City of Tampa
Urban Ecological Analysis 2006-2007

City of Tampa Parks and Recreation Department
Hillsborough County Florida
USF University of South Florida
University of Florida

City of Tampa Urban Ecological Analysis 2006-2007

Final Report to the City of Tampa

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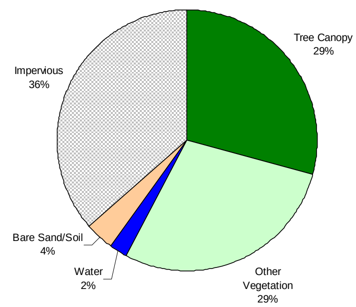
Executive Summary

In October 2006 the City of Tampa's City Council directed the Parks and Recreation Department to oversee an ecological analysis of the city's urban forest resources. This report describes the methodology used to conduct the inventory and assessment; quantifies the change in overall canopy coverage 1996 to 2006; provides a three-dimensional description of the forest structure and composition; and provides a detailed look into some of the economic and ecological values of the City of 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.

The University of South Florida combined the use of high resolution imagery (1 meter) and a more robust approach to spatial analysis than used in the 1996 study as part of its investigation into urban forest cover and distribution.

- Overall citywide tree cover increased between 1996 and 2006.
- Tree cover in 2006 appears to have returned to 1970's levels.
- High-resolution 2006 land cover classification indicated the City of Tampa was comprised of 29% tree canopy, 29% other vegetation, 2% water, 4% bare sand/soil and 36% impervious surface.
- Residential, public/quasi-public institutional and right-of-way were the top three land use categories in terms of acres of tree canopy, representing over 78% of the 21,716 acres of tree canopy within the City of Tampa.



During spring – early fall of 2007 the University of Florida School of Forest Resources and Conservation and Hillsborough County Extension established two hundred and one plots which were sampled and analyzed to determine the vegetative structure, functions, and values of the urban forest in Tampa.

Definitions of terms used in this report:

1. **Urban Forest**: Urban forests encompass the trees, shrubs, plants, and wild/domesticated animals that live in the area regardless of origin (native/non-native, naturally regenerated, or planted/introduced).
2. **Forest Structure**: a description of the distribution of vegetation both horizontally and vertically. Forest structure attributes are a function of the community of species.
3. **Forest Function**: determined by forest structure and includes a wide range of environmental and ecosystem services.
4. **Forest Value**: an estimate of the ecological and economic worth of the various forest functions.

Summary of Tampa's Urban Forest and associated functional values

Feature	**Measure**
Number of Trees	7,817,408
Tree Cover	28.1%
Top 3 Species	red mangrove, Brazilian pepper, black mangrove
Proportion of Trees < 6-inches DBH	84%
Pollution Removal	1,360 tons/year ($6.3 million/year)
Carbon Storage	511,141 tons ($10,386,389)
Gross Carbon Sequestration	46,525 tons/year ($945,396/year)
Value of Energy Conservation	$4,205,623
Compensatory Value	$1,465,600,097

Introduction

As citizens and natural resource professionals, we are witnessing the effects of population growth across the Tampa Bay watershed. The watershed's natural systems are increasingly stressed by demands for goods and services which raises many difficult questions. How do we maintain a healthy economy without damaging our environment? How can the Tampa Bay watershed develop in a sustainable manner so that we maintain a healthy environment for our children and grandchildren? There are no easy answers to questions like these, but we must begin to deal with them by using the best information we have right now.

During the past 40 years of rapid growth, large areas of the watershed's wild native forest have become intermixed with urban development. The remnants of the native forest in the form of parks, greenways, and trees along city streets and around homes are now seen as an integral part of the newly emerging urban forest of the Tampa Bay watershed. The physical boundary between the urban and wild native forest is being blurred. The ecological functions and the values of the wild native forest and the urban forest are being blurred. Restoring and conserving those functions and values of the forest that support sustainable development is now tied, in new ways, to the long-term management of the urban environment.

Tampa's urban forest plays a significant role in maintaining the vitality of urban life. The urban forest provides a wealth of benefits to neighborhoods and communities through the reduction of energy consumption, the removal of pollutants from the air and water, reduction in stormwater flows, increased valuation of private property, increased worker productivity, reduction in stress and violent crime, as well as providing recreational opportunities and aesthetic diversity. At the same time stresses from the urban environment including air pollution, increased impervious surface, soil compaction, and negligence reduce the diversity and magnitude of these benefits.

Close interaction of people and trees require that urban and community tree and forest resources be actively and diligently managed to ensure public safety. Reducing risks while maximizing value within this dynamic urban system requires that the city's urban forest management programs be grounded in ecological science and recognize the interplay between the bio-physical and social aspects of the city. The initial step in using an ecological approach to meet these challenges is the identification and organization of baseline information in the form of an inventory that describes the location, composition, structure, and health of the trees and woodlands within the urban forest landscape.

Through a collaborative effort that involved the University of Florida, the University of South Florida, and the Hillsborough County Extension, an extensive inventory of Tampa's urban forest was undertaken and analyzed during 2007. The inventory provided baseline information on location, composition, structure, and health while the analysis determined ecological function and economic value.

Definitions of terms used in this report:

1. **Urban Forest**: a woody tree/shrub dominated ecosystem that has been directly or indirectly impacted by development (urbanization). Urban forests encompass the trees, shrubs, plants, and wild/domesticated animals that live in the area regardless of origin (native/non-native, naturally regenerated, or planted/introduced). Within the matrix of urban forests are humans and their associated structures (homes, buildings, roads). Urban forests are found on both publicly and privately owned and managed lands.

2. **Forest Structure**: a description of the distribution of vegetation both horizontally and vertically across an area. Various physical attributes of forest vegetation can be measured and calculated to describe the structure such as: tree density, diameter and height distribution, crown area, tree health, leaf area, and biomass. Forest structure attributes are a function of tree, shrub, and herbaceous species, as well as the community of species found in a given area.
3. **Forest Function**: determined by forest structure and includes a wide range of environmental and ecosystem services such as air pollution removal and cooler air temperatures.
4. **Forest Value**: an estimate of the ecological and economic worth of the various forest functions.

Study Site

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 was defined as the City of Tampa political jurisdiction modified to follow the shoreline of Tampa Bay (Tampa 2007b). Total area of the study area was 132.6 square miles (74,884 acres). Although budgetary constraints limited the study area to the City of Tampa, the analysis of existing tree canopy was extended at minimal cost to include surrounding watersheds as defined by the Total Maximum Daily Load Program in Florida (FDEP 2007a). The decision to include surrounding watersheds was driven by goals to eventually examine the ecological role of Tampa's urban forest in the context of watershed management and an urban-rural land use gradient. Figure 1 presents both the study boundary and the extended analysis area.

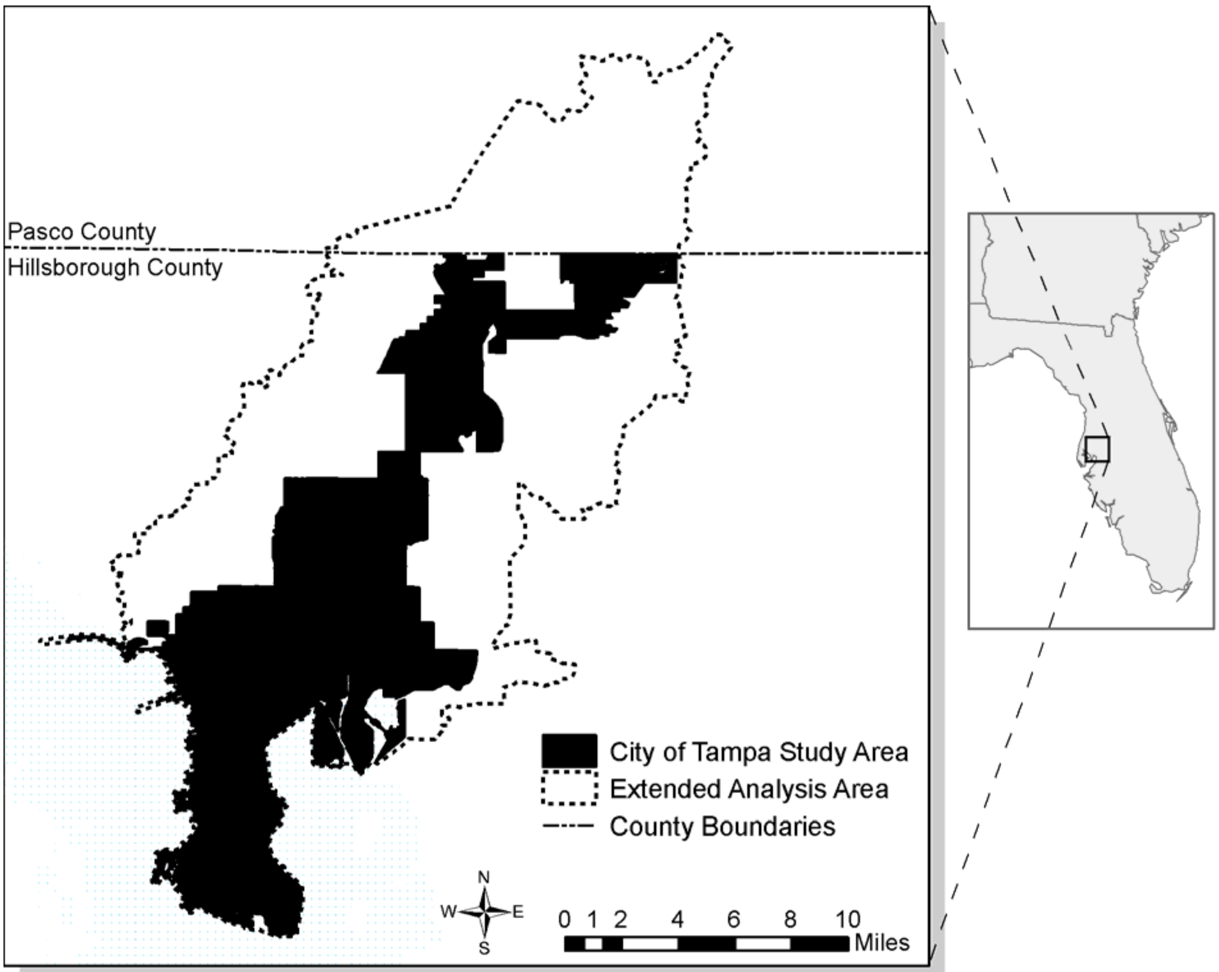


Figure 1. Location and extent of City of Tampa Study Area and extended analysis area.

According to the US Census Bureau, population within the City of Tampa was 280,015 in 1990, 303,447 in 2000, and estimated at 332,999 in 2006 (US Census Bureau 2000; 2007). In 2000, population density was 2,707.8 people per square mile and there were 135,776 housing units (US Census Bureau 2000). In 2006, the number of housing units was estimated at 149,317 (US Census Bureau 2007).

Tree Canopy Assessment

Remote sensing land cover classification techniques were used to estimate tree canopy cover within the City of Tampa and surrounding study area. The goal of these analyses were to 1) compare the overall and location specific changes to tree canopy cover between 1996 and 2006; 2) create a high-resolution land cover classification dataset of 2006 tree canopy cover for purposes of planning and urban forest management; and 3) examine differences in tree canopy cover by land use, neighborhood and other geographic delineations for the purpose of recommending urban forest management goals. The following section of this report documents the data, methods and the results from these analyses.

DATA

The study was very data intensive and included both secondary data usage as well as generation of data through remote sensing and field sampling techniques. This section describes the specific datasets used for the analysis.

Geographic Boundaries

Several secondary datasets were used for the selection of study areas and summarization of results. Unless otherwise stated, the area of the City of Tampa was defined by the latest incorporated limits for the City of Tampa modified to follow the shoreline of Tampa Bay (Tampa 2007b). The political boundary from 1996 (Tampa 1996) was used for reference as part of the change detection analysis. The extended analysis area boundary was created to include the City of Tampa (Tampa 2007b), watersheds intersecting the City of Tampa and the nearby sweetwater creek watershed (FDEP 2007a). Neighborhoods were defined by the City of Tampa City Neighborhood Association boundaries (Tampa 2007a). Total area included in some of the analyses was not equal to the 74,884 acre City of Tampa study area due to differences in scale and precision of the secondary spatial data used in this study.

Parcel Data

Parcel information was used to define land use, building age, and other characteristics used in the study. Parcel boundaries and attribute data were obtained from cadastral data for Hillsborough County (HCPA 2007) and Pasco County (PCPA 2007) and current as of January 2007. Several additional geoprocessing steps were required in order to incorporate right-of-way and water feature boundaries into the undefined regions of the cadastral data; defined parcel boundaries were left unchanged. Water feature polygons were added using a modified version of the National Hydrography Dataset (USF 2007b). Right-of-way polygons were defined as all areas within the study boundaries not defined as parcel or water polygons. Generalized land use categories (USF 2007a) were added for water and right-of-way polygons or based on parcel specific Florida Department of Revenue land use codes included with the original data. Parcel polygons encompassing smaller residential and commercial condominium polygons were assigned the land use of the condominium parcels (i.e. residential). All remaining parcels with missing land use codes were defined as unknown. Table 1 provides definitions for generalized land use categories.

Table 1. Definitions of Generalized Land Use Categories.

Generalized Land Use	Definition
Agricultural	Land classified as 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 residential, mobile home parks, condos, private retirement homes and institutional housing.
Right of Way / Transportation	Right-of-way areas associated with roads and railroads, marinas and transit terminals. Defined in original parcel data or added through geoprocessing.
Unknown	Areas undefined in parcel data and secondary sources.
Vacant	Vacant lands, including abandoned/unused commercial, institutional and industrial lands, and non-agricultural acreage.
Water	Areas undefined in parcel data but included from secondary sources.

Total land area assigned to each generalized land use category is summarized in Table 2 for the study area and the additional analysis area. The top five land use categories with the greatest percentage of land area in the City included residential, public/quasi-public/institutional, right of way / transportation, commercial and vacant. The top five land use categories including the additional analysis area were similar except for the relative increase in agricultural land and decrease in commercial lands, reflecting the inclusion of an urban to rural transition fringe.

Table 2. Total parcel area represented within each generalized land use.

