Rapid Methods for Estimating and Monitoring Tree Cover Change in Florida Urban Forests: The Role of Hurricanes and Urbanization

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Abstract

Urbanization other factors such as hurricanes have greatly affected tree cover in Florida cities, resulting in a loss of tree cover and a wide range of ecosystem changes. The goal of this project was to evaluate rapid, inexpensive, and simple methods to quantify, analyze and monitor urban tree cover change in three communities: Gainesville, Miami-Dade and Broward Counties between 1984 and 2005 and also between 2005 and 2007. Two Geographic Information System (GIS) methods that quantify, assess and monitor tree cover change were used in the study: (1) random photo-interpretation of points overlaid on the study area and (2) random 0.04 hectare photo interpretation plots where tree crowns were digitized and measured. ArcGIS, digital orthophotos, photo-interpretation, heads up digitizing, and field verification were used to evaluate these methods. Tree cover was then quantified using ocular estimates. Point and ocular plots were compared with actual field measurements of tree cover. The study showed that tree

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cover was reduced in the Miami-Dade study area between 1984 and 2005 and further reduced by 2007. It remained constant in Broward County and varied in Gainesville. Socio-economics, urbanization, and hurricanes affect tree cover spatially and temporally. This method provides a rapid and cost-effective method to analyze urban forest change.

Keywords. Census block data, zonal statistics, kriging, socio-economic analysis

Introduction

The effects of hurricanes and urbanization on Florida's urban forests can dramatically change urban ecosystem structure and function. The scale of these effects may range from individual trees to municipal, state, and regional impacts and decreases in ecosystem functions such as air pollution removal, carbon sequestration, and community values. Hurricane effects on urban forests also threaten public safety, generate tree debris, and create adverse economic consequences for state and local governments in the short and the long-term. Given the realities of urbanization and hurricanes in Florida, there is a need to support local and regional governments with rapid methods to measure and assess the extent and location of damage to urban forests, as well as tools to help plan for and manage the response and eventual restoration of the urban forest.

Aerial imagery and moderate resolution imagery such as Landsat Thematic Mapper have been used to assess areas affected by large scale disturbances such as hurricanes, ice storms and wildfires (Barnes et al., 2007; Olthof et al., 2004; Pickens et al., 2000; Scarr et al., 2003; Shedd, 2007; Lewis, 2004; McNab et al., 2006). Classification of these disturbances can also use conventional multispectral methods (Coburn and Roberts, 2004). Unfortunately these methods are expensive; require specific software and hardware and an advanced knowledge of GIS and remote sensing.

There many approaches that can be used to detect tree cover and change, including GIS and remote sensing based image recognition and classification systems and software such as Feature analyst in ArcGIS, unsupervised and supervised classification, vegetation indices, and the CityGreen software (American Forests, Inc.) that can be used to detect tree cover and change (Magnusson and Fransson, 2005; Lefsky et al., 2001; Gougeon, 2000; Gitelsen et al., 1998; Chavez and MacKinnon, 1994; Krivoruchko 2001). However, detecting tree cover and individual trees in most urban areas can be complex (Escobedo et al., 2006; Lipscomb et al., 2006; Key et al., 2001; Sugumaran et al., 2003), particularly after large-scale disturbances. In order to monitor changes and growth of urban forests, it is necessary to distinguish between urban and non-urban land (e.g. vegetation) cover. Classification is a standard approach for remotely sensed data and is used to detect unique and internally homogeneous classes. However, urban environments are very heterogeneous (roofing material, pervious and impervious surfaces, roads, lawns, trees, and water). Thus, cover classes cannot be easily broken into discrete nominal classes by a clustering-based classification, because clusters will have considerable overlap, thus complicating the determination of the probability of an unknown value's classification (Forster, 1985, Small, 2002). Furthermore, distinguishing between vegetation classes such as tree and herbaceous cover is problematic. Based on these complications, users should be aware of the complexity of traditional thematic classification algorithms for urban mapping.

Therefore, to rapidly assess and monitor urban forest change, methods must be developed which consider the range of complex conditions that occur over the entire urban ecosystem. Methods must also be inexpensive, rapid, and user-friendly. Easily accessible imagery and GIS can provide a means toward this goal (Lipscomb et al., 2006). The objectives of this study were to:

1. Use two GIS imagery photo-interpretation methods to measure and monitor tree cover change in an urban forest using photo interpretation points and 0.04 hectare (ha) circular plots
2. Evaluate the differences among photo interpretation points, digitized tree cover, ocular estimates, and field measured tree cover
3. Study the dynamic between hurricanes, urbanization and socio-economics on urban forest cover.

