Investigating the link between riparian weed invasion, riparian soil geochemistry and catchment urbanisation

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Key Points

- Increased catchment imperviousness was found to be associated with higher invasive plant cover and species richness, decreased native plant cover and species richness and elevated soil minerals and nutrients in riparian zones.
- Riparian soil calcium levels in highly urbanised catchments (mean 1184 mg/L) were over 2000 times greater than those in non-urban catchments (mean 0.56 mg/L).
- Mean soil salinity increased 11 times, from 10.0 µS/cm in non-urban catchments to 111.2 µS/cm in highly urbanised catchments
- Urban soils had a higher pH (mean 6.5 vs 5.0 in non-urban catchments) and higher phosphorus (mean 49 mg/kg in non-urban catchments to 390 mg/kg in urban catchments).
- The source of calcium in urban riparian soils is suspected to have derived primarily from concrete materials used within urban stormwater infrastructure.

Abstract

This study examined the effects of increased catchment imperviousness (as a surrogate for the intensity of urbanisation) on riparian vegetation and riparian soil geochemistry in the Georges River catchment in south-west Sydney. Soil sampling was undertaken in the riparian zone of 10 freshwater streams in non-urban and urban catchments in March to June 2013. This study found increased catchment imperviousness was associated with increased weed cover and elevated soil minerals and nutrients. Mean soil salinity increased 11 fold in the highly urbanised catchments. Urban soils had an elevated mean pH and elevated mean phosphorus. A major finding of this study was riparian soil calcium concentrations in highly urbanised catchments were over 2000 times greater than those in non-urban catchments. Changes in these factors are likely to have implications for weed invasion. The most important management message from this research and review of similar studies is that future urbanisation, particularly in catchments that are currently undisturbed and naturally vegetated, is likely to contribute to the contamination of riparian soils which in turn may provide ideal conditions for the colonisation of invasive plant species and therefore degrade riparian vegetation communities. We speculate the primary source of calcium in urban riparian soils derives from concrete materials used in urban stormwater infrastructure (e.g. pipes and gutters).

Keywords

Riparian soils, imperviousness, urban development, nutrients, salinity, calcium, concrete stormwater drainage materials

Introduction

Urbanisation is a well known contributor to weed invasion in riparian zones. It has been proposed by many researchers that survival of weed species may be enhanced by changed conditions provided by urbanisation (e.g. Sung *et al.* 2011). Exotic plants are often spread through anthropogenic means, thus their distribution is associated with areas of high human population density and activity (Maskell *et al.* 2006). Streams from urban areas can also facilitate the dispersal of exotic species by transporting propagules from upstream areas (Alston & Richardson 2006). Increased urbanisation has also resulted in riparian zones becoming increasingly fragmented, creating urban/wildland interfaces subject to 'edge effects' (Alston & Richardson 2006; Saunders *et al.* 1991). As a result plant communities become more susceptible to an array of disturbances which include increased light exposure, higher temperatures and altered soil conditions, which often causes mortality of endemic plant species (Alston & Richardson 2006; Saunders *et al.* 1991). In contrast, altered riparian conditions often favour exotic plant invasion (Alston & Richardson 2006) and both physical or mechanical disturbance of soil has been found to result in conditions which are suitable for invasion of space filling exotic species (D'Antonio & Meyerson 2002).

In addition to riparian disturbance by physical means, it is widely acknowledged that nutrient enrichment plays a major role in the colonisation of invasive species (King & Buckney 2000, 2002; Leishman *et al.* 2004). In an urban context, nutrients enter riparian vegetation communities via several means which include leakage and overflow of sewerage pipes, dumping of garden waste, fertilisers from gardens, pet excrement, introduced soil fill from construction sites and stormwater runoff (King & Buckney 2002).

