Cooperative Research Centre for Coastal Zone Estuary and Waterway Management

Technical Report 12

Photo: Bob Packett

Intertidal crabs as potential biomonitors in Port Curtis

Leonie Andersen
Karen Boundy
Alistair Melzer

2004

DOCTRINA PERPETUA
Central Queensland
UNIVERSITY
Where Students Come First.

CRC for Coastal Zone
Estuary & Waterway Management

INTERTIDAL CRABS AS POTENTIAL BIOMONITORS IN PORT CURTIS

Leonie Andersen & Alistair Melzer

Centre for Environmental Management
Central Queensland University
Gladstone QLD 4680

Researchers: Karen Boundy, Andrew Davis & Damon Shearer

2002

INTERTIDAL CRABS AS POTENTIAL BIOMONITORS IN PORT CURTIS

Andersen, L.E. & Melzer, A.

ABSTRACT

The fiddler crab (*Uca coarctata*) was assessed for its biomonitoring suitability in Port Curtis. Fiddler crabs have a sedentary lifestyle and their feeding and burrowing activities expose them to water, dietary and sediment-derived contaminants. They are therefore potentially, a useful biomonitoring tool for assessing site-specific differences in contaminants, including metals. Fiddler crabs and sediments were collected from a number of sites in Port Curtis, representing increasing distance from the source of likely anthropogenic inputs. Crabs and sediments were also collected from reference sites outside the harbour and analysed for metal concentrations. Overall, results did not indicate that any one site was more contaminated than any other site. Copper and metal burdens and to a lesser extent aluminium and cadmium, were elevated in fiddler crabs from inner harbour sites compared to outer harbour sites. Correlations were established between metal concentrations in fiddler crabs and sediment for copper and strontium, but no other metals although the relationships were not strong. Fiddler crabs appear to be able to play a role in monitoring programs, although, due to their abilities to regulate metals, they may not be as suitable for biomonitoring as net accumulators such as oysters or mussels.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

APPENDICES

INTRODUCTION

A recently completed investigation into shell disease in Port Curtis mud crabs (*Scylla serrata*) determined that metal concentrations were elevated in mud crabs from Port Curtis compared to those sampled from other locations in Queensland (Andersen & Norton, 2001). Copper concentrations in hepatopancreas, in particular, were found to be two to three times more elevated than at an impacted site in Brisbane (cf. Mortimer, 2000). In terms of site specificity, mud crabs do not meet the criteria as a suitable biomonitor species, due to their free ranging movement. Hyland et al. (1984) determined that the mean range of movement for mud crabs from their original capture site in one area of Moreton Bay, was 6.6km for females and 3.7km for males. Therefore, in order to detect site-specific differences within Port Curtis, a more sedentary biomonitor was required.

Ideally, a biomonitor needs to fulfil several criteria. The chosen species needs to be easy to identify and collect, sedentary, abundant in the area, long-lived and large enough to provide sufficient tissue for analyses. The ideal biomonitor should also be stress resistant, able to withstand varying levels of exposure to contaminants, but most importantly be a net accumulator of the contaminant in question (Rainbow, 1995). A simple correlation should exist between the concentration of a pollutant in the tissue of the chosen species and the ambient concentration in the area being studied (Phillips, 1990). For metals this correlation is the metal accumulation strategy of the organism, the most common being net accumulation, which occurs when metal excretion does not balance metal uptake (Rainbow, 1990) for example, oysters. Regulation is another accumulation strategy, whereby there is maintenance of approximately constant body metal concentrations over a wide range of ambient metal bioavailabilities, although there is a threshold metal concentration at which point regulation will breakdown. Many decapod crustaceans fall into this category (Rainbow, 1990).

Burrowing intertidal crabs have a universal distribution and are abundant within the Port Curtis area. *Uca coarctata*, a fiddler crab belonging to the Ocypodidae family was chosen to determine if intertidal crabs could be utilised as a biomonitoring tool to detect if site differences in metal concentrations exist in Port Curtis. Fiddler crabs are day time deposit feeders, ingesting organic matter from the exposed mud at low tide, depending more on meiofauna (e.g. bacteria, protozoans and diatoms) than mangrove detritus (Hogarth, 1999). The feeding and burrowing activities of intertidal crabs expose them to food, water and sediment-derived contaminants making them potential candidates as biological indicators (MacFarlane et al., 2000). Once recruited to an area they are sedentary or resident at that site and are therefore also suitable for intra-site comparisons of metal concentrations. Because of the close association of fiddler crabs with sediments, it was decided to examine metal concentrations in sediments at the same sites as those selected for fiddler crabs.

The aims of the project were:

1. To determine if site differences exist in the concentrations of metals in intertidal crabs and sediments from Port Curtis;

2. To determine whether intertidal crabs provide a suitable tool for monitoring the concentrations of metals in the harbour thereby allowing their incorporation into future eco-health monitoring programs.

METHODS

1.1. Site Location

Eight sites: Boat Creek (BC), Black Swan (BS), Graham Creek (GC), Enfield (EF), The Narrows (NR), Calliope River (CP), Auckland Creek (AK) and Wild Cattle Creek (WC) were selected within Port Curtis to represent increasing distances from likely sources of anthropogenic inputs (Figure 1). Three reference sites; Yellow Patch (YP)(Figure 1) an unimpacted oceanic site on the eastern side of Curtis Island, Ayr (AY)(North Queensland) and the fishing village of Baffle Creek (BC)(North of Bundaberg)(Figure 2) outside Port Curtis were selected for comparison. Ayr was selected because it was previously the main reference site in the mud crab shell disease investigation. Baffle Creek was also representative of a site in a non-industrialised area. The location of each site except Ayr were recorded using a Global Positioning System (GPS)(WGS 84) and are tabulated in Table 1.

Table 1. GPS location of each site for the collection of fiddler crabs and sediments.

Site	Description	Latitude/Longitude
1	Boat Creek	23° 48.793 / 151° 09.824
2	Black Swan	23° 41.200 / 151° 07.417
3	Grahams Ck.	23° 43.954 / 151° 11.720
4	Enfield	23° 46.238 / 151° 14.698
5	The Narrows	23° 38.132 / 151° 03.327
6	Calliope River	23° 51.376 / 151° 12.677
7	Auckland Ck.	23° 50.178 / 151° 14.864
8	Wild Cattle Ck	23° 57.919 / 151° 23.612
9	Yellow Patch	23° 50.459 / 151° 12.117
10	Baffle Creek	24° 32.071 / 152° 02.597
11	Ayr	Not recorded

