected during DPIF monitoring, including derivation of theoretical 'maximum consumption' limits.
Indo-Pacific Environmental (2009, 2010abc, 2011, 2012a, 2013, 2014)	MRM freshwater monitoring	MRM freshwater monitoring program, which involves targeted monitoring of rainbow fish, spangled perch, bony bream, prawns and mussels along the McArthur River system. Further sampling of Barramundi, Chequered rainbow fish and Fork-tailed catfish in Aug 2014.
Parry, D (2009, 2010); Streten-Joyce, C & Parry, D (2011), Indo-Pacific Environmental (2012b)	MRM marine monitoring	MRM marine monitoring program targets sediment, seagrass, molluscs and water quality around Bing Bong and the Pellew Islands.
Sharp, W (2014)	Drinking water quality	PowerWater drinking water analysis of Borroloola and Garawa bores between July 2013 and May 2014.
Skov, S (2015)	Initial risk assessment	Specific analysis of risks associated with consumption of aquatic fauna from the McArthur River

2.1.1 Freshwater monitoring data

No tissue metal data were collected as part of the original EIS submitted for MRM (NT EPU 1992), the 2005 EIS (Xstrata/URS 2005), nor as part of the biodiversity surveys undertaken in the intervening years (Burrows 2008; NCTWR 2015). That is despite concerns raised by the then Environment Protection Unit that *"…it is considered that the human risk from eating contaminated food, as well as the cultural implications of perceived contaminated food, has been handled by the proponent in a cursory manner"* (p37, NT EPU 1992). The only source of tissue metal data available is that collected by the MRM monitoring program and DPIF in late 2014. Results from the MRM monitoring program are briefly summarised below:

- Between 2005 and 2008, a variety of fish and crustacea were collected from the mine area (McArthur River and Surprise Creek).
- A reasonable dataset for the last 6 years (2009 – 2014) targeting rainbowfish, spangled perch, bony bream, prawns (usually but not always reported as *M. rosenbergii*[2]) and mussels. In 2014 some supplementary sampling was undertaken for Barramundi, Sooty grunter and Fork-tailed catfish. For the small fish species, 3-5 replicates of each were generally collected per site; between 5 and 10 replicates of the larger fish were generally collected per site.
- Monitoring sites within the mine area occasionally changed but typically the upstream/downstream sites were consistent. All sampling was typically undertaken between April – July in each year.
- The monitoring program was very focussed on McArthur River and tributaries near the mine area, with only very scant 'reference' data collected from one site on the Wearyan River (50 km east) in April 2010 and May 2011, and one site on the Limmen Bight River (100 km west) sampled in September 2010 and May 2011.

For the DPI monitoring conducted over two occasions in the dry season of 2014:

- There were two sampling rounds, July and August, during which a variety of fish was caught from 2 sites within the mine area (Surprise and Barney Creek diversion channel), upstream and downstream within McArthur River and from Limmen-Bight and Foelsche rivers. They also collected 27 mussels from Upstream Burkes Crossing (i.e. adjacent to Borroloola).

2.1.2 Marine monitoring data

The primary focus of this study is on the freshwater environment, but the marine monitoring reports were briefly reviewed:

- Annual monitoring between 2009 and 2012 targeted sediment, seagrass, molluscs and water quality. Mud crabs and limited sampling of juvenile Bluetail mullet were added to the sampling program in 2012.

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[2] Now *M. spinipes*

- Each year broadly the same results were reported – elevated lead and zinc in sediments and oysters sampled from the Bing Bong port channel and load-out area. The rest of the study area did not record any detectable impact attributed to MRM.
    - Lead and zinc concentrations from fish and crabs collected by DPIF in July 2014 from the mouth of Davey Creek, approximately 16 km southeast of Bing Bong, were all below screening levels of human health concern.
- Other notable findings from this monitoring program are elevated copper (in mud crabs and oysters) and cadmium concentrations (in mud crabs) in several samples collected across the study area and reportedly unrelated to MRM operations at Bing Bong. Crustaceans such as mud crabs typically have elevated copper levels as it forms a basis for their respiratory pigment.
    - Cadmium was elevated in almost all prawn, mud and sand crab hepatopancreas samples collected by DPIF in July 2014, but none of the corresponding flesh samples.

2.2 Analysis of available data

2.2.1 Risk assessment rationale

We have designed an initial human health risk assessment in accordance with Australian guidelines[3] (enHealth 2012a,b). The model for this approach is represented in Figure 2-1. An estimation of health risk, by definition, is a product of both the intrinsic hazard of a contaminant and the extent of exposure. To undertake this assessment, the tissue metal data used was screened against health guidelines, for which two approaches / methods were adopted.

[3] *Environmental Health Risk Assessment: Guidelines for assessing human health risk from environmental hazards* (enHealth 2002); *Australian exposure factor guide* (enHealth 2012)

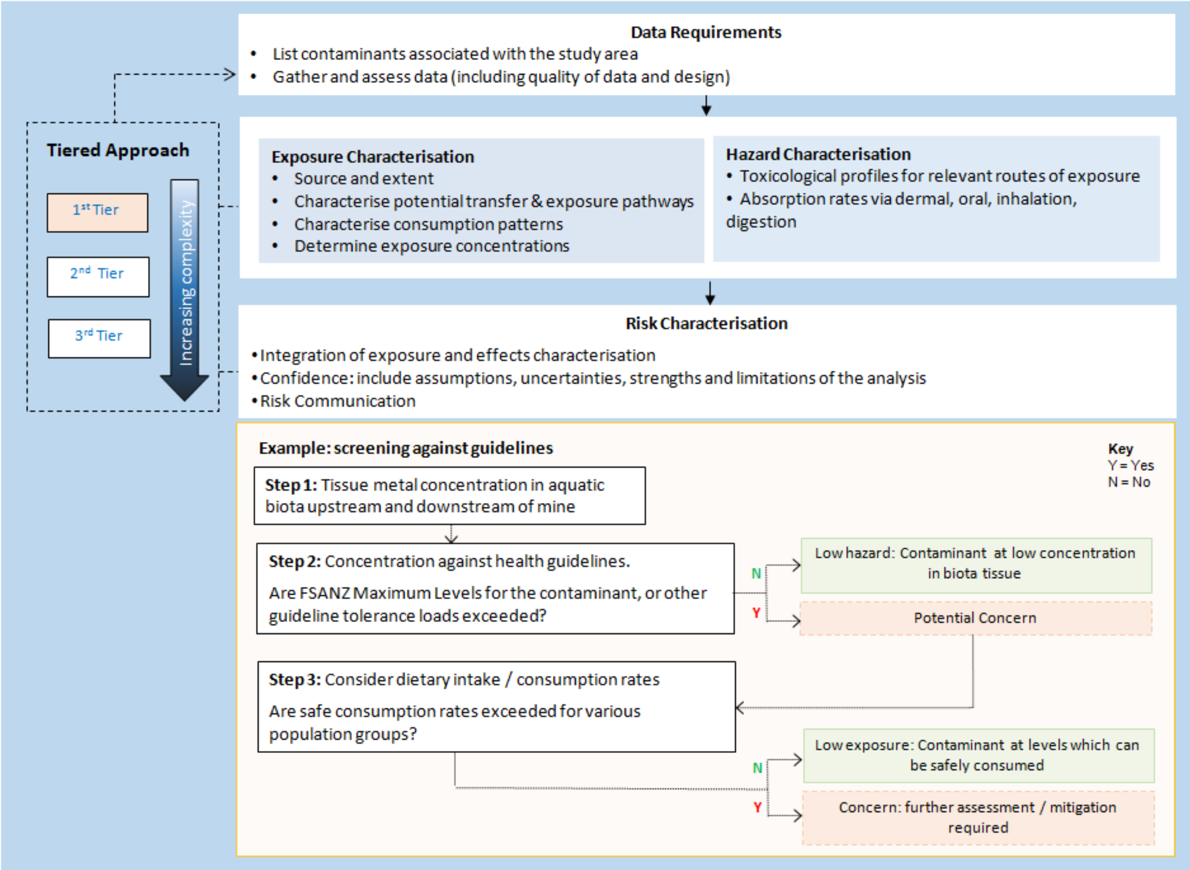

Figure 2-1 Conceptual human health risk assessment

The first approach adopted the method from FSANZ (2012 and 2013), which involved the comparison of measured metal concentration from samples with reported levels in two Australian Total Diet Studies (ATDS), the 22nd ATDS (2008) and 23rd ATDS (2011). We noted a variant of this approach was also used by Skov (2015). The mean / median dietary exposure to trace elements reported based on the 22nd and 23rd ATDS provided a good estimate of background dietary exposure to trace elements from all foods. This allowed an assessment whether there was an increased risk through higher dietary exposure to the measure metals compared with the general Australian intake.

For the second approach, as a further conservative measure, we compared individual tissue metal loads *per species, per sample* against the values listed in the Food Standards Australia / New Zealand (FSANZ) Code known as 'Maximum Levels' (MLs) for a contaminant within a particular food group (currently this falls under *Standard 1.4.1 Contaminants and Natural Toxicants* of FSANZ 2015). The MRM monitoring program used this approach, and incorporated several rescinded MLs from earlier food standards (Appendix 1). They were rescinded on the basis that there was inadequate evidence that they represented health hazards at those concentrations. Their rationale for inclusion in the MRM screening was that such inclusion nonetheless increased the level of scrutiny of the monitoring program, and results were interpreted with caution. This is a reasonable approach to take for an environmental monitoring program, but for our purposes we are only interested in metal/metalloids that have a health-based guideline (e.g. FSANZ ML such as lead and inorganic arsenic).

We specifically focused on tissue results where human consumption was likely to occur (i.e. flesh referred to in the dataset as either muscle/trunk/whole fish), and only assessed the liver from large-bodied fish (barramundi and catfish), which traditional owners indicated as a favoured food (specifically barramundi, see Section 2.3.1). Flesh samples provide the greatest information relating to risk of human health, as this is what is most commonly eaten in any great quantity.

2.2.2 Risk assessment method and summary

Following the generic conceptual risk assessment model, we therefore undertook the following tasks in assessing risk:

1. Data requirements: collated available tissue metal data, grouping according to metal, tissue type, year and location
2. Risk characterisation: Used data provided on tissue metal concentrations and compared this against guideline values using two methods (see Appendix 1 for more detail):
   i. Comparison against Australian Total Diet Survey (ATDS[4]) using the FSANZ (2012, 2013) approach by comparing metal tissue concentrations from the study area with relevant 'background' ATDS data (e.g. metal concentrations in tinned fish, prawns or some other analogous food product consumed in Australia and considered, by default, to be tolerable);
   ii. Comparison against Food Standards Australia / New Zealand (FSANZ) Code:
       - Where contaminants were identified at levels of *potential* human health concern through either method, step #3 was undertaken (also see Figure 2-1);
3. Assessed residual risk against estimated consumption patterns gathered during consultation for this study:
    - If levels were above those compared with background ATDS and/or FSANZ food standards code, potential exposure concentrations based on approach from FSANZ (2012, 2013) were determined. This was compared with calculated theoretical maximum intake to assess safe consumptions rates for two population groups (toddler and adult).

