City of Tampa 2011 Urban Forest Analysis

The Structure, Composition, Function and Economic Benefits of Trees and the Urban Forest

September 2013

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Report Printed on Recycled Paper

Acknowledgments

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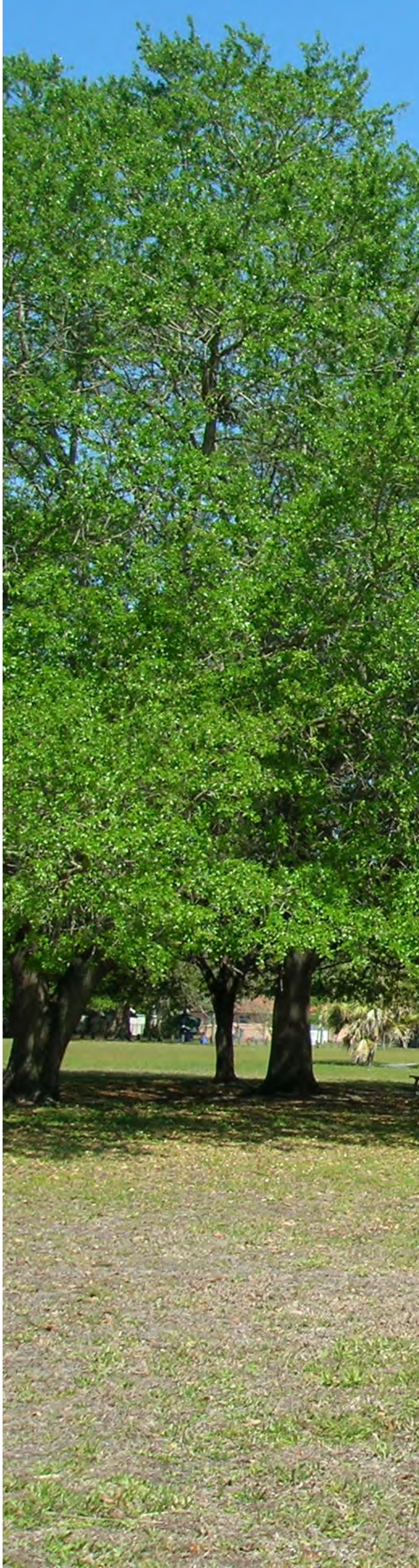
Contents



Appendices

References

Figures

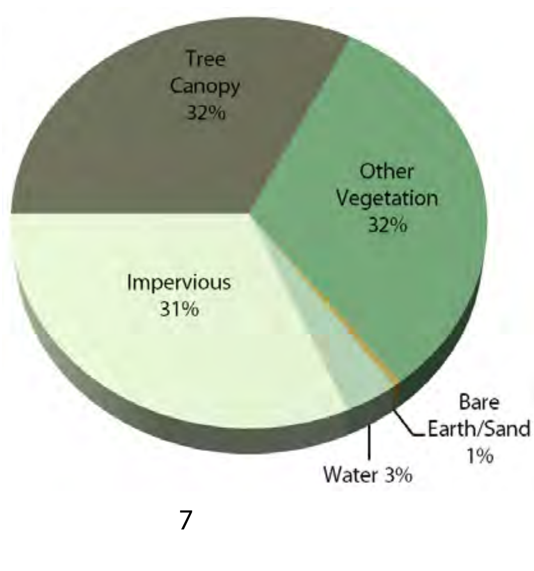
Tables

Executive Summary

The City of Tampa Urban Ecological Assessment provides a detailed scientific look into the economic and ecological values of the City of Tampa's urban forest. The City of Tampa tree ordinance (Ord. No. 2006-74, § 9, 3-23-06) requires a re-inventory of Tampa's tree canopy and urban forest every five years. This report provides detailed information about the 2011 conditions of the urban forest, as well as how the forest and associated benefits have changed over the five-year monitoring interval since 2006–7. Included is detailed information about the distribution of Tampa's tree canopy cover, results of extensive field sampling that describe forest composition, structure and health, and model results that quantify the economic benefits and ecosystem services provided by Tampa's urban forest. The outcomes from this study can serve as the basis for enhancing the understanding of the urban forest's values, improving urban forest policies, planning and management, and providing empirical data for the inclusion of trees within environmental regulations.

Satellite and high-resolution aerial photography from 2011 was used to classify and map the location of tree canopy, other vegetation, water, bare earth and impervious land cover. This accurate map was compared to the high-resolution map created in 2006. A four-decade long record of NASA Landsat satellite photographs was used to examine how tree canopy has changed since 1975 in Tampa.

- Tree canopy covered 32% of the City in 2011. An additional 32% of land area was covered by other vegetation (i.e., grass, short plants and shrubs), indicating large areas potentially available for tree planting.
- Tree canopy covered approximately 24,290 (+/- 1,215) acres of land in 2011 and 22,104 (+/- 1,105) acres in 2006.
- There was a slight, but not necessarily significant, increase of zero to 3% tree canopy cover between 2006 and 2011.
- Change in tree canopy between 2006 and 2011 varied throughout the City and ranged from a loss of more than 15% tree cover to a gain of greater 15%.



- The total acreage of tree canopy within the Residential 10 Units/Acre land use (37,035 ac) is twice as much as the land area covered by trees for all other land uses combined (17,285 ac).
- Public or Quasi-public represents four of the top twelve land use categories in terms of acreage of tree canopy, including: Environmentally Sensitive Areas (5,857 ac tree canopy); Right-of-way (2,742 ac); Public/Semi-public (733 ac); Recreation and Open Space (686 ac).
- By Planning District, the New Tampa Planning District has the highest proportion of tree canopy cover (45%), followed by USF Institutional (37%), South Tampa (29%), Central Tampa (27%) and Westshore TIA (15%).
- Based on the US Forest Service definition of Possible Urban Tree Canopy and the distribution of other vegetation in Tampa (e.g., grass and shrubs), the possibility of additional tree planting appears fairly large in all of the planning districts, in most zoning and land use categories, in all City Council Districts, and in many neighborhoods.

Approximately two-hundred permanent field plots were randomly distributed within the City, and sampled in 2006–7 and again in 2011. Forestry measurements were collected from these plots and then analyzed using the U.S. Forest Service i-Tree Tools to determine the vegetative structure, functions, and values of the urban forest in Tampa.

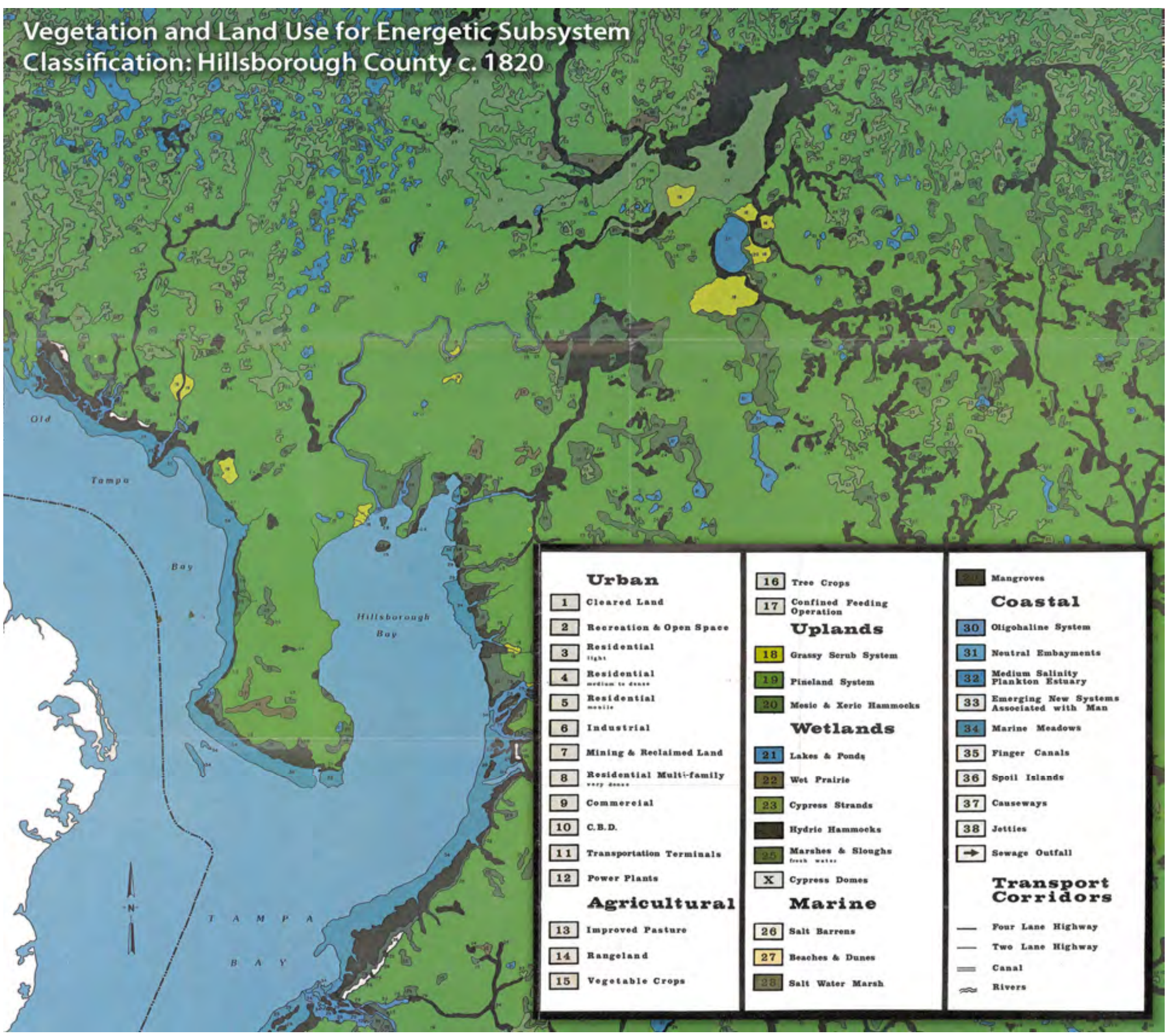
- Based on the 2011 field sampling, it was estimated that there were approximately 8.7 million trees in Tampa (i.e., a tree is defined as a woody stem with a diameter of at least 1 inch). This inland region (non-coastal areas; excluding mangroves) of the urban forest contained an estimated 4.4 million trees represented by 90 tree species.
- There was an increase in the estimated number of trees from 2006 to 2011 in all but three land use categories: Public/Quasi-public/Institutions, Public Communications/Utilities, and Right-of-way/Transportation.
- The top ten tree species, based on total number of stems, included: white mangrove, non-native invasive Brazilian pepper, red mangrove, black mangrove, cabbage palm, laurel oak, live oak, Carolina laurel cherry, sweetgum and the white lead tree (also a non-native invasive).
- The highest diversity of tree species was found in the Residential, Recreational/Open Space/Natural, and Right-of-way/Transportation land use categories.
- 82.6% of all trees (including mangroves) have a diameter of 6 inches or less.

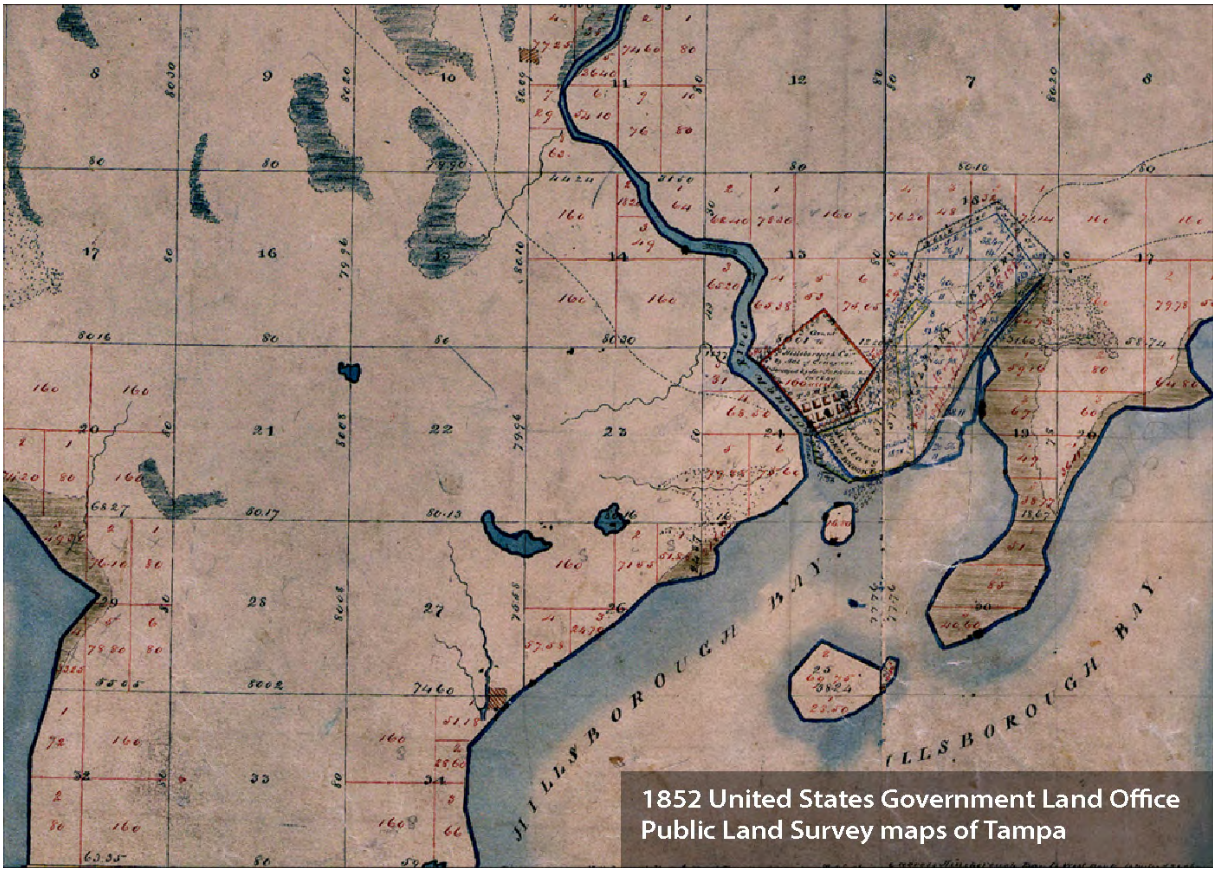
- Tree density, the number of trees per acre, was highest on the Recreational/Open Space/Natural (453 trees/ac) and Vacant (280 trees/ac) land use categories.
- The best available scientific models calculated with i-Tree Tools were used to estimate a monetary value that the ecosystem services of the urban forest provides to the residents, businesses and visitors of City of Tampa. These values include only a portion of the potential benefits provided by trees and the urban forest.
- Pollution removal by trees and shrubs was 1,163 tons/year and valued at $9.9 million/year. Pollutants include carbon monoxide, ozone, sulfur dioxide, nitrogen dioxide and particulate matter less than 10 microns. Values estimated include health effects and externality costs associated with pollutants.
- Carbon storage was 619,000 tons and valued at $44.1 million. This includes the amount of carbon bound up in the above-ground and below-ground parts of woody vegetation.
- Carbon sequestration rate was 52,600 tons/year and valued at $3.7 million/year. This is the annual removal of carbon dioxide from the air by vegetation.
- Oxygen production was 127,000 tons/year. A specific monetary value is not calculated, but oxygen is obviously important.
- Building energy savings was valued at $4.7 million/year and the associated avoided carbon emissions were valued at $578 thousand/year. This includes only residential energy savings resulting from shade provided by trees.
- Avoided cost of stormwater management was $10.8 million/year as a result of the estimated interception of 162 million cubic feet/year of rainfall by leaves of trees.
- Compensatory value was $1.83 billion. The compensatory value is an estimate of the amount of money it would cost to replace the trees in the City of Tampa if they were removed (e.g., deliberately or due to a storm).
- The overall annual value of all of the benefits mentioned above is approximately $34.6 million/year.

Background

Humans have long had a close relationship with trees and forests in the Tampa area. The area was once covered by extensive forests of upland pine trees, intermixed with wetland forests of large cypress trees and other hardwood species, mangroves, wet prairies and numerous oak species. A map developed to estimate circa 1820 vegetation and land use in Hillsborough County shows that Tampa was likely covered by extensive pine forests (Lee 1979). Downtown Tampa was a xeric (i.e., dry) oak hardwood forest and the Channelside District was a salt marsh. South Tampa was covered in pine, interspersed with wet prairie, marshes and hydric hammocks; Hyde Park was grassy scrub. East Tampa was almost entirely pine forest. West Tampa was dotted by marshes, cypress and hydric hammock. North Tampa had extensive wetlands, cypress strands, wet prairies, hydric hammocks and marshes.

The forest ecosystems of the Tampa area have long been impacted by the actions of people. Native populations in Florida managed the forests for thousands of years by starting fires for hunting and agriculture (TBHC 2006). Spanish visitors logged large cypress along the Hillsborough River for use as ship masts (Jahoda 1973). During the last half of the nineteenth century, sawmills in the Tampa area were supplying pine lumber and turpentine, and cedar was being milled into pencils for northern markets (Covington 1957; Maio et al. 1998). Similar to the widespread harvesting in the northern U.S. that occurred a century earlier, the forests of the Tampa area had been extensively cut by the early twentieth century (Leighty et al. 1958).





1852 United States Government Land Office Public Land Survey maps of Tampa

Settlement of the Tampa area by United States residents began with the establishment of Fort Brooke in 1824, three years after Florida became a U.S. territory. However, land ownership was prevented and timber resources were protected for use by the military within the 16-square mile military reserve established around the fort (Chamberlain 1985). It was not until 1848 that President Polk signed legislation giving Hillsborough County title to 160 acres to establish Tampa and allowing it to sell parcels to the 120–200 residents of the town (Brown 1998). Population growth was slow as a result of wars with the Seminoles, hurricanes (in 1848 and 1852), yellow fever, Civil War, and the lack of a railroad link to the rest of the country. In 1880, there were only 720 people living in Tampa (Mormino and Pozzetta 1998). An 1869 account of the route between downtown Tampa and Rocky Point, a route parallel to today's Kennedy Blvd., describes the undeveloped character of the open pine flatwoods forests which once dominated the land in Tampa:

> …the route, for the greater part of the distance of seven miles, is through an open forest of pines, of the species previously met with; the lack of undergrowth afforded pleasant and shaded vistas in every direction. In following the sandy road we waded through broad and shallow pools, miniature lakes made by the recent rains… (Stearns 1869, pg 456)

Large-scale population growth and development of forested lands came to the City of Tampa during the last two decades of the nineteenth century. Growth was facilitated by the building of Henry Plant's Florida Transit and Peninsula Railroad in 1884 connecting Tampa to Jacksonville, and the dredging of shipping channels in Tampa Bay to allow larger cargo ships to reach the port. Since that time, the population of the Tampa area has grown to over 300,000 people. Formerly native forests have become intermixed with urban development, and forests once harvested for timber have been replanted with residential landscapes. The physical boundary between the urban and wild native forest has been blurred, along with the ecological functions and the values that the forests provide. As residents of the City of Tampa, we now live within an area dominated by an urban forest.

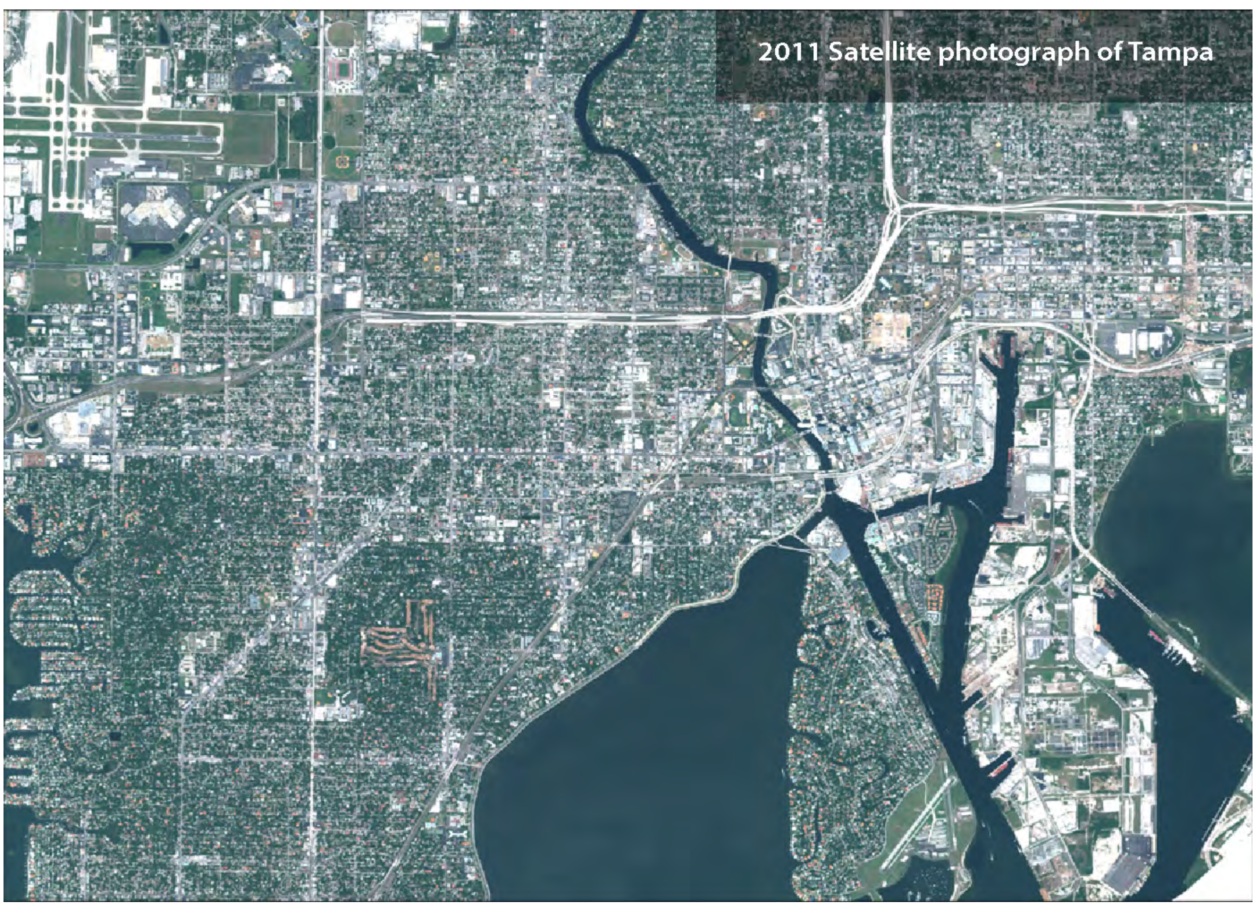
Tampa's urban forest plays an important role in maintaining the vitality of urban life. The urban forest provides a wealth of benefits to neighborhoods and communities, such as: lowering of air temperature, the reduction of energy consumption, removal of pollutants from the air and water, reduction in stormwater runoff and flooding, enhancement of property values, recreational opportunities and aesthetic diversity. Restoring, conserving and enhancing these benefits pro-

Urban Forest:
The urban forest consists of the remnants of native forest found within private property, parks, medians and rights-of-way; and planted trees, palms and shrubs found on all public and private property within the City of Tampa.

vided by trees and the urban forest are now tied to the long-term management of the urban environment within the City. Sustainable management requires deliberate and scientific monitoring in order to ensure that the City of Tampa's management programs and regulatory policies are effective and efficient, and increase the social, environmental and economic benefits of the urban forest.

The City of Tampa (City), University of South Florida (USF), University of Florida (UF) and the UF/IFAS Hillsborough Extension Service completed an ecological analysis of the City's urban forest in 2006–2007. Results of the project estimated that the 7.8 million trees in Tampa provided ecosystem services with an annual economic value in the tens of millions of dollars and have a replacement value of $1.4 billion. Analysis of long-term change concluded that average citywide tree canopy cover had returned to 1970s levels, but that change was not positive in all areas of the City. The effort produced a valuable inventory of baseline information and analysis that described the location, composition, structure, health, and estimated ecological function and economic value of the trees and woodlands within the urban forest landscape of the City of Tampa.

