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Assessment of biotic response to heavy metal contamination in *Avicennia marina* mangrove ecosystems in Sydney Estuary, Australia

Bibhash Nath [a,*], Punarbasu Chaudhuri [a,b], Gavin Birch [a]

[a] School of Geosciences, University of Sydney, Sydney, NSW 2006, Australia
[b] Department of Environmental Science, University of Calcutta, Kolkata 700 019, West Bengal, India

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ABSTRACT

Mangrove forests act as a natural filter of land-derived wastewaters along industrialized tropical and sub-tropical coastlines and assist in maintaining a healthy living condition for marine ecosystems. Currently, these intertidal communities are under serious threat from heavy metal contamination induced by human activity associated with rapid urbanization and industrialization. Studies on the biotic responses of these plants to heavy metal contamination are of great significance in estuary management and maintaining coastal ecosystem health. The main objective of the present investigation was to assess the biotic response in *Avicennia marina* ecosystems to heavy metal contamination through the determination of metal concentrations in leaves, fine nutritive roots and underlying sediments collected in fifteen locations across Sydney Estuary (Australia). Metal concentrations (especially Cu, Pb and Zn) in the underlying sediments of *A. marina* were enriched to a level (based on Interim Sediment Quality Guidelines) at which adverse biological effects to flora could occasionally occur. Metals accumulated in fine nutritive roots greater than underlying sediments, however, only minor translocation of these metals to *A. marina* leaves was observed (mean translocation factors, TFs, for all elements <0.13, except for Mn). Translocation factors of essential elements (i.e., common plant micro-nutrients, Cu, Ni, Mn and Zn) were greater than non-essential elements (As, Cd, Co, Cr and Pb), suggesting that *A. marina* mangroves of this estuary selectively excluded non-essential elements, while regulating essential elements and limiting toxicity to plants. This study supports the notion that *A. marina* mangroves act as a phytostabilizer in this highly modified estuary thereby protecting the aquatic ecosystem from point or non-point sources of heavy metal contamination.

1. Introduction

Mangrove ecosystems contribute valuable ecological functions in coastal environments (Harbison, 1986; Lacerda et al., 1991) and serve as an important habitat within coastal communities (Dahdouh-Guebas et al., 2000). These ecosystems safeguard estuarine aquatic environments from heavy metal contamination sourced mainly from intense human activities, such as urbanization, aquaculture and agriculture (Harbison, 1986; Saenger et al., 1991). The positive functions of mangroves in ecosystem maintenance and protection are mainly due to their ability to accumulate organic-rich muddy sediments and associated toxic pollutants and nutrients and reduce contaminant dispersion in coastal areas (Förstner and Wittmann, 1979; Adriano, 1986; Harbison, 1986; Lacerda et al., 1991; Peters et al., 1997; Qiu et al., 2011). Moreover, these ecosystems protect coastal environments from erosion and other weather-related extreme events, e.g., storm surges and cyclones (Kathiresan, 2008; Zhang et al., 2012). Due to these unique characteristics, mangroves are widely used to protect coastal ecosystems in many anthropogenically modified estuaries, especially in the tropics and sub-tropics where they grow in abundance with high species diversity (Jin-Eong, 1995; Harty, 1997).

Despite their unique properties and ecological functions, mangrove ecosystems are at risk of destruction, either from increasing instances of natural calamities, or from anthropogenic activities, especially urbanization (Farnsworth and Ellison, 1997; Valiela et al., 2001; Cuong et al., 2005). A global estimate in the reduction of mangrove vegetation cover of nearly 30 percent since approximately 1980 is due to widespread coastal urbanization and industrial activity in association with population growth (Polidoro et al., 2010). As a result, various national and international agencies and/or local governments have adopted management and conservation policies to protect these ecosystems from such alarming levels of degradation (FAO, 1994; van Lavieren et al., 2012).

* Corresponding author.
E-mail address: bibhash12@gmail.com (B. Nath).

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The contaminant status of Sydney Estuary (Australia) (considered in the present work to include the area up to the fresh water limit of all tributaries and not limited to Sydney Harbour), has been widely studied (e.g., Birch and Taylor, 1999; Birch et al., 2008, 2013; Lee et al., 2011). Sydney Estuary catchment has been extensively urbanized and industrialized for more than a century (Birch et al., 2013). Birch et al. (2013) showed wide-spread spatial variability in metal concentrations, such as Cu, Pb and Zn, in surficial sediments of the estuary, while Nath et al. (2014) reported the occurrence of potentially toxic levels of heavy metals in the intertidal areas of this system, while Chaudhuri et al. (2014) documented high metal concentrations in mangrove rhizosphere sediments and associated fine nutritive roots of *Avicennia marina*. However, only a localized field-based study has been conducted in Sydney Estuary on the accumulation of heavy metals in leaves of *A. marina*. In a localized study of the Newington wetlands of Sydney Estuary, MacFarlane et al. (2003) demonstrated a restricted mobility of Cu and Zn and a strong exclusion mechanism of Pb in *A. marina* leaf tissues and concluded that *A. marina* leaves could be employed as a bio-indicator for Zn, with temporal monitoring. A quantitative increase in peroxidase activity and in the chlorophyll *a*/*b* ratio has shown in *A. marina* with increasing sediment metal loadings in Sydney Estuary (MacFarlane, 2002). MacFarlane and Burchett (2001) observed visible toxicity to Cu, Pb and Zn at sediment concentrations of 400, >800 and 1000 μg/g, respectively based on laboratory ecotoxicological studies on *A. marina* seedlings collected from Sydney Estuary. Despite the abundance of mangroves of the *A. marina* variety in Sydney Estuary, there has been no systematic regional study of mangrove response to metallic contaminants in this estuarine system.