[4] The Australian Total Diet Study (ATDS) is Australia's most comprehensive assessment of consumers' dietary exposure (intake) to a range of food chemicals including food additives, nutrients, pesticide residues, contaminants and other substances. The 22nd and 23rd Australian Total Diet Surveys included surveys on metals relevant to this study.

2.2.2.1 Method 1 – comparison against background ATDS (FSANZ 2012, 2013 approach)

Table 2-2 outlines the median and/or mean[5] concentrations in fish (muscle, whole fish and trunk) and prawn (muscle) tissue samples from the MRM and DPIF monitoring studies. Table 2-3 presents similar data for fish livers (barramundi and catfish) and mussels. The metals analysed in biota tissue for MRM and DPIF were assessed against the 22nd and 23rd Australian Total Diet Surveys (ATDS, 2008 and 2011), and thus were used to provide information on representative national trace metal concentrations and background mean dietary exposures following the approach used in FSANZ (2012, 2013).

Key findings included:

- Fish flesh: consistently higher concentrations of aluminium, chromium, cobalt, lead, manganese, molybdenum and zinc in samples upstream and downstream of the Mine, but notably also within reference sites when compared with the background levels provided by ATDS;
- Prawn flesh: consistently higher concentrations of chromium, cobalt, lead, manganese and molybdenum found downstream and upstream of the Mine, and also within reference sites when compared with the background levels provided by ATDS;
    - With the exception of lead and chromium, concentrations higher than the ATDS noted for both fish and prawn flesh were largely related to essential metals rather than contaminant metals when compared with the background levels provided by ATDS;
- Mussels: consistently higher concentrations of the same suite of metals as fish and prawn flesh, plus elevated concentrations of copper and cadmium both downstream and upstream of the mine, and in reference sites.
- Fish livers: same pattern as observed for mussels.

However, when reviewing the theoretical maximum safe consumption amounts (Table 2-2) the exposure risk was practically removed for fish and prawn flesh (see Appendix 1 for further detail on calculation of these amounts including the tolerable threshold limits that were adopted):

- Cobalt and Manganese: a toddler would need to consume on average > 1.3 kg fish or 3.1 kg of prawns per day before ingesting hazardous concentrations (5.2 and 12.1 kg respectively for Cobalt);
- Lead and Zinc: maximum daily intakes were much lower, but still beyond the reasonable consumption limits of the 'average' toddler or adult (>500 g of fish/prawns per day on average for a toddler); and

[5] The use of a calculated median and/or mean for the tissue metal data was determined based on the ATDS approach (i.e. if for a specific metal/element the ATDS used the median then the median for the MRM data was calculated and compared).

- Similar, but even more nonsensical maximum consumption limits were calculated for adults.

For mussels and fish liver, the theoretical safe consumption amounts were less, but the exposure risk was substantially offset by the impracticality in being able to harvest sufficient quantities of mussels or fish livers on a daily basis.

- Mussels: maximum daily intakes in relation to lead concentration were about 65 g for a toddler or 190 g for an adult. This was slightly higher than the levels proposed in ToxConsult (2014) (43.3 g/day for a child), primarily due to a lower median concentration for our larger dataset (which included the mussels they assessed plus those collected by MRM) and a different approach to calculating tolerable intake.
    - Safe daily consumption rates of mussels due to potential health effects of Manganese were very low (25 g/day or less), but these results are extremely conservative and discussed further below in combination with the ToxConsult (2014) study (see Section 2.2.4)
- Fish liver:
    - For barramundi, a toddler would need to consume > 100 g of liver per day on average (about 7 livers) before ingesting hazardous concentrations (of cadmium, with other metals having much higher safe consumption amounts).
    - For catfish, where the median concentration of zinc was quite high (893 mg/kg, though sample numbers were very low), the FSANZ approach adopted indicated a maximum safe daily average consumption rate in the order of 10 – 70 g. This would equate to around 1 to 4 livers per day.

Table 2-2 Summary of metal and nutrient results (all in mg/kg unless otherwise noted) for fish and prawn flesh and compared with ATDS background levels (exceedance data are shaded)

Parameter	Tuna in brine	Prawns	Fish flesh						Prawn flesh					
			Upstream	Mine Lease	Downstream	Reference	Estuary	Max safe consumption (kg per day)	Upstream	Mine Lease	Downstream	Reference	Estuary	Max safe consumption (kg per day)
Aluminum	0.67	3.2	1	1	1.18	1	-	n/a	2.8	1	1	3	-	
Arsenic[1]	1.1	1.4	0.025	0.03	0.05	0.05	1.4		0.1	0.081	0.14	0.13	-	
Chromium[3]	0.012	0.014	0.05	0.05	0.03	0.04	-	n/a	0.032	0.041	0.025	0.034	-	n/a
Cadmium	0.011	0.066	0.002	0.002	0.002	0.007	0.01		0.007	0.003	0.008	0.008	-	
Cobalt[3]	0.0037	0.009	0.03	0.028	0.027	0.068	-	5.2 / 23.2	0.029	0.017	0.017	0.08	-	12.1 / 54.5
Copper[3]	0.55	8.8	0.34	0.407	0.292	0.444	0.21		10.21	9.6	9.6	11	-	
Gallium	-	-	0.01	0.01	0.01	0.01	-		0.01	650	0.01	0.01	-	
Lead	0.0028	0.008	0.026	0.044	0.03	0.03	0.4	0.6 / 1.7	0.018	0.015	0.01	0.012	-	1.4 / 4.2
Manganese[3]	0.13	0.63	4.1	5.4	4.2	3.9	-	1.3 / 0.87	2.2	1.3	1.1	2.3	-	3.1 / 2
Magnesium	-	-	310	340	300	345	-		330	330	360	342	-	
Molybdenum[3]	0.002	0.006	0.008	0.008	0.008	0.018	-	n/a	0.009	0.008	0.008	0.013	-	n/a
Nickel[2]	6.5	21.7	0.03	0.03	0.03	0.11	-		0.02	0.03	0.03	0.16	-	
Vanadium	-	-	0.03	0.026	0.03	0.014	-		0.015	0.006	0.019	0.012	-	
Zinc[3]	5.7	14	12	15	11	12	4.0	0.54 / 3.9	13	14	13	15	-	0.54 / 3.9

Note: 1 = arsenic measured values and trigger given is for total arsenic, inorganic arsenic trigger is 0.05 mg/kg; 2 = Nickel background level taken from 22nd ATD study; 3= mean concentration, all others are median concentration. Maximum safe consumption in kg eaten per day for Toddler / Adult. Toddler values are based on a 16 kg 2-3 year old, and adult values are based on 70 kg 30 year old for the highest concentration recorded across sites(mean and or/median concentration used to match reference standard calculation); n/a for contaminants where no accepted health-based guideline exists.

Table 2-3 Summary of metal and nutrient results (all in mg/kg unless otherwise noted) for mussel flesh and fish livers (barramundi and catfish) compared with ATDS background levels (exceedance data are shaded)

Parameter	Tuna in brine	Prawns	Mussel flesh						Fish livers (barramundi / catfish)					
			Upstream	Mine Lease	Downstream	Reference	Estuary	Max safe consumption (kg per day)	Upstream	Mine Lease	Downstream*	Reference	Estuary	Max safe consumption (kg per day)
Aluminum	0.67	3.2	19	17	48	1	-	n/a	1	1.6	2	-	-	n/a
Arsenic[1]	1.1	1.4	0.84	0.72	0.96	0.39	-		0.11	0.11	0.09	-	-	
Chromium[3]	0.012	0.014	0.07	0.10	0.21	0.03^	-	n/a	0.03^	0.03^	0.03^	-	-	n/a
Cadmium	0.011	0.066	0.013	0.026	0.042	0.009	-	0.2 / 0.7	0.044	0.082	0.051	-	-	0.1 / 0.36
Cobalt[3]	0.0037	0.009	0.09	0.13	0.17	0.04	-	2.1 / 9.3	0.055	0.028	0.229	-	-	1.5 / 6.9
Copper[3]	0.55	8.8	1.4	2.0	1.3	0.7	-	3.5 / 17	4.27	6.70	2.65[b] 31.3[c]	-	-	2.6 / 12.6[b] 0.2 / 1.1[c]
Gallium	-	-	0.02	0.02	0.02	0.01	-		0.01	0.01	0.01	-	-	
Lead	0.0028	0.008	0.21	0.36	0.40	0.04	-	0.065 / 0.19	0.004	0.012	0.005[b] 0.16[c]	-	-	5.6 / 16[b] 0.16 / 0.46[c]
Manganese[3]	0.13	0.63	382	339	488	280[4]	-	0.025 / 0.016	0.444	0.360	0.559	-	-	12.8 / 8.4
Magnesium	-	-	160	160	190	91	-		90	83	100	-	-	
Molybdenum[3]	0.002	0.006	0.040	0.043	0.061	0.025	-	n/a	0.156	0.086	0.210	-	-	
Nickel[2]	6.5	21.7	0.11	0.11	0.12	0.04	-		0.03	0.03	0.03	-	-	
Vanadium	-	-	0.13	0.15	0.20	0.02	-		0.200	0.074	0.280	-	-	
Zinc[3]	5.7	14	24	30	36	13	-	0.23 / 1.6	13.2	10.8	11.7[b] 893[c]	-	-	0.7 / 5[b] 0.01 / 0.07[c]

Note: 1 = arsenic measured values and trigger given is for total arsenic, inorganic arsenic trigger is 0.05 mg/kg (FSANZ 2012); 2 = Nickel background level taken from 22nd ATD study; 3= mean concentration, all others are median concentration; 4 = single sample only. Maximum safe consumption in kg eaten per day for Toddler / Adult. Toddler values are based on a 16 kg 2-3 year old, and adult values are based on 70 kg 30 year old for the highest concentration recorded across sites(mean and or/median concentration used to match reference standard calculation); n/a for contaminants where no accepted health-based guideline exists. ^all results were below the laboratory limit of detection, which is higher than the relevant ATDS background level. * For Cu, Pb and Zn, barramundi means are presented (denoted b) separate to catfish (c) means, the latter are markedly higher but only 3 samples in total were collected of catfish livers and only from downstream sites.

2.2.2.2 Method 2 – comparison against Food Standards Australia / New Zealand Code

There was no elevated lead or arsenic recorded from flesh of the following species, and therefore their regular consumption is considered to have no potential health risk related to these metals. The species which were identified during consultation as species that are preferentially caught for consumption (see Section 2.3.) are indicated with a '*'.

