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Research Paper

Linking urban land use to pollutants in constructed wetlands: Implications for stormwater and urban planning

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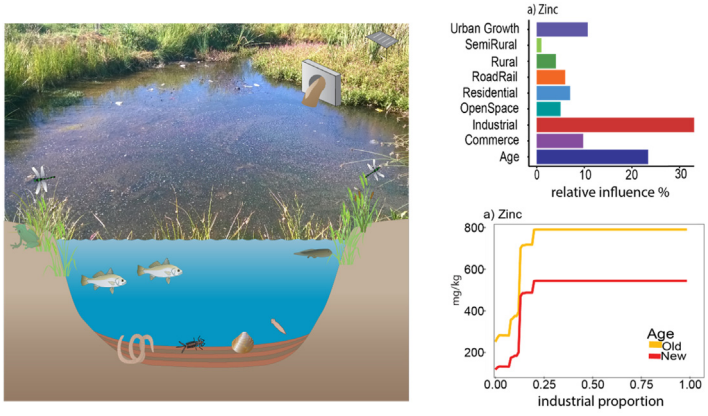
HIGHLIGHTS

- Sediment quality was assessed at 98 urban wetlands across an urban landscape.
- Land use type is an important determinant of the pollutant profile in sediments.
- Industrial wetlands have a much greater risk of exceeding ecological and waste disposal guidelines.
- Age of wetlands and their catchment geology significantly influences sediment quality.

GRAPHICAL ABSTRACT



Land use type is an important determinant of the pollutant profile in wetland sediments

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ABSTRACT

Constructed wetlands are recognised as a cost-effective and socially acceptable stormwater treatment option within urban landscapes, satisfying a range of urban design objectives, including flood protection and treating stormwater. While wetlands also provide habitat for aquatic biota, and often act as a refuge for wildlife, there is growing concern that as wetlands become polluted, they could become toxic to aquatic life and lead to extensive costs for the disposal of sediments. Currently, there is little consideration given to how land use activity in wetland catchments contributes to this pollution. Here we assessed the sediment quality of 98 constructed wetlands across an urban landscape and determined whether concentrations of pollutants present can be correlated to catchment land uses, geology or wetland age. Using boosted regression trees, we find that land use type is an important determinant of the concentrations of heavy metals and petroleum hydrocarbons in sediments. Wetlands with >10% industries in their catchments have significantly higher sediment-bound concentrations of trace metals than wetlands draining catchments with little industrialisation. Furthermore, these industrial wetlands have a much greater risk of exceeding ecological and waste disposal guidelines, while wetlands

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with catchments comprising primarily residential or *peri*-urban have significantly lower risk of becoming polluted. Results also suggest that the age of wetlands and their catchment geology significantly influences sediment quality. This research improves our understanding of the factors influencing pollution in urban areas and will enable wetlands to be better designed and managed to minimise their environmental impacts and maintenance costs.

1. Introduction

Presently, over 50% of the world's populations live within cities, with significant increases expected over the next 50 years (Grimm et al., 2008). Thus, it is critical that improvements to social, economic and environmental sustainability of cities worldwide are implicit and developed as part of future planning. Many chemical, physical and biological features of aquatic ecosystems are altered by changes in land use and human activities associated with urban living. Increases in urban populations intensify demand on aquatic ecosystems services, such as waste disposal and denitrification, affecting ecological, recreational and social values (Li et al., 2016). While ecosystem services can provide a framework to guide landscape planners and architects on future sustainable urban development (Woodruff & BenDor, 2016), maintenance of these ecosystem services as urban development increases becomes increasingly difficult (Díaz, Fargione, & Tilman, 2006). A major challenge facing cities globally is how to manage stormwater. To reduce pollutants discharged by stormwaters, several different initiatives have been developed worldwide, such as the National Pollutant Discharge Elimination System (NPDES) in the United States, the Flood and Water Management Act in the UK and the Australian Guidelines for Urban Stormwater Management in Australia 2000.

