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Street trees and equity: evaluating the spatial distribution of an urban amenity

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Abstract. While urban disamenities and pollution sources have received considerable attention in environmental justice research, few studies have examined sociospatial inequities associated with the distribution of desirable land uses. In this paper we focus on addressing this limitation by investigating the environmental equity implications of street trees—an important publicly financed amenity that provides several direct and indirect benefits to urban residents. The specific objective was to determine if the spatial distribution of public right-of-way trees is equitable with respect to race and ethnicity, income, and housing tenure in the city of Tampa, Florida, USA. We seek to extend research on equity analysis of urban amenities through several methodological innovations, including: (a) accounting for the heterogeneity of urban land use; (b) utilizing high-resolution remote sensing techniques to quantify parcel-specific tree cover; and (c) using multivariate regression models that control for spatial dependence within the data. The results support the inequity hypothesis by indicating a significantly lower proportion of tree cover on public right-of-way in neighborhoods containing a higher proportion of African-Americans, low-income residents, and renters. These findings have important implications for local public investment and policy strategies.

Introduction

Urban areas are typically characterized by a patchwork of both desirable and undesirable land uses (Boone and Modarres, 2006). This urban mosaic results in an uneven geography of environmental amenities (eg parks) or disamenities (eg hazardous waste disposal sites), leading to an unequal distribution of social benefits or burdens across people and places. Perceived and reported inequities in the distribution of various undesirable land uses and facilities (eg United Church of Christ, 1987; US General Accounting Office, 1983) fueled the growth of the US environmental justice movement during the 1980s, on the basis of the contention that racial and ethnic minorities and economically disadvantaged groups are disproportionately exposed to environmental hazards and risks. Concerns regarding environmental injustice have catalyzed federal regulatory actions in the US (eg Clinton, 1994) and a considerable amount of scientific research in the last two decades (see reviews by Liu, 2001; Zilney et al, 2006). In order to determine if principles of environmental justice have been violated, quantitative case studies have typically focused on testing the environmental equity hypothesis—whether all demographic or socioeconomic groups in a particular study area are equally affected by the existing spatial distribution of environmental benefits and burdens (Cutter, 1995).

The proliferating research literature on environmental equity assessment has relied on various statistical and spatial analytic methods to determine whether racial and ethnic minority and economically disadvantaged communities are disproportionately impacted by locally unwanted land uses (eg Been, 1994; Liu, 1997), hazardous waste facilities (eg Laurian, 2008; Mohai and Bryant, 1992), air pollution (eg Brainard et al, 2002;

Pearce et al, 2006), industrial facilities reporting toxic releases (eg Bowen et al, 1995; Mennis and Jordan, 2005), transportations systems (eg Chakraborty, 2006; Jacobson et al, 2005), and other noxious land uses. While the uneven geography of disamenities and pollution sources has received considerable attention in the research literature, a more recent line of inquiry focuses on the distribution of more desirable land uses, such as parks (eg Boone et al, 2009; Talen, 1997; Wolch et al, 2005), playgrounds (eg Smoyer-Tomic et al, 2004; Talen and Anselin, 1998), recreational facilities (eg Hewko et al, 2002; Wells et al, 2008), and green spaces (eg Comber et al, 2008; Lindsey et al, 2001). Also referred to as spatial equity (Talen and Anselin, 1998) or territorial justice (Jacobson et al, 2005), this research evaluates the benefits and burdens associated with the distribution of environmental and social amenities.

Although few equity studies have focused specifically on urban vegetation, trees represent an important amenity for urban residents. The direct and indirect benefits of trees to people living within densely populated towns and cities have been well documented. Vegetation moderates urban temperatures (Oke, 1989), reduces heating and air-conditioning requirements (McPherson, 1994), and mitigates particulate air pollution (Nowak, 1994). Trees are associated with an increase in residential property values (Anderson and Cordell, 1988; Tyrvainen and Miettinen, 2000) and consumers prefer business districts with trees (Wolf, 2005). Epidemiological research indicates the presence of street trees may lower rates of childhood asthma (Lovasi et al, 2008) and increase the longevity of elderly people (Takano et al, 2002). Access to green spaces and trees may contribute to increased social cohesion (Kweon et al, 1998), neighborhood vitality (Sullivan et al, 2004), and reduced aggression and crime (Kuo and Sullivan, 2001a; 2001b). Despite an abundance of evidence to document the value of trees (see also reviews in Grey and Deneke, 1986; Nowak and Dwyer, 2007), the spatial unevenness of the urban tree canopy suggests that the benefits are not equally distributed across people and places. The distribution of trees in a particular metropolitan area is influenced by factors that range from natural seed dispersal to private and public tree planting initiatives. The incorporation of street trees in the urban landscape gained popularity at the turn of the 20th century during the City Beautiful movement (Grey and Deneke, 1986) and remains an important component of contemporary urban design practices (eg Arnold, 1980; Duany et al, 2000). While trees on private lands generally result from private investment or natural colonization, public agencies hold the primary responsibility for street tree planting and maintenance on public right-of-way areas (ROWs). Public investment is therefore an important factor affecting the distribution of street trees and principles of environmental justice dictate that such investment should be nondiscriminatory with respect to race and ethnicity, income, or housing tenure. The question remains as to whether public investment in street trees is spatially distributed to benefit all residents equally. Evidence to the contrary might suggest a publicly financed environmental inequity.

In spite of its growing relevance, few empirical studies have examined the issue of equity within the context of urban trees (Heynen, 2006; Heynen et al, 2006; Pedlowski et al, 2002; Perkins et al, 2004) and no published study has specifically focused on assessing distributional equity for street trees. We seek to address this gap in the literature by evaluating the environmental equity implications of public ROW trees in the city of Tampa, Florida (United States). Following previous research (Grove et al, 2006a; Heynen et al, 2006), tree canopy cover is used in this study as an indicator of the spatial distribution of urban trees. According to the inequity hypothesis, a lower proportion of tree cover can be expected on public ROWs in neighborhoods that contain a higher proportion of racial and ethnic minorities and socioeconomically disadvantaged residents.