- Barramundi*
- Shovel nose catfish*
- Eel tail catfish*
- Fork tail catfish*
- Mullet
- Archerfish*
- Bull shark*
- Mangrove jack*
- Tarpon
- Queenfish*
- Freshwater yabby

The following non-conformances with the Food Standards code were recorded (Table 2-4):

- Arsenic: which occurs in organic and inorganic forms, where the organic forms are considered unavailable to uptake via consumption while inorganic forms present a greater hazard. The majority of the samples/data were presented as total arsenic and did not differentiate between the organic and inorganic forms. Table 2-4 shows that exceedances for arsenic occurred assuming all measured arsenic was in inorganic form (N.B. the ML is based only on inorganic arsenic). However, typically inorganic arsenic in aquatic organisms is at most 10% of the total arsenic load, in which case no samples would have exceeded the ML (2 mg/kg for fish and prawns, 1 mg/kg for molluscs). To support this, DPIF had two composite mussel samples from two different locations (*n* = 9 and 7 respectively) tested for total and inorganic arsenic, in both composite samples inorganic arsenic was below the detection level of 0.05 mg/kg. With a total arsenic load in the same sample of 1.5 mg/kg, the maximum possible inorganic arsenic load was < 3% (See also Francesconi and Edmonds (1996)). Thus:
    - No samples exceeded the inorganic arsenic maximum level, if it is assumed that at most 10% of the proportion of total arsenic (as reported in the dataset) was inorganic arsenic (i.e. the screening level for total arsenic would be 20 mg/kg rather than 2 mg/kg).
    - However, for the avoidance of any doubt if we assume, unrealistically, that 100% of the total arsenic recorded was actually inorganic arsenic then there were several non-conformances with the ML, but these are considered extremely unlikely to have been true exceedances:
        - A single fish (bony bream) downstream of the McArthur mine was above the arsenic screening level, while three non-conformances in blue salmon and for a single Javelinfish was noted within the estuary (adjacent to Davey Creek);
        - 36 mud crabs were purchased in 2014 and assessed for metals. The associated metal results have not been included in the table below as the origin of the purchased specimens was unknown. All of the flesh samples from the purchased mud crab samples exceeded the total arsenic ML, though as discussed above this does not consider organic/ inorganic speciation. The average total arsenic concentration in sampled mud crabs was 7.6 (± 0.67 se) mg/kg.
- Lead
    - Elevations above the lead maximum level in fish largely occurred in specimens collected from the mine itself. Fewer exceedances were noted upstream and downstream of McArthur mine, and within the reference sampling areas; and
    - Elevations above the maximum level largely occurred in small bodied fish, with only two larger, more commonly consumed fish (blue salmon and black

bream), having recorded concentrations above the maximum levels for arsenic and lead, respectively.

Table 2-4 Summary of number of samples that exceeded the FSANZ ML screening levels

Species	Arsenic^					Lead				
	Upstream	Mine Lease	Downstream	Reference	Estuary	Upstream	Mine Lease	Downstream	Reference	Estuary
Fish										
Bony bream*	-	-	*1 (2014) n = 5*	-	-	-	8 (2013, 14) *n* = 39	1 (2014) *n* = 5	-	-
Spangled perch*	-	-	-	-	-	5 (2010) *n* = 12	9 (2010, 13, 14) *n* = 104	-	1 (2010) *n* = 4	-
Black bream / Sooty grunter*	-	-	-	-	-	1 (2014) *n* = 29		-	-	-
Chequered rainbow fish	-	-	-	-	-	2 (2010, 13) *n* = 21	13 (all) *n* = 157	1 (2010) *n* = 8	2 (2010) *n* = 4	-
Barred grunter	-	-	-	-	-	-	-	1 (2014) *n* = 1	-	-
Western rainbow~	-	-	-	-	-	-	1 (2014) *n* = 1	1 (2014) *n* = 1	-	-
Blue salmon	-	-	-	-	*3 (2014) n = 6*	-	-	-	-	-
Javelinfish	-	-	-	-	*1 (2014) n = 3*	-	-	-	-	-
Crustaceans										
Freshwater prawn	-	-	-	-	-	-	1 (2012) *n* = 21	-	-	-
Molluscs										
Freshwater snail	-	-	*3 (2014) n = 7*	-	-	-	-	-	-	-

Note: ^ this is based on the assumption that the total arsenic recorded was 100% inorganic arsenic; typically inorganic arsenic in aquatic organisms is at most 10% of the total arsenic load, in which case no samples would have exceeded the screening level. *n* = the total number of samples collected of that species pooled for the years that recorded an exceedance. * indicates fish identified in the survey as species that are preferentially caught, though it is noted that bony bream and spangled perch are generally used as bait fish rather than direct human consumption (see Section 2.3). ~ indicates species listed as identified by DPIF but is highly likely to actually be the Chequered rainbowfish; the Western rainbow occurs west of the Adelaide River.

2.2.3 Lead isotope tracing

The MRM monitoring program included substantial lead isotope analysis of tissue metals in an effort to trace whether lead uptake by biota came from the MRM ore body. In our experience this approach works well for sediments, in terms of a 'sediment fingerprinting' study which can be used to infer catchment loads among other purposes (e.g. Pearson et al. 2013). However, the use of lead isotope tracing in biota may be premature, as the potential for selective lead isotope uptake by organisms has received little if any research. Any observed patterns may actually reflect or be influenced by any selective uptake of isotopes, rather than the isotopic ratios in the environment that they were purportedly exposed to, particularly for an element as heavy as lead.

We note that Indo-Pacific Environmental (2013) suggest that the lead isotope tracing may be of limited monitoring use. There is likely to be a similar catchment-wide lead isotope signature as it would have been the same process of mineralisation that formed the geologic landscape. A recent review by Cheng & Hu (2010) supports this conclusion "*Isotopic fingerprinting is limited to cases where the potential Pb sources have widely differing isotopic signatures and few quantitatively dominant sources exist. When local anthropogenic Pb sources, such as coal-firing power plants and mineral processing facilities, do not have unique isotopic signatures compared to local diffuse sources (e.g., background bedrocks and soils), source differentiation of lead pollution can no longer be based on isotopic fingerprinting*".

This dataset doesn't provide any useful input to a human health risk assessment.

2.2.4 ToxConsult mussel analysis

The report by ToxConsult (2014) attempts to 'model' safe consumption levels for lead and manganese based on mussels collected from Burketown Crossing (i.e. Borroloola). Their approach is analogous to Method 1 above, but uses a different measure of tolerable intake (see below). They assumed some control for actual intake or consumption based on established National 'western diet' standards, and multiplied this by the concentrations recorded in 2014 to calculate a maximum number of mussels that could be eaten and still fall below a reference standard for human tolerance.

2.2.4.1 Lead

Despite the differences in calculation method, their recommendations regarding intake related to lead contamination is of a similar order of magnitude as that presented here (43.3 g/day versus 65 g/day in Table 2-3). ToxConsult base their assessment on lead blood modelling, Method 1 above is based on dietary exposure levels considered to have negligible impact on IQ and systolic blood pressure (FAO/WHO 2010). There is no single, generally accepted tolerable intake level or calculation method, so both are equally valid. Despite this, the primary driver of the slightly different safe consumption recommendations is the median concentration of lead used; 0.52 mg/kg (DPIF mussels only) versus 0.4 mg/kg used here (DPIF and MRM mussels). If we substitute the higher median concentration, we get almost the same safe consumption rate (i.e. 50 g/day for a toddler). Thus the two lines of evidence produce the same conclusion: toddlers downstream of the mine should not eat more than around 10 mussels on average per day to avoid any potential hazardous effects due to lead.

2.2.4.2 Manganese

The concentrations of manganese in mussels collected within the McArthur River catchment are relatively high compared to levels recorded in fish and prawns, ranging from 100 to 1700 mg/kg both upstream, within the mine lease and downstream of the mine. In contrast, fish and prawn flesh contained median concentrations of around 4 mg/kg. Clearly, mussels are excellent at accumulating manganese in this system. Only a single mussel sample was collected outside the McArthur River channel, though it was still high (280 mg/kg). This suggests that manganese is probably elevated in mussels throughout the broader region, though this warrants further investigation.

ToxConsult (2014) used the same reference data and a similar health-based guideline value as that employed in Method 1 above to derive a safe consumption recommendation of up to 3 mussels per day, preferably less. This matches the outcomes summarised in Table 2-3 (25 g/day for toddlers, less for adults as they have higher intakes of manganese from other dietary sources). However, much of the apparent health concern associated with manganese is predicated on consumption of excess numbers of mussels daily, when a more realistic consumption pattern in the area is likely to be occasional 'feasts' on mussels only every now and then (e.g. weeks apart). The risk is further mitigated in that the calculations performed here, and in ToxConsult (2014), assumed that humans absorb 100% of the available manganese in the mussels when absorption efficiency is only approximately 10% (SCF 1993).

2.2.5 Other exposure vectors

Other potential vectors are beyond the scope of this report, but the primary potential exposure pathways of drinking water, air and bush meat are very briefly reviewed here.

- A drinking water quality report was provided for Borroloola and Garawa town water, indicating this was not a source of contamination as it harvests from a semi-confined aquifer at depths of 45-80 m within a sandstone formation (Sharp 2014). This aquifer was reportedly recharged by rainfall in the upgradient sandstone outcrops (i.e. perpendicular to the river). Bores at distant outstations may have different results, but it could be reasonably assumed that most bores would harvest from a shallow aquifer that is recharged by the various sandstone outcrops in the region. Any dense mineralisation near the surface would presumably already have been a target for mining exploration, and not favoured for water supply purposes.
- Air as a vector for lead or other heavy metal contamination is a real concern for areas near refinery or smelter operations (e.g. Mt Isa, which has extensive airshed monitoring and control systems). MRM is known to have air quality issues such as combustion of the overburden dump, dust associated with the dumps and Bing Bong operations (ERIAS 2014), as well as anecdotal reports that during westerly breezes a sulfur smell emanating from the Bing Bong concentrate shed extends across to West Island (Appendix 3). The dust is likely to contain amounts of particulate lead and zinc, though this doesn't appear to be monitored. However the remoteness of all these sites from outstations and Borroloola would indicate a very low level of risk to the general community.

- Other bush meat, or even cattle, may contain elevated metal concentrations. Well publicised spikes in lead recorded from the organs of cattle grazing the MRM station[6] suggest uptake by at least some terrestrial fauna. The level of exposure of local people via this avenue would be the subject of a separate study, but is probably less than that of aquatic fauna.

2.3 Consultation

Two primary rounds of face-to-face consultation were undertaken to support this project. From 2nd to 3rd September 2015, Dr Chris Brady (study team) and Dr Steven Skov (Department of Health) travelled to Borroloola to conduct an initial introduction to the project and collection of some basic facts. This involved discussions with:

- Interested locals outside the main town shops
- Traditional owners of the lands around the mine
- Li-Anthawirriyarra Sea Rangers
- Northern Land Council (Daniel Mulhollan)
- The Mabunji Aboriginal Resource Centre board of directors
- Health clinic
- King Ash Bay fishing club

The primary intention of this trip was to inform the local people of the project, and advise that the study team would be back in the area for more detailed consultation in early October 2015. Several suitable local 'facilitators' were also identified to assist with the follow-up consultation.

