Journal of Environmental Management 159 (2015) 1–10

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

Research article

Habitat complexity influences fine scale hydrological processes and the incidence of stormwater runoff in managed urban ecosystems

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ARTICLE INFO

Article history:
Received 3 January 2015
Received in revised form
24 April 2015
Accepted 4 May 2015
Available online xxx

Keywords:
Habitat complexity
Management
Urban hydrology
Soil properties
Litter
Vegetation

ABSTRACT

Urban ecosystems have traditionally been considered to be pervious features of our cities. Their hydrological properties have largely been investigated at the landscape scale and in comparison with other urban land use types. However, hydrological properties can vary at smaller scales depending upon changes in soil, surface litter and vegetation components. Management practices can directly and indirectly affect each of these components and the overall habitat complexity, ultimately affecting hydrological processes. This study aims to investigate the influence that habitat components and habitat complexity have upon key hydrological processes and the implications for urban habitat management.

Using a network of urban parks and remnant nature reserves in Melbourne, Australia, replicate plots representing three types of habitat complexity were established: low-complexity parks, high-complexity parks, and high-complexity remnants. Saturated soil hydraulic conductivity in low-complexity parks was an order of magnitude lower than that measured in the more complex habitat types, due to fewer soil macropores. Conversely, soil water holding capacity in low-complexity parks was significantly higher compared to the two more complex habitat types. Low-complexity parks would generate runoff during modest precipitation events, whereas high-complexity parks and remnants would be able to absorb the vast majority of rainfall events without generating runoff. Litter layers on the soil surface would absorb most of precipitation events in high-complexity parks and high-complexity remnants. To minimize the incidence of stormwater runoff from urban ecosystems, land managers could incrementally increase the complexity of habitat patches, by increasing canopy density and volume, preserving surface litter and maintaining soil macropore structure.

1. Introduction

Urban ecosystems provide numerous environmental, socio-economical and ecological benefits to cities and towns (Bolund and Hunhammar, 1999; Chiesura, 2004; McPherson et al., 1997). As extreme precipitation events are likely to increase with climate change (Yilmaz et al., 2014), the effective management of hydrological processes and related ecosystem services such as stormwater drainage, runoff mitigation, soil water storage and purification is becoming increasingly important to create more sustainable and resilient cities and towns (Bolund and Hunhammar, 1999; Cunningham et al., 2010; Pauleit and Duhme, 2000; Nouri et al., 2013).

The traditional approach in evaluating hydrological processes and benefits within urban areas has focused on mapping and modelling the hydrology of urban land cover types at large landscape scales, such as the city or catchment scale (Pauleit and Duhme, 2000; Perry and Nawaz, 2008; Sjömana and Gill, 2014; Tratalos et al., 2007; Whitford et al., 2001). These models have then been applied to estimate changes in hydrological processes under climate change scenarios (Gill et al., 2007) or calculate economical benefits associated with runoff reduction (Zhang et al., 2012). However, these models can be problematic as soil hydrological properties are likely to vary with soil physical properties which are highly variable at a very fine scale (Pickett and Cadenasso, 2009). Currently, very few studies have investigated the variability of soil hydrological properties in urban ecosystems through empirical measurements (e.g. Gregory et al., 2006; Yang and Zhang, 2011).

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http://dx.doi.org/10.1016/j.jenvman.2015.05.002
0301-4797/

Together with soils, other habitat components, such as litter and vegetation layers, are likely to exert significant effects on the hydrology of urban ecosystems (Nouri et al., 2013). The absolute amount of these habitat components (e.g. volume, surface area) also define the overall complexity of habitat patches (McCoy and Bell, 1990; Byrne, 2007), and may influence the presence of organisms, such as plant and invertebrates, able to affect hydrological processes at a fine scale (Bartens et al., 2008; Colloff et al., 2010). The hydrological impact of vegetation has been previously assessed in a few urban ecosystem studies. For example, throughfall and stemflow have been measured in some urban forests and under isolated trees and related to the complexity of vegetation layers (e.g. Guevara-Escobar et al., 2007; Inkiläinen et al., 2013; Livesley et al., 2014). Nevertheless, to date there have been no studies specifically investigating the hydrology of litter layers in urban ecosystems.

Management practices (or lack of) can alter directly or indirectly each of these system components, determining changes in the overall complexity of urban habitats (Byrne, 2007; Gaston et al., 2013), and therefore directly impacting on the local hydrological processes (Fig. 1).

Building on this bi-directional interaction, this study aims to holistically investigate the effects of management-driven differences in habitat complexity upon hydrological properties for each habitat component (soil, litter and vegetation). We addressed the following research questions:

- How do soil physical and hydrological properties vary in urban habitats characterized by different levels of habitat complexity?
- What is the hydrological role of each habitat component (soil, litter, vegetation)?
- How can our findings inform ecologically-sensitive urban habitat management to optimize urban water conservation and retention?

