RESEARCH & THEORY

CORRELATES OF URBAN FOREST CANOPY COVER
Implications for Local Public Works

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Scientists and managers often use urban forest canopy cover as an indicator of forest health. Furthermore, canopy cover is often the measure communities use to set tree planting goals. Little is known, however, about factors that contribute to variation in canopy cover. We describe canopy cover in 60 urban areas in Central Indiana. We then propose and test a model that treats canopy cover as a function of ecological and geographic factors, urban form, socioeconomic factors, and a policy index. Urban areas are more likely to have more canopy cover if they are in counties with more canopy cover, have higher proportions of their populations with college degrees, have older housing stock, have both more land and land with slopes greater than 15%, and have denser stream networks. Population density, median household income, and planning and zoning or status as a Tree City are not correlated with urban canopy cover.

Keywords: *public works; urban forest; tree canopy; Central Indiana*

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Public works managers have been responsible for urban forestry programs for decades, but new challenges and opportunities are emerging as technological innovations make possible better measurement and monitoring of the urban forest and scientists gain greater understanding of its importance. New remote sensing technologies and geographic information systems (GIS), for example, make it possible to measure and map forest canopy cover for the entire nation using standard protocols at scales that have relevance for local managers. Aided by these and other technologies, scientists have documented the importance of trees in urban environments and global environmental processes. As a result of this new understanding, pressure is growing on local public works departments to improve management of urban forests. American Forests, a national nonprofit association that argues there is a deficit of urban trees, distributes programs for calculating the economic value of trees in urban landscapes and encourages municipalities to adopt goals for tree canopy cover. The National Arbor Foundation, another nonprofit association, encourages municipalities to become Tree Cities by complying with a set of programmatic

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standards. Little systematic information historically has been available, however, on factors that affect tree canopy cover, especially among urban places within a particular region. To respond to these opportunities and challenges, public works managers need information about how tree canopy cover varies in urban places, factors that affect canopy cover, and canopy cover levels that are feasible to achieve.

This study links public works to urban forest ecology by analyzing variation in urban forest canopy cover among 60 urban areas in Central Indiana. Our primary objectives are to illustrate variation in canopy cover, to assess the relative importance of factors that correlate with canopy cover, and to explore the implications for local public works managers. Because urban places in Central Indiana share fundamental ecological characteristics, but also vary with respect to socioeconomic and political factors, they are particularly useful for understanding factors that enable or constrain managers responsible for local forestry programs.

We begin with a brief review of research related to the values of urban forests and variation in urban canopy cover. Urban canopy cover refers to the proportion of land area within geographic areas such as municipalities that is underneath or covered by the crowns of trees. We focus on canopy cover because it is the primary indicator used by scientists to describe the urban forest and because policy makers and analysts increasingly use it as an indicator of the health of the urban forest. Building on existing research, we hypothesize that urban canopy cover is a function of variables relating to ecology and geography, urban morphology or form, socioeconomic status of local residents, and local policy, including whether an urban place has planning and zoning or has been designated a Tree City. We test our hypotheses using bivariate correlations and a multivariate regression model. We conclude with discussions of the implications of our findings for researchers and practitioners in public works and related fields.

Urban Forests and Canopy Cover: Factors Affecting Variation

Trees have been recognized as an important component of urban landscapes for millennia (Miller, 1997), and they provide a broad range of environmental, aesthetic, economic, and even psychological benefits. Trees in urban landscapes, for example, moderate temperature and microclimates, thereby reducing needs for air conditioning and saving energy (Heisler, 1986; McPherson, 1990; Meier, 1991; Oke, 1989). Trees help improve air quality and sequester carbon (Nowak, 1993; Nowak & McPherson, 1993; Rowntree & Nowak, 1991; Smith, 1981, 1990), help control rainfall runoff and flooding (Sanders, 1986), reduce urban noise levels (Cook, 1978), and provide habitat that increases biodiversity (Johnson, 1988). Urban trees make neighborhoods more appealing aesthetically and add to the value of property (Schroeder, 1989). They also have been shown to reduce human stress levels (Ulrich, 1984), promote social integration of older adults with their neighbors (Kweon, Sullivan, & Wiley, 1998), and provide local residents with opportunities for emotional and spiritual fulfillment that help them cultivate a greater attachment to their residential areas and a sense of place (Chenoweth & Gobster, 1990). Economists have shown that these types of benefits may outweigh the costs of urban forestry programs by considerable margins (McPherson, 1992, 1994; McPherson & Biedenbender, 1991; McPherson et al., 1997; McPherson, Scott, & Simpson, 1998).

As these findings have emerged, interest in management of urban forests has grown, and researchers have begun new research programs to support management initiatives. Most relevant to this study, many cities, often at the urging of environmental advocates, have established goals for percentage of tree canopy cover within municipal boundaries. American Forests, for example, recommends average tree cover of 40% in urban areas where the potential ecological climax community is temperate deciduous forest (http://www.americanforests.org/graytogreen/treedeficit/). American Forests explicitly recognizes that canopy cover will vary by land use and recommends lower goals for canopy on commercial and industrial land and higher proportions on residential land. By implication, therefore, the feasibility of the recommended goal depends on the mix of land uses in a community and other factors. But until recently, little information has been available on the actual variation in canopy cover.