	City of Tampa Study Area		Tampa plus extended analysis area	
Generalized Land Use	**Total Acres**	**Percent of Area**	**Total Acres**	**Percent of Area**
Agricultural	1,937	2.6%	24,855	12.2%
Commercial	5,513	7.4%	10,209	5.0%
Industrial	3,002	4.0%	7,409	3.6%
Public / Quasi-Public / Institutions	21,589	28.8%	49,736	24.4%
Public Communications / Utilities	1,515	2.0%	4,781	2.3%
Recreational / Open Space / Natural	960	1.3%	7,119	3.5%
Residential	22,740	30.4%	54,539	26.8%
Right of Way / Transportation	12,103	16.2%	24,138	11.9%
Unknown	231	0.3%	1,218	0.6%
Vacant	4,728	6.3%	18,057	8.9%
Water	566	0.8%	1,621	0.8%
Total	74,884		203,683	

Typical of most cadastral maps, neither the Pasco County nor Hillsborough County Property Appraiser data were maintained as survey grade spatial accuracy (HCPA 2007; PCPA 2007).

As a result of these limitations, land use and parcel specific study results were affected by the spatial accuracy of the parcel boundaries. Variation in spatial accuracy of parcel layers was estimated by comparing parcel boundaries with 1 foot resolution aerial imagery. Error was measured as the distance from the parcel boundary to the estimated correct location viewed from the aerial image. Measurements were made at 108 locations on an alternating grid of sample points placed at approximately two mile intervals. Ordinary Kriging using the ESRI Geostatistical Analyst (ESRI 2006) was used to generate an interpolation map of estimated parcel boundary accuracy (Figure 2). Error within the City of Tampa was found to generally less than 10 feet, while maximum error of 20 feet was common north of the City (i.e. in Pasco County). Results presented in Figure 2 provide a measure of uncertainty for all parcel-based analyses. For the purposes of this study, the parcel boundary error was considered acceptable for parcel-based data analysis within the City of Tampa study area.

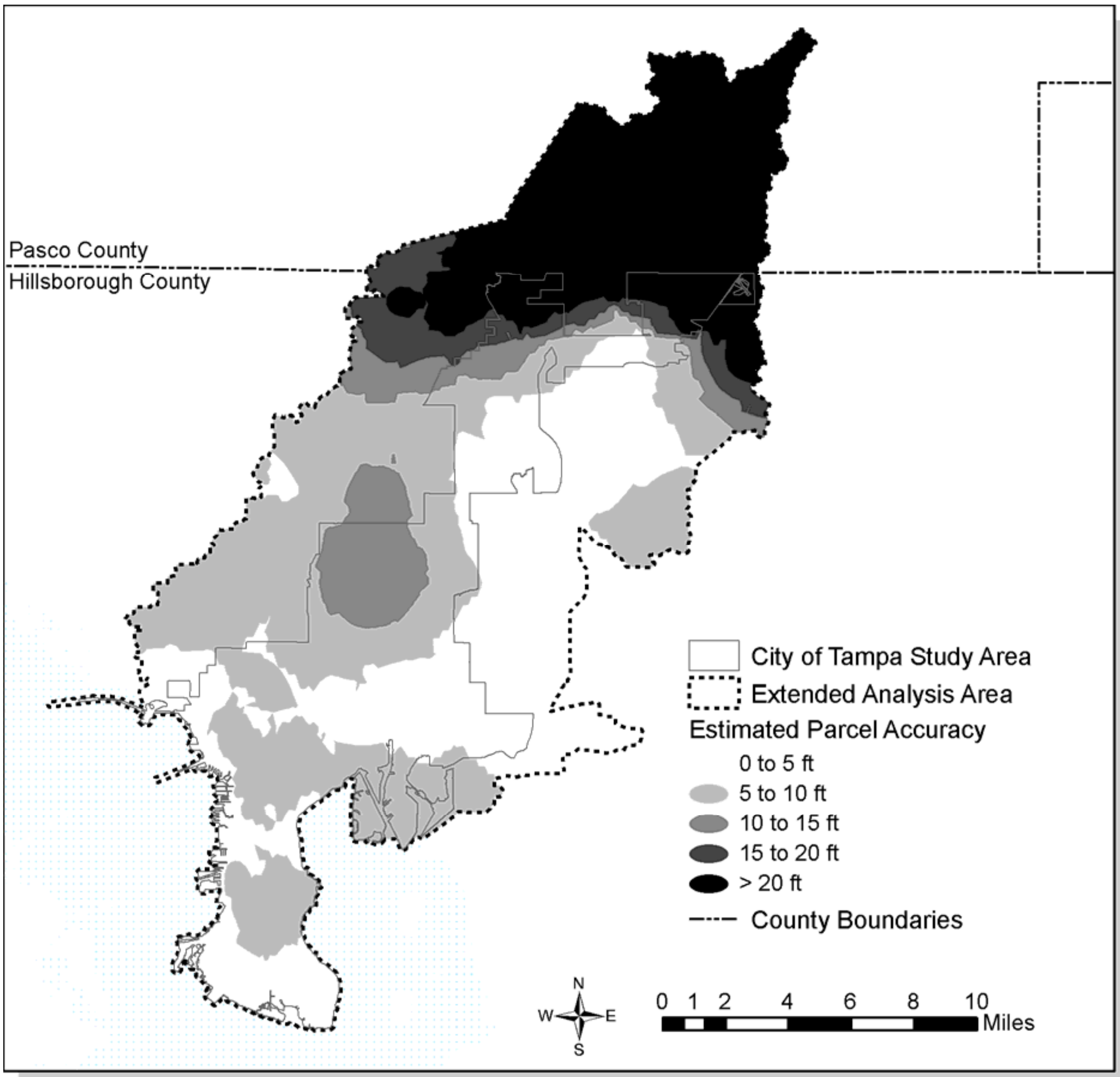


Figure 2. Estimated variation in the spatial accuracy of parcel boundaries.

Imagery Data

Imagery used as part of the project included high-resolution natural color aerial imagery and both moderate resolution and high resolution multispectral satellite imagery. Aerial imagery was used for reference in association with field sampling, as a reference for verification of classification results and for analysis of the spatial accuracy of parcel boundaries. Natural color aerial imagery for Hillsborough County was flown between 1/18/2006 and 1/31/2006. Natural color aerial imagery for Pasco County was flown between 2/8/2005 and 2/18/2005. All natural color aerial imagery was provided by the Southwest Florida Water Management District and had a resolution of one square foot on the ground per image pixel (SWFWMD 2006).

Moderate resolution Landsat 5 Thematic Mapper (TM) satellite imagery was used for the tree canopy cover change detection analysis in order to maintain consistency with the City of Tampa Urban Ecological Analysis (Campbell and Landry 1999). The date of the imagery was selected based on very low cloud cover and to represent approximately the same week of the year as the imagery used for the 1996 tree canopy cover analysis (i.e. late April). Only TM bands 1 (blue-green), 2 (green), 3 (red) and 4 (reflected/near infrared) were used as part of the analysis. Landsat 5 TM image had a resolution of 30 meters on the ground per image pixel. All scenes were provided as georeferenced to the Universal Transverse Mercator map projection (WGS84 Zone 17 North). Table 3 lists specific image dates, path/row numbers and scene identification information. Figure 3 provides a mosaicked image showing the extent of the three scenes.

Table 3. Landsat 5 TM Satellite Imagery Selected Information.

Path / Row	Acquisition Date	Scene Identifier
17/41	April 20, 1996	5017041009611110
17/40	April 20, 1996	5017040009611110
17/40	May 2, 2006	5017040000612210
17/41	May 2, 2006	5017041000612210
16/41	April 25, 2006	5016040000611510

Table 4. IKONOS Satellite Imagery Selected Information.

Scene	Acquisition Date	Cloud Cover	Source Image Identifier
0	April 3, 2006	<5%	2006040316115930000011627125
1	April 6, 2006	0%	2006040616204670000011631525
2	April 6, 2006	0%	2006040616211010000011631526
3	April 6, 2006	0%	2006040616213340000011631527

Figure 3. Mosaicked image of 2006 Landsat scenes labeled by Path and Row numbers.

Although Landsat imagery was necessary for the change detection analysis, the relative moderate resolution (i.e. 30 meter pixel) was not sufficient to provide the high level of spatial resolution desired for the classification of existing (i.e. 2006) tree canopy cover. High resolution IKONOS satellite imagery (GeoEye, Inc.) was acquired for the full study area and used to classify existing tree canopy cover. Georeferenced 1-meter resolution panchromatic and 4-meter resolution multispectral images were acquired. Imagery was selected based upon low cloud cover, availability, and temporal consistency with the Landsat imagery (i.e. April 2006). All scenes were provided as State Plane projection (NAD83 Florida West Zone 902). Table 3 lists specific image dates, path/row numbers and scene identification information for Landsat imagery. Table 4 lists image dates, cloud cover and image identifier information for the Ikonos imagery.

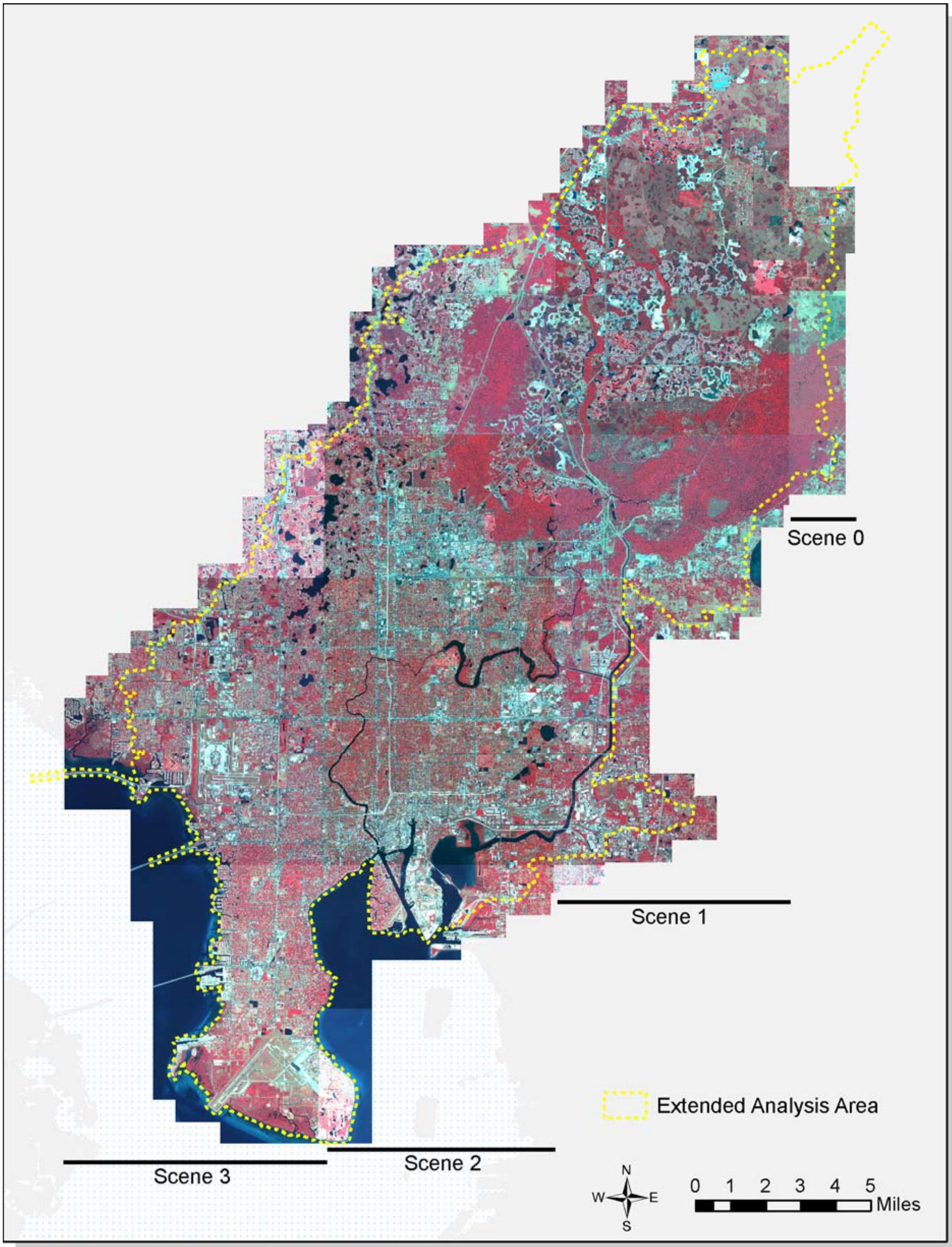


Figure 4. Mosaicked image of 2006 Ikonos scenes labeled by scene numbers. Lines indicate the horizontal extent of each scene. Notice the area within the extended analysis area where imagery was not available.

The difference in resolution between the Landsat and IKONOS datasets had important implications for the results of the study. The 30 meter pixel (i.e. $30x30=900m^2$) of the Landsat imagery had a resolution 900 times lower than the 1-meter pixel ($1m^2$) of the panchromatic and 56 times lower than the 4-meter pixel ($16m^2$) of the multispectral IKONOS imagery. Implications of these differences will be discussed in the results section of this report.

METHODS

Remote sensing land cover classification techniques were used to estimate tree canopy cover within the City of Tampa and surrounding study area. The goal of these analyses were to 1) compare the overall and location specific changes to tree canopy cover between 1996 and 2006; 2) create a high-resolution land cover classification dataset of 2006 tree canopy cover for purposes of planning and urban forest management; and 3) examine differences in tree canopy cover by land use, neighborhood and other geographic delineations for the purpose of recommending urban forest management goals. The following section describes the specific methods used for the land cover analyses.

Tree Canopy Temporal Change (Medium-resolution)

In the late 1990s, the City of Tampa and the University of South Florida examined the temporal change in tree canopy cover between 1975 and 1996 (Campbell and Landry 1999). Using methods available at the time, the change detection analysis estimated tree canopy cover using normalized difference vegetation index (NDVI). Landsat image data from 1975 (Landsat 2 MSS), 1985 (Landsat 5 MSS), 1986 (Landsat 5 TM) and 1996 (Landsat 5 TM) was used to calculate NDVI values for each pixel from red and near-infrared reflectance values. Although the use of NDVI is still an acceptable method of change detection analysis (Myeong et al. 2006), the relatively low spatial resolution of Landsat images was a limitation of the 1999 study (i.e. 80 meter for Landsat 2 MSS, 30 meter for Landsat 5). Despite the limitations of the 1999 change detection analysis, this study maintained consistency and used the same methods and satellite imagery (i.e. Landsat 5 TM) to examine change in tree canopy coverage between 1996 and 2006. Figure 5 provides an overview of the Landsat-based change detection procedures used in this study.

