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Enrichment, distribution and sources of heavy metals in the sediments of Deception Bay, Queensland, Australia

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ABSTRACT

Sediment samples from 13 sampling sites in Deception Bay, 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 (EF) 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. By contrast, the Nemerow pollution index (average 5.8) suggests that Deception Bay is heavily contaminated. Cluster analysis was undertaken to identify groups of elements. Strong correlation between some elements and two distinct clusters of sampling sites based on sediment type was evident. These results have implications for pollution in complex marine environments where there is significant influx of sand and sediment into an estuarine environment.

Increasing concern about the release of heavy metals and their effects on human and ecosystem health (Mitra et al., 2012; 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 biogeochemical recycling processes, 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, 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 potential for adverse environmental impact, the Queensland Government set up the Healthy Waterways program (DERM), which is charged with assessing and reporting the ecosystem health of major waterways, via its annual report cards by using 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 results from a number of previous studies (Abal et al., 2001; Dennison and Abal, 1999; McEwan, 1998). A major limitation in those studies is 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, and their 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

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et al., 2005, 2006). Similarly, estuarine environments are complex (Liu et al., 2003) because they receive contamination from a range of diverse sources (Blasco et al., 1999; Choi et al., 2011). Intense sedimentation within estuarine and marine environments traps heavy metals within fine grained particles which then precipitate and filter 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 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). Fig. 1 is a simplified schematic of the fate of heavy metals in the marine environment and illustrates some of the complex interactions which can occur between sources and sinks.

The research presented in the paper identified the range of heavy metals found in the sediments of Deception Bay, determined their enrichment and undertook their source identification.

Moreton Bay, 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, which 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 approximately 45 km north of Brisbane City. The region has witnessed exponential population growth (Fig. 2) since the latter stages of the twentieth century. As a result of 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 increases the potential for significant heavy metal enrichment of sediments in Deception Bay.

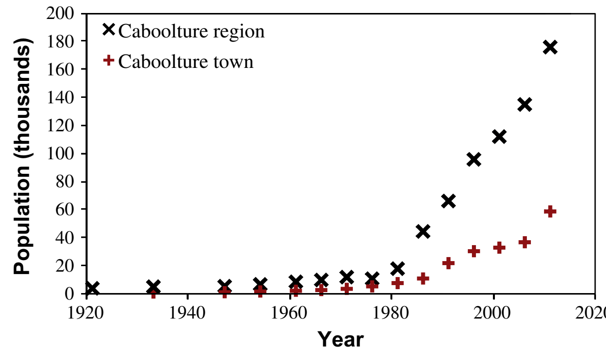

Fig. 2. Population of Caboolture and surrounding area since 1921.

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 Fig. 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 7.5 kg 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 2 mm 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 the experimental conditions outlined in Table 1. The samples were

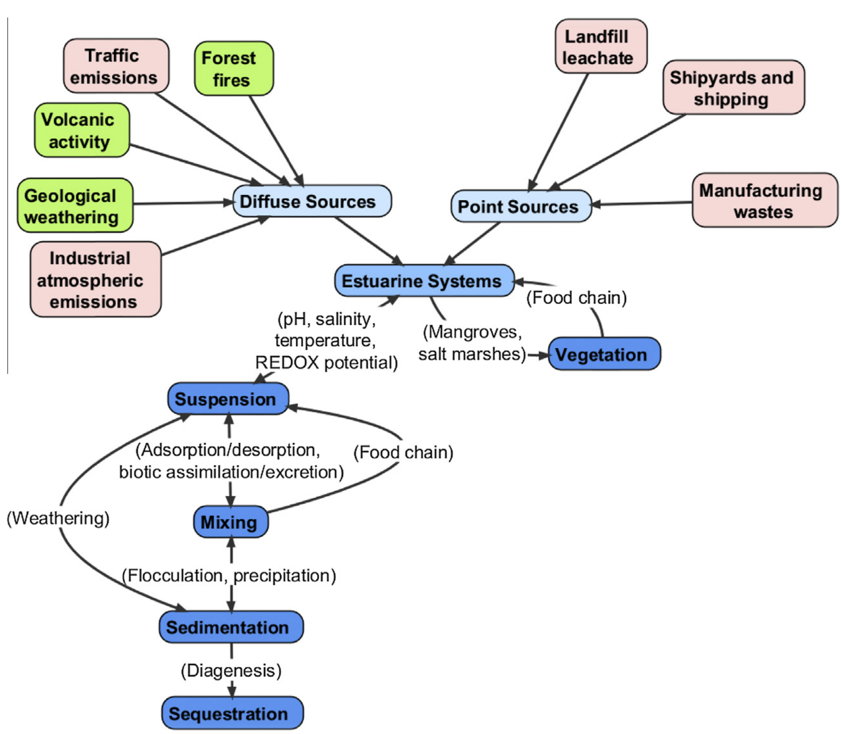

Fig. 1. Fates of heavy metals in estuarine environments.