The primary goal of this project was to re-inventory Tampa's urban forest, as required every five years by the Tampa tree ordinance (Ord. No. 2006-74, § 9, 3-23-06). The research approach has been designed to provide detailed information about the current condition of the urban forest, as well as how the forest and associated benefits have changed over the five-year monitoring interval. The results of these efforts include detailed mapping of the urban forest utilizing remote sensing technologies, field sampling that quantifies forest composition, structure and health, and scientifically proven modeling techniques that evaluate the economic benefits and ecosystem services provided by Tampa's urban forest. This project is part of the City's Urban Forest Program and its efforts to provide a sustainable future for Tampa by improving the lives of residents and investing in real tangible solutions to protect our natural environment for future generations.



Project Methods

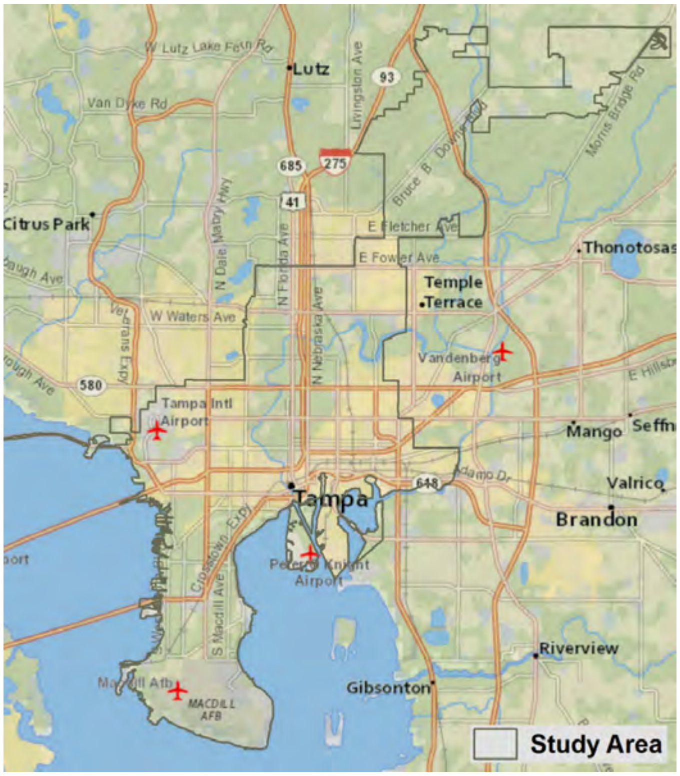


Figure 1. Project Study Area

Study Area

The City of Tampa, Florida (28°N, 82°W) is located on the west coast of Florida at approximately the mid-point of the peninsula. The study area (Figure 1) was defined as the City of Tampa political jurisdiction as of 2011 and modified to follow the shoreline of Tampa Bay (Tampa 2010). Total area of the study area was 117 square miles (75,108 acres).

According to the United States Census Bureau (www.census.gov), total population within the City of Tampa was 280,015 in the year 1990, 303,447 in the year 2000, estimated at 332,999 in 2006, and 335,709 in the year 2010. The total number of housing units increased within the City of Tampa from 135,776 units in the year 2000 to 157,130 in the year 2010.

Field Methods

The City of Tampa's initial urban forest assessment took place in 2006–2007[1]. A follow-up assessment was conducted five years later, in 2011–2012. For the initial assessment a systematic random sampling design was used to achieve a complete geographic distribution of inventory plots throughout the city. A hexagonal grid was projected onto the city, each hexagon representing 437 acres (Figure 2), with one sample point randomly generated per hexagon. Latitude and longitude coordinates (x,y) for each point were subsequently loaded onto a Trimble GeoXM®GPS unit to facilitate accurately locating plot center on the ground. Returning to the field in 2011, researchers located plots using a combination of navigation to the original GPS coordinates and relocation of ground-based reference objects in order to identify plot centers recorded in the 2006 data collection.

Two hundred and one permanent inventory plots were located within Tampa's political boundary. The 2011 follow-up assessment collected data at 197 plots out of the original 201 plots. Four new locations (not sampled in 2006) were added to the sample to replace locations researchers were unable to access in 2011[2]. A fixed-radius 1/10th–acre plot (r = 37.2 ft) was established at each plot center location. Data collected included land use, percent ground cover, percent shrub cover, percent tree cover, percent palm cover, tree diameter, crown width, height to live crown, total height, and tree health attributes. The existing land use category for each plot was determined in the field by the location of plot center (Table 1). A description of each field-determined land use category is provided in Appendix A. The acreage for each existing land use category (Table 1) was calculated using the 2006 parcel geo-database.

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[1] In City of Tampa Urban Ecological Analysis 2006–2007, Andreu et al., 2008, the sampling period was mistakenly reported as February to July 2007. The sampling period was conducted into September 2007.

[2] Sample locations were selected by stratified random sampling. The plots replaced were randomly selected from the same grid locations and from the same land use, specifically all four were classified Residential.

This study divides the urban forest into three distinct strata: tree, shrub, and ground cover. The tree stratum includes woody stems greater than or equal to 1 inch in diameter at breast height (DBH; 4.5 feet), the shrub stratum is made up of woody plants at least 1 foot tall but less than 1 inch DBH, and the ground cover stratum consists of woody or herbaceous vegetation less than 1 foot tall. Collecting data at different strata is important to understanding the vertical and horizontal distribution (structure) of the urban forest, which ultimately determines functions of the forest, such as pollution reduction and carbon sequestration.

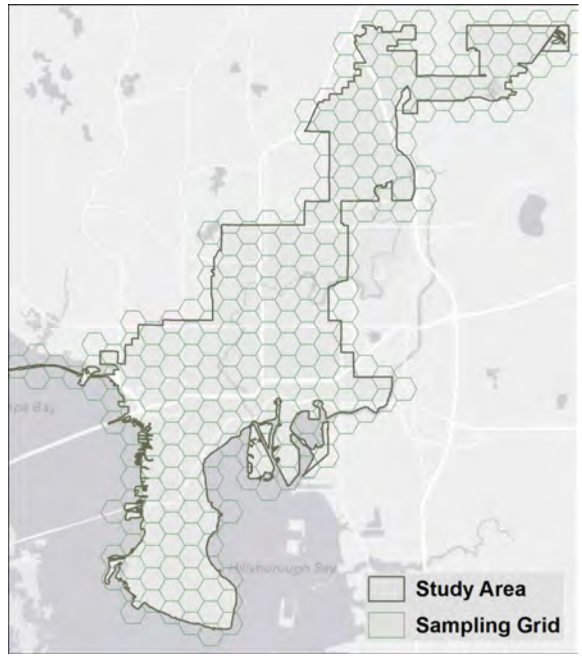


Figure 2. Study area with field sampling grid

We utilized the i-Tree Eco software tool (version 5) formerly known as UFORE (Urban Forest Effects Model) (Nowak et al. 2002) created by the US Forest Service to assist with the analysis of the data collected. It has been designed to calculate values for variables such as tree diversity, species origin, abundance, density, size, cover, and leaf area by land use categories. In addition, it quantifies the following urban forest functions: energy savings, air pollution removal, carbon storage, carbon sequestration, and compensatory or replacement values. The i-Tree model was originally developed for use in temperate regions of the U.S. We worked directly with with the developers of the model to include semi-tropical species, such as palms, into the urban forest analysis for the 2011 analysis and comparison of change.

The protocol used for sampling each plot can be referenced in the 2011 i-Tree User's Manual (v5), Phase III (www.itreetools.org/). One modification worth mentioning regards the addition of palm cover measurements. For the tree and shrub strata, measurements for palm tree and palm shrub cover were collected separately from measurements of woody tree and woody shrub cover and were added (palm and woody cover) for the purpose of calculating total cover.

Data collected in 2006 were reanalyzed using the updated version 5 of the i-Tree Eco software tool. The new analysis updates energy conservation, pollutant, and carbon storage and sequestration valuations to the most current estimations of dollars per ton. Additionally, the new analysis allows us to generate comparative outputs on stormwater and pollutant health impact savings unavailable in the outputs of previous versions of the UFORE/i-Tree Eco models.

Table 1. Land use categories used in this study and their associated number of plots and acreage

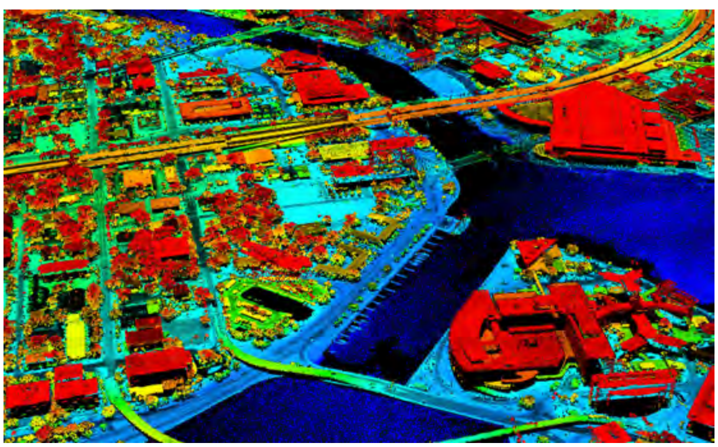
Land Use Category	Field Plots	Total Area (acres)	City Area
Agricultural	2	1,943	3%
Commercial	22	5,530	7%
Industrial	8	3,011	4%
Public / Quasi-public / Institutions	29	21,656	29%
Public Communications / Utilities	5	1,520	2%
Recreational / Open Space / Natural	35	963	1%
Residential	69	22,810	30%
Right-of-way / Transportation	24	12,140	16%
Unknown	0	0	6%
Water	3	568	1%
Total	**201**	**74,884**	**100%**

Tree Canopy Methods

Tree Canopy is the layer of leaves, branches and stems of trees that cover the ground when viewed from above. In addition to the sample-based field inventory used to estimate urban forest composition, structure, health and associated functional benefits, remote sensing land cover classification techniques were used to measure tree canopy cover and change over all areas of the City of Tampa. Measurements of tree canopy cover over time can provide an indicator of the geographic distribution of urban forest benefits within different areas of the city and how it has changed over time. There were three major goals of these analyses, including: 1) update the long-term (1975–present) citywide tree canopy trend dataset to include 2011; 2) create a high-resolution map of 2011 tree canopy cover for purposes of planning and urban forest management; and 3) examine how tree canopy has changed in different geographic areas or land uses of the City between 2006 and 2011.

The methods used to map 2011 tree canopy were similar to the 2006 City of Tampa Urban Ecological Analysis (Andreu et al. 2008; Landry and Pu 2010). The long-term trend analysis used the same tree cover mapping techniques and the same satellite imagery from the same season used for previous years (i.e., Landsat 5 Thematic Mapper data from April 30, 2011). It should be noted that Landsat imagery underestimates tree canopy due to the large image pixel size (i.e., 30 meters / 98 feet compared to less than 1 meter for the high-resolution analysis). However, the use of Landsat provides a consistent long-term measurement of change for several decades prior to the availability of high-resolution mapping techniques.

The high-resolution map of 2011 tree canopy cover was developed using a rules-based object-oriented image classification method. Object-oriented methods have been shown to be more accurate for mapping tree cover in the Tampa area than previous methods (Pu, Landry and Yu 2011). The classification was completed using methods developed by and in collaboration with Jarlath O'Neil-Dunne and colleagues of the University of Vermont, Spatial Analysis Laboratory and the United States Forest Service (www.nrs.fs.fed.us/urban/utc/).



High-resolution imagery data included 1.6 ft (0.5 m) resolution 8-band WorldView-2 imagery from May 11, 2011 (www.digitalglobe.com) and 1 ft (0.3 m) resolution 4-band aerial imagery from early spring 2011 obtained from the Southwest Florida Water Management District (SWFWMD; swfwmd.state.fl.us). Aerial LiDAR (LIght Detection And Ranging) data from the SWFWMD was converted to relative height above ground and used to differentiate between trees and grass or buildings and other impervious surfaces (image left). Additional ancillary data such as road centerlines and water/wetland boundaries were used as necessary. Rules were created to develop a land cover classification from the imagery, LiDAR and ancillary data (e.g., tall and green generally indicates a tree). Manual corrections were then made of the initial maps by visual examination of all sections of the study area. The final map was simplified to include five land cover classes: tree canopy (>8 ft tall); other vegetation (<8 ft tall); water; impervious surfaces; and sand/bare earth. Accuracy of the final 2011 land cover dataset was assessed by comparing the classified land cover with a visually determined land cover at 800 randomly distributed points.

Since the imagery and methods used to develop the 2006 and 2011 high-resolution tree canopy differed slightly, a separate and independent method was used to determine if there was a statistically significant change in tree cover between the two years. Approximately 3,000 points were randomly selected within the City of Tampa and a visual assessment was used to classify each point as tree canopy or not tree canopy using imagery from 2006 and 2011, respectively. This approach to estimate citywide tree canopy cover followed the "dot-based" estimation methods described by David Nowak and colleagues from the U.S. Forest Service (Nowak et al. 1996, Nowak and Greenfield 2012) and allowed for a direct comparison of the two years using a consistent method.

Results and Discussion

Urban Forest Composition

Tampa is located in a transitional zone between tropical south Florida and temperate north Florida. Tree species in Tampa are generally specific to either tropical or temperate zones so many tree species are at their northern and southern limits. Therefore, a unique and diverse suite of species coexist in this region of the state.

Forest Population and Diversity

Species richness or diversity is simply the number of species in a given area. Diversity is an important attribute in the urban forest and can be an indication of its vulnerability or resiliency to natural disturbances such as insect and/or disease outbreaks (Duryea et al. 2007, Raupp et al. 2006). Areas that have low species diversity are less likely to be resilient to such disturbances. In this study 93 tree species were identified in the City of Tampa (Appendix B). The Residential existing land use category had the highest diversity, containing 66% of the species. This is not surprising since homeowners are more likely to plant and maintain a broader suite of tree species than might be found in other urban areas. By comparison the Recreational/Open/Natural areas had only 40 tree species and the lowest diversity (2 species) was found on Agricultural lands (Figure 3).

In 2006, ninety-three tree species were also identified in the City of Tampa, but not the same ninety-three species identified in 2011. Fifteen species identified in 2006 were not resampled in 2011. The reasons for those differences included: removal of trees between the 2006 and 2011 sampling periods, identification of some trees to genus level only in 2006, and/or inaccessibility of some plots during the 2011 field season. Fifteen new species not recorded in the 2006 sampling were identified in 2011. The reasons for the new occurrences included new plantings, refinement of plant identification from genus to species level, and the inclusion of new sampling locations to replace those previously inaccessible. In total, the number of tree species recorded from both assessments in the City of Tampa is 108.

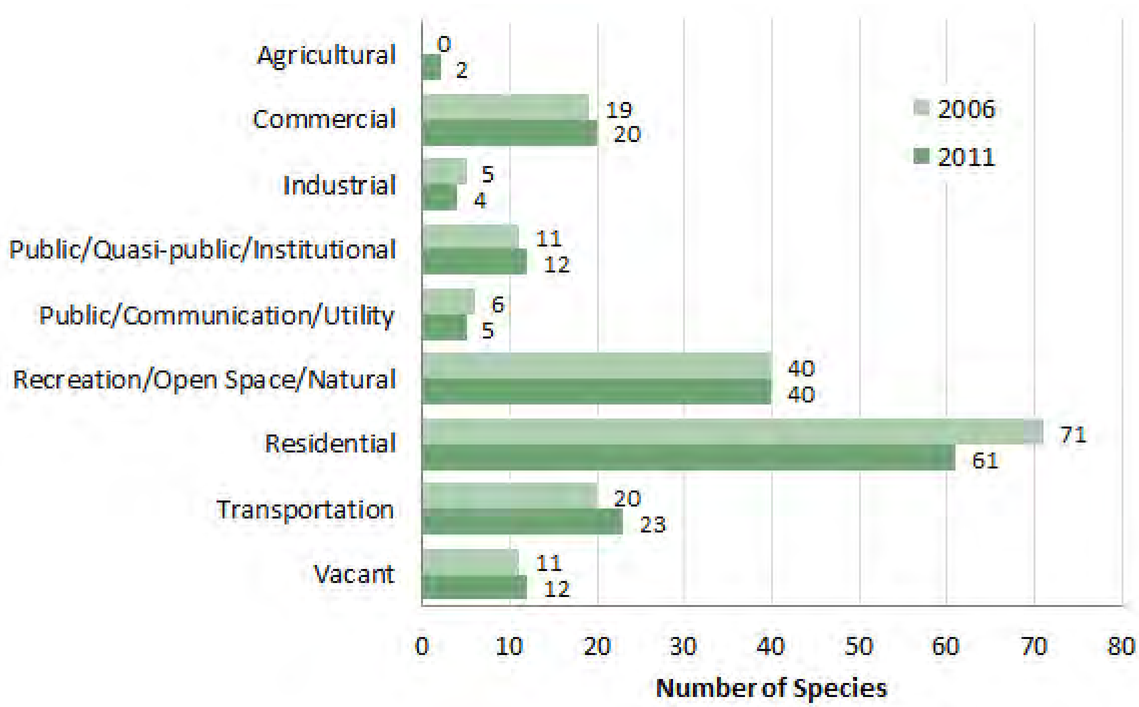


Figure 3. Comparison of the number of tree species by existing land use designation in 2006 and 2011.

Native and Non-native Tree Species

Native species are defined as those that were found in Florida prior to European colonization in the 16th century. Non-native species are those that have been introduced outside of their native range by humans, either intentionally as crops, ornamentals, etc. or by accidental transport across natural boundaries via boats, trains, etc. (Langland and Burks 1998). Some of the tree species in Tampa are also classified as "invasive". Invasive species are able to spread into and dominate an area due to a lack of natural predators and/or diseases. Invasive species can be native or non-native to Florida. Their presence can impact the abundance and distribution of native plants and animals.

Brazilian pepper *(Schinus terebinthifolius)* is the second most common tree species. *(Photo credit: Dan Clark; USDI National Park Service; Bugwood.org)*

Of the 93 tree species found in Tampa in 2011, 56% are native to North America and approximately 55% are native to Florida. Of greatest concern is the most common non-mangrove tree species in Tampa, Brazilian pepper (*Schinus terebinthifolius*) (Figure 4), which is both non-native and invasive. It readily spreads into disturbed areas such as vacant lots, fields and ditches, along canals, and parks and woodlands, creating thickets that are costly to eradicate. Brazilian pepper is estimated to be the second most common species (~17%) in the city. Thirteen species documented in 2011 were listed by the Florida Exotic Pest Plant Council (FLEPPC) as invasive species. Five of those species are classified as Category I (CAT I) invasive species, defined by FLEPPC as "altering native plant communities by displacing native species, changing community structures or ecological functions, or hybridizing with natives. This definition does not rely on the economic severity or geographic range of the problem, but on the documented ecological damage caused."

Abundance

It is estimated that there are ~ 8.7 million trees in the City of Tampa (Table 2), an increase of an estimated one million trees in comparison with the 2006 sampling period. For both studies a tree is defined as a woody stem with a DBH of one inch or greater. The two most common species, based on the estimated number of trees in the urban forest, are white mangrove (*Laguncularia racemosa*) (34%)[3] and Brazilian pepper (17%).

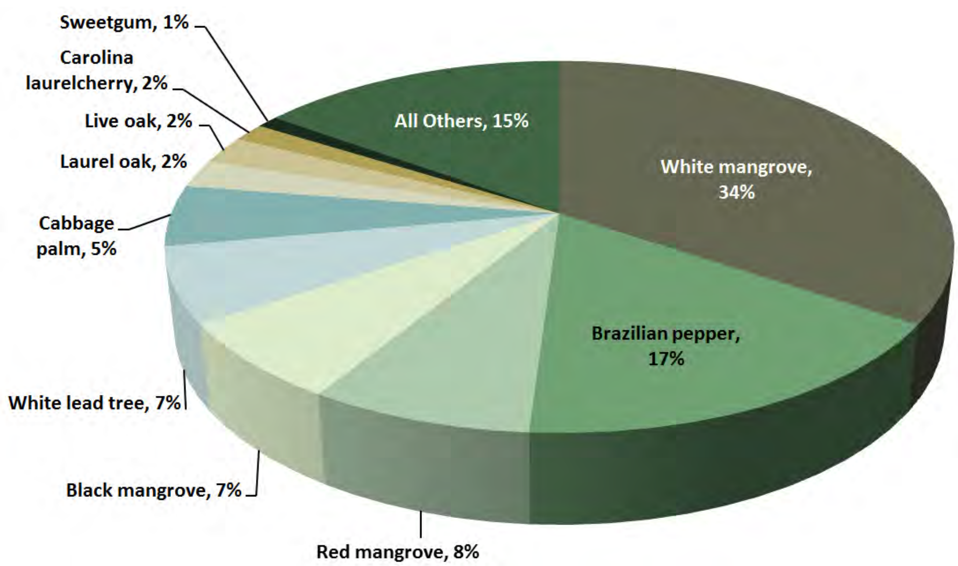


Figure 4. Top ten tree species and their associated percentages by estimated number of trees, 2011

The ten most common tree species account for approximately 85% of all trees (Figure 4). In addition to white mangrove and Brazilian pepper, the remaining top ten species are the native species red and black mangrove (*Rhizophora mangle* and *Avicennia germinans* respectively), cabbage palm (*Sabal palmetto*), laurel and live oaks (*Quercus laurifolia* and *Q. virginiana*), Carolina laurelcherry (*Prunus caroliniana*), sweetgum (*Liquidambar styraciflua*) and the non-native invasive white lead tree (*Leucaena leucocephala*) (Figure 4).

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[3] During the 2006 sampling white mangrove was misidentified as black mangrove in 3 locations and white mangroves were mislabeled on data sheets as red mangrove in one other location (field identification was correct). This led to an incorrect assessment of red mangrove as the species with the greatest number of estimated trees in the forest based on the UFORE model projections.

Mangroves and Inland Forest

Mangroves

Mangrove forests are a rare ecological community within North America. Because of mangroves' sensitivity to freezing temperatures, mangrove forests in the continental United States are limited to the southern coasts of Florida and Texas. In Tampa Bay, almost 50% of the mangrove forest has been lost in the past 100 years (U.S. Geological Survey 1996) .

The mangrove forest is valued for its ability to filter out pollution, stabilize sediments, protect shoreline from erosion, and to provide food, nesting, and nursery areas for a great variety of fish, shellfish, birds, and other wildlife. Mangroves are an integral part of the Tampa Bay estuary and the basis for the aquatic food chain that supports 75 percent of the game fish and 90 percent of the commercial fish species in southern Florida (Law and Arny).

The mangrove forest includes three tree species collectively called mangroves: red mangrove (*Rhizophora mangle*), black mangrove (*Avicennia germinans*) and white mangrove (*Laguncularia racemosa*). The three are found in overlapping ecological zones. These three species make up approximately 49% (an estimated 4.2 million trees) of the total number of trees (stems >1 inch diameter) in Tampa's urban forest. White mangrove accounts for 34% of the trees, black mangrove 7% of the trees, and red mangrove 8% of the trees in the City of Tampa (Figure 4). Within the mangrove forest, white mangroves dominate, accounting for 70% of the total number of trees, while red and black mangroves represent the remaining 30% (Figure 5).

