Is geochemical contamination from urban development contributing to weed invasions in high conservation value wetlands?

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Key Points

- Urban stream syndrome results in a unique urban ionic geochemical signature within aquatic ecosystems.
- Blue Mountains Upland Swamps with urban catchments exhibited elevated pH by 1.45 pH units and 4.5 times higher electrical conductivity in water compared to swamps in natural and non-urban catchments.
- Urban swamps contained higher concentrations of calcium, potassium and bicarbonate in water and wetland plant foliage tissue.
- However, the ecological implications of urban geochemistry within swamp communities, particularly potential associations with weed invasions, requires further research.
- Catchment urbanisation poses a threat to Blue Mountains Upland Swamps, which are high conservation value ecosystems that are listed as an endangered ecological community.
- This study highlights the potential for concrete surfaces in urban areas to be a possible source of geochemical contamination.
- We attribute much of the geochemical modification to the exposure of catchment runoff to concrete surfaces.

Abstract

Blue Mountains Upland Swamps are unique ecosystems that are restricted to less than 3000ha within the Blue Mountains, NSW and listed as an endangered ecological community under State and Federal legislation. Geochemistry of water, sediment and foliage was assessed within two urbanised and two naturally vegetated swamp catchments. Water in urban swamps exhibited elevated pH by 1.45 pH units and electrical conductivity by 4.5 times compared to naturally vegetated swamps. Calcium, bicarbonate and potassium concentrations differed between catchment types within water, sediment and foliage. The gradual dissolution and mobilisation of ions, including calcium, potassium and bicarbonate, from concrete is suspected to contribute to geochemical contamination within urban catchments. Urban development contributes to erosion, channelisation and water pollution within Blue Mountains Upland Swamps. Urbanisation is associated with Key Threatening Processes including altered natural hydrology, exotic weed invasions and altered fire frequency. However, the ecological implications of urban water chemistry on these sensitive swamps are unclear. We suspect that urban swamp geochemistry may favour exotic plant species. Improving understanding of how urban development may affect these unique ecosystems is essential to guide management practices, for example exploration of alternative materials to concrete for use in sensitive, poorly buffered environments, and promote conservation.

Keywords

Catchment urbanisation, urban stream syndrome, water chemistry, concrete water contamination, sediment chemistry

Introduction

The degradation of urban aquatic ecosystems has been well documented, referred to as 'urban stream syndrome' (Paul & Meyer 2001; Walsh et al. 2005). Urban development is associated with accumulation of nutrients, heavy metals and contaminants in urban soils (King & Buckney 2002; Grella, Renshaw & Wright 2018), and alteration of the growth and composition of vegetation communities due to nutrient enrichment, such as elevated Phosphorus (P) (Leishman & Thomson 2005). This phenomenon has been observed to occur on a global scale and has significant implications for biotic species as it can alter the physical and chemical environment within aquatic ecosystems, leading to a loss of sensitive species or promoting exotic weed invasions (Leishman, Hughes & Gore 2004; Tippler, Wright & Hanlon 2012).

Furthermore, there is increasing evidence that catchment urbanisation and urban development can alter environmental geochemistry by increasing inputs of major ions such as Calcium (Ca), Bicarbonate (HCO_3) and Potassium (K) into aquatic ecosystems (Kaushal et al. 2017; Moore et al. 2017), resulting in a distinct 'urban geochemical signature' (Chambers et al. 2016). A high coverage of impervious surfaces is recognised as a key factor impacting natural ecosystems, as it reduces infiltration and increases surface runoff that can contain concentrated urban contaminants (Wright et al. 2011; Tippler et al. 2014). Concrete dissolution and leaching can contribute ions, including Ca, HCO_3 and K to the environment (Davies et al. 2010; Grella et al. 2014), and this signature is increasingly being observed in field studies implicating concrete as a potential source of geochemical alteration (Wright et al. 2011; Tippler et al. 2014; Kaushal et al. 2017; Moore et al. 2017). In addition, concrete is linked with increased pH in urban waterways, contributing to the alkalisation of rivers, which is a key issue associated with catchment urbanisation (Kaushal et al. 2013).