Methods

We evaluated two methods for estimating urban forest cover change on two different Florida urban forest ecosystems. We used Gainesville to study hurricane and urbanization effects on an inland medium-sized city's urban forest and Miami-Dade and Broward County study the role of hurricanes and socio-economics on a hurricane-prone major metropolitan coastal urban forest. Digital monochromatic and true color aerial photography was downloaded from the Florida Department of Environmental Protection's Land Boundary Information System website for the Gainesville Florida city limits (Land Boundary Information System, 2008). Data in the form of digitized color-infrared and natural color aerial photography were acquired from the South Florida Water Management District for the Miami-Dade and Broward Counties study area. Color infrared and natural color aerial photographs in the form of digital orthophoto quarter quadrangles (DOQQ) taken in 1984 and also in 2004 with 1:40,000-scale original transparencies and resampled to 1 meter by 1 meter ground cell size were used. Sub-meter resolution imagery from 2007 was used to estimate tree cover in Gainesville and Miami-Dade County. Using the municipalities' shapefiles of county and city limits, the images were clipped to the urbanized portion of the study area.

Urban forest cover estimates

Our methods are based on aerial photo-interpretation and point-plot schemes discussed in Escobedo et al. (2006) and Lipscomb et al. (2006). Our first method overlaid 500 random points on the clipped DOQQs for the 121 km^2 Gainesville study area. The same photo points were interpreted for 1995, 2000, 2004, 2005 and 2007 and classified using the following six classes: Trees and shrubs, building, pervious, impervious, and water. A total of 1,398 assigned points were photo interpreted in the 1620 km^2 Miami-Dade County study using 1984 and 2004 images. One thousand points were used to estimate tree cover in the 1,092 km^2 Broward County study area. The points were interpreted and classified into the same classes as used in the Gainesville study area plus an additional Palm cover type.

A second method was employed for a more comprehensive estimation of urban forest cover. We randomly selected 500 points (Figure 1) in the Broward County study area and buffered an area

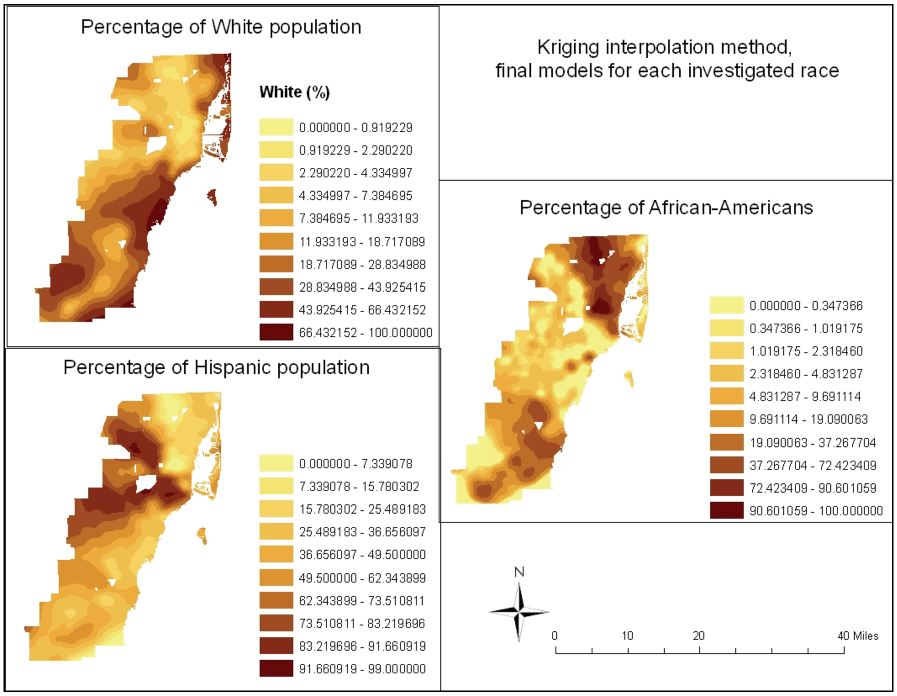

Figure 1. Percentage of ethnic group using a kriging interpolation method for Miami-Dade County.

of 0.04 ha around each point on the 2004 image. Individual tree crowns within the 0.04 ha plots were then digitized on screen to measure tree cover. Also, an independent ocular estimate of tree cover per plot was recorded. We used 250 0.04 ha plots to estimate tree cover in Miami-Dade County using ocular estimates of 2004 and 2007 sub-meter resolution digital imagery provided by the Miami-Dade County Department of Environmental Resources Management (DERM).

