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Urban stormwater run-off promotes compression of saltmarshes by freshwater plants and mangrove forests

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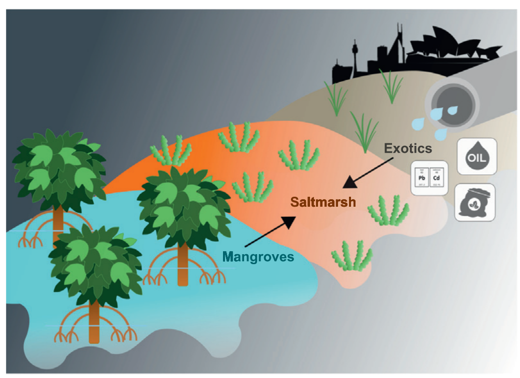
HIGHLIGHTS

- Urban wetlands receive nutrient and heavy metal polluted run-off through stormwater.
- High levels of metals due to previous uses did not affect vegetation composition.
- Stormwater alters the salinity below outlets and promotes exotic plant establishment.
- Elevated soil nutrients below stormwater outlets promote mangrove encroachment.
- Exotic plant and mangrove encroachment below outlets led to squeezing of saltmarshes.

GRAPHICAL ABSTRACT



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ABSTRACT

Subtropical and temperate coastal saltmarsh of Australia is listed as an endangered ecological community under the Commonwealth Environment Protection and Biodiversity Conservation Act (EPBC Act). Saltmarshes are under threat from sea level rise, landward migration of mangroves, and in urban regions from habitat loss, input of litter, nutrients, and other contaminants. In urbanised catchments, saltmarsh areas receive nutrient-enriched and pollutant-contaminated run-off, such as heavy metals, through the stormwater system. This study aimed to investigate the impact of urban stormwater on saltmarsh and mangrove species composition and distribution. To test the effect of stormwater run-off in urbanised catchments on saltmarsh communities, we analysed the soil for pollutant elements, salinity and nutrient concentration and recorded vegetation composition at eight sites in the Sydney region, Australia. We found that elevated total nitrogen (>0.4 wt%) and reduced salinity of the soil downslope of stormwater outlets facilitates establishment of exotic plants and might promote migration of mangroves into saltmarshes, resulting in a squeezing effect on the distribution of saltmarsh vegetation. Saltmarsh cover was significantly lower below stormwater outlets and exotic plant cover increased significantly with sediment calcium concentrations above 8840 mg/kg, which are associated with stormwater run-off. However, this effect was found to be strongest in highly industrialised areas compared to residential areas. Understanding the impact of pollutants on coastal wetlands will improve management strategies for the conservation of this important endangered ecological community.

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1. Introduction

Mangrove and saltmarsh communities occur along estuarine coasts and are composed of plants highly adapted to waterlogging and saline conditions. While serving as an ecotone between the terrestrial and oceanic environments, saltmarshes and mangroves also form important habitats and feeding grounds for invertebrates and birds, as well as nursery grounds for several fish species (Alongi, 2002; Mcleod and Salm, 2006). Saltmarshes are mostly confined to temperate climatic zones (Adam, 1990), whereas the distribution of mangroves is mainly limited by temperature. As mangroves are intolerant to frost (Hogarth, 2007; Stuart et al., 2007), they are completely replaced by saltmarshes at latitudes above 32°N and 40°S (Stuart et al., 2007). In the transition zone between tropical and temperate climates, saltmarshes and mangroves can share the same habitat. Their co-occurrence is highly dependent on the stability of the tidal system they inhabit. Saltmarshes are usually found landwards of mangrove forests as they can tolerate higher salt concentrations than mangroves (Osland et al., 2013; Saintilan et al., 2009b). Coexistence of saltmarshes and mangroves can be found in Florida, the Gulf of Mexico, between the north and south islands of New Zealand and along the eastern coast of Australia (Chapman, 1977). Anthropogenic influences in the form of reclamation and pollution, together with the consequences of climate change, are considered the biggest threat to mangroves and saltmarshes (Saintilan et al., 2009a; Zedler and Kercher, 2004). In Australia, 'Subtropical and temperate coastal saltmarsh of Australia' has been listed as an endangered ecological community under the Commonwealth Environmental Protection and Biodiversity Conservation (EPBC) Act. These arrangements were taken after a 60% loss of total saltmarsh area was found in south-eastern Australia (Grayson et al., 1999).

Saltmarshes in particular are primarily threatened by physical disturbances, such as reclamation, dredging and sea level rise (Valiela, 2006). These physical factors are impacting the tidal system and can influence the saltmarsh-mangrove boundary as well as environmental conditions such as nutrient availability and salinity (Laegdsgaard, 2006; Rogers et al., 2013). Much of the tenfold increase in urban population within the 20th century has occurred in coastal regions (Elmqvist et al., 2013) and has resulted in a decline of intertidal wetlands globally. Nevertheless, intertidal wetlands such as mangrove and saltmarsh communities, provide important services to urban areas and their population such as stabilization of the coastline, protection from storm surges and the filtration of pollutants (Guo et al., 2017; Woodward and Wui, 2001). In urban areas, pollutants such as highly concentrated nutrients and heavy metals enter adjacent wetlands via different pathways. Possible sources are industrial and agricultural discharge into waterways, overflow and leakage from sewerage pipes, dumping of garden waste and stormwater run-off (Al Bakri et al., 2008; Birch, 2007). Previous studies on freshwater systems have shown that stormwater discharge in urban areas increases the availability of nutrients and heavy metals in soil (Grella et al., 2018; Leishman and Thomson, 2005; Wuana and Okieimen, 2011).

