Enrichment, distribution and sources of heavy metals in the sediments of Deception Bay, Queensland, Australia: A preliminary survey

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Abstract

Sediment samples from 13 sampling sites taken from Deception Bay, which forms part of the Moreton Bay Marine Park which is an area of environmental significance in Southeast Queensland, Australia were analysed for the presence of heavy metals. Enrichment factors, modified contamination indices and Nemerow pollution indices were calculated for each sampling site to determine sediment quality. The results indicate significant pollution of most sites by lead (average enrichment factor of 13), but there is also enrichment of arsenic (average EF 2.3), zinc (average EF 2.7) and other heavy metals. The modified degree of contamination indices (average 1.0) suggests that there is little contamination while the Nemerow pollution index (average 5.8) suggests that Deception Bay is heavily contaminated. Cluster analysis was also undertaken to identify groups of elements. Strong correlation between some groups of elements and two distinct clusters of sampling sites based on sediment type was evident. This has implications for pollution in complex marine environments where there is significant influx of sand and sediment into an estuarine environment.

Keywords

Heavy metals pollution, Heavy metal enrichment, Heavy metal distribution, Deception Bay, X-ray Fluorescence

Increasing concern about the release of heavy metals and their effects on human and ecosystem health (Mitra et al.; Tang et al., 2010) has led to increased monitoring of the concentrations and study of the fate of heavy metals in the environment. This research is gaining importance with ever increasing understanding of the processes of biogeochemical recycyling and the consequent public health and ecological risks (Che et al., 2003; Liu et al., 2003) and the potential for these processes to enhance the bioavailability of heavy metals.

Chapman and Wang (2001) referred to marine areas adjacent to urban areas as “the septic tank of the metropolis”. Research into the effects that urbanisation has on the heavy metals content in urban soils, stormwater runoff and their adjacent marine environments is extensive and increasing (Abrahim and Parker, 2008; Chapman and Wang, 2001; González-Fernández et al., 2011; Herngren et al., 2005; Herngren et al., 2006; Jardine and Bunn, 2010; Li et al., 2012; Sörme and Lagerkvist, 2002). One of the sensitive marine areas which has seen rapid population growth and expanded industrial activity since the 1980s is Deception Bay, which is the northernmost embayment within Moreton Bay, Southeast Queensland, Australia. As a result of the rapid population and industrial growth in Southeast Queensland, and the consequent environmental degradation, the Queensland Government set up the Healthy Waterways program (DERM), which is charged with assessing and reporting on the ecosystem health of major waterways, via its annual report cards, which use a number of indicators to determine the ecological health of Moreton Bay (Pantus and Dennison, 2005; Waterways, 2008).

The current method of determining the health of Moreton Bay is based on a number of previous studies undertaken (Abal et al., 2001; Dennison and Abal, 1999; McEwan, 1998). The major limitation in these studies was that they examined nutrient parameters rather than heavy metals content and their distribution in Moreton Bay. This has resulted in the lack of understanding of the distribution of toxic metals, interactions with the ecosystem and mobility within the food chain.

Recent work by Morelli *et al*. (Morelli et al., 2012) inferred that industrialisation linked to the establishment of penal colonies in the Brisbane region in the early years led to minor enrichment of cadmium, lead, zinc and nickel. Their conclusions were based on the enrichment of metals found in core samples taken from two sampling sites in the intertidal regions of Deception Bay. However, it does not consider how sediments are mixed and sequestered within the bay.

Although a number of lithogenic sources of heavy metals can exist in the natural environment, the vast majority of heavy metals found in sediments near built up areas are of anthropogenic origin (Ahdy and Youssef, 2011; Binning and Baird, 2001; Wilber and Hunter, 1979; Wright and Mason, 1999). The primary mechanism of deposition of heavy metals found in the marine environment are deposition from the atmosphere (Choi et al., 2011; Romic and Romic, 2003; Tang et al., 2010); industrial and agricultural discharges (Tang et al., 2010) and stormwater runoff (Herngren et al., 2005; Herngren et al., 2006). Similarly, estuarine environments are complex (Liu et al., 2003) receiving contamination from a range of diverse sources (Blasco et al., 1999; Choi et al., 2011). Intense sedimentation within estuarine and marine environments trap heavy metals within fine grained particles which then precipitate, filtering heavy metals out of the immediate biosphere (Chapman and Wang, 2001; Choi et al., 2011; De Wolf et al., 2000; Riba et al., 2002). This intense sedimentation concentrates heavy metals, and also helps to limit their environmental impact (Ahdy and Youssef, 2011; Grecco et al., 2011). However, sequestration can be of concern due to the long residence times (Imperato et al., 2003) which increase the possibility of re-suspension and re-entry to the biosphere (Birch and Taylor, 1999; González-Fernández et al., 2011). Figure 1 is a simplified schematic of the fate of heavy metals in the marine environment and illustrate some of the complex interactions which can occur between sources and sinks.

The research discussed in the paper has identified the range of heavy metals found in the sediments of Deception Bay and determined their enrichment as well as source identification.

Moreton Bay is a shallow, subtropical bay in Southeast Queensland, Australia (27°15'S, 153°15'E), includes an extensive marine park and is home to a number of endangered animal species, such as dugong (*Dugong dugon*). Deception Bay (27°8'S, 153°6'E) is the northernmost embayment within Moreton Bay and the two waterway outfalls into Deception Bay are the Caboolture River and Pumicestone Passage. These waterways flow through urban, industrial and rural areas in the Caboolture region, which is a regional centre approximately 45 km north of Brisbane City. The region has witnessed exponential population growth (Figure 2) since the latter stages of the twentieth century. Consequent with this population increase, there has been significant expansion of housing and local industries. One of the impacts of this urban development has been an increase in sediment loadings through the Caboolture River into Deception Bay (Dennison and Abal, 1999). This is compounded by the fact that there is little mixing in Deception Bay (McEwan et al., 1998). This lack of mixing indicates potential for significant heavy metal enrichment of sediments in Deception Bay.

Sampling sites in Deception Bay were selected in order to achieve a systematic coverage of the study area, keeping within the limitations of the area (such as water depth and local weather). These sites are shown in Figure 3. In addition to the sites, a background sample was taken from the upper reaches of the Caboolture River at 27°6'30"S, 152°50'58"E, which correlates with the rural area of Rocksberg.