This study extends current research on environmental equity and urban amenities through the use of several methodological innovations. First, only a few empirical studies have examined tree cover within transportation corridor ROWs separately from other land uses (Grove et al, 2006a; Heynen et al, 2006; Pedlowski et al, 2002). We used land-use information from cadastral data and examined inequities associated with the distribution of trees on public ROWs. Second, the resolution of urban tree cover data used in previous research (except Grove et al, 2006a) was not geographically detailed to permit analysis of parcel-level land use. In this study, we used very high (ie 1 m) resolution urban remote sensing techniques to accurately quantify tree cover for every parcel and ROW in the study area. Finally, prior equity studies of urban amenities have rarely applied statistical techniques appropriate for analyzing geographic data, thus failing to account for spatial processes and effects. The spatial dependence of values at nearby locations, for example, could violate the assumption of independent observations and potentially bias the results of multivariate regression analysis (Anselin, 2005; Kissling and Carl, 2008; Lloyd, 2007). We addressed this particular challenge through the use of spatial autoregressive multivariate models that incorporate the effects of autocorrelation inherent in our data and study area.

Environmental equity and urban trees

An established body of literature has examined the spatial distribution of urban amenities from the perspective of environmental equity (eg Boone et al, 2009; Hewko et al, 2002; Lindsey et al, 2001; Smoyer-Tomic et al, 2004; Talen, 1997; Talen and Anselin, 1998; Wolch et al, 2005). Empirical support for the equity hypothesis, however, is certainly not unanimous. Studies have found racial and ethnic minorities and low-income residents to have relatively lower access to parks and green spaces in some cities (eg Talen, 1997; Wolch et al, 2005) and greater access in others (eg Lindsey et al, 2001; Talen, 1997). While examining this empirical evidence, it is important to distinguish between inequities in the current location pattern of amenities and disamenities (outcome equity) and the processes or factors responsible for causing the observed inequities (process equity). Although potential causal mechanisms have been discussed by many authors (eg Lindsey et al, 2001), few studies have used longitudinal analysis to directly investigate the complex temporal dimensions associated with process equity (eg Boone et al, 2009; Wells et al, 2008; Wolch et al, 2005). Most scholars have addressed methodological challenges associated with the assessment of spatial equity (Comber et al, 2008; Hewko et al, 2002; Smoyer-Tomic et al, 2004). The bulk of the equity literature on urban amenities focuses on parks and recreational facilities and the evidence consistently demonstrates a spatially uneven distribution of these amenities.

Urban tree cover is a particularly important environmental amenity that is often spatially heterogeneous within urban areas (Cadenasso et al, 2007; Goetz et al, 2003; Grove et al, 2006b). Although few authors have examined the spatial distribution of trees from the theoretical perspective of environmental equity (Heynen et al, 2006; Jensen et al, 2004; Pedlowski et al, 2002; Perkins et al, 2004), studies offer evidence of an uneven geographical relationship between the existing distribution pattern of trees and income, race and ethnicity, and home ownership. Several researchers found a positive relationship between median household income and vegetation cover (Grove, 1996; Heynen, 2006; Heynen and Lindsey, 2003; Pedlowski et al, 2002; Talarchek, 1990), diversity (Martin et al, 2004), and leaf area (Jensen et al, 2004). These findings seem to support the inequity hypothesis by suggesting that low-income neighborhoods may benefit less from the existing distribution of this amenity. Evidence of an inequity for different racial or ethnic groups is mixed. For cities with a high overall minority population, Talarchek (1990) found a lower percentage of tree cover in New Orleans neighborhoods with a higher proportion of African-American residents, while Troy et al (2007) found higher tree cover in the African-American neighborhoods of Baltimore. In the predominantly white city of Milwaukee, Wisconsin, Heynen et al (2006) found a negative relationship between tree cover and the percentage of Hispanic residents, a positive relationship with percentage of non-Hispanic whites, but no significant association with percentage African-American. Among studies that examined the equity of tree distribution with respect to housing tenure, Perkins et al (2004) considered processes affecting reforestation inequity and found low participation by renters in private or public tree planting initiatives, while Heynen et al (2006) reported a negative association between renters and residential canopy cover.

Several potential explanations have been suggested for the uneven spatial distribution of urban tree cover. From a theoretical framework of political ecology, some argue that the unevenness of urban tree cover is driven by past and present processes associated with socioeconomic status and power relations (Heynen, 2006; Heynen et al, 2006; Pedlowski et al, 2002; Perkins et al, 2004). For example, Perkins et al (2004) suggest that renters may not have participated in a tree planting initiative because they would not have reaped the rewards of increased property values resulting from such an investment. Others have implicated personal and household preferences to explain the spatial heterogeneity of tree cover. As a possible explanation of vegetation differences between wealthy neighborhoods in New Orleans, Talarchek (1990) speculated 'landscape tastes' associated with social and cultural groups as a causal factor. In one of the most methodologically robust studies to date, Grove et al (2006a) identified lifestyle behavior associated with household land management decisions as the best predictor of tree cover on private lands as well as public ROW in Baltimore. They suggest that a household's decisions are influenced not only by socioeconomic status but also by a desire to

> "assert its membership in a given lifestyle group and to uphold the prestige of the household's neighborhood" (Grove et al, 2006a, page 2).

Few studies have examined differences between the distribution of trees on private and public lands (Grove et al, 2006a; Heynen, 2006). We consider this to be an important gap in the literature for several reasons. First, unlike trees growing on private lands, trees on public lands such as ROWs provide a range of benefits which impact the lives of all residents of a neighborhood, including the health benefits when shaded streets promote outdoor exercise (Takano et al, 2002; Wolch et al, 2005). Urban designers have long advocated the use of street trees to improve the livability of cities (Duany et al, 2000; Jacobs, 1993; Spirn, 1984). Second, street trees and ROWs where trees could be planted are not a trivial component of the urban landscape. Two recent studies using high-resolution techniques show that trees on public ROWs represent up to 10% (Troy et al, 2007) and 11% (Andreu et al, 2008) of city-wide tree canopy in Baltimore, Maryland and Tampa, Florida, respectively. Third, low-income residents who lack financial resources to plant and maintain healthy trees on private property remain dependent on the benefits provided by street trees (Heynen et al, 2006). Finally, while private land owners bear the responsibility for the maintenance of trees on private lands, public agencies bear the primary responsibility and the expenses for the maintenance of street trees. Thus, an important environmental equity question is whether public investment in street trees has been nondiscriminatory with respect to race and ethnicity, income, or housing tenure. Given the benefits provided by street trees, the importance of public sector investment, and the potentially large proportion of ROW land in US urban areas, there is a growing need to analyze the distributional implications of urban tree cover on public ROWs.