Sample collection and analysis

Sample and data collection was undertaken in the riparian zone of 10 freshwater stream sites in the Georges River catchment (south-western Sydney) over April to June 2013. Sites were grouped according to the level of catchment imperviousness (as a surrogate for the intensity of urbanisation) with the category thresholds defined as low, moderate or high (low <5.0 %; moderate 5.0–18 %; high >18.0 %). These categories were chosen based on the strong link between water quality of streams and their ecological condition, according to freshwater macro invertebrates (Tippler *et al.* 2012). There were three streams in the 'low' category (<5% imperviousness), three in the 'moderate' (5-18% imperviousness) and four in the 'high' (>18% imperviousness) category. While sample site selection within the three categories was random, accessibility and the need to represent the range of land uses and geologies within the catchment was taken into account.

At each randomly chosen site (along a 200 m section of stream), an 8 m x 8 m sampling area was established parallel to the watercourse starting at the stream bank, as close as practical to the water line. Sub-sampling was then completed by stratified random sampling. Six one by one metre quadrats, were established at each location, three along the stream bank and three at a position of eight metres above the stream perpendicular to the stream. All groundcover plant species rooted within the quadrat were recorded and assigned a percentage cover. Plants taller than 0.6m were not included. Species were classified as 'weeds' if they were exotic or native plants that were not indigenous to the area. Percentage cover was independently estimated visually by two people. If there were discrepancies, the average was taken of the two estimates. Plants were identified on site using field guides. Any unknown specimens were collected and identified later by trained personnel.

For collection of soil samples each quadrat was subdivided into a 100 cm x 100 cm grid and a random number table was used to select a random coordinate on this grid as the location of the soil sample. One soil core sample (to a depth of 10 cm) was collected in each quadrat using a soil foot sampler, with 18 (3 X 6) samples collected overall per site. Samples were removed from the corer and were immediately stored in clean, labelled plastic zip lock bags. Two ring volume bulk density (BD) samples were taken in each of the locations at each site, one on the bank and one on the upper bank (eight metres perpendicular from the stream). Soil collection and analysis followed the 'Intact core method 503.01' as described in McKenzie *et al.* (2002).

All soil core samples were oven dried at 40°C for 7-14 days then dry- sieved to 1 mm. Six composite samples were made for each site by combining the three bank samples and three upper bank samples in each location using a randomised cone and quarter method. The soil fractions were halved into A and B samples. The A sample was used for analysis while the B sample was archived.

The analytical methods for soil EC and pH analysis followed methods [3A1] and [4A1] respectively as described in Rayment and Lyons (2010), (1:5 soil/solution ratio). Cation extraction and analysis (K and Ca) followed method [15D3] as described in Rayment and Lyons (2010). Analysis was undertaken by Atomic Absorption Spectroscopy (AAS) using a Varian SpectAA-800 at UWS Hawkesbury. Total P content of soil samples was analysed by SESL Australia using their in-house method CM0008 which is based on the American Public Health Association's (APHA) Water and Wastewater standards 3050B & 6010C. This method is endorsed by the NATA (National Association of Testing Authorities). Organic matter content of soil samples was determined by weight loss after sample combustion in a muffle furnace.

Data analysis

For each quadrat the percentage cover and species richness of total, native and weed species was calculated. These indices were then tested for significant differences between impervious categories (low, moderate, high). A Levene's test was performed to test for heterogeneity of variances. Weed and native species cover and total number of weed and native species had heterogeneous variances and were analysed using Kruskall-Wallis (non-parametric) tests. One –factor analysis of variance (ANOVA) was used to investigate whether total vegetation cover and species richness varied between the three impervious categories.

Soil parameters were compared between impervious categories using a one-way ANOVA with site as a random factor to account for clustering effects. Parameters were first evaluated for heterogeneity of variance using a Levene's test. Parameters that were found to have heterogenous variances were square-root or $\log_{10}$ transformed and variances were re-checked prior to ANOVA analysis. Parameters that were not able to be successfully transformed (i.e. a normal distribution could not be achieved) were analysed using a Kruskall-Wallis (non-parametric) test. All statistical analyses were performed using IBM SPSS Statistics version 22.