Samples from Deception Bay were taken using a Van Veem 7.5kg sample dredge that was lowered over the side of a boat. The samples were then pulled up from the bottom and dumped into a clean plastic container and scooped into a clean and labelled plastic sample bag whilst sediments samples taken from upstream sites were collected using a plastic scoop and storing in labelled plastic bags according to currently accepted international standards (Watts and Halliwell, 1996; Zhang, 2006). The samples were placed on ice, frozen for further analysis and freeze dried using a Vertis 5L freeze dryer before being screened for particles less than 2mm and crushed to <100 µm using a swing mill. The freeze dried sample was analysed by X-ray Fluorescence (XRF) using a XPECTRO XEPOS instrument to analyse 4g of loose sediment under experimental conditions outlined in

Table 1. The samples were then analysed for the elements, Al, Si, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Ga, Pb, As, Cd, Sb, Te, Ce, Hg, U and Th.

Quality control was performed in accordance with NATA (National Association of Testing Authorities) guidelines for method validation (NATA, 2012) and measurement uncertainty (NATA, 2009) by analysing certified reference material AC-E, which has a composition of 14.75% Al_2O_3; 70.61% SiO_2; 2.54% Fe_2O_3 and 0.06% MnO_2. Recoveries were 100.9% for Al, 100.2% for Si, 93.1% for Mn and 98.2% for Fe. The reference material was provided by Ametek (Berwyn, USA) with the instrument and analysed as a QC sample. The standard deviation for the reference material after five analyses was determined to be 0.05 for Al, 0.09 for Si, 0.0003 for Mn and 0.006 for Fe.

Data analysis used a number of single and multiple element indices to determine heavy metal pollution, including the use of enrichment factors and geoaccumulation indices, along with multi-element indices such as the Nemerow pollution index and modified degree of contamination index.

Enrichment factors (Qingjie et al., 2008) (E.F; Equation 1) were determined for all elements normalised against aluminium concentration, with enrichment factors greater than one being considered anthropogenic and requiring further investigation.

$$EF = \frac{\left(\frac{C_x}{C_{ref}}\right)_{Sample}}{\left(\frac{C_x}{C_{ref}}\right)_{Background}} \tag{1}$$

Modified degree of contamination (mC_d; Equation 2 and Equation 3) factors adapted from (Hakanson, 1980) method were determined for the suite of elements tested and compared against the sediment classifications given in Table 2.

$$mC_d = \frac{\sum_{i=1}^{n} Cf^i}{n} \tag{2}$$

Where:

$$Cf = \frac{C_{sample}}{C_{background}} \tag{3}$$

The Nemerow pollution index (Guang et al., 2010; Qingjie et al., 2008) (PI; Equation 4) was used to determine if sampling sites were polluted by comparing with the criteria given in

Table 3.

$$PI = \sqrt{\frac{\left(\overline{Cf}\right)^2 + (Cf_{max})^2}{2}} \tag{4}$$

Cluster analysis was performed on the data to identify links between elements and sampling sites using SPSS 19 software. Hierarchical cluster analysis was performed using both, cases and variables to develop groups. Dendrograms were plotted with linkages between groups using squared Euclidean distance.

PROMETHEE is a non-parametric data analysis method which uses multiple criteria in order to rank results in order from highest to lowest (or lowest to highest) using a range of variables or criteria (Herngren et al., 2006). GAIA is a visual representation of the PROMETHEE analysis, similar to a PCA plot with a decision axis (labelled as Pi) which can be used to indicate which variables which are most preferred for making a decision (Khalil et al., 2004).

PROMETHEE and GAIA analysis of the contaminant metals of interest (Cr, V, Co, Ni, Cu, Zn, As, Pb and Th) was performed using Decision Lab software (Inc, 1999). The criteria for the PROMETHEE analysis were; a v-shaped preference function with the maximum concentration of each contaminant metal used as a threshold and a complete ranking was determined. GAIA was used for the display of the PROMETHEE analysis results in a PCA biplot.

The concentrations of the major sediment elements (Al and Si) as well as the clay elements (Mn and Fe) are given in Table 4 and the concentrations of the other trace metals investigated are given in Table 5. In general, the concentrations of the heavy metals varied from site to site, although there is evidence of enrichment for most elements at sites which had a lower sand content, drawing a link between terrestrial sediment and heavy metals. When compared against the Australian Interim Sediment Quality Guidelines (SQGs) (Simpson et al., 2005), the concentration of Zn at site R2DB1 exceeds the high sediment quality threshold, whilst Cr is above the low SQG at all sites, including the background Caboolture River site, Ni exceeds the low SQG threshold at the Caboolture River Background site and sampling sites R2DB1, R2DB2, R2DB7, R2DB8, R2DB10, R2DB12 and R2DB13; while no other element for which a guideline exists has exceeded the low threshold. This indicates that further study of the bioavailability of Cr, Ni and Zn is required.

Samples taken from the background sampling site, as well as a site at the Northern mouth of Moreton Bay (site BJ) (27°S 4.132'S; 153° 12.325'E) were also analysed for elemental composition and the Si/Al ratio was determined to obtain the background Si/Al ratios (Figure4). These sites showed that the ratio of Si/Al at the background site was 4.2:1, whilst the sandy site (site BJ) had a Si/Al ratio of 220:1. Sampling sites DB3, DB4, DB5, DB6, DB9 and DB11 all showed elevated Si/Al ratios of over 10:1. This is indicative of sand intrusion into the sediment and cluster analysis allowed linkages to be drawn between sand intrusion and heavy metal contamination. Site DB11 shows an elevated Si/Al ratio of 10.4:1, which suggests that there is little deposition of terrestrial sediment, whilst sites DB3, DB4, DB5, DB6 and DB9 show intrusion of sand from Pumicestone Passage (sites DB3, DB4 and DB5) and mineral sands from outside of Moreton Bay (DB6 and DB9), as evidenced by the increased Si/Al ratios and enrichment of Th.

Sampling sites which had direct terrestrial input, such as DB1, DB2, DB7 and DB12 showed Si/Al ratios less than 5. This demonstrates that there are significant sedimentary inputs into Deception Bay from terrestrial sources such as the Caboolture River, and sedimentary transportations around the northern side of the Redcliffe peninsular (sites DB13, DB8, DB10). This suggests that the sediments are transported southwards from the Caboolture River and into Greater Moreton Bay due to currents pushing the sediment around the northern side of the Redcliffe Peninsular.

Considering the size of the sampling area, the enrichment factors (EFs) for Deception Bay were determined in order to build a broad overview of the extent of contamination of the area by the various heavy metals. Heavy metals determined to have an anthropogenic source included: Cr (EF 3.7); Zn (EF 2.7); As (EF 2.3); Pb (EF 13) and Th (EF 3.7), along with Mn (EF 1.0), Fe (EF 1.2), Ni (EF 1.1) and Ga (EF 1.1). The other elements (Co, Cu, Ag, Cd, V, Sb, and Hg) were shown not to have been enriched by anthropogenic activity as they had enrichment factors less than one.

