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Review article

A review of benefits and challenges in growing street trees in paved urban environments

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HIGHLIGHTS

- Street trees provide environmental, economic and social benefits to urban communities.
- Urban environments impose stress on street trees.
- Impermeable surfaces create conflicts between street trees and pavements.
- Methods have been tested to increase tree health and reduce pavement damage.
- Pervious paving is a new and promising method to improve tree growth.

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ABSTRACT

Street trees are an integral element of urban life. They provide a vast range of benefits in residential and commercial precincts, and they support healthy communities by providing environmental, economic and social benefits. However, increasing areas of impermeable surface can increase the stresses placed upon urban ecosystems and urban forests. These stresses often lead tree roots to proliferate in sites that provide more-favourable conditions for growth, but where they cause infrastructure damage and pavement uplift. This damage is costly and a variety of preventative measures has been tested to sustain tree health and reduce pavement damage. This review explores a wide range of literature spanning 30 years that demonstrates the benefits provided by street trees, the perceptions of street trees conveyed by urban residents, the costs of pavement damage by tree roots, and some tried and tested measures for preventing pavement damage and improving tree growth.

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1. Introduction

Urbanisation increases the area of land covered by impervious surfaces such as rooftops, roads, driveways and parking areas (Gill, Handley, Ennos, & Pauleit, 2007), which can impose dramatic changes on a catchment by altering its natural drainage characteristics (Lee & Heaney, 2003; Miller et al., 2014). Increasing the amount of impervious surface effectively seals off much of the underlying soil and prevents precipitation from infiltrating into the soil. An increase in impervious surface coverage in the urban environment can increase water stress on urban forests and ecosystems (Kjelgren & Clark, 1994; Iakovoglou, Thompson, Burras, & Kipper, 2001). Parks and street tree plantings create interesting and dynamic public spaces within the urban environment but tree growth may be limited when tree plots are not properly designed to minimise water stress. The primary purpose of street trees has changed over the last 30 years from an aesthetic role of beautification and ornamentation to one that also includes the provision of services such as stormwater reduction, energy conservation and improved air quality (Seamans, 2013). However, these benefits are not fully realised because street tree growth is often limited by critical landscape design issues that affect access of the tree roots to water, air and nutrients.

Tree growth is influenced by a range of abiotic factors including soil moisture, soil volume, soil porosity, soil chemistry, canopy irradiance and air quality (Iakovoglou et al., 2001; Morgenroth, Buchan, & Scharenbroch, 2013). A change in the availability of soil moisture and soil nutrients in the urban environment can result in costly damage to infrastructure. For example, tree roots proliferate in areas beneath impervious sidewalks and roads that provide sufficient water and nutrients for tree survival and growth (D'Amato, Sydnor, Kane, Hunt, & Bishop, 2002). The use of pervious surfaces, which allow water to infiltrate through the pavement surface and into the soil, has been the focus of recent research (Volder, Watson, & Viswanathan, 2009; Morgenroth & Visser, 2011; Mullaney Lucke, Johnson, Cameron, & Moore et al., 2012; Mullaney & Lucke, 2014). Most studies have investigated whether pervious pavements increase the growth or survival of street trees, while some studies have investigated whether permeable pavements minimise damage to pavements and other urban infrastructure (Mullaney & Lucke, 2014). The underlying theme of these studies is that the drainage layers required underneath permeable pavements may, effectively, create a root barrier beneath the pavement surface, forcing roots to grow at greater depths. These layers can potentially also increase the pavement's water storage capacity, promoting tree health directly while minimising pavement damage.

This review describes and discusses the benefits of street trees, residents' perceptions of street trees, challenges in growing trees in urban environments, and potential methods to increase street tree health and prevent pavement damage. The review focuses on interactions between pavements and street tree roots while acknowledging that other tree organs such as trunks and branches can also cause damage to urban infrastructure. Most of the available literature was derived from temperate regions including the United States and Europe, but the review also covers studies from tropical regions.

2. Street tree benefits

Street trees play an integral role in supporting healthy urban communities and they have a significant social impact by improving human health (Donovan et al., 2013), reducing crime (Kuo & Sullivan, 2001), increasing community interaction (Van Dillen, De Vries, Groenewegen, & Spreeuwenberg, 2012) and boosting property values (Pandit, Polyakor, & Sadler, 2012). The benefits provided by street trees are typically categorised as environmental, economic or social although some benefits span more than one category.

2.1. Environmental benefits

Street trees increase the liveability of towns and cities by reducing stormwater runoff, improving air quality, storing carbon, providing shade, and ameliorating the urban heat-island effect. Street trees also enhance biodiversity by providing food, habitat and landscape connectivity for urban fauna (Burden, 2006; Rhodes et al., 2011). Increases in impervious surface area and soil compaction, due to urbanisation, reduce water infiltration into soil and increase stormwater runoff and peak flow rates. For example, urban runoff from summer rainfall is much higher from asphalt (62%) than from surfaces with tree pits (20%) or turf (<1%), highlighting the effect that trees can have on stormwater reduction (Armson, Stringer, & Ennos, 2013). Leaves and branches intercept, absorb and temporarily store water before it evaporates from tree surfaces or gradually infiltrates into the soil. Mature deciduous trees, such as sweetgum, intercept between 1.89 and 2.65 kL of water per year (Seitz & Escobedo, 2011), while evergreen trees including pines can intercept more than 15.41 kL per year (Cappiella, Schueler, & Wright, 2005).

Emissions and noise from road traffic can be a serious health issue but trees are particularly effective at diminishing noise and capturing airborne pollutants including ozone, nitrogen oxides, sulphur oxides, sulphur dioxides, carbon monoxide, carbon dioxide (CO_2) and particles less than 10 μm in size (Tallis, Taylor, Sinnett, & Freer-Smith, 2011). Large healthy trees can remove between 60 and 70 times more air pollution than smaller trees (McPherson, Nowak, & Rowntree, 1994). Trees remove CO_2 from the atmosphere through photosynthesis, and they decrease the consumption of fuel for heating and cooling by providing shade and insulation (Ferrini & Fini, 2010). The inner-city tree population of Melbourne, Australia (~100,000 trees) is estimated to have sequestered one million tonnes of carbon (Moore, 2009). The cooling effect provided by trees is directly related to tree size, canopy cover, tree location, and planting density. As much as 80% of the cooling effect of trees results directly from shading (Shashua-Bar, Pearlmutter, & Erell, 2009). Street trees can reduce daytime temperatures by between 5 °C and 20 °C, making everyday activities more pleasurable and healthier (Killicoat, Puzio, & Stringer, 2002; Burden, 2006).

Street trees also provide habitat for urban fauna, and some fauna species are so well-adapted to urban environments that they are more abundant in cities than in surrounding natural vegetation (Alvey, 2006; Lambert et al., 2009; Davis, Taylor, & Major, 2012). However, fauna abundance is often lower in the inner city, where tree density is lower, than in suburban and outer-urban