Researchers interested in the roles of trees in urban landscapes historically have sought to understand issues of urban forest form, structure, and function (McPherson et al., 1997; Nowak, 1994; Sanders, 1984; Talarchek, 1990). The key indicator used to compare urban forests has been urban canopy cover measured via remotely sensed imagery. Most research to date on urban canopy variation has been conducted either at the macro (i.e., continental) scale (Dwyer, Nowak, Noble, & Sisinni, 2000; Nowak et al., 1996) or at the micro (i.e., site-specific) scale (Nilon, 1991; Rowntree, 1984; Whitney, 1985; Whitney & Adams, 1980). Few researchers have reported studies of factors of interest to local managers that contribute to variation in canopy cover in municipalities within a region (i.e., at the meso-scale). Although researchers have shown that urban canopy cover correlates with ecological and geographic factors and with urban form, they have not shown how canopy cover varies with socioeconomic and other conditions that are known to vary across localities in a region. Existing research can be used, however, to postulate a general model of factors that contribute to variation in canopy cover across municipalities in a region. Four broad categories of factors appear to be important: ecological and geographic factors, urban morphology or form, socioeconomic factors, and local policy.

ECOLOGICAL AND OTHER GEOGRAPHIC FACTORS

It is well known that natural vegetation in undisturbed environments primarily is a function of temperature and precipitation or geographic factors such as ecoregion or altitude that correlate with them. Work by Nowak et al. (1996) and Dwyer et al. (2000) show that urban canopy cover also is highest in forested ecoregions, followed by grasslands and deserts, thus confirming ecoregion as a main contributor to urban canopy variation at a continental scale. These findings are not surprising, but they are important, for they make it clear that human modification of vegetation in urban places through activities like irrigation have not superseded the general effects of ecoregion characteristics. At the site level, it is well known that micro-climates created through variations in topography, soils, and sunlight exposure influence tree growth and canopy cover (Whitney, 1985; Whitney & Adams, 1980). The effects of these types of micro-level factors aggregated in urban places within an ecoregion, however, are not well understood.

Holding macro factors such as precipitation and temperature constant, geographic factors that both vary within a region and impede development should be correlated with higher levels of canopy cover. For example, areas with greater topography (i.e., steep slopes) or higher densities of riparian corridors typically are less attractive for building because they increase the cost of construction and present greater risk to property owners (Ambrose, 1994). Because of the inherent difficulties of building on steep slopes or in riparian areas, the areas may be more likely to be preserved as open space, and development may be more likely to extend into urban peripheries. Many communities, in fact, limit development in floodplains by regulation; some also limit development on steep slopes. Because both economic and regulatory factors impede development in these areas, they are more likely to remain as open space and are thus reserved for forest growth. Researchers have not documented, however, whether in fact canopy cover systematically varies with these types of factors. We hypothesize here that urban canopy cover is correlated positively with greater areas of steep slopes and greater density of stream networks.

URBAN MORPHOLOGY OR FORM

Urban morphology or form, local land use, and other factors such as historic development patterns and age of development also are likely to influence urban vegetation and, therefore, canopy cover. Nowak et al. (1996) have shown that urban places with greater total land area are more likely, all other factors equal, to have more open space that may be occupied by trees.

Across urban areas, development patterns may vary considerably. In particular, the mix of land uses within urban places and their environs may affect urban forest structure and therefore variation in canopy. Urban trees tend to grow most abundantly on residential and vacant land, including open space in parks (Rowntree, 1984). These lands therefore account for the greatest proportion of the urban forest. The implication is that municipalities with higher proportions of residential land will have greater tree canopy cover.

Population density, which is directly related to urban land area and use, also is believed to affect urban forest canopy variation (Dwyer et al., 2001; Nowak et al., 1996). Because concentrated populations place many pressures on vegetation growth, a negative relationship between population density and urban forest variation is hypothesized.

The dynamic nature of both urban development and forest growth and succession complicates analysis of urban forest cover. For example, in Central Indiana, as in much of the United States, urban development typically has occurred through encroachment onto once forested farmland. Consequently, urbanization affects forest canopy cover less than it otherwise might and, in cases of residential or parkland development, may actually result in limited reforestation. The general implication is that the age of development in an urban place, particularly its housing stock, potentially may affect canopy cover (Nilon, 1991). In places with higher proportions of older housing stock, urban forests have had longer to mature and therefore may be characterized by greater canopy. Given typical patterns of urbanization, it is hypothesized that urban areas with newer housing stock have less canopy cover.

Other factors related to local land use and patterns of urbanization also potentially are relevant to understanding urban canopy variation. Because trees are more likely to grow on parkland, the percentage of space set aside for parks is likely to affect canopy cover positively. Similarly, the percentage of tree canopy cover in an urban place is likely to correlate positively with canopy cover in the county in which it is located. This correlation is likely because, within a region, the potential environment is the same and similar geographic factors influence land uses and canopy cover both inside and outside municipal boundaries. For example, steep slopes may impede cultivation as well as urban development. This relationship may not be straightforward, however. County forest canopy cover reflects local agricultural practices, which are influenced by stage of urbanization and an array of other economic factors.

