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Short communication

Stemflow chemistry in relation to tree size: A preliminary investigation of eleven urban park trees in British Columbia, Canada

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ABSTRACT

Given increased atmospheric loads in cities, quantification of stemflow chemistry is necessary for a holistic understanding of elemental cycling in urban ecosystems. Accordingly, the stemflow volume and associated solute fluxes (K^+, Ca^{2+}, Na^+, Mg^{2+}) were measured for eleven deciduous trees in a manicured park setting in Kamloops, British Columbia, Canada. Over nine rainfall events from late June to early September 2013, larger trees [diameter at breast height (DBH) > 30 cm] were found to generally produce higher event stemflow volumes but lower funneling ratios than the smaller trees (DBH < 30 cm). The median flux-based enrichment ratio, which compares the solute input of stemflow to that of rainfall on a per unit trunk basal area, also tended to be greater for smaller trees than larger ones. Under all-tree and single-leader tree conditions, significant negative non-linear relationships between tree DBH and mean flux-based enrichment ratios were found for Ca^{2+}, Na^+, and Mg^{2+}, but not for K^+. These preliminary results indicate that urban trees can considerably enrich rainfall that is partitioned into stemflow, and that ion concentrations and enrichment ratios exhibit notably high interspecific variability. In this study, tree size and presence of single versus multiple leaders explained some of this heterogeneity; however, further study into those physical tree characteristics that affect stemflow volume and stemflow chemistry must be carried out if the impact and challenges of urban greening, nutrient cycling, and stormwater management initiatives are to be more fully understood.

1. Introduction

Despite the fact that the benefits of urban trees far outweigh their costs (Soares et al., 2011), the successful implementation of urban greening initiatives is no small feat. Yet, it is probable that the fruition of a 'humane city' in the spirit of Short (1989) may be partly achieved through urban greening and an increased understanding of the bidirectional coupling between the biosphere-atmosphere. This is partly due to the fact that trees in urban settings interact with the surrounding environment in multi-faceted and complex ways with a variety of feedbacks (e.g., Livesley et al., 2014; Xiao and McPherson, 2015). Urban trees, for example, reduce stormwater runoff (Soares et al., 2011) and may also serve as biofilters removing nitrogen and phosphorus from stormwater runoff (Denman et al., 2016). The influence of precipitation interception by urban trees and the subsequent routing of some intercepted precipitation to the ground via throughfall and stemflow likely plays a role in the extent to which urban trees decrease urban runoff and improve water quality. However, Livesley et al. (2014) note that urban trees must be carefully selected to ensure that throughfall and stemflow do not exacerbate hydrological extremes of cities' "engineered xeriscapes" (p.1).

For isolated trees in California, Xiao et al. (2000) found that the single most important factor accounting for the magnitude of canopy interception loss was canopy surface storage capacity. These findings were further confirmed by Xiao and McPherson (2015). Of the meteorological conditions affecting canopy interception loss, rainfall amount was the most important (Xiao et al., 2000). For eucalypt urban street trees in Australia, Livesley et al. (2014) observed that canopy interception loss was related to canopy den-

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sity and that bark roughness exerted a detectable influence on stemflow amounts. Regarding stemflow chemistry, Takagi et al. (1997) found that urban street trees in Japan had a higher stemflow pH than those in the suburbs and ascribed this difference to increased capture of K^+, Ca^{2+}, and Mg^{2+} by the urban trees. Despite these studies, the role of urban trees in capturing atmospheric dryfall, intercepting rain, and redistributing intercepted water as throughfall and stemflow remains inadequately understood. Originating from a point of interest from a larger study examining stemflow inputs from urban trees (Carlyle-Moses and Schooling, 2015; Schooling and Carlyle-Moses, 2015), the primary aim of this work is to provide a better understanding of the effect of tree size on stemflow chemistry. This is justified by the fact that earlier work (as cited above) has found that both above-ground surface area and canopy surface storage capacity are directly related to tree size. In addition, tree size has been observed to affect stemflow funneling by trees in the tropics (Germer et al., 2010) and temperate forests (Levia et al., 2010; Siegert and Levia, 2014). This begs the question of whether tree size will impact stemflow chemistry inputs from urban trees.

2. Materials and methods

2.1. Study area

Rainfall and stemflow (*SF)* were sampled from 11 trees within McArthur Island Park, Kamloops, British Columbia, Canada (50.695° N, 120.377° W, elevation = 344 m above mean sea level). McArthur Island Park is a 51 ha multi-use green space in an area of the City of Kamloops (2011 census population of 85,678) characterized by a mix of institutional and low-density residential development. The park is bounded by the Thompson River to the south and a slough on the other sides. The park boundary is comprised of fairly continuous riparian vegetation that is largely made up of overlapping canopies, while in the manicured center of the park, trees are predominately isolated (i.e., had an unobstructed field of view at least 35° from vertical, centered where the lowest branch met the tree bole) and also tend to be deciduous (e.g., *Acer* spp., *Quercus* spp., *Fraxinus* spp.).