Evaluation/analysis

Tree cover estimates using the photo-interpretation points were evaluated against field estimates of Gainesville's urban forest cover using 93 random 0.04 ha plots measured in 2006-2007 with Urban Forest Effects (UFORE) field methods outlined in Escobedo et al. (2006). Digitized and ocular methods for estimating tree cover in the 500 Broward County plots were evaluated by testing for statistical differences using the 2004 image. Finally plot ocular tree cover estimates were evaluated against field estimates of 100 of the 250 photo interpreted 0.04 ha Miami-Dade field plots during 2007-2008.

Socio-economics

Given the complexity of disturbances and rapid temporal change of urban landscapes, we explored the role of socio-economics as an additional factor in driving tree cover change (Escobedo et al., 2006; Heynen and Lindsey, 2003) in Miami-Dade County employing a Normalized Difference Vegetation Index (NDVI) (Bounoua et al., 2000; Gitelson et al., 1998; Chavez and Mackinnon, 1994), Census block group data (U.S. Census Bureau, 2000), and spatial interpolation (Maantay, 2002; Granados, 2003) (Figures 1 and 2). Zonal statistics was used to generate a NDVI value for each percentage from 0-100, for 3 ethnicity groups: White, African-American, and Hispanic. Kriging was used to interpolate the percentage of total population data and a prediction surface by weighting the spatial relationship among the sample data location and prediction location (Johnston et al., 2001; He and Xudang, 2004). Pearson correlation coefficients were calculated in a range from (+1) to (-1) to statistically measure the association between the NDVI values and population percentages of each ethnic group. A correlation of (+1) meant that there was a perfect positive linear relationship between variables. The result was a vegetation indices image, where high values indicated more vegetation. The NDVI image (created in ERDAS IMAGINE from a Landsat TM 1996 image) was then exported using GRID format.

Results

Tree cover estimates

Results show that photo-interpretation points are well within the range of field measured tree cover estimates using UFORE field methods (Table 1). Results for Gainesville show the dynamics between urbanization and possible hurricane effects. Although tree cover in 2005 decreased following Hurricane Frances in September 2004, it recovered to pre-hurricane levels in two years. Urban forest cover (the sum of tree and shrub cover) in the city of Gainesville

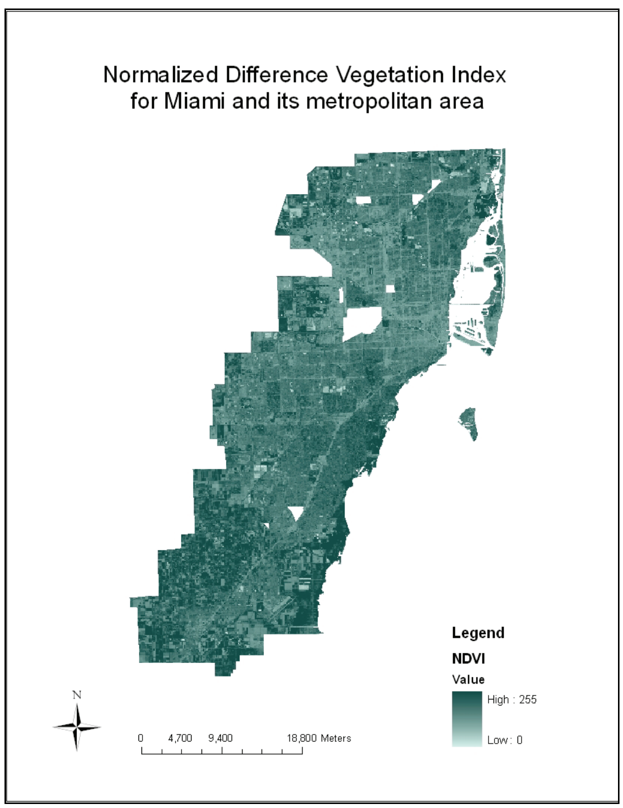

Figure 2. NDVI for the Miami metropolitan area.