In summary, while there is evidence to suggest the distribution of trees may not be equitable within all cities, social inequities associated with public ROW trees have not been investigated. With the exception of a few studies (Grove et al, 2006a; Heynen et al, 2006; Pedlowski et al, 2002), previous research has largely focused on the distribution of overall neighborhood tree cover without regard to land use. Until recently (see Grove et al, 2006a), the availability of urban tree cover data was not sufficient to permit a comprehensive city-wide analysis of public ROWs. Finally, conventional regression techniques used in previous studies may not have accounted for spatial processes that are inherent in geographically referenced data. We consider the outcome equity implications of street trees and aim to address these gaps in the literature by: (a) accounting for land use and focusing on the public ROWs; (b) utilizing very high-resolution urban remote sensing techniques to quantify parcel-specific tree cover; and (c) addressing a spatial data analysis challenge by using multivariate regression models that control for spatial dependence within the data.

Study area

The City of Tampa, Florida (28°N, 82°W) is located on the west coast of Florida at approximately the midpoint of the peninsula in Hillsborough County (figure 1). The population of Tampa has increased from only 720 persons in 1880 to over 100 000 by 1930, 274 970 in 1960 (Mormino and Pozzetta, 1998), and 303 447 by 2000 (US Census Bureau, 2000a). The growth of Tampa during the second half of the 19th century coincided with the expansion of the timber industry. Pine and cedar lumber

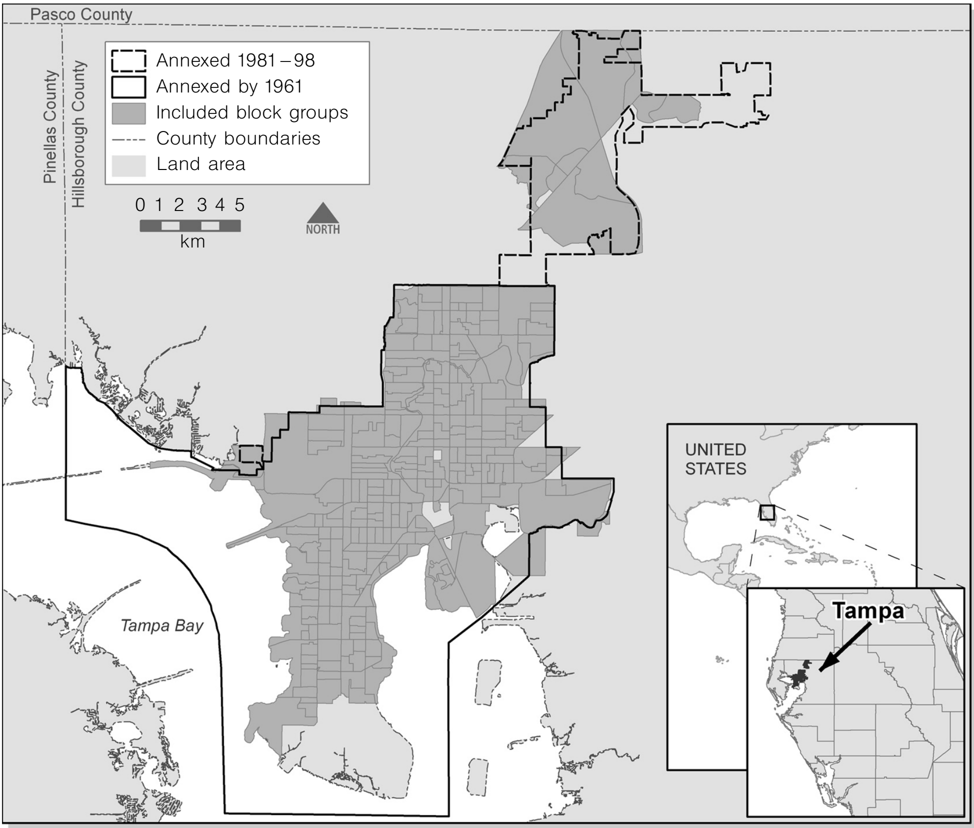


Figure 1. City of Tampa, Florida: land areas annexed by 1961 and during 1981 – 98.

mills were established by the 1860s (Brown, 2000), turpentine processing by the 1870s, and cypress harvesting by the 1890s (Maio et al, 1998). Timber mills closed as the local supply of trees was exhausted, and much of the industry had left the area before the 1930s (Covington, 1957; Maio et al, 1998). Although the precise impact of the timber industry on the trees in the areas currently occupied by Tampa is unknown, these signs suggest much of the area had been deforested by the early part of the 20th century. Given the large-scale deforestation and rapid urbanization during the early part of the 20th century, it could be argued that the majority of the existing trees within Tampa have been planted by residents and public sector investment, or through natural dispersal during the past century. Large tracts of remnant virgin forest are unlikely.

The geographic area of Tampa grew along with the population. By 1961 the jurisdictional areas included most of the southern portion of the present-day city—what Tampanians sometimes refer to as 'Old Tampa' (see figure 1). Annexations stalled during the 1960s and 1970s. During the 1980s and 1990s the large northern area known to Tampanians as 'New Tampa' was annexed (figure 1). Following the dispersed patterns of suburban development typical of many US metropolitan areas, population density in 2000 (US Census Bureau, 2000b) was drastically different between these two areas: 355 persons/km^2 in New Tampa compared with 1758 persons/km^2 in Old Tampa. To address this disparity, our study uses two different datasets: (a) the entire study area, which includes all lands annexed by 1998; and (b) Old Tampa, which includes only lands annexed prior to 1961. We included the larger area and the older subset to examine whether our results are sensitive to the difference in the age and density of housing developments, because we expect age and density to influence the distribution of urban trees and related inequities.

Consideration should be given to the character of public ROWs in Tampa as it affects the land available for planting and growth of street trees. Compared with the largest metropolitan areas of the US, Tampa has a lower population density and neighborhoods that are generally characterized by single-family homes on lots with large setbacks.

(a) (b)

Figure 2. Aerial imagery illustrating the general character of Tampa residential neighborhoods with (a) sidewalks and planting strips and (b) without sidewalks (source: SWFWMD, 2006).

In 2000, for example, Tampa's population density was only 1045 persons/km^2 compared with 4697 in Boston, 4923 in Chicago, 3041 in Los Angeles, 10 194 in New York, and 3923 in Miami (US Census Bureau, 2000a, table GCT-PH1). Planting areas in Tampa include unpaved strips approximately 3 – 6 ft wide along streets with sidewalks and generally wider ROW easements bordering streets without sidewalks. It is estimated that only 59% of city streets in Tampa have sidewalks (personal communication with Jan Washington, City of Tampa Department of Public Works, Sidewalk and Street Light Program Manager, 12 November, 2008). The City of Tampa street tree planting and management programs target all city streets regardless of sidewalks, and new sidewalk installations are designed to accommodate tree planting whenever possible (personal communication with Kathy Beck, City of Tampa Parks and Recreation Natural Resource Supervisor, 12 November, 2008). Aerial photographs illustrating the general character of ROW in residential neighborhoods with and without sidewalks are depicted in figure 2.