SOCIOECONOMIC FACTORS

Consistent with the observation that urban forests include trees on private land as well as street trees and trees in other public places, urban ecologists also hypothesize that socioeconomic factors within urban places influence canopy cover. Swyngedouw (1999), for example, concludes “that natural or ecological conditions and processes do not operate separately from social processes, and that the actually existing socionatural conditions are always the result of intricate transformations of preexisting configurations that are themselves inherently natural and social” (p. 445). One implication of this line of thinking is that income, education, and other factors related to socioeconomic status might influence variation in urban forest cover. Hedonic price analyses, for example, show clearly that trees add to the value of residential properties (Anderson & Cordell, 1985, 1988; Morales, 1980; Payne & Strom, 1975). This means that trees are a normal economic good and that people are willing to pay more for housing with trees. Because willingness to pay relates directly to household income and income is correlated with education (Massey & Denton, 1993; Wilson, 1987), a plausible hypothesis is that urban canopy cover is correlated positively with household income and education. Because there is wide variation in income and education across communities, and because indicators are readily available from the U.S. Bureau of the Census, these hypotheses can be tested. We hypothesize that urban canopy cover will correlate positively with both income and education.

Many communities develop comprehensive plans, regulate the location, density, and nature of development through zoning ordinances and subdivision regulations, and in some cases, require tree planting in new developments.

POLICY FACTORS

Urban form and socioeconomic factors are not the only human factors that affect urban forest structure and canopy cover. Whether and how local governments regulate development and the strategies local officials use to manage urban forests also may influence canopy cover (Grey, 1996; Miller, 1997; Sanders, 1984). Many communities develop comprehensive plans, regulate the location, density, and nature of development through zoning ordinances and subdivision regulations, and in some cases, require tree planting in new developments. Their existence is evidence that some communities place a higher priority on and make greater efforts to manage urban form than others. Strategies and approaches to urban forest management range from the sharing of responsibilities between municipal departments such as public works, parks and recreation, and planning, to hiring urban foresters to take primary responsibility for management, to participation in programs such as the National Arbor Foundation's Tree City USA program (http://www.arborday.org/programs/treecitydirectory.html; Miller, 1997; Tereshkovich, 1990). To be designated a Tree City, for example, municipalities must meet four standards. They must establish a tree board or department, pass a tree care ordinance, operate a community forestry program with an annual budget of at least $2.00 per capita, and pass a proclamation that calls for observance of Arbor Day. Although it is plausible to hypothesize that urban canopy cover is higher in communities with tree planning and zoning or that have been designated Tree Cities, no studies testing these hypotheses have been reported.

Study Area, Data, and Methods

CENTRAL INDIANA STUDY AREA

This research analyzes published estimates of urban forest canopy cover for 60 census designated places (CDPs) in urban areas in Central Indiana (Dwyer et al., 2000). Our study region is the 44-county Indianapolis Economic Region defined by the U.S. Bureau of Economic Analysis according to commuting patterns and media markets. The region is home to approximately three million people, or approximately 60% of the total population of Indiana. About half the population lives in the nine-county Indianapolis Metropolitan Statistical Area. The region includes 289 incorporated municipalities, 75% of which have populations less than 2,500. Because we are interested primarily in variation of urban canopy cover, we analyze only CDPs within the boundaries of urban areas. Thus, this analysis excludes many small municipalities in Central Indiana. In addition, our analysis excludes the city of Indianapolis because its size and characteristics make it atypical within the region.

The Central Indiana region is appropriate for an investigation of urban canopy cover because of the variation in both the built and natural environment. The region has experienced processes of urban restructuring and growth similar to many other major areas within the United States (Walcott, 1999), and recent analyses show that processes of urbanization and suburbanization of investment are continuing (Nunn, 2001). The northern section of the region was glaciated; the southern section was not and thus has greater topography and different soils. From an ecological perspective, the predominant presettlement vegetation for all places was temperate deciduous forest—typically either oak-hickory and beech-maple associations, depending on local soils, slopes, and other geographic factors (Lindsey, 1997).

DATA AND METHODS

Urban Forest Canopy Cover

The United States Department of Agriculture (USDA) Forest Service collected and published canopy cover data (Dwyer et al., 2000) in accordance with the Forest and Rangeland Renewable Resources Planning Act (1974), which requires the Forest Service to assess "the current and expected future conditions of all renewable resources in the Nation" (USDA Forest Service, 1989). The Forest Service has summarized results at state, county, metropolitan statistical area (MSA), urban area, and CDP levels for the entire contiguous United States. These estimates of canopy cover are based on the USDA's national resources inventory (NRI) and advanced very high-resolution radiometer (AVHRR) data. Urban forest canopy cover, on a 0-