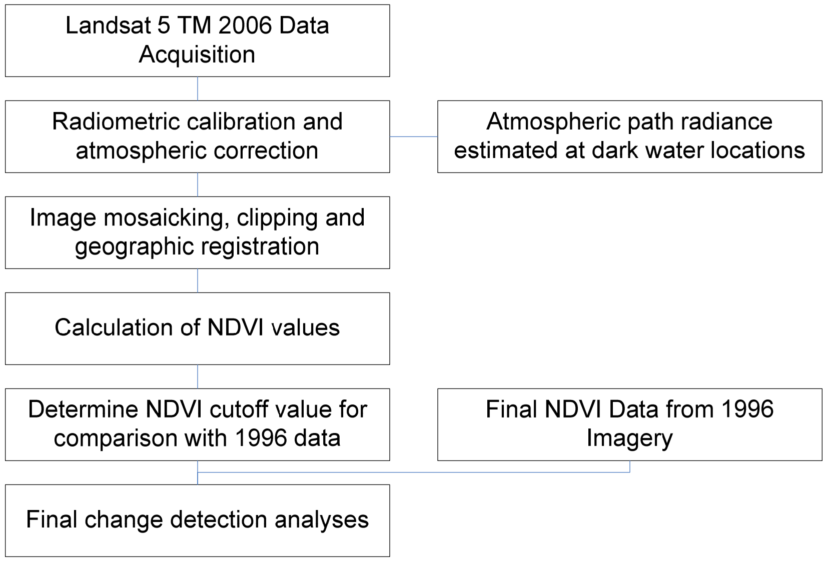


Figure 5. Flow chart depicting the change detection procedures used in this study.

Image processing of the 2006 Landsat data and change detection analyses were performed using the ENVI Version 4.3 software program (ITT 2006). Image processing of the 1996 Landsat data was performed during the original 1999 study using similar methods (Raabe and Stumpf 1997; Campbell and Landry 1999). Radiometric calibration was performed using the ENVI software Landsat TM Calibration tool to convert Landsat digital numbers to at-sensor reflectance values. Atmospheric correction was performed by deducting atmospheric path radiance estimated at pseudo-invariant dark water locations. At-surface reflectance values were first measured using a field spectrometer (ASD, Inc. FieldSpec3 Spectroradiometer, www.asdi.com) on several dark water locations on the Hillsborough River and Alafia River. Measurements were taken one-year later at approximately the same time of year as the IKONOS imagery was acquired (i.e. April 2). Atmospheric path radiance (reflectance) was then estimated by subtracting at-surface reflectance measured at pseudo-invariant dark water locations from at-sensor calibrated reflectance for the mid-point wavelength of each image band (i.e. 485nm, 560nm, 660nm, 830nm, 1650nm and 2215nm) at the same locations. Atmospheric correction for at-sensor calibrated values of each pixel of the 2006 image data was realized by subtracting the path radiance (reflectance) values. After atmospheric correction, the three scenes were mosaicked together, clipped to the boundaries of the study area and registered to the one-foot resolution natural color aerial imagery in state plane projection (NAD83 Florida West Zone 902). NDVI values were calculated for each pixel in the study area using the equation: NDVI=(red-NIR)/(red+NIR).

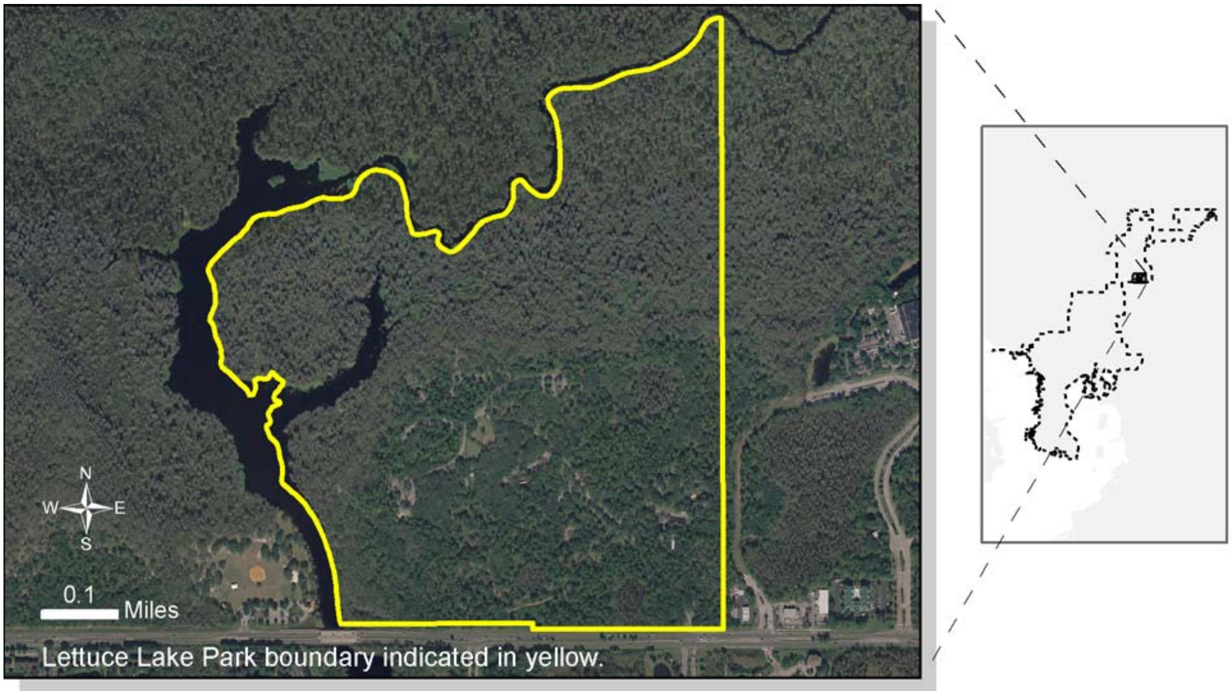


Figure 6. Lettuce Lake Park boundary with 2006 true color aerial imagery.

Canopy cover was estimated using a binary classification of each pixel based on a specified NDVI cutoff value (i.e. tree canopy present versus canopy absent). The 1996 canopy cover was determined using an NDVI value of 0.74 to classify a pixel as tree canopy (i.e. NDVI >= 0.74 equals tree canopy). Because of seasonal and temporal variation in tree canopy spectral reflectance values, it was not appropriate to use the same NDVI cutoff in 2006. To determine the appropriate NDVI cutoff value to use with the 2006 data, NDVI values for pixels from both datasets were compared for Lettuce Lake Park, a 237 acre forested park within the study area (Figure 6). According to park management, the area had not experienced any major changes to land cover, land management practices were unchanged between 1996 and 2006, and management practices which would have resulted in canopy changes, such as controlled burning, were not used at the park. In other words, although minor changes to leaf area index and crown closure may have occurred, major differences in NDVI values were likely the result of temporal variation rather than changes to the amount of canopy cover. The NDVI mean minus two standard deviations was calculated for pixels within the park for 1996 (~ 0.78) and 2006 (~0.69), and the difference (~0.09) was used as a correction to adjust the 1996 cutoff value to the appropriate value for use in 2006. A final NDVI value of 0.65 was used to classify the presence/absence of canopy for each pixel in the 2006 image.

Due the inherent difficulty in accurately co-registering 30 meter resolution Landsat imagery, pixel-based change detection was not attempted. Zonal-based overlay analysis was chosen to compare change in total tree canopy percentage within specific geographic areas. For example, the percentage of tree canopy in 2006 was compared to tree canopy in 1996 for the City of Tampa as defined by the 1996 political boundary (Tampa 1996).

High-resolution Tree Canopy Cover Assessment

Existing tree canopy was classified using the method of supervised maximum likelihood classification (Goetz et al. 2003). The final five land cover classes included tree canopy, other vegetation, water, sand and bare soil, and impervious. Figure 7 provides an overview of the Landsat-based change detection procedures used in this study.

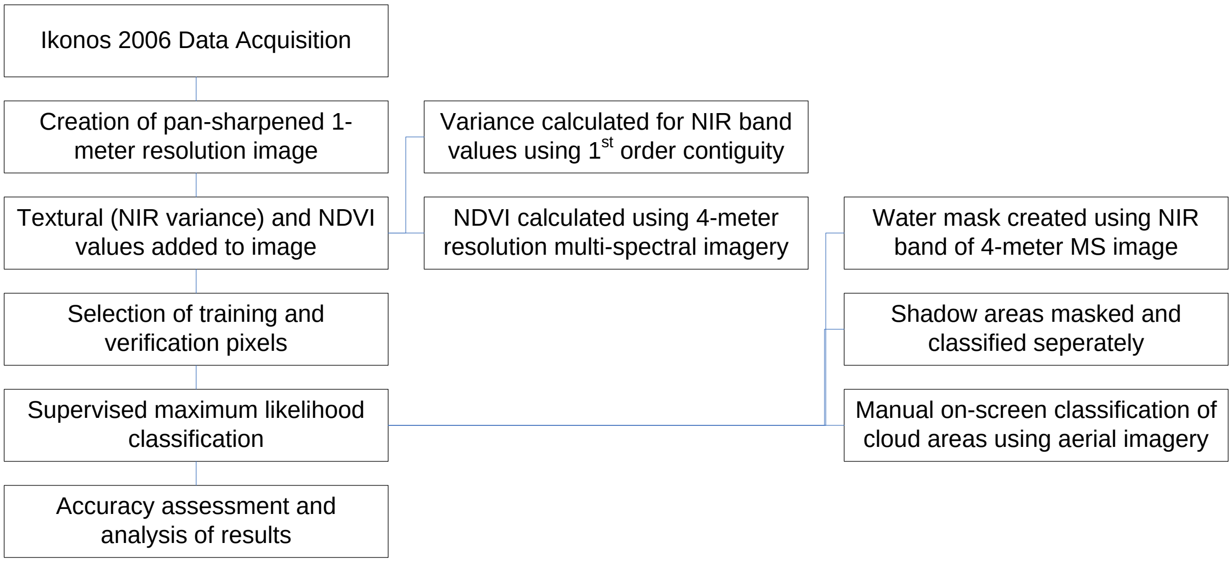


Figure 7. Flowchart depicting the classification procedures used in this study.

Pan-sharpened 1-meter images were created by fusing the 4-meter multispectral Ikonos image with the 1-meter panchromatic Ikonos imagery using the method of Gram-Schmidt Spectral Sharpening (ITT 2006). The use of pan-sharpened imagery has been shown to improve the classification of forests (Kosaka et al. 2005). Textural information and NDVI were added to each image as separate bands in order to aid in the classification. Textural information has been shown to be useful in land cover classification (Hirose et al. 2004) and was expected to improve the differentiation of tree canopy from heavily fertilized and irrigated lawns and golf courses. The NDVI vegetation index was added to improve the differentiation of vegetated from non-vegetated areas (Nichol and Wong 2007). Textural information was calculated for each pixel as the variance in the near-infrared band for the surrounding first order contiguity neighborhood of pixels. NDVI was calculated from each original 4-meter multispectral image, resampled to 1-meter pixels and added as a separate band to each pan-sharpened image. Each individual scene used in the classification process included the pan-sharpened blue-green, green, red and near-infrared bands, a near-infrared variance band and an NDVI band.

Prior to supervised classification, water was selected and masked from each scene using the raw (prior to pan-sharpening) spectral data of the near-infrared band. Spectral statistics were calculated for training pixels within each land cover class (see Figure 8). Radiance values for water in the near-infrared band was the lowest of any land cover class, followed by the radiance in shadow areas. Masked areas were selected as zero radiance to either the upper limit (mean plus one standard deviation) of water or the lower limit of shadow. In other words, radiance values were chosen so as not to overlap with shadow areas. Water mask was based on NIR digital number values of 0-222 for scene 0, 0-124 for scene 1, 0-106 for scene 2 and 0-111 for scene 3. Masked areas were added as water land cover to the final classification dataset.

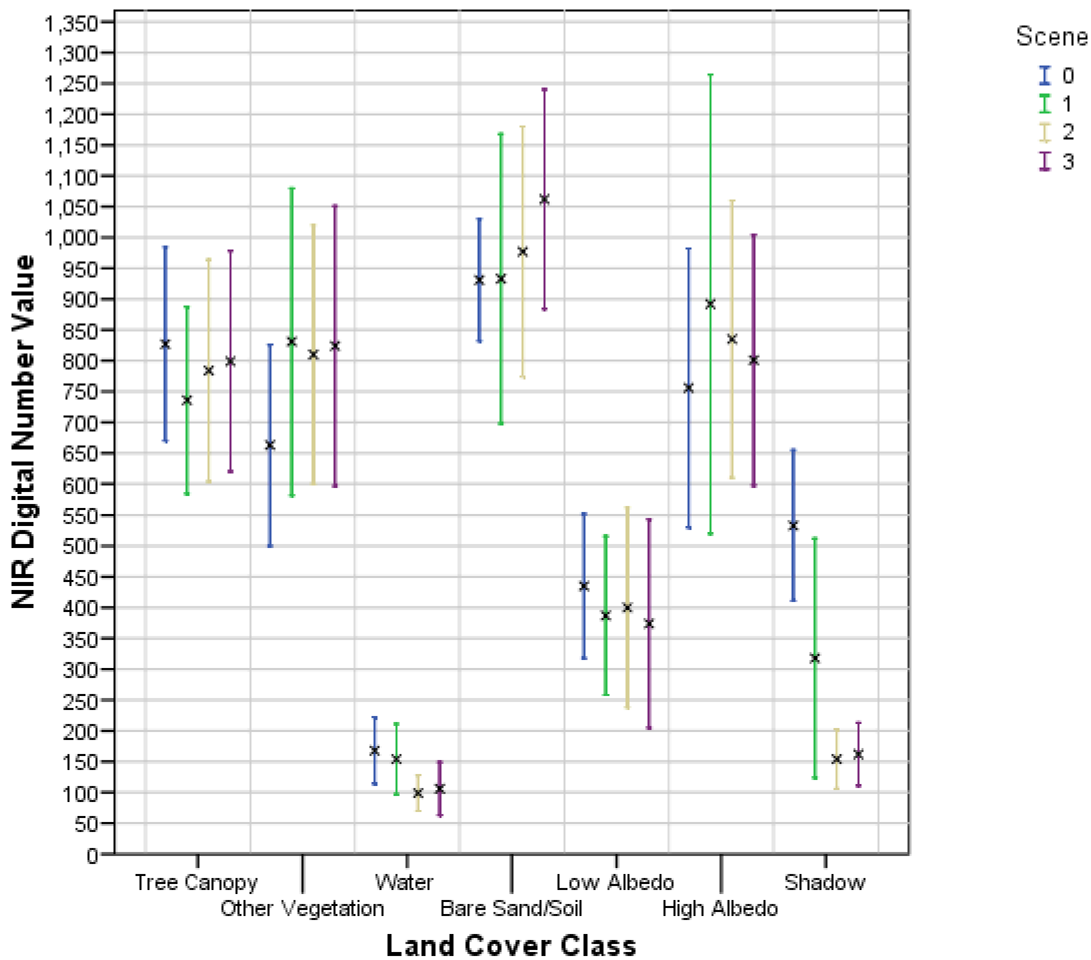


Figure 8. Near-Infrared band spectral plots of seven land cover classification categories for training areas in each of four scenes. Plots represent mean (symbol x) +/- 1 standard deviation.