Methods

Data

Environmental equity was examined with respect to the distribution of land-use-specific tree canopy cover aggregated for each US Census Block Group within the study area. Measures of neighborhood demographic and socioeconomic characteristics were based upon Census 2000 block group data (US Census Bureau, 2000b). Census 2000 block groups were chosen as the sampling unit because this is the smallest geographic unit for which relevant socioeconomic data are available. Only block groups located within the January 2000 City of Tampa boundary were included, after adjusting the boundaries to account for coastlines. Since the focus of this study was limited to residential housing units, several block groups were excluded due to lack of residential parcels and two small block groups were excluded because they represented only single parcels with high population density institutional housing. Two final datasets were generated: (a) all areas annexed by 1998 that included 284 block groups and represented a population of 290 601 or 96% of Tampa's 2000 Census population; and (b) 'Old Tampa' lands annexed prior to 1961 that included 274 block groups and represented a population of 266 670 or 88% of Tampa's 2000 Census population (see figure 1).

Land use associated with each property parcel was identified from 2006 cadastral data (HCPA, 2007). Public ROW and water polygons were added to the original parcel data for completeness. In order to identify ROW areas adjacent to residential parcels, each 30 m × 30 m section of public ROW was additionally labeled with the land use of the nearest parcel. Two ROW land uses were isolated as the focus of this study: (a) ROW bordering residential parcels; and (b) all ROW without regard to neighboring land use. We expected benefits to residents and the potential causal mechanisms related to tree cover to differ for ROW immediately adjacent to residences, compared with ROW not adjacent to residences. These potential differences were considered by conducting independent analyses on the datasets representing these two land uses.

Parcel-specific tree canopy cover was quantified using very high-resolution remote sensing techniques appropriate to the urban environment. Tree cover classification was based on 2006 pan-sharpened 1 m IKONOS imagery using the method of supervised maximum likelihood classification following Goetz et al (2003). Overall classification accuracy measured by validation procedures was 95.6% (Andreu et al, 2008). The final 1 m resolution classification dataset was used to calculate the percentage of tree cover within each parcel polygon. The method of 'polygon containment' identified and used in the environmental equity literature (eg Chakraborty and Armstrong, 1997; Talen and Anselin, 1998) was applied to associate tree cover and sociodemographic characteristics based on census block groups. Our application of polygon containment assumes that the benefits of a resource located within a block group boundary apply to all and only residents living within that block group. Although not necessarily appropriate for equity analysis involving park and facility amenities (Hewko et al, 2002; Talen and Anselin, 1998), this method was chosen for three reasons: (a) it was reasonable to assume the benefits of trees on public ROW could be realized by all individuals residing within the relatively small area of a block group; (b) the analytical simplicity and practicality was preferred over other buffering or proximity-based methods; and (c) the approach has been utilized in prior studies (eg Grove et al, 2006a; Troy et al, 2007). Tree cover percentages were calculated as the total area of tree cover on selected ROW polygons within each block group normalized by the total land area of the selected polygons. Two separate dependent variables were calculated for each block group: the percentage of tree cover within all ROWs (AROWs); and the percentage of tree cover within ROWs bordering residential parcels (RROWs).

Explanatory variables were chosen from previous environmental equity studies to represent race and ethnicity and socioeconomic status, and based on evidence from the literature on their association with tree cover (eg Grove et al, 2006a; Heynen, 2002; 2006; Heynen and Lindsey, 2003; Heynen et al, 2006; Martin et al, 2004; Pedlowski et al, 2002; Perkins et al, 2004; Talarchek, 1990). The percentage of the population identifying themselves as African-American (non-Hispanic) and Hispanic were selected as our race and ethnicity variables because they represent the two largest minority groups in Tampa, or 25% and 19% of the total population (US Census Bureau, 2000a), respectively. Following previous environmental equity research, median household income and percentage of owner-occupied housing units (homeownership rate) were chosen as measures of socioeconomic status.

Although our specific focus was on inequities related to race and ethnicity, income, and housing tenure, the inclusion of other variables allowed us to control for the effects of additional factors. For example, median building age and a quadratic term for median building age were included on the basis of prior evidence of a significant nonlinear relationship with tree cover (Grove et al, 2006a). Explanatory variables were limited to include only those indicating a statistically significant ($p < 0.05$) bivariate Pearson's correlation with tree cover. Variables found to be important in previous studies, such as population density (Troy et al, 2007) and educational attainment (Heynen and Lindsey, 2003), were excluded for this reason. Confounded variables, identified by significant Pearson's correlation values greater than 0.7 (Meyers et al, 2006), were excluded from the study. All variables were based upon 2000 Census data, with the exception of building age which was calculated from the cadastral data (HCPA, 2007) as the median value of residential parcels built before the year 2000 within each block group. The final list of independent variables included median building age (and building age squared), percentage African-American (ie Black or African-American non-Hispanic), percentage Hispanic, percentage owner-occupied, median household income, average household size, and estimated average age of householder.

Statistical analysis

The purpose of our analysis was to evaluate whether the distribution of trees is statistically associated with race and ethnicity, income, and housing tenure in Tampa, Florida, after controlling for the effects of other relevant explanatory factors. Multivariate regression models were used to analyze the percentage of tree cover on ROWs as a function of the explanatory variables at the block group level. Inequity for the distribution of trees in Tampa would be evidenced if tree cover on public ROWs was predicted by significantly negative regression coefficients for proportion of African-American or Hispanic residents, or a significantly positive coefficient for median household income or the proportion of home owners.

Our statistical analyses were composed of a three-step process. First, separate ordinary least squares (OLS) multivariate regression models were developed for each study area using the percentage of tree cover within AROWs and the percentage of tree cover within RROWs as dependent variables. Second, regression residuals (errors) from the OLS models were tested for global spatial autocorrelation using the Moran's I-statistic, to determine whether the model results might be biased due to spatial dependence. Finally, when spatial dependence was detected in the residuals of the OLS model, a spatial regression model was specified to include an additional term to account for spatial autocorrelation. Prior to analysis, each variable was tested for normality and collinearity. Concerns about normality were identified for proportion Hispanic and median household income and mitigated using ln transformations (see table 1). A $\ln(x + 0.01)$ transformation was required for proportion Hispanic to avoid the problem of negative infinity caused by zero values (Sokal and Rohlf, 1995). Collinearity diagnostics (ie variance inflation factors and tolerances) provided by the SPSS software program (SPSS 16.0 for Windows, SPSS Inc., Chicago, IL) for least squares regression analysis indicated no multicollinearity problems for our final set of independent variables.