The enrichment factors as a function of sampling sites for the five elements with the heaviest enrichment (Figure 5) shows that the magnitude of the enriched sediments in Deception Bay is generally low (less than 2), with the exceptions of Pb across all sites and the Bongaree Jetty site, which showed significant enrichment of Pb and Cr. The most likely explanation for the high enrichment factors for the Bongaree Jetty site is that the sample was sand and deficient in Al (Si/Al of 220:1) compared to the other sites, which contained a large portion of mud (between 2.6 - 35:1 Si/Al). This deficiency in Al resulted in inflated enrichment factors for the Bongaree Jetty site compared to the terrestrial background sampling sites due to the enrichment factors being normalised against aluminium.

Enrichment factors are limited as they are a single element index and they ignore the impact that multiple contaminant elements can have on sediment health. The Hakanson modified contamination index can overcome this limitation (Hakanson, 1980). Figure 6 shows that in general, contamination of Deception Bay across the suite of heavy metals is low according to Hakanson's sediment qualification guidelines (Table 2), as all of the sites have an index of less than 4.

Sites DB7, DB10 and DB12 had indices greater than 2, which is indicative of a moderate degree of pollution at these sites. The rest of the sites indicated a low level of contamination for heavy metals. The increased heavy metals contamination at sites DB7, DB10, DB12 and DB13 are indicative of sediment flows in Deception Bay.

The Nemerow pollution indices indicate that Deception Bay is seriously polluted at a number of sites, with the vast majority of the sites having a pollution index greater than 3 (Figure 7). This suggests heavy contamination by one or more elements at most of the sites, with the exceptions of the Bongaree Jetty sites, along with sites DB3 and DB11. Sites DB5, DB6 and DB9 show only moderate pollution.

A summary table (Table 6) of the pollution indices used for the sediment analysis of Deception Bay shows a number of salient features. In particular, it shows the artificially inflated enrichment factors for the Bongaree Jetty site caused by depleted aluminium concentrations in the sediment. More importantly, the Nemerow pollution indices clearly indicate that most of the sites (with the exceptions of the Bongaree Jetty site and sites DB3 and DB11) have been polluted to some extent, with sites DB1, DB2, DB7, DB8, DB10, DB12 and DB 13 being the most highly polluted.

The major source of that contamination, when compared against the enrichment factors is Zn for site DB1 and Pb for the other sites. However, it must also be recognised that there is significant enrichment of As, Cr and Th at many of the sites.

The heavy pollution of Deception Bay by Pb, coupled with the population increase in the Caboolture area demonstrates a linkage between population growth and contamination, with the most likely source of Pb being leaded fuels used in vehicles up to 2001. Contamination of site DB1 by Zn can be linked to the presence of two boat building yards in the vicinity of an anchorage in the Caboolture river estuary.

The enrichment of Th is most likely due to inflows of mineral sands into the northern half of Deception Bay from sand travelling up the coast due to current flows. As and Cr are also of concern, with the distribution of As suggesting that there is a plume travelling from the area around site DB2 towards the middle of Deception Bay, whilst Cr appears to be flowing from Pumicestone Passage (Site DB5) south towards the Redcliffe Peninsular and sites DB9 and DB10. The contamination of As may be related to an industrial source, whilst Cr is most likely due to the presence of the Bribie Island Marina at Pumicestone passage and some artificial enrichment due to depleted Al in the sediments at those sites.

The cluster analysis of the data suggests that there are several distinct groups of elements and sites, which allows for the tentative assignment of source. The dendrogram of sampling sites (Figure 8) shows that there are 2 distinct groups. The first group of sites consists of sampling sites DB3, DB4, DB5, DB6, DB9, DB11 and Bongaree Jetty. These are all sampling sites that have relatively high Si/Al ratios (figure 4), which correlates to sites containing more sand than sediment. The second group of sites DB2, DB7, DB8, DB10, DB12 and DB13 are linked to relatively lower Si/Al ratios, which is consistent with sediment input at these sites, as shown by Figure 4. The Site DB1 is by itself, which suggests that this site is unique. Examination of the data for site DB1 shows that there is significant enrichment of Zn (Table 6) which allows tentative linkagess to the element groupings in Figure 9. The cluster analysis also suggests that the background site at Caboolture River is significantly different from the sediment samples in Deception Bay.

The cluster analysis identified four clusters of elements of interest (Figure 9), with clusters of Si and Cr; Pb and Th; Al, Cu, V and Ni; Mn and As. Zn once again appears by itself, which suggests that it is unique and allows a tentative assignment to site DB1 and the shipbuilding yards and anchorage at the mouth of the Caboolture River.

The grouping of V and Ni is indicative of the combustion of crude oils (Lewan, 1984; Lewan and Maynard, 1982) and this suggests that the grouping of Al, Cu, V and Ni is linked to shipping in Moreton Bay and the Port of Brisbane. The grouping of Mn and As is most likely due to co-precipitation of the two elements in the environment, caused by manganese hydroxides and oxides in clay minerals acting as nucleation sites for adsorption of As (Takamatsu et al., 1985). The grouping of Si and Cr is linked to sand and the link between Th and Pb is linked to radioactive decay of mineral sands (Arogunjo et al., 2009) entering Deception Bay from the north.

The PROMETHEE analysis (Figure 10) identifies the least contaminated sites as DB5, DB4, DB6, Bongaree Jetty DB3, DB11 and DB9, which are the group of sites identified as being mostly sandy in the cluster analysis. The two most highly contaminated sites are identified as being DB8 and DB12, which are clustered together in the CA as well. However, these were less contaminated (according to the Nemerow pollution index) than site DB1, which is the fourth most contaminated site according to the PROMETHEE analysis.

The GAIA biplot (Figure 11) identifies a major group of sites (DB3, DB4, DB5, DB6, DB9, DB11 and BJ) which correlate to the sandy sites in the cluster analysis and the PROMETHEE analysis. The decision axis (Pi) points towards these sites, confirming that these sites are the least polluted. The second group of sites identified in the cluster analysis (DB 8, DB10 and DB12) are also grouped together in the GAIA biplot, which is indicative of similarity between these sampling sites too. DB7 and DB13 are grouped together, which is consistent with the grouping of DB7, DB13 and DB2 in the cluster analysis. However, the GAIA biplot shows that there are differences between DB2 and sites DB7 and DB13, which warrants further investigation. The background Caboolture site and site DB1 are independent of the other sites.

The groupings of elements show some differences to the cluster analysis. In particular, Cu is separated in the GAIA biplot (Figure 11) from the rest of the elements in the same cluster (Ni, V, Co).