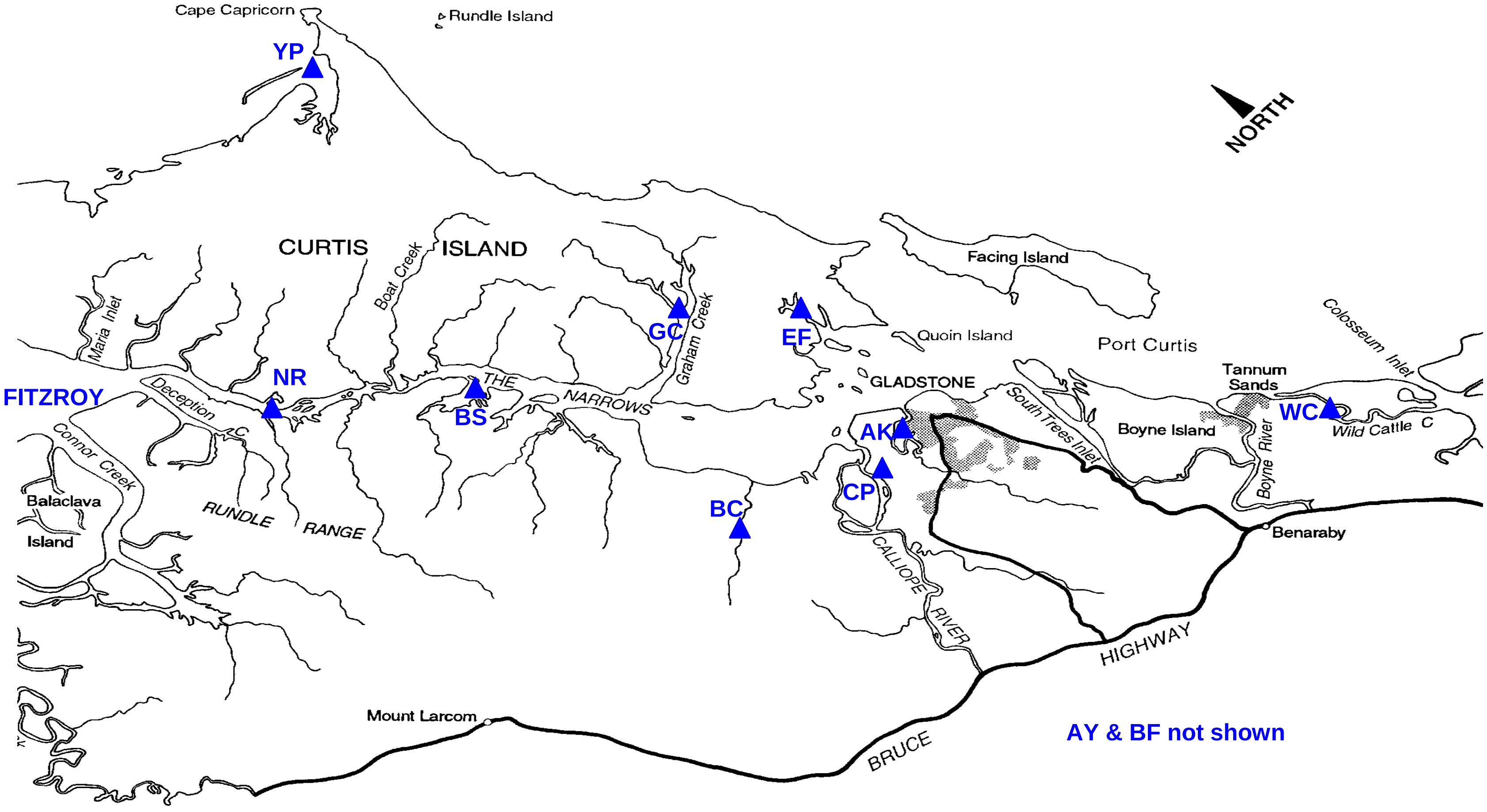


Figure 1. Location of fiddler crab and sediment sampling sites in Port Curtis. Boat creek (BK), Black Swan (BS), Graham Creek (GC), Enfield (EF), The Narrows (NR), Calliope River (CP), Auckland Creek (AK), Wild Cattle Creek (WC), Yellow Patch (YP). Ayr and Baffle Creek are outside of map boundaries (Figure 2.).

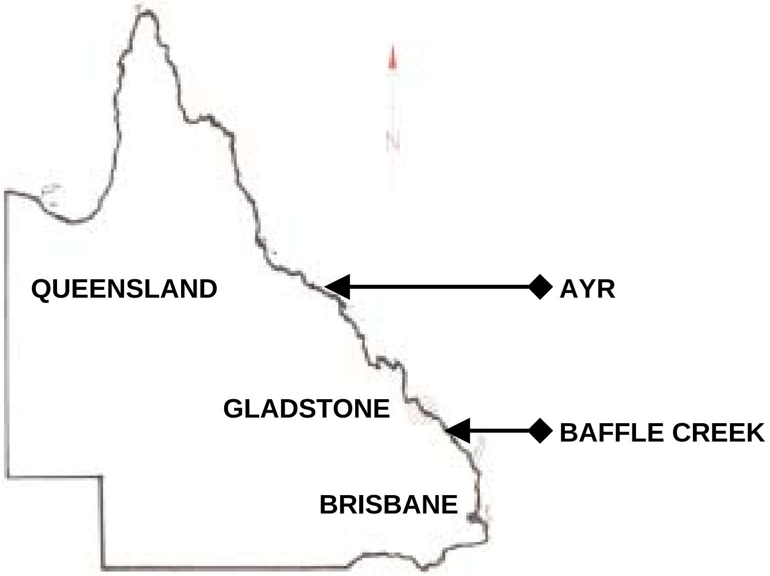


Figure 2. Location of Ayr and Baffle Creek sites in relation to Gladstone in Port Curtis.

1.2. Fiddler crabs

1.2.1. Collection

Seven male fiddler crabs (*Uca coarctata*) (Figure 3) were collected by hand from the intertidal zone from each site (Figure 4) except Wild Cattle and Baffle Creek where only 5 crabs were collected. This was due to data being provided from a previous project (Andersen et al., 2001). Fiddler crabs from Ayr were also collected, by other researchers and due to lack of sample numbers one female was included in this group. Crabs were rinsed onsite in seawater to remove sediments, placed in plastic zip lock bags, labelled and put on ice for transport to the laboratory. After identification, entire replicate crabs of similar size were further rinsed in deionized water (Millipore®) and frozen for transport to State Chemistry Laboratory, Adelaide for metal analyses.