Table 1. Summary and reference statistics for the Tampa study areas.

	Entire study area				Old Tampa study area			
	minimum	maximum	mean	sd	mini mum	maximum	mean	sd
All right-of-way area (ROW) tree cover (%)	0.04	0.58	0.21	0.10	0.04	0.58	0.21	0.10
All ROW total vegetation cover (%)	0.09	0.88	0.44	0.12	0.09	0.77	0.44	0.12
Residential ROW tree cover (%)	0.03	0.61	0.24	0.10	0.03	0.61	0.24	0.10
Residential ROW total vegetation cover (%)	0.08	0.90	0.49	0.12	0.08	0.78	0.49	0.11
Median building age (years)	6.00	66.00	34.12	9.01	7.00	66.00	34.97	7.93
Proportion African-American	0.00	1.00	0.25	0.30	0.00	1.00	0.26	0.30
Proportion Hispanic	0.00	0.87	0.19	0.17	0.00	0.87	0.20	0.17
Proportion owner-occupied	0.00	1.00	0.61	0.24	0.00	0.98	0.61	0.24
Median household income (US $)	8750	159949	39004	23811	8750	159949	37758	22868
Average household size (persons)	1.05	3.57	2.42	0.45	1.05	3.44	2.41	0.44
Estimated average householder age (years)	26.00	80.00	53.89	6.07	30.00	80.00	54.26	5.71

Spatial autocorrelation has been a frequent problem for the analysis of ecological and socioeconomic data (Kissling and Carl, 2008; Talen and Anselin, 1998). This problem is often caused by geographic clustering when values at nearby locations are more similar to or different from what would be expected of a random distribution. This phenomenon has the potential to cause spatial dependence of regression model residuals, thus violating the assumption of independent observations (ie uncorrelated errors). Spatial regression, or simultaneous autoregressive (SAR) models, provided one solution to address this problem by augmenting the standard linear regression model to include the effects of spatial dependence (Anselin and Bera, 1998). The need to utilize SAR models for our data was confirmed by a significant Moran's *I*-statistic for global autocorrelation calculated from the residual error values from each OLS regression.

The SAR model required the development of an appropriate set of neighbor relationships, or spatial weights matrix. The spatial weights matrix accounts for variation in the dependent variable explained by values at neighboring locations rather than by explanatory variables. While several methods are available, a row-standardization distance-based weights matrix was used instead of a contiguity matrix due to the lack of uniformity in census block group size and shape (Pastor et al, 2005). These weight matrices were generated on the basis of the Euclidean distance between block group centroids. Following the recommendations of Kissling and Carl (2008), the choice of maximum distance for the neighbor effect in the weights matrix was based on minimizing autocorrelation of SAR model residuals and maximizing model fit using the Akaike information criterion (AIC). Distance values were tested between 305 and 2743 m at decreasing increments until a final distance of 1518 m was found to meet the above-mentioned selection criteria.

The open-source spatial statistics application GeoDa (Anselin, 2004) was used to develop OLS and SAR models, generate weight matrices, and calculate Moran's *I*-statistics. There have been two common approaches to account for autoregressive effects using a spatial regression model: spatial error regression and spatial lagged regression. Spatial error regression (SAR_{err}) models assume that the autoregressive effect exists in a spatially dependent error term, while the spatial lagged regression (SAR_{lag}) assumes that the autoregressive effect occurs only in the dependent variable. Following the decision rules recommended by Anselin (2005), Lagrange multiplier test statistics generated from a preliminary OLS model indicated the SAR_{err} model was more appropriate than the SAR_{lag} model. A comparison of model fit between SAR_{err} and SAR_{lag} using the AIC statistic confirmed the appropriateness of the SAR_{err} model. The form of the SAR_{err} model is as follows:

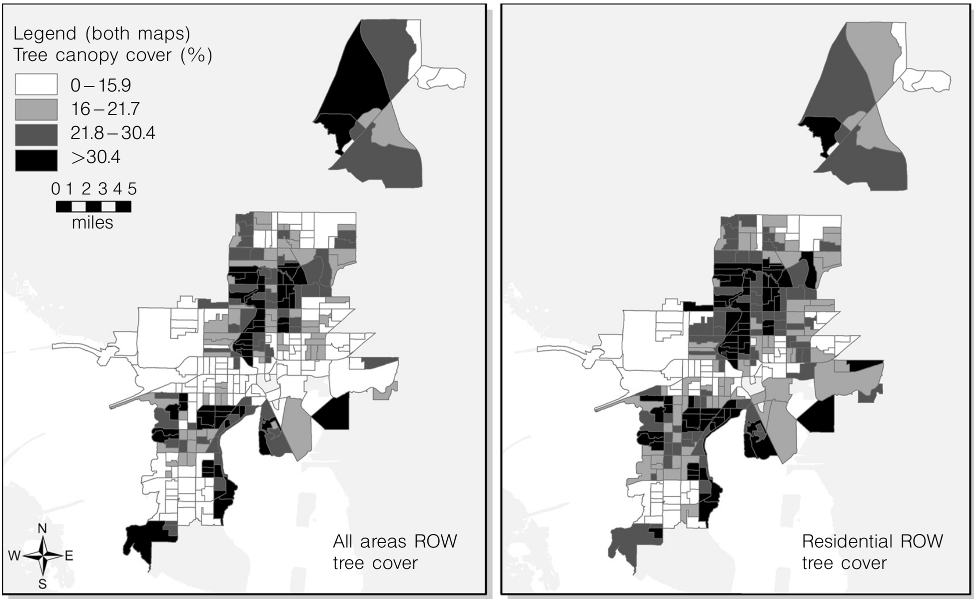
$$y = \alpha + \boldsymbol{\beta}\mathbf{X} + \lambda\mathbf{W}u + e\,,$$

where y is the percentage of ROW tree cover, α is the intercept (constant), $\boldsymbol{\beta}$ is the vector of slopes associated with the matrix of explanatory variables $\mathbf{X}$, λ is the spatial autoregression coefficient, $\mathbf{W}$ is the spatial weights matrix, u is the spatially dependent error term, and e is the random error term.