From 6-10th October 2015, a more detailed round of face-to-face consultation was undertaken by Dr Chris Brady and Simon Drummond. This was preceded by posters displayed on town noticeboards, and telephone/email correspondence with the NLC, Mabunji and the Sea Rangers. Attempts were made prior to the trip to identify a facilitator who was available from each of the four major clan groups from the region, ultimately facilitation was provided by Mr Ronnie Miller of the Sea Rangers, who was well known to most traditional owners of the region. His assistance was greatly appreciated by the study team.

To encourage conversation with people and improve information gathering, several 'props' were taken comprising A1-scale laminated maps of the study area and photos of the fish known to occur in the region (Appendix 1). People were encouraged to point out the fish they regularly caught or preferred for consumption, and to identify on the maps the areas they frequented (Figure 2-2). As a guide to the study team, a pro forma of questions was prepared (Appendix 1), but to reduce people's apprehension these forms were not actively completed

[6] http://www.abc.net.au/news/2015-08-31/wandering-cattle-mcarthur-river-mine/6737138

in front of people. The primary aim of this consultation was to address the following data gaps:

- How much/ often do people fish?
- Where do they fish?
- What fish do they regularly catch or prefer?

It is acknowledged that collecting data that meets the needs of a regional Total Dietary Survey was beyond the scope of this project. The intention was to collect a broad overview to inform the risk assessment for this study. The consultation schedule is summarised in Table 2-5, and detailed notes provided in Appendix 3.

Table 2-5 Consultation schedule 6 – 10 October 2015

Date	Location	Activity
6 October 2015		
AM	Malindari Store	Let people know we were in town for the week, talked to anyone interested, sought permission to visit their outstations where appropriate
PM	Waralungku Arts Centre	Consulted with elder women
	Bing Bong port, Mule Creek, Batten Creek road crossing	Site appreciation
7 October 2015		
AM	Sea Rangers headquarters	Consulted with senior rangers, and arranged facilitator/s for outstation visits (Ronnie Miller)
	Cow Lagoon people town camp	Consultation
PM	Showgrounds	MRM conducted a Community Reference Group meeting and requested to meet team (after their meeting)
	Cow Lagoon outstation	Consultation
	Ryan's Bend (Batten Creek)	Site appreciation
	Rocky Creek and McArthur River crossing	Site appreciation
	NLC Office	Consultation but closed
	Black Rock landing	Consultation
8 October 2015		
AM	Wearyan Crossing	Consultation
	Wearyan River freshwater pool	Site appreciation
PM	Manangoora outstation	Consultation
	NLC Office	Closing – advised by receptionist Daniel Mulholland away all week
	King Ash Bay	Consultation
9 October 2015		
AM	Health Clinic	Brief staff on project

Date	Location	Activity
	Malindari Store	Consultation Billy Coolabah
PM	Bauhinia Downs outstation	Consultation
	Surprise Creek	Site appreciation
	8 Mile lagoon	Site appreciation
10 October 2015		
AM	Limmen Bight Fishing Camp	Consultation

Figure 2-2 Consultation with people living at Cow Lagoon outstation (left) and Robert Anderson at his Manangoora property

2.3.1 Key findings

The detailed consultation successfully captured a broad spectrum of the local population, albeit with a deliberate focus on traditional owners that are considered to be more likely to consume and rely on fish caught from the area. Information was collected from traditional owners:

- living in town or in outstations and cattle stations around the mine (e.g. Billy Coolabah and the Lansen family);
- in adjacent catchments (e.g. the Andersons at Manangoora, Cow Lagoon people along Batten Creek);
- downstream (e.g. Black Rock Landing people, Simon Johnstone from Vanderlin Island);
- further afield (e.g. Desmond Lansen at Bauhinia Downs, the Barretts on Limmen Bight River); and
- people, particularly elder ladies, that now spend most of their time in town but have a lifetime of fishing experience in the region.

Recreational users from the King Ash Bay fishing club and the Manangoora campground were also interviewed, but as detailed below, their risk profile irrespective of any potential contamination was very low given the relatively short periods they would fish in the region.

How much / often do people fish?

This question was based on acquiring information on how often people fish in the regions and forms a basis for their consumption on fish from the rivers related to this study. On the basis of the responses provided during consultation, very few (none that were actually interviewed) people in the region now rely on fish or other aquatic biota as a primary source of protein in the study area. Fishing was often viewed as a recreational or family activity, something that was done on the weekend. Typically the fish that were caught were eaten, but the bulk of their protein diet came from either other forms of harvested meat (e.g. turkey, kangaroo, geese etc.) or food bought from town.

Where do they fish?

Most freshwater fishing appears to be done either in areas adjacent outstations, or for people based in town, either Batten Creek or upstream of the mine. Examples of popular fishing spots associated with outstations included:

- Cow Lagoon people fished in adjacent Batten Creek or the permanent waterhole on this system known as Ryan's Bend lagoon;
- Bauhina Downs – fish caught from Bauhinia Creek;
- Manangoora – fish the upstream Foelsche and Wearyan Rivers, or in the estuary and marine environment;
- Black Rock Landing / Kangaroo Island – McArthur estuary and marine environment; and
- Cox Bend and Maria Lagoon – Cox Creek and downstream Limmen Bight River.

People who spent most of their time in town indicated that popular fishing spots included:

- Ryan's Bend lagoon, and the reach of Batten Creek that the highway crosses (prior to the McArthur River confluence);
- 8 Mile lagoon – part of the series of large, permanent waterbodies within McArthur River beginning around 8 km upstream of the mine (also known as Merlin Crossing, referring to the access road to the closed Merlin diamond mine);
- Wearyan River at waterholes above (freshwater) and below (saltwater) the highway crossing near a leased station called Budjanga;
- around Borroloola at either Rocky Creek in the wet season (very good for barramundi apparently), or at the rocky outcrop beneath the highway crossing (also known as Burketown Crossing); and
- Port of Bing Bong channel off the rocks.

Appendix 4 contains a map and photo log of popular fishing locations.

What fish do they regularly catch or prefer?

Quite a few respondents in town indicated that they no longer eat fish or mussels from McArthur River, on the basis that they believe they are contaminated. Much of this concern stems from the Department of Health warnings. Not everybody agreed with this, and some people in town said they still fish around town. Regarding the Port of Bing Bong, most people said they would no longer eat oysters or mussels from there but still fish in the channel.

Many people recognised most of the fish presented on the poster. People indicated that they most regularly caught, or preferred, the following fish in freshwater areas (in no particular order):

- Barramundi
- Black bream (also known as Sooty Grunter)
- Archerfish
- Catfish (several species)
- Bony Bream and Spangled Perch – primarily for bait

People also identified Redclaw crayfish, freshwater mussels and cherabin (large freshwater prawns, usually *Macrobrachium spinipes*) as species they occasionally collected. Long-neck turtle and Worrell's turtle were also apparently seasonally collected, typically in dried mud of billabongs associated with 8 Mile lagoon and Robinson's River. Of particular interest, the 'guts' of the barramundi and turtles are also readily consumed by traditional owners.

Several estuarine/marine species were also commonly identified such as: Queenfish, trevally, rays (marine not the freshwater species), Bull sharks, Mangrove jack (also known as red snapper), and Golden snapper. Nobody indicated they actively hunt fresh or saltwater crocodile, and turtle and dugong consumption was still typically related only to certain celebrations.

Summary

- The people interviewed fish occasionally, and do not appear to rely on locally caught fish as a primary source of protein. However, fishing is an important activity and they do eat the fish that they catch. In some instances, they also eat organs or 'guts' (e.g. barramundi and turtles);
- Favoured waterholes exist within McArthur River upstream and downstream of the mine, and in adjacent catchments; and
- The preferred catch is large-bodied fish including Barramundi, Sooty grunter and catfish but also Archerfish. Small-bodied fish such as Bony bream and Spangled perch are primarily used as bait, if caught.

2.4 Risk Assessment Summary

Table 2-6 provides a summary of the risk assessment undertaken.

Table 2-6 Risk assessment summary

1. Data requirements	Assessment
Collation of MRM and DPIF monitoring data For data available refer to Section 2.1. Review of data gaps and underlying assumptions of the risk assessment are addressed in Section 4.1	n/a
2. Risk Characterisation (tissue concentrations compared with guidelines)	
Method 1 – Median concentrations against background ATDS	
In fish and prawn flesh, consistent elevations in aluminium, chromium, cobalt, lead, manganese, molybdenum and zinc found downstream and upstream of the Mine, but notably also within reference sites	Low Risk
In fish livers and mussels, elevations of the same suite of metals as flesh, plus elevated copper and cadmium. All upstream and downstream of the mine, but almost no sampling outside the McArthur River system (only one mussel from Robinson River).	Moderate Risk
For contaminants of health concern, theoretical maximum daily consumption for fish and prawn flesh were calculated which largely negated the risk as consumption rates exceed those that could be reasonably consumed: • 2 year olds would need to consume at least 500 g of fish per day to reach the maximum intake for lead or zinc, even more fish consumption required for cobalt or manganese • 30 year olds would need to consume at least 1.7 kg of fish per day to reach the maximum intake for lead, even more for other contaminants.	Very Low Risk
Theoretical maximum daily consumption rates for fish livers vary depending on the target species: • For barramundi, the preferred fish for visceral consumption, a 2 year old would need to consume > 100 g of liver per day to reach the maximum intake (higher for adults) • For catfish, although sample numbers were very small, the maximum intake is substantially lower, 10 – 70 g / day.	Very Low Risk Moderate Risk
For mussels, maximum daily consumptions rates for toddlers are between 25 and 65 g/day, or about 5 – 12 mussels due to potential health concerns related to manganese and lead respectively.	Moderate Risk
Method 2 – Individual sample concentrations against FSANZ MLs	
There was no elevated lead or arsenic recorded from flesh (muscle/trunk/whole body) from all but one large-bodied fish sample. The exception was a Sooty grunter muscle sample collected in 2014 upstream of the mine. For small-bodied fish, elevations above the lead ML in fish largely occurred in specimens collected from the mine area itself. Many fewer exceedances were noted upstream and downstream of McArthur mine, and within the reference areas. Arsenic concentrations all fell below the ML (with the assumption that 10% of total arsenic is in inorganic form). Some arsenic speciation had been undertaken on mussels, confirming that inorganic arsenic comprised < 3% or total arsenic (possible less as results were below lab detection limits), though future monitoring should include speciation of arsenic in various species as a routine measure to overcome this uncertainty..	Low – Moderate Risk

3. Assess residual risk against local consumption patterns	
Consultation for this project indicated that the local community are, at best, average fish consumers (i.e. they probably fall within the bounds of the ATDS). Where people or groups were identified that relied much more heavily on fish, then this would warrant reassessment.	Low Risk
Greatest potential risk is related to daily consumption of moderate numbers of mussels, or quite large amounts of catfish liver. It is anticipated that mussels are more likely consumed in larger numbers only occasionally, rather than regular moderate consumption (i.e. dozen or so every few weeks, not 10 per day). Regarding catfish liver, while this might be consumed as part of the overall fish it is unlikely there is anyone targeting this as a food source (unlike barramundi, but even that could be considered a 'delicacy').	Low Risk
Gaps existed in the dataset that will need filling (e.g. for community surveys, favoured consumption of guts, increased analytical power from reference sites and sample number for specific targeted fish). This feeds back into step 1 underlying the assumptions and data gaps.	Moderate Risk
4. Overall Risk	
On the basis of the above assessments, the currently known tissue metal load in fish, prawns and mussels of the study area is considered to be Low Risk, but is subject to refinement based on the gaps identified in the dataset (Section 4.1).	Low Risk

3 IS CONTAMINATION ATTRIBUTABLE TO MRM?

As noted in Section 4.1, the MRM dataset contains limited reference site data. That is, data collected outside the McArthur River catchment. Instead, it relies heavily on concentrated sampling efforts within the mine lease area. For example sites SW16 and SW12, also SW7 and SW21, are respectively only about 2.5 km apart along the McArthur River, yet they were all sampled in 2011 and 2012 (one from each was dropped in 2013). It is acknowledged that this design may serve some other purpose in monitoring environmental performance, as after all that was the primary intention of the MRM program. However, the fish species that were monitored are very dispersive and will move many kilometres every wet season. Within the course of days or weeks even small rainbowfish may forage along the length of the mine lease (or upstream/downstream). Spangled perch are known to migrate great distances over difficult terrain (being able to traverse flooded fields, see Pusey et al. 2004). Therefore while the program contains upstream 'controls', and sites within the downstream receiving environment, this data is confounded.

