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Urban forests and social inequality in the Pacific Northwest

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ABSTRACT

Research has shown there is a positive relationship between urban greenness and the well-being of city residents. But greenness is often unevenly distributed across a city, raising environmental justice issues. In 2011 and 2012 the USDA Forest Service, Forest Inventory and Analysis program installed ground plots in the urbanized areas of Oregon and Washington. We analyze these data for the urban areas west of the Cascade Mountains, linking it with demographic data from the U.S. Census to examine the relationship between greenness and socioeconomic status at a sub-regional scale. To explore some relations between urban forest measures and socioeconomic conditions and measures we developed four models: presence of tree canopy cover with a logistic mixed model, and on a subset of the data, percent tree canopy cover with a linear mixed model and tree count and tree species count with Poisson mixed models. We found that median household income, house value, land use, and years in the Tree City USA program contributed to explaining measures of greenness, such as canopy cover presence, percent canopy cover, tree counts, and tree species counts. This agrees with other studies, but does so at a broad scale covering the most densely populated areas in the Pacific Northwest.

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1. Introduction

Studies conducted in several U.S. cities have shown that urban neighborhoods with higher socioeconomic status (SES) tend to be greener. This finding raises significant environmental justice concerns. Vegetation in the urban environment provides a range of important benefits to local residents, including the removal of air pollutants (Nowak, 1994; Nowak et al., 1996, 2006), moderating air temperatures (Akbari and Taha, 1992; Simpson and McPherson, 1998; Akbari, 2002; Donovan and Butry, 2009), and a green environment has been found to reduce psychological stress and has been linked to better health (Ulrich, 1984; Schroeder and Cannon, 1987; Smardon, 1988; Dwyer et al., 1991, 1992; Donovan et al., 2011; Kardan et al., 2015).

The positive association with human health might be the most potent benefit of natural areas in the urban environment. Jennings and Gaither (2015) report on numerous studies that suggest the active engagement with green spaces is associated with improvements in both physical and psychological well-being. In England, Mitchell and Popham (2008) found lower rates of death due to stress-related illnesses for urban residents with greater exposure to greenness. Access to greenness was also associated with a reduced disparity in human health measures in areas where social inequality existed. Therefore, in addition to a correlation with better health, greenness has been associated with improved health outcomes even where SES indicators are considered low.

Studies that link SES and greenness mainly fall into two categories: those that measure vegetation using remote sensing (e.g., satellite imagery), and those that measure vegetation using a ground-based sampling system such as sample plots. The majority of studies have relied on remote sensing data, for example, Iverson and Cook (2000) used satellite imagery to quantify the relation between land-use, urban development, tree cover, housing density, and household income in the Chicago metropolitan region. They found a positive correlation between the density of canopy cover and neighborhoods with higher levels of income. Gowen and Mellnik (2013) report on a study done in Washington, D.C. that found racial segregation was higher in neighborhoods with higher impervious surface area and lower tree-canopy cover. In a regional-scale study of several metropolitan areas, Jesdale et al. (2013) found a similar relationship within densely populated racially segregated neighborhoods, more impervious surfaces, and less canopy cover. They concluded this puts minority populations living in large cities at a greater risk of heat-related illnesses than non-Hispanic whites living in the same city.

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Although satellite imagery has allowed several authors to identify a relationship between socioeconomic status and the natural environment, satellite resolution of 20–30 m may be too coarse to characterize the natural environment in highly heterogeneous urban areas. For example, satellite imagery provides very limited information on species diversity and density or vertical structure of vegetation. This is important because past research has shown, for example, that taller trees provide more benefits than smaller trees (Nowak et al., 2006; Donovan and Prestemon, 2012). Larger trees of some species are also more cost effective because their life expectancy and, therefore, longevity of ecological, esthetic, and social benefits is greater than that of smaller or faster-maturing trees (Geiger, 2004). Quantifying species diversity can help planners prepare for potential threats. As Boyd et al. (2013) report, the number of invasive tree pests identified in the U.S. is rising dramatically, and since pests often prefer a narrow range of hosts, the resilience of urban forests can be increased by emphasizing genetic or species diversity (Raupp et al., 2006).

Fewer studies have used ground-based vegetation surveys to assess the SES – greenness relationship. Hope et al. (2003) and Kinzig et al. (2005) studied the diversity of plants and birds in the Phoenix, AZ metropolitan area and found a positive correlation between diversity and both income and house value. Szantoi et al. (2012) augmented data from aerial photography and satellite imagery with ground plots in the metropolitan areas of Miami-Dade County, Florida. They reported the amount of neighborhood canopy cover was positively linked with several socioeconomic factors, including income, education, and home ownership. De la Maza et al. (2002) and Escobedo et al. (2008) grouped boroughs (or *comunas*) in Santiago, Chile's metropolitan area into three socioeconomic strata to examine species diversity and the removal of air pollution by trees. Using the Urban Forest Effects Model (UFORE; Nowak and Crane, 2000) to compile tree data collected on ground plots, they found the boroughs in the wealthiest strata had greater species diversity, tree leaf area and subsequent air-quality benefits, than boroughs in the lower-ranked strata. Pedlowski et al. (2002) stratified 10 neighborhoods in Campos dos Goytacazes, Rio de Janeiro, Brazil by wealth and found higher levels of species diversity in street and park trees in wealthier neighborhoods.