2. Materials and methods

2.1. Study area

The study was conducted in the south-eastern Melbourne metropolitan area, Australia. The geology of the study area was restricted to quaternary and tertiary sandstones and therefore sandy soils, such as Podosols and Tenosols (sand > 89%). The study area was also confined to a single ecological vegetation class, herb-rich, heathy woodland (The State of Victoria, Department of Environment and Primary Industries, 2013), so that differences in soil properties amongst habitat types were brought about through management practices since the suburbs were established. The altitude is between 15 and 50 m a.s.l., the annual mean maximum and minimum temperatures are 19.7 and 10.1 °C, while the average annual precipitation (1950–2014) is 711 mm (Bureau of Meteorology, 2014).

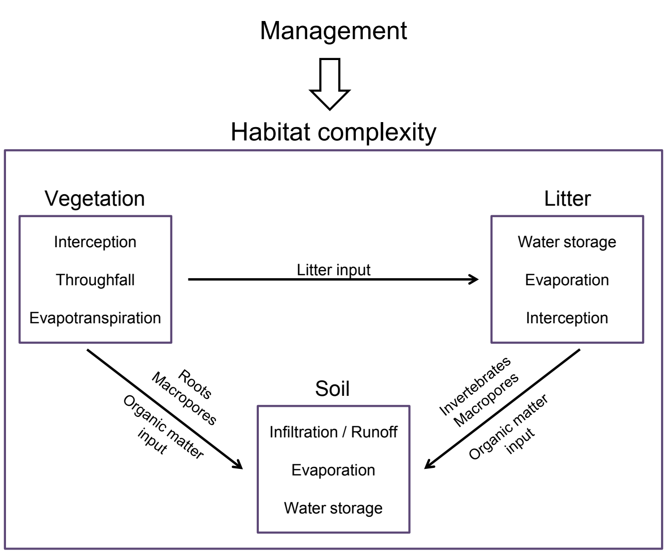

Fig. 1. Diagram exemplifying the effects of management on the three habitat components and the overall habitat complexity. Boxes indicate hydrological processes characterizing each component, while arrows the relations between components.

We selected 3 habitat types based upon their structural complexity and management history (Fig. 2), and established 10 research plots (20 × 30 m) within each type. Plots were selected in flat areas to minimize soil erosion and transport due to superficial runoff. Low-complexity parks (LCP) were characterized by an overstory of various *Eucalyptus* species and a simplified herbaceous understory. Plots were consistently mown since the establishment of the park and the herbaceous ground layer remained <5 cm tall. These plots did not receive irrigation or fertilization and the soil profile had been minimally disturbed. High-complexity parks (HCP) had a similar overstory of various *Eucalyptus* species but with a complex understory layer of shrubs, small trees and herbs. Since their establishment these habitats were not actively managed, allowing the natural regrowth of vegetation and the accumulation of leaf litter. High-complexity remnants (HCR) were structurally similar to high-complexity parks, but they differed with respect to previous land use and current management. High-complexity remnants represented the native vegetation of the study area, and were included to provide a baseline for natural pedological and hydrological conditions. High-complexity remnants sites are managed for conservation purposes and subjected to sporadic management practices including weed removal and supplementary planting of native plants for revegetation. High- and low-complexity park sampling plots were selected from out-of-play areas in five golf courses established on former agricultural land, ranging in age from 43 to 100 years since establishment, and have been consistently managed since then to maintain their current form. High-complexity remnant plots have been selected in five nature reserves managed by local city councils and do not have an age since establishment by definition, being remnant ecosystems.

2.2. Measurement of soil hydrological properties

The field-saturated hydraulic conductivity (Kfs) represents the amount of water infiltrating a soil under ponded conditions. The unsaturated hydraulic conductivity (K), on the other hand, indicates the amount of water infiltrating a soil through meso- and micropores, by excluding the macropores that dominate infiltration rates under ponded conditions. By measuring these two hydrological parameters the proportional importance of macropore flow was estimated. Kfs was measured at four randomized points within each plot with a single ring infiltrometer (30 cm diameter). K was measured at six randomized points within each plot using a tension infiltrometer (MiniDisk, Decagon Devices™, Pullman WA, USA) with the suction adjusted to 2 cm. Infiltration measurements were taken during winter (May–July 2013) after testing for the absence of soil hydrorepellency that can occur in these sandy soils particularly during summer.

2.3. Measurement of soil physical properties

Soil bulk density (BD) is the mass of soil per unit of volume, including soil voids. Soil BD was measured taking one core (diameter 7.4 cm, depth 10 cm) after the single-ring infiltrometer measurement and weighing the oven dried soil (105 °C, 48 h). Soil strength was measured in a 5 × 4 m grid using a hand-held penetrometer (Model PSC, The Meter Man, Toowoomba, Australia) and recorded as penetration depth (PEN) achieved at a penetration resistance of