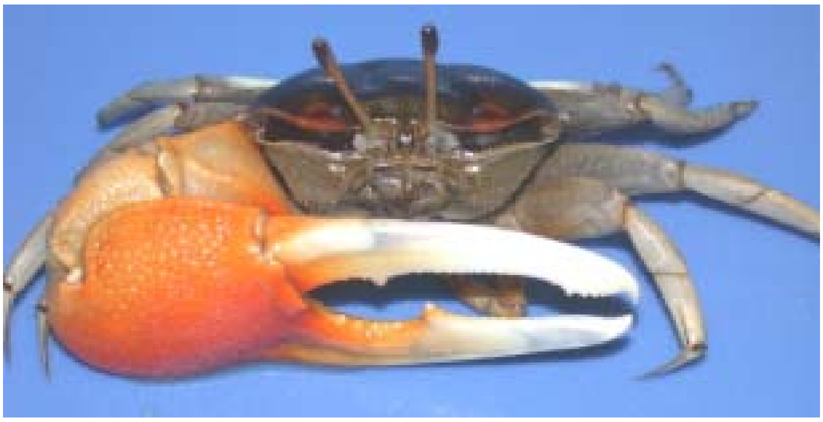


Figure 3. Fiddler crab (*Uca coarctata)*

Figure 4. Hand collection of fiddler crabs from the intertidal zone and (inset) fiddler crabs adjacent to their burrows.

1.2.2. *Dry matter*

Frozen tissue samples were first thawed overnight in a refrigerator. The whole animal/tissue sample was then placed in a pre-weighed evaporation basin (W1) and the shell of whole crabs was crushed to expose the insides of the crab. The weight of the evaporation basin and tissue were recorded (W2) and the evaporation basin was then placed overnight in an oven at 105°C. After drying the basin containing dried sample was placed in a desiccator to cool. The weight of the evaporation basin and dried sample were recorded (W3) and the % dry matter of the samples were calculated with the formula,

$(W3-W1)/(W2-W1) \times 100 = \%$ dry matter.

The sample was then milled to a sample size of one millimetre.

1.2.3. *Elemental analyses*

Samples were analysed for 13 different metals: Aluminium (Al), Arsenic (As), Cadmium (Cd), Cobalt (Co), Chromium (Cr), Copper (Cu), Iron (Fe), Manganese (Mn), Molybdenum (Mo), Lead (Pb), Nickel (Ni), Strontium (Sr) and Zinc (Zn).

Microwave acid digestion was used to digest a predetermined weighed sub sample of dry sample in a mixture of concentrated nitric acid or concentrated nitric acid and hydrogen peroxide. The analytical determination was performed using Inductively Coupled Plasma – Mass Spectrometer (ICP-MS) for most heavy metals with the exception of Fe for which Inductively Coupled Plasma – Emission Spectrometer (ICP-ES) was used. For arsenic an alternate method was used. Open tube block digestion was used to digest the dried sample in a mixture of concentrated nitric acid and concentrated perchloric acid. The analytical determination was performed using

Vapour Generation/ Inductively Coupled Plasma – Mass Spectrometer (VG/ICP-MS) at State Chemistry Laboratory, Adelaide.

1.2.4. *Statistical analyses*

Prior to analysis, the KS test for normality was applied. For any metal concentration reported as "below detection level", half the detection level was used as the nominal concentration to allow comparison with other sites/samples. If data were heteroscedastic, either square root, $\log_2$ or $\log_{10}$ transformation was applied to achieve homogeneity (= equality) of sample variances. Between-site (n=11) differences in the concentration of each metal were tested using parametric one-way ANOVA, with *a posteriori* Tukeys HSD multiple range test applied to locate site differences where there was a significant main effect. Mean concentration (± 1 SDEV of the mean) of each metal at each site was tabulated to allow interpretation of between-site differences. Where equality of variances could not be achieved, Kruskal-Wallis non-parametric one-way ANOVA was applied. For those metals with a significant difference, means (+/- 95% confidence intervals) were plotted. To establish if there was a significant difference in metal concentrations between inner harbour sites (Sites 1-4 and 6-7 combined) compared to outer harbour sites (Sites 5 and 8-11 combined) for Cu, a one-way ANOVA as above was also performed.

Total metal burdens for each crab at each site were calculated. Within each metal, the values were standardised to a scale of zero to 1 by the equation:

xnew = (x-xmin)/xrange.

This provided a relative indication of the burden of each metal in each fiddler crab (i.e. samples with a high concentration of a metal would have a value close to 1 and samples with a low concentration would have a value close to zero). To derive a total burden of all metals in each of the 75 samples, the sum of the individual burdens across the 13 metals was calculated for each crab. Between-group differences in metal burden were tested using one-way ANOVA as above with the five and seven samples within each group acting as replicates.

1.3. Sediments

1.3.1. *Collection*

Surface sediment core samples were collected by driving a 25mm plastic conduit that had been rinsed in seawater, approximately 5cm into the surface mud at each site, in the vicinity where fiddler crabs were collected. No sediments were collected at Wild Cattle Creek due to fiddler crab data from this site being provided by a previous project (Andersen et al., 2001). At each site three replicates, each consisting of two pooled sediment cores were placed into plastic zip lock bags, labelled and put on ice for transport to the laboratory. Samples were frozen and sent to Australian Laboratory Services P/L, Brisbane for metal analyses.

1.3.2. *Particle size determination*

Approximately 100 g of air-dried sediment was ground to discreet particles with mortar and pestle. The resultant sample was weighed and then sieved through an agitated stack of Endecott test sieves with apertures of 2mm, 1mm, 500µm, 250µm, 125µm and 63µm respectively. After dry sieving, the sediment fractions remaining on the sieves were then wetted with a 0.004% sodium hexametaphosphate dispersing solution and allowed to stand for approximately one day. The resultant slurry was then hand washed through the sieve stack with water until the wash water was clear and the remaining material air dried at 40°C until constant mass was reached. Each fraction's mass was calculated as a percentage of the total mass of the sample. The fraction less than 63µm (mud) was calculated as the difference between the sum of the fractions greater than 63µm and the total mass of the sample (AS 1289. C6.1, 1977).

1.3.3. Elemental analyses

Samples were analysed for the same suite of metals as the fiddler crabs. USEPA method 3051 was used for metal analyses. This method is applicable to the microwave assisted acid digestion of sludges, sediments, soils and oils for the determination of a wide range of metals. A representative sample of up to 1g was digested in 10mL of concentrated nitric acid for 10 minutes using microwave heating with a suitable laboratory microwave unit. After cooling, the vessel contents were diluted to volume and analysed by the appropriate method (Inductively Coupled Plasma Atomic Emission Spectroscopy (ICP-AES)).

1.3.4. Statistical analyses

Using the assumption that metals and trace metals are not homogenously distributed over the total grain size spectrum of sediment and that the coarse sandy material contains little or no metals (Muller et al., 2001), concentrations of metals for each sediment sample were normalised to correct for differences in particle size at each site. Within each metal, the values were normalised by the equation:

normalised metal concentration = total metal concentration x 100/(%<63 um fraction).

Results for sediment metals were treated similarly to those of fiddler crab metals, with tests for normality and homogeneity being performed prior to one-way ANOVA and post hoc Tukeys HSD multiple range tests. Total metal burdens for each sediment sample at each site were also calculated as for the fiddler crabs in section 1.2.4. A comparison of inner harbour compared to outer harbour sediment copper concentration was also performed. Additionally, Pearson product moment correlation was applied to determine if there were any relationships between metal concentrations in fiddler crabs and normalised metal concentrations in sediments.