The present study aimed to assess the biotic response in *A. marina* mangrove ecosystems to heavy metal contamination in Sydney Estuary through the use of metal bio-concentration factors and translocation factors. The relationship between heavy metals in leaves, fine nutritive roots and sediments was observed to assess the heavy metal phytostabilization potential of *A. marina* habitats under spatially variable sediment chemistry.

2. Materials and methods

2.1. Study area

Sydney Estuary is a 30-km long drowned river valley with a water surface of approximately 50 km^2 (Fig. 1). The estuary supports important socio-economic functions, especially navigation, recreational boating and water sports, of ~4.6 million inhabitants of the Sydney Metropolitan region. The catchment is highly urbanized and industrialized (86 percent) with limited open spaces and parkland (Birch and Taylor, 2000). The estuary is divided into five regions, Upper, Central and Lower Harbour, and Middle and North Harbour (Fig. 1). The intertidal areas of this estuary are densely populated with mono-specific domination of the mangrove species *A. marina* (Burchett et al., 1984; McLoughlin, 2000) containing trees of a variety of ages and densities. The major present-day source of metallic contaminants to this estuary has been attributed to stormwater from the catchments with estuarine sediment metal levels amongst the highest globally (Birch et al., 2013).

2.2. Collection of core sediments and A. marina leaves

Mangrove sediments from intertidal zones of Sydney Estuary were collected from fifteen sites across five major embayments during June 2012. These embayments were selected on the basis of mangrove distribution (McLoughlin, 2000), sedimentary metal concentration gradients (such as Cu, Pb and Zn) and history of anthropogenic disturbances (Birch et al., 2013). At each site, a healthy *A. marina* mangrove tree was selected in the intertidal zone. Four equally-spaced sediment cores (20 cm long and 6 cm in diameter) were retrieved encircling the base of the mangrove tree ($n=60$) during low tide. The sediment cores were placed in an ice box upon retrieval and transferred back to the laboratory at 4 °C until further processing. Leaves were also collected from each mangrove tree following the procedure detailed in MacFarlane et al. (2003). Twenty leaves were collected from each tree and pooled to make four samples ($n=60$). Leaves were stored in a zip-lock plastic bag and kept in an ice box before being transferred to the laboratory for storage at 4 °C until further processing.

2.3. Sample processing in the laboratory

Sediment cores were sectioned at every 5 cm intervals. In the laboratory, a representative sample from each interval was pooled to make a single sample for each core. Pooled samples were air-dried at ~25 °C and homogenized with a mortar and a pestle for chemical extractions. Fine nutritive roots of *A. marina* attached to sub-surface sediments were recovered through wet sieving using

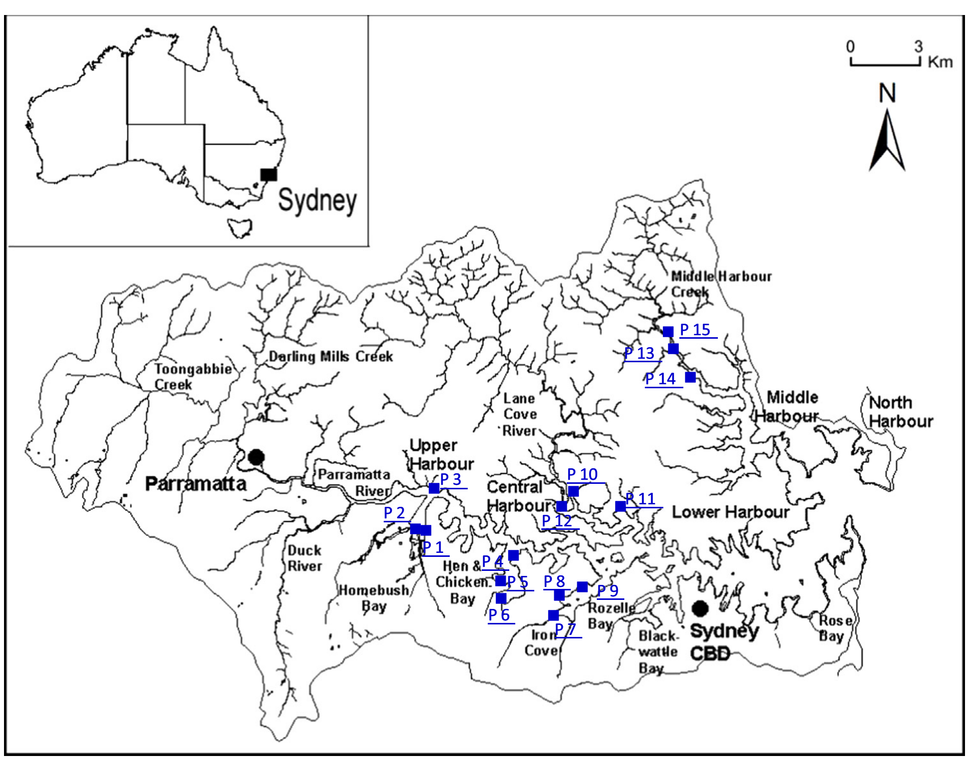

Fig. 1. Map of the study area showing sampling locations ($n=15$) in five major embayment of Sydney Estuary (Australia). This figure is modified after Nath et al. (2014).