Blue Mountains Upland Swamps (BMUS) are peat swamps formed on sandstone in the Blue Mountains region in NSW at altitudes of 500-1000m (Fryirs, Freidman & Kohlhagen 2012). BMUS are comprised of distinct communities of sedgeland and heath species, including sedges such as *Gymnoschoenus sphaerocephalus* (Button Grass) and *Lepidosperma limicola* (Razor Sedge,) and shrubs including *Hakea teretifolia* (Dagger Hakea) and *Leptospermum spp.* (Tea Tree) (Keith & Benson 1988). BMUS have high conservation value as they are restricted to an area of less than 3000 hectares (Belmer, Wright & Tippler 2015) and contain endangered and endemic species of flora and fauna, including the Blue Mountains Water Skink (*Eulamprus leuranensis*) (Gorissen, Greenlees & Shine 2016) and the Giant Dragonfly (*Petalura gigangtea*) (Baird 2012). These swamps also provide valuable ecosystem services such as water filtration, nutrient cycling and habitat for flora and fauna (Hensen & Mahoney 2010). These unique ecosystems are listed as an 'endangered ecological community' under the Environment Protection and Biodiversity Conservation Act 1999 (Commonwealth) and the Threatened Species Conservation Act 1995 (NSW) (Fryirs et al. 2014). BMUS are poorly buffered and nutrient limited ecosystems, making them susceptible to disturbance from urban areas (Belmer, Wright & Tippler 2015). The effects of urbanisation are recognised as having major impacts on BMUS, resulting in altered geomorphology and channelisation (Fryirs, Freidman & Kohlhagen 2012; Fryirs et al. 2014), negative impacts on biotic species (Gorissen, Greenlees & Shine 2016; Belmer, Tippler & Wright 2018) and modified water chemistry (Belmer, Wright & Tippler 2015).

This study investigated whether urban BMUS exhibit modified water, sediment and foliage chemistry reflective of the typical urban geochemical signature. The aim was to enhance understanding of BMUS in urban ecosystems, identify factors that may be leading to degradation, such as weed invasions, so that potential management practices can be explored and guide further research that seeks to investigate the ecological implications of catchment urbanisation within BMUS.

Methodology

Study sites

This study was conducted at four BMUS sites, with site selection and catchment type (urban and naturally vegetated) determined based on research conducted by Belmer, Wright & Tippler (2015). Two urbanised catchments were located at Bullaburra (-33.727310, 150.413019) and Lawson (-33.713197, 150.427043), where the percentage of catchment imperviousness was estimated to be 27.3% and 10.2% respectively (Belmer, Wright & Tippler 2015). Two naturally vegetated catchments at Mount Hay (-33.668644, 150.346508) and Hat Hill (-33.599261, 150.328683) were also assessed, which contained no urban development or impervious surfaces within the swamp catchments (Belmer, Wright & Tippler 2015). Water, sediment and foliage tissue samples were assessed from each BMUS site during one sampling event in September 2017.

Water, sediment and foliage sampling

Water quality was tested in the field from surface water at the exit stream of each BMUS site (excluding Bullaburra which was tested in the centre of the swamp due to the availability of surface water). pH and electrical conductivity (EC) were assessed using a calibrated TPS AQUA-Cond-pH meter, with five replicates per parameter (Belmer, Wright & Tippler 2015). Duplicate samples per swamp were collected in sterilised plastic bottles and stored at 4°C.

Sediment samples were collected from the top 5cm of soil using a trowel and gloves and stored in sterile glass jars (King & Buckney 2002; Grella, Renshaw & Wright 2018). Five spatial replicates of sediment samples were taken from within each swamp catchment, with the location determined using a random number table.

Foliage tissue samples (50-100g) were collected from three dominant native plant species at each site, determined by visual inspection. Native species collected included *Leptospermum juniperinum* (Prickly Tea Tree; from all sites), *Acacia longifolia* (Sydney Golden Wattle; Bullaburra), *Gymnoschoenus sphaerocephalus* (Button Grass; Bullaburra, Lawson and Mount Hay), *Gleichenia dicarpa* (Pouched Coral Fern; Hat Hill and Lawson), *Banksia spinulosa* (Hairpin Banksia; Mount Hay), and *Lepidosperma limicola* (Razor Sedge; Hat Hill). Three dominant exotic species were also collected from Bullaburra BMUS, including *Lonicera japonica* (Japanese Honeysuckle), *Pennisetum clandestinum* (Kikuyu Grass) and *Verbena incompta* (Purpletop Vervain), as this was the only site where exotics were present. Native and exotic species results were combined to give mean ionic concentrations for urban swamp foliage geochemistry. Foliage was dried (using a Labec laboratory incubator S4218, Laboratory Equipment Pty Ltd) for six days at 40°C (determined by maximum temperature available for equipment). Dried tissue was then ground for 30 seconds (using a Sunbeam Multigrinder II EMO405), sieved (1000µm) and stored in sterile glass jars (Wang & Moore 2014).