This study into heavy metals distribution and enrichment in Deception Bay has established that the sediments are contaminated by a number of heavy metals, including As, Pb, Th, Cr and Zn with the enrichment factors indicating that the major contaminant is Pb. There is also strong evidence that some sites are contaminated with Zn and As.

The modified contamination indices show that the sediments are moderately polluted although the Nemerow pollution indices indicate very clearly that most of the sites in Deception bay have been seriously contaminated by one or more elements, with Pb being the most prominent, although As and Zn are also candidates.

The cluster analysis shows that the pollution of sediments in Deception Bay can be linked to shipping (V, Ni and Cu, which precipitated with Al) and sand (Cr and Si). In addition, there is evidence that sediment type, such as sand content (from Si/Al ratios), which has implications for pollutants of interest according to sediment type. Arsenic contamination is linked to manganese-rich sediments (such as clays), whilst contamination of site DB1 by high concentrations of Zn can be linked to boat building and anchorages at the mouth of the Caboolture river. The PROMETHEE and GAIA analysis clearly identifies that the sandy sites are the least contaminated, while DB2 and DB8 are the most contaminated with heavy metals. The GAIA biplot identifies the Caboolture background site and site DB1 as being independent of the others while elements such as Pb, Th and As are clustered together (as shown in the cluster analysis) and the elements Ni, V and Co are clustered together, which correlates to the cluster analysis. The results have implications for pollution in complex marine environments, especially where there is significant influx of sand and sediment into an estuarine environment.

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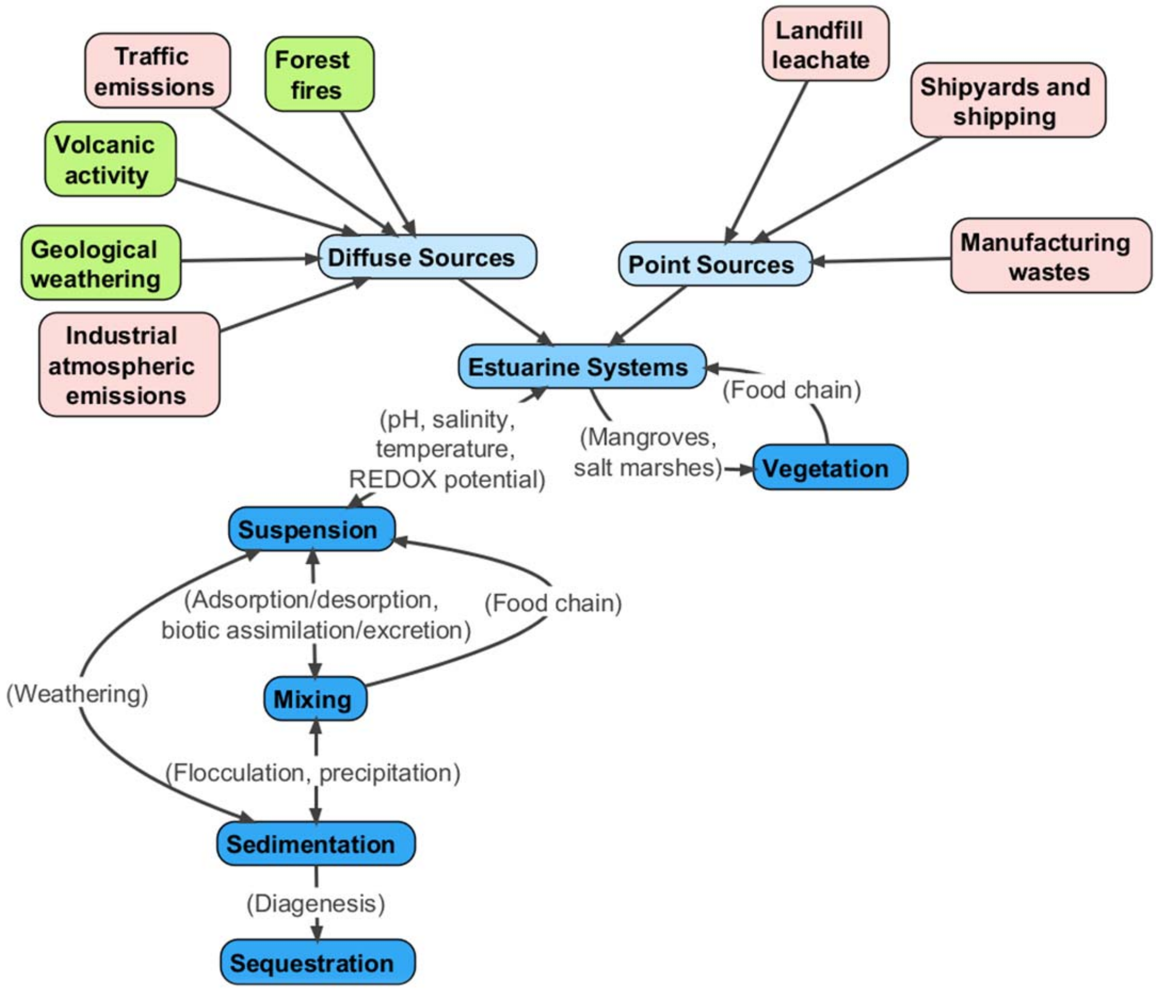