RESULTS

1.4. Fiddler crabs

Of the 13 metals, there was one metal (Zn) that was significant as tested by non-parametric Kruskal-Wallis (Table 2) and 9 that had significant between-site differences as tested by parametric ANOVA (Table 3). The means (+/- 95% confidence intervals) for Zn are plotted in Figure 5. There was no consistent trend of any site having elevated concentrations of all metals compared to other sites. Fiddler crabs from Ayr followed by Auckland Creek tended to have the highest metal concentrations for most metals and Baffle Creek and Wild Cattle Creeks the lowest, which was also reflected in the comparison for metal burdens. In all instances however, concentrations in fiddler crabs were higher or lower than only one or two other sites but not all other sites. There was insufficient sample for five of the seven crabs from Ayr to be analysed for As and therefore comparisons for this metal at this site are limited.

Table 2 Kruskal-Wallis non-parametric one-way ANOVA comparing whole fiddler crab metal concentrations (mg/kg dry wgt) between sites. Sites arranged in ascending order of mean rank concentration.

Metal	df	Chi-square	p	Sites in ascending order of mean ranked concentration										
Zn	10	48.098	<0.0001	WC	BC	BF	BS	YP	AY	GC	AK	EF	NR	CP

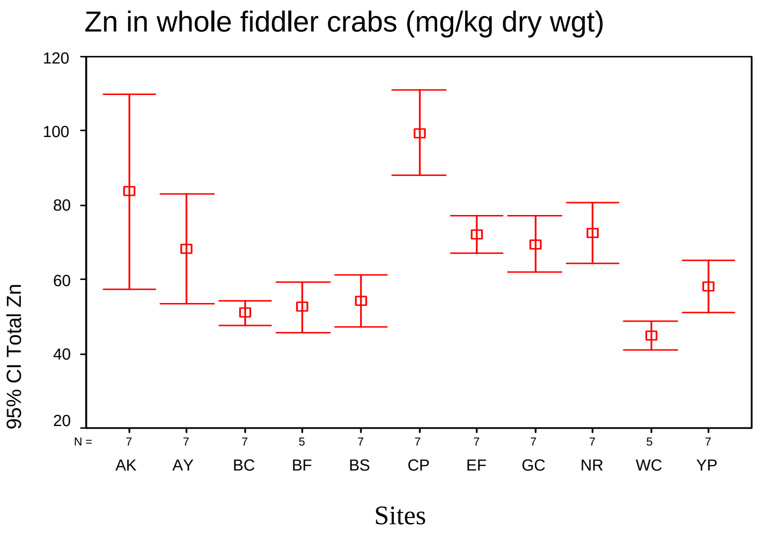


Figure 5. Zn in whole fiddler crabs (means +/- 95% confidence intervals).

Table 3. One-way ANOVA comparing whole fiddler crab metal concentrations (mg/kg dry wgt). Data were transformed to achieve homogeneity of variances where indicated. Where a significant main effect was detected, *a posteriori* Tukeys HSD multiple range test was applied to locate between-site differences. Sites not significantly different from each other are joined by a common line and sites are arranged in ascending order of arithmetic means. Inner harbour sites are highlighted in red.

Metal	df	F	p	Tukeys HSD Multiple Range Test										
Al	10,62	2.562	0.012	BF	YP	WC	NR	GC	BC	EF	CP	BS	AK	AY
(sqrt) **As**	10,57	4.160	<0.0001	BC	CP	AK	AY	YP	BS	GC	BF	WC	NR	EF
(log 2) **Cd**	10,59	5.340	<0.0001	NR	WC	BF	AK	CP	BS	EF	YP	GC	BC	AY
Co	10,62	5.323	<0.0001	WC	BC	BS	BF	CP	YP	GC	EF	NR	AK	AY
(log2) **Cr**	10,62	3.261	0.002	BF	BS	BC	WC	YP	GC	CP	NR	EF	AK	AY
Cu	10,62	7.139	<0.0001	YP	WC	AY	NR	CP	BF	AK	EF	GC	BS	BC
Fe	10,62	3.606	0.001	BF	GC	WC	BC	NR	EF	BS	CP	YP	AY	AK
(sqrt) **Mn**	10,62	6.990	<0.0001	BF	BC	GC	WC	NR	EF	CP	BS	YP	AY	AK
Mo	10,62	1.427	ns	GC	WC	BC	BS	BF	CP	YP	EF	AY	NR	AK
Ni	10,62	1.102	ns	BF	YP	WC	BC	BS	CP	GC	AK	NR	AY	EF
(sqrt) **Pb**	10,62	6.142	<0.0001	BF	BC	YP	GC	NR	WC	EF	CP	BS	AK	AY
Sr	10,62	0.894	ns	BS	BC	GC	WC	EF	NR	AK	AY	CP	YP	BF
Metal **Burdn**	10,62	3.788	0.001	WC	BF	YP	BC	BS	NR	GC	CP	EF	AK	AY
Cu	1,9	13.4	0.005			Outer Harbour Sites					Inner Harbour Sites			
Mean **(SE)**						61.03 (4.09)					80.38 (3.42)			

Al, Cd, Cu and metal burdens tended to have higher concentrations at inner harbour sites (highlighted in red in Table 3) compared to outer harbour sites, although the difference was not always significant. There was, however, a significant difference in copper concentrations in fiddler crabs from combined inner harbour sites compared to combined outer harbour sites (Table 3). The mean value of copper at Boat Creek (94.29mg/kg + SE 7.34) was almost twice as high as the mean lowest concentration (59.00 + SE 4.54) at Yellow Patch. Results for metals are expressed in mg/kg dry wgt., with the Mean concentration (+ 1 SDEV of the mean) of each metal tabulated in Appendix 1.

1.5. Sediments

Although greater than 43% of sediment particle size was less than 63 microns at all sites (Table 4), there was some difference in particle size distribution, confirming efforts to normalise data to accommodate for these differences. Sediments at Yellow Patch and Baffle Creek tended to be coarser (sandier) compared to other sites, which were not that different from each other.

Table 4. Particle size distribution of sediments at all sites expressed as a percentage of the total fraction.