A set of multivariate regression models was used to test the sensitivity of the analysis to the study area (ie the entire study area compared with Old Tampa) and definition of ROWs (ie AROWs compared with RROWs). A total of eight regression models were thus generated: (a) OLS model of AROWs for the entire study area; (b) SAR_{err} model of AROWs for the entire study area; (c) OLS model of RROWs for the entire study area; (d) SAR_{err} model of RROWs for the entire study area; (e) OLS model of AROWs for Old Tampa; (f) SAR_{err} model of AROWs for Old Tampa; (g) OLS model of RROWs for Old Tampa; (h) SAR_{err} model of RROWs for Old Tampa.

Results

The spatial distribution of tree canopy cover within the entire study area, aggregated by block group, for AROWs and RROWs is illustrated in figure 3. For the purpose of comparison, these choropleth maps are grouped into the same four categories based on the quantile values calculated from the residential ROW tree cover. A visual comparison indicates a difference depending on whether ROW tree cover was calculated for AROWs [figure 3(a)] or only RROWs [figure 3(b)]. Descriptive statistics presented in



(a) (b)

Figure 3. Tree canopy cover for (a) all right-of-way areas (ROWs) and (b) residential ROWs by block groups classified into quartiles based on residential ROW tree cover.

table 1 indicate that the mean tree cover is 3% higher for ROWs bordering residential areas. Tree cover for RROWs ranged from 11% lower to 18% higher than tree cover for AROWs. These results illustrate the importance of including both measures as a sensitivity analysis for the examination of ROW tree cover.

OLS and spatial regression (SAR_{err}) model results for the entire study area and old Tampa study area are presented in tables 2 and 3, respectively. Model coefficients are presented along with the t-statistic for the OLS model and the z-statistic for the SAR_{err} model. In all SAR_{err} models the spatial autoregressive coefficient used to supplement the regression model was very large and highly significant ($p < 0.001$). Measures of model fit are provided by the adjusted R^2 for the OLS model and the pseudo R^2 for the SAR_{err} model, and the AIC for both models. Moran's I-statistic was generated from the residual error values of each model.

Model comparisons confirm that the SAR_{err} models were more appropriate for analyzing our dataset than the OLS models. While the adjusted R^2-values indicate a reasonably good fit for all OLS models (eg 0.205 to 0.235), the statistically significant and moderately high Moran's I-values (eg 0.361 to 0.384) indicate that our OLS models suffered from spatial autocorrelation of the error term and thus violated the assumption of uncorrelated errors. The reduction in the Moran's I-statistic after including the spatially autoregressive error term indicate the SAR_{err} models accounted for the majority of the spatial dependence. Although not directly comparable to the R^2-statistics of the OLS model, the high pseudo R^2 (eg 0.556 to 0.577) for the SAR_{err} models suggests a better model fit. Finally, the reduction in AIC for the SAR_{err} models, a more appropriate comparison (Anselin, 2005; Lloyd, 2007), further indicates an improved fit over the OLS models. Differences in significance of explanatory variables between the OLS and SAR_{err} models illustrate the risk of misinterpretation if the effects of spatial autocorrelation were not considered. For example, estimated average householder age was a significant predictor of tree cover in one of the OLS models but not in any of the SAR_{err} models for the Old Tampa study area. Similarly, the proportion of African-American residents was a significant coefficient in one SAR_{err} model but in none of the OLS models. All specific model results discussed in this section, unless indicated otherwise, thus refer to the SAR_{err} models.

Table 2 summarizes the model results for the entire study area. The percentage of tree cover on RROW increases significantly with median household income and the proportion of owner-occupied housing ($p < 0.05$ for both), and declines significantly with the proportion of African-American and Hispanic residents ($p < 0.10$ for both). The significant and negative coefficient indicated by the quadratic term for median housing age suggests a downward concave relationship; tree cover on residential ROW increases more rapidly in block groups characterized by lower housing age compared with those with higher housing age. When AROW is considered, median household income ($p < 0.01$) the proportion of owner-occupied housing units ($p < 0.10$), and householder age ($p < 0.10$), are significant predictors of increased tree cover, while the Hispanic proportion is found to have a negative effect ($p < 0.10$).

Table 2. Ordinary least squares (OLS) regression and spatial regression (SAR_{err}) of residential right-of-way (RROW) and all right-of-way (AROW) tree canopy cover for the entire study area.

	RROW		AROW	
	OLS	SAR_{err}	OLS	SAR_{err}
Median building age (years)	0.007	0.005	0.004	0.002
	(2.652)***	(1.764)*	(1.380)	(0.573)
(Median building age)^2 (years^2)	−0.0001	−0.0001	−0.0001	−0.00004
	(−2.321)**	(−1.972)**	(−1.473)	(−1.198)
Proportion African-American	−0.040	−0.069	−0.032	−0.044
	(−1.086)	(−1.935)*	(−0.884)	(−1.244)
Proportion Hispanic	−0.012	−0.014	−0.009	−0.013
[$\ln(x + 0.01)$]	(−1.357)	(−1.809)*	(−1.109)	(−1.669)*
Proportion owner-occupied	0.107	0.055	0.109	0.050
	(3.193)***	(2.115)**	(3.322)***	(1.925)*
Median household income	0.044	0.043	0.046	0.044
[US $ $\ln(x)$]	(2.114)**	(2.523)**	(2.260)**	(2.632)***
Average household size (persons)	−0.025	−0.001	−0.007	0.013
	(−1.321)	(−0.072)	(−0.395)	(0.851)
Estimated average householder	−0.001	0.0003	−0.001	0.001
age (years)	(−1.528)	(0.480)	(−0.799)	(1.927)*
Intercept	−0.299	−0.403	−0.349	−0.428
	(−1.290)	(−2.132)**	(−1.542)	(−2.303)**
Adjusted R^2	0.205		0.225	
Pseudo R^2		0.556		0.561
F-statistic	10.101***		11.270***	
Akaike information criterion	−531.479	−683.924	−545.289	−693.078
Moran's I	0.369***	−0.055**	0.361***	−0.059**

*$p < 0.10$, **$p < 0.05$, ***$p < 0.01$.
Note: t-values (OLS) and z-values (SAR_{err}) in parentheses.

Table 3 presents the model results for the Old Tampa study area. The percentage of tree cover on RROWs is significantly associated with higher median household income, higher proportion of owner-occupied housing units, lower proportion of African-American residents ($p < 0.05$), and a lower proportion of Hispanic residents ($p < 0.10$). The percentage of tree cover for RROWs increases significantly with median household income ($p < 0.05$) and the proportion of owner-occupied housing units ($p < 0.10$), and declines significantly with the proportion of Hispanic residents ($p < 0.10$).