Table 1. Comparison of photo-interpretation points (2007) and field estimates of percent tree and building cover (2006-2007).

Cover type	Photo interpretation points	Field plot estimates
Tree, shrub	59.0	67.0
Building	10.0	9.0

decreased from 1995 and 2007 by nearly 7% (Figure 3). The major loss of urban forest cover occurred between 2000 and 2005 and might be a result of hurricane effects and increasing urbanization. Between 1995 and 2000, Gainesville's tree and shrub cover increased by 1%, then between 2000 and 2004 this coverage decreased 7%. Between 2004 and 2005 the rate of loss of

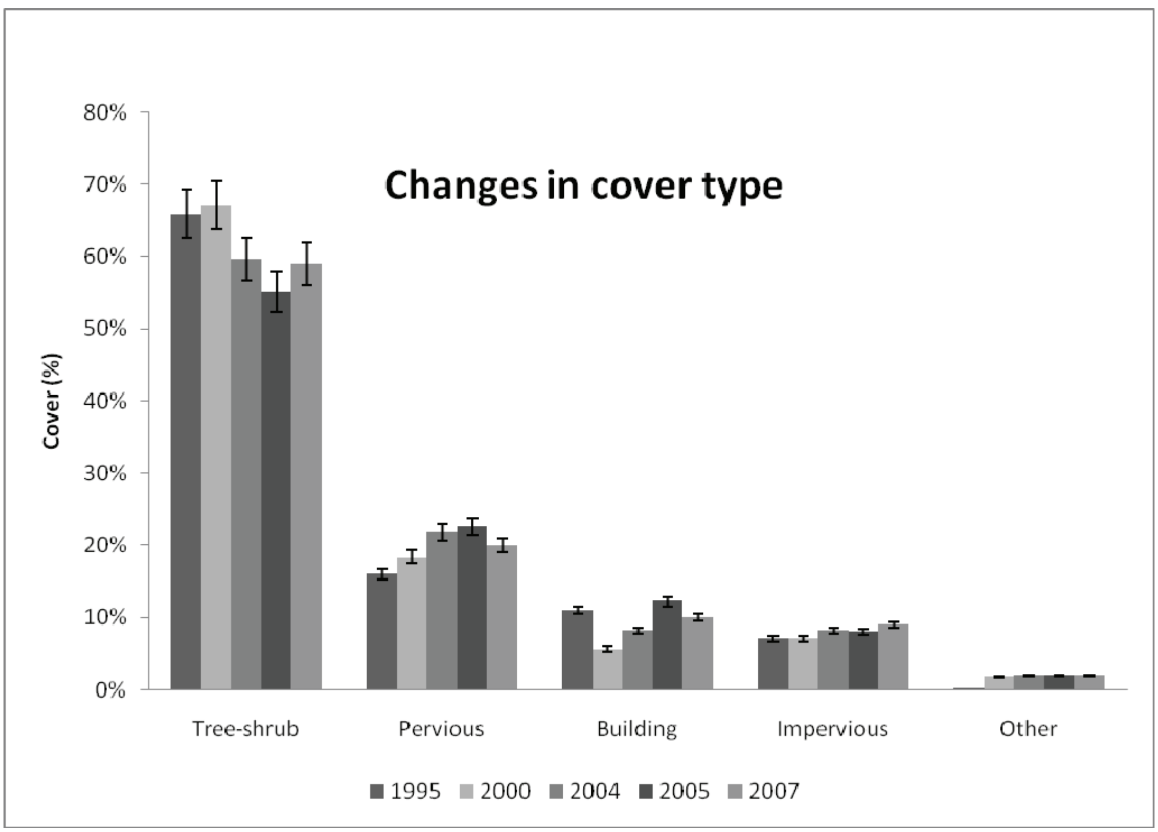

Figure 3. Changes in cover type in Gainesville, FL (Source: Wayne Zipperer, USDA Forest Service).

tree and shrub coverage was nearly 4%, yet there was an increase of 4% from 2005 and 2007. Of the entire area covered by trees or shrubs in the year 1995, 6% was converted to an impervious surface or a building by 2007.