Figure 1: Fates of heavy metals in estuarine environments

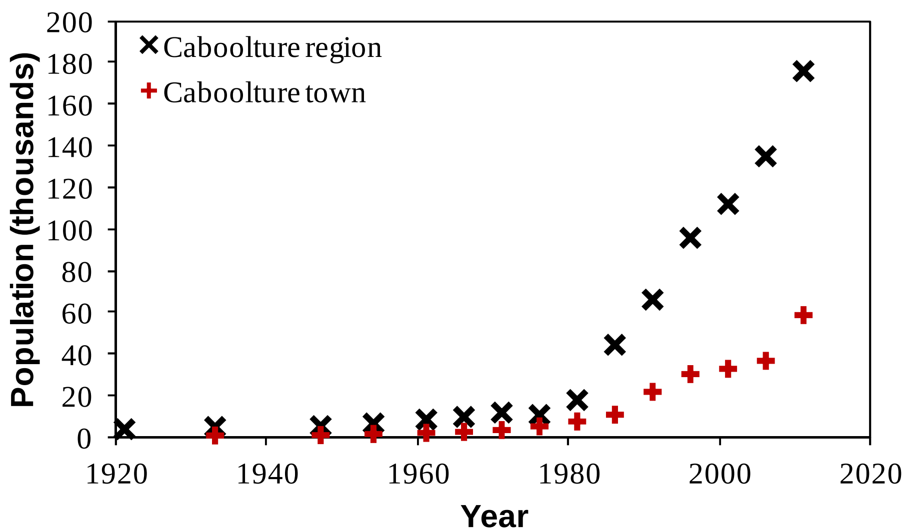

Figure 2: Population of Caboolture and surrounding area since 1921

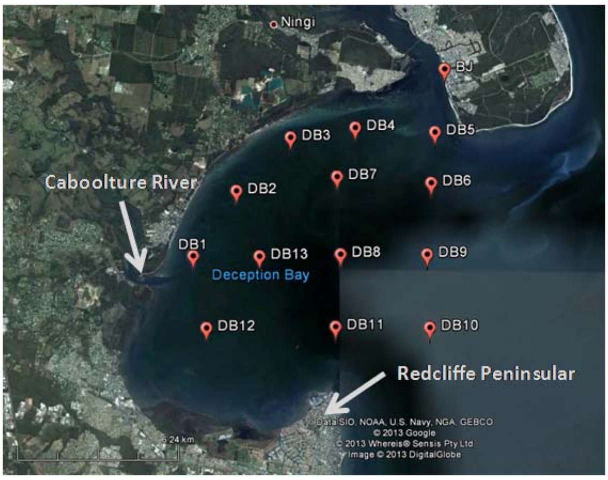

Figure 3: Sampling locations in Deception Bay

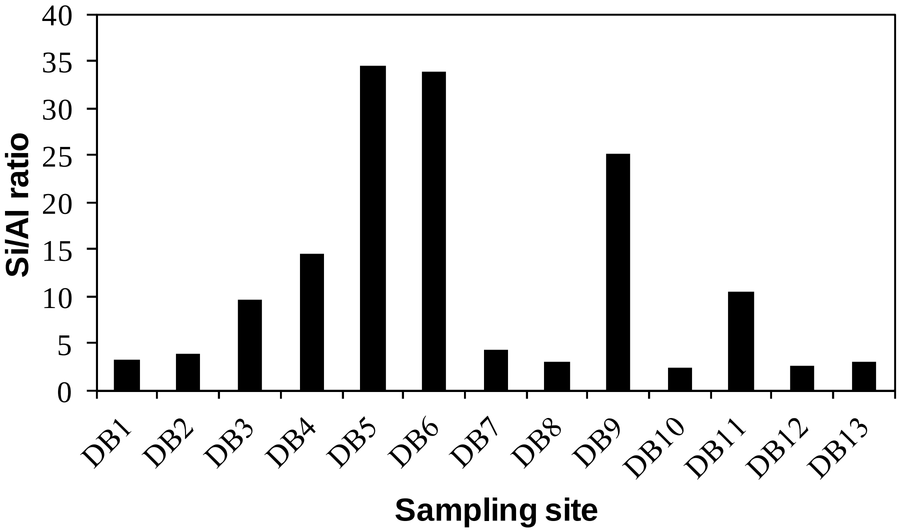

Figure4: Si/Al ratio by sampling site (site BJ excluded from this figure due to scale)