All samples (water, sediment and foliage) were analysed at a commercial National Association of Testing Authorities (NATA) accredited laboratory for concentrations of Ca, K and HCO_3, as these ions are typically associated with urban environments and materials such as concrete (Wright et al. 2011). All data was analysed in SPSS (version 22) using independent samples Mann-Whitney U test.

Results

Water physical and chemical properties

Water in urban swamps had elevated pH by 1.45 pH units and mean EC in urban swamps was 4.5 times higher at 128.06µS/cm compared to 28.51µS/cm in the non-urban swamps (Table 1). Ca, K and HCO_3 were below detection in water in naturally vegetated catchments, however were significantly elevated in urban swamp catchments (Figure 1a).

Sediment chemistry

Mean Ca concentrations were significantly higher in urban sediment (2848.18mg/kg) compared to the naturally vegetated swamp catchments (194.91mg/kg), representing an increase of 14.6 times (Figure 1b). However, K remained at similar levels between catchment types, and despite HCO_3 being slightly higher in urban sediments, this difference was not significant.

Foliage chemistry

Foliage from urban catchments (mean comprising both native and exotic species) had significantly elevated concentrations of K, Ca and HCO_3 compared to foliage from the non-urban catchments (containing only native species; Figure 1c). Mean K was approximately six times higher in urban foliage (17,740mg/kg) compared to foliage in non-urban catchments (3128.57mg/kg), whereas Ca and HCO_3 were three and five times higher respectively in urban foliage.

Table 1. Summary of mean water, sediment and foliage results comparing urban (n=2) and naturally vegetated (n=2) BMUS catchments. Units for Ca, K and HCO_3 in water are mg/L, and sediment and foliage are mg/kg. BD refers to below detection, - denotes that the variable was not tested for in that component and (ns) indicates that the variable was not statistically significant (p>0.05).

	Water			Sediment			Foliage		
	Urban	Naturally vegetated		Urban	Naturally vegetated		Urban	Naturally vegetated	
Variables	Range (Mean)	Range (Mean)	*U* statistic (p value)	Range (Mean)	Range (Mean)	*U* statistic (p value)	Range (Mean)	Range (Mean)	*U* statistic (p value)
pH (pH units)	5.86-6.93 (6.41)	4.48-5.36 (4.96)	0.00 (p<0.001)	-	-	-	-	-	-
Electrical Conductivity (µS/cm)	106.6-140.4 (128.06)	23.2-31.5 (28.51)	0.00 (p<0.001)	-	-	-	-	-	-
Calcium	11-19 (14.88)	BD	0.00 (p<0.001)	60-8200 (2848.18)	30-530 (194.91)	11.50 (p<0.01)	2900-26000 (8550)	900-5100 (2742.86)	8.00 (p<0.01)
Potassium	0.90-2.10 (1.48)	BD	0.00 (p<0.001)	60-940 (326.36)	60-970 (371.82)	53.00 (ns)	3400-59000 (17740)	1700-4500 (3128.57)	6.00 (p<0.01)
Bicarbonate	18-59 (32.13)	BD	0.00 (p<0.001)	320-3400 (1633.64)	200-1200 (600)	32.00 (ns)	510-14000 (5521)	BD-3400 (1034.29)	13.50 (p<0.05)

Discussion

This study found that BMUS with urbanised catchments had altered geochemistry compared to naturally vegetated BMUS. Water in urban swamps exhibited increases in pH and EC, and concentrations of Ca, K and HCO_3 were below detection in non-urban swamps, however were elevated in urban water. Urban sediment had significantly elevated Ca levels, and foliage from urban catchments reported increased concentrations of Ca, K and HCO_3 compared to non-urban swamps. These results suggest that there is the potential for catchment urbanisation to alter environmental geochemistry across multiple tiers of a sensitive aquatic ecosystem, however the ecological implications of this remain largely unclear. This study suggests emerging findings regarding the ionic composition of foliage and sediment in urban wetlands and highlights the need for further research to investigate the ecological consequences of catchment urbanisation on sensitive swamp communities.

