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Review

The relationship between urban forests and income: A meta-analysis

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ABSTRACT

Urban trees provide substantial public health and public environmental benefits. However, scholarly works suggest that urban trees may be disproportionately low in poor and minority urban communities, meaning that these communities are potentially being deprived of public environmental benefits, a form of environmental injustice. The evidence of this problem is not uniform however, and evidence of inequity varies in size and significance across studies. This variation in results suggests the need for a research synthesis and meta-analysis.

We employed a systematic literature search to identify original studies which examined the relationship between urban forest cover and income (n = 61) and coded each effect size (n = 332). We used meta-analytic techniques to estimate the average (unconditional) relationship between urban forest cover and income and to estimate the impact that methodological choices, measurement, publication characteristics, and study site characteristics had on the magnitude of that relationship. We leveraged variation in study methodology to evaluate the extent to which results were sensitive to methodological choices often debated in the geographic and environmental justice literature but not yet evaluated in environmental amenities research.

We found evidence of income-based inequity in urban forest cover (unconditional mean effect size = 0.098; s.e. = 0.017) that was robust across most measurement and methodological strategies in original studies and results did not differ systematically with study site characteristics. Studies that controlled for spatial autocorrelation, a violation of independent errors, found evidence of substantially less urban forest inequity; future research in this area should test and correct for spatial autocorrelation.

1. Introduction

Traditionally, quantitative environmental justice research has been concerned with the extent to which low-income and minority communities are exposed to environmental hazards and lack access to environmental amenities. As research increasingly considers the causes of and potential remedies for environmental inequity, important questions remain about the size and scope of the problem itself. While several reviews have been conducted of the environmental hazards literature (Ringquist, 2005; Mohai, Pellow, & Roberts, 2009), little synthesis has been conducted on the distribution of environmental amenities. We conducted a systematic review and meta-analysis of an important environmental amenity, urban forest cover, and its relationship to income.

Urban forests—the land in and around areas of intensive human influence which is occupied by trees and associated natural resources (definition modified from Strom, 2007)—provide many environmental and health benefits to urban residents (Rosenzweig et al., 2006; Kuo, 2001; Donovan & Butry, 2010). Over the last several decades, studies have considered the empirical distribution of the urban forest with respect to an array of socioeconomic characteristics. Findings across studies have been mixed with respect to income; most studies find a positive relationship between urban forest cover and income (Danford et al., 2014; Heynen, Perkins, & Roy, 2006; Landry & Chakraborty, 2009; Locke & Grove,2014; Pham, Apparicio, Séguin, Landry, & Gagnon, 2012; Schwarz et al., 2015) but there are some exceptions (Pham, Apparicio, Landry, Séguin, & Gagnon, 2013; Grove, Locke, & O'Neil-Dunne, 2014).

While some evidence suggests income-based urban forest inequity exists, the magnitude of estimates varies across studies and the average magnitude is unknown. Moreover, the city-specific nature of previous research and variation in methodological choices across studies raise questions about the source of differences—does variation in results reflect real differences between study sites, or is it a product of methodological choices? Answering these questions will inform current research on the drivers of urban forest cover inequity, methodological choices in environmental justice research, and ongoing efforts to increase forest cover in cities around the world (McPherson & Young, 2010). This project aggregated information from many city-specific

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studies to estimate the average effect size (average relationship) between urban forest cover and income. A companion paper examined the relationship between urban forest cover and race (Watkins & Gerrish, 2017). Our analysis also examined potential explanations for variation across studies by controlling for characteristics of the original studies such as their empirical strategies and study location. By quantifying the findings from the relevant literature, meta-analysis yields a more complete summary of the state of our collective knowledge as compared to a systematic review.

Meta-analysis is particularly useful in the case of urban forest equity because it synthesizes several literatures that might not normally interact. In addition to studies that are explicitly concerned with environmental justice and inequity, there are many studies that estimate the same relationship to achieve other research objectives, including to evaluate competing theories about drivers of urban land use (Boone, Cadenasso, Grove, Schwarz, & Buckley, 2010; Grove, Cadenasso, Burch, Pickett, Schwarz, O'Neil-Dunne, et al., 2006), draw insights about the choices of private citizens (Pham et al., 2013; Grove, Locke, & O'Neil-Dunne, 2014) or public servants (Landry & Chakraborty, 2009), and improve urban forest cover measurement (Szantsoi, Escobedo, Dobbs, & Smith, 2008). This study diversity gave us a unique ability to evaluate the sensitivity of study results to methodological choices, a concern articulated by environmental justice scholars but not yet evaluated with respect to environmental amenities.

A note on terminology: scholars define and measure both urban forest cover and income in numerous ways. For example, some scholars include herbaceous cover (grass and shrubs) in their measure of urban forest cover, while others limit their measure strictly to trees or tree cover. For simplicity, we use *urban forest cover* as a catch-all term for our outcome of interest. We use *income* to describe measures of financial resources, including poverty rates or "high poverty" dichotomous indicators.