Figure 3 also demonstrates the increase in pervious cover (e.g. soil, lawns, herbaceous). The decrease in tree and shrub cover might suggest an inverse relationship between urban forest and pervious cover. Changes in pervious surface cover could be related to changes in conversion of tree-shrub surface to a grass or herbaceous surface, which are common during the process of urbanization. Increases in impervious surface cover due to roads, sidewalks, driveways and others appear to be negligible during this time period.

Results for Miami-Dade County using photo interpretation of points show a decreasing trend in urban forest cover from 1984-2004 (Tables 2 and 3). This is likely due to increased urbanization and the effects of Hurricane Andrew in 1992. However, urban forest cover in Broward County during this same time period decreased from 16 to14%. Tables 2 and 3 indicate the influence of increasing the number of photo-interpretation points on percent surface cover estimates for Miami-Dade County. The proportional change was similar but the actual percent surface cover varied.

Tree cover was also estimated for Broward County using the area of digitized individual tree crowns for each plot in addition to subsequent ocular estimates of tree cover for that same plot. Ocular estimates were based on reference charts for estimating proportions of mottles that are used by the United States Department of Agriculture (U.S. Soil Conservation Service, 1993). Tree cover estimates using these two methods were comparable as indicated by a high correlation coefficient of over 96% (Table 4).

Table 2. Percent surface cover using photo-interpretation in the urbanized portion of Broward (1,000 points) and Miami-Dade (1,398 points) Counties, Florida, 1984-2004.

	Broward				Miami-Dade			
	1984		2004		1984		2004	
Cover type	(%)	SE[a]	(%)	SE[a]	(%)	SE[a]	(%)	SE[a]
Tree	16.4	1.2	13.5	1.1	28.5	1.2	16.2	1.0
Buildings	11.8	1.0	17.8	1.2	9.9	0.8	14.6	0.9
Pervious	49.0	1.6	32.9	1.5	40.3	1.3	40.1	1.3
Impervious	16.7	1.2	25.7	1.4	16.7	1.0	22.1	1.1
Palm	---	---	1.2	0.3	---	---	0.6	0.2
Water	6.1	0.8	8.9	0.9	4.4	0.6	6.3	0.7

[a] Standard error

Table 3. Percent surface cover change using photo-interpretation in the urbanized portion of Miami-Dade County (250 points), Florida during 1984-2004.

	1984		2004	
Cover type	Percent tree cover	Standard error	Percent tree cover	Standard error
Tree	38.0	3.1	21.2	2.6
Buildings	11.6	2.0	18.0	2.4
Pervious	28.8	2.9	31.6	2.9
Impervious	18.0	2.4	24.0	2.7
Palm	---	---	0.8	0.6
Water	3.6	1.2	4.4	1.3

Table 4. Comparison of percent tree cover between digitized tree cover and ocular estimates per 0.04 ha plot using 2004 Broward County imagery. The correlation between ocular and digitized measurements is 0.965.

Measure	Digitized tree cover	Ocular estimate
Mean tree cover	26.6%	26.4%

Actual implementation of this method for digitizing individual tree crowns is time and cost-prohibitive. Therefore, since our Broward County ocular tree cover was consistent with digitized tree cover (Table 2), we used ocular estimates of tree cover in Miami-Dade County due to ease and cost-effectiveness. Tree cover change using ocular estimates between 2004 and 2007 also shows a decrease in tree cover which is consistent with photo-interpretation results (Table 5). Tree covers was 24% in 2004 and decreased to 16% in 2007. Results also show that ocular estimates of 0.04 ha plots in Miami-Dade County are well within the range of field measured estimates of tree cover for the same year (Table 4). Following the 2004-2005 hurricane season, Miami-Dade's urban development boundary had 18% tree canopy cover in 2006 (Joy Klein, Miami-Dade County DERM, personal communication, 2008). Table 5 indicates that palm cover makes up 27% of Miami-Dade's urban forest cover.

Tree cover losses are likely due to not only hurricanes, but to urbanization and community values as well. Population density in Miami-Dade county has been steadily increasing as indicated by a 7% increase from 2000-2006, 16% from 1990-2000 and 19% from 1980-1990 (U.S. Census

Table 5. Urban forest ocular cover in Miami-Dade County using ocular estimates for 2004 and 2007.