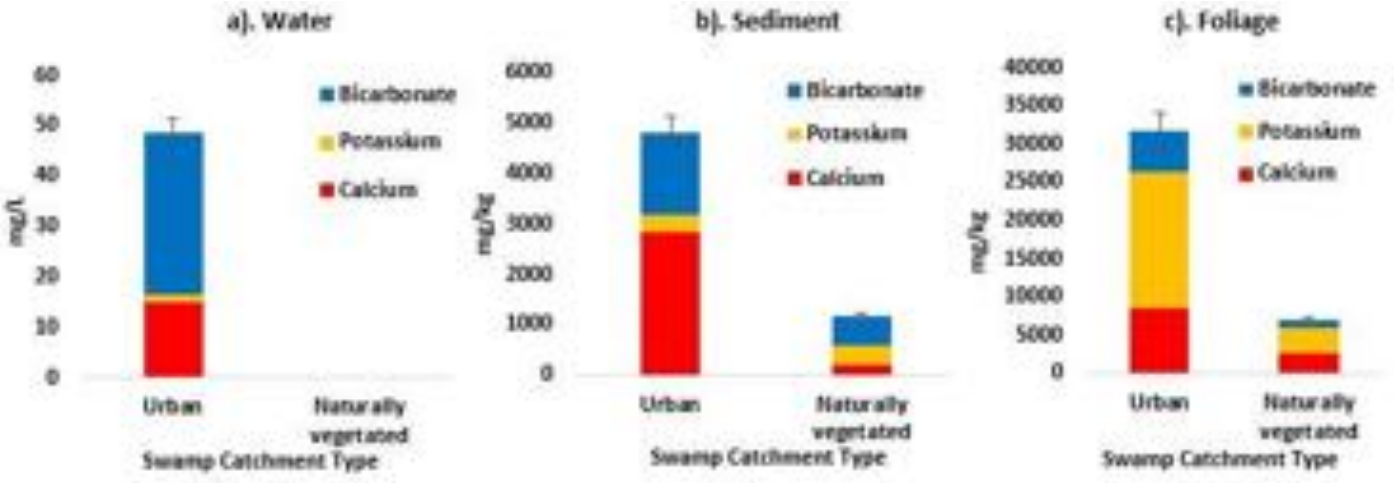

Figure 1. Summary of mean geochemistry results from urban (n=2) and naturally vegetated (n=2) BMUS catchments, including concentrations of Ca, K and HCO_3 in a). water, b). sediment and c). foliage tissue. Urban foliage consists of native and exotic species, and foliage from naturally vegetated catchments consists of natives only as no exotic species were present.

Urban BMUS exhibited higher pH compared to non-urban catchments. This is consistent with previous research conducted within BMUS (Belmer, Wright & Tippler 2015), and global trends of river alkalisation of urban aquatic ecosystems (Kaushal et al. 2013). Exposure of water to concrete surfaces is also suggested to increase pH (Davies et al. 2010; Grella et al. 2014), highlighting the potential for concrete to contribute to the alteration of natural swamp conditions. pH is a key factor that determines the bioavailability of nutrients, therefore the modification of pH from highly acidic to towards alkaline could impact nutrient availability and toxicity, which may in turn affect biotic species (Bolan, Adriano & Curtin 2003). Belmer, Wright & Tippler (2015) examined water quality in seven BMUS catchments and observed that all non-urban, naturally vegetated swamps were highly acidic (range of 4.2-5.4 pH units; n=3) compared to urban wetlands (range of 5.8-9.2 pH units; n=4). This large difference in pH ranges between catchment types suggests that vegetation in urban BMUS are exposed to environments which differ greatly to natural conditions, which may have implications for biodiversity. However, further research on the implications for native and exotic species is required.

Calcium levels were elevated in water, sediment and foliage, and HCO_3 was higher in water and foliage within urban BMUS. This is in line with water chemistry observed in BMUS by Belmer, Wright & Tippler (2015). This trend of elevated Ca and HCO_3 is consistent with previous research in urban aquatic ecosystems including water and riparian soils (King & Buckney 2002; Wright et al. 2011; Tippler et al. 2014; Kaushal et al. 2017; Grella, Renshaw & Wright 2018). Sources of Ca and HCO_3 can be natural, such as weathering of geology and aeolian deposition (Brahney et al. 2013; Tippler et al. 2014). However, the dominant geology in the area typically lacks karst features (Tippler, Wright & Hanlon 2012). Therefore, the significant differences between catchment types suggests that urban inputs may be a major contributing factor. Ca and HCO_3 have been associated with the weathering of concrete and other urban materials (Davies et al. 2010; Wright et al. 2011). However, further research is required to better understand the contributions of natural and urban sources of Ca and HCO_3 in these environments, and how elevated levels, in combination with changes to pH, may affect native vegetation.

