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Complex relationships between shallow muddy benthic assemblages, sediment chemistry and toxicity in estuaries in southern New South Wales, Australia

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ABSTRACT

Synoptic sediment quality triad (contaminants, benthic assemblages, toxicity testing) data were collected for sites in Sydney estuary, adjacent Cooks River and five less-modified southern estuaries. Matching data tested relationships between contaminants and benthic assemblages, correlations with specific contaminants, and the ability of sediment quality guidelines to predict the risk of adverse effects.

Significant but weak relationships occurred in complex patterns between assemblages, contaminant concentrations and environmental variables. Maximum benthos abundance occurred where sediment contamination was high and was dominated by polychaetes. Spionidae (polychaete) and Galeommatidae (mollusc) abundances were strongly correlated with site environmental characteristics and with varying mixtures of metals and organic contaminants.

The risk of adverse effects on benthic assemblage structure increased with increasing sediment toxicity except for areas of very high contamination and for non-bioavailable anthropogenic chemicals. The overall weight-of-evidence scores differentiated the highly modified sites from less-contaminated southern estuaries, where toxicity scores were higher than predicted.

1. Introduction

Urban estuaries are highly susceptible to anthropogenic pressures. In particular, a variety of chemicals contaminate sediments, especially the fine muds which are habitat for numerous benthic invertebrate species. The effects of sediment contaminants on benthic invertebrates has attracted substantial research but, unfortunately, there are few broad-based, interdisciplinary studies needed to refine our understanding of benthic ecosystem (ill) health and define priorities for habitat remediation and management.

Recent interdisciplinary studies include assessment of macrobenthic biodiversity, characterisation of sediment-bound contaminants and ecotoxicology using a limited range of benthic species, termed "triad" studies (Dagnino et al., 2008: Bay and Weisberg, 2012). Few studies in Australia contain datasets that are sufficiently large to adequately characterise entire estuaries, or include comparison to a range of estuaries historically subject to varying degrees of sediment modification (Dafforn et al., 2013; McKinley et al., 2011, 2012). The sequestration of triad studies in the grey literature reduces the availability of comparative data and hampers efforts to develop cost-effective indicators of ecosystem health and development of priorities for management of these productive ecosystems (EVS (EVS Environmental Consultants), 2002; OECD, 2004; ECI, 2008). This work, undertaken over a period of 5 years in Sydney estuary and in estuaries on the southern New South Wales (NSW) coastline, attempts to address the lack of integrated information on shallow, subtidal benthic ecosystems in this region.

Sydney estuary is approximately 30 km long and 3 km wide with an area of about 50 km^2 (Fig. 1). The estuary is a drowned river valley with a narrow, sinuous channel and irregular bathymetry (max. 46 m depth). Embayments on the southern shores of the upper and central estuary are shallow (< 7 m) and mantled with muddy sediments, whereas the lower estuary is moderately deep (~20 m) and contains sandy surficial material. Sydney estuary catchment (~530 km^2) is intensely (77%) urbanised and industrialised and supports a population of

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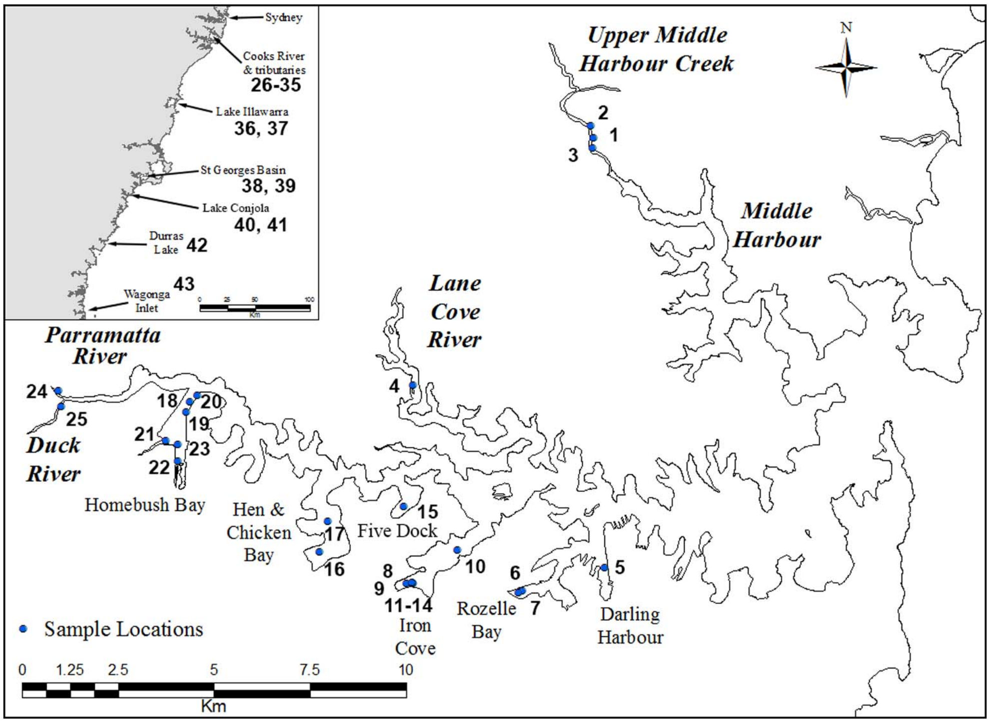