Table 1: Characteristics of Census Designated Places

Variable	*Maximum*	*Minimum*	*Mean*	*Standard Deviation*
Dependent variable				
% urban forest canopy cover[a]	55.7%	13.7%	31.7%	10.4
Ecological and geographic factors				
Urban slope				
USGS Digital Elevation Model				
(1:24,000,30 meter cells)—% of land w/ > 15% slope	15.8%	0%	1.2%	2.6
Urban stream density[b]	3.67 km/km^2	0	.56 km/km^2	.55
Urban form measures				
Weighted % county forest canopy cover[a]	63.5%	21.7%	36.4%	11.2
% county federal/state land[c]	33.5%	0%	2.7%	6.4
Urban land area[a]	98.1 km^2	1.4 km^2	15.8 km^2	18.5
Population density[d]	2047.8	82.8	919.9	323.7
Housing stock age (% older than 1979)[d]	98.6%	25.8%	85.8	11.5
Socioeconomic status measures				
Median household income[d]	$54,505	$17,263	$26,315	8,586.8
Education (% w/ B.A. degree or higher)[d]	51.3%	4%	14.3%	10.6
Policy index				
0 = no policies		0 = 15 CDPs		
1 = Tree City USA/city forester OR zoning ordinance		1 = 38 CDPs		
2 = Tree City USA/city forester AND zoning ordinance		2 = 7 CDPs		

a. Dwyer et al. (2000).
b. U.S. Census Tiger Data (2001).
c. Indiana Department of Natural Resources (2000, 2001).
d. U.S. Census Bureau (1990).

100 percentage scale, was calculated for every 1 km^2 in the United States using statistical models for particular physiographic regions and 1991 AVHRR data. These statistical models predict forest density per square kilometer based on the proportion of individual AVHRR pixels or cells within it with particular land cover. Selected jurisdictional boundaries (e.g., state, county, urban area) were added to the dataset after the complete coverage for the United States was generated. The accuracy of the estimates of canopy cover was determined through comparisons with canopy inventories of selected urban areas around the United States based on aerial photography (Nowak et al., 1996). Dwyer et al. (2000) caution that the data are statistical estimates and not 100% accurate. Despite this limitation, the data are well suited for this type of analysis. The estimates for this region, unlike other regions in the United States, were shown to have little error associated with them (Dwyer et al., 2000), and the errors that exist are spatially consistent. This means that they are evenly distributed across geographic sub-areas like counties and municipalities.

Estimates of canopy cover in county areas outside of CDPs are weighted averages calculated from Dwyer et al. (2000). These estimates were calculated by determining total acres and total acres with forest canopy in the county, subtracting the area of the CDP and the acres of forest canopy cover within the CDP from the respective county totals and recalculating the percentage of county canopy cover.

Ecological/Geographic, Urban, Socioeconomic, and Policy Data

Data used to explain variation in urban canopy cover come from the U.S. Bureau of the Census, the U.S. Geological Survey (USGS) (2001), the Indiana Department of Natural Resources (IDNR), and the National Arbor Foundation (see Table 1). Ecological and geographic information includes slopes, stream densities, and location with glaciated or unglaciated areas. Data on stream networks and slopes in urban areas come from U.S. Census Tiger Files (2001) and USGS, respectively. Urban stream densities (Black, 1996) were calculated as the length of stream networks on the Tiger maps for the CDP divided by the area of the CDP and are presented in units of kilometers per square kilometer. Urban slopes, in degrees, were calculated using a

USGS digital elevation model with a 1:24,000, 30 m^2 cell resolution. Researchers then determined the area within each CDP with slopes greater than 15%, using this number because steeper slopes present significant obstacles to development (Marsh, 1997).

Information related to urban form includes data on park land, land area, population density, and age of housing stock (see Table 1). Data on the percentage of federal and state park land within Central Indiana counties come from the IDNR. Estimates of urban land areas are from the Census as reported in Dwyer et al. (2000). Data on urban population density and age of housing stock also come from the U.S. Census Bureau. Median household income and percentage of population with college degrees are used as indicators of socioeconomic status and are taken from the Census.

The National Arbor Day Foundation (2001) provided information about Tree City status. Data about zoning ordinances are from an inventory of planning and zoning practices in Central Indiana (Lindsey & Palmer, 2000) and supplemented by a telephone survey of local officials in the CDPs. The data were used to build a policy index with values shown in Table 1.

The analysis includes presentation of basic descriptive statistics (mean, range, and standard deviation), bivariate correlations, and an ordinary least squares regression model that treats urban forest canopy cover as a function of ecological, urban morphological, land use, socioeconomic, and policy variables. The values of selected variables in the regression model were logged prior to estimation of the model to correct for nonnormality of the distributions. All statistical analyses were done using Microsoft Excel, the Statistical Package for the Social Sciences (SPSS©), and ARCVIEW.

Variation in Urban Canopy Cover in Central Indiana

Urban forest canopy cover in Central Indiana varies considerably among CDPs. Although the intra-regional variation is less than the variation in the continental United States, it is comparable to variation in forested ecoregions in the United States. The mean urban forest canopy cover in the 60 CDPs is 31.7% (see Table 1) the mean for all urban areas in the United States is 27.1% (Dwyer et al., 2000), and the mean for forested ecoregions in the United States is 31.1% (Nowak et al., 1996). The canopy cover among the CDPs in Central Indiana ranges from a high of 55.7% in the small town of Spencer to a low of 13.7% in Seymour (see Table 1 and Figures 1 and 2). Canopy cover in Spencer is as high as cover in Baton Rouge, Louisiana (55%), which has one of the highest canopy covers in the United States (Nowak et al., 1996). Urban canopy cover in Seymour (14%) is comparable to Eugene, Oregon (16%), a city in a forested ecoregion at the lower end of the national distribution (Nowak et al., 1996).