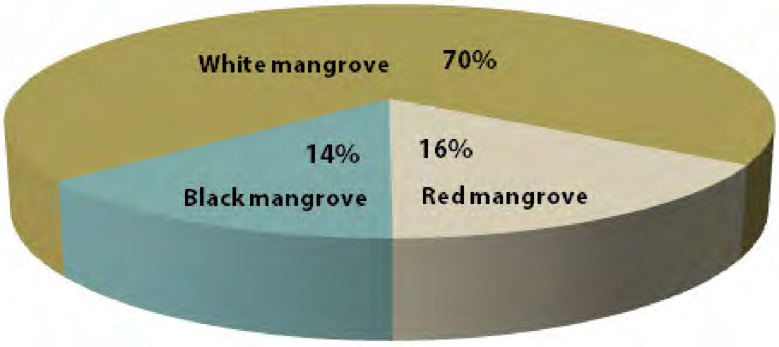


Figure 5. Proportion of mangrove species, 2011

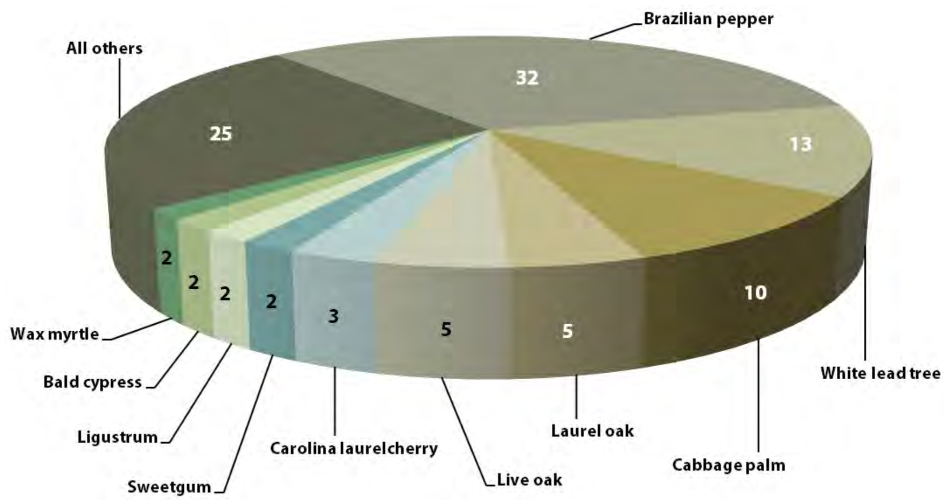


Figure 6. Top ten tree species (without mangroves) and their associated percentages, 2011

Inland Forest

The City of Tampa maintains regulatory authority of trees and woodlands within its jurisdiction, outside of the mangrove ecosystem found along the intertidal zone of Tampa Bay. This inland region of the urban forest contains an estimated 4.4 million trees (Table 2) represented by 90 tree species.

Within the inland portion of the urban forest Brazilian pepper is the dominant species (32%) followed by white lead tree (13%) and cabbage palm (10%) (Figure 6). Both Brazilian pepper and white lead tree are nonnative invasives. The ten most common species make up three quarters (75%) of the total number of trees in Tampa for the inland urban forest. Each of the 80 species that make up the remaining twenty-five percent of the urban forest contribute less than one percent each to the total inland urban forest. The near doubling of white lead tree from the 2006 estimates can be attributed to the documented ingrowth on the Industrial land use.

The Residential land use had the greatest estimated number of trees in 2006 and the second highest estimated number of trees in 2011

Table 2. Estimated number of trees with and without mangroves and Brazilian pepper, 2011

	Total Trees	Proportion of Total Trees
With Mangroves	8,676,844	100
Without Mangroves	4,429,219	51
Without Mangroves and Brazilian pepper	2,991,426	34

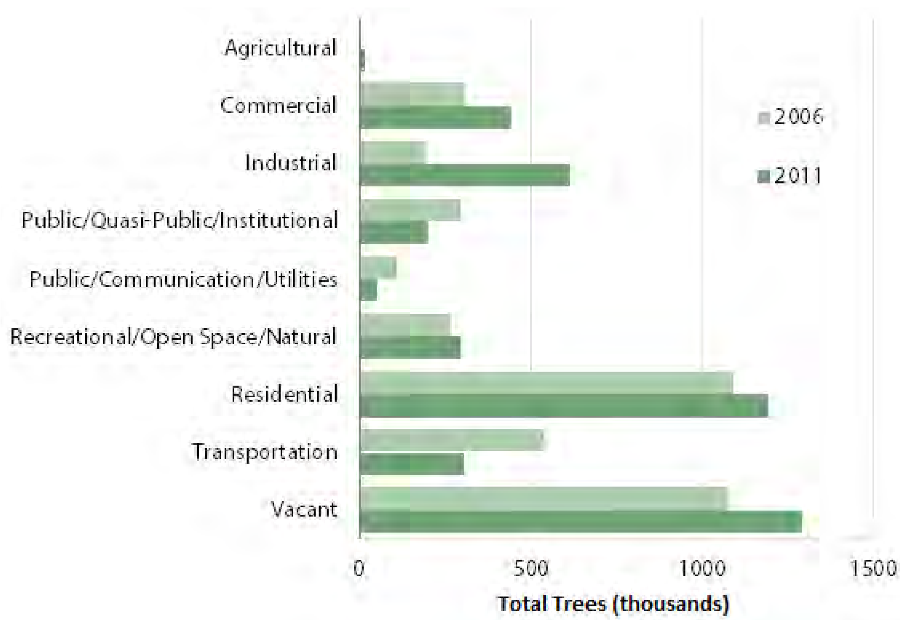


Figure 7. Comparison of the number of trees (without mangroves) by existing land use in 2006 and 2011

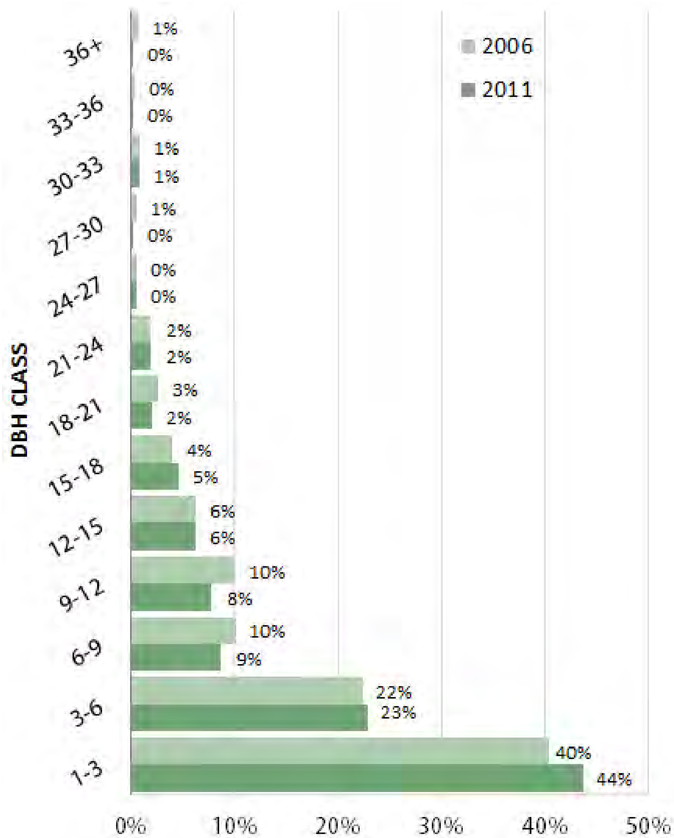


Figure 8. Comparison of diameter class distribution of trees (without mangroves) in 2006 and 2011

(Figure 7). This is due in part to the large portion of residential land within the city. Vacant lands had the greatest estimated number of trees in 2011 which largely can be explained by the high density of small-diameter Brazilian pepper trees which make up approximately 73% of all estimated trees in the Vacant land use category. The total estimated number of trees within the inland urban forest, with Brazilian pepper and mangroves excluded, is 2,991,426 (Table 2). Increases in the estimated number of trees from 2006 to 2011 were recorded in all but three land uses (Public/Quasi-public/Institutions, Public Communications/Utilites, and Right-of-way).

Approximately 67% of the city's inland trees are in the smaller (1–6 inches) diameter classes (Figure 8). In the 1–3 inch diameter class, 20% is made up of non-native invasive Brazilian pepper and another 15% by non-native invasive white lead tree. Native, small-stemmed species like wax myrtle contribute approximately 15% to this diameter class. In the 3–6 inch diameter class, cypress and oak trees each contribute 17%, and 14% is made up of Brazilian pepper. In the larger diameter class of 36+, 83% of the trees are oaks while bald cypress and ear tree each contribute 8%.

Palms

Palms are a distinct structural element of the city's landscape. Palm species are commonly used on residential sites and public rights-of-way to accent the city's semi-tropical climate. While not truly trees (palms are monocots), they function as trees and represent a significant portion of Tampa's urban forest (7%) which remains unchanged overall since 2006. The physical structure and metabolism of palms differ from flowering and coniferous trees. Their function and economic values were determined by i-Tree models more appropriate to capture their unique qualities. The ecological values of palms have been included in the overall description of the city's urban forest and in the description of the inland urban forest.

The total number of palms in Tampa was estimated to be 583,211. In 2011 the Residential and Vacant land uses had the greatest number of palms. While the Vacant lands contained only one species (cabbage palm), the Residential land use had the greatest diversity with 8 different palm species (Figure 9) but three fewer species than in 2006[4].

Florida's state tree, the cabbage palm (*Sabal palmetto*) is the only native palm of large stature found in the city[5]. It is one of the top-ten dominant species found in the urban forest canopy (5% of all trees) and the most common of the palms (79% of all palms).

Queen palm (*Syagrus romanzoffiana*), the second most common palm in the city (11% of all palms), is an inexpensive large palm commonly used for landscaping. Estimates of queen palms have nearly doubled since 2006 estimates. It is worth noting that the queen palm and Mexican fan palm are both considered to be Category II invasives by the Florida Exotic Pest Plant Council (www.fleppc.org).

[4] One plot not accessible in 2011 contained 2 additional palm species recorded in 2007 and the third species had been removed.

[5] Native Florida royal palm (*Roystonea elata*) also of large stature, is infrequently planted in Tampa which is north of its natural native range. No Florida royal palms were captured in either the 2007 or 2011 samples of Tampa's urban forest.

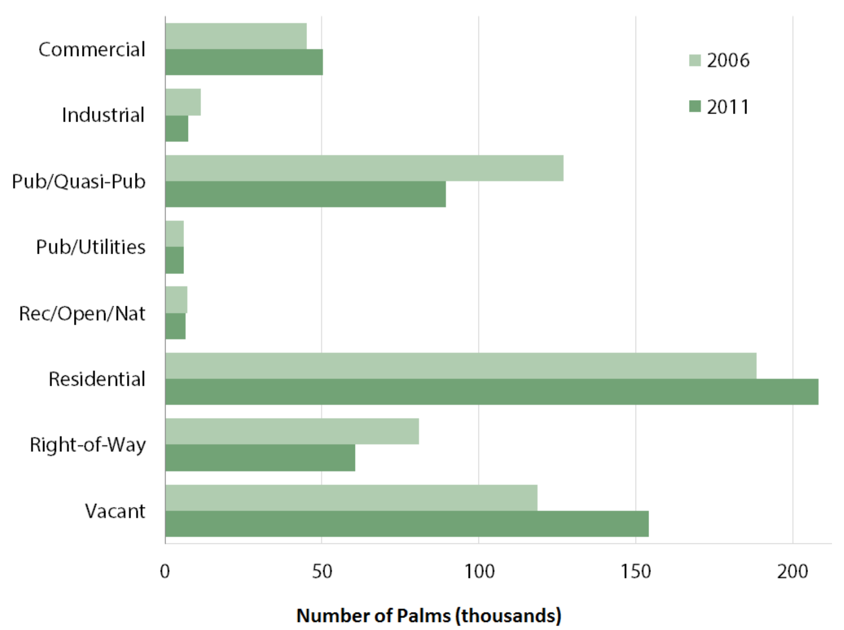


Figure 9. Number of palms by land use, 2006 and 2011

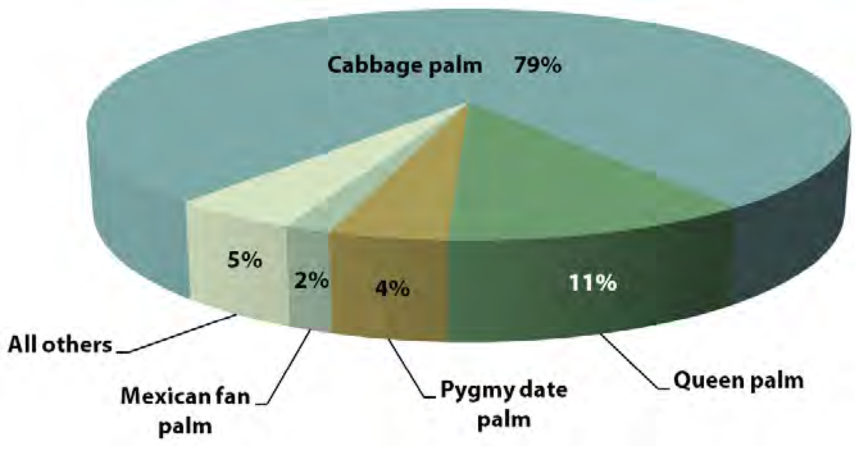


Figure 10. Relative number of the top five palm species based on the estimated number of trees, 2011

Significant Diseases Affecting Palms in the City

In 2005 the pathogen *Fusarium oxysporum* was identified as the causal agent in the rapid decline and death of queen palms in the Tampa Bay region. In 2006, the same pathogen was identified in the rapid decline and death of Mexican fan palms (*Washingtonia robusta*), another large stature palm found in Tampa. Researchers now suggest that the pathogen is likely being spread by the wind, and that palms, especially queen palms and Mexican fan palms, should not be replanted into a site where a palm with this disease was removed.

A new disease for Florida palms, Texas Phoenix palm decline (TPPD), was identified in Hillsborough County during 2006. The disease was known to cause the decline and death of Canary Island date palm (*Phoenix canariensis*), edible date palm (*Phoenix dactylifera*) and Senegal date palm (*Phoenix reclinata*). While these palms are not truly common within Tampa's urban forest, largely due to their size and cost, they are extensively used as central elements in formal landscape design throughout the city. In 2008 it was discovered that Tampa's most prevalent palm species, cabbage palm, was also susceptible to TPPD. Cabbage, Canary Island date and Senegal date palms represent 80% of all palm species within the City of Tampa.

Urban Forest Structure

Forest structure is defined as the distribution of vegetation, both horizontally and vertically, across a given area. Various physical attributes of the forest vegetation can be evaluated to help determine forest structure such as: tree density, diameter and height distribution, crown area, tree health, leaf area, and biomass. An accurate assessment of a forest's structure is vital in order to evaluate its ability to perform ecological functions and provide ecosystem services. The following sections review various quantifiable attributes (metrics) of Tampa's urban forest structure. These metrics are useful for helping managers and policy makers understand how forest structure influences the environmental services provided by the urban forest and aids in making informed decisions about the management of the urban forest.

Density

Tree density (or number of trees per acre, TPA) is a useful metric for characterizing tree distribution. This inventory estimated an average of 116 TPA throughout the City of Tampa, an ~11% increase from 2006. The land use with the highest density of trees (453 TPA) is Recreational/Open Space/Natural areas (Figure 11). As was stated in the 2008 report of analyses (Andreu et al. 2008), in general, of the ten land use categories utilized in this study, the Recreational/Open Space/Natural land use is thought to have had the least direct impact by urbanization, and is therefore a useful benchmark against which the values from other land uses can be compared. The significant increase in trees per acre in the Industrial land use from 2006 to 2011 (+215%) can be attributed to ingrowth of trees on plots in this land use. Ingrowth can be defined as new trees that germinated and reached greater than one inch DBH in the five years, or existing trees that were less than one inch in 2006 but are greater than one inch in 2011.

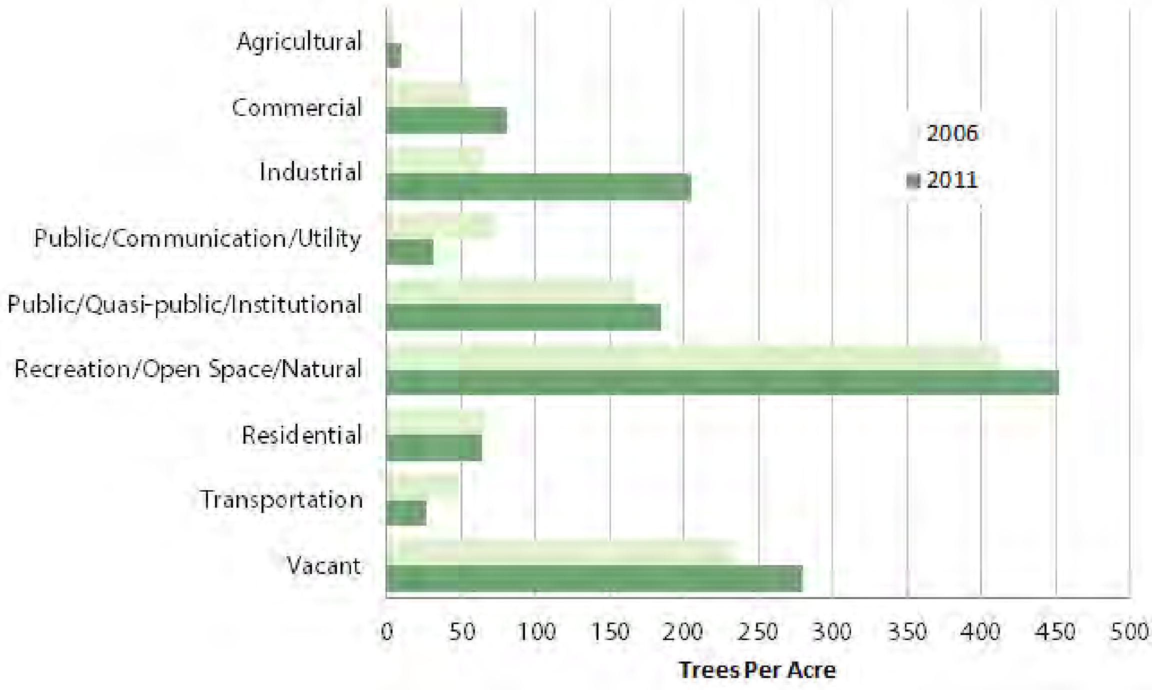


Figure 11. Comparison of average trees per acre (TPA) for each land use designation in 2006 and 2011

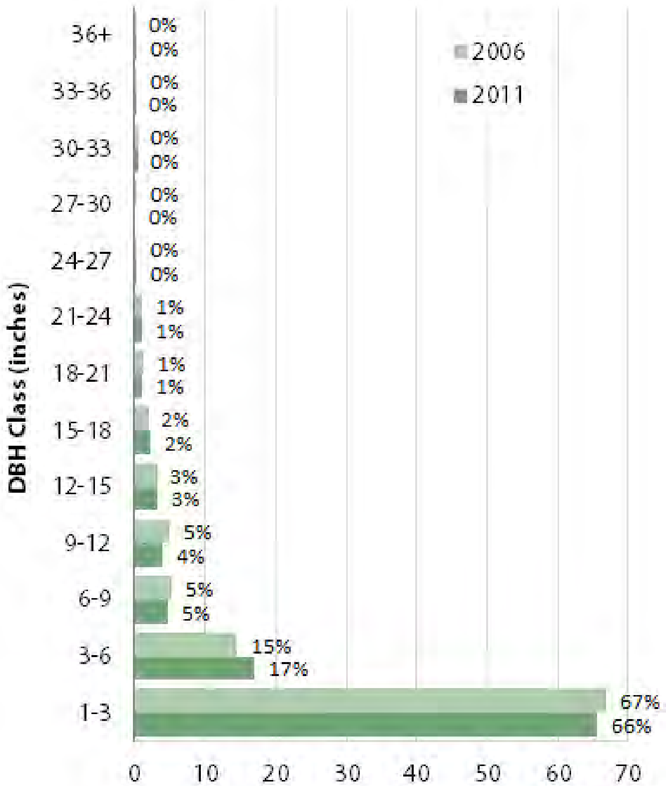


Figure 12. Comparison of diameter (DBH) distribution by diameter class in 2006 and 2011 for trees

Size Distribution

The diameter distribution of trees in Tampa is skewed towards smaller diameter classes (Figure 12). It is tempting to postulate that these small trees represent a young population but this would be a poor interpretation. In the 1–3 inch diameter class, mangroves (red, black, white) represent 56% of the trees and Brazilian pepper makes up an additional 9%. Since both of these tree species tend to maintain a small diameter throughout their life, this represents a relatively stagnant portion of the size class distribution. The largest diameter class, trees greater than 36 inches, represents just three tenths of a percent (0.3%) of the estimated population (Figure 12). In general, these trees are larger because they are older and their physiology allows them to obtain such diameter growth as they age. Trees in this size class are represented in large part by native long-lived species such as oaks (83%) but even these trees will eventually decline and die from old age or be removed as land is developed. Therefore managers and planners may want to consider how to ensure these trees are replaced over time and to do this they will need to develop a comprehensive strategic management plan for the urban forest of Tampa.

Cover of Urban Forest Strata

Tree Cover

Tree canopy cover is a common, ecologically important metric used to investigate the amount of area directly and indirectly influenced by trees. It indicates how much of an effect the forest has on the microclimate (e.g. shade in parking lots and homes) as well as its ability to intercept rainfall (stormwater flow). It is also a metric that is commonly used to determine the effectiveness of urban tree ordinances and policies. Based on the field sampling approach used to characterize the structure and function of the urban forest, the estimated citywide average tree cover in 2011 remained the same as the 2006 estimate of ~28% (<± 1% @ 95% confidence interval). It is important to note that this tree cover is variable and not homogeneously distributed across the city. The tree canopy analysis section of this report provides detailed information about the distribution of tree cover and results of the change analyses.

Shrub Cover

Shrub cover is often overlooked and undervalued as a component of the urban forest. Like tree cover, it is an estimate of the amount of area in the urban forest covered by the shrub stratum. Shrub cover is an important attribute of the urban forest because it adds structural complexity and diversity, both of which have ecological and aesthetic value. In addition to providing some of the same benefits as trees, such as preventing soil erosion and nutrient runoff, shrubs also help remove pollutants from the atmosphere. Because the tree and shrub layers are in overlapping strata their cover estimates are not additive.

In Tampa it is estimated that approximately 11% of the city is covered with shrubs. This is a slight decrease from the value of 14% estimated in 2006. Seven out of the ten land uses showed decreases in shrub cover in 2011. The industrial land use, for which increases in tree canopy cover (+30%) were recorded in 2011, showed a sizeable increase (+200%) in shrub cover (Figure 13). For the shrub layer, the land use with the most cover in both 2006 and 2011 is in Recreational/Open Space/Natural areas (35%), which is notable as we have suggested it might be considered the land use least impacted by urbanization.