Table 3. Ordinary least squares (OLS) regression and spatial regression (SAR_{err}) of residential right-of-way (RROW) and all ROW (AROW) tree canopy cover for the Old Tampa study area.

	RROW		AROW	
	OLS	SAR_{err}	OLS	SAR_{err}
Median building age (years)	0.001	−0.0003	−0.001	−0.003
	(0.231)	(−0.102)	(−0.283)	(−0.838)
(Median building age)^2 (years^2)	−0.00001	−1.138	0.000004	0.00001
	(−0.231)	(−0.252)	(0.071)	(0.180)
Proportion African-American	−0.037	−0.078	−0.030	−0.053
	(−0.984)	(−2.174)**	(−0.833)	(−1.499)
Proportion Hispanic	−0.010	−0.015	−0.009	−0.014
[ln($x + 0.01$)]	(−1.163)	(−1.926)*	(−0.997)	(−1.877)*
Proportion owner-occupied	0.113	0.061	0.115	0.052
	(3.251)***	(2.189)**	(3.380)***	(1.890)*
Median household income	0.039	0.038	0.043	0.042
[US$ ln(x)]	(1.831)*	(2.215)**	(2.056)**	(2.465)**
Average household size (persons)	−0.017	0.005	0.0002	0.020
	(−0.881)	(0.283)	(0.008)	(1.266)
Estimated average householder	−0.002	−0.0004	−0.001	0.001
age (years)	(−2.192)**	(−0.518)	(−1.262)	(1.130)
Intercept	−0.104	−0.206	−0.216	−0.278
	(−0.409)	(−1.006)	(−0.869)	(−1.386)
Adjusted R^2	0.210		0.235	
Pseudo R^2		0.566		0.577
F-statistic	10.047***		11.500***	
Akaike information criterion	−513.725	−649.328	−525.732	−660.251
Moran's I	0.384***	−0.050*	0.376***	−0.061**

*$p < 0.10$, **$p < 0.05$, ***$p < 0.01$.
Note: t-values (OLS) and z-values (SAR_{err}) in parentheses.

The relative importance of the statistically significant explanatory variables within each model can be evaluated on the basis of their corresponding z-statistic values. For all SAR_{err} models, higher median household income was the strongest predictor of higher tree cover on both RROWs and AROWs. Indicators of race (proportion African-American) and ethnicity (proportion Hispanic) are relatively weaker predictors of tree cover when compared with either income or housing tenure (proportion of owner-occupied housing units).

Discussion

We have sought to address specific limitations of prior environmental equity studies on urban amenities through several methodological improvements. The objective of our case study was to assess locational inequities in the distribution of street trees in the city of Tampa by: (a) acquiring landownership data and isolating public ROWs; (b) implementing advanced urban remote sensing techniques that accurately quantify parcel-level tree cover; and (c) controlling for spatial dependence in the data using spatial error regression models. Results from this study support the inequity hypothesis by indicating that trees on public ROWs are disproportionately distributed with respect to economic status and, to a lesser extent, housing tenure and race and ethnicity. Our statistical results reveal a significantly lower proportion of tree cover in ROWs in neighborhoods with lower median household income. Tree cover in the RROWs (ie excluding commercial and other areas) consistently decreases in areas containing a higher proportion of renters. In the areas of Tampa annexed prior to

1961 (ie Old Tampa), tree cover in the RROWs declines in block groups with a higher proportion of African-American residents. Given the importance of street trees (indicated by tree cover) as an urban amenity, this disproportionate distribution indicates an environmental inequity in Tampa. Our evidence suggests that residents of neighborhoods characterized by low-income households, renters, and African-American individuals lack the same access to the benefits provided by ROW trees as areas populated by more affluent, white, and homeowning Tampanians.

The disproportionate distribution of public ROW tree cover may not necessarily reflect an inherent unevenness in the availability of plantable spaces for street trees. In many urban areas, street tree planting is often limited by the availability of planting strips designed into the sidewalk (Arnold, 1980; Spirn, 1984). As previously mentioned, only 59% of Tampa streets have sidewalks and new sidewalk installations are designed to accommodate planting strips whenever feasible. In areas without sidewalks, planting occurs in the ROW easement between the street and private property. The percentage of total vegetation cover in the ROWs represents land surface not covered by built structures such as houses, roads, sidewalks, and driveways and can be considered possible locations for tree planting (Troy et al, 2007). Summary statistics presented in table 1 show that minimum and mean total ROW vegetation cover is at least twice as high as the corresponding percentage of tree cover in both study areas. Thus, the data suggest that existing areas of low street tree cover may not be due to a lack of available planting areas in Tampa ROWs.

Although this investigation was purposefully focused on public ROWs, the results are consistent with previous studies that examined urban tree cover on private lands or mixed land uses. Several studies found a positive relationship between tree canopy cover and median household income (Grove, 1996; Heynen, 2006; Heynen and Lindsey, 2003; Pedlowski et al, 2002; Talarchek, 1990). Heynen and Lindsey (2003) suggest that people are willing to pay more for properties with trees because of the associated increase in property values (eg Anderson and Cordell, 1988). Grove et al (2006a) demonstrate that preference for trees is not ubiquitous among wealthy households even when high-income neighborhoods have more land available for tree planting (Troy et al, 2007). While the debate regarding the causal mechanisms still continues, research shows that affluent neighborhoods generally have a greater extent of tree canopy than economically disadvantaged neighborhoods.

The consistency between previous results for private land and our results for public ROWs in Tampa is not surprising for several reasons. One obvious explanation is that there are usually no barriers to prevent trees planted on private land from extending above public ROWs. Another explanation is that households with greater purchasing power can afford to buy homes in neighborhoods with existing tree-lined streets. Households may plant trees on public ROWs as a way of investing in the 'curb appeal' of their own property or neighborhood, as suggested by Grove et al (2006a). The persistence of socioeconomic status in predicting the presence of tree cover on AROWs may also be suggestive of political influence. Assuming tree-lined streets are a desirable quality of a neighborhood, it would be reasonable to suggest that both residents and/or property owners would exert political pressure on public agencies to promote public sector investment in ROW tree planting near their residence.

