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Research

Using Remote Sensing and Geographic Information Systems to Study Urban Quality of Life and Urban Forest Amenities

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ABSTRACT. This study examines urban quality of life by assessing the relationship between observed socioeconomic conditions and urban forest amenities in Terre Haute, Indiana, USA. Using remote-sensing methods and techniques, and ordinary least squares regression, the paper determines the relationship between urban leaf area and a population density parameter with median income and median housing value. Results demonstrate positive correlations between urban leaf area, population density, and their interaction with median income and median housing value. Furthermore, leaf area, density, and their interaction statistically account for observed variance in median income and median housing value, indicating that these variables may be used to study observed quality-of-life metrics. The methods used in this study may be useful to city managers, planners, and foresters who are concerned with urban quality-of-life issues, and who are interested in developing and implementing alternative policy assessment regimes.

INTRODUCTION

Cities and the sustainability of urban environments have emerged as a primary concern for city planners, policy makers, and residents. As such, the availability of urban environmental amenities and the distribution of these resources across space should be of increased public salience in future years, insofar as urbanization and sprawl alter the environmental dynamics of cities. To understand the shifting dynamics of cities, we propose investigating urban forests.

This study investigates the socioeconomic characteristics associated with the urban forest in the Terre Haute, Indiana, USA area. As part of our study, we explicitly question whether the observed socioeconomic conditions covary with leaf area index (LAI).

The rationale for this study is based, in part, on earlier research that indicates real-estate markets are improved by urban forests (e. g., Anderson and Cordell 1985, Sydor et al. 2003, Laverne and Winson-Geideman 2003). However, this study is necessarily informed by the vast literature within the field of geography and across the social sciences on the sociospatial dynamics of environmental degradation and urban inequalities (e. g., Pulido 2000, Harner et al. 2002). In concert, these two themes lay the foundation for a paper that examines how the economic, environmental, and psychic benefits of resources are unevenly distributed across urban space, and how these resources may or may not interact to produce divergent market conditions and, by implication, shared neighborhood geographies.

Urban Forestry

Urban forestry is an increasingly prominent sub-field in many social-science disciplines interested in unlocking the structure and meaning of humanity’s urban habitat. Urban forestry—the sustained planning, planting, and protection of trees, residential tree lines, and forests in urban areas (Blouin and Comeau 1993)—is valued for aesthetic, ecological, and economic reasons. Aesthetic benefits include pleasant landscape, peace and quiet, screening and privacy, and recreation opportunities, as well as the intangible benefits of an improved quality of life for residents (Sheets and Manzer 1991, Hull 1992, Kennard et al. 1996, Tyrvainen and Vaananen 1998, Summit and Sommer 1998). In addition to intangibles, such as improved psychic capital, trees have been found

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to increase property values, influence the decision-making process of potential homebuyers or renters, and partially structure local real-estate markets (Getz et al. 1982, Anderson and Cordell 1985, Sydor et al. 2003, Laverne and Winson-Geideman 2003). In terms of socioeconomic conditions, urban forestry has been preliminarily linked to a full range of observed conditions (Talarchek 1990, Heynen and Lindsey 2003). Both these studies found positive correlations can be observed based on rudimentary measures of urban forests (percentage of urban forest cover). In short, research suggests that natural spaces improve urban environments and make communities more livable.

Urban forests also have many environmental benefits. For example, trees absorb gaseous pollutants through leaf stomata and can dissolve or bind water-soluble pollutants onto moist leaf surfaces. Tree canopies intercept particulates and reduce local air temperatures in the summer through increased albedo and evapotranspiration; they reduce air ozone concentrations, either by direct or indirect absorption of ozone or other pollutants such as NO_2, or by reducing air temperature, which reduces hydrocarbon emission and ozone formation rates (McPherson et al. 1998). Finally, urban trees support a host of wildlife that people are able to enjoy close to home.

In addition to the strictly ecological and economic benefits of urban forests, trees have the capacity to reduce the urban heat island effect (UHIE)—thereby producing combined economic and ecological benefits. The UHIE is caused in part by land-cover conversion and the replacement of the land surface by nonevaporative and nonporous materials, such as concrete and asphalt. In addition, air-conditioning systems can introduce a significant amount of heat into the urban landscape (Jensen 2000). Two studies (Lo et al. 1997, Quattrochi and Ridd 1998) evaluated several cities using thermal remote-sensing data to document the effect. They found that, during the daytime hours, commercial land cover exhibited the highest temperatures, followed by service, transportation, and industrial areas. Conversely, the lowest daytime temperatures were found over water, vegetation, and land devoted to agricultural use. At night, commercial, service, industrial, and transportation land covers cooled relatively rapidly, but their predawn temperatures were still slightly higher than those of vegetated and agricultural areas. Sailor (1995) found that the urban heat island was diminished when vegetation was increased. Likewise, Quattrochi and Luvall (1999) found that urban forests had a significant dampening effect on the UHIE.