Approximately 35% of the 60 CDPs have canopy cover between 30% and 40%. A higher proportion (43%) have canopy less than 30%, whereas fewer (22%) have canopy greater than 40%, the average canopy cover recommended by American Forests. Ten places have canopy cover less than 20%, nearly three times as many as the number with canopy cover of 50% or more. The distribution of canopy cover in the sample is not significantly different from normal (KS statistic = .565).

The CDPs with the highest levels of canopy cover are located disproportionately in the area of Central Indiana that was not glaciated and generally is unsuitable for farming, but 8 to 13 CDPs with 40% or more canopy cover are in the unglaciated area (see Figure 1). The amount of federal and state land in park use varies considerably (from 0% to 34%) as do slope and stream density. Within the CDPs, the percentage of area with slopes greater than 15% ranges from 0% to 15.8%. Stream density varies from 0 to 3.67 km/km^2.

The CDPs and urban areas in the analysis vary considerably in size, population density, socioeconomic status, and stage of development. The places range in population from 71,035 in Muncie to 687 in the town of McCordsville and in land area from 98.1 km^2 in Anderson to 1.4 km^2 in West Terre Haute (see Table 1). Population density ranges from slightly more than 80 persons per square kilometer to almost 2,050 persons per square kilometer. Median household income ranges from slightly more than \$17,000 to approximately \$54,000 (see Table 1). The

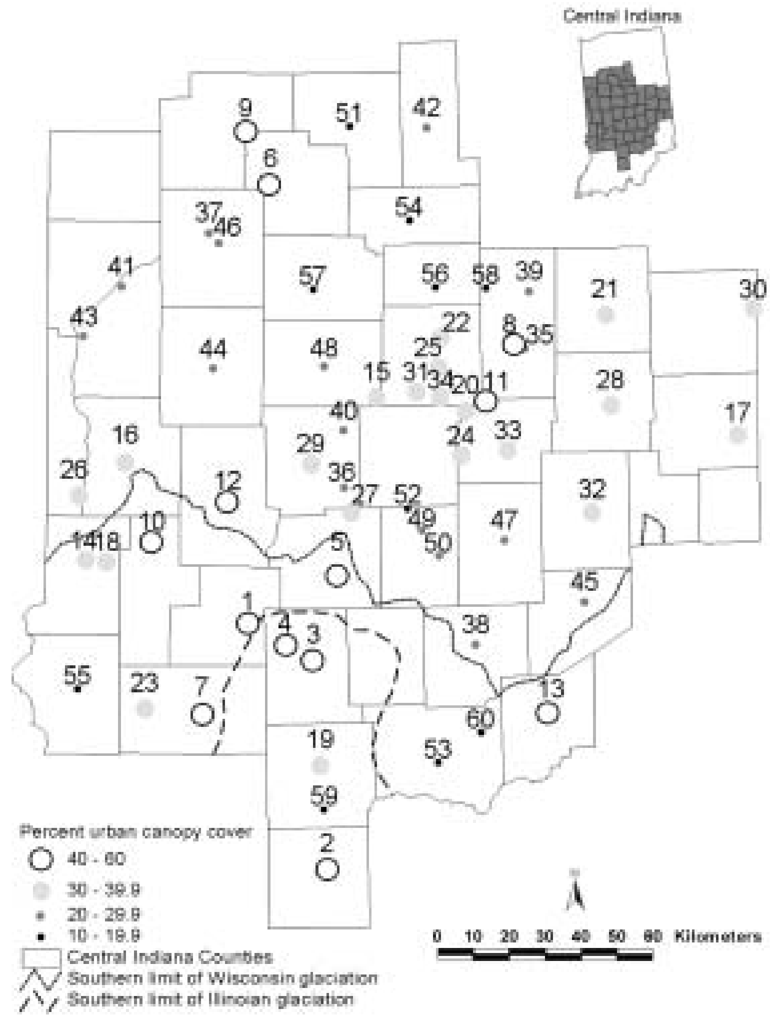

Figure 1: Canopy Cover in Census Designated Places in Central Indiana
NOTE: Numbers of urban places are indexed in Figure 2 with canopy cover percentage.

percentage of people who have earned a bachelor's degree or higher ranges between 4% and 51.3%. On average, about 86% of the housing stock was constructed before 1979, although housing stock is newer in some communities. For example, in at least one place, nearly 75% of the housing post-dates 1979. Eleven places have either an urban forester on staff or have earned Tree City USA status, and 42 places have enacted zoning policies.

Correlates of Urban Canopy Cover in Central Indiana

We hypothesized that nine measures related to ecology and geography, urban form, socioeconomic status, and local policies would correlate with urban canopy cover. We explore these hypotheses using bivariate correlations and a standard ordinary least squares regression model that treats canopy cover as a function of nine of these factors. Results are presented, respectively, in Tables 2 and 3.

ECOLOGICAL AND GEOGRAPHIC FACTORS

Within places in the same ecoregion, we hypothesized that factors that make building difficult and increase open space available for tree growth may correlate with urban canopy cover.

