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Research Paper

Land use and socio-economic determinants of urban forest structure and diversity

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ABSTRACT

The spatial distribution of urban greenness within a city is largely influenced by land use configuration and social factors. This study builds upon previous research focusing on urban forest patterns in relation to land use and socio-economic determinants, while expanding the set of measures used to represent the forest structure. Instead of focusing on canopy cover alone, this study examines two additional attributes, stem density and species diversity, and evaluates the relative importance of land use and socio-economic indicators in determining the urban forest structure in Cook County, Illinois. A combination of remotely sourced data sets and tree records from field surveys are used collectively in addressing the following hypotheses: (H_0) Canopy cover alone sufficiently describes the predominant forest patterns in Cook County, (H_1) Forest structure measured as described by canopy cover, stem density, and species diversity, varies across census tracts, and (H_2) Spatial variability is explained by the land use distributions and a defined set of socio-economic variables. Our results show that the land use and socio-economic factors are better correlates with canopy cover and stem density than species diversity. Overall, Cook County's urban forest is unevenly distributed across census tracts, with wealth, education, racial composition, and home ownership playing different roles in shaping the forest structure. Our study also identifies the many challenges the urban forest is currently facing and highlights key priorities for future planning and management efforts towards a healthier, more diverse regional forest.

1. Introduction

Urban forests constitute an important part of metropolitan region landscapes. They provide a wide spectrum of benefits in the form of reduced air temperature and energy use, improved air and water quality, reduced water runoff, more diverse wildlife habitat, and increased property value (Barron, Sheppard, & Condon, 2016; Nowak, Crane, & Stevens, 2006; Siriwardena, Boyle, Holmes, & Wiseman, 2016; Talarchek, 1990). Additionally, they improve human health and well-being by providing numerous health and recreational benefits, making the urban environment a more pleasant and aesthetic place to live (Akpinar, Barbosa-Leiker, & Brooks, 2016; Payton, Lindsey, Wilson, Ottensmann, & Man, 2008; Ulrich, 1986).

Urban forests can be considered both natural and anthropogenic in that they exist as a result of ecological, social, and political actions and decisions (Talarchek, 1990). Land use has been associated with urban forestry as a physical attribute that creates spaces for trees (Rowntree, 1984; Sanders, 1984). However, land use by itself fails to adequately describe forest patterns as it involves various human activities that generally are not directly related to trees. Socio-economic conditions are an important driver of forest distribution and structure (Hope et al., 2003; Iverson & Cook, 2000; Watkins, Mincey, Vogt, & Sweeney, 2017), and studies have identified strong relationships between canopy cover and neighborhood socio-economic characteristics (Grove et al., 2006; Heynen & Lindsey, 2003; Landry & Chakraborty, 2009). Such within-region variation could contribute greatly to disparate access to positive urban amenities and their environmental, social, and health benefits among different social groups, as indicated in the income inequality hypothesis (Conway & Bourne, 2013; Grineski, Bolin, & Boone, 2007; Heynen, Perkins, & Roy, 2006).

To date, most urban forest research has focused on forest structure represented by canopy cover (Grove et al., 2006; Iverson & Cook, 2000; Talarchek, 1990). Urban tree canopy cover is relevant as many tree benefits and ecosystem services are linked directly to the leaf area of

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plants (Bhaskaran, Paramananda, & Ramnarayan, 2010). Further, the advancement of geographic information technologies and availability of very high-resolution satellite imagery provide unique opportunities for effective urban forest mapping at unprecedentedly large spatial scales (MacFaden, O'Neil-Dunne, Royar, Lu, & Rundle, 2012; Myint, Gober, Brazel, Grossman-Clarke, & Weng, 2011; Zhou & Troy, 2008).

Stem density is another important attribute of forest structure that has received relatively less attention in urban forest research. It measures the number of stems per unit area and is an important indicator of stem abundance in a region. In contrast to tree canopy, stem density treats all trees equally regardless of their canopy size. A high stem density in urban areas may serve as a positive indicator of an expanding urban forest, while in urban woodlands and savannahs it could also indicate an overabundance of invasive or successional species. In comparison with canopy cover, stem density is under immediate control of forest managers and land owners and thus is hypothesized to show great variations across land use types and socio-economic groups (Conway & Bourne, 2013).

The benefits and importance of promoting and preserving a diverse forest have been increasingly acknowledged within urban forestry (Bourne & Conway, 2014). Urban biodiversity has a wide spectrum of biological and social functions to the city, including ecosystem services, biological resources, and education and recreational opportunities (Jim & Chen, 2009). In addition, higher levels of species diversity provide effective protection against environmental changes and abrupt conditions such as climate change, disease, and pest outbreaks (Alvey, 2006). There has been a growing body of literature focusing on species diversity in relation to socio-economic conditions such as income, attitudes, housing density, and building age (Acar, Acar, & Eroğlu, 2007; Hope et al., 2006; Kirkpatrick, Davison, & Daniels, 2012; Martin, Warren, & Kinzig, 2004; Nitoslawski, Steenberg, Duinker, & Bush, 2017). Much fewer studies, however, have examined the variation in species diversity across land use types, with a few studies focusing exclusively on one land use (Hobbs, 1988; Li, Ouyang, Meng, & Wang, 2006; Trammell & Carreiro, 2011), or a combination of all land use types in a region (Heynen & Lindsey, 2003; Muthulingam & Thangavel, 2012). Since many planting options, decisions, and actions are land use-dependent, studying species diversity in the context of land use classes is needed to understand the mechanism and factors driving diversity, and to provide guidance for future planning and management (Bourne & Conway, 2014; Nitoslawski, Duinker, & Bush, 2016).