The supervised maximum likelihood classification was developed using visually interpreted training areas within each image scene. Seven land cover types were originally classified: tree canopy, other vegetation, water, bare sand or soil, low albedo impervious (e.g. asphalt), high albedo impervious (e.g. concrete) and shadow. A total of 1,903,504 training pixels were chosen, representing an area of approximately 470 acres; 291,567 pixels from scene 0, 494,762 from scene 1, 533,090 from scene 2 and 584,085 from scene 3. Impervious land cover was separated into high albedo and low albedo in order to improve the differentiation between bare sand and concrete during the classification process (Nichol and Wong 2007). High and low albedo impervious land covers were combined into a single land cover class after classification. After classification using the maximum likelihood algorithm, a majority filter using a 3x3 pixel moving window was applied in order to remove speckles (e.g. pixels which were probably incorrectly classified as bare/sand soil and surrounded by impervious).

Shadow was separated as a distinct class in order to reduce classification error resulting from the shadow of tall multi-story buildings. Classified shadow was then masked from each image and new training data were developed from the masked areas. Supervised maximum likelihood classification was then used to reclassify the shadow areas into six land cover classes: tree canopy, other vegetation, water, bare sand or soil, low albedo impervious and high albedo impervious. The classified areas were then added to the final classification, replacing areas originally classified as shadow.

Cloud cover did not exist on any images within the City of Tampa study area. However, a small area (345 acres) of cloud cover located in the surrounding watershed area in scene 0 was removed from the supervised classification results. A cloud and cloud shadow mask was created for 345 acres of scene 0 (Figure 4, northwest quadrant in scene 0). Land cover within the mask was manually digitized on-screen from 2005 and 2006 natural color aerial imagery (SWFWMD 2006). The manually digitized areas were incorporated into the final classification results.

A final classification dataset for each scene was created by combining the supervised classification results with the masked water areas, reclassified shadow areas, and reclassified cloud areas. Classification accuracy was assessed using a total of 1,511,313 validation pixels selected from the four scenes and visually interpreted to the appropriate land cover class. Overall classification accuracy was 95.6% (kappa=0.94).

Table 5. Accuracy assessment of final land cover classification.

Land Cover Category	**Validation Pixels**	**Classified Pixels**	**Correctly Classified Pixels**	**Producer's Accuracy**	**User's Accuracy**
Tree Canopy	259,857	267,816	256,377	98.7%	95.7%
Other Vegetation	474,270	464,241	456,035	96.2%	98.2%
Water	376,476	374,924	372,997	99.1%	99.5%
Bare Sand/Soil	51,628	66,550	40,297	78.1%	60.6%
Impervious	349,082	337,781	319,465	91.5%	94.6%
Total	1,511,313	1,511,312	1,445,171		

As shown in Table 5, producer’s accuracy and user’s accuracy measures for tree canopy are 98.7% and 95.7%, respectively. These accuracy results were similar to those found by Goetz et al (Goetz et al. 2003) using decision tree based classification algorithms. Producer accuracy measures the probability that existing tree canopy pixels were classified as tree canopy, while user’s accuracy measures the probability that pixels classified as tree canopy were actually tree canopy. Detailed accuracy assessment results suggest that the low accuracy results for bare sand/soil and impervious was a result of the limited ability to differentiate these two classes (see Appendix C: Accuracy Assessment Results of Ikonos Classification). However, since the focus of this study was tree canopy and other vegetation, the confusion between sand/soil and impervious did not affect most study results.

Original scenes and classified images were registered to the one-foot resolution natural color aerial imagery in state plane projection (NAD83 Florida West Zone 902), mosaicked together, and clipped to the study boundaries. Results were summarized using raster-based tools within the ArcGIS 9.2 software package with the Spatial Analyst software extension.

RESULTS

The purpose of the land cover analysis was two-fold: quantify the overall change in tree canopy cover that occurred within the City of Tampa since 1996; and create a high resolution classification of existing tree canopy coverage. Tree canopy coverage values were summarized and aggregated based on several different geographic boundaries, including: the City of Tampa regions, neighborhood associations, parcel-base landuse and census block groups. The data summaries presented in this section were chosen from the virtually unlimited number of additional choices (e.g. watersheds, political districts, etc.) based upon the requirements of the City of Tampa.

Tree Canopy Temporal Change (Medium-resolution)

The Landsat imagery analysis results show that citywide tree canopy cover increased from 19% in 1996 to 22% in 2006 (Figure 9). As shown in the next section of this report, results from the Ikonos imagery analysis of existing tree canopy indicated a 29% tree canopy cover in 2006. Given the inherent differences between the methods, the Ikonos imagery analysis was assumed to yield more accurate results. Based upon this assumption, we could speculate that actual tree canopy cover reported for previous years could also have been higher than reported; we could also speculate that all previous year estimates were underestimated by approximately the same amount such that the magnitude of decadal change was accurate. The reader is cautioned that the validity of this speculation was not tested. Furthermore, the reader is encouraged to consider the inherent limitations of the land cover analysis discussed in Appendix D: Limitations of the Land Cover Analyses.

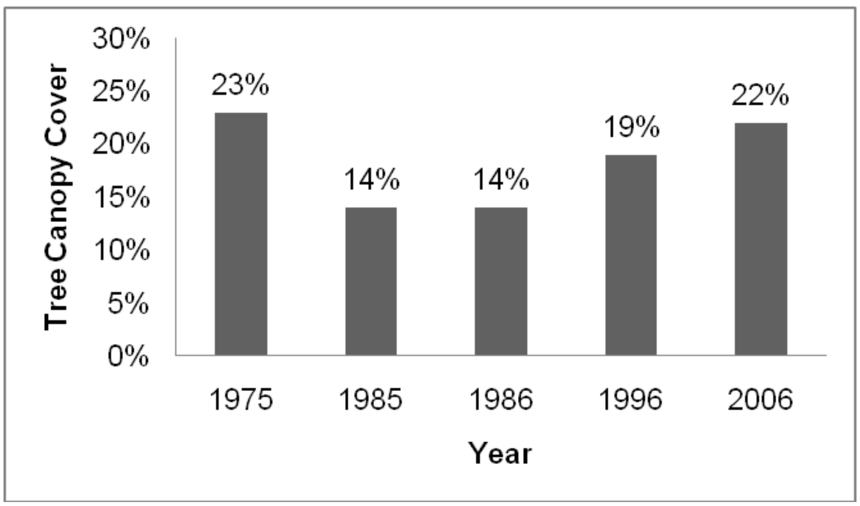


Figure 9. Citywide tree canopy cover for the period of 1975 to 2006. For consistency, analysis area for all years was defined by the 1996 City of Tampa boundary.

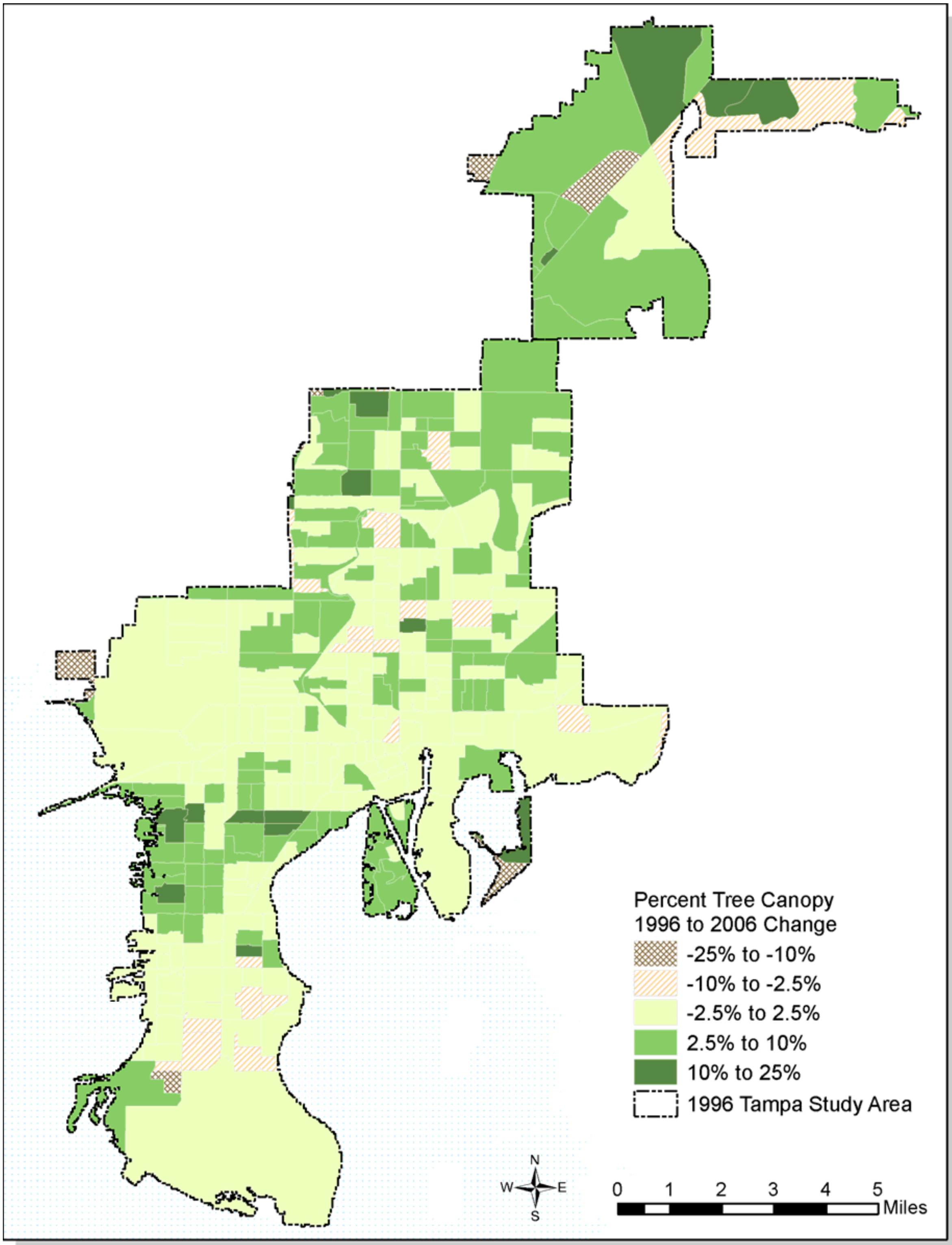


Figure 10. Census block group level tree canopy change between 1996 and 2006. Values indicate the difference in tree canopy percentage by subtracting 1996 canopy from 2006 canopy; positive indicates canopy and negative indicates canopy loss.

Change detection analyses in rural areas or for large study area (i.e. regional or national) often calculate pixel-by-pixel changes. This study avoided the use of this technique because the patchiness of the urban environment would require exact geographic coordinate registration for each set of imagery to be compared, but an exact registration was not feasible due to the limited resolution of the Landsat imagery. Instead, canopy cover for each year was summarized by zonal area and change was calculated as the change in canopy within the zonal area. Localized gains and losses to tree canopy between 1996 and 2006 were summarized using the 2000 census block group as the zonal areas (Figure 10). Results indicate a patchy distribution of canopy gains and losses. Scientific analysis of the specific factors related to these localized changes was not within the scope of this study.

High-resolution Tree Canopy Cover Assessment

Based upon the supervised maximum likelihood classification of 2006 Ikonos imagery, land cover within the City of Tampa study area is comprised of 29% tree canopy, 29% other vegetation, 2% water, 4% bare sand/soil and 36% impervious surface (Figure 11). Total vegetation cover can be calculated as the sum of tree canopy and other vegetation. Land cover classification results indicate that total vegetation cover within the City of Tampa was 58%.

Although land cover estimations are reported here for impervious and sand/soil, it is important to remember that classification accuracy was relatively low for both of these land cover classes. The rest of this report will focus on the tree canopy and other vegetation land cover classes only. It is also important to remember that remotely sensed classification methods could only classify what was visible from above (i.e. earth's orbit). Additional limitations of the overall land cover analysis are discussed in Appendix D: Limitations of the Land Cover Analyses. These methods were not designed to detect smaller trees, other vegetation, impervious, water or bare sand/soil underneath a tree canopy. Results of the Ecological Assessment (see Ecological Assessment) describe land cover underneath the tree canopy.