The BIOENV procedure in PRIMER (Clarke & Ainsworth 1993) was used to assess which tested environmental variables (pH, EC, moisture %, BD, OM%, Ca, K, TP, catchment imperviousness % area) were most highly correlated with the variation of vegetation assemblages. This procedure identifies combinations of environmental variables that give the maximum ranked correlations between species and environmental similarity matrices. Environmental variables were first normalised to correct for differences in measurement units and the vegetation square root similarity matrix was used.

Results and Discussion

Significant differences were found between the percentage ground cover and number of native and weed species between the three impervious categories (Table 1, Fig. 1). The percentage cover and number of weed species increased from low to high impervious sites (p < 0.0001 and p< 0.0001 respectively, Table 1), while the opposite pattern was observed for the number and percentage cover of native species. Abundance and percentage cover of total species showed no significant changes between impervious categories (Table 1).

Riparian soils from the most urbanised sites (i.e. with the highest coverage of imperviousness) were highly enriched with Total P, K^+ and Ca^{2+}, when compared to moderate and low impervious streams (Table 2). The most urbanised riparian soils also had the highest percentage of organic matter, highest pH and highest salinity (Table 2).

Soil chemical attributes varied significantly between impervious categories (Table 2). Mean concentration for each parameter increased progressively across impervious categories. The greatest differences across the impervious categories were in soil Ca^{2+} levels. The mean Ca^{2+} concentration of high impervious sites (111.84 mg/L) was more than 2000 times higher than low impervious sites (0.56 mg/L) while concentrations of moderate impervious sites were intermediate (539.26 mg/L) which were more than 900 times greater than low impervious sites (Table 2, Fig. 2).

Salinity (as measured by EC in µS/cm) rose more than 11 times from low to high impervious sites (mean EC = 10.0 and 111.25 µs/cm) (Table 2). Mean P increased by almost 8 times from low impervious sites (49 mg/kg) to high impervious sites (390.60 mg/kg) (Table 2). Mean K^+ also increased significantly from low to high impervious sites (29.83 to 80.65 mg/L) (Table 2). For each chemical attribute the mean levels were approximately mid-way at moderate impervious sites.

Soils at low impervious sites were acidic (mean pH 5.03) while soils at high impervious sites were circumneutral (mean pH 6.49) (Table 12, Fig. 3). Organic content of soil showed a smaller but significant increase from low to high impervious sites (5.56 to 9.33 %) (Table 2). BD and moisture did not show significant differences between impervious categories (Table 2).

Table 1. Summary statistics and significance results comparing riparian vegetation cover and species richness grouped according to catchment imperviousness (low, moderate, high) (n=54 low; n=54 moderate; n=72 high)

Variable	Significance results (ANOVA - F value, p value OR Kruskal-Wallis p value)	Sample size (L,M,H)	Level of Catchment Imperviousness		
			Low	Moderate	High
			Mean (±s.e.)	Mean(±s.e.)	Mean(±s.e.)
Total vegetation cover	ns (ANOVA)	54,54,72	51.06 (4.15)	57.54 (4.72)	56.26 (4.30)
Weed cover	p < 0.0001 (K-W)	54,54,72	3.33 (1.56)	30.72 (5.52)	50.1 (4.44)
Native cover	p < 0.0001 (K-W)	54,54,72	47.72 (4.27)	26.81 (4.00)	6.17 (1.90)
Total species richness	ns (ANOVA)	54,54,72	2.56 (0.18)	2.48 (0.19)	2.46 (0.18)
Weed species richness	p < 0.0001 (K-W)	54,54,72	0.15 (0.06)	1.02 (0.19)	2.18 (0.16)
Native species richness	p < 0.0001 (K-W)	54,54,72	2.41 (0.19)	1.46 (0.16)	0.28 (0.06)