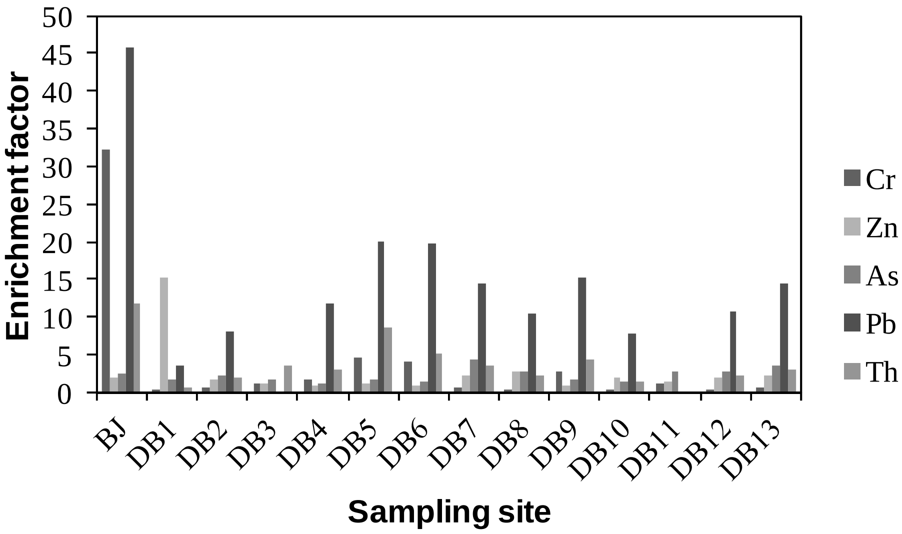

Figure 5: Enrichment Factor by sampling site

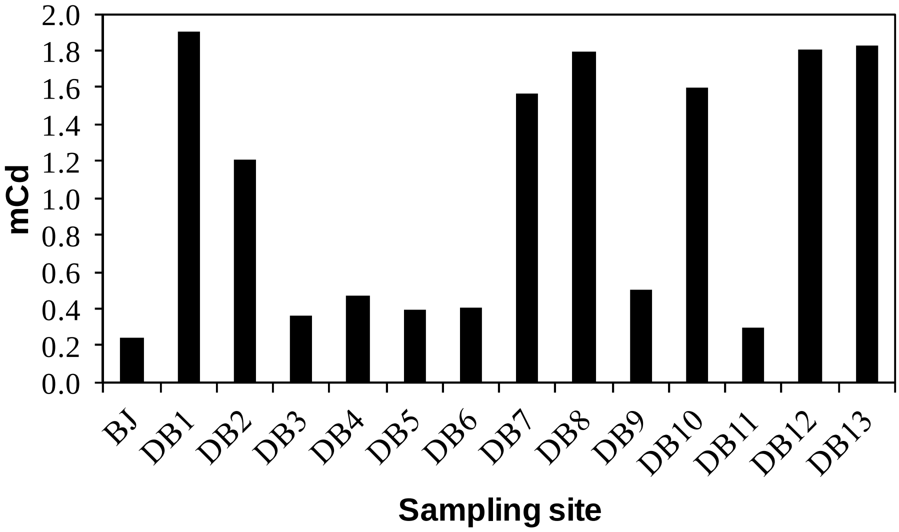

Figure 6: Modified contamination indices for sampling sites

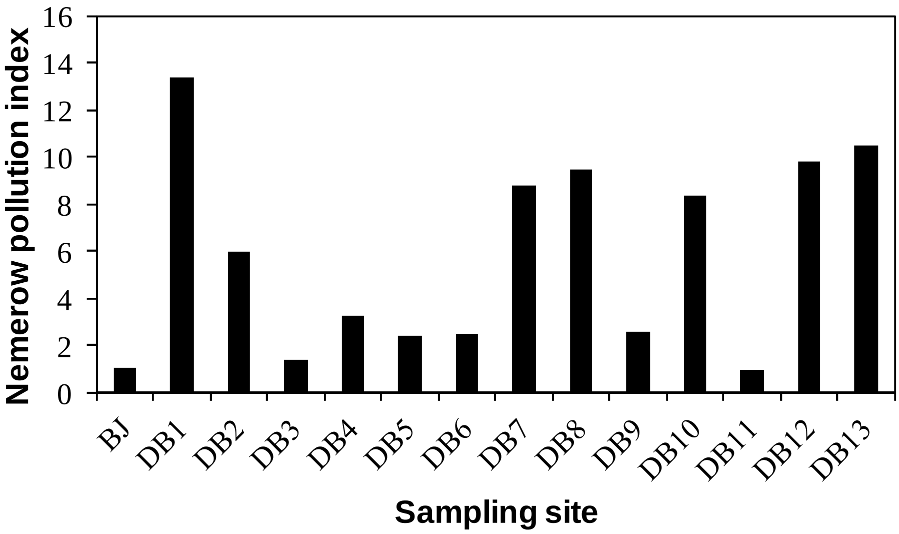

Figure 7: Nemerow Pollution indices by sampling site

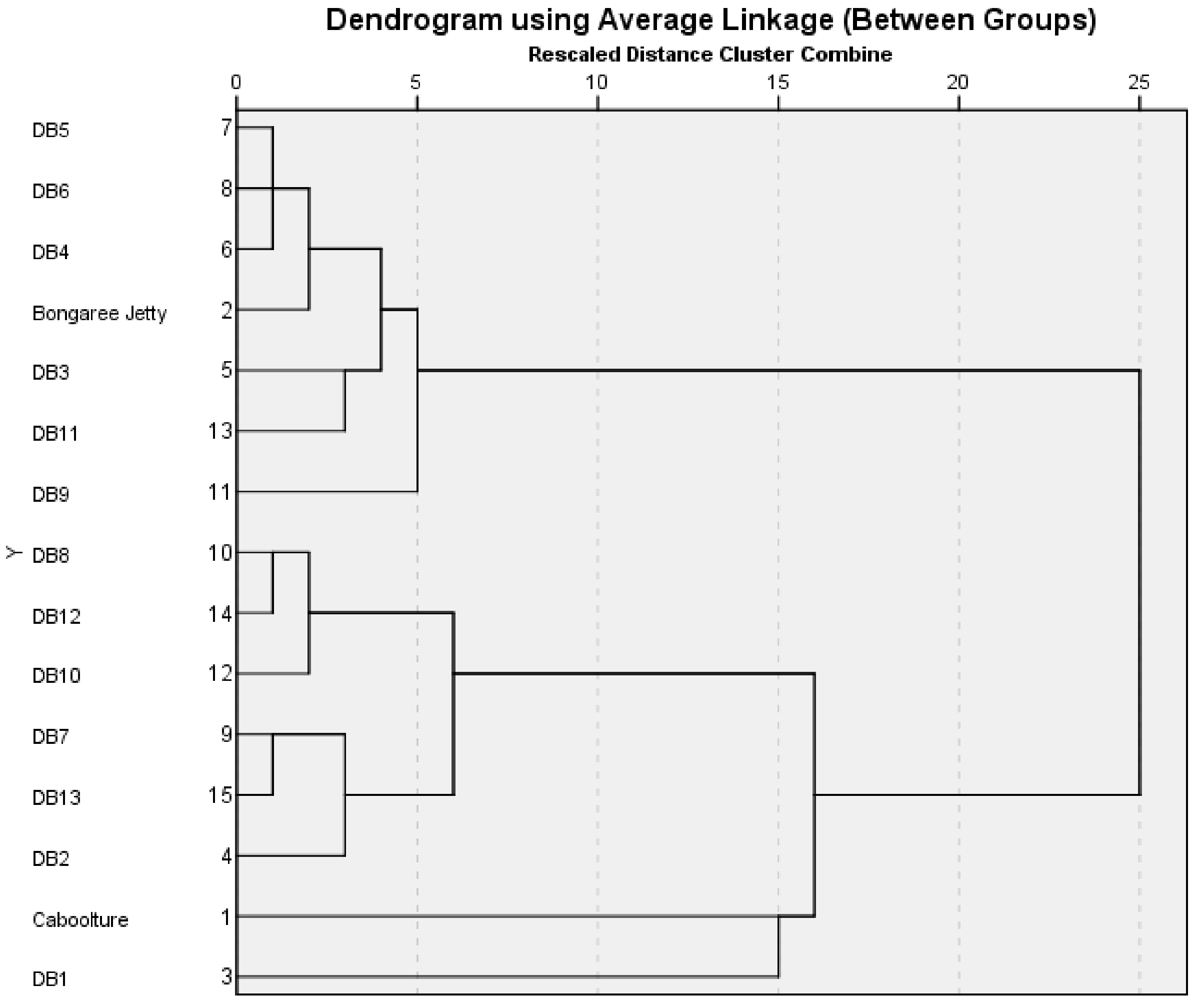

Figure 8: Dendrogram of sampling sites

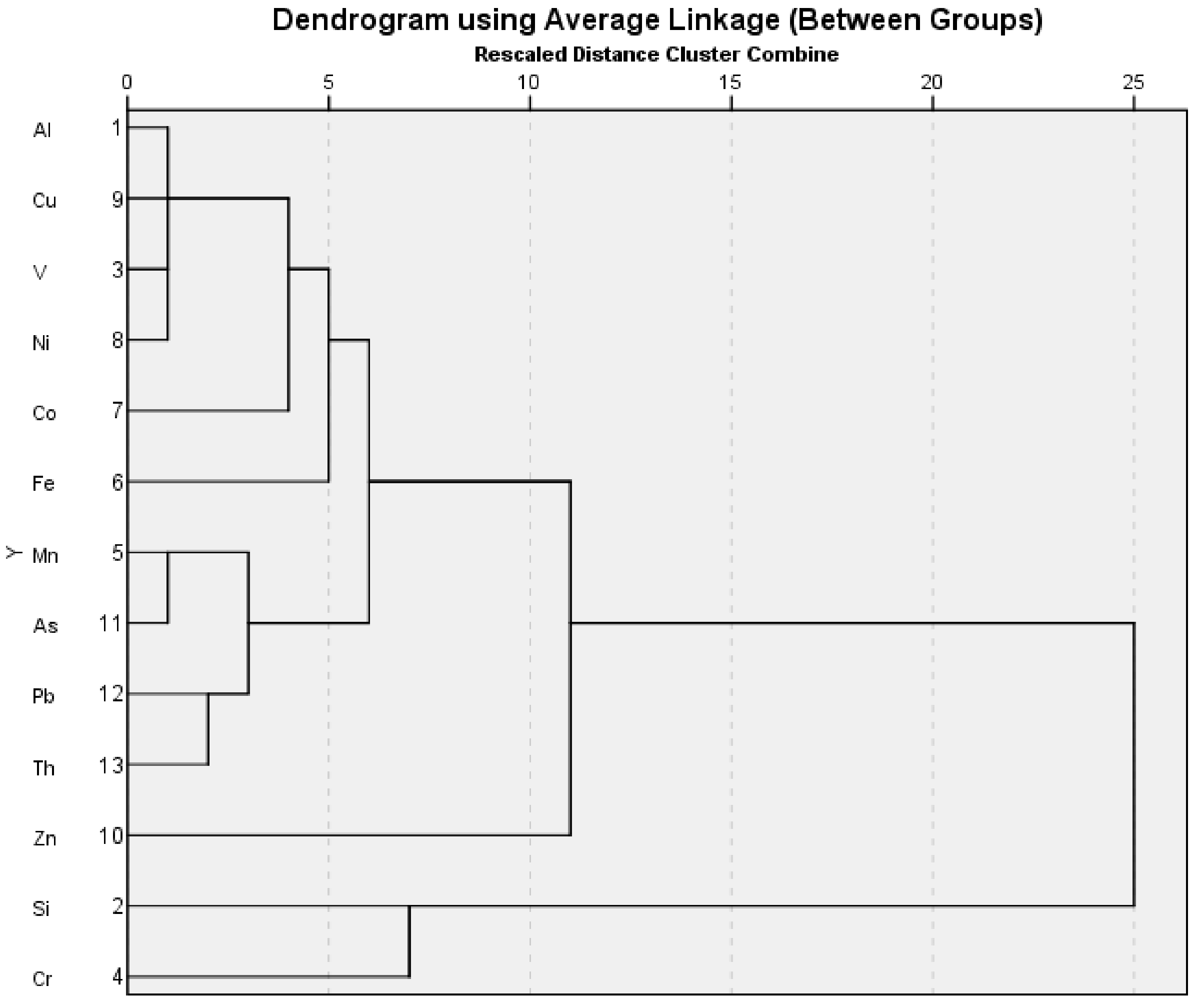