Cover type	Field plots 2007-2008	Ocular estimates 2007[a]	Ocular estimates 2004[b]
Urban forest[c]	15.4%	16.0%	24.0%

[a] Sub-meter resolution
[b] 1-meter resoution
[c] Urban forest is the sum of tree, shrub, and palm cover

Bureau, 2008). The photo interpretation of the 2004 and 2007 images revealed that many plots had visibly changed from undeveloped open spaces to developed urbanized areas.

Socio-economics

Historically, many areas in Miami that have not experienced substantial urbanization have been characterized by low tree cover regardless of hurricane effects. This lack of tree cover might therefore be a result of socio-economic factors (Escobedo et al., 2006; Heynen and Lindsey, 2003; Maantay, 2002). To explore the role of socio-economics, as defined by race (using the zonal statistics dataset) the Pearson Correlation Coefficient was calculated for each ethnic group. Table 6 indicates significant differences in the spatial distribution of Miami's urban forest. Citywide NDVI is positively correlated with whites (0.270) at $p \leq 0.05$ while NDVI values were negatively correlated with African-Americans (-0.292) at $p \leq 0.05$ and Hispanics (-0.579) at $p \leq 0.01$.

Discussion

A loss in urban forest cover can result in a decrease in ecosystem services and community well-being. One acre of tree cover in Gainesville can sequester 1000 kg of C, 26 kg of air pollution,

Table 6. Pearson Correlation Coefficients for each Ethnic Group.

Ethnic group	Pearson correlation coefficient	Alpha level
African-Americans	-0.292	0.05
Hispanics	-0.579	0.01
Whites	0.270	0.05

and contribute to over 1 million dollars in building energy reduction savings (Wayne Zipperer, Research Forester, USDA Forest Service, personal communication, 2008). Tree cover provides a measure for assessing the amount and distribution of urban forest structure. Additionally knowing where tree cover is located in an urban area can facilitate debris management and planning.

This assessment presented two simple and cost-effective methods to quantify and monitor tree, shrub, and palm cover change over time. Results using our methods were comparable to actual field measurements. Results were also similar to a recent 2004-2006 tree cover assessment by DERM using high resolution (1 meter pixel resolution), digital data to measure changes in land cover from 2004 and 2006 and found an 18% tree cover and 3% loss in tree canopy during this time period (Joy Klein, unpublished data). Additional studies have found consistent and similar results between points and field estimates (Escobedo et al., 2006). Field plots established in this analysis are being used in an on-going study to quantify urban forest structure and function and as permanent hurricane and urbanization monitoring sites. Ocular estimates using photo-interpretation and double sampling with field estimates can be used to better quantify urban forest structure and heterogeneity (Hidiroglou, 2001). Results indicate that the type of accessible imagery and the number of photo-interpretation points can influence cover estimates.

Results also indicate that hurricane effects might only be one of the factors affecting urban forest cover loss. Urbanization, community values, and individual homeowner preferences as expressed by socio-economics in both the Gainesville and the Miami-Dade study areas also affected urban forest cover in this analysis. Although no statistical relationship was explored between tree protection ordinances between both counties, Broward County has, in general, stricter tree protection ordinances and enforcement than Miami-Dade. The presence and enforcement of tree protection ordinances might be one explanation for urban forest cover change differences between Miami-Dade and Broward Counties. Combining satellite imagery data and US Census data, the analysis indicates that there is an unbalanced distribution of urban forest cover within Miami and its metropolitan area. Results suggest that those census tracts with higher percentage of non-Hispanic White neighborhoods are more likely to have greater NDVI value, indicating more urban forest.

Conclusions

Results show that photo interpretation of random points and plots using ocular estimates in GIS can be used to effectively and efficiently estimate urban forest cover following disturbances. Ocular estimates in addition to field sampling can be used in a double sampling approach to more accurately capture the heterogeneity of urban forest structure across an urban landscape. Ocular estimates of DOQQs using a simple GIS procedure were well within the range of more expensive and complicated digitized and field measured tree cover estimates. Urban forest cover varies spatiotemporally across an urban landscape. When setting urban forest management goals, temporally static tree cover values used to characterize tree cover and to determine restoration goals following hurricanes should consider the role of policies, socio-economic realities, and community values.

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