The 30-year climatic norm (1981–2010) for Environment Canada's "Kamloops A*" climate station (Environment Canada 2014), situated 4.4 km WNW of the study site at an elevation of 345 m above mean sea level, suggests that the study area has a mean annual temperature of 9.3 °C (ranging from −2.8 °C in January to 21.5 °C in July) and a mean annual precipitation of 278 mm with approximately 224 mm (81%) falling as rain and the remainder as snow. Although the region is characterized as having a mid-latitude, semi-arid steppe climate (BSk Köppen climate type), the park is modified to a humid, temperate climate (Cwb Köppen climate type) due to extensive irrigation throughout the spring and summer months in order to sustain tournament-standard turf and cultivated, non-native trees.

2.2. Rainfall and stemflow field sampling and storage

Rainfall and *SF* were measured on an event basis from late June to early September 2013. An Onset® (Onset Computer Corporation, Bourne, MA, USA) RG3-M tipping bucket rain gauge (TBRG) connected to an Onset® Hobo® U-30 USB datalogger recorded rainfall depth and intensity. The TBRG and an adjacent manually read polyethylene rain gauge (diameter = 29.0 cm) were between 80 and 770 m from the study trees. Stemflow collection collars of corrugated polyethylene hose were wrapped twice around each tree and angled to promote drainage. The inner edge was stapled to the trunk and sealed with 100 % silicone. Each collar drained to a 17-L polyethylene pail inside a 114-L lidded polyethylene reservoir to accommodate overflow; each reservoir was weighted and its lid secured with elastic cord. The 11 trees selected (see Table 1 for a listing of tree species and diameter at breast height) were considered isolated, (as defined above).

Table 1
Species listing, tree labels, diameter at breast height (1.37 m, DBH), and leader type for the eleven trees in this study.

Tree species	Tree label	DBH (cm)	Leader type (single/multi)
Cercidiphyllum japonicum (Siebold & Zucc.)	1	10.2	single
Tilia cordata (Mill.)	2	17.2	single
Prunus virginiana (L.) 'Shubert'	3	18.8	multi
Acer rubrum (L.) 'Columnare'	4	19.0	single
Fraxinus pennsylvanica (Marsh.)	5	19.7	single
Quercus macrocarpa (Michx.)	6	21.5	single
Acer x freemanii (L.) 'Armstrong'	7	24.1	single
Prunus padus var. *commutata* (L.)	8	34.3	single
Fagus sylvatica (L.) 'Riversii'	9	38.8	multi
Quercus palustris (Münchh.)	10	43.0	single
Quercus palustris (Münchh.)	11	60.7	single

Prior to anticipated rain events, *SF* collars, the 17-L pails housed inside the reservoirs, and the manually read polyethylene rain gauge were rinsed with de-ionized water. Within 12 h of the conclusion of each rain event, field samples were taken of rain as well as *SF* from any of the selected 11 trees that produced >10 mL *SF*. Samples were taken from unmixed *SF* in the collection pail using a glass beaker rinsed with de-ionized water and poured unfiltered into storage containers that were then placed on ice in a cooler.

If there was more *SF* than needed to fill sample containers, the total *SF* volume was measured and recorded before discarding any excess. Stemflow samples in the cooler were delivered within 2–4 h to the chemistry laboratory at Thompson Rivers University where they were stored in polypropylene tubes at 4 °C until analysis.

2.3. Sample preparation and analysis

All *SF* samples were filtered using 0.45 μm nylon filters. To prepare the sample, 1.4 mL of *SF* was placed into a sample vial and vacufuged to dryness at 30 °C. The cation (K^+, Ca^{2+}, Na^+, Mg^{2+}) samples were then dissolved in a 90:10 water:buffer solution. The buffer solution used for the cation analyses consists of 40 mM imidazole, 3 mM 18-crown-6, 10% (v/v) 1-propanol at pH 5.01.

Samples were then transferred into 2 mL vials for analysis. All cation determinations were done on a Beckman P/ACE MDQ system (Beckman Coulter Inc, Fullerton, CA, USA) equipped with a UV detector. The detector was set to 214 nm for analysis. Cation separation used a 50 μm internal diameter fused silica capillary (Polymicro Technologies, Phoenix, AZ, USA) with a total length of 50.9 cm and an effective length of 40 cm. Temperature was maintained at 25 °C (±0.1 °C) by means of a liquid fluorocarbon coolant (Beckman Coulter Inc, Fullerton, CA, USA) in the capillary cartridge. To modulate the electro-osmotic flow and achieve better separation, dynamic capillary coating was adopted using a procedure developed in our lab (Jmaiff and Donkor, unpublished work).

2.4. Flux-based stemflow enrichment ratio

The flux-based stemflow enrichment ratio, *E*, is calculated as follows:

$$E = (Cs \times S)/(Cp \times Pg \times Ba) \quad (1)$$

where *Cs* is the solute concentration in stemflow, *S* is the stemflow volume, *Cp* is the solute concentration of bulk precipitation, *Pg* is