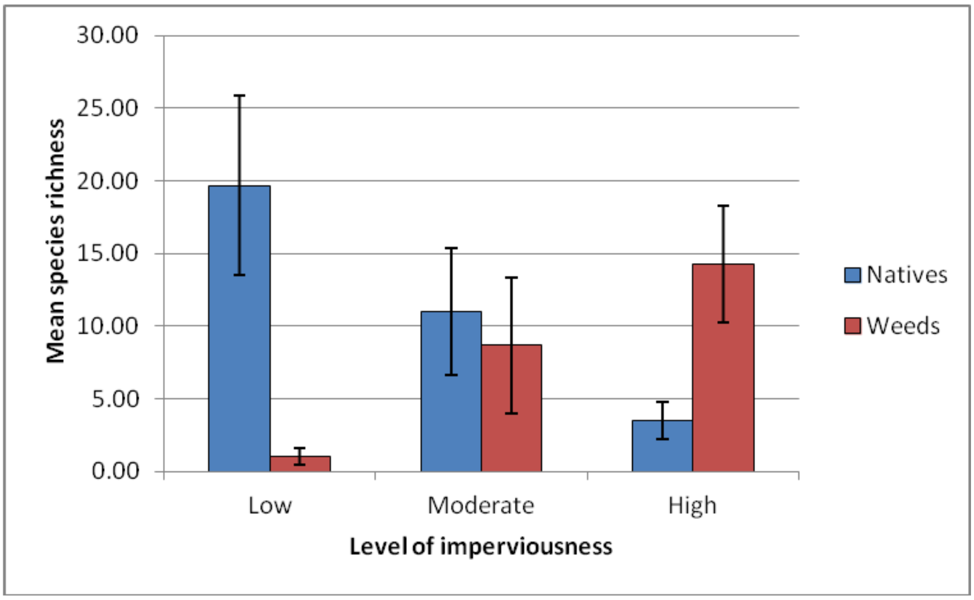

Figure 1. Mean (±SE) of native and weed species richness from riparian zones of low, moderate and high impervious sites in the Georges River catchment

Table 2. Summary statistics and significance results comparing soil physical and chemical factors of composite soil samples collected in the Georges River catchment grouped according to catchment imperviousness (low, moderate, high).*indicates values were square root transformed prior to analysis while **indicates values were $\log_{10}$ transformed prior to analysis

Variable	Significance results (ANOVA – F value, p value) OR (Kruskal-Wallis p value)	Sample size (L,M,H)	Level of Catchment Imperviousness								
			Low			Moderate			High		
			Mean(±s.e.)	Range		Mean(±s.e.)	Range		Mean(±s.e.)	Range	
				Min	Max		Min	Max		Min	Max
BD (g/cm^3)	ns (ANOVA)	18,16,24	1.16 (0.05)	0.59	1.45	1.13 (0.07)	0.54	1.47	1.14 (0.04)	0.80	1.49
Moisture (%) *	ns (ANOVA)	18,16,24	19.91 (3.74)	4.14	64.35	29.19 (7.72)	1.44	93.17	24.77 (3.18)	7.19	61.59
OM (%) *	8.53, p = 0.001 (ANOVA)	18,17,24	5.57 (0.43)	2.10	9.59	7.63 (1.05)	3.50	20.78	9.33 (0.68)	4.49	14.89
pH	p < 0.0001 (K-W)	18,17,24	5.03 (0.08)	4.47	5.90	5.33 (0.07)	4.86	5.74	6.49 (0.16)	4.91	7.66
EC (µs/cm) **	26.93, p <0.0001 (ANOVA)	18,17,24	10.00 (1.62)	0.00	20.00	30.59 (10.59)	0.00	190.00	111.25 (26.16)	20.00	620.00
Ca^{2+} (mg/L)	p < 0.0001 (K-W)	18,17,24	0.56 (0.41)	0.00	7.00	539.26 (164.85)	0.00	2750.00	1184.96 (138.69)	79.97	2677.11
K^+ (mg/L)	12.11, p <0.0001 (ANOVA)	18,17,24	29.84 (5.42)	1.50	75.00	48.16 (8.01)	6.00	139.95	80.65 (9.18)	25.53	181.88
TP (mg/kg)	p < 0.0001 (K-W)	18,17,24	49.00 (3.68)	26.30	91.31	175.42 (30.09)	56.63	436.31	390.61 (40.84)	115.86	732.25

