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Original article

Tree canopy change and neighborhood stability: A comparative analysis of Washington, D.C. and Baltimore, MD

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ABSTRACT

Trees provide important health, ecosystem, and aesthetic services in urban areas, but they are unevenly distributed. Some neighborhoods have abundant tree canopy and others nearly none. We analyzed how neighborhood characteristics and changes in income over time related to the distribution of urban tree canopy in Washington, D.C. and Baltimore, MD. We used stepwise multiple regression analysis to identify strong predictors of UTC, from variables found in neighborhoods with different patterns of wealth-stability over time. We then built spatial lag models to predict variation in UTC cover, using the results of a Principal Component Analysis of the socioeconomic, demographic, and housing characteristics of the two cities. We found that: (1) stable-wealthy neighborhoods were more likely to have more, and more consistent, tree canopy cover than other neighborhood types; (2) decreases *and* increases in income were negatively associated with UTC in Washington, D.C. but not Baltimore, where income stability in both wealthy and impoverished neighborhoods was a significant predictor of UTC; and (3) the association of high socioeconomic status with UTC coverage varied between the two cities.

1. Introduction

Trees provide a variety of ecosystem services and environmental benefits for urban residents. The environmental benefits of urban forests include heat-stress mitigation, carbon sequestration, noise reduction, air and water quality improvement, and stormwater reduction. Tree management is an important sustainability priority for municipalities because trees are an essential component of a well-functioning urban ecosystem and can be important for mitigating natural hazards such as flooding and excessive heat. Many cities have set ambitious goals for increasing tree canopy cover. Our study cities, Washington, D.C. and Baltimore, MD plan to increase tree canopy cover from a current 35% to 40% by 2032 (O'Neil-Dunne, 2009b; District of Columbia Urban Tree Plan, 2013) and from 27% to 40% by 2037, respectively (Baltimore Sustainability Plan, 2009). If the cities are to meet these goals, the majority of tree growth will have to occur on residential property (O'Neil-Dunne, 2009a,b). But tree planting alone does not constitute an effective urban tree canopy (UTC) plan. Such plans also need to take into account how the interactions in social-ecological systems influence current tree distribution and conservation. Trees can survive for decades in cities when they are properly maintained. Therefore, investments to increase tree canopy coverage are long-term investments that are subject to the long-term dynamics of urban environments, which are heterogeneous socio-ecological systems (Grove et al., 2015). To contribute to the understanding of these long-term dynamics as they relate to UTC, we analyzed how changes in neighborhood characteristics (income over time, educational attainment, racial and ethnic composition, age distribution, and residential real-estate development) correlated to tree canopy coverage across census tracts in Washington, D.C. and Baltimore, MD.

Theories about human population density, social stratification, and reference-group behavior have been used to explain tree canopy distribution (Locke and Grove, 2016). One theory holds that human population density drives vegetation change through development, which

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alters land (Smith et al., 2005; Marco et al., 2008; Cook et al., 2012). But variables other than population density influence vegetation cover in an area, and social stratification theory suggests three: 1) wealthier people have more social and spatial mobility than those with lower incomes, and are therefore able to live in neighborhoods that provide attractive amenities, including green spaces (Logan and Molotch, 2007; Roy Chowdhury et al., 2011); 2) the level of public investment in green infrastructure is positively correlated with the socioeconomic status and political power of residents (Grove et al., 2006); and 3) wealthier residents have more disposable income to invest in landscaping and can afford to maintain trees in their yards and neighborhoods (Hope et al., 2002, 2006; Martin et al., 2004). A study of urban trees in six U.S. cities concluded that the more affluent the neighborhood, the more extensive the tree canopy (Schwarz et al., 2015). But wealth differences are not the sole determinant of the uneven distribution of urban trees. In some places, the higher the percentage of racial- and ethnic-minority residents, the lower the tree canopy cover; however, the strength of association varies geographically (Schwarz et al., 2015). Reference-group behavior theory recognizes the influences of population density, mobility, differentiated political power and income, and economic power on land management, but it puts more emphasis on the role of group identity in shaping neighborhood landscapes and maintaining the so-called "ecology of prestige" (Troy et al., 2007; Zhou et al., 2009; Grove et al., 2014). The ecology of prestige theory holds that household vegetation symbolizes membership in a desirable social group. Of course, present-day tree canopy coverage may also reflect inherited landscapes (Luck et al., 2009; Clarke et al., 2013; Locke and Baine, 2015). For example, Boone et al. (2010) found that *past,* rather than present, neighborhood lifestyles and socioeconomic characteristics were better predictors of urban tree canopy cover in Baltimore.