Contemporary Quality of Life in Urban Areas

Urban quality of life (UQL) is a relatively new urban issue that gained notoriety in the 1980s by initiating new forms of environmental rules and regulations, and introduced alternative strategies and tactics to mainstream environmentalism (Floyd and Johnson 2002). Following President Clinton's Executive Order 12898 (United States Government 1994), the issue of environmental equity and justice in natural resource allocation received increasing attention (Tarrant and Cordell 1999). Since then, much research has been completed to address these issues, and UQL has become a major focus within environmental social science (Weinberg 1998). Furthermore, UQL has become a major focus for planners, funding agencies, and local communities (Steinberg 2000). At the center of this focus are recognition and awareness of the distribution of environmental costs and benefits.

Recent UQL studies have used geographic techniques, such as geographic information systems (GIS) and remote sensing, to analyze observed urban conditions and elucidate the core policy issues and stratagems to improve the material conditions of everyday life, and the overall quality of life of residents (e. g., Porter and Tarrant 2001, Harner et al. 2002, Mennis 2002). In 2002, Pedlowski et al. examined the relative wealth, species diversity, and abundance of urban forests in Brazil. Although not definitive, the Brazilian analysis suggests a relationship between class and urban forest amenities. Our study is unique because it combines the analytical framework of GIS and remote sensing with an explicit understanding that urban forests are constructed—in terms of environmental policy—as a desired condition that promotes the inherently uneven and even problematic notion of an improved "quality of life."

To accomplish the tasks described above, this paper empirically examines the relationship between a biophysical variable (estimated LAI as a measure of observed greenness) and standard socioeconomic factors. As forested land gives way to urban expansion, and downsizing of local governments leads to drastic cuts for urban forest management (McPherson and Luttinger 1996), equitable distribution of the urban forest will be debated for years to come.

METHODS

Study Area

The city of Terre Haute is located in Vigo County along the banks of the Wabash River in west-central Indiana, USA (Figs. 1 and 2). Terre Haute has made a conscious effort to maintain the urban tree canopy through a comprehensive tree ordinance that governs tree removal and tree planting. The ordinance is administered by a rotating tree board, which may also grant exceptions to the code. Terre Haute had a population of 69,614 in 2000, with an observed county-wide median income of $33 184 and median housing value of $72 500 (United States Census Bureau 2000).

Fig. 1. A tree-lined street in Terre Haute (photo taken by R. Jensen).

Socioeconomic Variables

Variables measured during the 2000 census were used in this study. The measures are: population density (D), median income (I), and median home value (H). The variables were aggregated at the block group level.

Leaf Area Index

This study quantified the urban forest in Terre Haute by measuring LAI (m^2 of leaves per m^2 of ground) throughout the city. Leaf area index was measured using a Decagon AccuPAR® ceptometer that measures photosynthetically active radiation (PAR, 0.40–0.70 µm) above and below forest canopies. These PAR measurements are then applied to the Gap fraction theory. Gap fraction theory states that, for whole canopies, the decrease in light intensity (light attenuation) with increasing depth can be described by the equation

