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The impact of a high magnitude flood on metal pollution in a shallow subtropical estuarine embayment

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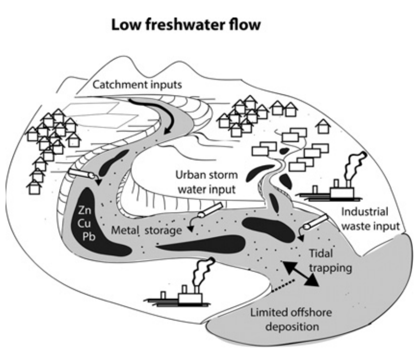
HIGHLIGHTS

- Zn, Cu, and Pb increase in concentration in subtidal sediments of a shallow bay following an extreme flood event
- The importance of intermittent flooding on pollutant transport to coastal waters in subtropical climate regions is demonstrated

GRAPHICAL ABSTRACT



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ABSTRACT

Drought-breaking floods pose a risk to coastal water quality as sediments, nutrients, and pollutants stored within catchments during periods of low flow are mobilized and delivered to coastal waters within a short period of time. Here we use subtidal surface sediment surveys and sediment cores to explore the effects of the 2011 Brisbane River flood on trace metals zinc (Zn), lead (Pb), copper (Cu), nickel (Ni), chromium (Cr), manganese (Mn), and phosphorus (P) deposition in Moreton Bay, a shallow subtropical bay in eastern Australia. Concentrations of Zn, Cu, and Pb in sediments in central Moreton Bay derived from the 2011 flood were the highest yet observed in the Bay. We suggest flushing of metal rich sediments which had accumulated on the Brisbane River floodplain and in its estuary during the preceding 10 to 40 years of low flows to be the primary source of this increase. This highlights the importance of intermittent high magnitude floods in tidally influenced rivers in controlling metal transport to coastal waters in subtropical regions.

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1. Introduction

Estuarine embayments are among the most sensitive marine environments to human induced disturbances in coastal catchments.

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These embayments act as sinks for sediments and contaminants, including trace metals, organic compounds, and pathogens transported from adjacent land surfaces by runoff (Kennish, 2002). Trace metals are used in many different industrial practices and inputs to coastal environments have increased as a result of the ongoing expansion of industry and urbanized centres. The inherent biological toxicity of some metals (i.e. Pb, Hg, Cd, Ni, Zn, Cu, Cr), and their non-degradable nature, is a major threat to the ecological health of many coastal areas (Bryan and Langston, 1992; Matthiessen et al., 1998). These pollutants also contaminate seafood consumed by humans, including shellfish and fish (Wren et al., 1995; Lewtas et al., 2014).

Metals have a high affinity for fine grained organic and mineral sediments due to the large surface area and reactivity of these particles (Forstner, 1977; Dong et al., 1984; Foster and Charlesworth, 1996). Fe and Mn hydroxides also strongly sorb metals and are typically associated with fine clays (Arakel and Hongjun, 1992). Fine grained sediments are easily transported in suspended loads of rivers and thus provide an efficient pathway for the transport of metals from catchments downstream to coasts (Coynel et al., 2007; Martínez-Santos et al., 2015; Roussiez et al., 2013). Large floods within estuarine settings provide an instance when fine sediments and associated metals can be transported seaward, beyond regions initially affected by contamination. The deposition of fine sediments and associated trace metals in low energy environments such as enclosed embayments may lead to such environments being significant reservoirs for these contaminants (Ridgeway and Shimmield, 2002; Liu et al., 2003). Metals in these environments can then be released into the water column through physical, biological, and chemical processes that rework the sediments (Peterson et al., 1998; Swales et al., 2002; de Souza Machado et al., 2016). Accordingly, not only do discrete flood events within urbanized catchments pose an immediate risk to the ecological health of adjacent estuaries and bays, but the persistence of metals in these reservoirs may represent an enduring source of contamination.

Sources of anthropogenic metals commonly found in aquatic environments can be grouped into the two principle categories: 1) point and 2) diffuse sources. Typical point sources include industrial and municipal effluent, and landfill leachate. In the marine environment this can also include shipping anchorages and yards that use antifouling paints. Diffuse sources include agricultural and urban storm water run-off with contamination arising from the use of a range of materials such as road tyres, grease and oils, roofing, asphalt, pesticides and fungicides, among others (Gobel et al., 2007; Davis et al., 2001; San-Miguel et al., 2002; Zhang and Shan, 2008; Tang et al., 2010). Diffuse sources transported via run-off can represent a significant contributing source of metal pollution in urbanized rivers and estuaries (Birch and Taylor, 1999). Characterizing the contributions of metals from different sources is an important objective in efforts aimed at reducing contamination (Beck and Birch, 2014).