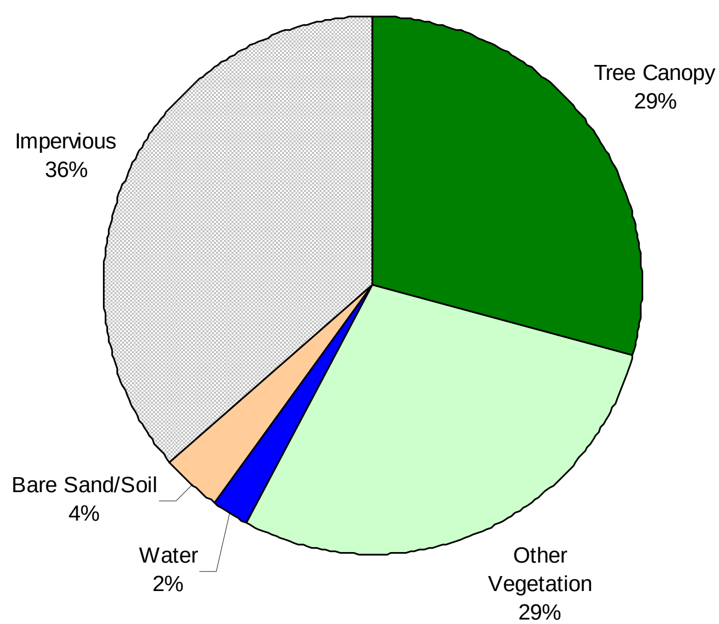


Figure 11. Summary of Land Cover Classification Results within the City of Tampa.

Existing tree canopy and other vegetation summarized using parcel-based existing land use categories is presented in Table 6. Residential (8,641 acres), public/quasi-public institutional (6,045 acres) and right-of-way (2,300 acres) were the top three land use categories in terms of acres of tree canopy, representing over 78% of the 21,716 acres of tree canopy within the City of Tampa. Within the top five land use categories in terms of citywide acreage, total percentage tree canopy cover was greatest on residential (38%), followed by vacant (32%), public/quasi-public institutional (28%), right-of-way (19%) and commercial (18%). Within these same land use categories, total tree canopy and other vegetation was greatest on vacant (72%), followed by public/quasi-public institutional (66%), residential (60%), right-of-way (44%) and commercial (31%). Single family parcels represented the largest acreage within the residential land use category and the greatest percentage tree canopy (40%).

Table 6. Vegetative land cover classifications summarized by parcel-based generalized existing land use category within the City of Tampa. Sub-categories also shown for residential generalized land use. Total citywide acreage of parcels within each land use category presented for reference.

Generalized Land Use Category	**Citywide Acreage in Land Use Category**	**Percent Tree Canopy**	**Total Acreage Tree Canopy**	**Percent Other Vegetation**	***Total Tree Canopy and Other Vegetation***
Agricultural	1,937	21%	*407*	72%	*94%*
Commercial	5,513	18%	*992*	13%	*31%*
Industrial	3,002	11%	*330*	19%	*30%*
Public / Quasi-Public / Institutions	21,589	28%	*6,045*	37%	*66%*
Public Communications / Utilities	1,515	84%	*1,273*	7%	*91%*
Recreational / Open Space / Natural	960	31%	*298*	52%	*82%*
Residential (Total)	22,740	38%	*8,641*	22%	*60%*
Condominium	27	23%	*6*	28%	*51%*
Group Quarters	26	24%	*6*	15%	*38%*
Mobile Home	218	22%	*48*	21%	*43%*
Multi-Family (<10 Units)	796	35%	*279*	21%	*57%*
Multi-Family (10+ Units)	2,155	27%	*582*	16%	*43%*
Residential Public Institutions	325	30%	*98*	23%	*52%*
Single Family	19,193	40%	*7,677*	23%	*63%*
Right of Way / Transportation	12,103	19%	*2,300*	25%	*44%*
Unknown	231	12%	*28*	13%	*24%*
Vacant	4,728	32%	*1,513*	40%	*72%*
Water	566	6%	*34*	4%	*10%*
Citywide Total	*74,884*	*29%*	*21,716*	*29%*	*58%*

Comparison between City of Tampa and Surrounding Watershed Areas

The Ikonos land cover classification was extended beyond the City of Tampa to include surrounding watershed areas (see map of areas in Figure 1). Existing (i.e. 2006) percentage tree canopy was summarized using the 2000 census block group as the zonal areas. Figure 12 is a thematric map of percentage tree canopy cover by block group for all areas of the extended study area where imagery were available. As shown in the map, percentage tree canopy cover appears highly variable both within the City of Tampa and within the surrounding watershed areas of the extended study area.

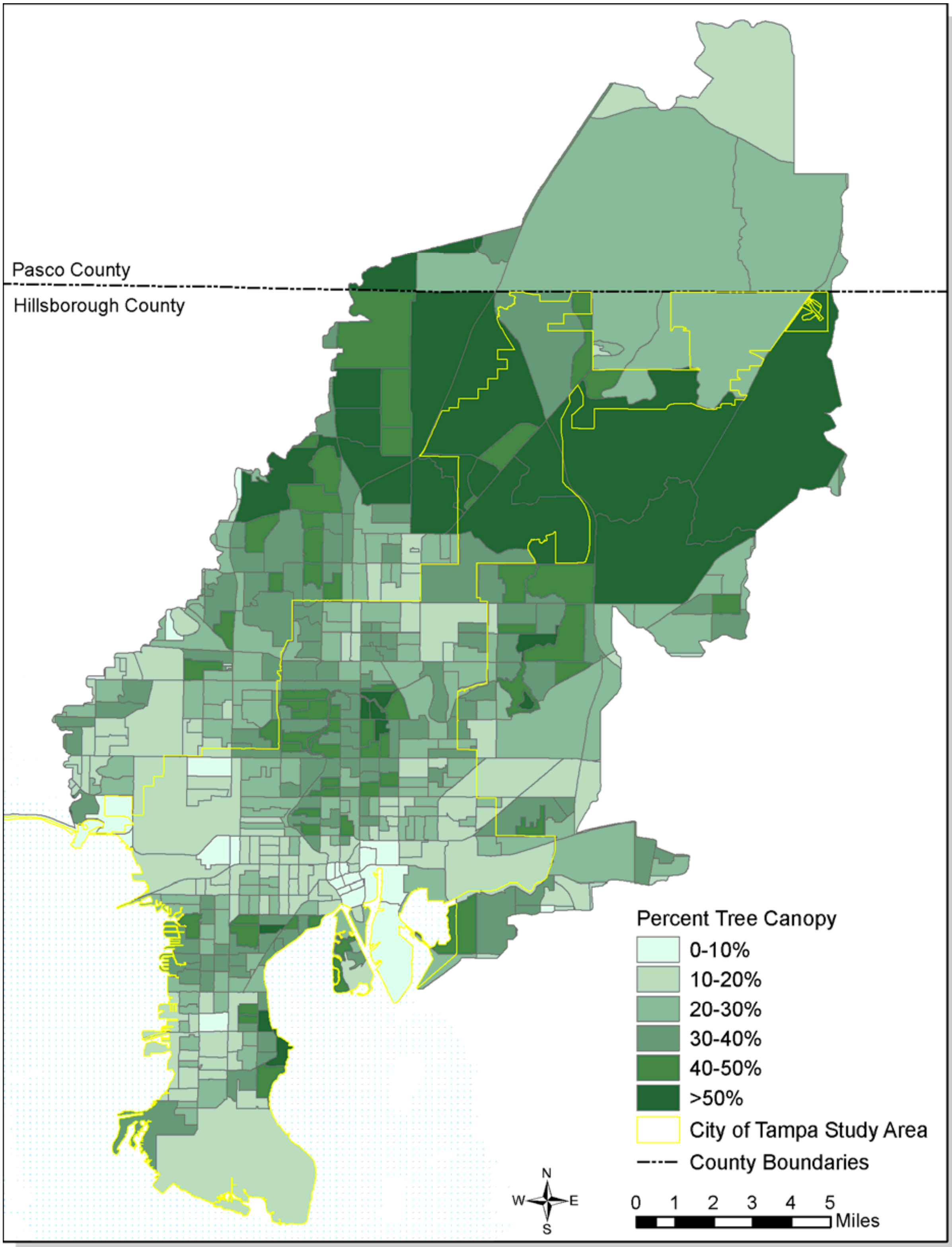


Figure 12. Total percentage tree canopy within each 2000 census block group.

A direct comparison between areas inside and outside of the City of Tampa was completed based upon land use information. The spatial accuracy of parcel boundaries was not deemed sufficient to permit parcel-based analysis of tree canopy north of Tampa (see Figure 2). Instead, a comparison of tree canopy and other vegetation between the City of Tampa and surrounding watershed areas used 2005 1:12,000 scale Land Use/Cover Classification (SWFWMD 2007) to delineate land use/cover boundaries. Tree canopy and other vegetation cover was summarized by Florida Land Use, Cover and Forms Classification System (FLUCCS) level one for all areas, and FLUCCS level two for areas of urban and built-up lands (Table 7). Overall tree cover is 10% less in the City than in the surrounding watershed areas. Tree cover was greater in the surrounding watershed areas for all land use and cover categories except for residential high density, recreational, rangeland, industrial and wetlands.

Table 7. Comparison of percentage tree canopy cover and other vegetation cover by land use cover between the City of Tampa and surrounding watershed areas. Diff. with Outside Tampa is the tree cover in the City minus the tree cover in the surrounding watershed area.

	City of Tampa			**Surrounding Areas**			**Diff.**
Land Use and Cover Classification (FLUCCS Code/Level)	**Acres in LULC**	**Tree Cover**	**Other Veg. cover**	**Acres in LULC**	**Tree Cover**	**Other Veg. cover**	**with Outside Tampa**
Total Urban and Built-up (1/L1)	51,263	23%	29%	51,038	27%	30%	-4%
Residential Low Density* (11/L2)	379	29%	39%	7,350	35%	42%	-6%
Residential Medium Density* (12/L2)	2,232	30%	23%	9,433	43%	26%	-13%
Residential High Density* (13/L2)	24,955	33%	24%	16,028	26%	24%	7%
Commercial and Services (14/L2)	9,880	12%	18%	5,998	15%	20%	-3%
Industrial (15/L2)	2,302	9%	24%	3,635	9%	18%	0%
Extractive (16/L2)	0	na	na	319	7%	47%	na
Institutional (17/L2)	6,889	7%	50%	1,501	13%	37%	-6%
Recreational (18/L2)	2,407	20%	54%	1,714	18%	53%	2%
Open Land (19/L2)	2,217	20%	50%	5,063	21%	45%	-1%
Agricultural (2/L1)	2,234	4%	79%	11,565	13%	72%	-9%
Rangeland (3/L1)	810	43%	45%	5,279	18%	72%	25%
Upland Forests (4/L1)	2,674	67%	26%	9,558	67%	24%	0%
Water (5/L1)	2,414	9%	8%	5,178	11%	9%	-2%
Wetlands (6/L1)	8,759	83%	14%	25,850	82%	15%	1%
Barren Land (7/L1)	157	10%	30%	150	11%	61%	-1%
Transportation, Communication and Utilities (8/L1)	6,574	5%	33%	3,891	7%	38%	-2%
Total All LULC Classes	74,884	29%	29%	112,510	39%	31%	-10%

* Residential densities are generally <2 units/acre for low, 2-5 units/acre for medium and >5 units/acre for high.

Land Cover Summarized by Neighborhood

Neighborhoods provide a meaningful way to divide a larger city into localized communities. The Neighborhood and Community Relations Office of the City of Tampa provides guidelines and a mechanism for citizens to form neighborhood associations. Although neighborhood boundaries are likely defined for historical, cultural and demographic reasons, these geographic boundaries are defined by each association with approval required by the City. The results of the land cover classification using 2006 Ikonos imagery were summarized for each neighborhood association within the City of Tampa based upon the latest association boundaries (Tampa 2007a). Because neighborhood associations were primarily citizen oriented, as opposed to business oriented, results were summarized two different ways: all parcels including right-of-way areas; and residential parcels only.

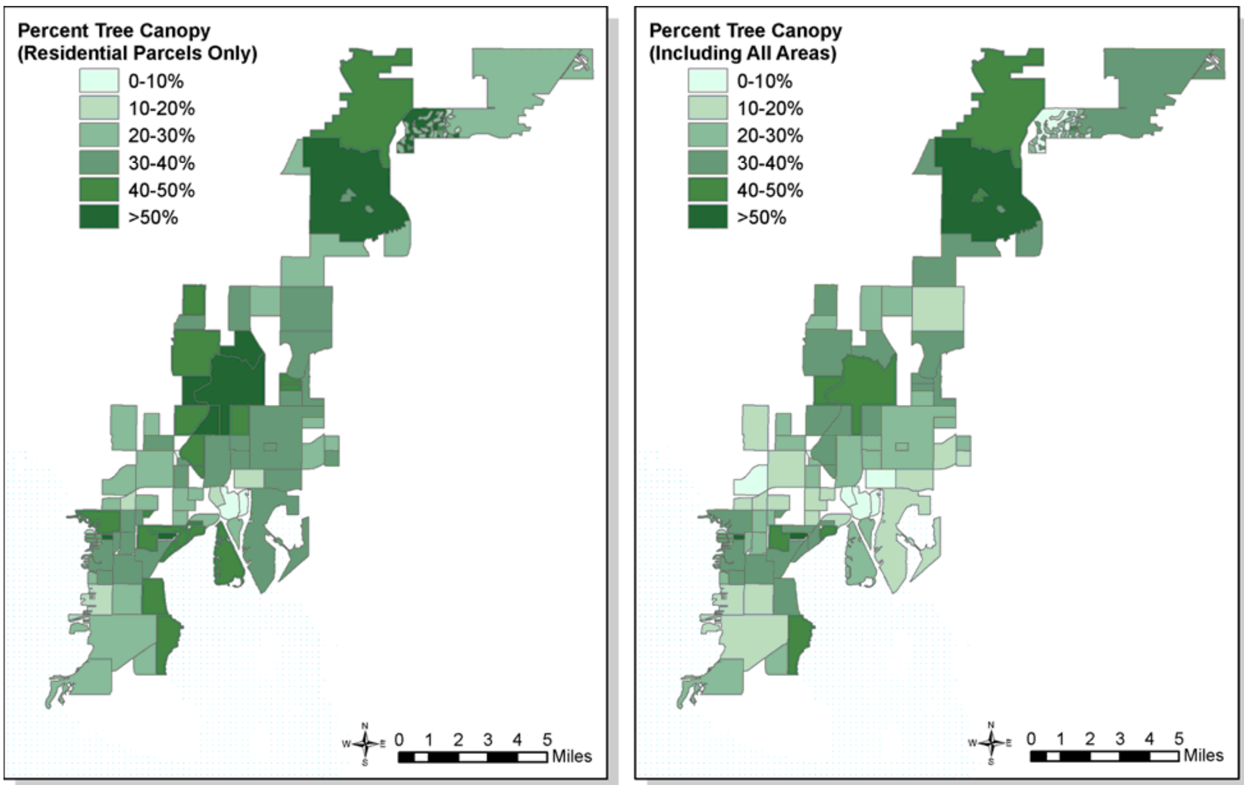


Figure 13. Total percent tree canopy for each neighborhood association area within the City of Tampa. Areas included in the total values for each neighborhood include residential parcels only (left) and all parcels and right-of-way areas (right).