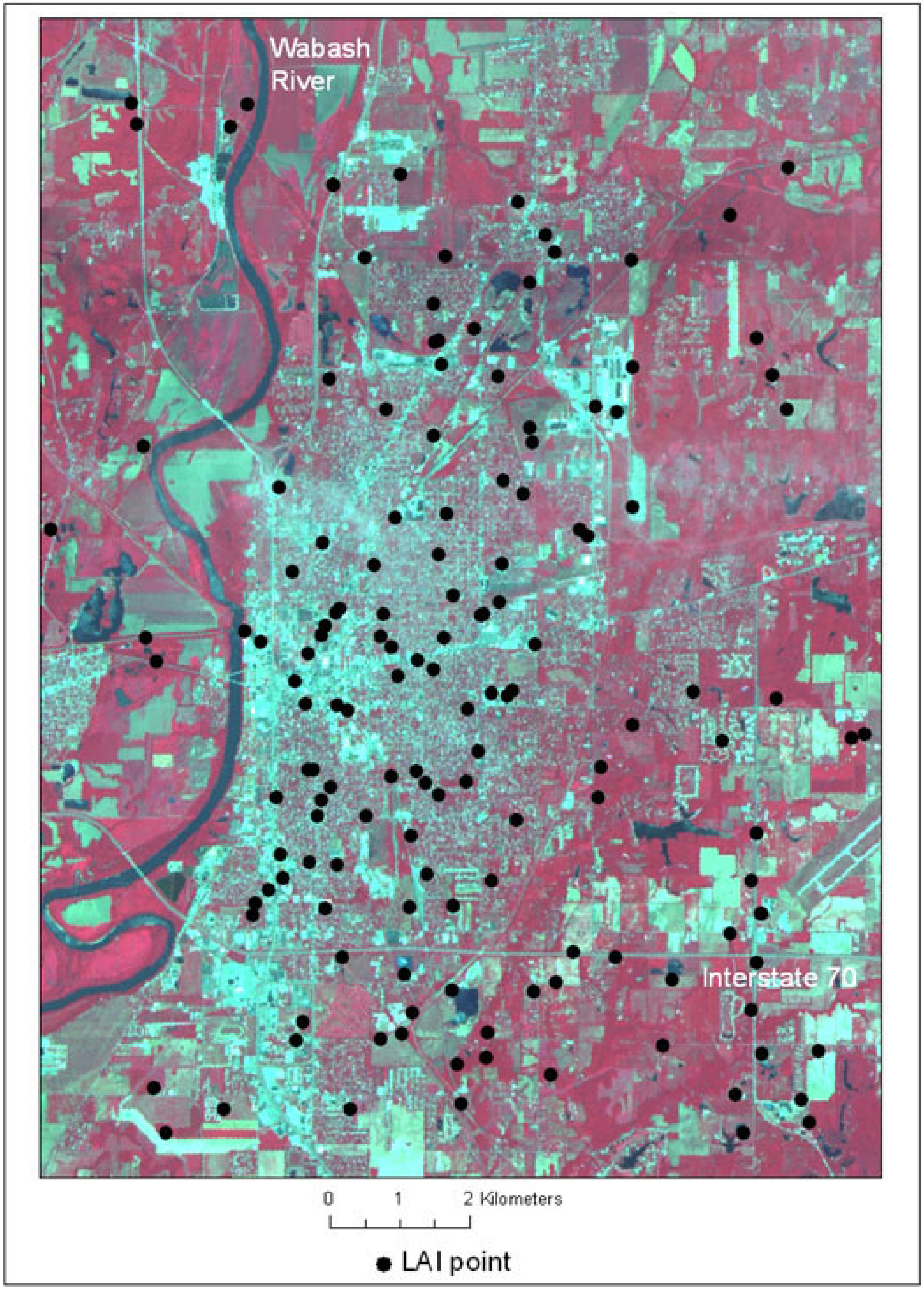
$$IL / IO = e^{-kLAI(L)} \quad (1)$$

where *IL/IO* is the proportion of incident light at the top of the canopy (*IO*) reaching depth *L* in the canopy, *LAI* is the cumulative LAI from the top of the canopy to point *L*, *k* is a stand- or species-specific constant, and *e* is the base of natural logarithms (Larcher 1975, Aber and Melillo 1991). The PAR measurements were made during July and August 2001 in each cardinal direction on each corner (16 total PAR measurements) of 20 x 20 m quadrats, and averaged in 143 random locations that were generated using a random-point generator in Arc®GIS (Fig. 3). Twenty-meter quadrats were measured to offset the amount of heterogeneity in the urban landscape and make the model applicable to many areas. In addition, the quadrats more closely approximate the method of distance-weighted brightness value extraction used in the ARC/INFO® “latticespot” command. Global positioning system (GPS) points were taken in the middle of each quadrat for later input into a GIS program to extract remote-sensing brightness values.