Figure 9: Dendorgram of elements

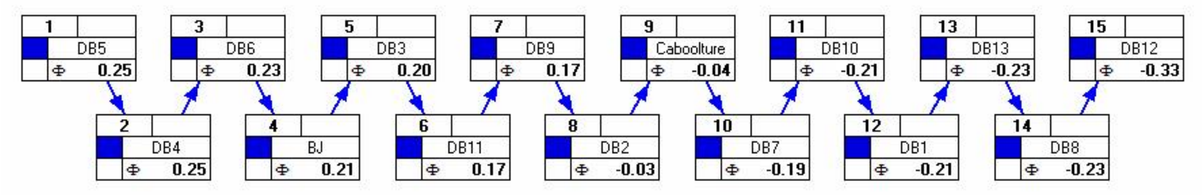

Figure 10: Promethee rankings of Deception Bay sampling sites

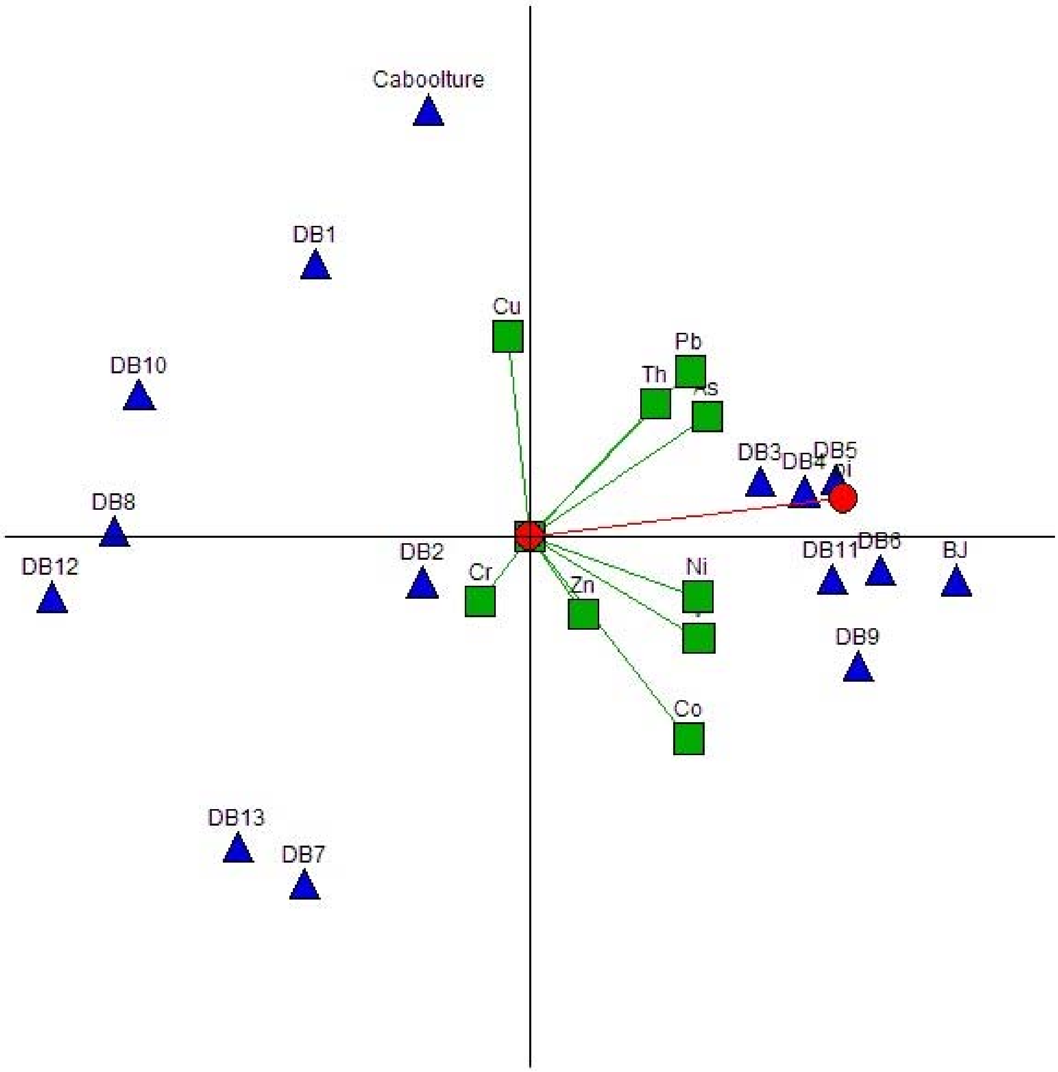

Figure 11: GAIA biplot of Deception Bay sampling sites

Table 1: XRF analysis conditions

Target	Molybdenum	Aluminium oxide	Cobalt	Bragg/HOPG
Flush gas	He	He	He	He
Energy (keV)	40	49.5	35	17.5
Current (mA)	0.88	0.70	1.00	2.00