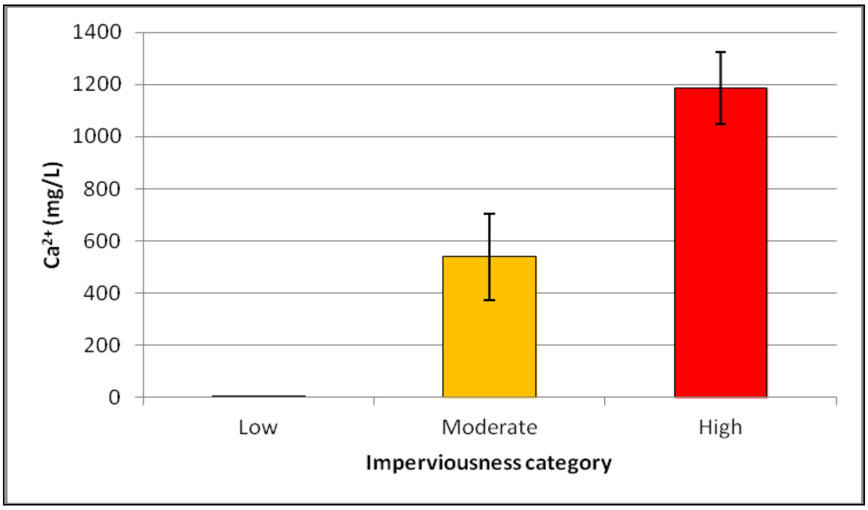

Figure 2. Mean (±SE) Ca^{2+} mg/L of composite soil samples collected from low, moderate and high imperviousness sites in the Georges River catchment (low n = 18, moderate n = 17, high n = 24)

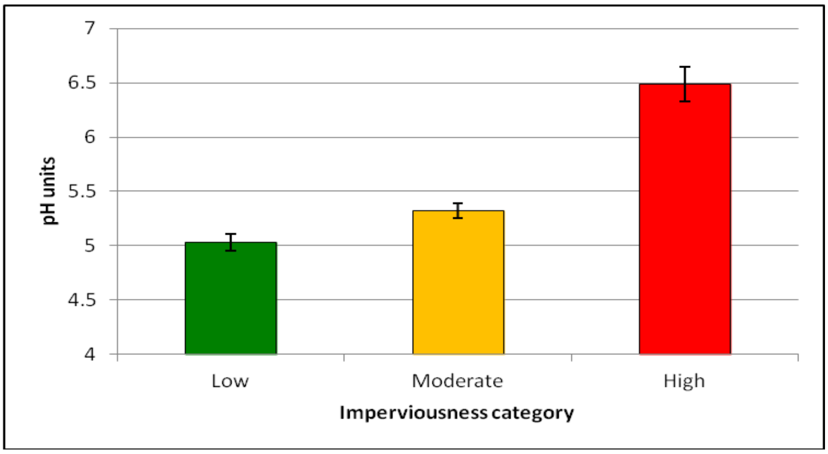

Figure 3. Mean (±SE) pH of composite soil samples collected from low, moderate and high impervious sites in the Georges River catchment (low n=18, moderate n = 17, high n=24)

The riparian soils in the most urbanised catchments (i.e. those with highest coverage of impervious surfaces) were physically and chemically very different to those from less urban catchments. BIOENV analysis identified soil pH as the most significant environmental factor correlated with the variation of riparian vegetation assemblages. Other influential factors were soil moisture %, soil Ca^{2+}, soil EC and the percentage of catchment effective imperviousness. All factors except for moisture % varied significantly according to the impervious category (low, moderate or high).

Some of these findings are novel and others are consistent with studies comparing urbanised to non-urbanised bushland and riparian zones. Vegetation communities of the Sydney basin have been particularly well studied, with the majority of the research focusing on the importance of major plant nutrients, particularly phosphorus and its link as a key chemical contaminant in the proliferation of invasive weeds (e.g. Leishman *et al.* 2004). This study provides additional support that soil phosphorus is higher in urban riparian soils.