Previous studies have also indicated a larger extent of tree cover in neighborhoods with a higher percentage of owner-occupied housing (Heynen et al, 2006; Perkins et al, 2004). These authors argue that home owners have a greater financial incentive to invest in environmental amenities on their property than renters. The results of our analysis seem to support these arguments for Tampa, where home ownership rate is a strong predictor of tree cover on ROWs bordering residential parcels. First, similar to the mechanism proposed by Perkins et al (2004) for private land, renters may also be less willing to invest in tree planting on the ROWs adjacent to their residence. Second, the greater financial incentives may drive homeowners to exert more political pressure than renters to promote public sector investment in ROW tree planting within their neighborhoods.

Evidence of a racial inequity in the distribution of tree cover on ROWs was limited to areas of Old Tampa. The racial and socioeconomic differences between the study areas may point towards a possible explanation for this finding. While the African-American proportion is marginally higher and median household income is slightly lower in Old Tampa compared with the entire study area, a closer examination of the data reveals a substantial racial and economic disparity. The percentage of residents identified as African-American for block groups located in suburban areas (ie New Tampa) is only 5%, compared with 26% in Old Tampa. Median household income in New Tampa is US $73 149, nearly twice that of Old Tampa (ie US $37 758). The concentration of minority residents in lower income and older neighborhoods could bias our findings on racial inequities in the distribution of tree cover in some areas of Tampa. Studies of urban segregation have identified the difficulties associated with separating race from income in residential housing market analysis (eg Been, 1994; Schweitzer and Stephenson, 2007). Other researchers argue that the processes explaining environmental equity go beyond market forces (Pastor et al, 2001) and are not independent of the forces of institutional racism or 'white privilege' (Pulido, 2000). While it is difficult to make definitive claims about racial injustice on the basis of this case study, future research needs to focus on disentangling the effects of race and income to better understand sociospatial inequities related to tree cover.

It is important to mention specific limitations associated with our case study and methodology. First, our cross-sectional analysis focuses only on inequities measured at a specific point in time (outcome equity) and not on the mechanisms and processes that caused the observed outcomes (process equity). The current association between tree cover on ROWs and race and ethnicity, income, or housing tenure does not necessarily reflect neighborhood conditions at the time of the original tree planting. Identifying specific processes responsible for the observed inequities will require additional and substantial longitudinal analysis that is beyond the scope of the current study. Second, temporal differences between land cover (in 2006) and the sociodemographic data provided by the latest US Census (2000) could potentially introduce some bias in our results, due to possible changes in the racial and ethnic or socioeconomic composition of individual neighborhoods, or changes in the tree canopy cover, between 2000 and 2006. Third, while the theoretical implications of the study relate to the social benefits provided by urban trees, the empirical analysis was limited to the use of tree cover as a proxy for these benefits. The results may have been different if we had measured the actual benefits provided by the street trees within each neighborhood, such as their role in reducing particulate air pollution (Nowak, 1994). Finally, this study considered only the benefits and not the potential burdens associated with trees, such as the adverse impact of storm damage (Duryea et al, 1996; Jim and Liu, 1997).

While studies on urban forest equity have used multivariate regression analysis, the potential for spatial autocorrelation has not been addressed previously. As indicated in this paper, the failure to account for spatial dependence may have resulted in a different interpretation of the results. For example, racial inequities in the distribution of tree cover was detected only after including the spatially autoregressive error term in our multivariate regression models.

The spatial dependence in our data also suggests the need for additional future research because our models probably excluded other relevant explanatory variables (Kissling and Carl, 2008; Lloyd, 2007). Our quantitative analysis needs to be augmented by a detailed qualitative longitudinal study to reveal additional explanatory factors and potential causal mechanisms to explain the unevenness of tree cover. Anecdotal evidence suggests, for example, that some residents of the low-income East Tampa neighborhood were not in favor of street tree planting near their property out of concern for storm damage (personal communication with Steve Graham, City of Tampa Natural Resources Superintendent, 11 November 2006). If indeed this sentiment was widespread, possible efforts by the city to achieve an equitable distribution of street trees would have been hindered by local residents. By documenting the existence of outcome inequity, we have set the stage for future spatiotemporal investigation to identify the processes which led to the disparate distribution of street trees with respect to race, income, and housing tenure in Tampa.

Conclusion

Urban trees serve as environmental amenities that provide several direct and indirect benefits for urban residents. The equitable distribution of street trees is an important consideration because planting and management of street trees is the primary responsibility of government, and such public investment should be nondiscriminatory. There is a large body of work suggesting a disproportionate distribution of urban trees with respect to particular demographic and socioeconomic groups. However, only a few studies have examined these issues in the context of environmental equity (Heynen et al, 2006; Pedlowski et al, 2002; Perkins et al, 2004) and none of these studies has specifically considered the unevenness of public sector investment in trees on public ROW land.

Swyngedouw and Heynen (2003) suggested that

> "policy innovations that plan for an equitable allocation of urban resources should be continually sought. While 'planning' does not necessarily imply a more equitable outcome, it does increase the likelihood that attention will be focused on the issue" (page 912).

Although urban forest management policies in the City of Tampa do not specifically address environmental equity, improving the quality of life for disadvantaged areas has been a goal of specific street tree planting and management strategies. For example, a recent tree planting effort in the low-income and largely African-American neighborhood of East Tampa would likely reduce the inequity that is evidenced by the existing low tree cover in this area. In order for the city to plant a street tree in front of a residential property, residents were asked to water the newly planted trees for a brief period of establishment (personal communication with Steve Graham, City of Tampa Natural Resources Superintendent, 11 November, 2006). Despite this seemingly well-intentioned strategy, achievement of an equitable outcome may have been hindered in areas where the watering requirement posed an undue burden for low-income residents. An empirical study by Perkins et al (2004) also revealed a problem of policy inequity with a government urban reforestation program in Milwaukee. Further research is necessary to address the question of whether strategies of urban forestry programs inadvertently promote conditions of environmental inequity.

The City of Tampa, in their Tampa Comprehensive Plan Update (HCCCPC, 2008), recognize the value of street trees as an amenity and suggest that achieving a sustainable city includes distributing opportunities and risks equitably. Although the results of our study suggest an environmental *outcome* inequity for low-income households, renters, and African-American residents, the good news for the City of Tampa and these groups is that a large amount of potential planting area remains within existing public ROWs. Tree cover averaged 21% of the land occupied by AROWs included in this study. The same land cover data revealed that an additional 25% of city-wide ROWs were occupied by plantable areas composed of other vegetation such as shrubs and ground cover (Andreu et al, 2008). Planting trees in these vegetated areas could result in a doubling of the tree canopy cover within the public ROWs. While uncovering the causes of the inequity is an important long-term goal, the City of Tampa should implement policies to address current disparities by targeting street tree planting within the available planting areas of the affected neighborhoods.

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