		Particle size				
Site	**Location**	**<63**	**63**	**125**	**250**	**500**
1	Boat Creek	78.25	8.36	7.54	3.61	2.24
2	Black Swan	83.71	6.29	8.88	0.83	0.29
3	Graham Creek	79.75	14.34	4.61	1.00	0.31
4	Enfield	83.71	8.90	6.36	0.94	0.09
5	The Narrows	76.45	18.44	4.25	0.58	0.29
6	Calliope River	74.98	13.10	11.30	0.38	0.23
7	Auckland Creek	72.97	13.18	8.24	2.61	2.99
9	Yellow Patch	43.50	36.26	15.40	4.65	0.19
11	Ayr	76.71	5.26	10.77	5.00	2.26
10	Baffle Creek	50.50	40.84	6.89	1.43	0.33

Of the 13 metals analysed, there were 8 that had significant between-site differences as tested by parametric ANOVA (Table 5) and one metal (Mn), that was significant as tested by non-parametric Kruskal-Wallis (Table 6). For two metals (Mo and Cd) the concentrations were below limits of detection. The means (+/- 95% confidence intervals) for Mn are plotted in Figure 6. There was no consistent trend of any site having elevated concentrations of all metals compared to other sites. There was a trend for Enfield followed by Yellow Patch to have the lowest concentrations for most metals and Baffle Creek the highest, although this site was not consistently or significantly higher than other sites. Strontium was significantly higher at Yellow patch compared to all other sites, and Baffle Creek, Auckland Creek and Calliope River were the next highest, being significantly more elevated than the remaining sites. Apart from strontium, however, in all instances concentrations in sediments were higher or lower than only one or two other sites but not all other sites. As for Cu in fiddler crabs, the concentrations of this metal were significantly higher in inner harbour site sediments compared to outer harbour site sediments (Table 5).

Table 5. One-way ANOVA comparing normalised sediment metal concentrations (mg/kg dry wgt). Data were transformed to achieve homogeneity of variances where indicated. Where a significant main effect was detected, *a posteriori* Tukeys range test was applied to locate between-site differences. Sites not significantly different from each other are joined by a common line and sites are arranged in ascending order of arithmetic means. Inner harbour sites are highlighted in red.

Metal	**df**	**F**	**p**	**Tukeys HSD Multiple Range Test**									
(log10) **Al**	9,20	1.681	ns	EF	GC	YP	AY	NR	AK	BF	BS	CP	BC
As	9,20	1.316	ns										
Cd	<LOD												
Co	9,20	4.159	0.004	YP	EF	GC	BS	NR	AY	AK	CP	BF	BC
Cr	9,20	5.215	0.001	EF	AY	GC	CP	AK	BS	BC	YP	NR	BF
Cu	9,20	13.49	<0.0001	YP	BF	NR	EF	AY	BS	GC	AK	BC	CP
(log2) **Fe**	9,20	1.242	ns										
Mo	<LOD												
Ni	9,20	6.170	<0.001	EF	GC	YP	AK	CP	BC	BF	AY	BS	NR
Pb	9,20	5.215	<0.001	EF	AY	GC	CP	AK	BS	BC	YP	NR	BF
Sr	9,20	74.30	<0.0001	EF	GC	BS	BC	NR	AY	CP	AK	BF	YP
(sqrt) **Zn**	9,20	5.083	0.001	EF	YP	GC	NR	BS	BF	AY	BC	CP	AK
Metal Burden	9,20	5.776	0.001	YP	BF	EF	GC	AK	NR	CP	AY	BS	BC
Cu **Mean** **(SE)**	1,8	8.433	0.02			Outer Harbour Sites 16.25 (2.33)					Inner Harbour Sites 24.99 (1.91)		

Table 6. Kruskal-Wallis non-parametric one-way ANOVA for Mn comparing normalised sediment metal concentrations (mg/kg dry wgt) between sites. Sites arranged in ascending order of mean rank concentration.

Metal	**df**	**Chi-square**	**p**	**Site in ascending order of mean ranked concentration**									
Mn	9	23.340	0.005	BS	AK	NR	GC	EF	CP	BF	YP	AY	BC

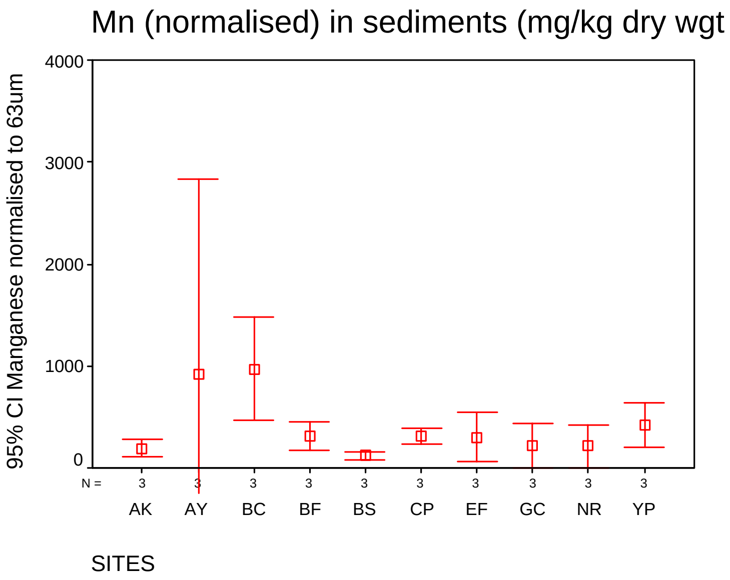
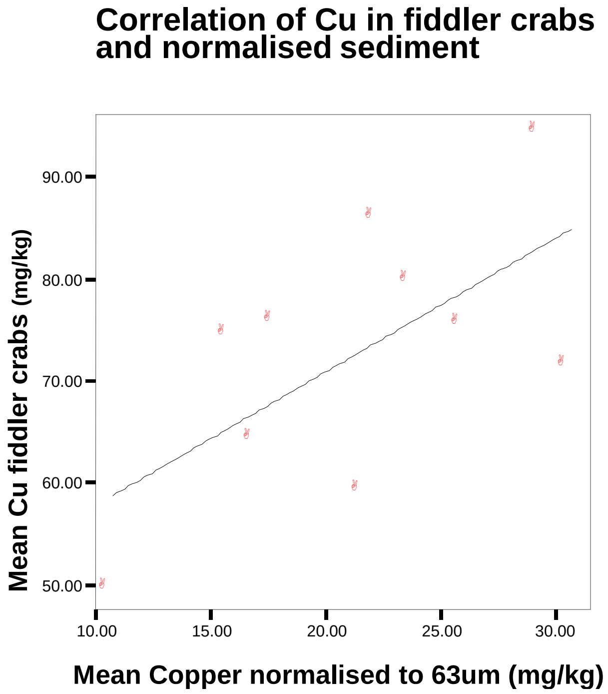


Figure 6. Mn in normalised sediments (means +/- 95% confidence intervals)

Significant but weak correlations were established between fiddler crabs and normalised sediments for Cu (R = 0.633 p = 0.049)(Figure 7) and Sr (R = 0.653, p = 0.041)(Figure 8). However, the data for strontium was unevenly distributed around the line of best fit and therefore this relationship is not very strong.



R = 0.633

Figure 7. Significant correlation of Cu concentrations in fiddler crabs against normalised Cu concentrations in sediments.