This paper builds on previous efforts by focusing on the spatial variation in the abundance, density, and diversity of the urban forest in Cook County, IL. We quantify the spatial variability of the forest structure and evaluate its associations with the land use and socio-economic conditions in the region. For the purpose of this research, we define "forest pattern" as the spatial distribution of forested areas over the urban landscape especially in relationship to land use classes and urban development, and we define "forest structure" as the expression of forest characteristics such as abundance, size, height, and density. We aim to address the following hypotheses: (H_0) Canopy cover alone describes the predominant forest patterns in Cook County, (H_1) Forest structure as described by canopy cover, stem density, and species diversity, varies across census tracts, and (H_2) Spatial variability is explained by the land use distributions and a defined set of socio-economic variables.

2. Methods

2.1. Study area

The area of investigation is Cook County, Illinois (Fig. 1). Cook County is the second most populous county in the United States (after Los Angeles County) and is home to more than five million residents (US Census Bureau, 2010). Its county seat, Chicago, is among the largest and most densely populated cities in the world, accounting for 24% of the land area in Cook County and 51.5% of its total population. Situated along Lake Michigan, this region is characterized by a humid continental climate with an average high temperature of 27.2 °C in the summer and an average low temperature of −8 °C in the winter (Hartz, Brazel, & Golden, 2013).

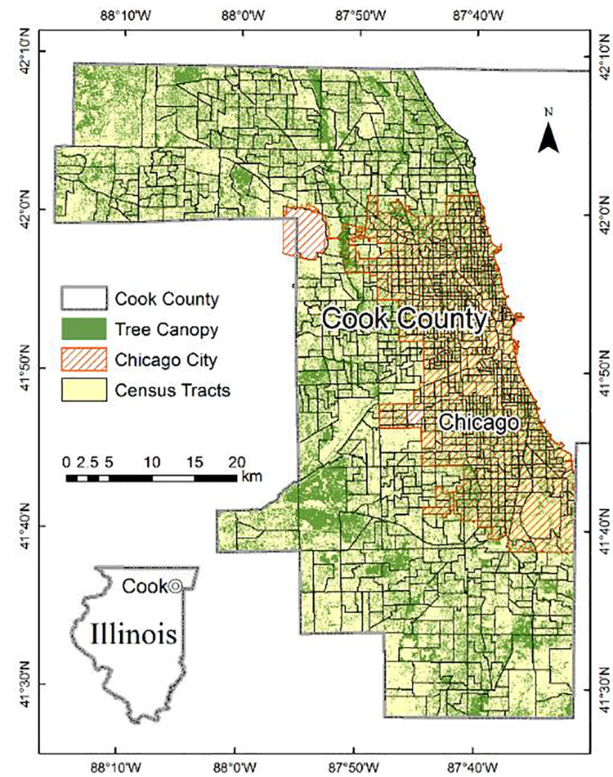

Fig. 1. Study area located in Cook County, Illinois.

While the city of Chicago's population was 2,695,598 residents as of 2010 (US Census Bureau, 2010), the city's population has declined since the middle of the 20th century, from over 3.6 million in 1950 to 2.7 million in 2010 (Chicago Tribune, 2017). Some neighborhoods experienced more evident population loss, disinvestment and economic downturn, especially in the south and western part of the city (Johnston, Manley, & Jones, 2016; Sandoval, 2011). In contrast, downtown Chicago has experienced a housing boom, partly driven by urban gentrification, higher concentration of most skilled jobs, with population almost doubling in the 2000s (Hwang & Sampson, 2014; Levy & Gilchrist, 2012; Testa & Sander, 2016). Specifically, the area within two miles of the downtown has increased by 48,000 from 2000 to 2010 (Testa & Sander, 2016)

Tree canopy covers 18.7% of land area in Chicago and ∼28.5% in Cook County in 2010, compared with a canopy cover of 11% in Chicago and 23% in suburban Cook County back in 1993 (McPherson, Nowak, Sacamano, & Prichard, 1992). Despite the increased canopy cover, the urban forest in this region faces multiple challenges and is currently in the state of transition (Nowak et al., 2013). A major factor for the transition is the massive loss of ash trees to the emerald ash borer (*Agrilus planipennis*), an invasive species that is killing 13 million ash trees across the seven-county Chicago metropolitan region. The lack of species diversity and prevalence of exotic invasive species pose additional challenges, and highlight the pressing need for a good understanding of the composition of the regional forest (Nowak et al., 2013).

2.2. Data collection and processing

Quantification of tree canopy cover was accomplished according to the Urban Tree Canopy (UTC) protocols from the United States