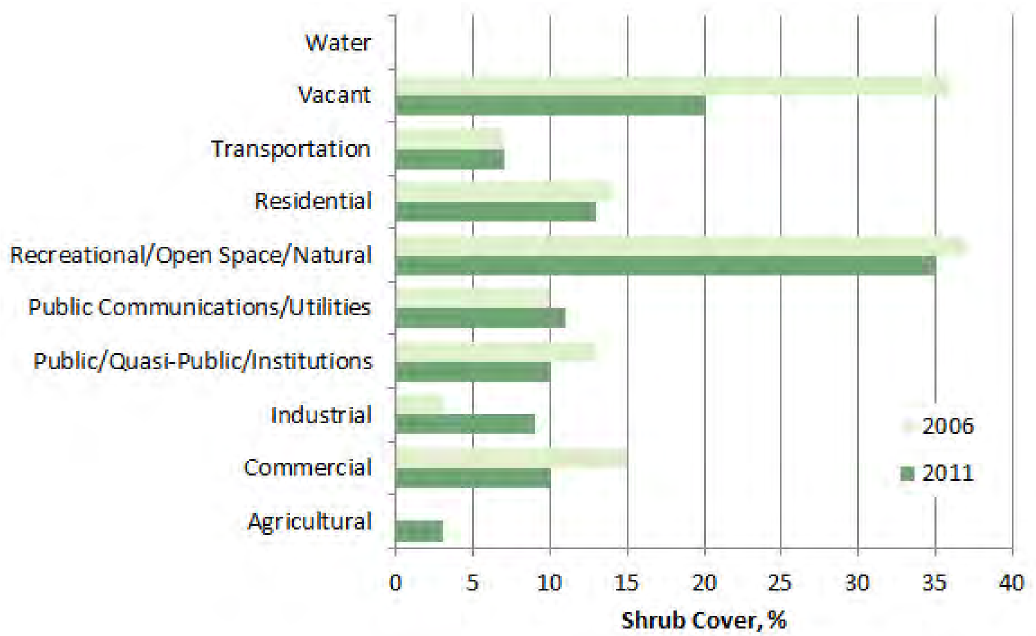


Figure 13. Comparison of percent shrub cover by land use in 2006 and 2011

Ground Cover

Ground cover is divided into two broad categories: impervious (asphalt, buildings, and cement) and pervious (bare soil, leaf litter, herbs, maintained grass, rock, unmaintained grass, and water) surfaces. Urbanization tends to increase the amount of impervious surface area which affects hydrological processes such as aquifer recharge and surface runoff (Alberti 2008). Thirty-five percent of the ground cover in the city is classified as impervious (Figure 14). The land use areas with the greatest amount of impervious surfaces were those designated as Right-of-way (57%), Industrial (53%), and Commercial (49%) (Figure 15). For comparison purposes, Recreational/Open/Natural land use areas had nearly 12% (the same as 2006) impervious ground cover surface, demonstrating that they are not without some impacts from urbanization. Overall there were only small increases in impervious groundcover percentages recorded in 2011 for five out of the ten land uses. Notably, the Industrial land use saw an increase from ~43% to ~53% impervious surface area from 2006 to 2011. As noted previously, the Industrial land use also recorded the largest increases in estimated tree and shrub cover in comparison with the 2006 data.

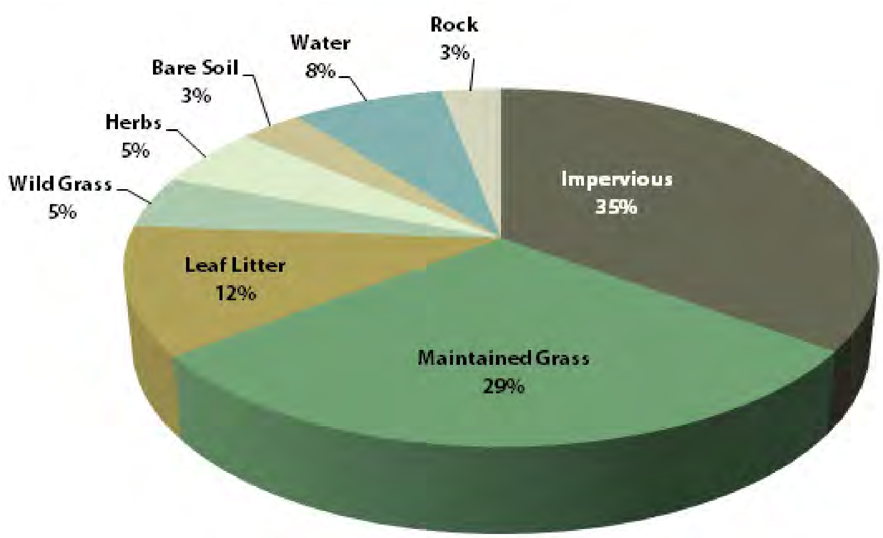


Figure 14. Distribution of ground cover types by percent, 2011

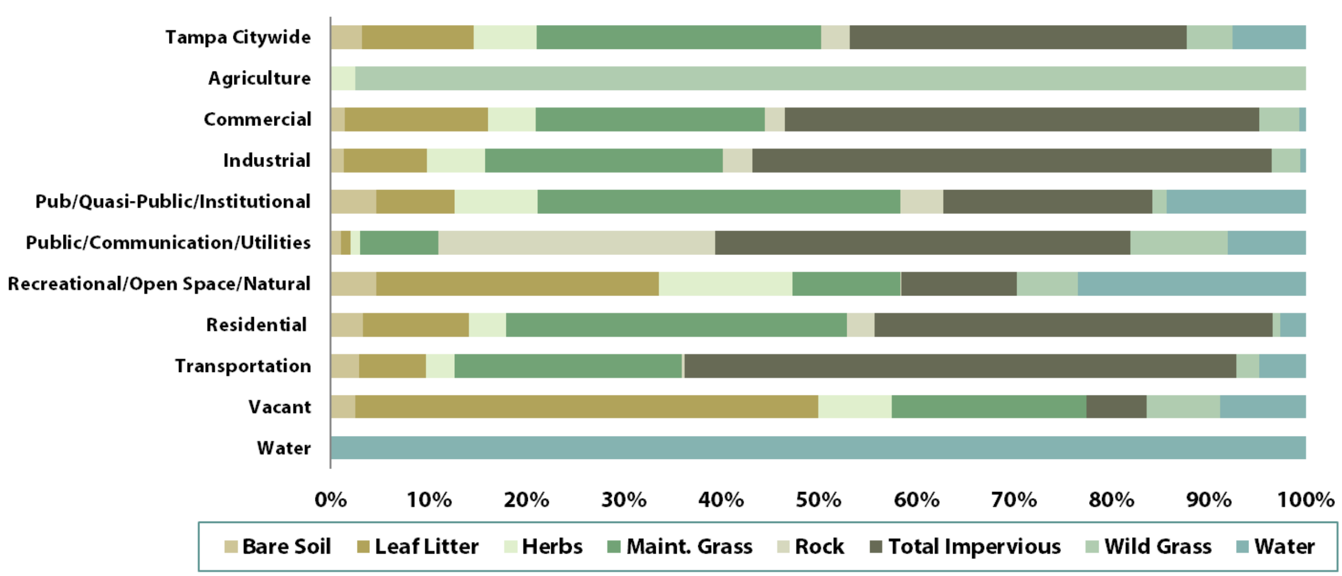


Figure 15. Proportional distribution of ground covers by land use, 2011

The land use categories with the greatest amount of pervious surface ground cover were Agriculture (100%), Vacant land (94%) and Recreational/Open Space/Natural (88%) (Figure 15). Our study classified the pervious surface area into seven categories (Figure 14) since there are different inferences one can make about the hydrological impacts of each. For example, 29% of pervious surfaces are classified as maintained grasses or lawns. In Florida, approximately "one-third of the freshwater use is for municipal use, half of which is used to water lawns." (Cervone et al. 2003). According to the 2011 Annual Status Report on Regional Water Supply Planning produced by the Florida Department of Environmental Protection, the demand for water is expected to increase by 28% in Florida by 2030 (FDEP 2011).

The land uses with the highest percentage of maintained grass were Public/Quasi-public/Institutions (37%) and Residential (35%). Increases of 50% or more were noted for percentages of maintained grass in Industrial and Commercial land use categories since 2006. This information can help policy makers and educators target educational programs to increase awareness of water conservation techniques and practices.

Leaf Area

Leaf area is a measure of the total green leaf surface area on a tree or shrub. This measure is used in the model to estimate services trees provide (e.g., pollution removal). Because some species of trees are deciduous and others are evergreen, leaf area may vary depending on the time of year. For this report, leaf area is calculated based on the time field observations were made which was during a time when leaves were on the trees.[6]

In 2011, cabbage palms and live oaks were the two species with the greatest total leaf area, representing 35% of the total leaf area (18% and 17% respectively). The contribution to leaf area of these two species is especially notable as they represent only 7% of the total tree stems. Alternatively, white mangrove and Brazilian pepper were the most common tree species representing over 50% of the tree stems (34% and 17% respectively) yet only contribute 5% of the total leaf area. Clearly, the contribution or lack of contribution to ecosystems services is not simply determined based on the number of stems of individual species; rather, one must consider other attributes of the trees such as leaf area.[6]

[6] The i-Tree Eco model calculates leaf area of individual species using regression equations for urban tree species. Estimates of leaf area are adjusted downward based on tree condition less than excellent and crown light exposure (CLE) values for individual trees (Nowak 1996).

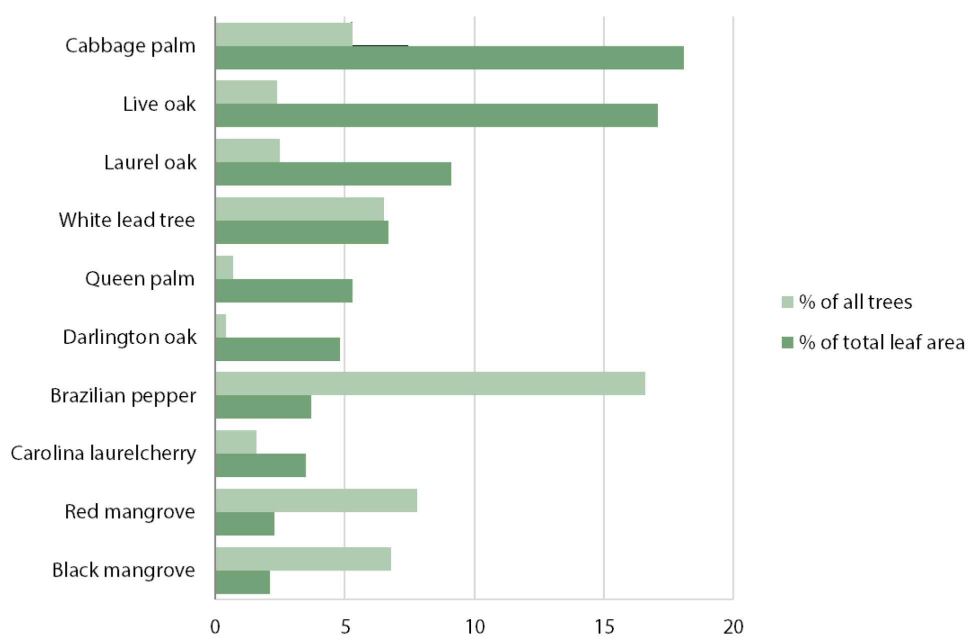


Figure 16. Percent leaf area by species and the percentage of total trees each species represents, 2011

Importance Values

From the example in the above leaf area section of the report it is evident that by using an individual metric such as number of stems or leaf area one can get a false impression as to the contribution of a species to the functioning of the forest. Ecologists have overcome this uncertainty by calculating an importance value (IV) based on multiple attributes. For this report the IV is calculated by adding its relative abundance and leaf area.

Using this method, the four species with the greatest IV are white mangrove, cabbage palm, Brazilian pepper and live oak (IV= 35, 23, 20 and 20 respectively). It is notable that Brazilian pepper, a non-native and invasive species, is the third most important species in Tampa. This type of information is of great value for developing strategies and policies to address the management of this species. Also of interest is the ranking of cabbage palm and live oak; both of these species are particularly long-lived and considered to be able to withstand wind events such as hurricanes.

Finally, the white mangroves, despite representing only 1% of the total leaf area, are so abundant that they are ranked the highest IV. This is interesting as these species are confined primarily to coastal areas of the city. Some suggest that the mangroves are not really a part of Tampa's urban forest. Yet given this ranking, along with the additional values mangroves provide to fisheries and coastal protection, this ranking may cause some to reconsider their position and ensure that these coastal forests are included in the management planning process.

Table 3. Comparison of importance value (IV) in 2006 and 2011 for the ten species with highest IV in 2011 (IV= %Pop +%LA)

	2006	2011	2006	2011	2006	2011
Common Name	**%Pop[a]**		**%LA[b]**		**IV[c]**	
White mangrove	2.4	34.4	1.2	1.0	4	35
Cabbage palm	5.6	5.3	11.8	18.1	17	23
Brazilian pepper	16.4	16.6	13	3.7	29	20
Live oak	3.5	2.4	20.6	17.1	24	20
White lead tree	3.1	6.5	1.4	6.7	5	13
Laurel oak	2.4	2.5	5.1	9.1	8	12
Red mangrove	42.2	7.8	3	2.3	45	10
Black mangrove	5.6	6.8	1.2	2.1	7	9
Queen palm	n/a	0.7	n/a	5.3	n/a	6
Darlington oak	1.1	0.4	8.8	4.8	10	5.2

[a]percent of population; [b]percent of leaf area; [c]percent Pop + percent LA

Tree Canopy Analysis

Tree canopy cover is an important measure of the amount of area and locations which are directly and indirectly influenced by trees. It is ecologically important because it indicates the potential of the urban forest to affect microclimate (e.g. shade in parking lots and homes), air pollution removal, and rainfall interception. Trees also provide many benefits, or ecosystem services, to communities, including: saving energy, lowering summer temperatures, reducing air pollution, improving water quality, enhancing property values, providing wildlife habitat, facilitating social and educational opportunities, and providing aesthetic benefits. Although the ecosystem services provided by trees can only be estimated with a thorough understanding of urban forest structure and functions, the distribution of tree canopy is a useful indicator of where these benefits occur within the city. Tree canopy measurements are commonly used to assist with the development and monitoring of urban tree management policies.

The results of this tree canopy analysis are organized into two major sections. The first section updates the long-term (1975-present) citywide tree canopy trend dataset that was initially developed in 1999 (Campbell and Landry 1999) and updated in 2008 (Andreu et al. 2008). The second section focuses on the distribution of tree canopy within the City of Tampa. Citywide comparisons are made between the high-resolution map of 2011 tree canopy cover and the map of 2006 tree canopy. Additional maps and summaries show where tree canopy is located and how it has changed in different geographic areas or land uses of the city.

Long-term Trends in Citywide Tree Canopy

Historic black-and-white photographs and aerial images show that the types and locations of trees and tree canopy have changed dramatically since the Tampa area was settled over a hundred years ago. We have been able to map tree canopy cover for the past four decades, using the NASA Landsat satellite images, the world's longest continuously acquired collection of satellite images. Although the very large pixel size of Landsat images (i.e., 30 meters / 98 feet) is known to result in an underestimation of the amount of tree canopy, they provide a consistent method to monitor long-term change.

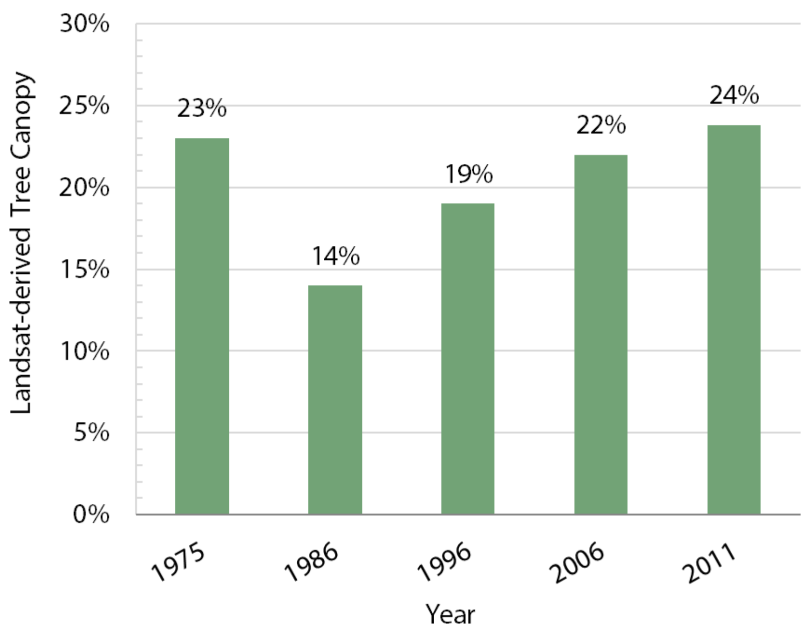


Figure 17. Long-term change in City of Tampa tree canopy cover.
Note: Specific tree cover values are consistently underestimated when compared to high-resolution tree cover analysis.

The long-term change in tree canopy cover was mapped using Landsat satellite images from the month of April of 1975, 1986, 1996, 2006 and 2011. The trend shows that canopy cover decreased substantially between 1975 and 1986, most likely a result of the large-scale development of New Tampa which occurred during that time period. Since 1986, citywide tree canopy cover has been increasing. The current amount of tree canopy cover indicates that the city has slightly more tree canopy now than it did in 1975. Unfortunately, it is unknown whether Tampa has more or less tree canopy than in periods prior to 1975. In order to quantify tree canopy prior to 1975, additional research could focus on identifying a longer-term trend using historic aerials.

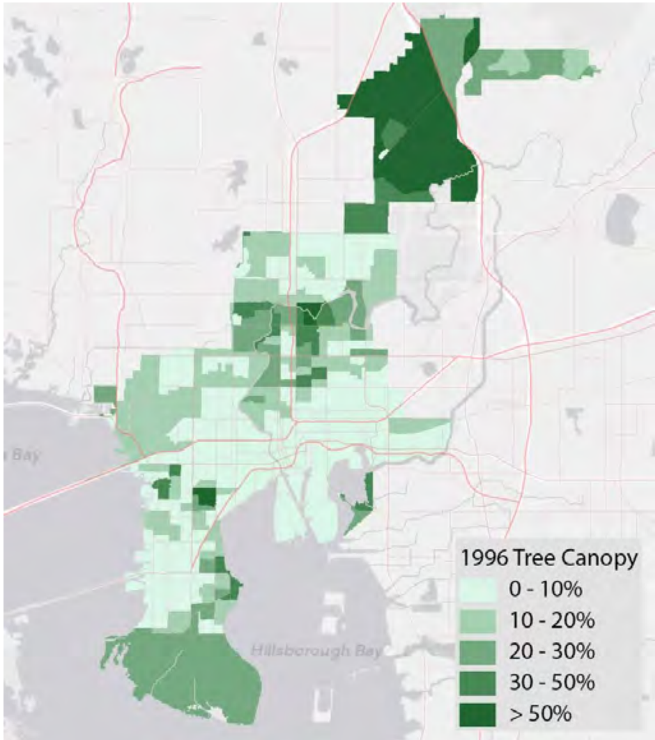


Figure 18. 1996 tree canopy cover estimated from Landsat images and mapped by Census Block Group

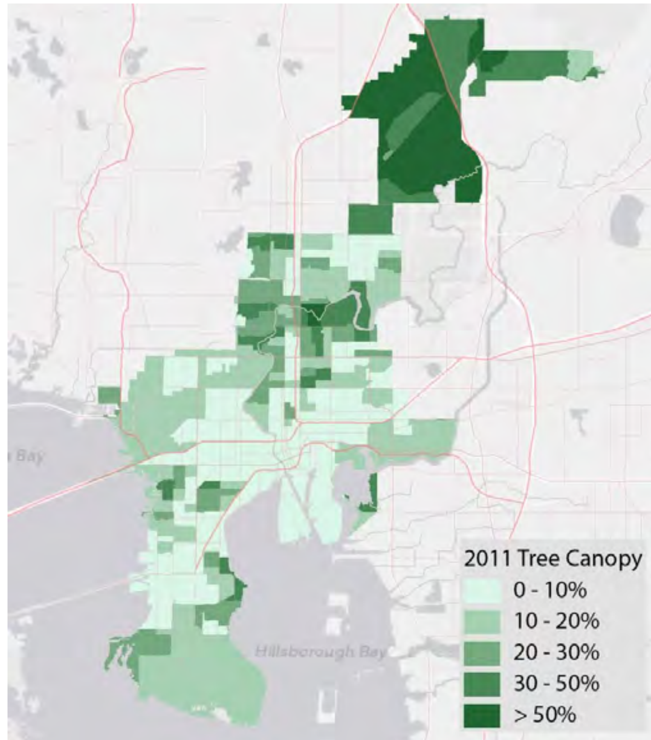


Figure 19. 2011 tree canopy cover estimated from Landsat images and mapped by Census Block Group

The maps of tree canopy cover estimated from the Landsat images show large increases in the north Tampa area. These increases might be expected because the northern regions of Tampa are some of the most recently developed, where growth of trees planted after development would be expected. For example, the loss of tree canopy during the recent large-scale New Tampa development would be followed by an increase in canopy as newly planted trees mature. Older areas, such as South Tampa, East Tampa, Seminole Heights and Tampa Heights show a combination of increases and decreases that are characteristic of redeveloping portions of a city. Many areas of the city show no change (i.e., +/- 5%) between the years 1996 and 2011 according to the Landsat image analysis.

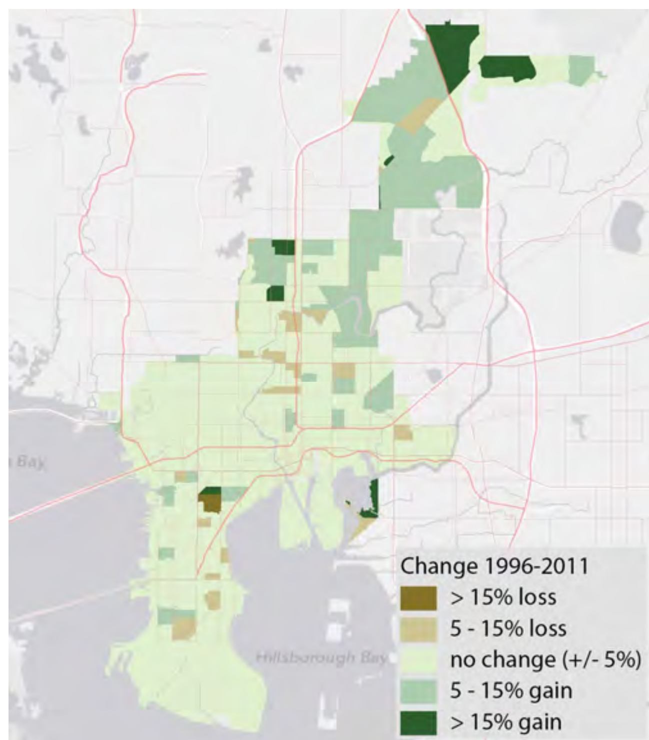


Figure 20. Estimated change in total tree canopy cover between 1996 and 2011

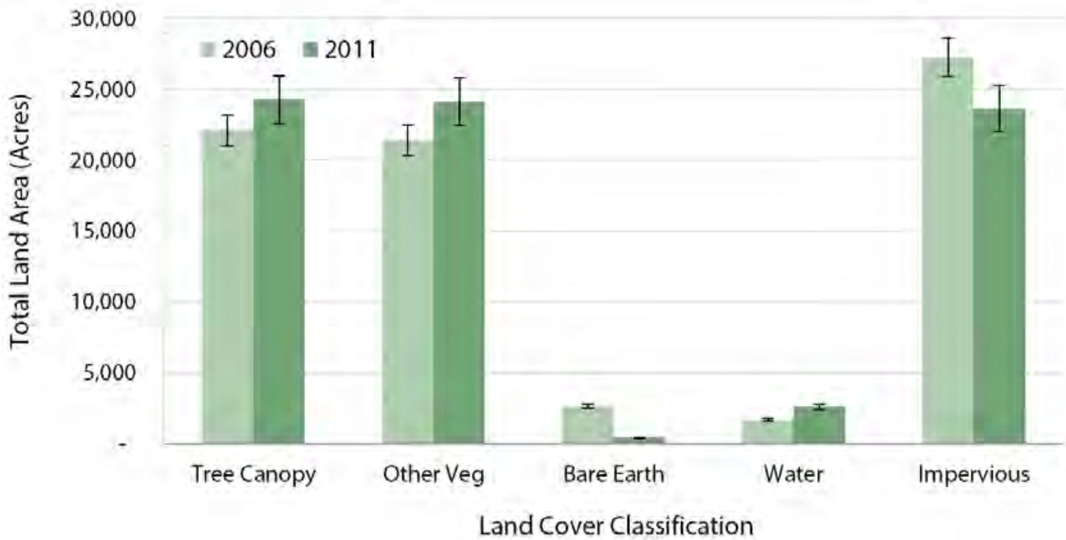


Figure 21. Acreage of land cover types within the City of Tampa.