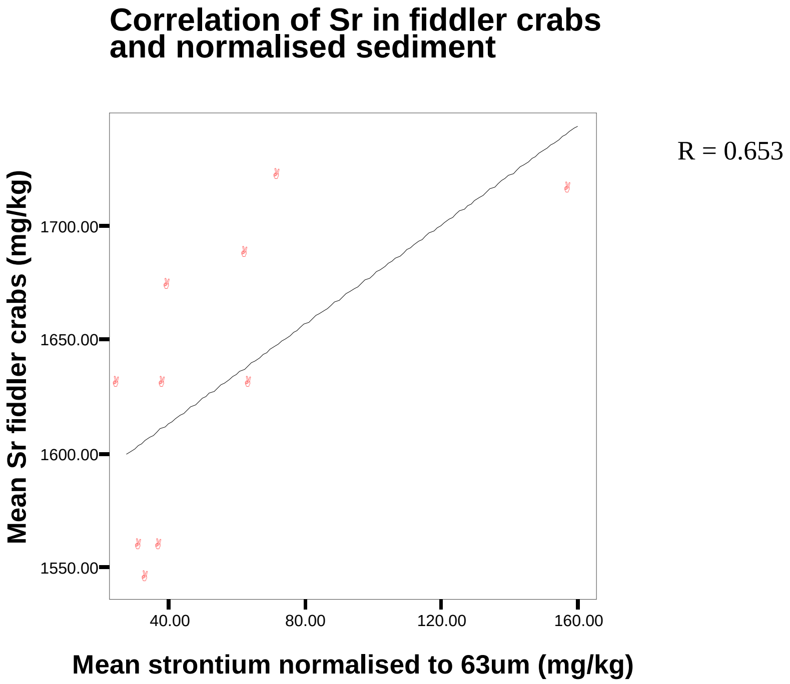


Figure 8. Significant correlations of Sr concentrations in fiddler crabs against normalised Sr concentrations in sediments.

DISCUSSION

Trace metals, which are taken up and accumulated by aquatic organisms, come from a number of surrounding mediums. Crustaceans through permeable surfaces such as gills and other membranes take up metals in dissolved forms (Rainbow, 1997). Diet is another source of metal uptake (Chou et al., 2000), by the consumption of previously accumulated pollutants in other biota and the ingestion of water during feeding. Fiddler crabs feed by using their mouthparts to scrape organic matter from the substrate (Miller, 1961), in addition to spending part of their lifecycle in water filled burrows (Hogarth, 1999). These characteristics potentially allow the fiddler crab to be a candidate for biological monitoring, as potentially integrate water, diet and sediment derived pollutants.

Concentrations of metals in fiddler crabs did not highlight any one site as being more contaminated than other sites, although total metal burdens tended to be higher in inner harbour sites compared to outer harbour sites. The results did not emphasize Yellow Patch, an unimpacted site outside the harbour as having the lowest metal concentrations in fiddler crabs, as might be expected. Fiddler crabs from the reference site at Ayr tended to have the highest concentrations of metals. This is in contrast to mud crabs (*Scylla serrata*) from Port Curtis in which metal burdens were found to be elevated in comparison to those from Ayr (Andersen & Norton, 2001).

Specimens from Ayr were collected by other researchers and were observed to be smaller than those from other sites. Not all crabs had intact limbs and one female was also included in this group, which may have had an effect on results. MacFarlane et al. (2000) noted a sex difference in lead accumulation of the intertidal crabs (*Heloecius cordiformis*) they studied. They also noted that smaller males accumulated more lead than larger males, suggesting size is also an important consideration. However, Ayr fiddler crabs did tend to have lower copper concentrations than Port Curtis fiddler crabs. A similar finding was established for mud crabs (Andersen & Norton, 2001) with hepatopancreas copper concentrations being two to three times more elevated in Port Curtis mud crabs compared to those from Ayr.

There was a trend for Baffle Creek and Wild Cattle creeks to have the lowest metal concentrations in fiddler crabs. This trend, however, tended to be reversed in Baffle Creek sediments for some metals. Surprisingly Enfield, considered an inner harbour site, tended to have the lowest sediment metal concentrations. Copper accumulations in fiddler crabs and sediments tended to follow a similar pattern with a weak but significant correlation between the two being established. MacFarlane et al. (2000), however, determined that changes in sediment copper concentrations between sites, was not reflected in accumulated copper concentrations in crab hepatopancreas tissue in *Heloecius cordiformis.* Chou et al. (2000) also did not observe a relationship between sediment and digestive gland metal concentrations in lobsters (*Homarus americanus*). The difference in results of these authors compared to this study may be due to a species difference or a difference in the tissue type sampled.

Copper was more elevated in fiddler crabs and sediments from inner harbour sites compared to outer harbour sites, with concentrations in fiddler crabs at the highest site (Boat Creek) being almost twice that at the lowest site, Yellow Patch. Mortimer (2000) found that mean copper concentrations in whole burrowing tuxedo crabs

(*Australoplax tridentata*) ranged from 62.5 – 110 mg/kg dry wgt for 21 sites between Brisbane and Cairns, which was similar to our findings for *Uca coarctata* (range 59.0 – 94.3 mg/kg dry wgt.). The mean concentration of copper for tuxedo crabs from Ross Creek an industrial port area in Townsville, however, was 245 mg/kg dry wgt. (SE = 23.0), which is higher than that determined by Mortimer (in prep) for *Uca coarctata* from a nearby area (78 mg/kg dry wgt.) Species difference may account for this disparity.

Mortimer (in prep) also sampled *Uca coarctata* from a number of other sites in Queensland. The mean copper concentrations of whole fiddler crabs from a number of sites in Brisbane ranged from 90.3 – 128.2 mg/kg dry wgt. (Logan River) which was slightly more elevated than our findings for fiddler crabs from inner harbour Port Curtis sites. Mean copper concentrations at less impacted sites at Jacobs Well (south of Brisbane)(range 55.2 – 64.7 mg/kg dry wgt.) were similar to values at some outer harbour sites for this study. The mean copper concentration for 12 *Uca coarctata* collected from an inner harbour site in Gladstone in 1994 by Mortimer (unpub.) was 107.6 mg/kg (+/- 21.9) and appears therefore not to have differed noticeably since that time.

Wiggins (1992) determined the mean range of copper concentration from a number of sites in Brisbane was 179.68 – 283.85 mg/kg dry wgt, which was higher than that found for our crabs or the studies by Mortimer. The methodology was different with the author removing the limbs of the crab before analyses. As the hepatopancreas is the preferred site for copper accumulation in crabs (Bjerregaard & Visle, 1986, Arumugam & Ravindranath, 1987), the addition of limbs in our analyses may have served to dilute the overall copper concentration.

The findings of this study highlights the need to assess each trace metal separately. MacFarlane et al. (2000) noted that copper and zinc were mainly regulated whereas lead was accumulated in *Heloecius cordiformis.* Decapod crustaceans also accumulate cadmium (Rainbow, 1988). Iron concentrations in decapods are extremely variable and are often associated with sediment particles in the gut (Rainbow, 1988), especially in undepurated specimens such as ours. Manganese may also be regulated in some decapods including the crab *Carcinus maenas* and the lobster *Homarus vulgaris* (Rainbow, 1985). There is, however, a limit to the regulation abilities of an organism with regulation breakdown and subsequent net accumulation if thresholds of metals are exceeded (Rainbow, 1988).