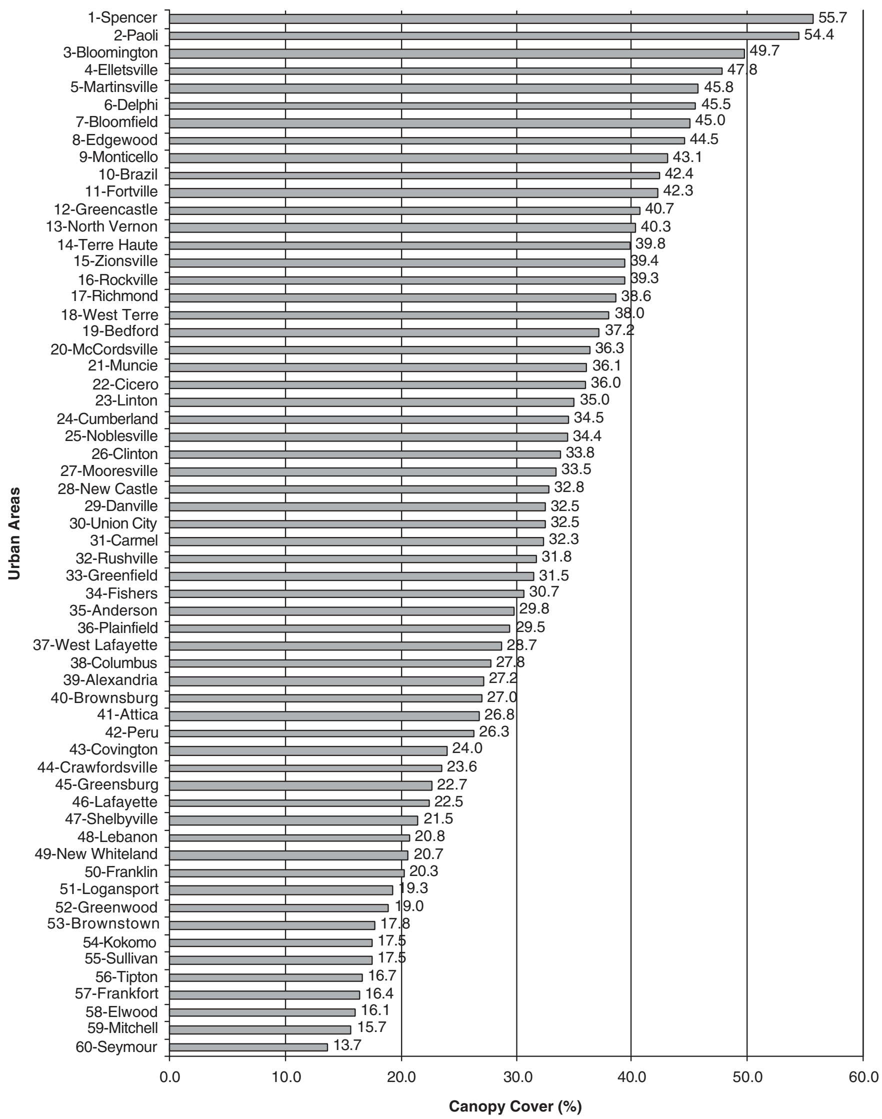

Figure 2: Central Indiana's Urban Forest Canopy Cover With a Place Name Index for Figure 1

We tested three measures and present two here: the percentage of land within each CDP that exceeds 15% in slope and urban stream density. Pearson's correlations indicated a significant positive relationship between urban canopy cover and urban slope at the .05 level (see Table 2). When the effects of other relevant factors were controlled, the effects of slope remained positive and significant (at the .05 level) (see Table 3). Urban stream density and urban canopy were not significantly correlated, although stream density was significant at the .1 level in the regression model (Tables 2 and 3). We also tested the presence of a CDP in the glaciated area of the region, but it had no independent, significant effects on canopy cover.

URBAN FORM

With respect to urban morphology and local land use, we hypothesized that urban land area, county canopy cover, federal and state parkland, and age of housing stock would correlate positively with urban canopy cover and that population density would correlate negatively with urban canopy cover. Results indicated that, with the exception of land area, relationships were in

Table 2: Bivariate Correlation Matrix: Forest Canopy Cover and Explanatory Variables

	Urban Canopy	*County Forest*	*Fed/State Parkland*	*Urban Slope*	*Urban Stream Density*	*Population Density*	*Urban Land Area*	*Housing Stock Age*	*Median Household Income*	*Education*
Urban canopy										
Weighted county forest	.550*									
Fed/state parkland	.312*	.616*								
Urban slope	.490*	.508*	.313*							
Urban stream density	.008	–.281*	–.106	.005						
Population density	–.173	–.094	.080	–.162	–.070					
Urban land area	–.166	–.112	.012	.081	.018	–.141				
Housing stock age	.009	.113	–.012	.017	–.176	.179	–.167			
Median household income	–.058	–.426*	–.170	–.233	–.224	–.218	–.027	–.581*		
Education	.157	–.210	.032	–.035	–.050	–.103	–.297*	–.664*	.665*	
Policy	–.088	–.145	.105	–.109	.059	–.015	.588*	–.195	.139	.414*

* significance at $\alpha = .05$.