Fig. 1. Map of sampling sites and locations on the east coast of New South Wales, Australia.

almost two million (Birch et al., 2015). 'Sydney estuary' is used in the current work to describe the entire estuarine system, rather than 'Sydney Harbour' or 'Port Jackson', which refers to restricted parts of the waterway (McLoughlin, 2000; Birch et al., 2009). Industrial and domestic waste was discharged directly into the estuary until 1890 when ocean outfalls were commissioned. Water quality began improving with the advent of the Clean Waters Act and Regulations in 1976, which outlawed dumping of waste into the waterway. The harbour is slowly reverting to mainly commuter, tourist and recreational use, while industry, shipping and naval facilities are moving out of the port.

A sustained research effort to assess the contamination status of Sydney estuary between 1990 and 2005 established the waterway as one of the best characterised worldwide. This work showed that extensive parts of the estuary were mantled with sediments containing high concentrations of a wide range of anthropogenic chemicals and that these sediments were among the most contaminated of any capital port (Birch and Taylor, 1999, 2000; McCready et al., 2000, 2004, 2005, 2006a, 2006b, 2006c). Sediment quality guidelines (SQGs) were applied to these chemical data as a preliminary test of possible toxicity (Birch and Taylor, 2002a, 2002b, 2002c), which allowed bottom sediments to be ranked according to the risk of adverse biological effects and enabled stratification of the estuary for further sampling. A large study then established the spatial extent of sediment toxicity in Sydney estuary based on matching chemical and toxicity data collected from 69 sampling sites across 21 strata (Birch et al., 2008). A very large benthic community data set (45,971 infauna sorted and counted) collected concurrently with the original chemistry/toxicity study has, to date, never been reported.

The transfer of contaminants from abiotic to the biotic system has been demonstrated in previous research on sediments, flora and fauna in Sydney estuary. Metals (copper, lead and zinc) have been shown to bioaccumulate in tissue of mussels (Birch and Apostolatos, 2013), oysters (Scanes and Roach, 1999; Dafforn et al., 2012; Birch et al., 2014a), prawns (Lewtas et al., 2014) and fish (Chvojka, 1998; Alquezar et al., 2006a, 2006b; McKinley et al., 2012), as well as in flora, e.g. mangroves (Chaudhuri et al., 2014; Nath et al., 2014a, 2014b), macroalgae (Roberts et al., 2008) and seagrass (Cox, 2014). Sedimentary metals have also been shown to alter habitats (McKinley et al., 2011), modify bacterial communities (Wilson et al., 2010; Sun et al., 2012) and larval fish distributions (McKinley et al., 2010) and possibly cause skeletal asymmetry in smooth toadfish (Lajus et al., 2015) in Sydney estuary. These studies show the importance of understanding the relationship between sediment chemistry and biological response.

Benthic community structure in Sydney estuary has been examined in several studies. Investigations of the Powells Creek wetland (Robinson et al., 1983) and estuarine environments of Homebush Bay (Jones and Francis, 1988) determined that macrobenthic fauna was similar to that present in other similar NSW estuarine habitats. Parramatta River sediment contained few species and low species density relative to other NSW estuaries. Polychaetes dominated benthic assemblages with minor contributions of amphipods and bivalves in a comprehensive investigation of Homebush Bay (Berents, 1993) with similar results repeated in later studies (EVS (EVS Environmental Consultants), 1999, 2001) which also noted domination by spionid and sabellid polychaete worms and molluscs dominated by tellinid bivalves.

The relationship between patterns of sediment contamination and estuarine macrobenthic communities was investigated in Sydney estuary (11 sites) and adjacent Hawkesbury River (2 sites) and Georges River (2 sites) by Chariton et al. (2010). Metals were the contaminant of concern and explained the largest proportion of variation in macrobenthic distributions. Abundance in Sydney estuary was dominated (94.4%) by polychaete species (Spionidae, 53–74% of polychaetes, Capitellidae, 12–16% of polychaetes and Sabellidae, 6–12% of polychaetes), followed by molluscs (3.2%) and crustaceans (2.4%).

Dafforn et al. (2013) sampled benthic infauna and sediment contaminants in estuaries ranging from Sydney to Wagonga Inlet on the NSW South Coast, from similar water depth and geographical range to the present study. Across a range of sediment types, infaunal assemblages differed significantly, corresponding to levels of estuary modification and sediment contamination. Polychaetes dominated communities in estuaries with elevated levels of metals and polycyclic aromatic hydrocarbons (PAHs) with significant differences in polychaete richness (determined at family level) and abundance compared to relatively unmodified estuaries (Dafforn et al., 2013).

Patterns of dominance of polychaetes have been reported in other