It was not feasible to measure LAI at every location in Terre Haute, so these point LAI values were integrated with remote-sensing imagery and an artificial neural network (ANN) to estimate LAI over those parts of the community where LAI was not measured in situ. This was done using the GPS locations to extract interpolated reflectance values from the Advanced Spaceborne Thermal Emission Radiometer (ASTER, acquired 9 July 2001) imagery in the GIS. The ASTER measures reflectance in three different portions of the electromagnetic spectrum at 15 x 15 m: green (0.52–0.60 µm), red (0.63–0.69 µm), and near infrared (0.76–0.86 µm). Remote-sensing data have been used in many LAI studies (e. g., Chen and Cihlar 1996, Fassnacht et al. 1997, Lawrence and Ripple 1998), and ANNs have proved to be accurate for estimating LAI (e. g., Jensen et al. 2003).

Fig. 2. False color composite (ASTER bands NIR, Red, Green → RGB) of the study area, with the Wabash River and Interstate 70 labeled.

Fig. 3. Map of the in situ LAI points.



Reflectance values and LAI measurements were used to create and train an ANN where LAI was the output and remote-sensing reflectance values were the inputs. Of the original 143 in situ LAI points, it was determined that 27 of them had no overhead canopy or green vegetation (e. g., soybeans, corn, grass) beneath the ceptometer. Therefore, the ANN model was created without these 27 points (Boulton 2003). The ANN had one hidden layer, where weighted synapses determined how reflectance values related to LAI measurements. The ANN method was compared with statistical methods, and ANN was determined to be the most accurate (root mean square error = 1.33). Using the ANN, LAI was then estimated in an additional 364 random locations that were generated in ArcGIS.

Table 1. A listing of Pearson's correlation coefficients (*r* values) for the obtained study parameters. All of the correlation coefficients are statistically significant at or beyond the significance level of α = 0.01.

	Median Income (I)	Median Housing Value (H)	LAI (L)	Density (D)
Median Housing Value (H)	0.710			
LAI (L)	0.411	0.321		
Density (D)	-0.489	-0.465	-0.334	
Interaction (L□D)	-0.285	-0.345	0.218	0.620

The Models

After identifying the key parameters for the study and defining the variables, Pearson's correlation coefficients (*r*) were calculated for the entire data set (see Table 1.) The calculated coefficients ranged from moderately strong to moderately weak, and were used to inform development of the study models. The only exception—as might be expected—is the high degree of correlation observed within and between socioeconomic variables (housing cost and income). Based on the observed Pearson's *r* values, the data obtained from the 364 random locations were subjected to ordinary least squares (OLS) regression analysis to determine if canopy dynamics can be used to account statistically for the covariance of socioeconomic parameters. The OLS models were estimated using the variables described above. The response variables were: median housing value (H) and median household income (I). The explanatory variables were population density (D), LAI (L), and the interaction between population density and LAI (DL). The density variable has been used because population density is closely associated with (1) the geographical phenomenon of distance decay, (2) land use, and (3) land rent in urban areas (Clark 1951, Alonso 1964, Cadwallader 1996). Indeed, population density can be effectively used to model the basic structure of the urban real-estate market. Hence, population density and its interaction with LAI are used to elucidate the impact of "greenness" on the local urban market and the associated geography of household income.

The interaction variable DL was created using the standard expansion method (D*L) proposed by Casetti (1972). The approach enables researchers to pursue "creative" research and aids in the development of models that explore the many and diverse sets of local contingencies that shape sociospatial relationships (Casetti 1972, Jones and Hanham 1995). The method incorporates socioeconomic diversity, rather than building increasingly *"more elaborate models in the hope of taming it"* (Jones and Hanham 1995). In practice, the method interconnected variables not modeled directly, with a allows researchers to account statistically for a variety of minimum number of variables entered on the "right hand" of the equation. In this structure, variables of a global model are expanded in terms of other attributes (Eldridge and Jones 1991).

Recently, human geographers and others have proposed using the expansion method as a vehicle for modeling complex human–environment interactions. In particular, Gatrell and Bierly (2002) developed a novel application of the method to model the dynamic interaction between observed voter turnout and weather conditions over time and across space. Using ten primary and general election cycles, they demonstrated that the interaction between human and environmental parameters varies across space and is locally dependent with respect to a wide variety of socioeconomic and sociopolitical contexts.

Although the expansion method has been used historically by human geographers and more recently to explore human–environment interactions, Miles et al. (1992) demonstrated the utility of adopting the approach within physical geography—specifically using remote-sensing data. In this study, the expansion method is used in a similar fashion to understand the complex sociospatial relationships that exist within and across the urban landscape. In particular, the study examines the ability of LAI—as a rough estimate of observed environmental conditions and quality-of-life attributes—to predict observed sociospatial characteristics.