Potassium was elevated in urban swamp water, similar to Belmer, Wright & Tippler (2015). K was also significantly higher in foliage tissue in urban swamps, which poses the question as to whether increased K may offer any competitive advantages to exotic weed species in BMUS. This study highlights the importance of exploring the role of K in the growth and development of native and exotic species, in addition to other recognised macronutrients, such as Nitrogen (N) and P (Leishman, Hughes & Gore 2004). Ca, K and HCO_3 all play important roles in plant growth and development, however there is a lack of comparative data that compares how foliage tissue and sediment are impacted in urban wetlands. Further research that utilises a larger sample size and additional sampling events is required to enhance knowledge of how altered pH and geochemistry may impact vegetation communities.

The greater Blue Mountains region is a recognised World Heritage Area (Chalson & Martin 2009), however the effect of increasing urban development remains a concern. BMUS are poorly buffered, fragile ecosystems that are vulnerable to external changes in the surrounding catchment (Belmer, Wright & Tippler 2015). Yet the implications of modified environmental geochemistry for the biotic community remains unclear. Altered water chemistry due to urbanisation is known to negatively affect sensitive macroinvertebrate species (Belmer, Tippler & Wright 2018) and endangered species such as the Blue Mountains Water Skink (Gorissen, Greenlees & Shine 2016). However, the implications for vegetation communities are not well-known.

Weed invasion is recognised as an issue within BMUS and identified species of concern include *Ligustrum sinense* (Small-leaved Privet), *Lonicera japonica* (Japanese Honeysuckle) and *Rubus fruticosus* (Blackberry) (Office of Environment & Heritage 2016). This was apparent at Bullaburra BMUS, where honeysuckle and blackberry were abundant. Weed invasion and a higher prevalence of exotic species has previously been linked with stormwater outlets and urban runoff contributing to P enrichment (Leishman, Hughes & Gore 2004; Thomson & Leishman 2004; Leishman & Thomson 2005). Urban BMUS exhibited a distinct geochemical signature in water, sediment and foliage compared to naturally vegetated swamps, with elevated Ca, K and HCO_3. Therefore, we suspect that urban geochemistry, including elevated pH, K, Ca and HCO_3 are potential factors contributing to weed invasions in sensitive BMUS communities. However, further research is required to identify whether urban geochemistry creates conditions more conducive to exotic species or alternatively impedes native species. Tentatively we suggest that the characteristic water geochemistry (i.e. acidic, dilute and poorly buffered) of BMUS in non-urban, naturally vegetated catchments could be 'protecting' BMUS from invasive weeds. In addition, we also suggest that urban development of BMUS catchments strongly modifies the natural geochemistry, providing water quality more favourable for invasive species.

This study demonstrates the need to carefully consider the use of concrete surfaces and urban development in close proximity to these swamps, as it poses a potential source of geochemical modification. The Threatened Species Conservation (TSC) Act (1995) identifies Key Threatening Processes (KTPs) that adversely affect threatened species, populations or communities (TSC Act 1995, Part 2, Division 2, Section 13). Recognised KTPs of concern within BMUS include alteration to the natural flow regime of rivers and wetlands, invasion and establishment of exotic vines and scramblers, and high fire frequency resulting in disruption of life cycle processes in plants and animals and loss of vegetation structure and composition (Office of Environment & Heritage 2016). However, catchment urbanisation, urban development and a high coverage of impervious surfaces such as concrete are directly and indirectly associated with and contribute to these KTPs. This raises the question as to whether concrete and urban development could be considered a KTP in these poorly buffered, fragile environments. This study highlights the potential to investigate alternative materials to concrete for use in these sensitive ecosystems. For example, the use of local products such as sandstone, and the potential to coat concrete to reduce leaching (Grella et al. 2014) may be explored.

Conclusions

The effect of urbanisation on aquatic ecosystems is a global issue that is set to increase in the future, and urban stream syndrome remains a widespread concern. However, there is limited information available regarding the ecological consequences of urban impacts on sensitive wetland communities. Urban swamps exhibited elevated pH, EC and key ions including Ca, K and HCO_3. Findings from this study suggest that catchment urbanisation and the presence of concrete remains a potential source of geochemical contamination and it is suspected that this can contribute to weed invasions. BMUS are endangered ecological communities with high conservation value. Enhancing knowledge of urban pressures within these unique swamps is essential to aid in the management and protection of BMUS.

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