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Research article

Canopy of advantage: Who benefits most from city trees?

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ABSTRACT

Urban tree canopy provides a suite of ecological, social, and economic benefits to the residents of urban areas. With an expanding recognition of these benefits among city residents, there is growing concern that access to these benefits is not distributed equally and may represent the presence of an environmental injustice. This study examines the spatial relationship between median household income and tree canopy variables, specifically realized tree canopy cover and potential tree canopy cover, for Toronto, Canada. Toronto provides a strong empirical focus as it is a densely populated urban setting reported to be exhibiting an increase in the geographic polarization of residents based upon household income. Spatial relationships between median household income and tree canopy variables are evaluated using the bivariate Moran's I statistic, a specialized local indicator of spatial autocorrelation (LISA). This method explicitly identified where statistically significant spatial clusters of high and low household income coincide with significant clusters of high and low urban tree canopy, providing the basis for an examination of the policies and management decisions that led to this temporal snapshot. The importance of these spatial clusters is examined from the perspective of understanding the impact of urban change (both socio-demographic and built form), and from the standpoint of improving equality of access to city trees and their benefits resulting from future tree planting decisions.

1. Introduction

With the emergence of urban forestry as a substantive discipline over the last several decades (see Konijnendijk et al., 2006), there has been rapid expansion in the quantity and focus of scholarship relating to city trees. Initially concentrating on definitions and determinants of urban forest structure (Rowntree, 1984; Sanders, 1984; Talarchek, 1990), the research emphasis quickly expanded to include the identification and quantification of a wide range of perceived ecological, social, and environmental urban forest benefits (Dwyer et al., 1992; McPherson, 1992; McPherson et al., 1997). With a considerable area of North American urban forest loss projected from continuing urbanization (Nowak and Walton, 2005), the focus on the quantification of tree benefits was an important step in moving an understanding of the importance of urban vegetation outside the academic sphere and into public focus to inform policy decisions, especially at the municipal level. Coupled with a shifting focus towards sustainability, a consequence of this broader recognition, several of North America's largest cities have undertaken large-scale urban forest studies to quantify the value of this environmental good. In some cases, such as the Million Trees initiatives in Los Angeles (McPherson et al., 2011) and New York (Locke et al., 2010), new commitments to expand urban tree canopy coverage have resulted. With this broader public awareness, however, has come yet another important expansion in the scope of urban forestry research: who receives the benefits of access to the urban forest?

This research paper quantifies the connection between the spatial distribution of urban tree canopy and median household income in Toronto, Canada through the application of a bivariate local indicator of spatial autocorrelation, bivariate Moran's I. This method explicitly identifies where statistically significant spatial clusters of high and low household income coincide with significant clusters of high and low urban tree canopy. Identification of these clusters provide the basis for an examination of the policies and management decisions that led to this temporal snapshot, and

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whether any distributional inequalities stemming from these decisions could result in a potential environmental injustice with respect to urban tree canopy.

1.1. Ecological aspects of urban forestry

The benefits of urban trees are considerable. In addition to higher residential property values observed with the presence of greater neighbourhood urban tree cover (Anderson and Cordell, 1988; Sander et al., 2010), city trees provide several ecological services often leading to direct economic benefits for both individual residents and to municipalities. The ability to mitigate storm water runoff through increased interception of rainfall can reduce stress on storm water management infrastructure (Berland and Hopton, 2014; Sanders, 1986; Xiao et al., 1988), thus offsetting maintenance and expansion costs to the responsible municipality, as well as reducing the frequency, and damage, associated with residential flooding (Nowak et al., 2010). The shading properties of city trees, complemented by cooling through evapotranspiration, can play an important role in reducing built surface temperatures in cities at different spatial scales.

At the microscale, individual dwellings with strategically planted trees have been shown to exhibit reduced temperatures and associated reductions in energy for summer cooling (Akbari et al., 2001). Through the simulation of irradiance to evaluate the influence of vegetation in shading on residential heating and cooling in four U.S. cities, McPherson et al. (1988) concluded that shading from vegetation considerably reduced the space cooling requirements in temperate and hot climates. Further research by McPherson and Simpson (2003) concluded that in aggregate, the existing trees in California provide an estimated reduction in annual electricity use for cooling by 6407.8 GWh. At the mesoscale, Greene and Millward (2017) concluded that temperature variation in the surface urban heat island of Toronto is moderately explained by canopy density variables. Energy savings at the household scale provide direct financial benefits to residents and can contribute to additional pollution reduction by offsetting energy generation required to meet cooling demands (Akbari, 2002).