On the basis of the available tissue metal data, it is not possible to derive a quantitative assessment of whether contamination in the freshwater environment is attributed solely to MRM. The lead isotope data did not prove useful for the purpose of this assessment (see Section 2.2.3).

Certainly, however, there is evidence to suggest that there may be exacerbated contamination associated with MRM, either through its activities or localised geology. The area obviously contains a concentration of lead and zinc (and silver) relatively close to the surface which has been the target of mining for the past 20 years. Unconfirmed anecdotes suggest that prospectors reportedly used to collect lead nuggets from Surprise Creek to make bullets back in the 1950s (Appendix 3). Yet MRM controls should manage this type of surface water runoff. During consultation, Surprise Creek was observed from the highway crossing to contain a surprisingly large amount of standing water for an ephemeral system at the end of the dry season (Figure 3-1). Seepage from the adjacent tailings dump has been raised as an issue by MRM, which to date has been addressed through recovery bores prior to the creek line (ERIAS 2014), but it would appear that these bores are not capturing all the seepage. It is noted that some form of telemetered water quality meter had recently been installed, as well as a water level sensor.

Fish and aquatic biota accumulate lead gradually over time. High lead levels recorded in fish are more likely to be indicative of fish that took refuge during the dry season in waters and sediments with elevated lead. As noted above, site SW19 is infamous for recording elevated lead levels in 9 out of 10 rainbowfish collected in 2013, and again in 2014 (albeit lower numbers). Site SW19 is within the Barney Creek diversion channel, downstream of the confluence of Surprise Creek. A reasonable hypothesis may be that the source of the contaminated fish is Surprise Creek, which appears to have maintained dry season refugia during recent seasons despite historically being ephemeral. As noted above, Surprise Creek is also the site of historical prospecting, so may contain relatively high levels of lead irrespective of seepage from the tailings dump.

Figure 3-1 Upstream (left) and downstream views of Surprise Creek viewed from the Savannah Highway crossing October 2015

4 EFFICACY OF EXISTING MRM MONITORING PROGRAM

The existing MRM monitoring program is ostensibly designed to monitor and detect environmental impact. It's efficacy in this fashion is not addressed here, and is a matter for the Independent Monitor (ERIAS 2014). As the review of available data and Gap Analysis indicate, it is not suitable for assessing human health risk. Chief among the shortcomings is a focus on small-bodied fish species that are not regularly consumed by local people (though small-bodied foragers do make better indicators in many respects for an environmental monitoring program), and a lack of appropriate and repeated sampling from reference catchments.

4.1 Gap Analysis

A gap analysis is summarised in Table 4-1 based on our review of available data taken in the context of a human health risk assessment.

Table 4-1 Gap analysis

Aspect	Ideal Scenario
Design	
Most data describes small-bodied fish unlikely to be consumed by people Until 2014, most sampling has focussed on small-bodied fish species and limited collections of crustaceans or molluscs. This makes sense for an environmental monitoring program, which is what MRM is enacting. For human health, sampling needs to focus explicitly on the food groups (e.g. fish, crustaceans and molluscs) people consume, rather than attempting to infer risk from lower trophic groups/species.	**Specific program that targets species most regularly consumed by local people** The inclusion of some larger-bodied fish and predators in MRMs 2014 monitoring is moving towards this position. The DPIF sampling also targeted these species. Consultation undertaken for this study provided some initial insights into the fish people target (see Section 2.3).
Limited reference data from freshwater systems uninfluenced by MRM In the absence of historical data (i.e. pre-mining), it is difficult to differentiate impacts that may be caused or exacerbated by MRM activities from what may be natural background concentrations. The limited reference data collected indicated elevated lead on one occasion, but this was not seen in DPIF's sampling.	**Reference data captured coincident with McArthur River sampling** Given the region is mineralised, and the results of the 2010/2011 monitoring in Limmen Bight and Wearyan Rivers, it is reasonable to assume there may be naturally elevated lead uptake in fish from these rivers. However, this is going to be strongly tied to the strength of each wet season. It is inappropriate to compare, say, 2014 samples with reference samples collected in 2010. The program needs to include reference sampling each and every round.

Aspect	Ideal Scenario
No seasonal sampling Most of the MRM dataset is based on early dry season sampling, a time when many fish have just completed large dispersion movements during the wet season. There are likely to be more fish to catch at this time, relative to late dry season, but they were possibly many kilometres from where they were caught several months earlier, maybe even in other (sub-)catchments. This makes it difficult to infer that any recorded high metal load is necessarily related to where the fish was caught. Conversely sampling during the late dry season, where fish were more confined to refugia, would likely provide a stronger link between metal loads and location, particularly for small, shorter-lived species. Metal loads accumulate primarily over time, not from short spikes.	**Trial seasonal sampling** There are two reasons for this: to reflect when people may be eating more fish, and to provide a closer tie between metal loads and catch location. Anecdotal information collected during consultation for this study that, for example, people catch a lot more Barramundi near Borroloola during the early wet season as Rocky Creek runs. A more detailed consumption survey may reveal people eat more fish during a particular season. If so, the monitoring program would need to reflect this.
Assumption of sessile fish populations The analytical design of the program assumes the fish population is relatively sessile, rather than mobile. This is not our experience for these species elsewhere – they are all generally known to be very dispersive and during each wet season will move many kilometres or more.	**Assessment of catchment patterns to determine fish mobility rates** The sampling design needs to take into account the high mobility of fishes in the MacArthur River, via use of appropriate analyses and interpretation, such as via considerations of gradients of exposure.
Trace elements / metals selected for the survey. A comprehensive list of metals was surveyed, with a focus on arsenic and lead due to the relevancy for the region. Some other metals could be considered in future sampling (and eliminated/removed if deemed no concern).	**Inclusion of additional parameters** In further surveys metals such as mercury and selenium could be considered (unless their potential risk has already been assessed) as they have a potential to bioaccumulate in the food chain and particularly, mercury can be relevant in accumulating in large predatory fish such as barramundi and also considered hazardous for human consumption.
QA data MRM monitoring reports, and DPIF inputs provide no discussion of Quality Assurance related to sampling or laboratory processing. Several different laboratories are used, likely involving different preparation approaches and calculations.	**QA program** Each event requires an assessment that no external contamination or error entered the dataset. This could be via tissue processing (e.g. reuse of gloves or scalpel), damage during transit, calculation methods to attain wet weight equivalence and so on. Overt analysis and reporting of quality assurance sample results is required before the quality of a monitoring program can be assessed.

Aspect	Ideal Scenario
Processing and analysis	
Tissue metal analysis undertaken on raw samples Raw tissue can be used where the population is known to eat large amounts of raw fish, or as a conservative screening measure. However it typically overestimates metal concentrations compared to samples processed 'as consumed' (i.e. processed, washed and/or cooked in some way). Further, FSANZ screening levels are based on 'as prepared for consumption' samples, not the sampling of selected tissues typically targeted for environmental exposure monitoring.	**Where risk is indicated, focus program on 'as consumed' analysis** The program could also be tiered, raw tissue as a conservative measure and where a risk was indicated, proceed with 'as consumed' analysis to determine whether there was still a risk to human health.
Tissue samples to match what is typically consumed In part reflecting the small-fish focus of much of the dataset, many of the 'elevated' lead samples come from whole fish samples. Where contamination is reported in larger fish, it was from the liver. The type of whole fish samples collected in the study area (albeit fin and gut removed; Indo-Pacific Environmental 2010a) are rarely consumed in Australia. Liver may only be eaten in some cases where people are eating the whole fish and thus the concentration that someone might consume needs to be balanced by the proportion of a fish that this organ occupied. Thus, contaminated liver samples while interesting from an environmental perspective are largely irrelevant for a human health risk assessment for Australian populations. Conversely, the guts of some species are favoured by some people but were removed prior to analysis in the current dataset.	**Refined tissue sampling program** Starting from a species list that matches what people regularly consume, a specific tissue sampling program would target what parts were actually eaten such as muscle of catfish, muscle and guts of barramundi, prawn tail and so on. As outlined above, the program could either focus solely on 'as prepared for consumption' tissue or use raw tissue as a conservative measure.
Exposure assumptions No Total Dietary Studies (TDS) have been conducted on this region, nor in the Territory, but the broad Australian TDS may be relevant where it was determined that locals are 'average' (or lower) fish consumers. There is a need to understand how much people eat fish, what fish they eat and where the fish comes from. Fish/biota may not be the only source of contaminant exposure in the region. Other vectors could include: bush meat or cattle, air and drinking water.	**Consumption survey** This study collected initial insights into local fishing habits (see Section 2.3), suggesting people are not above average fish consumers. It may then be appropriate to 'model' maximum consumption guidelines of certain fish/biota using ATDS standard consumption rates – once appropriate tissue metal data has been collected (see above gaps). This is the approach used by FSANZ (2013), ToxConsult (2014) and Skov (2015). If it was decided people may be above average fish consumers, it would be more appropriate to enact a detailed consumption survey which would involve substantial on-ground social surveys (e.g. 24hr and weekly dietary recall diaries).