The remainder of this paper is organized as follows: the next section discusses our data collection process, including the literature search process and the inclusion criteria. We then discuss reasons that urban forest cover inequity may vary across studies according to the literature. We then discuss our coding of effect sizes and relevant covariates and the meta-analytic methods used in this analysis (forest plots and meta-regression). We report results, discuss their implications for research and urban forest policy, and conclude.

2. Literature search and inclusion criteria

2.1. Literature search

We implemented this meta-analysis as outlined by Ringquist (2013) and Borenstein, Hedges, Higgins, and Rothstein (2009). First, in the scoping stage we refined and operationalized our research question and identified the focal predictors (see inclusion criteria below). Second, we populated a complete list of acceptable measures of the dependent variable (i.e. urban forest cover) and generated coding instruments.

We then conducted a systematic and exhaustive search of the existing literature to identify all original studies that have empirically tested the relationship between urban forest cover and socio-demographic characteristics. To identify appropriate studies, we identified (1) a set of search terms that would yield original studies that met our inclusion criteria and (2) relevant repositories that would contain original studies. In each repository, we conducted the same set of 16 unique searches—each search included the word "urban," one of four search terms related to the dependent variable urban forest cover, and one of four terms related to the distribution of that forest cover. The four dependent variable search terms were "*tree cover,*" *canopy*, *forest*, and *vegetation*. The four other terms were *socioeconomic*, *demographic*, *distribution*, and *equity*. We conducted these searches in the following academic research databases: Academic Search Premier, American Psychological Association (APA) PsycNET, Google Scholar, Google Books, JSTOR, National Bureau of Economic Research (NBER), ProQuest Dissertations and Theses Database (PQDT), Social Science Research Network (SSRN), and the local version of WorldCat (USDCat) for all articles and then again for books only.

Each search permutation (e.g. *urban "tree cover"* by *socioeconomic* using Google Scholar as the search engine) returned several study results, termed "hits." Using the title alone, we evaluated whether the study was *potentially relevant* by determining whether the study could satisfy our inclusion criteria (see below). If we determined from the title that a study was potentially relevant, we read the abstract. Using the title and abstract we determined whether each potentially relevant study was *relevant*, meaning that study could plausibly meet our inclusion criteria. Finally, if the study was relevant, we read the full text to determine whether it satisfied our inclusion criteria and was *acceptable*. We then coded each acceptable study (see study coding). We completed database searches on October 3, 2016.

In addition to database searches, we employed three strategies to identify all relevant studies, including conference proceedings and presentations, government reports, and white papers. First, we emailed the first three authors of each acceptable study, informed them of our project, noted their acceptable study(ies), and requested any additional relevant published or unpublished studies that they authored. Second, we conducted an ancestry and legacy search for each acceptable study. We reviewed each citation in the study (the study's ancestry) for potentially relevant titles and used Google Scholar's "cited by" function to find studies that had cited the acceptable study (the study's legacy). Finally, we sent a request for studies to subscribers of the Urban Forest Listserv, a listserv that facilitated discussion on theoretical and applied urban forest research (managed by the University of South Florida).

2.2. Inclusion criteria

The inclusion criteria listed non-negotiable requirements for any study to be included in our meta-analysis. If a study met the inclusion criteria, other study variation was tolerated.

The first inclusion criterion was that the outcome measure must have measured urban trees or urban vegetation (could also have included trees and could also have included shrubs and grass). Outcome variables were typically the dependent variable in a regression analysis or one of the two variables in a correlation. We excluded studies that used other measures of urban environmental condition, including measures of herbaceous cover (grass and shrubs only), the distribution of parks, and measures of ecosystem services related to urban trees (e.g. atmospheric temperature, carbon storage). We also excluded tree species diversity.

The second inclusion criterion required the focal predictor to be a measure of either absolute or relative income, or race or ethnicity (as mentioned above, the focal predictor race was analyzed in a companion piece, Watkins & Gerrish (2017)). Studies used different measures of income but the most common were median income (70 percent of effect sizes) and poverty rate (20 percent of effect sizes). We would have also included a measure of total wealth, but no such measure was used in any study. We excluded studies that used other socioeconomic proxies for income such as education, property value, or percent renters. We excluded effects that did not measure income independently of other factors. For example, Nielsen's PRIZM neighborhood segmentation data combined a set of neighborhood-level socioeconomic factors into one indicator, from which we could not isolate income.

Third, we included studies only if they had intra-city variation. Studies that exclusively compared urban forest cover between cities without any variation *within* cities were excluded (for example, Heynen & Lindsey, 2003). We excluded studies without intra-city variation because this would likely mask locally-driven relationships between income and urban forest cover. For the purposes of this analysis, we also excluded any effects for which the independent and dependent variables were measured more than ten years apart (e.g. Locke & Baine,