By lessening demand for energy required for air conditioning, urban trees are indirectly responsible for pollution reduction in cities. Moreover, in addition to the ability to remove and sequester atmospheric carbon (Nowak and Crane, 2002; Rowntree and Nowak, 1991), city trees are of great importance to the direct removal of several airborne pollutants common in urban environments (Dwyer et al., 1992; McPherson et al., 1998; Nowak et al., 2006). Examining several urban centres across the United Kingdom, Beckett et al. (2000) demonstrated direct reduction of particulate matter less than 10 μm (PM_{10}), through physical filtration mechanisms, by trees of varying size and age. Formation of ground level ozone is inhibited in urban environments when temperature extremes are minimized; microclimatic temperature moderation by city trees has been shown by Nowak et al. (2000) to lower ozone concentrations. Although results varied by city, season, and the time of day, further work by Nowak et al. (2006) demonstrated significant reductions of several airborne pollutants (O_3, PM_{10}, nitrogen dioxide, sulphur dioxide, carbon monoxide) in cities across the conterminous United States. The ability to estimate and quantify reductions in air pollution is now a routine feature in urban forestry software tools (Nowak et al., 2010).

1.2. Human-centered aspects of urban forestry

While the tangible and intangible values of urban trees are considerable, prior literature indicates access to such benefits may be unequal, often disproportionately benefitting certain socio-demographic groups while reducing access for others. A positive relationship between median household income and proximity to tree canopy cover has been established in several notable studies with a focus on North American cities, though the strength of this positive relationship varied by urban centre. Examining the Chicago metropolitan region, Iverson and Cook (2000) concluded there was a moderately strong correlation between household income and landcover, particularly land-cover classes with trees. As a part of a study examining ecosystem services and riskscapes related to the urban heat island in Phoenix, Jenerette et al. (2011) observed an increasingly strong, positive spatial correlation between income and vegetation presence over three decades. Similar results were found by Landry and Chakraborty (2009) when examining the distribution of street trees in Tampa Bay, with lower proportions of street trees more common in the right of ways of lower income neighbourhoods.

Furthermore, other variables have been found that exhibit significant relationships with the spatial distribution of urban tree cover at the micro-scale (i.e., how the percentage of urban tree canopy varies among sub-city units such as census aggregation units). Several recent studies have identified a positive relationship between level of resident education and proximity to trees. Examining the participation in a voluntary tree planting program based in Toronto, Greene et al. (2011) observed a positive relationship between the proportion of the population with post-secondary qualifications and rate of program participation, though the proportion of variation explained varied by sub-region. In addition to the observed correlation in household income and vegetation abundance, Iverson and Cook (2000) also noted a negative relationship between household density and vegetation, particularly trees. Other authors have uncovered connections between the ethno-cultural background of city residents and their relationship to trees (Berland et al., 2015; Conway and Bourne, 2013).

1.3. Positioning urban forestry in an urban sustainability framework

The importance of maintaining and expanding urban vegetation, particularly urban trees, transcends more reductionist questions of ecological benefits or human benefits, and can be positioned as a necessity to achieve stronger sustainability outcomes. Strong approaches to sustainability focus on natural capital assets, with sustainability only being achieved when an equal or greater amount of natural capital is transferred to future generations (Costanza and Daly, 1992; Goodland, 1995; Rees, 1995). When viewed through a lens of strong sustainability, and with the considerable suite of benefits provided by the urban forest to city residents, this resource should be considered a natural capital asset, one that can considerably improve the quality of living in dense urban environments (Bassuk and Whitlow, 1988; Nowak et al., 2001). With this recognition of urban tree canopy as a natural capital resource, however, comes an obligation to consider the social principles of sustainability, particularly intergenerational, intragenerational, and geographic equity (see Haughton, 1999 for detailed descriptions). Considering this ethical paradigm of strong sustainability, over the long term it is imperative to ensure that the benefits of urban trees are protected for future generations (i.e., intergenerational equity), particularly when those benefits could aid in offsetting some of the potential impacts of climate change. In the short-term, it is also important to consider how those benefits are spatially distributed, and to whom (i.e., geographic and intragenerational equity).

With growing interest from academics and policy makers concerning studies that identify unequal access to the benefits of the