Table 3: Regression Results for Model of Urban Forest Canopy Cover ($n = 60$)

Variable	*B*	*Beta Coefficient*	t *Score*	*Sig.*
Constant	–5.738		.086	.932
Geographic variables				
Urban slope	.951	.472	2.013	.050*
Urban stream density	.003	.184	1.769	.083**
Urban form variables				
County forest	.456	.492	3.795	.000*
Urban land area (log)	–6.688	–.269	–2.076	.043*
Population density	–.004	–.124	–1.194	.238
Housing stock age	.268	.296	2.189	.033*
Socioeconomic variables				
Median H.H. income	–7.354	–.085	–.518	.607
Education	24.285	.586	3.509	.001*
Policy variable				
Policy index	–.267	–.015	–.120	.905
Adjusted $R^2 = .475$				

* significance at $\alpha = .05$. ** significance at $\alpha = .10$.

the expected direction (see Table 2). Pearson's correlations indicated that urban canopy cover was significantly correlated with both county canopy cover ($r = .550$) and percentage of county in federal and state parkland ($r = .312$) but that the relationship between county forest cover and federal and state parkland was significant and stronger ($r = .616$). Therefore, to avoid problems of multicollinearity in the regression model, federal and state parkland was not included.

After the effects of other factors were controlled, urban land area, county canopy cover, and the age of housing stock were significant (at the .05 level) (see Table 3). All other factors equal, urban canopy cover was significantly more likely to be greater in CDPs in counties with greater canopy cover. For every percentage increase in county canopy cover, urban canopy cover is expected to be about one half percentage higher.

The relationship between land area and canopy cover was not significant but was negative, the opposite of the direction that was hypothesized. Population density, as expected, was correlated negatively with urban canopy cover: all other factors equal, greater numbers of people within the same amount of space reduces space available for trees. The bivariate relationship was not significant.

Although the relationship between development patterns, succession, and urban canopy cover is complex, we hypothesized that communities with older housing stock would have higher canopy coverage because greater periods of time since construction would allow succession to proceed. This appeared to hold true. Although our measure for this construct, percentage of housing stock built since 1980, was not significantly correlated with urban canopy cover in a bivariate model, the relationship was significant (at the .05 level) when other relevant factors were controlled (see Table 3). The direction of the effect was as expected. Higher proportions of housing built before 1980 were associated with higher canopy cover.

SOCIOECONOMIC FACTORS

Drawing on theories of urban political ecology and standard economics, we hypothesized that income and education, two standard socioeconomic indicators, would correlate positively with urban canopy cover. The interrelationship between income and education was significant and positive as expected (see Table 2). Higher median household incomes are associated with higher percentages of adult populations with a bachelor's degree or higher. Although neither variable was correlated significantly with urban canopy cover in the bivariate model (see Table 2), education was correlated significantly when other factors were controlled (see Table 3). Holding other factors equal, the larger the proportion of adults who have earned a bachelor's degree or higher, the higher the percentage of urban canopy cover. Income was not correlated significantly with canopy cover, and the sign was not in the expected direction (see Table 3).

POLICY FACTORS

Some communities are making deliberate efforts to increase urban canopy cover by hiring foresters, embarking on tree planting programs, or enacting local ordinances to control and shape developments to preserve trees. To explore the effects of these types of policy variables, we tested whether urban canopy cover was higher in communities that had policies linking forestry or management of trees, either Tree City USA status (or an urban forester) or planning and zoning, or both Tree City status and planning and zoning. The relationship between this policy variable and canopy cover was not significant, and the sign was not in the expected direction (Tables 2 and 3). Possible explanations of this result are discussed below. Several outcomes related to these factors are worth noting, however. Larger places are significantly more likely to have Tree City USA status or to have hired an urban forester, and places with higher proportions of the adult population with only a high school education are significantly less likely to have these indicators of commitment to increasing canopy cover (see Table 2).

Some communities are making deliberate efforts to increase urban canopy cover by hiring foresters, embarking on tree planting programs, or enacting local ordinances to control and shape developments to preserve trees.

Observations and Implications

Overall, our model explains almost half (47.5%) of the variation in urban canopy cover in urban areas in Central Indiana (see Table 3). Our results generally support our conceptual model, although some of the factors were not statistically significant, and the signs on some of the coefficients of the independent variables were the opposite of the direction theorized. Five variables—county canopy cover, elevation, area, educational attainment, and housing stock age—were significant at the 5% level. Stream density was significant at the 10% level. Urban places are, other things equal, likely to have more canopy cover if they are in counties with more canopy cover, have higher proportions of their populations with college degrees, have older housing stock, and have more land with slopes greater than 15%. However, our policy index, which accounts for both the presence or absence of planning and zoning and whether a CDP had an urban forester or has Tree City USA status, had no significant effects on canopy cover. Other variables that had no significant effects on canopy cover included household income and population density.

We can interpret the relative importance of these variables from a statistical perspective by examining the standardized regression coefficients, or beta coefficients, in Table 3. In general, the beta coefficients indicate the relative importance of the independent variables, with higher values indicating greater effects on the dependent variable. Education emerges as the most important factor affecting levels of canopy cover, followed by county forest canopy cover, urban slope, and housing stock age. By this measure, the policy index is the least important factor.