High-Resolution Tree Canopy Classification

The urban forest and tree canopy change over time as a result of climatic and ecological factors, but also as a result of the actions of Tampa's government, businesses and residents. Information about the location of existing tree canopy can be useful when making urban forest management decisions. This section of the report presents the high-resolution map of 2011 tree canopy cover that shows the distribution of canopy for every one square foot in the city. The 2011 map is compared with the high-resolution map of 2006 tree canopy to show where change has occurred during the five-year period between urban forest assessments. In addition, multiple tree cover measurement methods are presented as part of a discussion of whether there was significant change in tree cover between 2006 and 2011. In addition to classifying tree canopy, the high-resolution analysis also classified other land cover types, including: other vegetation less than eight feet tall, water, bare earth and sand, and impervious surfaces such as buildings, concrete and pavement.

Citywide

In 2011, the results of the high-resolution classification indicated that the total citywide tree canopy was 32% and other vegetation was also 32%. Buildings, roads and other impervious surfaces was 31%; water was 3% and bare earth and sand was approximately 1%. Accuracy of the tree cover classification was estimated to be 95%, based on the manual inspection of eight hundred random points. When considering the results of these analyses and comparisons, it is important to remember that there is approximately 5% error in these measurements.

There are approximately 75,108 acres (117 miles^2/304 km^2) of land area within the boundaries of the City of Tampa. There were 24,290 (+/–1,215)

POSSIBLE URBAN TREE CANOPY

In addition to knowing where trees are located, it can also be useful to identify where there is room to plant trees. The US Forest Service, as part of their analysis of tree canopy in New York City (Grove et al. 2006, Locke et al. 2010), introduced the term Possible Urban Tree Canopy (UTC) to refer to non-road, non-building and non-water land, whereit is biophysically feasible to plant trees. Within this City of Tampa Report, the amount and location of the other vegetation land cover category meets the US Forest Service definition of Possible UTC. In other words, the vegetation category can be used to indicate the amount of tree canopy that could be achieved if trees were planted in these areas. However, the US Forest Service has also been careful to suggest that it is not necessarily socially desirable or economically feasible to plant trees in all of these areas.

acres of tree canopy in 2011. The City of Tampa also has over 24,000 acres of other vegetation, or 32% of citywide land area. These areas represent spaces of Possible Urban Tree Canopy (see box). The fact that other vegetation is such a high proportion of the City means that there is possibly a substantial area of land available to increase tree canopy.

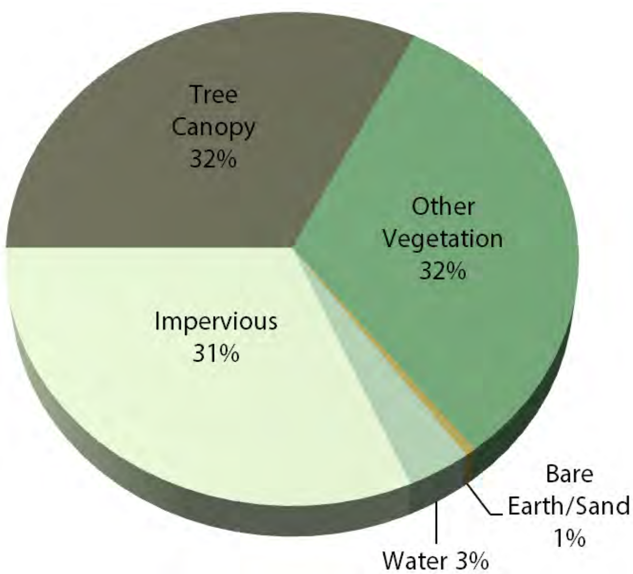


Figure 22. Percentages of land cover composition within the City of Tampa.

City	Year	Tree Cover
Albuquerque, NM	2009	38.1%
Atlanta, GA	2009	52.1%
Baltimore, MD	2005	28.5%
Boston, MA	2008	27.9%
Chicago, IL	2009	18.0%
Denver, CO	2009	9.6%
Detroit, MI	2009	22.5%
Houston, TX	2009	27.4%
Kansas City, MO	2009	28.0%
Los Angeles, CA	2009	20.6%
Miami, FL	2009	21.6%
Minneapolis, MN	2008	24.1%
Nashville, TN	2008	49.8%
New Orleans, LA*	2005	32.9%
New York, NY	2009	19.7%
Pittsburgh, PA	2008	41.6%
Portland, OR	2009	30.9%
Spokane, WA	2007	21.8%
Syracuse, NY	2009	26.9%
Tacoma, WA	2005	23.0%
Tampa, FL**	2011	32.0%

* New Orleans prior to Hurricane Katrina
** Results from this study

TREE COVER IN 20 U.S. CITIES

There is no "correct" amount of tree cover for the City of Tampa. However, tree canopy cover goals are useful performance indicators against which to measure a comprehensive urban forest management plan. The City of Tampa is in the process of developing such a plan, but has not yet adopted specific tree cover performance indicators. In the meantime, a comparison with the 20 U.S. cities studied by David Nowak and Eric Greenfield of the US Forest Service (Nowak and Greenfield 2012) shows that Tampa's 2011 tree canopy cover was greater than ¾ of the cities studied.

Tree Canopy Change 2006-2011

Was there a change in tree canopy between 2006 and 2011? A determination of whether or not change occurred must consider the inherent error and uncertainty with scientific methods. Based on the error estimates of the tree cover data, the actual percentage of tree canopy was somewhere between 31% to 34% in 2011 and 28% to 31% in 2006. This overlap suggests that there may have been an increase in tree canopy, but the change may not have been statistically significant.

Method	Tree Canopy Estimates		
	2006	2011	2006–2011 Change
Landsat image analysis	22%	24%	2% increase
Field Sampling Methods	28%	28%	No change
Land cover classification	29%	32%	3% increase
Dot-based change analysis	31%	33%	2% increase

Table 4. Comparison of tree canopy estimates in 2006 and 2011 using various methods.

Detecting change is also complicated by the fact that the remote sensing imagery used in 2011 was different, albeit better, than the imagery used in 2006. The ground resolution, or pixel size, of the imagery used for the tree canopy classification was one square foot for the 2011 data and ten square feet for the 2006 data. This difference meant that smaller patches of tree canopy could have been detected in 2011 than were possible in 2006, especially for small trees surrounded by sidewalks and pavement. The 2011 tree canopy map is more complete than the 2006 map, and therefore would be expected to have a higher percentage of tree cover due to differences in methods alone.

This report presents several different approaches to measuring tree canopy cover. The long-term trend analysis using Landsat data is a comparable method, but it consistently underestimates tree canopy. The long-term analysis showed a 2% increase in tree canopy. The field methods are extremely important for measuring urban forest structural and functional characteristics, but the tree canopy estimate is based on a relatively small sample size. The field methods did not detect a change in tree canopy between 2006 and 2011. Land cover classification methods using high-resolution imagery provide very accurate maps of tree cover, but differences in pixel resolution pose limits on the determination of change. The land cover classification method found a 3% increase in tree canopy cover. Finally, an independent dot-based change analysis method (Nowak et al. 1996) using 3,000 randomly selected points provided a consistent and comparable approach to determine tree canopy change between the two years. The results of this method indicated that tree canopy cover was 31% in 2006 and 33% in 2011; a 2% increase.

The combined results of these four approaches suggest that there was most likely a small increase in tree canopy cover during the five-year period between 2006 and 2011.

TREE CANOPY AND LAND COVER MAPS

The distribution of tree and other land cover classes is highly variable at a very local level within the City. In order to see the overall differences within Tampa on a single map, the results of the high-resolution land cover classification were summarized by U.S. Census Block boundaries. The maps on the following pages show the distribution of 2011 tree canopy cover, change in tree cover between 2006 and 2011, 2011 other vegetation cover and 2011 impervious surfaces.

Figure 23. Resolution of imagery used for long-term trend (Landsat), 2006 analysis and 2011 analysis, from left to right.

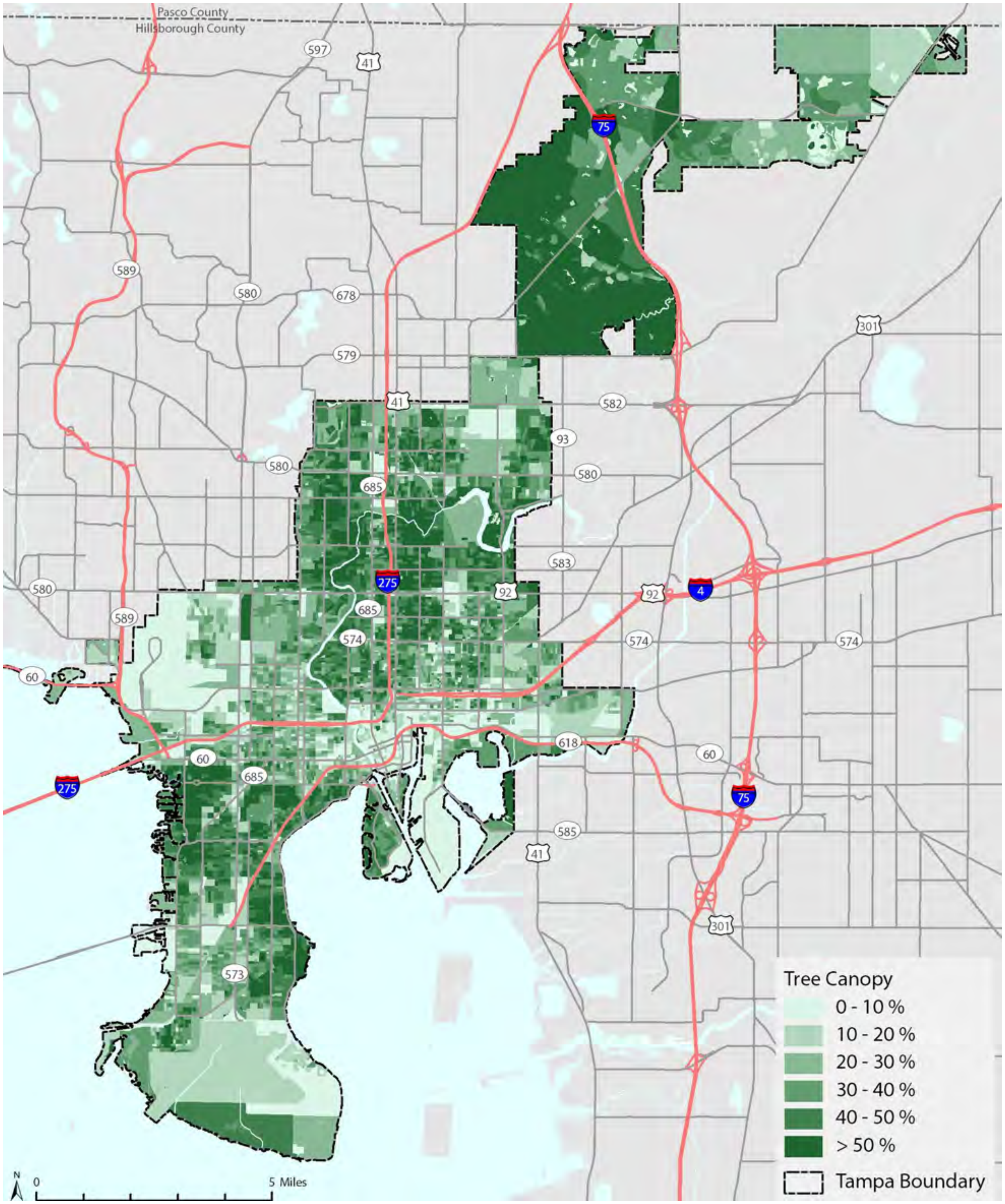


Figure 24. Distribution of 2011 tree canopy cover

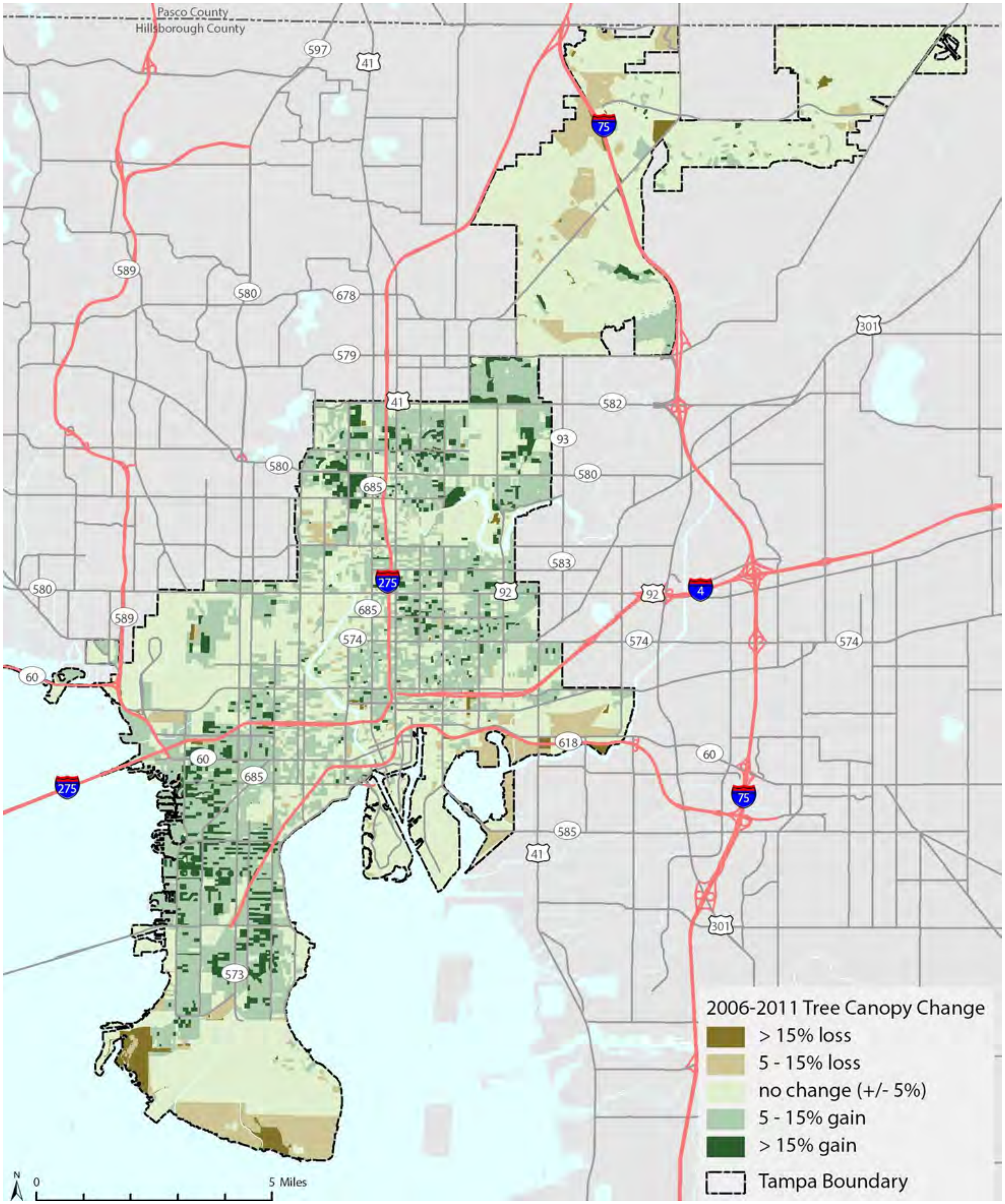


Figure 25. Distribution of tree canopy change, 2006–2011

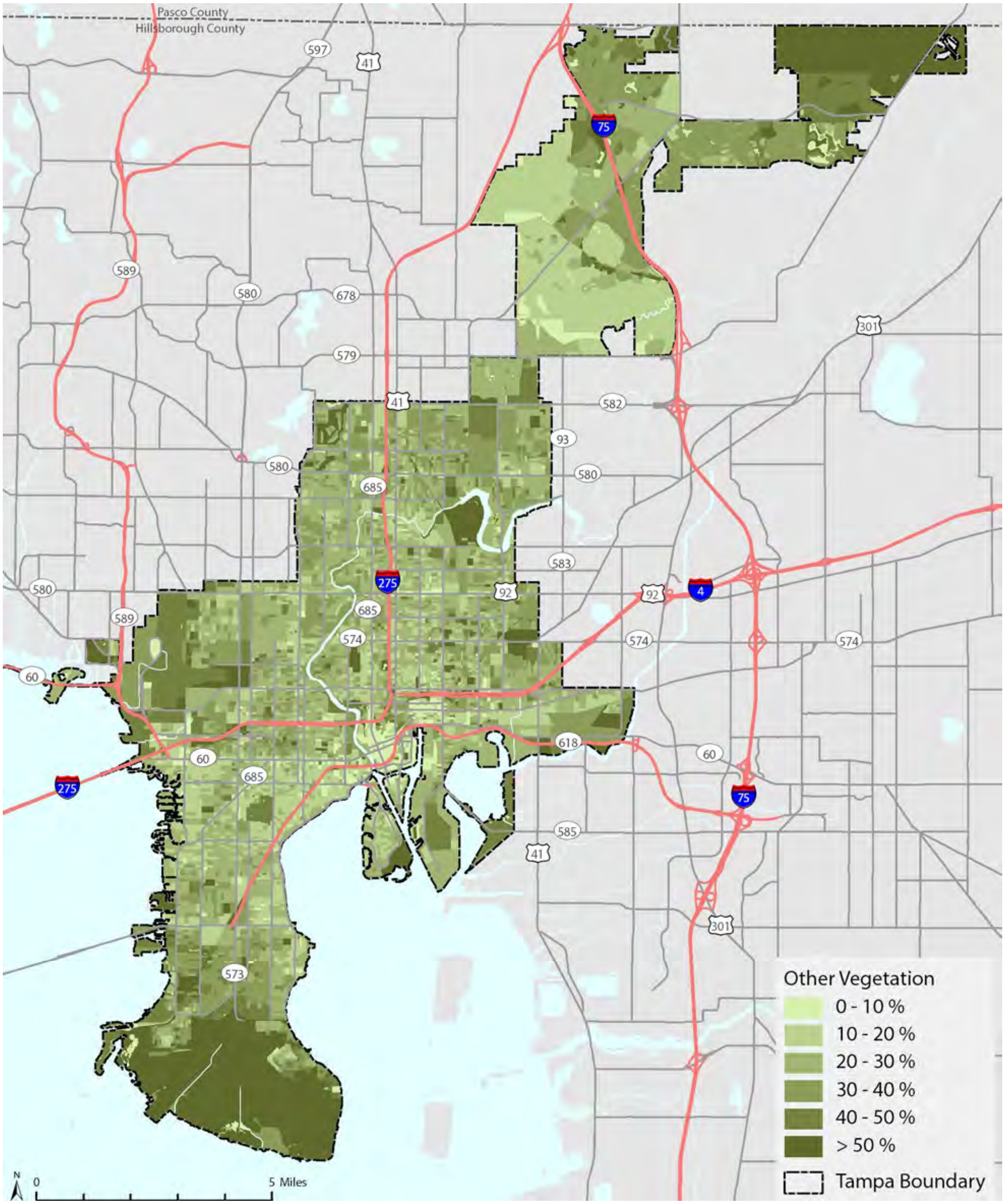


Figure 26. Distribution of 2011 vegetation, other than tree canopy

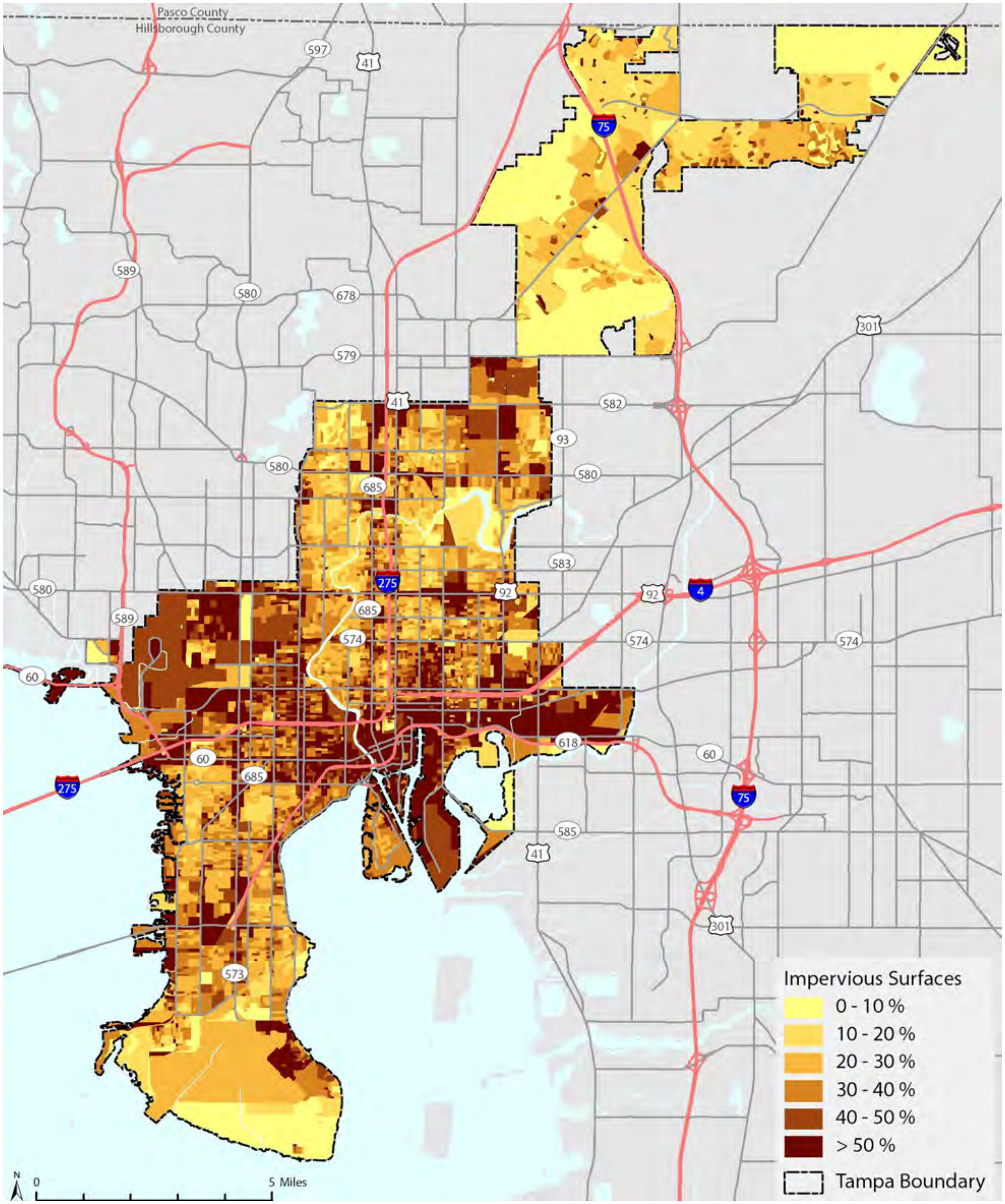


Figure 27. Distribution of 2011 impervious surfaces

Future Land Use

Future Land Use is regulated through the Tampa Comprehensive Plan and is mapped on the Future Land Use Map. The map provides a graphic aid which depicts the various uses of land subject to the goals, objectives, and policies of the Future Land Use Element. Future Land Use along with the Zoning & Land Development code determine applicable land use and development regulations. Table 5 summarizes tree canopy and other vegetation cover within each Future Land Use category within the City. The proportion of each category covered by tree canopy ranges from 4% over Water to 77% over Environmentally Sensitive Lands. Excluding these two relatively undeveloped land uses, the lowest proportion of tree canopy (8%) is in both the Central Business District and the Rural Estate. This comparison illustrates a phenomenon well known to urban forest management professions; building density alone does not explain tree canopy cover in a city. The Future Land Use categories with more than ¾ of land area covered by vegetation include Rural Estates, Environmentally Sensitive Areas, Recreation and Open Space, Suburban Mixed Use–3, and Residential–10. Of all categories, only the Environmentally Sensitive Areas lost tree canopy between 2006 and 2011 (-5%).