Table 2. Estimated regression equations for both study models (median income and median housing value) with all independent variables included. *P*-values are provided in italics and parentheses. The obtained r^2 values are significant at or beyond $\alpha = 0.001$.

	Median Income (I)	Median Housing Value (H)
Constant	36792	81305
	(0.00)	*(0.00)*
LAI (L)	3052	5219
	(0.00)	*(0.00)*
Density (D)	-5.436	-7.498
	(0.03)	*(0.04)*
Interaction (L□D)	-2.024	-5.394
	(0.00)	*(0.00)*
r^2	.327	.286

RESULTS

The models statistically account for 32.7% and 28.6% of observed variation in median income (I) and median home value (H), respectively, in Terre Haute (see Table 2). Based on the *p*-values, the performance of the LAI (L) and interaction term (DL) confirm, in part, the assertion that urban forest amenities are a key quality-of-life determinant with respect to observed socioeconomic conditions. Specifically, LAI is positively related to observed home values and income. Moreover, the interaction term clearly indicated that, as density increases, the overall relationship diminishes across space. Likewise, the performance of the density variable is entirely consistent with the general literature (e. g., Clark 1951).

DISCUSSION

This study shows that LAI and population density statistically account for some of the observed variance in median income and median home value in Terre Haute, Indiana, USA. Relationships such as these may help to focus urban management and planning to ensure that future investments in urban forestry are equitable. Although the actual r^2 values may seem small, it is important to remember many of the other factors that may be influencing urban leaf area, such as soil types, neighborhood requirements or conditions, and general preference of the homeowner. It is hoped that studies such as this one will be completed in larger urban and suburban areas to examine whether this trend is observed elsewhere.

Based on the results, future policy makers and researchers can further explore whether the ecological and economic benefits of urban forests are evenly or unevenly distributed within and between spaces and groups. This is an especially poignant question, as it may help to determine whether a city's urban forestry efforts are unfairly skewed to those areas that are “better off” than other areas. The answers to this and other related questions are important as policy makers, citizen groups, and researchers seek to explore the true dynamics of environmental resource allocation (Environmental Protection Agency 2002). Indeed, natural amenities—including green space—are increasingly of interest to the urban planners and ecologists (Bullard and Johnson 2000, Bullard et al. 2001).

Whereas previous studies have implied the ability of urban amenity variables, such as LAI, to predict observed socioeconomic conditions, this study has operationalized the general hypothesis that urban forest amenities covary with positive socioeconomic conditions. As such, urban amenity variables can be used to explain and investigate the uneven distribution of urban resources. Admittedly, we do not know whether high LAI values preceded higher housing values and higher incomes, or whether the opposite is true. However, this study did determine that the two are positively related. Furthermore, other variables, such as lot size and age of developments, were not analyzed. Future research could focus on analyzing these other variables through time with temporal remote-sensing data and past censuses. Future research could also address the issue of urban resident proximity to features such as city parks, golf courses, and even landfills.

Although so-called "fuzzy" concepts (see Markusen 1999) such as quality of life, creativity, or culture are difficult to quantify, the growth and expansion of these concepts within and across the economic and regional development literatures is undeniable (e. g., Malecki 1991, O'Farrell et al. 1993, Glasmeier and Howland 1994, Florida 2002). Indeed, the specific issue of amenities "packages" associated with places has become a key locational determinant of regional development and broader place competition (Glasmeier and Howland 1994, Gatrell 1999). As such, place character and local amenity packages, and the specific relationship between quality of life and socioeconomics are core qualities to consider when contemplating policy change. Although the concept of quality of life is admittedly "fuzzy" and relational, this paper focuses narrowly on urban forests as a single class of urban characteristics that have been linked to local aesthetics and an overall improved quality of life (see Gatrell and Jensen 2002).

Finally, understanding and exploring the dynamics of urban forestry are essential as the United States' urban forests occupy roughly 3% of the country's total land area and serve as habitat for approximately 80% of the human population (United States Census Bureau 2000). Hence, it is useful to examine the distribution of urban forests within and between communities and their individual neighborhoods. With so much priority being given to habitat quality for other species in public and policy discourses, it is useful to examine the habitat in which humans live as well, and determine factors that may positively or negatively influence our urban habitat.

Responses to this article can be read online at: http://www.ecologyandsociety.org/vol9/iss5/art5/responses/index.html

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