Although these studies used ground-based inventory to investigate the SES – greenness relationship, the authors have used a model-based sampling approach where cities were pre-stratified based on land cover or demographic characteristics. In contrast, a design-based approach assumes all areas are of equal importance, plots under the model-based approach are installed to sample each strata for the attributes of interest (e.g., Escobedo et al., 2006). In addition, model-based studies have typically focused on single metropolitan areas and the neighborhoods or suburbs within them. Single-city studies have limited scope of inference; however, a small-scale model-based approach is understandable, given the cost of collecting data and heterogeneous urban land ownership patterns. Nevertheless, the validity of a model-based strategy depends on making the right stratification and modeling assumptions. For example, a model-based study might assume a linear relationship between tree cover and income. A likely sampling strategy would, therefore, concentrate on areas with very high or very low income. If the linearity assumption is correct, then the sampling strategy may reveal more about the relationship between trees and income than a design-based approach with the same sample size. However, if the linearity assumption is incorrect, then the model-based sampling strategy would under sample areas with moderate income, which may result in inefficient or biased coefficient estimates.

The USDA Forest Service, Forest Inventory and Analysis (FIA) inventory is design-based. The sample plots are part of a national grid; their locations are independent of cover, ownership, and land use, so the validity of the sampling inferences does not depend on modeling assumptions (U.S. Department of Agriculture Forest Service, 1992; Bechtold and Patterson, 2005.).

We address the gap in the literature using data from the first regional FIA inventory of urban trees in the U.S. This unique dataset allows us to explore the relationship between neighborhood socioeconomic status, land use, tree cover, tree size, and species diversity across multiple cities in the Pacific Northwest. The sample is also broader than past studies in both geographic area and the number of cities included. We also consider a city's length of membership in the Tree City USA (2013) program as a surrogate for recognizing the benefits of urban trees by having a budget and a plan for promoting urban trees via an urban forestry program. We examined the following questions:

(1) What is the relation between the existence, or presence, of tree canopy cover in urban FIA subplots and neighborhood socio-economic indicators and measures?
(2) What is the relation between tree canopy cover (as measured by percent canopy cover) in urban FIA subplots and neighborhood socio-economic indicators and measures?
(3) What is the relation between tree counts, in subplots with measureable canopy cover, in urban FIA subplots and neighborhood socio-economic indicators?
(4) What is the relation between tree species counts, in subplots with measureable canopy cover, in urban FIA subplots and neighborhood socio-economic indicators and measures?

2. Methods

2.1. Location

The urbanized area (U.S. Department of Commerce Bureau of the Census, 2002) included in this study is located west of the Cascade Mountain Range in Northwest Oregon and Western Washington (Fig. 1). The FIA plots had been installed in areas Census had identified as urbanized, located on a GIS overlay, which included metropolitan areas with a core population of 50,000 or more. Our study area ranged from Eugene, Oregon in the south (44.0519° N Latitude) to Bellingham, Washington, 550 km (335 miles) to the north (48.7502° N Latitude), and located between 122.1633° and 123.2760° West Longitude. The total land area included in the study is roughly 5160 km^2. This encompasses the larger metropolitan areas of Seattle and Portland, and their adjacent suburban cities.

The Köppen climate classification (Kottek et al., 2006) indicates these urban areas reside within a (Csb) zone, characterized by a cool-mild wet winter and dry summer, with warmer summers in the south. Temperatures in this region range from average to winter low of 0 °C in the north to summer highs of 28.2 °C in the south. This area supports two class III ecoregions, as defined by Omernik (1987) and updated by the U.S. Environmental Protection Agency (2013). In Washington, all but the southern portion of the study area is in the Puget Lowland ecoregion, while Vancouver, Washington and all of the study area in Oregon are in the Willamette Valley ecoregion.

2.2. FIA Inventory

The U.S. Department of Agriculture Forest Service, Pacific Northwest Research Station, Resource Monitoring and Assessment (RMA) Program is part of the national FIA effort. The traditional role of FIA is to manage a sampling framework consisting of a set of permanent ground plots on a systematic-random grid that includes all lands in all states (Bechtold and Patterson, 2005). Plots are spaced roughly 5.4 km apart and all plots, prior to 2014, had the same basic design.