In addition to considering the proportion of tree canopy and other vegetation as metrics that describe urban forest distribution, the total land area covered by vegetation should also be considered. For exam-

POSSIBLE URBAN TREE CANOPY

Using the US Forest Service definition of possible urban tree canopy, the proportion of tree canopy could double in at least 70% of the Future Land Use categories if other vegetation were planted with trees. The Right-of-way category has a very large area of possible urban tree canopy, where 3,246 ac of Right-of-way land area is covered by other vegetation. The area of other vegetation in all public land uses is slightly more than 8,000 acres.

Table 5. Total acres and vegetation cover in each Future Land Use category

Future Land Use Category (# is units/acre)	Total Acres	2011		2006		Change 2006-2011	
		Tree Canopy	Other Vegetation	Tree Canopy	Other Vegetation	Tree Canopy	Other Vegetation
Central Business District	264	8%	10%	5%	8%	3%	2%
Community Commercial - 35	2,451	19%	19%	15%	16%	4%	3%
Community Mixed Use - 35	2,306	20%	24%	15%	20%	5%	4%
Major Environmentally Sensitive Areas	7,640	77%	19%	82%	12%	-5%	6%
General Mixed Use - 24	85	13%	16%	8%	14%	5%	2%
Heavy Industrial - 1.5	3,349	10%	30%	10%	26%	0%	4%
Light Industrial - 1.5	1,694	24%	27%	21%	24%	3%	3%
Municipal Airport Compatibility Plan	336	25%	24%	19%	19%	6%	6%
Public/Semi-Public	5,324	14%	45%	11%	43%	3%	2%
Recreation and Open Space	1,990	34%	50%	30%	49%	5%	1%
Right-of-Way	11,845	23%	27%	18%	25%	5%	3%
Residential - 3	1,551	21%	40%	19%	26%	2%	14%
Residential - 6	1,843	49%	22%	40%	20%	9%	2%
Residential - 10	77,096	48%	28%	40%	27%	8%	1%
Residential - 20	2,491	41%	29%	33%	27%	8%	1%
Residential - 35	1,853	29%	26%	21%	23%	8%	3%
Residential - 50	117	29%	18%	22%	15%	7%	3%
Residential - 83	87	31%	22%	23%	18%	8%	4%
Rural Estate - 10	289	8%	90%	8%	87%	0%	2%
Regional Mixed Use - 100	1,182	12%	21%	9%	17%	3%	4%
Suburban Mixed Use - 3	3,336	11%	67%	12%	59%	-1%	7%
Suburban Mixed Use - 6	4,808	37%	31%	36%	25%	0%	6%
Transitional Use - 24	454	32%	30%	29%	27%	3%	3%
Urban Mixed Use - 60	1,011	15%	24%	12%	17%	4%	7%
Water	842	4%	5%	7%	6%	-2%	-1%

ple, a percentage difference in vegetation cover in a Future Land Use category with 1,000 acres of land in Tampa is a lot different than in a category with 10,000 acres (ac). Residential (10 units per ac) occupies more land area (77,096 ac) than all other categories combined (57,147 ac), and the total acreage of tree canopy (37,035 ac) is twice as much as the land area covered by trees for all other Future Land Use categories combined (17,285 ac). One percent (1%) tree canopy in the Residential-10 category is greater than the total land area of tree canopy on 20 of the 25 land uses.

The graph in Figure 28 shows the top twelve Future Land Use categories with the greatest total land area of total vegetation cover. Among this group are four public or quasi-public categories with substantial tree canopy: Environmentally Sensitive Areas (5,857 ac tree canopy); Right-of-way (2,742 ac); Public/Semi-public (733 ac); Recreation and Open Space (686 ac).

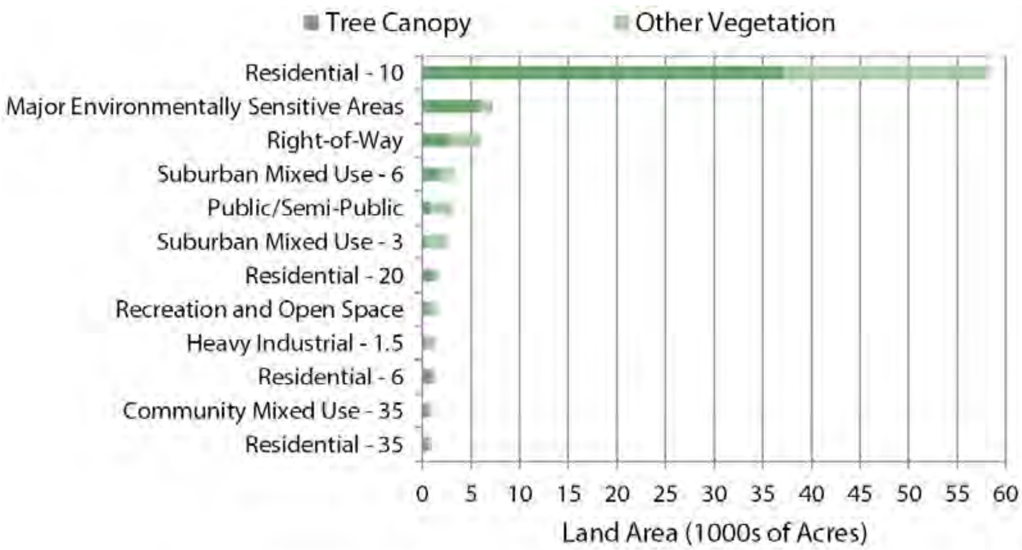


Figure 28. Top 12 Future Land Use categories in terms of acres of vegetation

Zoning and Land Development Code

The City of Tampa Zoning and Land Development Code has three primary purposes: 1) to implement the public purpose and objectives of the Tampa Comprehensive Plan; 2) promote the public health, safety, morals, convenience, comfort, amenities, prosperity and general welfare of the City; and 3) divide the City into districts of such number, shape, characteristics, area, common unity of purpose, adaptability or use as will accomplish the objectives of the Tampa Comprehensive Plan. Development standards are set in the Zoning and Land Development Code.

Table 6 summarizes tree canopy and other vegetation cover by Zoning and Land Development Code category. There is a large amount of variation in the proportion of tree canopy and other vegetation within the City of Tampa categories. Tree canopy cover ranged from a low of 5% (Ybor City – Site Plan Controlled) to a high of 73% (Community Unit). Not surprisingly, the Channel District, Central Business District and Ybor City – Central Commercial Core had the lowest total proportion of vegetation at 20%, 19% and 15%, respectively. Two of the categories lost a large proportion of tree canopy between 2006 and 2011: Community Commercial (-27%) and Multi-Family Residential/MHP (-17%).

The proportion of tree canopy in a Zoning and Land Development Code category may be less important when the total land area is small. The majority of categories comprise less than 1,000 acres of land and less than 500 acres of total vegetation cover. Residential Single-family has by far the most acreage of tree canopy (9,160 ac) and other vegetation (6,422 ac) than other categories. The top 11 (out of 35) categories in terms of land area have 22,294 acres of tree canopy, compared to only 717 acres of tree canopy in the remaining categories. The top two categories, Residential Single-family and Planned Development Alternative, have 50% more tree canopy and total vegetation than all other Zoning and Land Development Code categories combined.

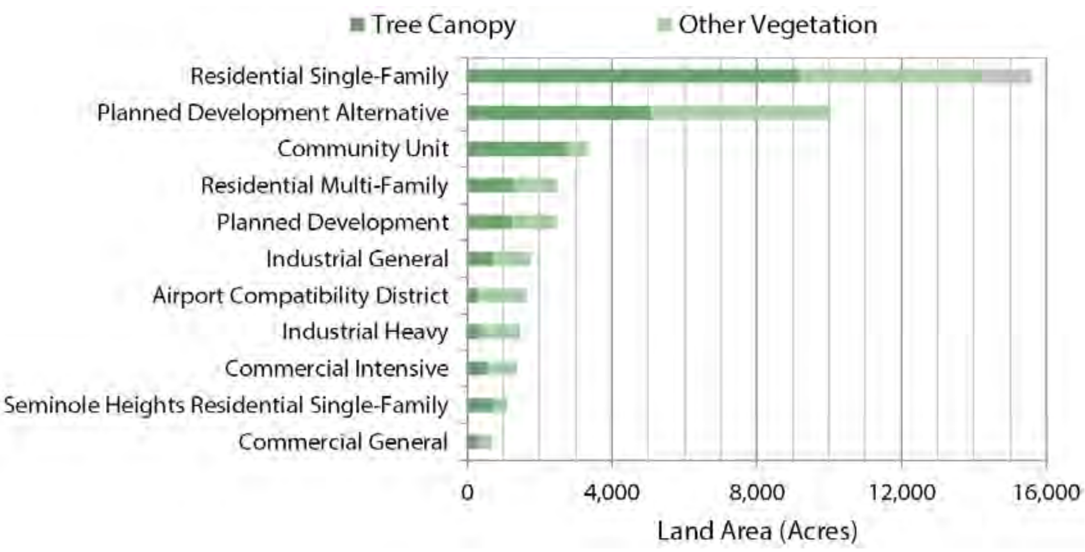


Figure 29. Zoning and Land Development Code categories with more than 500 acres of total vegetation cover

Table 6. Total acres and vegetation cover in each Zoning and Land Development Code category

Zoning & Land Development Code Category	Total Acres	2011		2006		Change 2006-2011	
		Tree Canopy	Other Vegetation	Tree Canopy	Other Vegetation	Tree Canopy	Other Vegetation
Agricultural (A)	378	25%	73%	26%	70%	-1%	3%
Airport Compatibility District (M-AP)	3,005	10%	44%	9%	41%	1%	3%
Central Business District (CBD)	518	8%	11%	5%	9%	3%	1%
Channel District (CD)	131	5%	15%	3%	6%	3%	9%
Commercial General (CG)	2,009	16%	19%	10%	16%	5%	3%
Commercial Intensive (CI)	3,775	14%	22%	10%	19%	4%	4%
Commercial Neighborhood (CN)	89	25%	26%	18%	25%	7%	1%
Community Commercial (CC)	22	52%	30%	79%	18%	-27%	12%
Community Unit (CU)	3,731	73%	16%	75%	14%	-2%	2%
Industrial General (IG)	3,250	22%	33%	21%	28%	1%	5%
Industrial Heavy (IH)	3,773	9%	30%	10%	25%	-1%	5%
Multi-Family Res/MHP (R-3 MH)	59	67%	28%	84%	13%	-17%	15%
Office Professional (OP)	311	15%	20%	11%	16%	4%	4%
Planned Development (PD)	4,720	26%	27%	23%	23%	3%	5%
Planned Development Alternative (PD-A)	13,172	38%	38%	39%	31%	-1%	7%
Residential Multi-Family (RM)	4,167	30%	30%	24%	27%	6%	3%
Residential Office (RO)	257	31%	18%	23%	17%	8%	1%
Residential Single-Family (RS)	22,122	41%	29%	34%	28%	8%	1%
Seminole Heights Commercial General (SH-CG)	106	24%	17%	20%	15%	4%	2%
Sem. Heights Commercial Intensive (SH-CI)	138	13%	13%	10%	10%	3%	3%
Sem. Heights Commercial Neighborhood (SH-CN)	2	30%	16%	21%	20%	9%	-4%
Sem. Heights Planned Development (SH-PD)	3	53%	27%	45%	27%	8%	0%
Sem. Heights Residential Multiple-Family (SH-RM)	79	43%	21%	35%	22%	8%	0%
Sem. Heights Residential Office (SH-RO)	3	45%	22%	44%	15%	1%	7%
Sem. Heights Residential Single-Family (SH-RS)	1,547	46%	26%	41%	24%	5%	2%
University Community District (UC)	805	25%	31%	14%	36%	11%	-5%
Ybor City - Central Commercial Core (YC-1)	74	7%	7%	4%	6%	3%	2%
Ybor City - Community Commercial (YC-6)	90	10%	18%	6%	16%	4%	2%
Ybor City - General Commercial (YC-5)	65	11%	16%	6%	13%	5%	3%
Ybor City - Hillsborough Community College (YC-3)	32	16%	22%	11%	18%	4%	4%
Ybor City - Mixed Use (YC-7)	59	14%	19%	9%	18%	5%	1%
Ybor City - Mixed Use Redevelopment (YC-4)	65	16%	20%	11%	17%	6%	3%
Ybor City - Residential (YC-2)	192	21%	31%	15%	26%	6%	4%
Ybor City - Residential Single-Family (YC-8)	18	20%	43%	14%	27%	6%	16%
Ybor City - Site Plan Controlled (YC-9)	2	5%	29%	5%	22%	0%	7%

Planning Districts

Planning Districts are used to set standards which define the character of development in an area, such as permitted uses, building setbacks and height, or other zoning regulations. City Council retains authority to establish such limitations and regulations as it deems necessary. Tree canopy and other vegetation cover for both 2006 and 2011 is summarized by Planning District in Figure 31. There are large differences between the proportion of tree canopy in the different planning districts. The lowest proportion of tree canopy cover is where Tampa International Airport is located, Westshore TIA. New Tampa has the highest proportion of tree canopy cover (45%) and the highest overall vegetation cover (tree canopy and other vegetation 79%). Tree canopy increased between 2006 and 2011 by greater than 3% in all planning districts except for New Tampa, where the change was minimal.

POSSIBLE URBAN TREE CANOPY

The high vegetation cover is partly explained by the large proportion (37%) of Environmentally Sensitive (i.e., protected) lands in the New Tampa planning district.

The high proportion of other vegetation in all districts suggests that the amount of tree canopy is not necessary constrained by lack of possible planting areas.

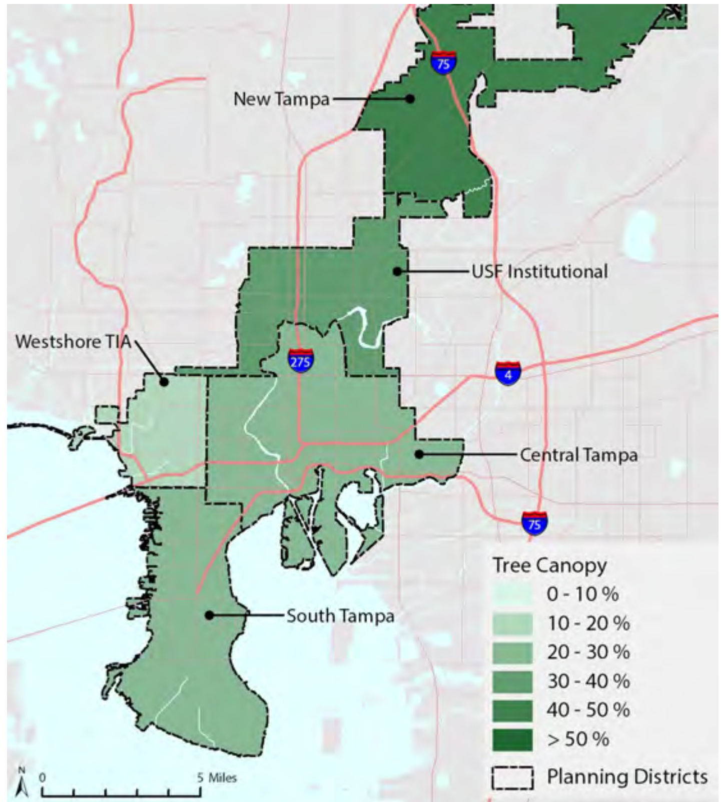


Figure 30. Map of planning districts

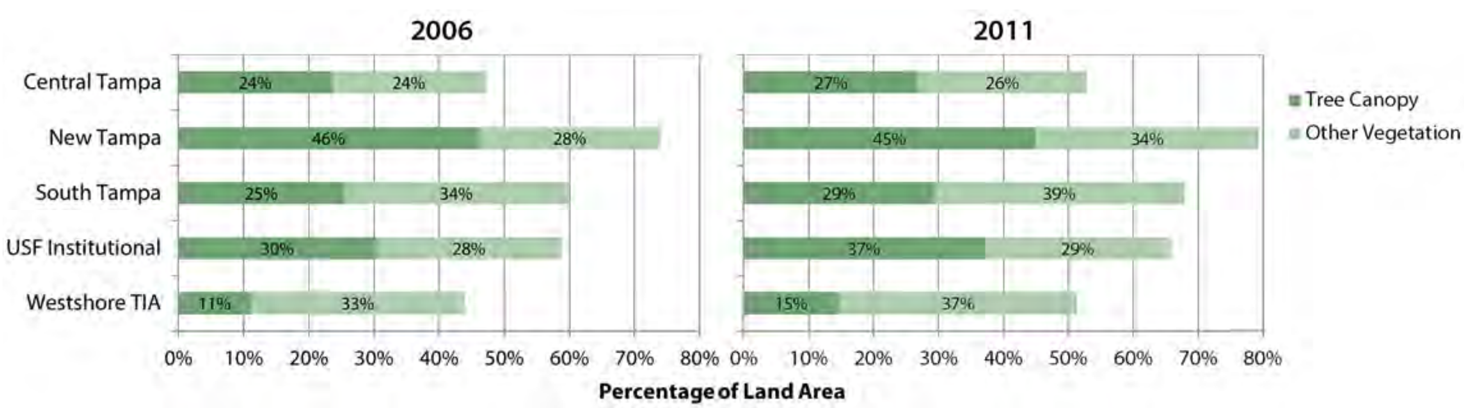


Figure 31. Comparison of Tree Canopy and Other Vegetation by Planning District, 2006 and 2011

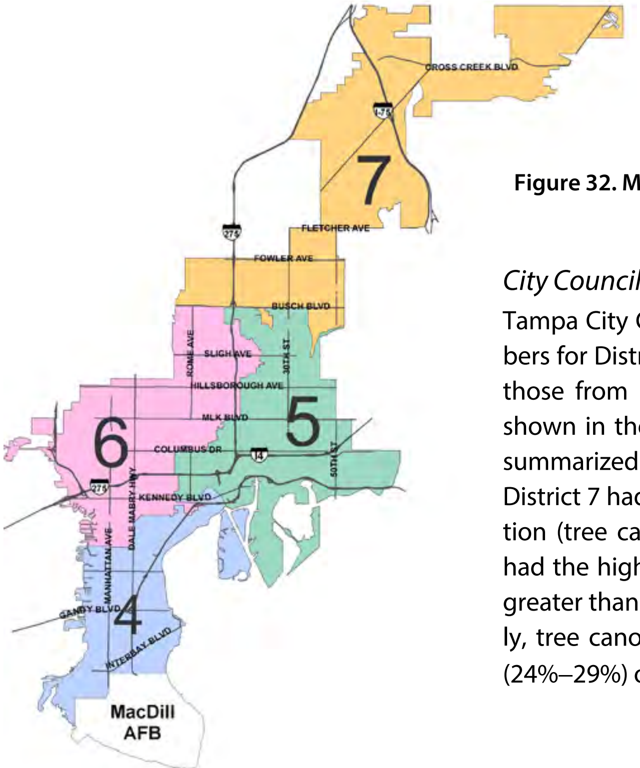


Figure 32. Map of Tampa City Council Districts.

City Council Districts

Tampa City Council is composed of seven Council members. Council members for Districts #1, #2, and #3 are elected at-large (meaning city-wide) and those from Districts #4 through #7 are elected in the individual districts shown in the map. Tree canopy and other vegetation in 2006 and 2011 is summarized by City Council District in Figure 33. In both 2011 and 2006, District 7 had the highest percentage of tree canopy cover and total vegetation (tree canopy plus other vegetation) than all other Districts. District 4 had the highest proportion of other vegetation. All Districts in the city had greater than 25% tree canopy and greater than 27% other vegetation. Finally, tree canopy increased slightly in all Districts, and the greatest increase (24%–29%) occurred in District 6.

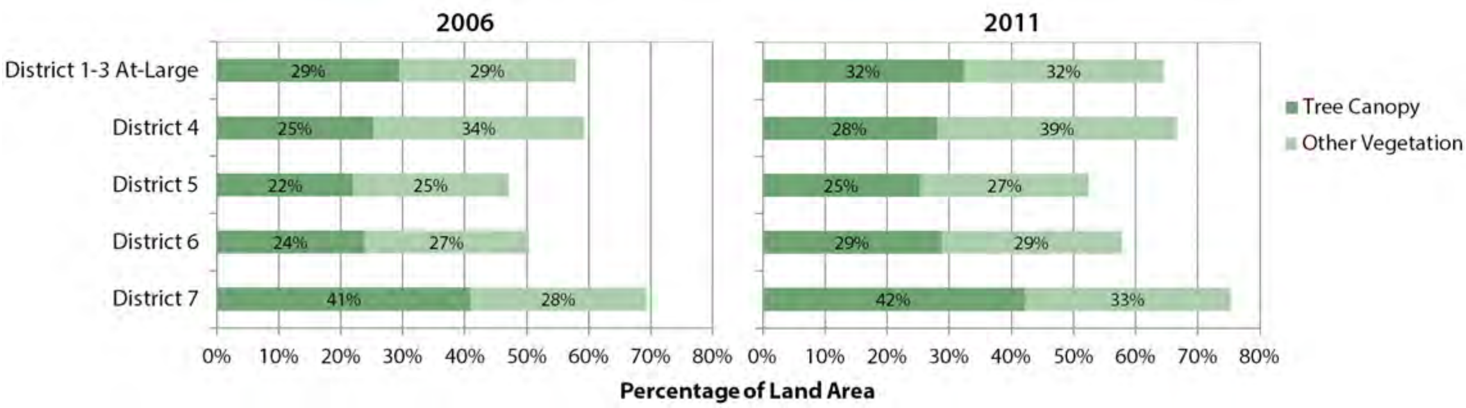


Figure 33. Comparison of Tree Canopy and Other Vegetation by City Council District, 2006 and 2011.

Neighborhood Associations

The City of Tampa maintains a neighborhood registry that is the official list of active neighborhood associations. A neighborhood is defined as an integrated area related to a larger community of which it is a part, and may consist of residential districts, a school or schools, shopping facilities, religious buildings and open spaces. Neighborhood associations are formed by residents and the boundaries of these neighborhoods are defined by the association members, based on approval by the City of Tampa's Neighborhood Services Department. The summary of tree canopy by neighborhood was created using the neighborhood association boundaries provided by the City.

Table 7. The top 10 neighborhoods in terms of total acreage of vegetation.

Neighborhood Association	Tree Canopy	Other Vegetation
Hunter's Green Community	428	361
Terrace Park	450	552
Lowry Park Central	667	372
Palmetto Beach	330	710
Gandy/Sun Bay South	530	796
East Tampa Business & Civic	704	660
Old Seminole Heights	938	512
West Meadows	1,978	1,495
Tampa Palms	3,699	1,127
New Tampa	8,738	6,530
Totals	**18,462**	**13,115**

The proportion of neighborhood land area covered by tree canopy (2011) ranged from 6% in the Channel District and 7% in the Tampa Downtown Partnership to a high of 65% in Culbreath Bayou and 64% in Tampa Palms. Although the proportion of tree canopy decreased between 2006 and 2011 in six neighborhoods, the amount of loss (less than 2%) was so close to the measurement error that it would be more appropriate to label this as no change. In contrast, more than half of the neighborhoods realized a gain in tree canopy of 5% or more. The amount of other vegetation, or land available for potential tree planting, is equal to the existing proportion of tree canopy in 31 of the 92 neighborhoods listed.

The total area covered by tree canopy and other vegetation is closely related to the total land area within the neighborhood. The three largest neighborhoods (i.e., New Tampa, Tampa Palms and West Meadows) have more acres of tree canopy than all other neighborhoods combined. Table 7 shows the top ten neighborhoods in terms of total acreage of vegetation.