Aspect	Ideal Scenario
Non-Standardised Body Size Statistical analysis of the MRM dataset (not presented here) indicates that organism body size was a significant factor related to tissue metal load. This is unsurprising, body size is commonly used to infer age in environmental monitoring datasets in the absence of intrusive dissection methods. The MRM monitoring procedure indicates samples should be standardised as "mature" and presents first maturity length estimates as guides. Despite this, body size of samples varied greatly within sites and between years.	**Standardised Body Size** Electrofishing and fykes are the primary catch methods used by MRM and DPIF. These techniques are typically non-lethal, therefore it should be possible to continue sampling a site until X number of appropriately sized replicates are collected, within reason.
Methods presented by MRM	
Tissue processing and handling The MRM sampling procedure (Indo-Pacific Environmental 2010a), nor the shortened method statements in each annual report clarify the actual tissue dissection process. To eliminate cross-contamination of samples, each individual fish/prawn/mussel needs to be processed under 'clean room' conditions, e.g. new sterile scalpels, forceps (or some method of thoroughly cleaning forceps between specimen), gloves, plastic bench sheet and so on. It is probable this is already being undertaken by MRM and their consultants, but the methods do not include this level of detail.	**Clean room conditions** Document all procedures.
Specimen size and weight The MRM sampling procedure does not specify that the size (i.e. length) and weight of each whole specimen (fish/prawn/mussel etc) needs to be recorded prior to freezing or release. These are important parameters that help determine that biota are being compared within a similar age bracket. The provided dataset indicates size is measured, but did not contain weights. Once frozen, the length and weight will reduce over time as the specimen dehydrates.	**Field protocol** Document all field procedures.

4.2 Proposed program to address perceived human health risk

While this study assessed the risk to human health as being Low, this may do little to alleviate the perceived concerns already present in the local community (see Section 2.3). Where there is a desire to enact a program that may assist in alleviating these concerns, and confirming this preliminary risk assessment, then it is recommended that the future monitoring incorporate the modifications (or augmentations) identified as 'ideal scenario' in the Gap Analysis (Section 4.1).

5 SUMMARY

Based on the data reviewed and people consulted for this study, the risk to human health posed by consumption of fish, prawns and mussels from the McArthur River system is considered low. This is particularly true when compared against the likely consumption patterns that our early consultation works suggest exist across the study area. Certainly, the calculations of theoretical maximum daily consumption rates indicate that even the most ardent fisherperson is not going to breach the tolerable intake of a particular contaminant in the study area.

However, we have identified several knowledge gaps that, when addressed, may warrant reassessment. Principal among these gaps are:

- Insufficient representation of reference sites in the dataset from outside the McArthur River catchment. The DPIF sampling goes some way to addressing this, but future sampling should incorporate reference data collected at the same time as the area of interest and sufficient samples for each species collected.
- The monitoring program does not match the species favoured by people that fish in the area. Again, recent efforts by DPIF and MRM have attempted to address this but there still remains some mismatch between species that are consumed and those tested. Prime examples include turtles and the guts of barramundi (and turtles).
- The sampling design needs to take into account the high mobility of fishes in the MacArthur River, via use of appropriate analyses and interpretation, such as via considerations of gradients of exposure.

Any further efforts to quantify human health risks are best addressed through incorporation of the recommendations outlined in the Gap Analysis (Section 4.1).

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APPENDIX 1 RISK CHARACTERISATION METHODS

We use two screening approaches to this study, and used both the MRM 2010 – 2014 and DPIF 2014 datasets.

1. **Comparison against ATDS:** As per FSANZ (2013), which essentially compared mean/median metal concentrations grouped by type (e.g. flesh, so all species combined), year and location (Table 6-3) against a nominal 'background' level from the 22nd or 23rd Australian Total Diet Survey (ATDS). The background level is for an analogous food product consumed in Australia and considered, by default, to be tolerable (e.g. metal concentrations in tinned fish, market available prawns etc.).

   Where sample data exceeded the ATDS level, calculations of the theoretical maximum consumption level before exceeding the daily tolerable intake were made for two scenarios: a 16 kg 2 year old (worst case scenario) and a 70 kg 30 year old. The calculation is:

$$\frac{\text{Health-based guidance value} - \text{Mean Dietary exposure from ATDS}}{\text{Mean or median trace metal concentration from sites grouped into upstream/downstream etc.}} = \text{Theoretical maximum daily consumption rate (kg / day)}$$

   The health-based guidance values are based on those used in FSANZ (2013) and summarised in Table 6-2.

   Presented in this study are two scenarios: a 16 kg two year old and a 70kg 30 year old. The median dietary exposure to each trace metal/metalloid was sourced from the 22nd or 23rd ATDS. This provides an approximation of how much the 'average' Australian is exposed to these trace metals through their whole diet, thus determining how much 'additional' trace metals are tolerable in aquatic biota harvested across the study area. Table 6-1 provides a worked example for lead.

Table 6-1 Worked example of calculation of theoretical maximum daily consumption rates

Inputs to calculation formula	Variable
Scenario	16 kg two year old
Median concentration of lead in fish flesh caught within the 'Mine Lease', based on a total of 377 muscle samples collected by MRM and DPIF of small and large-bodied fish species	**0.044 mg/kg**
Relevant health-based guideline (Table 6-2)	1.9 µg/kg bw/day
health-based guideline adjusted for weight (16 kg)	**30.4 µg/day**
Mean dietary exposure to lead from all foods (23rd ATDS)	0.27 µg/kg bw/day
dietary exposure adjusted for weight (16 kg)	**4.32 µg/day**
Theoretical maximum daily consumption rate	**0.593 kg/day**

Table 6-2 Source of health-based guidance values (after FSANZ 2012)

Trace metal	Health-based guidance value adopted	Source of guidance value
Aluminum		*none available*
Arsenic (inorganic)		*none available*
Chromium		*none available*
Cadmium	25 µg/kg bw/month	FAO/WHO 2010
Cobalt	0.023 mg/kg bw/day	Expert Group on Vitamins and Minerals 2003
Copper	0.5 mg/kg bw/day	FAO/WHO 1982
Gallium		*none available*
Lead	< 16 years old: 1.9 µg/kg bw/day > 16 years old: 1.2 µg/kg bw/day	FAO/WHO 2010
Manganese	10 mg/day	SCF 1993
Magnesium		*none available*
Molybdenum		*none available*
Nickel	0.02 mg/kg bw/day	WHO 2005
Vanadium		*none available*
Zinc	1 mg/kg bw/day	FAO/WHO 1982, 2011

2. **Comparison against Food Standards Australia / New Zealand Code:** individual tissue sample concentrations compared against Maximum Levels in the Food Standards Australia / New Zealand Code (Table 6-4). Analysis conducted at the species level.

Table 6-3 Sampling regions and associated monitoring sites for the MRM and DPIF monitoring programs (their naming conventions)

Downstream	Mine Lease	Estuary	Reference	Upstream
Above Burketown Crossing	Diversion	Site 2	Limmen River	8 Mile Creek
Above Crossing	Djirinmini		Wearyan River	Eight Mile
Upper Crossing	Old McArthur		Wearyan	Kilgour
Site 1	Surprise Creek		Robinson River	Kilgour J
SW8	SW12		Foelsche	Kilgour Junction
	SW15			Kilgour River
	SW16			Merlin
	SW19			Top Crossing
	SW2			
	SW21			
	SW23			
	SW7			
	SW11			

Table 6-4 Screening levels in mg/kg applied in MRM freshwater monitoring (from Indo-Pacific Environmental 2010a)

	Metal / metalloid	Fish	Crustacea	Molluscs
Al	Aluminium			
As	Arsenic (inorganic)	2	2	1
Cd	Cadmium	0.2^	0.2^	2
Ca	Calcium			
Cr	Chromium			
Co	Cobalt			
Cu	Copper	10^	10^	70^
Ga	Gallium			
Fe	Iron			
Pb	Lead	0.5	1.5^	2
Mg	Magnesium			
Mn	Manganese			
Mo	Molybdenum			
Ni	Nickel			
U	Uranium			
V	Vanadium			
Zn	Zinc	150^	150^	150^

Note: values are based on FSANZ (2015) with the exception of those denoted with ^ which are derived from FSANZ (2000) cited in Indo-Pacific Environmental (2010a)

APPENDIX 2 CONSULTATION TOOLS

Aquatic Species Questionnaire

McArthur River Survey (ref # 15-036-NTG)

Outstation/area:

Name of recorder:

Survey date(s)/hours:

Area and Population

River system/Coast/Island:
Catchment / sub-catchment:
Number of people at outstation:
What is the season now:

Rainy *Dry* *Transition* *No clear seasonality*

Fishing in General

How many people in your community fish:

All *Many* *Some* *Few* *None*

Men only *Women only* *Men and women*

Do children fish?

Is fishing done in:

Groups *How many:*

With one other person

Alone

Fishing Sites

Where do you catch most of your fish in (mark-up map):
Waterhole
River by boat
River bank
Estuary
Island
Open ocean

Do you keep or grow any fish or other aquatic species (e.g. crocodiles, turtle)?

Aquatic species

The following questions are to be asked using the aquatic species chart
Which 5 aquatic species are most common in the area:
1.
2.
3.
4.
5.

Which 5 aquatic species are the easiest to catch in the wet season:
1.
2.
3.
4.
5.

Which 5 aquatic species are the easiest to catch in the dry season:
1.
2.
3.
4.
5.

Which are the 5 aquatic species most preferred for eating:
1.
2.
4.
5.
6.

Are most of the aquatic species caught : *Eaten* *Baitfish* *Sport* *Other:*

Are there any other uses for fish or other aquatic species within the community (e.g. pets):

Are fish or other aquatic species swapped or exchanged for other goods:

Are there any species that live here that are not seen very often:

Are there any species that used to live here that do not live here anymore:

Cultural Significance

The following questions are to be asked using the aquatic species chart

Are there any aquatic species that have particular cultural significance? *(time of year? to certain people?)*

Are there certain taboos on specific fish species (e.g. not allowed to eat)?

Additional information

Is there any additional information the interviewees would like to provide regarding aquatic species?