Total percentage of tree canopy cover within each neighborhood association boundary is shown in Figure 13. Areas not defined by a neighborhood association were not included in the analyses. Percentage of total land cover classified as tree canopy, other vegetation and total tree canopy and other vegetation within each neighborhood association is listed in Table 8. The five neighborhood associations with the largest percentage canopy cover on residential parcels only were Tampa Palms, Hunters Green Community, Culbreath Bayou, Riverbend and New Suburb Beautiful, in that order. The five neighborhood associations with the largest percentage canopy cover calculated for all areas of the neighborhood were Tampa Palms, Culbreath Bayou, New Suburb Beautiful, Tampa Palms - The Sanctuary and Hyde Park Preservation. The five neighborhood associations with the largest percentage total vegetation cover on residential parcels were Riverbend, Old Seminole Heights, Sulphur Springs, Rivergrove and Woodland Terrace.

These results illustrate not only the differences in land cover between neighborhoods, but also the impact of residential versus non-residential parcels on land cover characteristics within a neighborhood. Tree canopy cover on residential parcels within a neighborhood was sometimes very different than the total tree canopy cover calculated from all areas of the neighborhood. For example, tree cover for all areas of the Hunters Green Community was only 5%, but tree cover calculated for residential parcels only was 55%. It is also worth noting that a neighborhood with a small proportion of tree canopy may not necessarily contain a small proportion of total vegetation, vice-versa. However, 14 of the top 20 neighborhoods in terms of residential tree canopy were also in the list of top 20 neighborhoods in terms of total vegetation: Culbreath Bayou, Golfview, Hunters Green Community, Hyde Park Preservation, Lowry Park Central, New Suburb Beautiful, Old Seminole Heights, Parkland Estates, Ridgewood Park, Riverbend, Rivergrove, Riverside Heights, South Seminole Heights, Southeast Seminole Heights, Sulphur Springs, Tampa Palms, Wellswood and Woodland Terrace. Additional study would be required to fully characterize the meaning and implications of these differences.

Table 8. Percentage of total land cover classified as tree canopy, other vegetation and total tree canopy and other vegetation for all areas of the neighborhood, and residential parcels (Res. Parcels) only within defined neighborhood association boundaries.

	Tree Canopy		**Other Vegetation**		**Total Tree Canopy and Other Vegetation**	
Neighborhood Association	**All Parcels**	**Res. Parcels**	**All Parcels**	**Res. Parcels**	**All Parcels**	**Res. Parcels**
Ballast Point	42%	45%	20%	19%	62%	64%
Bayshore Beautiful	40%	44%	21%	19%	61%	63%
Bayshore Gardens	34%	40%	15%	10%	49%	50%
Bayside West	16%	19%	26%	24%	42%	44%
Beach Park	34%	41%	19%	18%	54%	59%
Beach Park Isles	18%	19%	14%	13%	32%	32%
Belmar Gardens	30%	36%	27%	27%	57%	63%
Belmar Shores	25%	28%	21%	23%	46%	51%
Bon Air	25%	36%	22%	26%	46%	61%
Bowman Heights	28%	38%	21%	24%	50%	62%
Carver City / Lincoln Gardens	9%	22%	28%	29%	37%	51%
Channel District	3%	6%	6%	2%	9%	9%
College Hill	26%	33%	28%	26%	54%	59%
Cory Lake Isles	9%	0%	65%	67%	74%	67%
Courier City / Oscawana	19%	27%	11%	12%	30%	39%
Culbreath Bayou	55%	54%	15%	14%	70%	68%
Culbreath Heights	21%	39%	26%	24%	47%	63%
Culbreath Isles	31%	31%	17%	16%	48%	48%
Davis Islands Civic Association	29%	43%	26%	14%	55%	57%
Davis Islands Task Force	30%	43%	26%	14%	55%	56%
Drew Park	11%	27%	23%	27%	34%	54%
East Tampa Business & Civic	23%	35%	29%	27%	52%	62%
East Ybor Historic	13%	32%	21%	22%	34%	54%
FairOaks/Manhattan Manor	14%	24%	27%	25%	40%	50%
Florence Villa/ Beasley/Oak Park	15%	33%	27%	34%	43%	67%
Forest Hills Community	30%	37%	34%	29%	63%	67%

	Tree Canopy		Other Vegetation		Total Tree Canopy and Other Vegetation	
Neighborhood Association	**All Parcels**	**Res. Parcels**	**All Parcels**	**Res. Parcels**	**All Parcels**	**Res. Parcels**
Forest Hills Neighborhood	33%	44%	39%	26%	71%	70%
Gandy/Sun Bay South	15%	21%	28%	28%	43%	49%
Golfview	43%	49%	25%	16%	68%	66%
Grant Park	20%	25%	33%	34%	53%	59%
Gray Gables	32%	41%	18%	20%	50%	62%
Harbour Island	25%	26%	8%	8%	33%	34%
Highland Pines	19%	27%	30%	29%	49%	56%
Historic Hyde Park	37%	42%	15%	13%	52%	56%
Historic Ybor	7%	12%	16%	19%	23%	31%
Hunters Green - Brookfield	23%	20%	17%	17%	39%	36%
Hunters Green - Cypress Ridge	27%	24%	17%	18%	45%	42%
Hunters Green - Deer Creek	26%	26%	17%	17%	43%	43%
Hunters Green - Esprit	26%	28%	14%	16%	40%	43%
Hunters Green - Fox Chase	28%	29%	17%	17%	45%	45%
Hunters Green - Hampshire	31%	31%	9%	9%	40%	40%
Hunters Green - Hampton On The Green	29%	29%	15%	16%	44%	45%
Hunters Green - Heather Downs	36%	36%	15%	15%	51%	51%
Hunters Green - Heritage Oaks	19%	20%	33%	28%	53%	48%
Hunters Green - Lakeside	21%	20%	11%	10%	31%	29%
Hunters Green - Laurel Ridge	35%	34%	8%	8%	43%	43%
Hunters Green - Lockwood Links	23%	23%	14%	14%	37%	37%
Hunters Green - Magnolia Chase	27%	27%	17%	17%	45%	45%
Hunters Green - Nathans Court	24%	23%	10%	10%	34%	34%
Hunters Green - Oak Crest	14%	14%	11%	11%	26%	26%
Hunters Green - Oak Trace	32%	32%	10%	10%	43%	43%
Hunters Green - Osprey Point	21%	21%	17%	17%	38%	39%
Hunters Green - Parkside	37%	37%	10%	10%	47%	47%
Hunters Green - Pinnacle	31%	31%	12%	12%	43%	43%
Hunters Green - Quail Creek	27%	27%	14%	14%	41%	41%
Hunters Green - Stonebridge	41%	41%	11%	11%	51%	51%
Hunters Green - Waterforde	20%	18%	12%	12%	32%	30%
Hunters Green - Wynstone	30%	29%	15%	15%	45%	44%
Hunters Green Community	5%	55%	21%	14%	26%	69%
Hyde Park North	20%	26%	14%	10%	34%	36%
Hyde Park Preservation	46%	45%	10%	10%	56%	55%
Interbay	25%	23%	41%	34%	65%	57%
Live Oaks Square	30%	38%	30%	29%	60%	66%
Lowry Park Central	39%	47%	25%	24%	64%	72%
New Suburb Beautiful	55%	52%	11%	11%	66%	63%
New Tampa	33%	26%	38%	20%	71%	46%
North Bon Air	12%	19%	26%	31%	38%	50%
North Hyde Park	15%	26%	19%	22%	34%	48%
North Tampa Community	25%	36%	27%	28%	52%	64%
Northeast Community	31%	34%	25%	27%	56%	61%
Northeast Macfarlane	16%	22%	28%	25%	44%	47%
Northview Hills	21%	24%	36%	30%	56%	54%
Oakford Park	19%	26%	25%	29%	43%	55%
Old Seminole Heights	40%	52%	23%	21%	63%	73%

	Tree Canopy		Other Vegetation		Total Tree Canopy and Other Vegetation	
Neighborhood Association	**All Parcels**	**Res. Parcels**	**All Parcels**	**Res. Parcels**	**All Parcels**	**Res. Parcels**
Old West Tampa	20%	31%	21%	22%	42%	53%
Palma Ceia	30%	40%	20%	17%	50%	57%
Palma Ceia West	23%	37%	22%	26%	45%	62%
Palmetto Beach	15%	30%	24%	20%	39%	51%
Parkland Estates	40%	48%	15%	14%	55%	62%
Plaza Terrace	24%	29%	23%	24%	48%	52%
Port Tampa City	28%	28%	36%	28%	65%	56%
Ridgewood Park	35%	45%	19%	22%	55%	67%
Riverbend	43%	53%	24%	22%	67%	74%
Rivergrove	38%	48%	21%	24%	60%	73%
Riverside Heights	39%	46%	25%	23%	63%	69%
South Seminole Heights	40%	50%	20%	19%	60%	69%
Southeast Seminole Heights	36%	47%	23%	24%	60%	71%
Stadium Area	21%	31%	22%	28%	42%	59%
Stoney Point	27%	27%	18%	15%	45%	41%
Sulphur Springs	36%	51%	22%	22%	58%	73%
Sunset Park	37%	39%	20%	19%	57%	58%
Swann Estates	27%	37%	22%	23%	49%	60%
Tampa Downtown Partnership	5%	10%	9%	13%	14%	23%
Tampa Heights	25%	40%	25%	20%	50%	60%
Tampa Palms	67%	56%	15%	15%	82%	71%
Tampa Palms - The Kensington	30%	30%	15%	15%	45%	45%
Tampa Palms - The Sanctuary	48%	40%	21%	25%	69%	64%
Temple Crest	32%	36%	25%	29%	56%	64%
Terrace Park	20%	31%	32%	31%	52%	62%
The Marina Club Of Tampa	6%	9%	17%	23%	23%	32%
Undefined Neighborhood	19%	34%	37%	24%	56%	57%
University Square	25%	30%	28%	29%	52%	58%
Uptown Council	7%	15%	9%	5%	16%	20%
Virginia Park	30%	36%	23%	24%	53%	60%
VM Ybor	24%	34%	20%	18%	44%	52%
Wellswood	32%	45%	24%	23%	57%	68%
West Meadows	45%	43%	25%	20%	70%	63%
West Riverfront	19%	27%	23%	21%	42%	48%
Westshore Palms	19%	27%	24%	24%	44%	50%
Woodland Terrace	40%	48%	29%	24%	69%	72%
Ybor Heights	29%	38%	21%	23%	50%	60%

Discussion

The City of Tampa devotes resources toward the planting and maintenance of urban trees on public lands and right-of-way, provides regulatory protection of trees on private land and dedicates resources toward the education of citizens on issues pertaining to the urban forest. However, the City currently lacks an overall urban forest management plan. The results of this study should provide valuable information for the City of Tampa to use as part of the development of an overall urban forest management strategy. Furthermore, these results provide baseline information to use as the basis of additional scientific study of the urban forest ecosystem and specific urban forest management strategies. The history of urban forest management within the City of Tampa has included several politically contentious debates, especially related to the Tampa Tree Ordinance. The authors of this study have been careful to remain focused on issues related to the science of urban forest management and ecosystem study. This discussion is provided to highlight some of the important results of the study and to point out some issues which should be considered for future study or as part of separate policy discussions.

In 2006, 29% of the City of Tampa land cover was classified as tree cover using the high resolution Ikonos imagery. Unfortunately, there are no known scientific methods to determine whether this was the "correct" amount of tree cover for the City, or even what an appropriate goal would be for tree canopy. American Forests, the non-profit organization advocating "healthy forest ecosystems for every community", recommends a goal 40% citywide tree cover, 50% suburban residential tree cover, 25% urban residential tree cover and 10-15% tree cover in the urban core (American Forests 2007). Indeed, some of the tree cover values for Tampa (e.g. 38% residential tree cover) appear to exceed these recommendations even if overall tree cover is much less. However, in order to serve as a target for future urban forest management strategies, the City of Tampa should set specific tree cover and other urban forest related goals.

The 29% tree cover value could be put into perspective based upon a comparison with other cities. Table 9 summarizes tree canopy cover for selected southeastern cities based upon the published and unpublished work of other researchers (Nowak et al. 1996; American Forests 2007). Because the methods and dates vary for the results presented here, caution should be used when interpreting these results. Jacksonville represents perhaps the best comparison in terms of location, methods and timeframe; Tampa's tree cover ranks only somewhat lower.

Table 9. Reported tree cover in selected southern cities.

	Tree Cover	**Reported Sampling Date**	**Source**
Baton Rouge, LA	55%	bef. 1992	Nowak et al. 1996
Austin, TX	39%	1977	Nowak et al. 1996
Birmingham, AL	37%	1977	Nowak et al. 1996
Montgomery, AL	34%	2002	American Forests 2007
Jacksonville, FL[a]	32%	2004	American Forests 2007
Atlanta, GA	29%	1996	American Forests 2007
Tampa, FL	*29%*	*2006*	*This Study*
Dallas, TX	28%	1985	Nowak et al. 1996
San Antonio, TX	27%	bef. 2003	American Forests 2007
New Orleans, LA	24%	2001	American Forests 2007

[a] Downtown Jacksonville only

Results from the tree canopy change analysis indicated an overall increase in tree cover between 1996 and 2006 within the City of Tampa. In fact, after experiencing a net loss in tree canopy cover during the 1970s and 1980s, tree cover in 2006 returned to almost the same amount as in 1975 (see Figure 9). These results were surprising when one considers that population was estimated to increase nearly 10% between 2000 and 2006 (US Census Bureau 2007). If one assumed a net positive benefit provided by trees, then this result was encouraging. The cause of the increase could be one or more of any number of factors, including: tree maintenance and planting practices of citizens, businesses and/or government; enforcement of tree regulations; landscaping practices by developers; public tree planting initiatives; climatic factors; or other reasons. Unfortunately, given the available data it is impossible to determine the specific cause of the apparent increase in tree canopy cover between 1996 and 2006. Likewise, it is also impossible to predict the magnitude and direction of future changes to citywide tree cover. A more detailed study would be required to elucidate the most important drivers of tree canopy cover change in Tampa.