Table 8. Summary of tree canopy analysis by neighborhood

Neighborhood Association (short name)	Total Acres	2011		2006		Change 2006-2011	
		Tree Canopy	Other Vegetation	Tree Canopy	Other Vegetation	Tree Canopy	Other Vegetation
Ballast Point	745	48%	24%	42%	20%	6%	4%
Bayshore Beautiful	617	51%	19%	40%	21%	11%	-2%
Bayshore Gardens	129	37%	18%	33%	15%	4%	4%
Bayside West	620	27%	32%	16%	26%	11%	5%
Beach Park	557	49%	18%	37%	20%	13%	-2%
Beach Park Isles	26	25%	21%	18%	14%	7%	7%
Bel Mar Shores	79	37%	22%	25%	22%	12%	1%
Belmar Gardens	165	47%	22%	30%	27%	16%	-5%
Bon Air	81	36%	24%	25%	22%	11%	3%
Bowman Heights	54	31%	23%	28%	21%	3%	1%
Carver City / Lincoln Gardens	554	15%	31%	9%	28%	7%	3%
Channel District	163	6%	13%	3%	6%	3%	7%
College Hill	67	36%	25%	26%	28%	10%	-3%
Cory Lake Isles	590	18%	34%	19%	18%	0%	16%
Courier City / Oscawana	160	23%	14%	19%	11%	4%	3%
Culbreath Bayou	40	65%	14%	55%	15%	10%	0%
Culbreath Heights	97	33%	30%	20%	26%	13%	4%
Culbreath Isles	89	39%	22%	30%	17%	9%	5%
Davis Islands Civic Association	873	30%	31%	29%	26%	0%	5%
Drew Park	828	18%	28%	11%	23%	7%	5%
East Seminole Heights	322	31%	26%	23%	26%	8%	0%
East Tampa Business & Civic	2,371	30%	28%	23%	28%	7%	-1%
East Ybor Historic	540	14%	25%	13%	21%	2%	5%
Eastern Heights	291	28%	46%	21%	48%	7%	-3%
Easton Park	520	9%	64%	10%	47%	-1%	17%
Fair Oaks/Manhattan Manor	659	22%	30%	14%	27%	8%	4%

Table 8 (continued). Summary of tree canopy analysis by neighborhood

Neighborhood Association (short name)	Total Acres	2011		2006		Change 2006-2011	
		Tree Canopy	Other Vegetation	Tree Canopy	Other Vegetation	Tree Canopy	Other Vegetation
Florence Villa/ Beasley/Oak Park	162	18%	30%	15%	27%	2%	3%
Forest Hills Community	286	40%	32%	30%	34%	10%	-1%
Forest Hills Neighborhood	505	38%	39%	33%	39%	5%	0%
Gandy/Sun Bay South	2,239	24%	36%	15%	28%	9%	7%
Golfview	340	44%	31%	43%	25%	2%	6%
Grant Park	158	31%	31%	20%	33%	11%	-2%
Gray Gables	46	42%	20%	32%	18%	10%	2%
Hampton Terrace	162	49%	20%	42%	23%	8%	-3%
Harbour Island	186	25%	17%	25%	8%	0%	8%
Heritage Isles	763	34%	44%	36%	31%	-2%	13%
Highland Pines	447	21%	31%	19%	30%	3%	1%
Historic Hyde Park	207	41%	17%	36%	16%	5%	2%
Historic Ybor	405	11%	18%	7%	16%	4%	2%
Hunter's Green Community	1,131	38%	32%	36%	23%	2%	9%
Hyde Park North	186	25%	16%	20%	14%	6%	1%
Hyde Park Preservation	142	44%	15%	44%	12%	1%	4%
Interbay	405	33%	43%	25%	41%	9%	2%
Live Oaks Square	243	40%	27%	30%	30%	10%	-3%
Lowry Park Central	1,463	46%	25%	39%	25%	7%	0%
Macfarlane Park	1,000	22%	30%	16%	28%	7%	1%
The Marina Club Of Tampa	22	9%	25%	6%	17%	3%	8%
New Suburb Beautiful	82	56%	15%	55%	11%	1%	4%
New Tampa	19,332	45%	34%	46%	28%	-1%	6%
North Bon Air	174	24%	30%	12%	26%	12%	3%
North Hyde Park	308	20%	24%	15%	19%	5%	5%
North Tampa Community	693	34%	29%	25%	27%	9%	3%
Northeast Community	284	38%	22%	30%	25%	8%	-3%
Northview Hills	86	23%	37%	18%	37%	5%	0%
Oakford Park	244	29%	26%	19%	25%	10%	2%
Old Seminole Heights	2,090	45%	24%	40%	23%	5%	1%
Old West Tampa	239	25%	24%	20%	21%	5%	2%
Palma Ceia	445	40%	21%	30%	20%	10%	1%
Palma Ceia Pines	280	29%	18%	21%	14%	8%	3%
Palma Ceia West	244	34%	24%	23%	22%	11%	3%
Palmetto Beach	2,348	14%	30%	16%	25%	-2%	6%
Parkland Estates	171	43%	19%	40%	15%	3%	4%
Plaza Terrace	240	27%	26%	24%	23%	3%	3%
Port Tampa City	790	33%	44%	28%	42%	5%	3%
Rainbow Heights	164	38%	29%	27%	31%	10%	-2%
Ridgewood Park	83	39%	20%	35%	19%	3%	1%
Riverbend	442	46%	26%	43%	24%	3%	2%
Rivergrove	121	43%	23%	38%	21%	4%	1%

Table 8 (continued). Summary of tree canopy analysis by neighborhood

Neighborhood Association (short name)	Total Acres	2011		2006		Change 2006-2011	
		Tree Canopy	Other Vegetation	Tree Canopy	Other Vegetation	Tree Canopy	Other Vegetation
Riverside Heights	446	40%	27%	39%	25%	2%	2%
South Seminole Heights	387	42%	22%	40%	20%	3%	1%
Southeast Seminole Heights	427	45%	22%	36%	23%	9%	-1%
Stadium Area	329	24%	25%	21%	22%	4%	4%
Stoney Point	17	42%	18%	28%	18%	14%	-1%
Sulphur Springs	639	42%	25%	36%	22%	6%	3%
Sunset Park	513	48%	21%	37%	20%	11%	1%
Swann Estates	244	40%	23%	27%	22%	13%	1%
Tampa Downtown Partnership	354	7%	11%	5%	9%	3%	1%
Tampa Heights	926	31%	26%	25%	25%	6%	1%
Tampa Palms	5,742	64%	20%	67%	15%	-2%	5%
Temple Crest	1,015	37%	26%	32%	25%	5%	1%
Terrace Park	1,682	27%	33%	20%	32%	7%	1%
University Square	655	34%	30%	25%	28%	9%	2%
Uptown Council	167	9%	11%	7%	9%	2%	2%
Virginia Park	579	44%	23%	30%	23%	14%	0%
VM Ybor	266	30%	21%	24%	20%	6%	1%
Wellswood	600	32%	29%	32%	24%	0%	4%
West Meadows	4,624	43%	32%	45%	25%	-2%	8%
West Riverfront	135	22%	25%	19%	23%	3%	2%
West Riverside Heights	124	32%	21%	29%	18%	3%	2%
Westshore Palms	162	28%	33%	19%	24%	9%	9%
Woodland Terrace	120	49%	28%	40%	29%	9%	-1%
Ybor Heights	211	34%	22%	29%	21%	6%	0%

The Value of Tampa's Urban Forest

The urban forest is a valuable resource for many reasons. It provides vegetative and wildlife biodiversity and habitat, and performs many ecological functions. Some of these relate to topics beyond the scope of this report, such as hydrological flow and biogeochemistry, but none are separate from their cumulative beneficial effects on the health and well-being of humans. As we will discuss in the following sections, the urban forest can contribute to the reduction of energy use, greenhouse gas emissions, and atmospheric pollutants in many ways.

Energy Conservation

Trees can reduce the need to heat or cool a building. This reduction in energy use saves consumers money, reduces the amount of carbon emitted into the atmosphere by power plants that provide this energy, and decreases the demand for non-renewable fossil fuels, a global concern today. Trees near buildings can provide shade during the day, helping to reduce temperatures of buildings and the energy required to cool them. The residential use energy conserved by trees in Tampa's urban forest was calculated. Trees that were 20 feet tall and less than 60 feet from a residential building that was less than 3 stories tall were considered to have an influence on energy consumption (increase or decrease) (McPherson and Simpson 1999). Trees and residential buildings that met these criteria were located, identified, measured (height and crown area), and mapped on all inventory plots. Data was input into the i-Tree Eco model to calculate an energy conservation estimate in megawatt hours (MWh) and million British thermal units (MBtu). The total amount of carbon emissions avoided due to a decrease in energy production was estimated. Energy conservation estimates were calculated only for residential homes in the Residential land use category, utilizing the average amount of energy consumed by residential buildings in Tampa, 2006 and 2011(McPherson and Simpson 1999). In 2011 rates were provided as part of the i-Tree Eco analysis and were calculated with Florida statewide averages of $117.60/MWh and $17.72/MBtu. The 2006 values have been updated to reflect the averages of value per MWh and MBtu.

The total amount of energy conserved in cooling residential buildings was 39,894 MWhs with an associated value of $4.7 million dollars (Table 8). In addition, the amount of energy expended by increasing the need to heat a building due to shading was approximately 1,333 MBtus, at an annual cost to Tampa's citizens of ~$24,000 citywide. The total amount of carbon emissions avoided from energy production by power plants as a result of conserving energy was 8,152 tons with an associated value of ~$580,000. In 2011, trees saved Tampa residents a total of $5.2 million dollars.

Table 9. Comparison of energy conserved and associated dollar values* due to the proximity of residential buildings to trees in 2006 and 2011 (note: negative numbers indicate an increased energy use or carbon emission and associated costs)

	Heating		Cooling		Total	
	2006	**2011**	**2006**	**2011**	**2006**	**2011**
Energy Conserved:						
MBtu[a]	(8,301)	(1,333)	n/a	n/a	(8,301)	(1,333)
MWh[b]	(406)	(104)	40,478	39,998	40,072	39,894
Carbon avoided	(209)	(42)	8,250	8,152	8,040	8,110
US Dollars Saved:						
MBtu	($147,096)	($23,621)	n/a	n/a	($147,096)	($23,621)
MWh	($47,746)	($12,230)	$4,760,213	$4,703,765	$4,712,467	$4,691,534
Carbon avoided	($14,915)	($2,983)	$587,494	$580,508	$572,579	$577,525
				Total Savings:	**$5,137,950**	**$5,245,438**

[a] Million British Thermal Units
[b] Megawatt-hours

*Savings calculated in 2011 with Florida statewide averages of $117.60/MWh and $17.72/Mbtu and $71/short ton carbon
Savings calculated in 2006 with adjusted 2011 rates listed above

Air Pollution Removal

Some of the most serious air pollutants in an urban environment are carbon monoxide (CO), nitrogen dioxide (NO_2), ground-level ozone (O_3), coarse particulate matter (PM10), fine particulate matter (PM2.5) and sulfur dioxide (SO_2). Carbon monoxide is a toxic gas that enters the atmosphere through the combustion of fossil fuels (e.g. automobiles and power plants). Nitrogen dioxide is a respiratory irritant and can cause serious health problems. It is also an ingredient in the formation of ground-level ozone (smog). Smog is created in the presence of sunlight, when NO^2 and other volatile organic compounds react with one another. This reaction rate increases as temperatures increase.

Trees can play a vital role in lowering temperatures in urban areas and thus reduce the rate of ground-level ozone formation (Nowak and Dwyer 2007). Particulate matter 2.5–10 micrometers in size (PM10) is associated with serious respiratory issues. PM10 consists of suspended microscopic droplets (liquid or solid) that are small enough to be inhaled and eventually penetrate into the lungs. Trees intercept particulate matter on their leaves. New to the 2011 analysis are numbers relating the interception of fine particulate matter (less than 2.5 micrometers, PM2.5), even smaller particles than PM10 which are able to penetrate deeply into the lungs and are associated with numerous deleterious health effects.

Trees also remove gaseous pollutants from the atmosphere through uptake via the stomata on their leaves. Such pollutants include carbon monoxide (CO), nitrogen dioxide (NO_2), ozone (O_3), and sulfur dioxide (SO_2).

Reanalysis of the 2006 data generated adjusted estimates of approximately 8% fewer tons of pollutants removed by trees and shrubs, but new monetary valuations indicate a nearly 70% increase in the estimated value of those pollutants removed in 2006 (Table 1). In 2011, the model estimated that Tampa's trees and shrubs removed 1,163 tons of pollution with an estimated value of

Table 10. Tonnage and associated dollar values for pollutants removed by trees and shrubs, 2006 and 2011

		2006		2011	
	Pollutant	**U.S. short ton**	**U.S. Dollars**	**U.S. short ton**	**U.S. Dollars**
Trees	**CO**	58	$ 65,823	57	$ 64,909
	NO_2	43	20,297	41	19,648
	O_3	444	1,528,844	429	1,478,051
	PM10	204	3,207,200	197	3,067,562
	PM2.5	12	2,182,979	11	2,075,913
	SO_2	65	13,920	64	13,535
Shrubs	**CO**	28	$ 31,740	23	$ 25,696
	NO_2	23	10,760	19	9,081
	O_3	232	799,671	194	668,732
	PM10	109	1,710,859	93	1,458,110
	PM2.5	7	1,212,774	6	1,068,465
	SO_2	34	7,168	28	5,963
	Total	**1,258**	**$ 10,791,972**	**1,163**	**$ 9,940,518**

$9.9 million dollars (Table 10). The i-Tree Eco model calculates the amount of pollution eliminated from the atmosphere based on 2007 Environmental Protection Agency (EPA) air pollution and weather monitors in Tampa and assumes pollution reduction does not happen during rain events. Value estimates for CO and PM10 were calculated with guidelines suggested by Murray et al. (1994) and Ottinger et al. (1990). Value estimates for O_3, SO_2, and NO_2 were calculated based on the U.S. EPA Environmental Benefits Mapping and Analysis Program (BenMAP) model (US EPA 2012).

New to analysis in 2011 are data from the BenMAP model, which estimates the reduction in health impacts and the associated economic benefits derived from changes in air quality. Estimates of pollutant reduction from the i-Tree analysis entered into the BenMAP model yield estimates of potential savings in health care costs (e.g. reduced incidence of respiratory illness and related hospital visits or days lost from work/school) associated with pollutants removed by Tampa's forest trees and shrubs. It is estimated that Tampa's trees and shrubs, by reducing pollutants, save the population an estimated $5.4 million in airborne pollutant-related health care costs (Table 11).

Table 11. Estimated economic benefits of reduced health impacts from airborne pollutant reduction by trees and shrubs, 2011

	Value ($/Year)			
2011	**NO_2**	**O_3**	**PM2.5**	**SO_2**
Tree	$19,648	$1,478,051	$2,075,913	$13,535
Shrub	$9,018	$672,303	$1,095,439	$5,947
Subtotal	$28,665	$2,150,354	$3,171,352	$19,482
Total	**$5,369,853**			

Forest Health and Carbon Storage

Carbon dioxide (CO_2) is a greenhouse gas but it is also used by trees in the process of photosynthesis. As trees grow they incorporate atmospheric carbon into their tissue which is then considered to be sequestered or locked up for the life of the tree. Carbon sequestration rates vary by species but, in general, healthier and more vigorous trees tend to sequester carbon at higher rates than unhealthy trees. The 2011 analysis indicates that approximately 52% of the trees are considered to be in excellent or good health, 17% are in fair health, and the remaining 31% are in poor condition or lower.

Tree health was evaluated by land use. The i-Tree methodology to determine estimates of tree health is based on canopy condition assessments. These estimates of health do not reflect structural integrity. The highest percentage of healthy trees (defined as excellent and good categories) in Tampa are those that were under some degree of public management: Rights-of-way (91% healthy), and Public Communications/Utilities (94%) (Figure 34). Approximately 62–68% of trees in Vacant, Residential, and Industrial land uses were in excellent or good health. A greater percentage of trees (20%) in Industrial areas were in fair condition (20%) than were those in Vacant and Residential areas (14–15%). In the land use we consider a natural benchmark (Recreational/Open Space/Natural), 69% of the trees were classified in excellent or good health and 19% in fair condition. The lowest percentage of healthy trees occurs on Public/Quasi-public/Institutions lands and the highest percentage of unhealthy or dead trees occurred on Commercial lands.

The amount of carbon that a tree stores fluctuates as it grows (increases), declines (decreases) or dies (ceases). The total amount of carbon currently stored by the trees of Tampa's urban forest is estimated to be 619,000 tons with a current value of $44.1 million (Figure 35). The value of carbon (stored and sequestered) is calculated as $71 per short ton of carbon (IWG SCC 2010), an increase from $20.32/ton used in 2006 (Fankhauser, 1994)[7]. In Tampa, 33% of the stored carbon and 20% of the sequestered carbon is in live oaks, which are known to live up to 300 years. An additional 37% of carbon is stored in Darlington oak (*Quercus hemisphaerica*) and laurel oak (*Quercus laurifolia*) combined.

[7]The current valuation of carbon at ~$71/short ton is based on estimates determined by the US Interagency Working Group on Social Cost of Carbon (2010) .

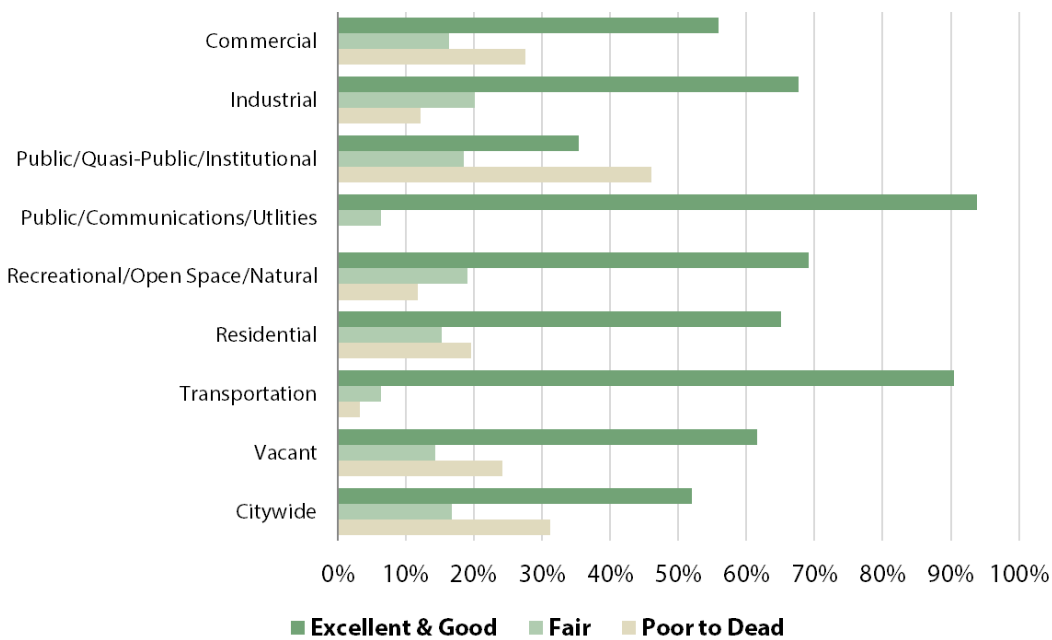


Figure 34. Relative tree health condition classes by designated land use, 2011

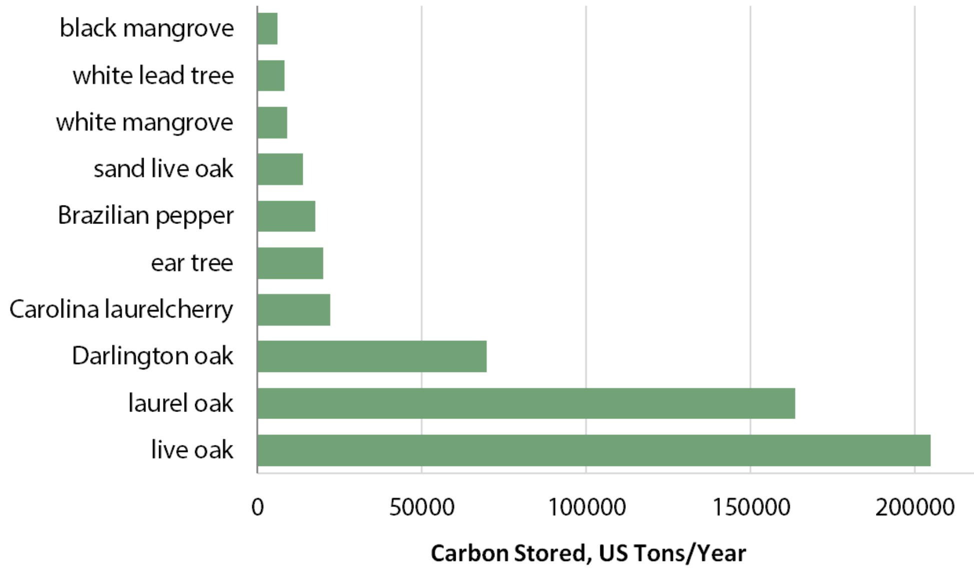


Figure 35. Amount of carbon (C) stored by species, 2011

The i-Tree model estimates that the amount of gross carbon sequestered (i.e., removed) from the atmosphere in 2011 was approximately 52,600 tons with a value of $3.75 million (Table 14). The total net carbon sequestered annually by Tampa's urban forest is about 47,700 tons. Net carbon sequestration is the amount of carbon sequestered less the estimated amount of carbon emitted as dead trees decay. The urban forest of Tampa is a carbon sink (stores more carbon than it emits). The urban forest only reduces citywide carbon emissions by approximately 1% per year, approximately the amount of carbon emitted in 3.7 days by the population of Tampa.

The rate of carbon sequestration by an individual tree is a function of its species, its size, and its condition (vigor). Trees greater than 30 inches in DBH account for approximately 52% of the carbon stored, but the rate at which carbon is sequestered is greater in the smaller diameter trees of 1–12 inches DBH (47% of total carbon sequestered annually) (Figure 36). The tree species with the highest rate of carbon sequestration in Tampa is live oak, which is also the species that stores the greatest amount of carbon (Figures 35 and 37).

Table 12. Change in tree health condition by designated land use, 2006–2011.