Another way to gain insight into the practical importance of these variables is to analyze the effect of variation in independent variables on the predicted levels of canopy cover. For example, if the values of all independent variables are set equal to the mean for the dataset, the predicted level of urban forest canopy cover is 18.1%. If the minimum (4%) and maximum (51.3%) values for education (i.e., percentage with a B.A. degree) are used in the calculation and values for the other eight variables are held at the mean, the predicted canopy cover ranges from 6.7% to 33.7%. Similarly, if canopy cover is predicted using the minimum (21.6%) and maximum (98.6%) values for the percentage of housing stock built before 1979 while holding the values for other variables at their means, the predicted canopy cover ranges from 2.1% to 21.6%. In contrast, the predicted effect of changing the policy variable is negligible.

This type of sensitivity analyses makes clearer both the relative effects of the different independent variables and the potential for results from purposeful action to increase canopy. The explicit policy instruments—planning and zoning and designation as a Tree City—do not appear to have the potential for large increases in canopy cover, although, from a practical perspective, they may reinforce the importance of education and may increase the likelihood that canopy will increase over time as housing stock ages.

Taken together, these findings have important implications for researchers, policy makers, and managers. First, they illustrate the problems with adopting average goals in particular communities and underscore the importance of critical evaluation of local conditions during debates over how best to manage urban forests. In our sample, for example, more than 20% of the CDPs already have canopy cover greater than 40%—the average goal recommended by American Forests. What should goals for urban forestry be in these communities? It is likely that the health of the urban forest can be improved. Although canopy cover may exceed norms, this situation is not a justification for no action. Conversely, most CDPs that do not meet the American Forests goal of 40% canopy cover have less than 30% cover. As such, a goal of 40% may be inappropriate or infeasible in these areas due to structural conditions. Careful assessment of local factors like those analyzed here is essential if public works managers are to develop meaningful policy goals that are responsive to the needs of residents. Managers can use these results to illustrate to stakeholders in local processes that recommended goals may not be appropriate and that goals must reflect local conditions.

The most interesting and potentially useful result concerns the significant effect of education on levels of canopy cover. From a research perspective, this result substantiates the claims made by Swyngedouw (1999) and others that social factors have an important effect on local ecological conditions. From a managerial perspective, this result provides indirect evidence that education may be a useful part of an overall strategy to improve management of urban forests. Because many local jurisdictions will be unwilling to regulate management of trees on private property, educational programs likely will be a common strategy for addressing the public benefits of trees on private property. This finding also provides another justification for local efforts to build human capital. As local populations become more educated, they may be increasingly likely to support tree planting programs or to undertake tree planting themselves.

The finding that population density has no significant correlation with canopy cover has implications for urban planning and land management. Planners now recommend clustering and other practices to increase housing densities on portions of sites in the hopes of increasing open space. These results underscore the importance of these recommendations, for they indicate that density is not inherently at odds with expanding the urban forest. If clustering is successful, the health of the urban forest should increase over time.

The finding that land area has no significant effect is inconsistent with previous studies and perhaps may be explained either by the modeling approach, which controls for other related factors (like population density), or by the specific characteristics of this sample of communities. Alternatively, the result could be a function of ecological scaling. Descending from macro- to meso-scale analyses often brings to light different explanatory factors (Swyngedouw, 1997). Additional research is needed to sort out the independent effects of land area.

The finding that our policy index has no significant, independent effects on canopy cover illustrates the difficulty of developing programs to increase canopy cover, but it should not be construed to imply that programs like Tree City USA have no beneficial effects on urban forests. The lack of significance may occur because the policy variables are not sufficiently refined or because programs have not been in place long enough to have caused meaningful change. Historical data on requirements for tree-planting may be a better measure than planning and zoning, and the proportion of municipal budget or per capita expenditures on tree-planting may be better indicators than Tree City USA status. Time series analyses and detailed case studies may be required to evaluate the effectiveness of particular programs.

One limitation of our research thus pertains to the specific measures used to operationalize the conceptual model. Perhaps alternative measures of the independent variables yield different results and better insights. For example, percentage of land area in floodplains might be a better indicator of open space available for land than average stream density. These indicators, however, are not available. As ecological and social data become more widely available at different geographic scales, more detailed investigations will be possible. Examples of potentially relevant ecological data include soils, hydrology, and other factors that contribute to variations in micro-climates in urban places and therefore tree growth. One important variable that needs attention concerns the mix of land use in a community. All other factors equal, canopy cover is likely to be higher in communities with greater proportions of residential land use and lower proportions of commercial and industrial uses. New national-level datasets such as the National Land Cover data from the USGS are becoming available and will enable testing hypotheses about the different effects of land use (http://landcover.usgs.gov/natllandcover.html). Examples of other potentially relevant data include data on urban built structures and demographic data related to race or ethnicity.

As more communities recognize the benefits of urban forests and establish goals for canopy cover, interest in the factors that contribute to variation in cover will grow. Within regions that share basic ecological characteristics, social factors that reflect the myriad of choices people make daily likely will emerge as some of the most important determinants of urban canopy cover. Future research can build on these findings to develop a better understanding of factors that affect the urban forest.

Within regions that share basic ecological characteristics, social factors that reflect the myriad of choices people make daily likely will emerge as some of the most important determinants of urban canopy cover.

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