Tree cover can serve as a valuable indicator of the status and health of the urban forest. However, urban areas are much too complex to simply suggest that more tree cover is always better or that cities should strive to maximize tree cover without considering other factors. Existing tree cover in the City was 29% in 2006. If achieving maximum tree cover was the only goal, the City could conceivably plant tree in areas classified as other vegetation (29%) and achieve a 58% tree cover. Following the work of the USDA Forest Service Raciti et al. 2006, these areas where trees could be planted include “possible urban tree canopy”. Neighborhood statistics (Table 8) from this study indicate that the possible urban tree canopy as calculated by total vegetation cover was 26% or greater for over 97% of all neighborhoods. However, one should also consider where it is economically feasible and socially desirable to plant trees.

Results from this study indicate that the possible tree canopy as measured by tree cover plus other vegetation is fairly large within most areas of the City and within most land uses. Possible tree canopy on the three most extensive land uses, public/quasi-public institutional, residential and right-of-way was 66%, 60% and 44%, respectively. Due in part to conflicts with underground utilities, it is unlikely that all areas of right-of-way could be planted with trees. Similarly, it would certainly not be desirable to plant trees on the ball fields of public institutions. When establishing urban management goals, the City of Tampa should take a holistic approach by considering environmental, economic and social issues. Tree cover goals should attempt to maximize the benefits provided to people and ecosystems while minimizing the economic, environmental and social costs. Furthermore, since the urban forest includes both public and private lands, the City should develop urban forest goals through an inclusive stakeholder-driven process.

Geographic information system (GIS) is a generic term used to describe the collection of data and analytic tools used to capture, view, manage and analyze spatial information. One of the products of this study was an existing land cover GIS data layer and its subset, a *green infrastructure* data layer which included the location of tree cover and other vegetation cover within the City and surrounding areas. Just as grey infrastructure (i.e. roads, sidewalks, utilities, etc.) has been managed to provide important services, green infrastructure should be managed to provide ecosystem services, such as: carbon storage and sequestration, pollution removal, stormwater runoff reduction and energy savings. The green infrastructure data layer should be integrated into the City’s geographic information system and used by planners, urban foresters, civil and environmental engineers, developers and others as part of their daily management and decision making.

Finally, changes to tree canopy occur as a result new tree plantings, protection and maintenance of existing trees, and mortality due to natural or human-induced causes. All of these factors must be considered when trying to develop an urban forest management strategy or when trying to explain the causal mechanisms of past changes. Unfortunately, scientific knowledge related to urban tree mortality has been extremely limited, and understanding the impact of tree plantings or protection and maintenance efforts would generally require long-term, intensive study. The Ecological Assessment sample plots established as part of this study, together with a periodic (every five years) high-resolution classification of land cover should provide the basis for such study. When forming urban forest management goals and policies, the City should develop measurable indicators to evaluate the management plans that could be tested as part of future urban ecological assessment research.

Ecological Assessment

The ecological assessment provides a detailed look into some of the economic and ecological values of the City of 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. During spring to early fall of 2007, two hundred and one plots were sampled and analyzed to help determine the vegetation structure, functions, and values of the urban forest in Tampa. The following section of this report documents the methods and the results from these analyses.

METHODS

The City of Tampa's urban forest assessment was conducted from February to July, 2007. 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 represented 437 acres (Figure 1), and one sample point was 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.

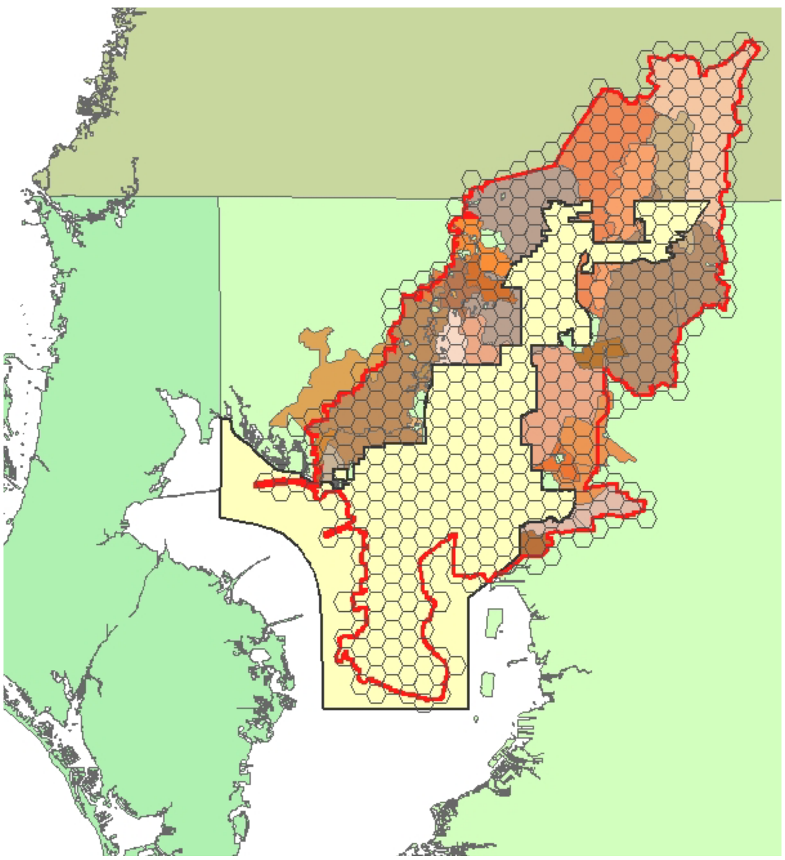


Figure 1. Study area (Tampa in yellow) with grid overlay.

Two-hundred and one permanent inventory plots were located within Tampa's political boundary. 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 (for shrubs and trees), tree diameter, crown width, height to live crown, total height, and tree health attributes. The 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 and a comparison to January 2007 parcel data is provided in Appendix E. The acreage for each land use category (Table 1) was calculated using the 2007 parcel geo-database.

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)**
Agricultural	2	1,943
Commercial	22	5,530
Industrial	8	3,011
Public / Quasi-Public / Institutions	29	21,656
Public Communications / Utilities	5	1,520
Recreational / Open Space / Natural	35	963
Residential	69	22,810
Right of Way / Transportation	24	12,140
Vacant	4	4,743
Water	3	568
Total	201	74,884

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.

We utilized the **U**rban **For**est **E**ffects Model (UFORE) (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. Being that Tampa is a subtropical city some features of the model needed to be modified because it was designed for temperate ecosystems. For example, the model only considers dicots as ‘woody’ species. However, palms (mononcots) are an important component to all strata in the urban forest of Tampa. Our research team worked directly with the developers of this model in order to account for palms in the data collection process and model outputs. As a result, the definition of each stratum was modified to include palm species.

The protocol used for sampling each plot can be referenced in the 2008 i-Tree User’s Manual (v2.0), section 1.7 (www.itreetools.org/resource_learning_center/elements/i-Tree_v20_UsersManual.pdf). 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 but they can be added (palm and woody cover) for the purpose of calculating total cover.

The Composition of Tampa's Urban Forest

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.

Diversity

Species richness or diversity is simply the number of species in a given land use area. Diversity is an important attribute in the urban forest and can be an indication of its vulnerability or resiliency to such natural disturbances as insect and/or disease outbreaks. Areas that have low species diversity are more likely to be less resilient to such disturbances. In this study 93 tree species were identified in the city of Tampa (Appendix F). The *Residential* land use had the highest diversity, containing 76% 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 (5 species) was found on *Industrial* lands (Figure 2).

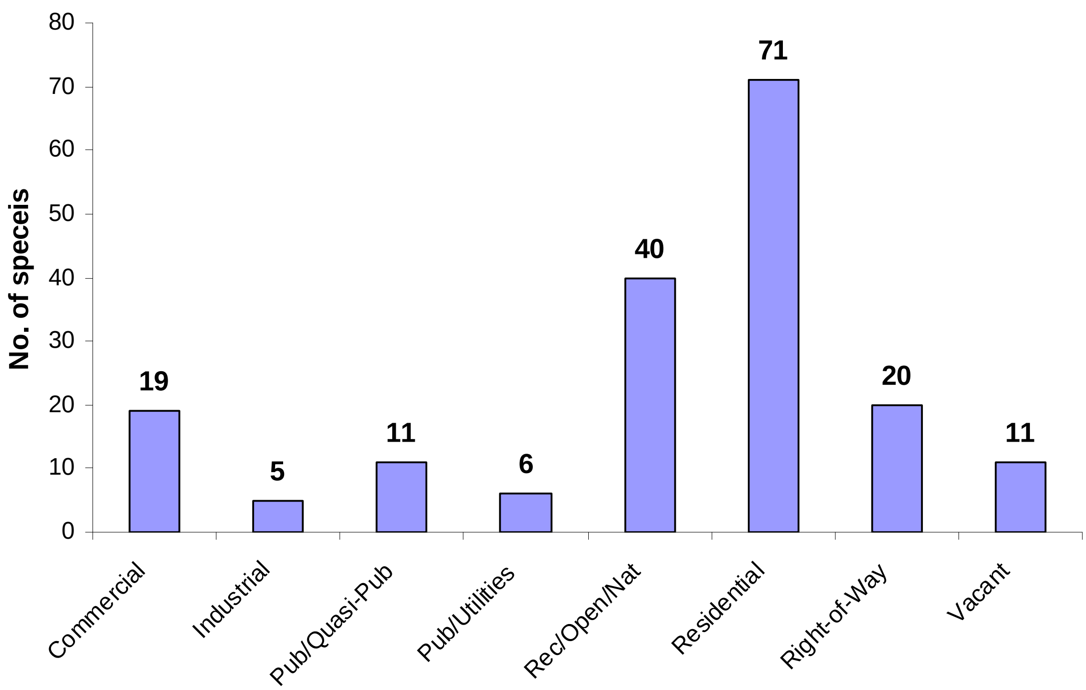


Figure 2. Number of tree species by land use designation in Tampa.

Native and Non-native (Exotic) 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 tend to be non-native but can also be native, regardless they are considered invasive species because they negatively impact ecological functions of the forest by reducing species diversity.

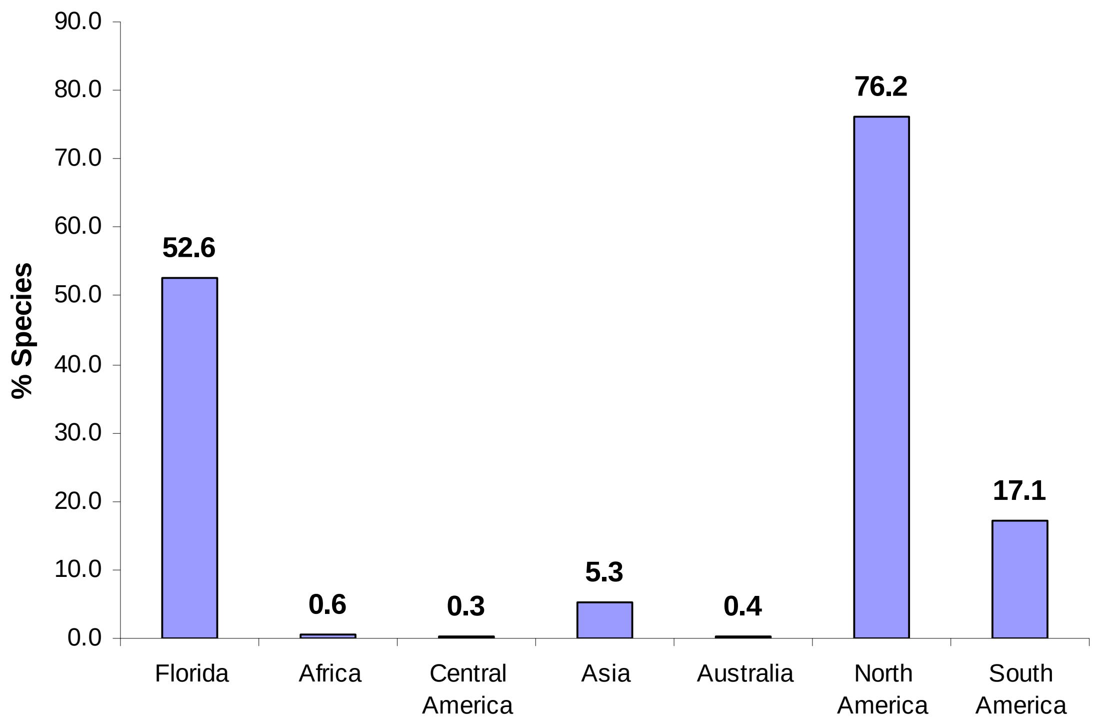


Figure 3. Percentage of tree species found in the study by their respective region of origin. Species native to Florida are a subset of the species native to North America.

Of the 93 tree species found in Tampa, 76% are native to North America and approximately 50% are native to Florida (Figure 3). Ecologically, the fact that only half of the species are native to this state is less than desirable. But perhaps of greater concern is that one of the most common tree species in Tampa, Brazilian pepper (*Schinus terebinthifolius*) (Figure 4), is both non-native and invasive. It readily spreads into disturbed areas such as fields and ditches, along canals, and in flatwood forests, creating thickets that are costly to eradicate. The dominance of this species is not confined to Tampa; it is estimated to be established on over 1 million acres throughout the state (Langland and Burks 1998). Considering Brazilian pepper is the second most common species in the city it will be important to develop a comprehensive plan to manage this species.