However, it is somewhat surprising that potassium and phosphorus were not found to be significantly associated with vegetation assemblages, a finding in contrast to studies by Leishman *et al.* (2004) and Thomson & Leishman (2004). However, the results of this study concur with the work of King and Buckney (2000, 2002) and Le Brocque and Buckney (1995) that vegetation responds to a complex combination of variables, and phosphorus is not the most important factor driving difference in plant communities.

As pH influences a number of critical soil properties such as nutrient availability and metal toxicity (Charman & Murphy 2007), it is not so surprising that it was identified as being the most important soil factor influencing vegetation communities. It has been demonstrated that soil pH is an important predictor of vegetation composition (Alston & Richardson 2006). Mean soil pH in this study increased by almost one and a half units from low to high impervious streams. Alkalinisation of riparian soils can have serious implications for weed invasion. Hawkesbury sandstone communities are naturally acidic and nutrient poor (Lambert & Turner 1987; Leishman *et al.* 2004), so changes in such a critical soil property are likely to influence vegetation. Weed species, especially those of Eurasian origin that are naturally adapted to high pH soils may have a competitive advantage if soil pH rises in the advent of increased urbanisation.

Phosphorous is well known as a key limiting nutrient in sandstone communities (Leishman *et al.* 2004; Thomson & Leishman 2004). Species endemic to low nutrient habitats are often very sensitive to increases in P as they already have specialised mechanisms in place to acquire P, such as forming symbiotic associations with mycorrhizal fungi (Lambers *et al.* 2013). With pHs below 5.5 or above 7.5, P availability is reduced as it reacts with Al and Fe compounds in acidic conditions, and Ca in alkaline conditions to form insoluble complexes (Gardiner & Miller 2008). Increases in soil pH as noted in high impervious sites can mobilise P, causing toxicity in such species (Lambers *et al.* 2013) whilst simultaneously promoting the growth of exotic species. This problem may be compounded with the addition of nutrients from urban runoff. Indeed, the mean Total P of streams in high impervious sites exceeded the ANZECC (2000) guideline for ecosystem protection, which is evidence of stream nutrient pollution.

Ionic attributes of urban soils were significantly more elevated in urban sites compared to peri-urban and non-urbanised sites. This is evident with salinity (EC) in urban riparian soils being 11 times higher than non-urban soils (and 3 times higher than peri-urban sites). The level of salinity is a reflection of any dissolved (ionic) components of the soil chemical solution. Both K and Ca increased significantly from low to high impervious sites, thus they are likely to be significantly influencing the ionic composition of the salinity. The scale of the difference (more than 2000 times) between Ca levels in soils at urban versus non-urban sites is an extraordinary finding and has not previously been detailed by other researches. There are also many other ions (e.g. Na^+, Mg^{2+}, SO_4^{2-}, OH^- etc.) that contribute to salinity, however the levels in riparian soil in this study are unknown and require further investigation.

Conclusions

It is evident that urbanisation in the Georges River catchment has caused significant modifications to riparian vegetation and soil geochemistry. The large increase in Ca concentration strongly suggests that there may be a process of Ca accumulation occurring in soil. Shale soils may be more susceptible to this as they have a higher percentage of clay (which is negatively charged), giving them a higher colloidal content and ability to adsorb cations. The soils of the Sydney region are typically sandstone dominated, with only small portions of limestone geology occurring in the far south-west of the area (Hayes & Buckney 1995). There is no known limestone geology in the Georges River catchment (Tippler *et al.* 2012). As many of the streams in the catchment flow through sandstone areas (Hayes and Buckney 1995), increases in Ca may thus be attributed to mineral leaching of concrete impervious surfaces.

It is evident that urbanisation increases a number of nutrients, not just P. While each nutrient studied (i.e. K, Ca, P) is individually important to plant nutrition, it is likely there are synergistic effects between them. Other plant macro and micro-nutrients are also influential in determining plant communities, thus changes in their relative concentrations will have significant implications for both native and weed species.

Acknowledgments

Mr Mark Emmanuel from UWS assisted with soil analysis and ran the soil cation analyses. Mr Peter Lister from UWS and Mr Robert Peprah from Greening Australia assisted in plant specimen identification.

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