In conclusion the findings of this study were similar to that of an investigation into shell disease and associated metal concentrations in mud crabs from Port Curtis in that copper, zinc and metal burdens were found to be elevated in comparison to some reference sites (Andersen & Norton, 2001). Copper and metal burdens and to a lesser extent aluminium and cadmium, tended to be more elevated in fiddler crabs from inner harbour sites compared to outer harbour sites in this study. The high variation in metal concentrations in fiddler crabs at each site may have precluded more significant differences being established, as it did in the mud crab study. Copper concentrations in Port Curtis mud crabs were two to three times more elevated than mud crabs from other areas in Queensland (Andersen & Norton, 2001). This magnitude of difference in copper concentrations, however, was not seen in Port Curtis fiddler crabs in comparison to those from other areas in Queensland (Mortimer, in prep). The carnivorous, adult mud crab maintains a fairly high trophic position with fiddler crabs being a major food source (Thimdee et al., 2001). This position in the food chain as a top order consumer augments the bioaccumulation of metals from other food sources. In contrast, the fiddler crab is a first level feeder preferring benthic microalgae (bacteria, protozoans & diatoms) to mangrove detritus (France, 1998, Thimdee et al., 2001). The different trophic positions may partly account for the relative difference in copper accumulations between the two species.

In terms of their sedentary lifestyle and abundance in the area, fiddler crabs meet the ideal biomonitoring criteria. However, they are quick moving and difficult to catch compared to other intertidal species, which is a notable biomonitoring disadvantage. As a regulator of some metals they may not be as suitable as organisms such as oysters or mussels, which ideally reflect ambient environmental concentrations of metals. They have, however, demonstrated their ability to identify between site gradients for some metals. Although there were weak correlations between fiddler crabs and sediment metal concentrations for copper and strontium, it appears that this relationship is not the norm for most metals. Perhaps other mediums such as water or diet may be an alternate source of metals for fiddler crabs.

Acknowledgements. A University Research Grant, from the Centre for Environmental Management, Central Queensland University, funded this research. We would like to thank Boyne Smelters Limited and Dr. Munro Mortimer for allowing us to include some of their comparative data in this report. The project was completed as part of the Cooperative Research Centre for Coastal Zone and Waterway Management Port Curtis projects.

REFERENCES

Andersen, L. E., Lewis, S. and Melzer, A. (2001) Fluoride and metals in Spillway creek crustacea. Centre for Environmental Management, Central Queensland University, Gladstone. 1-53 pp.

Andersen, L. E. and Norton, J. H. (2001) Port Curtis mud crab shell disease; nature, distribution and management. Centre for Environmental Management, Central Queensland University, Gladstone. 115 pp.

Arumugam, M. and Ravindranath, M. H. (1987) Copper toxicity in the crab, *Scylla serrata,* copper levels in tissues and regulation after exposure to a copper-rich medium. Bulletin of Environmental Contamination and Toxicology, 39**:** 708-715.

Bjerregaard, P. and Visle, T. (1986) Effect of copper on ion- and osmoregulation in the shore crab *Carcinus maenas*. Marine Biology, 91**:** 69-76.

Chou, C. L., Paon, L. A., Moffatt, J. D. and Zwicker, B. (2000) Copper contamination and cadmium, silver, and zinc concentrations in the digestive glands of American lobsters (*Homarus americanus*) from the Inner Bay of Fundy, Atlantic Canada. Bulletin of Environmental Contamination and Toxicology, 65**:** 470-477.

France, R. (1998) Estimating the assimilation of mangrove detritis by fiddler crabs in Laguna Joyuda, Puerto Rico, using dual stable isotopes. Journal of Tropical Ecology, 14**:** 413-425.

Hogarth, P. J. (1999) The biology of mangroves. Oxford University Press, New York.

Hyland, S. J., Hill, B. J. and Lee, C. P. (1984) Movement within and between different habitats by the portunid crab Scylla serrata. Marine Biology, 80**:** 57-61.

MacFarlane, G. R., Booth, D. J. and Brown, K. R. (2000) The Semaphore crab, Heloecius cordiformis: bioindication potential for heavy metals in estuarine systems. Aquatic Toxicology, 50.**:** 153-166.

Miller, D. C. (1961) The feeding mechanism of fiddler crabs, with ecological considerations of feeding adaptions. Zoologica, 46**:** 89-100.

Mortimer, M. R. (2000) Pesticide and trace metal concentrations in Queensland estuarine crabs. Marine Pollution Bulletin, 41**:** 359-366.

Mortimer, M. R. (in prep) Biological monitoring in Queensland estuaries. Queensland Environmental Protection Agency, Brisbane.

Muller, G., Ottenstein, R. and Yahya, A. (2001) Standardized particle size for monitoring, inventory, and assessment of metals and other trace elements in sediments: <20um or <2um? Journal of Analytical Chemistry, 371**:** 637-642.

Phillips, D. J. H. (1990) Use of macroalgae and invertebrates as monitors of metal levels in estuaries and coastal waters In:(Eds), Furness, R. W. and Rainbow, P. S., Heavy metals in the marine environment. CRC Press, Inc., Boca Raton, Florida, pp. 81-99.

Rainbow, P. S. (1985) Accumulation of Zn, Cu and Cd by crabs and barnacles. Estuarine, Coastal and Shelf Science, 21**:** 669-686.

Rainbow, P. S. (1988) The significance of trace metal concentrations in decapods. Symposium of the Zoological Society of London, 59**:** 291-313.

Rainbow, P. S. (1990) Heavy metal levels in marine invertebrates In:(Eds), Furness, R. W. and Rainbow, P. S., Heavy metals in the marine environment. CRC Press, Inc, Boca Raton, Florida, pp. 67-79.

Rainbow, P. S. (1995) Biomonitoring of heavy metal availability in the marine environment. Marine Pollution Bulletin, 31**:** 183-192.

Rainbow, P. S. (1997) Ecophysiology of trace metal uptake in curstaceans. Estuarine, Coastal and Shelf Science, 44**:** 169-175.

Thimdee, W., Deein, G., Sangrungruang, C. and Matsunaga, K. (2001) Stable carbon and nitrogen isotopes of mangrove crabs and their food sources in a mangrove-fringed estuary in Thailand. Benthos Research, 56**:** 73-80.

Wiggins, M. (1992) Pollution impacts on *Uca coarctata* (fiddler crab) as measured by morphological asymetry and variation in genetic structure. Bachelor of Science (honours). School of Environmental Studies, Griffith University, Brisbane. 116 pp.

APPENDICES

Appendix 1. Mean (+/- 1 standard deviation) metal concentrations (mg/kg dry wgt.) of whole fiddler crabs from collection sites. (*N = 2 for As at site Ayr).