Hydrobiology

55. Freshwater mussel

56. Oyster

57. Mud crab

58. Freshwater prawn

59. Worrell's turtle

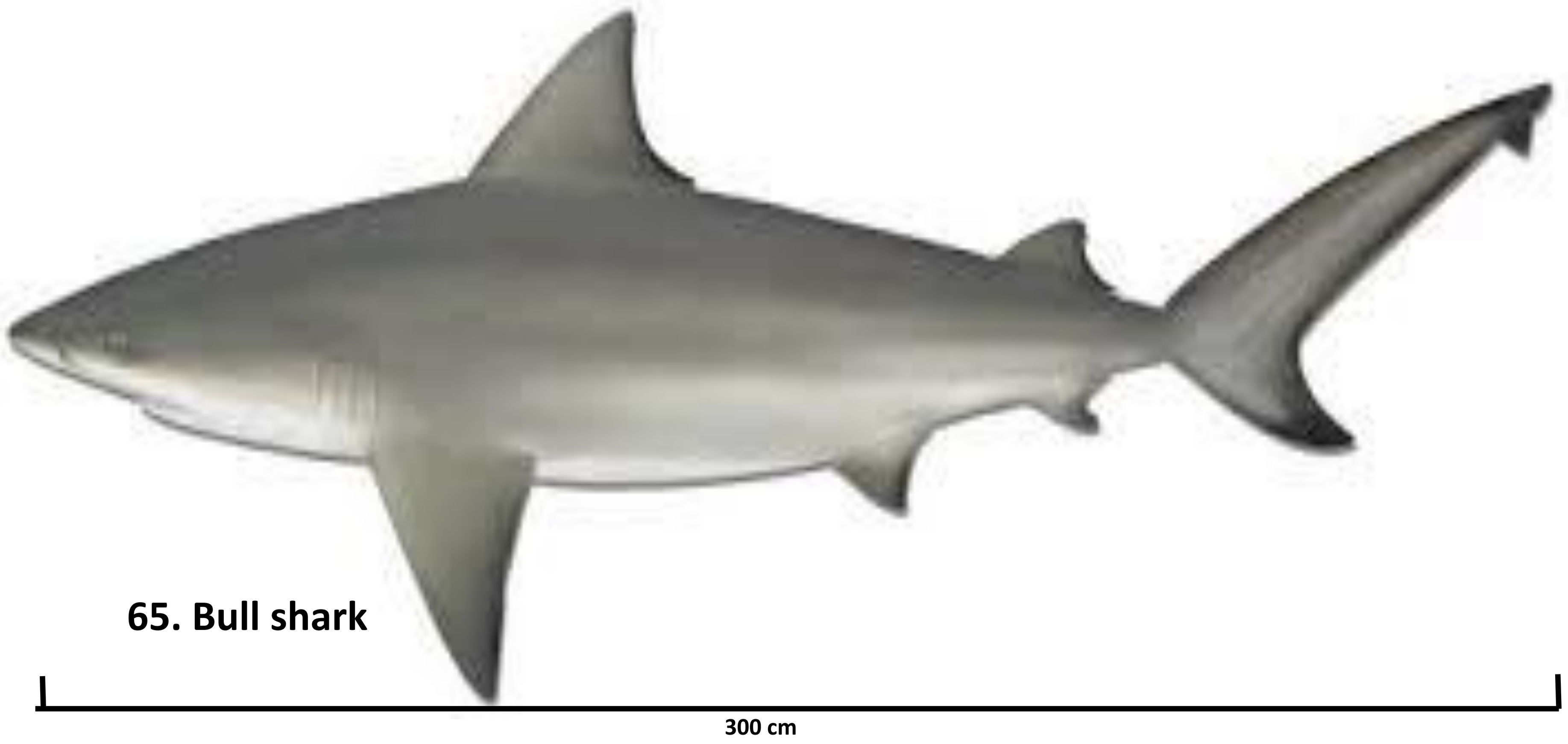
60. Northern snake-neck turtle

61. Green turtle

62. Freshwater crocodile

63. Dolphin

64. Dugong



65. Bull shark

66. Saltwater crocodile

Limmen
Maria Lagoon
Nathan River
Barranyi (North Island)
North Island
Yanyuwa (Barni - Wardimantha Awara)
West Island
South West Island
Wada Warra
Kangaroo Island
Black Rock Landing
Wada Wadalia
Milibunthurra
Manangoora
Wonmurri
Sandridge
Wandangula
Mara
Borroloola
Yanyula
Garawa 2
Munyallini
Goolminyini
Cow Lagoon
Tawallah
Garanbirini
Bauhinia Downs
Billengarrah
Warby Outstation
Budjanga
Doolgarina
Bujan
Seven Emu
Wundigalla
Spring Creek
Pungalina Station
Marinini
Robinson River
Mimina
Yangulinyina
Mcarthur River
Balbirini
Malapunyah
Kiana

GULF OF CARPENTARIA
GULF OF CARPENTARIA
Limmen
Maria Lagoon
Nathan River
Lorella Spring
West Island
Jimilaya
North Island
Barranyi (North Island)
Mooloowa
South West Island
Vanderlin Island
Yanyuwa (Barni - Wardimantha Awara)
Babungi
Yulbara
Uguie
Sir Edward Pellew Group
Long Reef
Wada Warra
Kangaroo Island
Black Rock Landing
Wada Wadalla
Milibunthurra
Sandridge
Wandangula
Mara
Borroloola
Yanyula
Garawa 2
Munyalini
Goolminyini
Tjoungouni
Cow Lagoon
Tawallah
Ijarra
Caranbirini
Bauhinia Downs
Billengarrah
Manangoora
Wonmurri
Warby Outstation
Budjanga
Doolgarina
Bujan
Seven Emu
Wulaburri
Wundigalla
Spring Creek
Pungalina Station
Mariniri
Robinson River
Mimina
Yangulinyina
Garrinjinny
Mcarthur River
Cape Crawford
Balbirini
Mallapunyah
Kiana
BARKLY TABLELAND

APPENDIX 3 CONSULTATION NOTES OCTOBER 2015

Name	Area	Relevance	Species identified	Areas fished	Notes
6 October 2015 – outside Malandari store in Borroloola town					
Clinton Daylight	Black Rock / Kangaroo Island	Traditional owner (late 50s)	Sooty grunter Black bream Archerfish Catfish (shovelnose but possibly others to) Barramundi Queenfish long-neck turtle in dried mud of billabongs Worrel's turtle in upper McArthur and Robinsons Freshwater mussel not for a long time Freshwater crocodile a little bit	Batten Creek at Bing Bong road, water all year Kangaroo Island and surrounds when at outstation	Doesn't fish much anymore, mostly food from town Uses spangled perch and bony bream as bait Some people eat the guts, not liver, of fish as well Has occasionally seen parasite worms in some catfish and giant gudgeon Dolphins sometimes come up the McArthur as far as town
<withheld name>	Milbunthurra	Traditional owner (30ish)	Black bream mostly Catfish Trevally Long neck turtle from billabong in dry season after burn-off Cherabin occasionally	Black Rock area estuary and near shore	
Linda McInney	Manangoora	Traditional owner (grandmother in her 60s)	Black bream Sooty grunter Barramundi Queenfish Trevally Bony bream (whole fish) Stingray (marine) Bull shark Mullet (bait)	Manangoora when at outstation Used to fish in McArthur River but not anymore	Don't fish in McArthur River anymore, waiting for mine to say fish are "OK"
Isa McInney	Manangoora	Traditional owner (Linda's eldest daughter in her 40s)	Black bream Catfish (salmon, black) Archerfish Yellow-finned javelin fish Barramundi Sooty grunter Milkfish Mullet (bait)	Nowhere at present, used to fish mostly around Borroloola in McArthur River / Rocky Creek	Known around town as a 'fisherwoman' A fish kill of Barramundi at the Borroloola crossing 'scared them off' (*note: probably related to early wet flushing not necessarily contamination*)

Name	Area	Relevance	Species identified	Areas fished	Notes
			Mussels from the sea or freshwater lagoon, not flowing river		Doesn't eat fish from McArthur River anymore on advice from the "doctor from the mines" (*note: believe meant Steven Skov*)
Robert Anderson	Manangoora	Traditional owner and on NLC (40s)	Black bream Sooty grunter Archerfish Barramundi long-neck and Worrel's turtle green turtle dugong	Fish on Foelsche River and Wearyan River all year round	Guts of Barramundi, turtles and dugong also eaten Very sceptical of anything to do with the mine, fracking and so on
Simon Johnston	Vanderlin Island	Traditional owner	Marine species including trepang, oysters, turtle and dugong	Around the islands, never over near Bing Bong but due to geography not danger (plenty of sea to fish in before he gets there)	Live off sea harvest, but also eat cattle/goats other meat that are on the island Dubious about the 'danger' of eating fish
6 October 2015 – Waralungku Arts Centre					
Katie Thelma Marjorie Peggie Leanne Diana Rhoda	Throughout the area	Elder ladies at the Waralungku Arts Centre	Barramundi Sooty grunter Black bream Archerfish Redclaw crayfish Marine mussels long-neck and Worrel's turtle First 3 are the 'favourites' they are most worried about	Batten Creek Fletcher Creek Eastern Creek 8 mile lagoon on McArthur River Bing Bong off the rocks in the channel Foelsche River Robinson River	Known in the town as people that still fish, or used to fish a lot Patchy consumption, usually weekend fishing Stopped fishing in McArthur due to health warning and perceived risk Most fishing done in rivers with a handline Women do most of the fishing Also eat turkey/kangaroo/geese and store food so fish not primary source of protein Don't eat oysters/mussels from Bing Bong anymore, but still fish there Eat guts of Barramundi/turtles/dugong Less mud crabs recently around Bing Bong (*note: this may be*

Name	Area	Relevance	Species identified	Areas fished	Notes
					seasonal due to poor wet seasons)
7 October 2015 – Sea Rangers headquarters (li-Anthawirriyarra)					
Graham Friday Ronnie Miller Lester Timothy	Black Rock / Kangaroo Island Islands Cow Lagoon	Patrol the area Traditional owners (50ish)	Dugong/turtle take is < 50 per year Black bream Barramundi Mangrove jack/ Red snapper Turtles Bull shark Mullet (bait)	8-mile lagoon is a popular area in McArthur River Fish every weekend at outstations (e.g. Kangaroo Island) Pools up Batten Creek People don't fish just in 'their country' but everywhere in the area, no problems	Assisted some dugong and turtle tissue metal sampling in the 1990s, Kathy somebody, around the islands Group is involved in the marine monitoring and assisted NT Fisheries in freshwater sampling in 2014 Not as many freshwater mussels in the river as there used to be Mud crab – too many professional crabbers for example used to get mud crab in the creek on West Island on incoming tide now there are none Only fish kills noticed by rangers are associated with first rains Dubious of poisoned fish talk Previous Independent Monitor gave them some equipment for sampling but they were not trained / was not used (WQ probe?) On King Tide saltwater pushes up beyond the town Surprise Creek used to be seasonal, now permanent water suspect associated with downstream dump and diversion
7 October 2015 – Borroloola camp of the Cow Lagoon people					
Susan Ahwon Fracie Ahwon Silvia Ahwon	Cow Lagoon	Traditional owners live in town camp, occasionally outstation	Barramundi Black bream Sooty grunter Freshwater turtles Catfish	All along Batten Creek, particularly Ryan's Bend lagoon (permanent waterhole) 8 Mile lagoon on McArthur River	Fish mostly in the wet season, not every day just whenever they feel like it while at outstation Eat guts of turtles but not fish