Table 2: modified contamination index sediment quality indicators

mC_d Value	Qualification of Sediment
$mC_d < 1.5$	Nil to very low degree of contamination
$1.5 < mC_d < 2$	Low degree of contamination
$2 < mC_d < 4$	Moderate degree of contamination
$4 < mC_d < 8$	High degree of contamination
$8 < mC_d < 16$	Very high degree of contamination
$16 < mC_d < 32$	Extremely high degree of contamination
$mC_d > 32$	Ultra high degree of contamination

Table 3: Nemerow pollution index sediment quality indicators

PI Value	Qualification of Sediment
PI < 0.7	Non-polluted sediment
0.7 < PI < 1	Nearly polluted sediment
1 < PI < 2	Lightly polluted sediment
2<PI < 3	Moderately polluted sediment
3<PI	Seriously Polluted sediment

Table 4: Major element concentrations in the sediments of Deception Bay (mg/kg)

	Al	Si	Mn	Fe
MDL (mg/kg)	**20**	**5**	**1**	**1**
Caboolture	73720±90	311500±200	472±1	40090±30
R2DB1	2100±10	309500±300	299±1	37140±30
R2DB2	91200±100	295100±200	548±2	36170±30
R2DB3	76110±80	388800±200	188±1	16770±20
R2DB4	39830±70	419900±300	73.3±0.5	8129±9
R2DB5	29030±60	434600±300	54.5±0.5	4017±6
R2DB6	12570±30	442800±300	59.8±0.5	3829±6
R2DB7	13090±90	273700±200	685±2	44070±40
R2DB8	62300±100	284000±200	593±2	44730±30
R2DB9	92870±60	435500±300	148.2±0.7	52533±7
R2DB10	17300±100	277100±200	522±2	45930±30
R2DB11	110700±80	384100±200	307±1	17080±20
R2DB12	36800±100	251500±200	773±2	46160±40
R2DB13	94500±100	232200±200	785±3	41230±30

Table 5: Trace metal concentrations in the sediments of Deception Bay (mg/kg)

	Cr	V	Co	Ni	Cu	Zn	As	Pb	Th
MDL (mg/kg)	**1**	**1**	**3**	**1**	**0.5**	**0.5**	**0.5**	**1**	**1**
Australian SQG* Low (mg/kg)	**80**	**N/A**	**N/A**	**21**	**65**	**200**	**20**	**50**	**N/A**
Australian SQG High (mg/kg)	**370**	**N/A**	**N/A**	**52**	**270**	**410**	**70**	**220**	**N/A**
Caboolture	233±1	146±3	9±2	36.7±0.5	16.6±0.4	29.1±0.3	2.7±0.1	ND	2.1±0.3
R2DB1	153±1	118±4	11±2	29±0.5	20.2±0.5	548±0.5	6.1±0.2	4.4±0.1	1.5±0.1
R2DB2	138±1	106±5	ND	25.7±0.6	12.5±0.6	51.7±0.5	6.4±0.2	8.4±0.3	4.2±0.2
R2DB3	163±1	34±2	ND	12.3±0.3	6.3±0.3	19.4±0.3	2.5±0.1	ND	4±0.2
R2DB4	158±1	12±1	ND	8.3±0.3	4.5±0.3	11±0.2	1.3±0.1	4.6±0.3	2.5±0.2
R2DB5	186±1	8±1	ND	6.5±0.2	2.2±0.3	5.5±0.1	0.8±0.1	3.4±0.2	3.1±0.2
R2DB6	175±1	ND	ND	6.6±0.2	1.9±0.3	4.9±0.1	0.7±0.1	3.5±0.2	1.9±0.2
R2DB7	122±1	78±4	ND	26.9±07	12.3±0.7	58.1±0.6	10±0.3	12.3±0.5	6.3±0.3
R2DB8	130±1	108±5	8±1	34.2±0.7	19.9±0.6	99.8±0.7	9.1±0.3	13.3±0.4	6.1±0.2
R2DB9	156±1	9±1	ND	7.1±0.2	3.4±0.3	7.2±0.2	1.1±0.1	3.6±0.2	2.1±0.2
R2DB10	107±1	117±4	13±2	35.3±0.6	20.8±0.6	87.3±0.6	6.4±0.2	11.7±0.3	4.4±0.1
R2DB11	145±1	32±2	ND	12.5±0.4	6.7±0.4	21.4±0.3	3.8±0.1	ND	ND
R2DB12	110±1	107±5	13±2	33.8±0.7	20.1±0.7	79.2±0.7	9.8±0.3	13.8±0.4	5.8±0.2
R2DB13	139±2	97±6	ND	29.9±0.8	15.9±0.8	68.7±0.7	9.6±0.3	14.7±0.6	6.6±0.3

*Australian Interim Sediment Quality Guidelines (SQG) (Simpson et al., 2005)

Table 6: Summary of pollution indices for Deception Bay sediments

Site	Enrichment Factors					mCd	PI
	As	Cr	Pb	Th	Zn		
BJ	2.6	32.3	45.7	11.7	1.9	0.2	1.0
DB1	1.8	0.5	3.6	0.6	15.2	1.9	13.4
DB2	2.3	0.6	8.1	1.9	1.7	1.2	6.0
DB3	1.7	1.3	0.0	3.5	1.2	0.4	1.4
DB4	1.2	1.7	11.7	3.0	1.0	0.5	3.3
DB5	1.7	4.7	19.9	8.7	1.1	0.4	2.4
DB6	1.5	4.2	19.7	5.1	0.9	0.4	2.5
DB7	4.4	0.6	14.6	3.6	2.4	1.6	8.8
DB8	2.7	0.4	10.6	2.3	2.7	1.8	9.5
DB9	1.7	2.8	15.3	4.3	1.1	0.5	2.6
DB10	1.6	0.3	7.8	1.4	2.0	1.6	8.4
DB11	2.8	1.2	0.0	0.0	1.5	0.3	1.0
DB12	2.8	0.4	10.8	2.2	2.1	1.8	9.8
DB13	3.5	0.6	14.5	3.1	2.3	1.8	10.5