Site	Location		N=	Total Al	Total As	Total Cd	Total Co	Total Cr	Total Cu	Total Fe	Total Mn	Total Mo	Total Ni	Total Pb	Total Sr	Total Zn
1	Boat Ck	Mean	7	2142.86	2328.57	0.14	0.85	10.51	94.29	965.71	75.14	0.65	5.24	0.43	1557.14	51.00
		SDEV		1006.41	776.13	0.04	0.21	8.11	19.41	485.45	27.90	0.22	2.55	0.13	207.02	3.46
2	Black swan	Mean	7	2371.43	2771.43	0.11	0.93	9.17	85.86	1080.00	52.00	0.66	5.99	0.50	1542.86	54.14
		SDEV		682.43	381.73	0.04	0.22	3.44	16.26	294.90	24.74	0.15	1.58	0.11	222.54	7.54
3	Grahams	Mean	7	2042.86	2814.29	0.13	1.16	14.31	79.57	948.57	81.14	0.54	6.56	0.43	1557.14	69.57
		SDEV		345.72	701.02	0.04	0.31	5.90	11.70	167.18	26.64	0.09	2.60	0.09	139.73	8.16
4	Enfield	Mean	7	2242.86	4314.29	0.12	1.20	18.86	75.71	1057.14	70.00	0.72	8.13	0.46	1628.57	72.00
		SDEV		229.91	1068.38	0.03	0.06	10.44	12.59	136.96	28.35	0.16	2.70	0.04	95.12	5.42
5	Narrows	Mean	7	2000.00	3685.71	0.06	1.23	16.90	64.14	1021.43	63.43	0.77	6.97	0.44	1628.57	72.57
		SDEV		387.30	872.60	0.02	0.14	8.97	6.49	204.08	15.26	0.24	2.49	0.08	95.12	8.98
6	Calliope	Mean	7	2271.43	2342.86	0.11	1.05	14.14	71.43	1081.43	88.29	0.68	6.06	0.50	1685.71	99.57
		SDEV		738.72	927.11	0.06	0.13	3.24	4.54	370.69	40.12	0.21	2.56	0.15	89.97	12.51
7	Auckland	Mean	7	2657.14	2285.71	0.11	1.26	22.79	75.43	1514.29	81.86	0.92	6.87	0.59	1628.57	83.71
		SDEV		492.81	260.95	0.06	0.08	12.54	15.09	247.85	17.90	0.32	2.77	0.06	170.43	28.45
8	Wild cattle	Mean	5	1880.00	3740.00	0.076	0.796	11.74	58.20	960.00	41.20	0.58	5.24	0.49	1600.00	44.80
		SDEV		396.23	1409.96	0.03	0.10	6.25	16.24	149.67	6.61	0.10	1.35	0.12	141.42	3.19
9	Yellow P	Mean	7	1785.71	2628.57	0.13	1.08	18.80	49.43	1135.71	58.00	0.69	5.10	0.43	1714.29	58.14
		SDEV		397.61	793.13	0.06	0.25	19.90	6.50	286.00	15.53	0.32	3.33	0.09	106.90	7.73
10	Baffle	Mean	5	1380.00	3120.00	0.092	1.036	6.00	74.40	760.00	58.20	0.672	4.10	0.36	1720.00	52.60
		SDEV		311.45	925.74	0.03	0.12	1.98	11.28	84.26	5.26	0.11	1.30	0.10	216.79	5.50
11	Ayr	Mean	7*	2685.71	2300.00	0.29	1.33	27.86	59.00	1372.86	151.43	0.76	7.53	0.79	1671.43	68.14
		SDEV		796.72	141.42	0.16	0.24	16.84	12.00	278.37	54.90	0.26	5.10	0.20	269.04	15.99

Appendix 2. Mean (+/- 1 standard deviation) metal concentrations (mg/kg dry wgt.) of sediments from collection sites (normalized for particle size).

Site	Location		N =	Cu norm	Al norm	As norm	Co norm	Cr norm	Fe norm	Mn norm	Ni norm	Pb norm	Zn norm	Sr norm
1	Boat Ck	Mean	3	29.39	21383.90	14.91	14.91	33.65	38934.03	972.07	17.89	33.65	71.14	39.62
		SDEV		2.21	1378.34	1.48	1.48	3.22	3141.54	201.48	2.56	3.22	13.12	2.21
2	Black Sw	Mean	3	22.30	18714.66	17.92	9.95	33.05	33128.92	120.65	18.71	33.05	48.18	35.84
		SDEV		1.38	1855.73	0.00	0.69	3.65	2975.21	15.53	1.82	3.65	5.39	4.31
3	Grahams	Mean	3	23.82	16049.91	16.30	10.03	27.59	30093.58	216.92	13.79	27.59	43.47	33.86
		SDEV		3.76	2801.00	1.25	1.25	4.52	3662.16	86.63	2.17	4.52	7.66	2.17
4	Enfield	Mean	3	17.92	14454.33	14.73	9.56	24.69	26877.88	300.63	11.55	24.69	40.22	27.48
		SDEV		3.16	2331.71	2.49	2.39	4.20	4686.32	94.94	1.82	4.20	7.30	4.31
5	Narrows	Mean	3	17.00	17746.09	18.75	10.46	37.93	33573.69	214.52	23.11	37.93	43.60	40.99
		SDEV		0.00	1112.50	3.02	1.31	1.31	840.97	83.99	0.76	1.31	1.51	6.58
6	Calliope	Mean	3	30.67	20049.12	16.45	12.45	30.67	35341.58	307.63	15.56	30.67	70.68	65.35
		SDEV		2.31	2573.39	0.77	0.77	3.53	2894.35	31.34	1.54	3.53	8.11	5.81
7	Auckland	Mean	3	26.04	18180.61	15.53	11.88	30.61	32158.67	194.14	15.07	30.61	63.04	66.24
		SDEV		3.63	2769.20	1.58	1.58	4.41	5683.99	36.32	2.37	4.41	8.34	8.37
9	Yellow P	Mean	3	10.73	16552.74	19.92	9.20	34.48	29810.25	419.18	14.56	34.48	41.38	160.16
		SDEV		1.33	1540.84	3.51	0.00	2.30	3443.37	86.31	1.33	2.30	2.30	8.07
10	Baffle	Mean	3	15.84	18335.97	20.46	13.86	37.62	35444.27	309.56	17.82	37.62	53.46	74.58
		SDEV		3.96	2431.29	4.12	1.98	3.96	4878.51	57.40	1.98	3.96	5.24	13.18
11	Ayr	Mean	3	21.73	16989.79	17.82	11.30	26.07	40453.96	910.32	18.25	26.07	59.09	42.15
		SDEV		4.935217	5308.46	6.561132	2.713587	2.25784	16957.03	775.1601	4.70007	2.25784	20.45946	13.56793