The timing and magnitude of entrainment and delivery of trace metals from catchment sources to sinks is intimately linked to its hydrology (Foster and Charlesworth, 1996; Roussiez et al., 2013). For example, the highest concentrations of pollutants in storm water runoff are often associated with the initial discharge that follows a prolonged dry phase (Sansalone and Buchberger, 1997). This is due to the build-up of contaminants in the catchment during dry periods that can then be readily transported in stormwater. The interim storage of metal pollutants within drainage networks, before they are received by coastal waters, has long been recognised. Remobilization of this stored material from erosion susceptible areas during floods, including channel beds, banks and floodplains can represent an additional source of metals to downstream riverine and coastal environments (Bradley and Cox, 1990; Ciszewski, 2001; Kruger et al., 2005; Coynel et al., 2007). The inundation of industrial areas, which are often found on coastal floodplains can also present an additional source of metal rich sediments to the river and estuarine waters. Considering the combined effect, the total load of metals species associated with suspended particulate matter (SPM) is in some instances highest during flood events (Zonta et al., 2005).

The urbanization and industrialization of the Australian coast has been relatively rapid, occurring since the mid-19th century following European colonization. Moreton Bay in South East Queensland is an estuarine embayment and the receiving waters of the Brisbane River (Fig. 1). The Brisbane River estuary flows through Brisbane city which has a population of over 2 million people. The region as a whole has one of the fastest growing populations in Australia (currently 2.73 -million people; 2026 projection ~4 million people) (Leigh et al., 2013). The regional climate is subtropical with a summer dominant rainfall and is subject to the effects of the El Nino Southern Oscillation (ENSO). This results in high inter-annual variability in rainfall. Over longer periods this variability is also modulated by the Pacific decadal oscillation (Power et al., 2006; Klingaman et al., 2013), and it is also shown to be a dominant driver of inter-annual discharge volumes of east coast rivers (Rodriguez-Ramirez et al., 2014). East coast Australian rivers have some of the most variable annual discharges in Australia if not the world (Finlayson and McMahon, 1988). Between 2002 and 2007 the region sustained below average rainfall and resulted in one of the most intense droughts on record for east coast Australia. This was followed by widespread rainfall from 2009 to 2013 which caused major flooding in eastern Australia (Fig. 2a). The 2011 Brisbane River flood was the largest in the last 40 years, and around the 10th largest in the ~180 years of instrumental records. Two high tides coincident with the flood pulse increased the total flood height in the Brisbane City by ~20–30 cm (Fig. 2b). Flood waters inundated metropolitan Brisbane and caused extensive damage to infrastructure, inundating large areas of residential, commercial, and industrial land (Fig. 2c,d), with damage costs for council infrastructure estimated at $ AUD 440 million (BCC, 2012), with insured losses totalling $ AUD 2.55 Billion. This flood delivered an estimated 5–10 million tonnes of fine sediment, derived from agricultural soils, channel banks and urban sources, to the Bay (Stevens et al., 2014; Coates-Marnane et al., 2016). These estimates are >10 times the average annual load estimates of the Brisbane River.

Here we examine the effects of this flood on trace metal concentrations in bottom sediments across Moreton Bay. We first map the distribution of fine sediments and the concentrations of major elements Al, Fe, Ca, and P and trace metals Zn, Cu, Pb, Ni, Mn and Cr and compare concentrations to those previously reported for the intertidal margins of the Bay, the Brisbane River and tributaries of the lower Brisbane River (Semple and Williams, 1998; Cox and Preda, 2005; Morelli and Gasparon, 2014) (Table 1). In addition, dated sediment cores are used to explore temporal in trace metal input to the central Bay. Previously, sediment cores of intertidal sediments in western Moreton Bay have been used to examine temporal trends in Zn, Cu, and Pb enrichment as a result of gradual urbanization and industrialization of adjacent catchments (Morelli et al., 2012). However, Morelli and Gasparon (2015) found interpreting a temporal trend of enrichment at many intertidal sites was complicated by sediment reworking and bioturbation; a feature typical of these high energy sedimentary environments. Here we use sub-tidal sediment cores taken in 10 m of water depth, within the pro-delta of the Brisbane River delta. As a relatively stable setting this sedimentary environment lends itself to temporal reconstruction of trace metal input to the region. Together, these data sets provide novel insights into the role of flooding on metal transport from the catchment to the coast, particularly those metals that are known to be derived from urban, industrial and agricultural sources and that are principally transported to the coast via runoff (i.e Pb, Zn, and Cu).

2. Study site

Moreton Bay is a shallow estuarine embayment located on the subtropical east coast of Australia (Fig. 1). The Bay supports numerous habitats including seagrass meadows, mangrove forests, and coral reefs (Dennison and Abal, 1999). The Bay is bordered in the east by

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