	% Exc & Good			% Fair			% Poor–Dead		
	2006	2011	Change	2006	2011	Change	2006	2011	Change
Commercial	50.0	55.9	12%	17.2	16.4	5%	32.8	27.6	-19%
Industrial	28.9	67.7	134%	30.8	20.1	53%	40.4	12.2	-231%
Public/Quasi-Pub	95.9	35.4	-63%	1.4	18.5	-92%	2.7	46.0	94%
Public/Utilities	80.5	93.8	17%	13.9	6.3	121%	5.6	0.0	-100%
Rec/Open/Nat	41.2	69.2	68%	21.3	19.1	12%	37.4	11.7	-220%
Residential	50.8	65.1	28%	31.3	15.2	106%	17.8	19.6	9%
Right of Way	95.3	90.5	-5%	2.8	6.3	-56%	1.9	3.2	41%
Vacant	18.1	61.6	240%	8.5	14.3	-41%	73.4	24.2	-203%
Tampa	69.4	52.0	-25%	10.9	16.8	-35%	19.7	31.2	37%

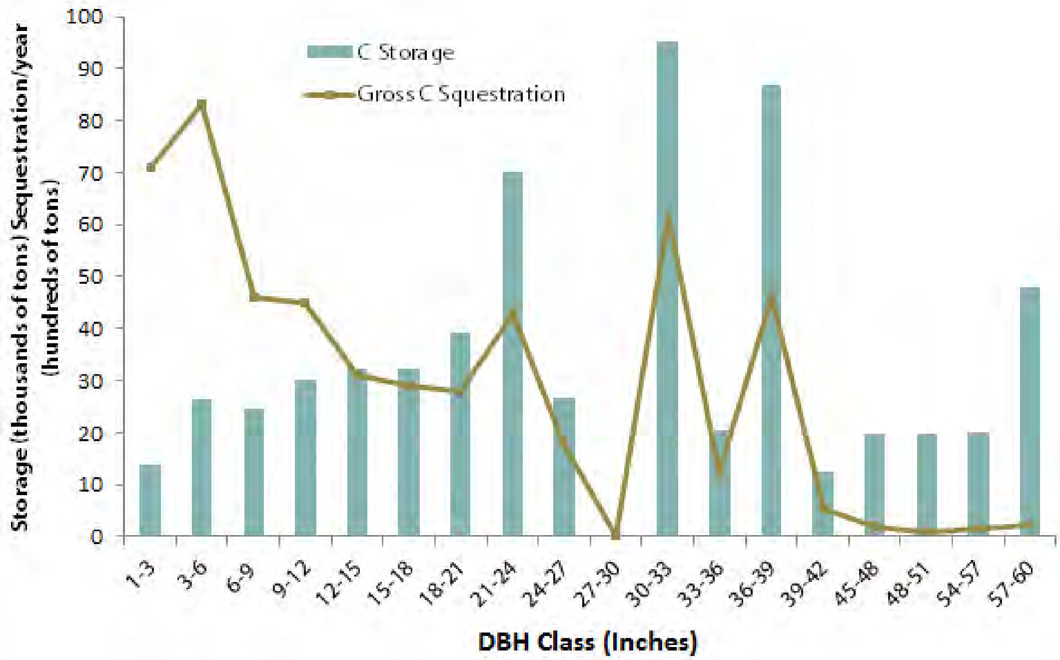


Figure 36. Carbon (C) stored and annual carbon sequestered by diameter class for trees, 2011

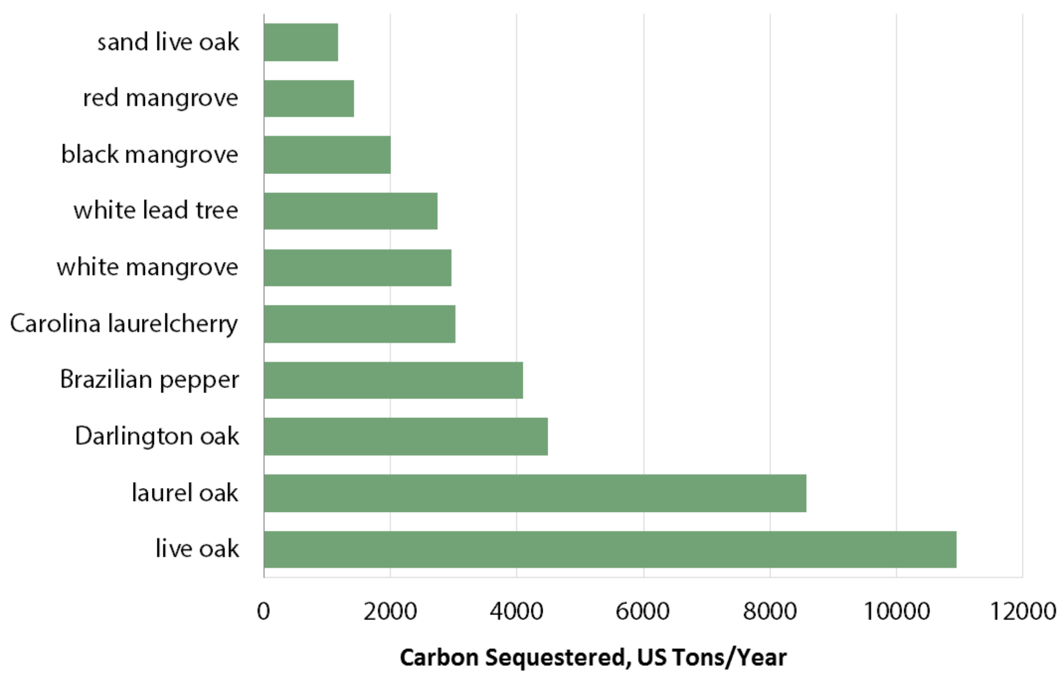


Figure 37. Annual rate of carbon (C) sequestered by species, 2011

Damage from tornado that touched-down in April 2011 along Interbay Boulevard in Tampa.

Compensatory Value

The compensatory value is an estimate of the amount of money it would cost to replace a tree with a similar species if it were to be removed (Nowak et al. 2002).

The estimated compensatory value of trees in Tampa's urban forest is $1.8 billion dollars. This value was calculated using the industry standard methodology developed by the Council of Tree and Landscape Appraisers. A compensatory value was estimated for all tree species (except palms[8]) that occurred in the 2011 inventory, including those considered to be problematic (e.g. Brazilian pepper). Initially it seemed logical to remove these trees from the appraised value but because they are part of Tampa's urban forest, there will be a cost associated with replacing them. Hence it was concluded that the estimate of the compensatory value would represent all trees inventoried in this study.

Rainfall Interception

Trees influence urban hydrology by improving water quality through the interception of pollution and the reduction of stormwater flows. One study found that for each 5% increase in tree cover, stormwater flow is reduced by 2% (Coder 1996). New to the 2011 analysis is the calculation of annual savings in stormwater control costs associated with the estimated interception of precipitation by the trees of Tampa's forest. In 2011 it is estimated that rainfall interception from trees in the Tampa forest saved the city approximately $11 million in stormwater control costs (Table 13).

Rainfall interception is calculated using the estimated number of trees and their associated leaf area. Cabbage palm, while representing only 5% of the overall estimated population, accounts for nearly one fifth (18%) of the total estimated rainfall interception and savings in stormwater control costs. Live oak trees, with their broad canopies, account for 17% of the estimated rainfall interception and savings. The ten species with the greatest estimated leaf areas account for 73% of all estimated interception and savings (Figure 38).

[8] Compensatory values are not calculated for palm species in the i-Tree Eco model.

Table 13. Estimated annual savings of stormwater-related costs from rainfall interception by trees, 2011

Land Use	Rainfall Interception (ft^3/yr)	Rainfall Interception Value ($)
Agricultural	43,141	$2,890
Commercial	11,140,491	$746,413
Industrial	10,981,972	$735,792
Public/Quasi-public	25,987,121	$1,741,137
Public Utilites	2,043,694	$136,928
Recreation/Open Space/Natural	7,336,029	$491,514
Residential	73,433,533	$4,920,047
Transportation	17,061,887	$1,143,146
Vacant	14,363,046	$962,324
Total	**162,390,915**	**$10,880,191**

Note: Rainfall interception is based on a value of $0.067/$ft^3$

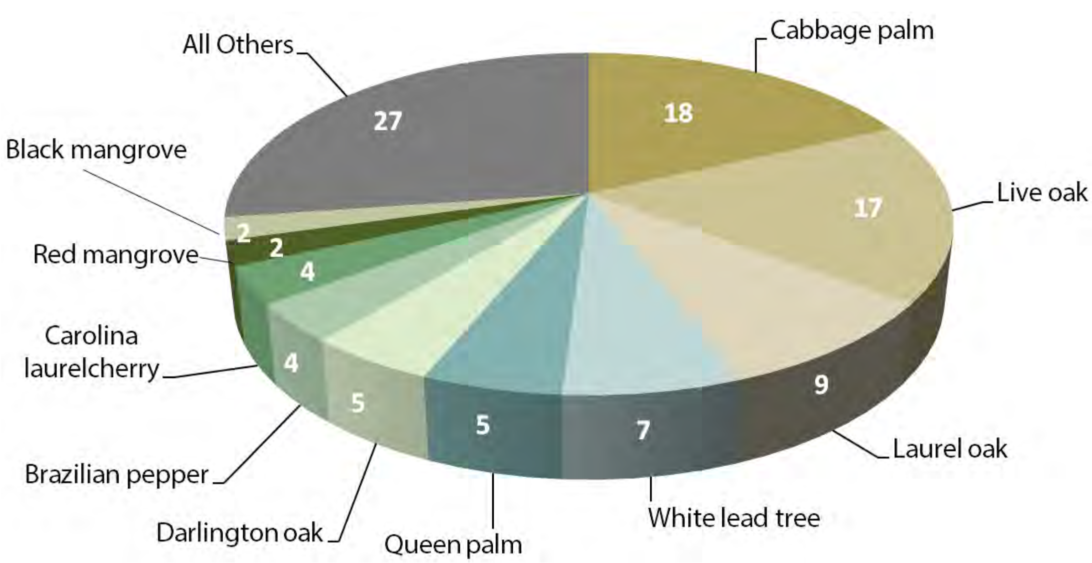


Figure 38. Percent rainfall interception by species, 2011

Economic Value of Ecosystem Services

By establishing economic values for the ecological functions of Tampa's urban forest, managers and citizens can begin to see that there are tangible benefits to investing in the management of this asset. In 2011 this forest had an economic value in excess of $1.8 billion dollars (Table 14). The annual value[9] for 2011 is $34.6 million dollars.

[9] Pollution Removal + Gross Carbon Sequestration + Value of Energy Conservation + Rainfall Interception + Reduced Health Impacts

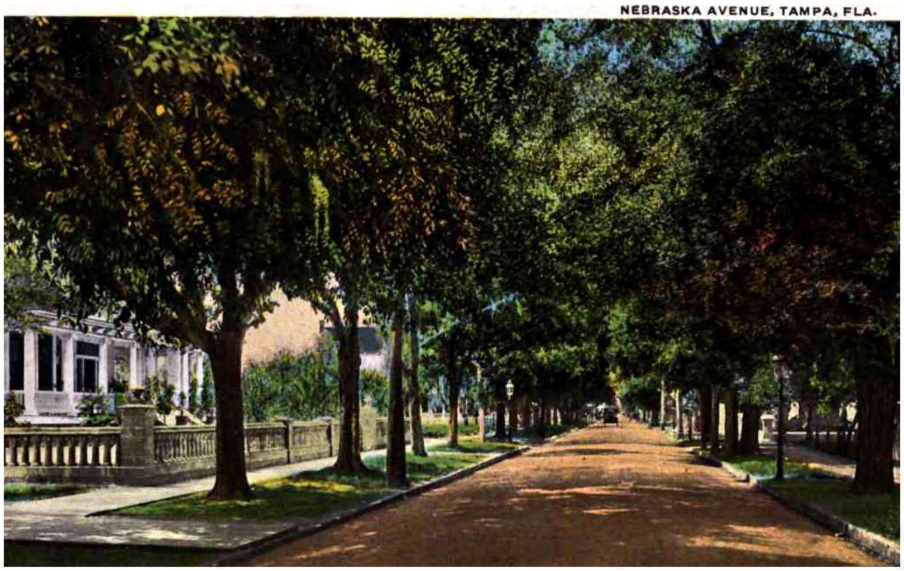
Table 14. Comparison of summaries of Tampa's Urban Forest and associated functional values in sampling years 2006 and 2011

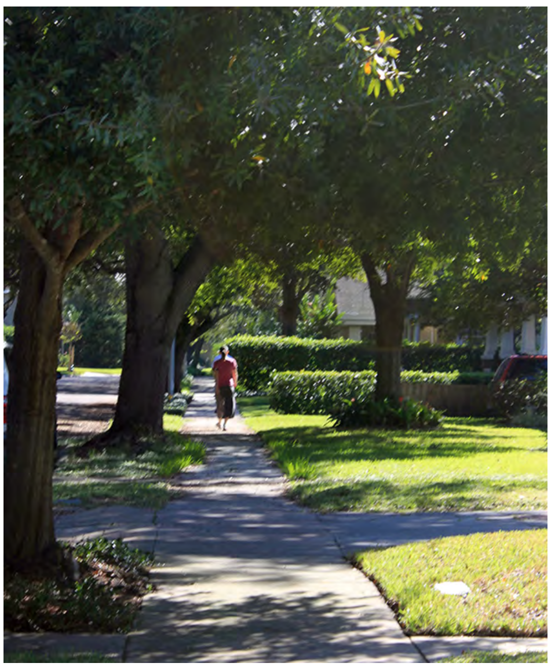
Feature	2006	2011
Number of Trees	7,817,000	8,677,000
Compensatory Value	$1.6 billion	$1.8 billion
Carbon Storage	525,000 tons ($37.4 million)*	619,000 tons ($44.1 million)*
Pollution Removal	1,258 tons/year ($10.7 million/year)**	1,163 tons/year ($9.9 million/year)**
Gross Carbon Sequestration	48,000 tons/year ($3.4 million/year)*	52,600 tons/year (3.7 million/year)*
Value of Energy Conservation	$4.6 million/year	$4.7 million/year
Rainfall Interception	n/a	$10.9 million/year
Reduced Health Impacts	n/a	$5.4 million/year

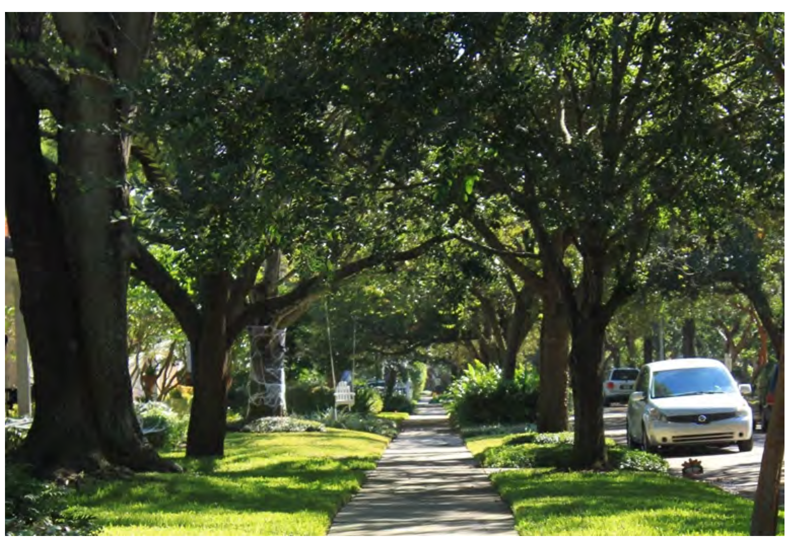
*Value for carbon estimated at $71.2/US short ton.

**Pollution removal value is calculated based on the prices of $1,136 per ton (carbon monoxide), $15,565 per ton (PM10). Ozone, sulfur dioxide, nitrogen dioxide and particulate matter less than 2.5 microns are calculated based on US EPA BenMAP model.

Energy savings values calculated by $117.6/MWh and $17.72/MBtu







Top image: Nebraska Avenue, ca. 1920. Hampton Dunn Collection of Florida Postcards. Other images: Street and sidewalk photographs from 2013.

Appendices

Appendix A: Land Use Related to Ecological Assessment

In an effort to represent the City's existing land use categories accurately, the i-Tree model used the land uses confirmed in the field by the forest survey team. Land use category descriptions used for all field plots and i-Tree model results are given below. These categories are based on existing land use that was observed in the field. These categories differ slightly from the future land use categories used within the tree canopy cover section of this report.

Land Use Category	Definition
Agricultural	Pasture, crop land, orchards, feed lots, fish farms, poultry houses, and other agricultural usage
Commercial	All commercial land uses including: stores, hotels/motels, night clubs, restaurants, entertainment venues, office buildings, malls, markets, mixed-use, and parking lots
Industrial	Manufacturing, warehouses and storage, mining, packing plants, and food processing
Public / Quasi-public / Institutions	Hospitals, libraries, fire/police stations, government offices, schools, courts, military, club/union halls, and churches
Public Communications / Utilities	Utility lands and sewage/waste treatment
Recreational / Open Space / Natural	Timber lands, golf courses, forests, and park lands
Residential	Single and multi-family residences, mobile home parks, condos, private retirement homes, and institutional housing
Right-of-way / Transportation	Right-of-way areas associated with roads, railroads, marinas, and transit terminals
Unknown	Anything not defined in these descriptions
Vacant	Abandoned/unused commercial, institutional, and industrial lands, and non-agricultural acreage
Water	An area that permanently holds water

Appendix B: Ecological Assessment Species-Level Results

Tree species identified in Tampa's urban forest:

a Percent of leaf area
b Percent of tree population + percent of leaf area
c Native, Exotic (non-native), and Invasive status of tree species

Common Name	Scientific Name	% Trees	% LA[a]	IV[b]	N, E, I[c]
American elm	*Ulmus americana*	0.2	1.4	1.7	N
American holly	*Ilex opaca*	0.1	0.0	0.1	N
American sycamore	*Platanus occidentalis*	0.1	0.8	0.9	N
apamate	*Tabebuia rosea*	0.3	0.0	0.3	E
areca palm	*Dypsis lutescens*	0.0	0.4	0.4	E
avocado	*Persea americana*	0.1	0.0	0.1	E
baldcypress	*Taxodium distichum*	0.0	0.2	0.2	N
Benjamin fig	*Ficus benjamina*	0.1	0.1	0.2	E
black cherry	*Prunus serotina*	0.0	0.0	0.0	N
black mangrove	*Avicennia germinans*	6.8	2.1	9.0	N
Brazilian pepper	*Schinus terebinthifolius*	16.6	3.7	20.3	E, I
button bush	*Cephalanthus occidentalis*	0.1	0.0	0.2	N
button mangrove	*Conocarpus erectus*	0.1	0.0	0.1	N
cabbage palm	*Sabal palmetto*	5.3	18.1	23.4	N
camellia	*Camellia japonica*	0.0	0.0	0.1	E
camphor tree	*Cinnamomum camphora*	0.2	0.3	0.5	E, I
Canary island date palm	*Phoenix canariensis*	0.1	1.2	1.3	E
Carolina ash	*Fraxinus caroliniana*	0.1	0.2	0.3	N
Carolina laurelcherry	*Prunus caroliniana*	1.6	3.5	5.1	N
carrotwood	*Cupaniopsis anacardioides*	0.0	0.0	0.0	E, I
chinaberry	*Melia azedarach*	0.4	0.3	0.7	E, I
Chinese elm	*Ulmus parvifolia*	0.2	1.3	1.6	E
Chinese hibiscus	*Hibiscus rosa-sinensis*	0.0	0.0	0.0	E
citrus spp.	*Citrus* spp.	0.3	0.5	0.8	E
common crapemyrtle	*Lagerstroemia indica*	0.3	0.2	0.5	E
common persimmon	*Diospyros virginiana*	0.0	0.0	0.0	N
coastal plain willow	*Salix caroliniana*	0.2	0.1	0.3	N
dahoon	*Ilex cassine*	0.2	0.2	0.4	N
Darlington oak	*Quercus hemisphaerica*	0.4	4.8	5.2	N
ear tree	*Enterolobium cyclocarpum*	0.1	1.2	1.3	E
eastern baccharis	*Baccharis halimifolia*	0.3	0.1	0.4	N
eastern red cedar	*Juniperus virginiana*	0.0	0.1	0.2	N
eastern redbud	*Cercis canadensis*	0.1	0.2	0.3	N
fetterbush lyonia	*Lyonia lucida*	0.0	0.0	0.0	N
Florida royal palm	*Roystonea elata*	0.1	0.6	0.6	N
Florida strangler fig	*Ficus aurea*	0.0	0.3	0.4	N
Fraser photinia	*Photinia x fraseri*	0.1	0.0	0.1	E
goldenrain tree	*Koelreuteria paniculata*	0.2	0.2	0.4	E, I
grapefruit	*Citrus x paradisi*	0.1	0.3	0.4	E

Appendix B (continued)

Common Name	Scientific Name	% Trees	% LA[a]	IV[b]	N, E, I[c]
green ash	*Fraxinus pennsylvanica*	0.0	0.0	0.0	N
Japanese viburnum	*Viburnum japonicum*	0.3	0.0	0.3	E
laurel oak	*Quercus laurifolia*	2.5	9.1	11.6	N
lemon	*Citrus limon*	0.1	0.1	0.2	E
ligustrum	*Ligustrum japonicum*	0.9	0.6	1.5	E
lime	*Citrus aurantifolia*	0.1	0.0	0.1	E
live oak	*Quercus virginiana*	2.4	17.1	19.5	N
longleaf pine	*Pinus palustris*	0.7	1.1	1.8	N
loquat tree	*Eriobotrya japonica*	0.3	0.0	0.4	E
rusty staggerbush	*Lyonia ferruginea*	0.0	0.0	0.0	N
mango	*Mangifera indica*	0.0	0.2	0.3	E
Mexican fan palm	*Washingtonia robusta*	0.1	0.3	0.4	E, I
mountain ebony	*Bauhinia variegata*	0.0	0.1	0.2	E, I
Norfolk island pine	*Araucaria heterophylla*	0.0	0.6	0.6	E
northern white cedar	*Thuja occidentalis*	0.1	0.2	0.3	E
oleander	*Nerium oleander*	0.3	0.0	0.3	E
orange	*Citrus sinensis*	0.2	0.4	0.7	E
orchid tree	*Bauhinia purpurea*	0.1	0.0	0.1	E
other species		0.1	0.1	0.2	
paper mulberry	*Broussonetia papyrifera*	0.2	1.4	1.6	E, I
parsley hawthorn	*Crataegus marshallii*	0.0	0.0	0.0	N
pecan	*Cary illinoinensis*	0.0	0.0	0.0	E
pond cypress	*Taxodium ascendens*	0.9	1.3	2.2	N
pygmy date palm	*Phoenix roebelenii*	0.3	0.3	0.6	E
queen palm	*Syagras romanzoffiana*	0.7	5.3	6.0	E, I
red mangrove	*Rhizophora mangle*	7.8	2.3	10.1	N
red maple	*Acer rubrum*	0.2	0.3	0.5	N
red mulberry	*Morus rubra*	0.1	0.2	0.2	N
redbay	*Persea borbonia*	0.0	0.0	0.0	N
sago palm	*Cycas revoluta*	0.0	0.0	0.1	E
sand live oak	*Quercus geminata*	0.6	0.9	1.5	N
sand pine	*Pinus clausa*	0.0	0.0	0.0	N
sea grape	*Coccoloba uvifera*	0.2	0.1	0.3	N
Senegal date palm	*Phoenix reclinata*	0.1	1.1	1.2	E, I
shining sumac	*Rhus copallinum*	0.1	0.0	0.1	N
slash pine	*Pinus elliottii*	0.4	1.1	1.5	N
small-leaf arrowwood	*Viburnum obovatum*	0.0	0.0	0.0	N
sour orange	*Citrus aurantium*	0.2	0.1	0.3	E
southern magnolia	*Magnolia grandiflora*	0.1	1.0	1.1	N
sparkleberry	*Vaccinium arboreum*	0.0	0.0	0.0	N
stiff dogwood	*Cornus foemina*	0.1	0.0	0.1	N
swamp bay	*Persea palustris*	0.3	0.0	0.3	N
swamp tupelo	*Nyssa biflora*	0.5	0.7	1.2	N

Appendix B (continued)

Common Name	Scientific Name	% Trees	% LA[a]	IV[b]	N, E, I[c]
sweetbay	*Magnolia virginiana*	0.0	0.1	0.1	N
sweetgum	*Liquidambar styraciflua*	1.0	0.5	1.5	N
tallowtree	*Triadica sebifera*	0.0	0.0	0.1	E, I
tangerine	*Citrus reticulata*	0.1	0.2	0.3	E
water hickory	*Carya aquatica*	0.0	0.0	0.0	N
water oak	*Quercus nigra*	0.7	0.3	1.0	N
wax myrtle	*Myrica cerifera*	0.8	0.6	1.4	N
weeping bottlebrush	*Callistemon viminalis*	0.1	1.2	1.3	E, I
white lead tree	*Leucaena leucocephala*	6.5	6.7	13.2	E, I
white mangrove	*Laguncularia racemosa*	34.4	1.0	35.4	N
winged elm	*Ulmus alata*	0.0	0.0	0.0	N
yew podocarpus	*Podocarpus macrophyllus*	0.2	0.1	0.3	E

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Project Partners

This report was completed for the City of Tampa to provide a detailed scientific look into the economic and ecological values of the City of Tampa's urban forest and to comply with the City's tree ordinance (Ord. No. 2006-74, § 9, 3-23-06) which requires a re-inventory of Tampa's tree canopy and urban forest every five years.

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