The increase of nutrient levels, such as phosphorus and nitrogen, facilitates exotic plant growth (Goldberg et al., 2017; Liu and van Kleunen, 2017) and establishment, especially in naturally nutrient poor soils (Leishman et al., 2004; Uddin and Robinson, 2018). Mangroves respond to nutrients with increased growth which seems to affect the boundary between saltmarsh and mangrove communities (Reef et al., 2016). The landward migration of mangroves, and consequently loss of saltmarsh, has been observed worldwide (Saintilan and Rogers, 2015). The replacement of saltmarsh by mangroves changes not only the plant community in these ecosystems but also the faunal diversity, microclimate, soil organic content and sediment accretion (Guo et al., 2017; Smee et al., 2017). As mangroves can only tolerate moderate salinities, the input of freshwater from stormwater run-off might lead to an encroachment of mangroves into the saltmarshes (Adam, 1990) as well as to the facilitation of exotic plant establishment from the landward site (Leishman et al., 2004). While organic pollutants, such as nutrients, deposited via stormwater into saltmarsh and mangrove communities, may be degraded or converted to harmless compounds through microbial activity in the rhizosphere (Batty and Dolan, 2013), heavy metals are not degraded and thus persist in soil for long periods of time (Kirpichtchikova et al., 2006). Most plant species are sensitive to the harmful effects of heavy metals, as they can inhibit growth, affect the plant water status and inhibit photosynthesis, resulting in plant death (Lutts and Lefèvre, 2015). It is thought that because of their adaptation to high salinities, saltmarsh and mangrove species can also tolerate high concentrations of heavy metals and some species are considered as potential heavy metal bioaccumulators (Lutts and Lefèvre, 2015; Nath et al., 2014b; Parvaresh et al., 2011). Moreover, due to the reputation of wetlands as pollutant filters, stormwater is often discharged into existing wetlands and in fact wetlands are constructed for this purpose (Carleton et al., 2000; Keller et al., 2017). Apart from the effect of pulsing freshwater events on nutrient and heavy metal availability in wetland soils, it has also been shown that increased freshwater input accelerates soil organic carbon loss. Consequences of the loss of organic carbon is a degradation of saltmarsh resilience to sea level rise due to a diminished ability of vertical marsh accretion (Chambers et al., 2013).

As urban development increases, impervious surfaces will increase and with it the amount of urban catchment run-off discharged into wetlands at the edge of urban development (Grella et al., 2018). It is unclear to what extent the input of nutrient and pollutant-laden freshwater from stormwater discharge affects saltmarsh vegetation and its sensitive boundary to the adjacent mangrove forests. It is unknown whether a higher density of impervious surfaces and historical industrial use in highly urbanised areas increases the effect of stormwater run-off on urban wetland ecosystems.

In this study, we assessed the sediment salinity, pollutant elements, such as heavy metals, and nutrient content below stormwater run-off outlets in highly industrialised and residential areas of Sydney and analysed whether elevated concentrations influenced the abundance of three different plant types, i.e. saltmarsh species, mangroves and exotic plants. The questions we addressed were: (1) Is the nutrient (i.e. nitrogen, phosphorus and potassium) and pollutant elements content of saltmarsh and mangrove sediment greater below stormwater outlets in industrial areas compared to residential areas? (2) Does stormwater run-off facilitate exotic plant establishment in saltmarshes? (3) Does stormwater run-off promote mangrove encroachment into saltmarshes?

2. Methods

2.1. Study sites

We assessed environmental conditions (salinity, sediment nutrient and pollutant elements concentrations) and vegetation at coastal wetland sites within the Sydney region and adjacent Central Coast of New South Wales, Australia. Land use adjacent to our study sites included industrial and residential areas. Mangrove forests and saltmarshes of Sydney and the Central Coast area grow on sediment that is derived from highly permeable sandstone (Clarke and Hannon, 1967). The sediment is well drained, acidic and has a sandy surface structure with low nutrient content (Clarke and Hannon, 1967). Average grain size of estuarine sediment of eastern New South Wales ranges from ~63 μm to 500 μm with bigger grain size closer the mouth of the estuary where estuarine silt is replaced by estuarine sand (Kelleway et al., 2017). Salt concentration in wetlands tend to be lower in frequently inundated areas and can vary widely in less inundated areas on the upper shore due to evaporation (Clarke and Hannon, 1967; Saintilan et al., 2009a).

We selected eight study sites where urban run-off is discharged from stormwater outlets located at the saltmarsh/urban land use boundary (Fig. A1). Five study sites were located adjacent to current or previous industrial areas within Sydney: Parramatta River, Duck