Most studies of UTC have used a single point in time or "snapshots" to compare social and built-environment characteristics with vegetation cover (Landry and Pu, 2010; Pham et al., 2012; Romolini et al., 2013). But tree distribution is determined by complex social-ecological dynamics over time. Therefore, we incorporated changing conditions at the neighborhood scale to evaluate how neighborhood stability influences the extent of canopy cover. Further, we compared two cities in the same geographic area, rather than focusing on just one city or metropolitan area, as most UTC studies have done. While there is clear value in understanding the idiosyncratic role of places and their individual histories, we argue that more comparative analyses are necessary to advance theory in urban ecology (Roy Chowdhury et al., 2011; Cook et al., 2012).

We used time-series social and biophysical data to examine the dynamics of social characteristics and UTC in two cities that occupy a similar biome and have relatively common biophysical constraints and opportunities for vegetation growth: Washington, D.C. and Baltimore, MD. Our study has two parts. First, we quantified the spatial distribution of UTC in the two cities and examined the relationship between changes in income and built-environment characteristics with the amount of tree canopy at a fine scale (defined by an area with 100-m radius). This allowed us to consider whether positive or negative changes in income are related to the distribution of UTC, conditioned by whether a city is growing in terms of population (D.C.) or declining (Baltimore). Second, we compared predictors of urban tree canopy distribution at the census-tract scale for both cities. The methods for this analysis employed a set of socioeconomic and biophysical variables, principal component analysis (PCA) for data reduction, and spatial regression models of the PCA components for each city.

2. Materials and methods

We first tested six hypotheses to identify the relationships among income change, and percentage of UTC at the neighborhood level in both cities. We sorted neighborhoods into five classes by their income change status, and observed UTC in these neighborhoods. Second, we used stepwise regression models to identify significant predictors of UTC. In this second part, we built spatial lag models, using the results of PCA of a set of variables, to predict UTC at the census-tract level for both cities.

2.1. Study areas

Washington, D.C. and Baltimore, MD are located in the mid-Atlantic region of the eastern United States, adjacent to the Chesapeake Bay. Baltimore is about 60 kilometers northeast of Washington, D.C. Both cities are majority African-American and highly segregated (Logan et al., 2014). Baltimore was established in 1729 and Washington, D.C. in 1790, but the majority of urban expansion in both cities occurred in the 20th century, under similar technological regimes dominated by the automobile. Population peaked in both cities in 1950, followed by decades of population decline as surrounding suburbs boomed. The paths of these two cities have diverged more recently. Between 2000 and 2014, the population of Baltimore declined by ~30,000 residents, while Washington grew by nearly 10% (current populations are 622,000 and 660,000, respectively). Median household income is rising faster in Washington, D.C. Gentrification is occurring in some parts of both cities, but the magnitude is greater in Washington and corresponding rents are also higher (US Census ACS 2013; US Census 2000). Washington can be characterized as a "pull" city, drawing people and investment into the city, while Baltimore remains largely a "push" city, with people leaving for the suburbs and other locations (Gottdiener and Hutchison, 2006). Both cities are undergoing change at both the city-wide and neighborhood levels. With their geographic and historical similarities and contrasting recent growth patterns, Baltimore and Washington offer an opportunity to compare how population and socioeconomic change relate to urban tree canopy.

2.2. Data

We analyzed high-resolution tree canopy data for Washington and Baltimore with data from the University of Vermont Spatial Analysis Laboratory. The Washington dataset quantified tree canopy change, including loss, gain, and persistence, from 2006 to 2011. The only available high-resolution information for Baltimore was from a 2007 land-cover raster map. The two datasets were derived from Quickbird, LiDAR, and National Agricultural Imagery Program data. Resolution for the raster data was set at 0.6 m^2. The shapefile for UTC change (loss, gain, no change) had a minimum mapping unit of 8 square meters. The canopy-change shapefile for Washington (Tree Canopy Change, Washington D.C., 2006–2011) and the Baltimore land-cover raster (Land Cover Baltimore 2007) are freely available and distributed under the Creative Commons Share Alike 3.0 license. Our comparative analyses are based on the static state of the tree canopy coverage in relation to income change in the two cities (UTC for Washington, D.C. for 2006 and Baltimore for 2007). In addition, we examined UTC change over time for Washington D.C.

Consistent spatial units are necessary to study socioeconomic, demographic, and building-characteristic change at the neighborhood level. However, geographic boundaries for the U.S Census Bureau can change over time. To make the Census data comparable over time, we aligned historical census information to year 2010 Census boundaries, using the Longitudinal Tract Data Base program. The program uses proportional area weighting to assign census-variable values to the appropriate space (Logan et al., 2014). As of 2013, Washington had 179 Census tracts (including the National Mall and Capitol Hill) and Baltimore had 200. Median household income data in inflation-adjusted dollars were acquired from the year 2000 Census and 2013 American Community Survey (ACS) from the U.S. Census Bureau.