Name	Area	Relevance	Species identified	Areas fished	Notes
		(20s to 60s)	Archerfish (barramundi bait)		
7 October 2015 – Cow Lagoon outstation					
Reneta Ahwon Vicki Ahwon	Cow Lagoon	Traditional owners live at outstation much of time, small kids (30s)	Black bream Sooty grunter Catfish Archerfish Barramundi Cherabin Redclaw crayfish Freshwater mussel Freshwater turtles	Batten Creek next to outstation and down to Ryan's Bend	Fish occasionally Some eat guts of Barramundi, turtles Geo exploration team on property at moment doing seismic tests, husband working for them
7 October 2015 – Black Rock landing					
Carol Simon Diana Quayle Bob Wettinhall	Black Rock / Kangaroo Island	Traditional owner, outstation caretakers, long-term residents (50s)	Jewfish Cherabin in the wet Prawn sometimes Mud crabs – note less this year Sooty grunter Mangrove jack Golden snapper Barramundi	Black Rock Estuary including little creeks between the McArthur mouth and Mule Creek	Mudskippers have apparently disappeared Story from an old prospector that he used to collect lead nuggets in Surprise Creek 50+ years ago
8 October 2015 – Wearyan River Crossing leaseholder					
Charlie Klemzig (?)	Budjanga	Yugoslavian immigrant lived in area for 40 years (68)	Barramundi Black bream Sleepy cod Spangled perch Archerfish Bony bream The odd eel Bull shark Mangrove jack	Wearyan River, saltwater below the crossing freshwater above Borroloola people fish at the freshwater lagoon in the Wearyan adjacent his property	Made his own freshwater turtle dam and has stocked it! (for conservation purposes) Eats fish 2-3 times per week Dubious about the health warnings
8 October 2015 – Manangoora outstation					
Steph Green (nee Anderson) Warren Green	Manangoora	Traditional owner, administers the tourist camp here as well (late 20s)	Black bream Catfish Barramundi Turtles fresh and marine Dugong Mussels (marine) Mud crab	Freshwater Wearyan and Foelsche Vanderlin Island area	Fish in the Foelsche/Wearyan freshwater every Sunday as a family Eat fish couple of times a week Eat guts also of Barramundi, turtles, dugong

Name	Area	Relevance	Species identified	Areas fished	Notes
					Freshwater sawfish up the Wearyan and Robinson Rivers Keen to read Independent Monitor reports
Robert Anderson (again) Alma Anderson	Managoora and Vanderlin Island	Traditional owners (Alma early 70s)	Black bream Shovelnose catfish (good for curry) Barramundi Sooty grunter A lot of other marine fish Cherabin and prawn Giant gudgeon, tiger mullet, threadfin, freshwater sawfish all very rare now	Freshwater Wearyan and Foelsche Vanderlin Island area	Eat guts of turtles (intestines the best) and dugong Noted big flood in 2001 had big fish kill and dugong meat turned a funny green colour – didn't eat for 2 years 3 pro mud crabbers live on his property but considers them to be overharvesting or using illegal techniques (bait net)
8 October 2015 – King Ash Bay					
Current Club Committee Berney ? (Power Hire), former club president	King Ash Bay	Residents and tourists (40s to 50s)	n/a	Most people fish in the lower estuary and out amongst the islands	This year 'quite a few' people had voiced concerns over the 'poisoned fish' as reported in newspapers, and may not have come fishing this season Still lots of people this season, numbers down probably largely due to the poorer wet season
9 October 2015 – Malindari Store					
Billy Coolibah	Campbell Springs	Traditional owner of MRM area (late 50s)	Black bream Sooty grunter Catfish Barramundi	Borroloola crossing Devil's Springs area	Mostly eats tinned fish these days People won't believe outsiders, need to involve locals more such as rangers assisting monitoring program Mine needs to talk to the community more Supports an independent arbiter such as this study
9 October 2015 – Bauhinia Downs outstation					
Desmond Lansen	Bauhinia Downs	Traditional owner, station manager	Black bream Barramundi Catfish	Fish with family every weekend from Bauhinia creek right next to station	Eat guts of Barramundi and turtles Eat a 'lot' of fish

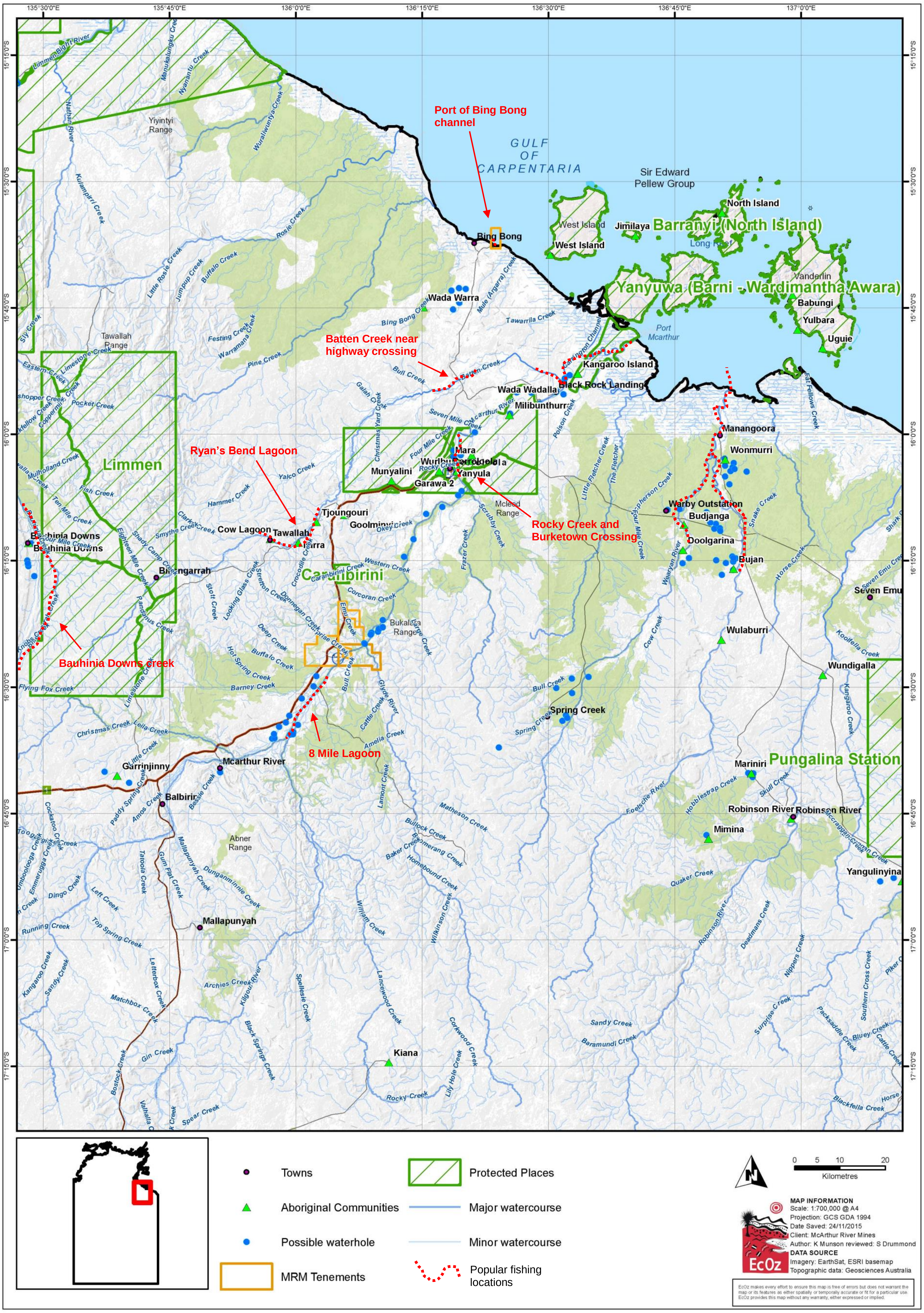
Name	Area	Relevance	Species identified	Areas fished	Notes
		(30s)	Freshwater turtles Little fish as bait	Used to fish in McArthur River near Devils Spings are but not anymore as can sometimes the air smells bad wafting down from the mine	Supportive of monitoring in his area Noted Surprise Creek still has water when it used to dry up Concerned about: wet season flush from mine area, effect on tourism, effect on river
10 October 2015 – Limmen Bight fishing camp					
David Barrett Chris Barrett	Limmen Bight river and estuary	Traditional owners and sea rangers (late 20s)	Black bream Barramundi Sooty grunter Queenfish Freshwater turtles Dugong – not often	Freshwater areas of Limmen Bight river above crossing Cox Creek Estuary/ocean	Some elders live up at Cox Bend camp and would likely rely on fish a lot Maria Lagoon outstation only used every now and then – no one at present Keen to further assist with sampling, including doing own WQ sampling but no funding Assist dolphin and turtle research, helped NT Fisheries with sampling in 2014 Never got feedback from NT Fisheries, keen to read Independent Monitor reports On West Island you can sometimes smell pungent lead/mineral fumes from Bing Bong, during recent Turtle Camp tourists/scientists commented on this (*note: Mine manager and family were all on this camp this year*) When Western Deserts was operating iron staining everywhere, barges uncovered would blow iron throughout port and during transit clouding waters, iron dust 1km up in the air – very messy operation

Name	Area	Relevance	Species identified	Areas fished	Notes
					Concerned about mud crab numbers, Borroloola area highest commercial catch in NT Since the McArthur diversion put in by the mine, the road between Cape Crawford and the mine now floods in the wet season – it never used to.

APPENDIX 4 POPULAR FISHING LOCATIONS

The map below displays the popular fishing locations as reported during the consultation component of this study. It does not purport to display all fishing locations. Just because an area is not flagged here does not mean that it is not fished, and indeed may be fished regularly.

A photo log for context purposes is also appended below for the popular fishing locations observed during consultation activities (October 2015).



Port of Bing Bong channel
GULF OF CARPENTARIA
Sir Edward Pellew Group
North Island
Barranyi (North Island)
West Island
Bing Bong
Wada Warra
Yanyuwa (Barni - Wardimantha Awara)
Vanderlin
Babungi
Yulbara
Uguie
Port Mcarthur
Batten Creek near highway crossing
Kangaroo Island
Black Rock Landing
Wada Wadalla
Milibunthurri
Manangoora
Wonmurri
Ryan's Bend Lagoon
Limmen
Munyalini
Mara
Yanyula
Garawa 2
Rocky Creek and Burketown Crossing
Mcleod Range
Tjoungouri
Cow Lagoon
Tawallah
Warby Outstation
Budjanga
Doolgarina
Bujan
Bauhinia Downs
Borroloola
Caranbirini
Bukalara Range
Seven Emu
Wulaburri
Wundigalla
Bauhinia Downs creek
Spring Creek
8 Mile Lagoon
Garrinjinny
Mcarthur River
Balbirini
Mariniri
Pungalina Station
Robinson River
Mimina
Yangulinyina
Abner Range
Mallapunyah
Kiana
Towns
Aboriginal Communities
Possible waterhole
MRM Tenements
Protected Places
Major watercourse
Minor watercourse
Popular fishing locations
0 5 10 20
Kilometres
MAP INFORMATION
Scale: 1:700,000 @ A4
Projection: GCS GDA 1994
Date Saved: 24/11/2015
Client: McArthur River Mines
Author: K Munson reviewed: S Drummond
DATA SOURCE
Imagery: EarthSat, ESRI basemap
Topographic data: Geosciences Australia
EcOz

Ryan's Bend Lagoon (Batten Creek)

Batten Creek Highway Crossing (between Borroloola and Bing Bong) – mostly dry at time of inspection

Port of Bing Bong channel

Rocky Creek and McArthur River downstream of Burke's Crossing (i.e. around Borroloola town), crocodile trap in McArthur River

Upstream and downstream of the highway crossing of the Wearyan River

Foelsche River at highway crossing

Upstream Wearyan River

8 Mile Lagoon (McArthur River)

Cox Creek