These initiatives aim to manage the quality and quantity of stormwater entering receiving waters. It is recognised that as impervious areas increase, due to increases in hard spaces, such as roofs and roads, coupled with changes in land use activities, so do concentrations of pollutants entering receiving waters. This can also lead to alterations to local faunal composition and diversity in downstream environments (Konrad & Booth, 2005). The stormwater pollutant profile of any catchment area (CA) is determined largely by land use and associated anthropogenic activities, with the relationship between land use and aquatic ecosystem condition clearly demonstrated (Foley et al., 2005). Determining the most appropriate stormwater management option is critical for reducing the impact that stormwater inputs have on receiving environments. For some time, constructed wetlands have been used as a cost-effective, socially acceptable and efficient way to treat stormwater (Malaviya & Singh, 2012), although their implementation for treating stormwater has been somewhat varied in terms of design guidelines and management across the world (Lucas, Earl, Babatunde, & Bockelmann-Evans, 2015).

Though constructed wetlands are built primarily to protect downstream environments from pollutants, they are also often used as ecological refuges for a range of biota, including frogs, birds, fish and macroinvertebrates. However, as wetlands accumulate pollutants, the possibility has been raised that poor quality wetlands could become ecological traps that may reduce the fitness of local species and increase the risk of extinction to local populations (Hale, Coleman, Pettigrove, Swearer, & Strecker, 2015; Tilton, 1995). This is especially true if they are particularly attractive to wildlife due to high quality habitat (Pérez-García, Sebastián-González, Alexander, Sánchez-Zapata, & Botella, 2014). In addition, constructed wetlands have a finite lifespan before they require either de-commissioning or resetting (sediment dredged from macrophyte zone). This can quickly escalate maintenance and treatment costs (Steer, Aseltyne, & Fraser, 2003; Taylor & Fletcher, 2004), especially when contaminants in dredged sediments exceed local soil hazard disposal thresholds (Sharley, Carew, & Pettigrove, 2012). For example, dredged sediments exceeding local disposal guidelines in our study region are not only subject to various levies per tonne depending on pollution levels (Table 1), but local environmental authorities also request polluted sediment be transported to prescribed waste facilities, further increasing costs. To improve urban wetland planning and stormwater management best practice, it is critical that managers and planners are informed on the broad-scale factors influencing generation of pollutants from urban landscapes.

Wetland designs consider several factors including catchment impervious area, aesthetic value and landscaping to maximise stormwater filtration efficiency and ecosystem services (IWCW, 2000). However, planners and designers rarely consider the implications of catchment land use and locality within the landscape on long term ecological and asset sustainability. Studies have shown that adjacent land use can affect water and sediment quality (Houlahan & Findlay, 2004; Simon, Snodgrass, Casey, & Sparling, 2009) as well as ecological condition (Findlay & Houlahan, 1997; Houlahan & Findlay, 2003). A recent study by Kellar et al. (2014) showed that stormwaters discharged from catchments with industrial activity are more likely to have higher concentrations of heavy metals, hydrocarbons and other pollutants, compared to other land use types. By using boosted regression tree (BRT) models, we examine potential relationships between land use characteristics, age of wetland, underlying geology and sediment quality. Boosted Regression Trees, unlike traditional statistical approaches work by combining many single models to improve model performance (i.e. Boosting), using recursive binary splits to relate responses to predictor variables (i.e. Regression trees) (Elith, Leathwick, & Hastie, 2008), which is useful when assessing complex ecological datasets (Hale, Marshall, Jeppe, & Pettigrove, 2014; Lewin, Mehner, Ritterbusch, & Bramick, 2014).

The objective of this study was to determine how urban land use characteristics and other factors such as age of wetland and underlying geology significantly influence sediment quality in constructed wetlands. Our study area was the urban area of Melbourne, Australia. This city offers a variety of wetlands with over 600 constructed in this area in the past 30 years. In addition, there are two distinct catchment geologies (Silurian Sedimentary Sands and Tertiary Basalts) with distinct soil metal profiles and different properties in adsorbing heavy metals (Pettigrove & Hoffmann, 2003). Assessing sediment quality from 98 wetlands and land use characteristics from each subsequent watershed, we investigate how generation of pollutants from catchments affect sediment quality, disposal costs and ecological condition of constructed wetlands. We discuss our results in the context of integrating watershed characteristics into the decision-making process when deciding on the most appropriate stormwater treatment option for a given urban landscape.