Abundance

It is estimated that there are over 7,817,408 million trees in the city of Tampa (Table 6). For this study a tree is defined as a woody stem with a DBH of 1 inch or greater. The two most common species, based on the number of stems in the urban forest, are red mangrove (*Rhizophora mangle*) (42%) and Brazilian pepper (16%). This is an interesting and somewhat unexpected result because red mangrove is not typically considered to be dominant and Brazilian pepper is an ecologically undesirable invasive species.

By establishing plots throughout the entire urban forest and not just focusing on street trees in the inland areas this inventory promotes a stronger understanding of the complexity of Tampa's forest composition and an awareness of the relative abundance of species that otherwise might have been overlooked.

Red mangroves are a state protected coastal tree species and they serve many important ecological functions such as stabilizing sediments, filtering nutrients, providing protection from storm surge, preventing flooding and coastal erosion, and providing habitat for a large quantity of wildlife including microorganisms, invertebrates, fishes, amphibians, reptiles, birds, and mammals, some of which are threatened and endangered (Odum and McIvor 1990). Brazilian pepper is a non-native species originally from South America and is considered to be highly invasive in Florida, meaning it has a negative impact on ecosystem function. It aggressively competes with native vegetative species for resources such as light, nutrients, and space, and currently does not have any predators to help control its spread in Florida (Langland and Burks 1998; Gioeli and Langeland 2006). This species is considered to be undesirable in our state, yet as we will report, it currently provides some positive functional values to Tampa in the form of carbon sequestration and pollution reduction.

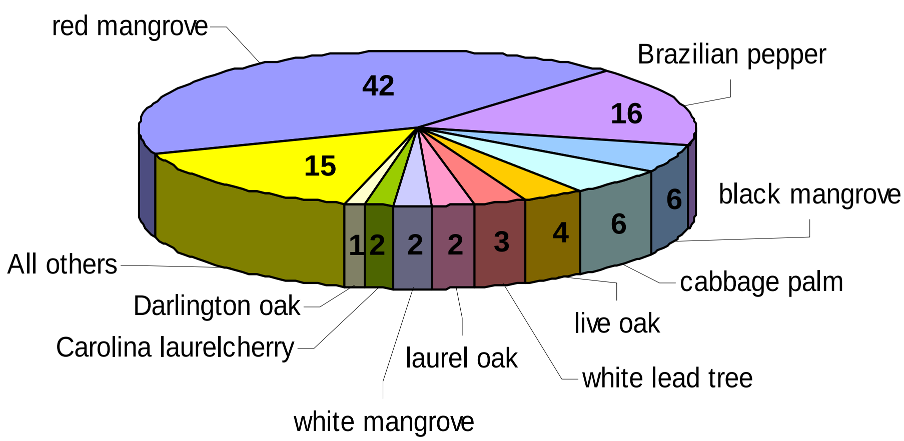


Figure 4. Top ten trees species and their associated percentages by the number of stems in the city of Tampa.

The ten most common tree species account for approximately 84% of all stems (Figure 4). In addition to red mangrove and Brazilian pepper, the remaining top ten species are the native species black and white mangrove (*Avicennia germinans* and *Laguncularia racemosa* respectively), live oak (*Quercus virginiana*), laurel oak (*Q. laurifolia*) and Darlington oak (*Q. hemisphaerica*) oak), cabbage palm (*Sabal palmetto*), Carolina laurel cherry (*Prunus caroliniana*), and the non-native invasive white lead tree (*Leucaena leucocephala*) (Figure 3).

The Structure of Tampa's Urban Forest

Forest structure is defined as a description of the distribution of vegetation, both horizontally and vertically, across a given area. Various physical attributes of the forest vegetation can be measured and calculated to help determine forest structure such as: tree density, diameter and height distribution, crown area, tree health, leaf area, and biomass. When we are able to quantify and identify the structure of the forest, it is then possible to relate this structure to certain functions. 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 within the city. This inventory estimated an average of 104 TPA throughout the city of Tampa. The land use with the highest density of trees (413 TPA) is *Recreational/Open/Natural (RON)* areas (Figure 5). In general, of the ten land use categories utilized in this study, the *RON* land use is thought to have had the least direct impact by urbanization. Therefore we suggest that the *RON* land be used as a benchmark to which other, more highly urbanized land can be compared and we make such comparisons throughout this report.

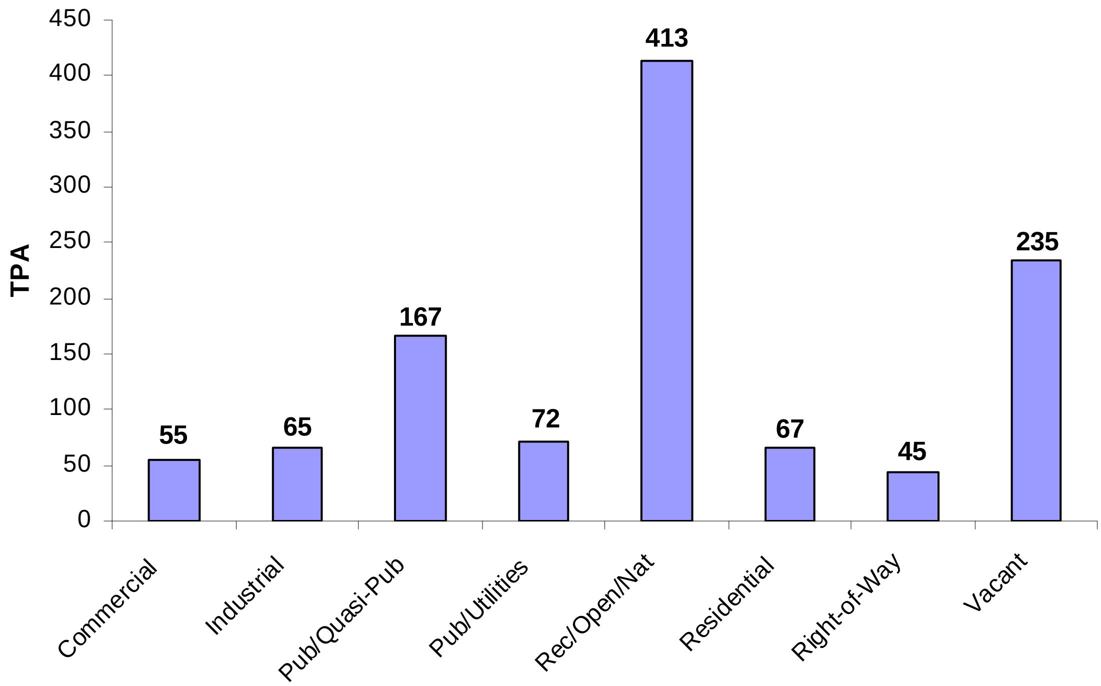


Figure 5. Average trees per acre (TPA) for each land use in Tampa.

Size Distribution

The diameter distribution of trees in Tampa is skewed towards smaller diameter classes (Figure 6). 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 63% of the stems and Brazilian pepper makes up an additional 7%. 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, or trees greater than 36 inches, represents just a tenth of a percent (0.1) of the population (Figure 6). 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 (67%) and bald cypress (16%) 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.

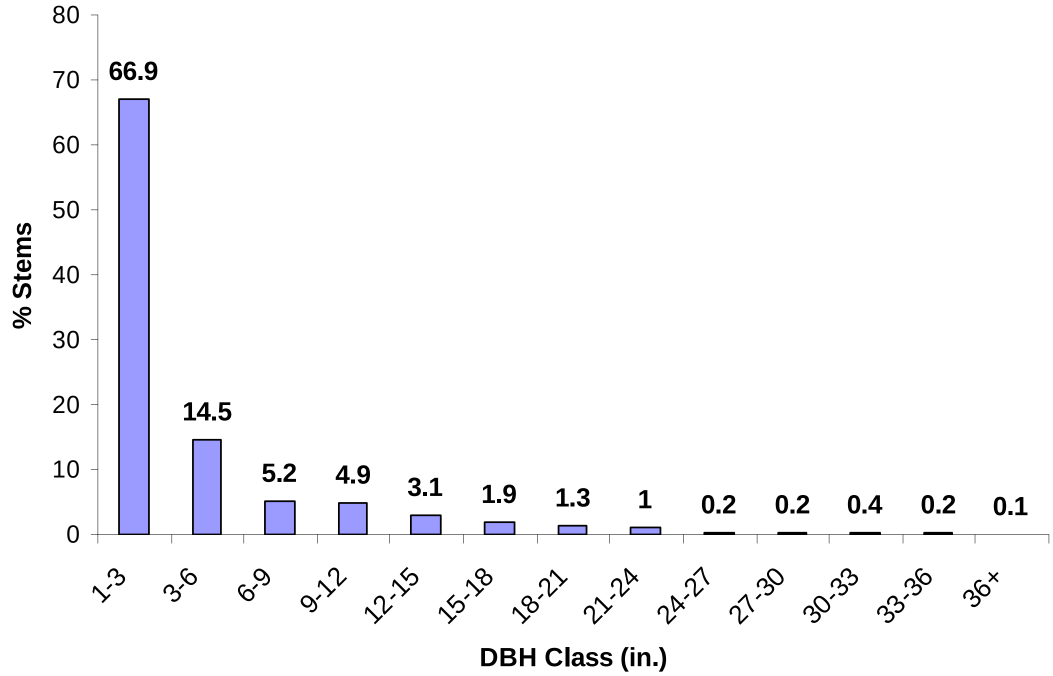


Figure 6. Diameter (DBH) distribution by diameter class for trees in the city of Tampa.

Cover of Urban Forest Strata

I. Tree Cover

Tree canopy cover is a common metric used to investigate the amount of area directly and indirectly influenced by trees. It is ecologically important because it indicates how much of an effect the forest has on the micro climate (e.g. shade in parking lots and homes) as well as the interception of rainfall (storm water flow). It is also a metric that is commonly used to determine the effectiveness of urban tree ordinances and polices.

The city wide average tree cover is 28.1% (± 5.5% @ 95% confidence interval). It is important to note that this tree cover is variable and not homogeneously distributed across all land uses (Table 2). The land uses where canopy cover exceeds the city's estimated average canopy cover are: *Residential* (35.8%), *Recreational/Open/Natural* (52.0%), and *Vacant land* (76.3%). Together they represent approximately 58% of the total tree cover within the city. If one considers the *Recreational/Open/Natural* land use as a benchmark for comparison, its average tree cover is nearly twice that of the average tree cover in the city.

Table 2. Percent canopy cover by land use* and their proportional contribution of cover in Tampa.

Land Use	**Percent Tree Cover**	**Proportion (%)**
Commercial	22.5	6
Industrial	18.1	3
Public / Quasi-Public / Institutions	16.6	17
Public Communications / Utilities	26.0	2
Recreational / Open Space / Natural	52.0	2
Residential	35.8	39
Right of Way / Transportation	24.6	14
Vacant	76.3	17
Average Tree Cover	**28.1**	**100**

*Land uses not listed had canopy cover of zero.

While tree canopy is important to measure and has been a useful attribute in the past, it only provides information about one of the many values trees furnish. With the outputs produced by the UFORE model, we are able to view the forest in its entirety. The outputs that describe forest composition (species that make up the forest), structure (DBH, height, spatial arrangement, etc.) and function (air pollution removal, carbon storage and sequestration, and energy savings) offer greater insight into the benefits of the urban forest and how we can manage this resource.

II. 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.

Table 3. Percent shrub cover by land use* and their proportional contribution of cover in Tampa.

Land use	**Percent Shrub Cover**	**Proportion (%)**
Commercial	15.2	8
Industrial	3.1	1
Public / Quasi-Public / Institutions	13.2	28
Public Communications / Utilities	10	2
Recreational / Open Space / Natural	37	4
Residential	14.3	32
Right of Way / Transportation	6.9	8
Vacant	36.3	17
Average Shrub Cover	**13.5**	**100**

*Land uses not listed had a shrub cover of zero.

In Tampa it is estimated that approximately 13.5% of the city is covered with shrubs (Table 3). For the shrub layer, the land use with the most cover is in *Recreational/Open/Natural* areas (37%), which is notable as we have suggested it might be considered the land use least impacted by urbanization.

III. Ground Cover

Ground cover is divided into two broad categories: impervious (asphalt, buildings, and cement) and pervious (bare soil, duff, 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 three percent of the ground cover in the city is classified as impervious (Figure 7). The land use areas with the greatest amount of impervious surfaces were those designated as *Right Of Way* (56%), *Commercial* (46%), and *Industrial* (43%) (Figure 8). For comparison purposes *Recreational/Open/Natural (RON)* land use areas had nearly 12% impervious ground cover surface demonstrating that they are not without some impacts from urbanization.

The land use categories with the greatest amount of pervious surface ground cover were, *Vacant* (91%) and *RON* (88%) (Figure 8). It is often assumed that pervious surfaces have positive hydrological impacts. Our study sub-divided the pervious surface area into seven categories (Figure 6) since there are different inferences one can make about the hydrological impacts of each. For example 30% 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 2007 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 22% in our region by 2025 (FDEP 2007b). Therefore, the amount of area in maintained grass can be important to understand when developing water conservation strategies and policies.

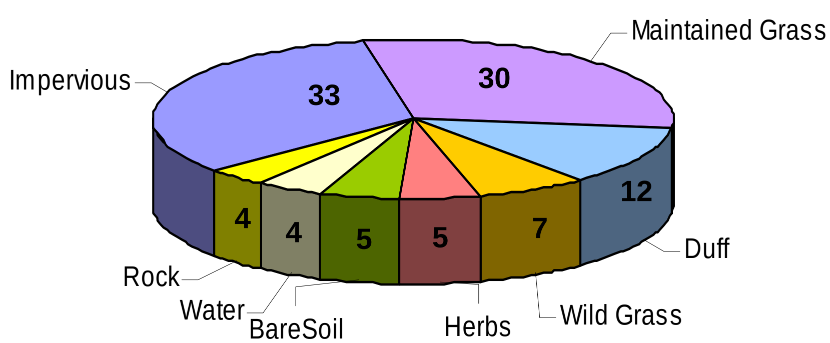


Figure 7. Distribution of ground cover types by percent in Tampa.

The land uses with the highest percentage of maintained grass was *Public/Quasi-Public/Institutions* (43%) and *Residential* (36%). This information can help policy makers and educators target programs to increase awareness of water conservation techniques and practices.

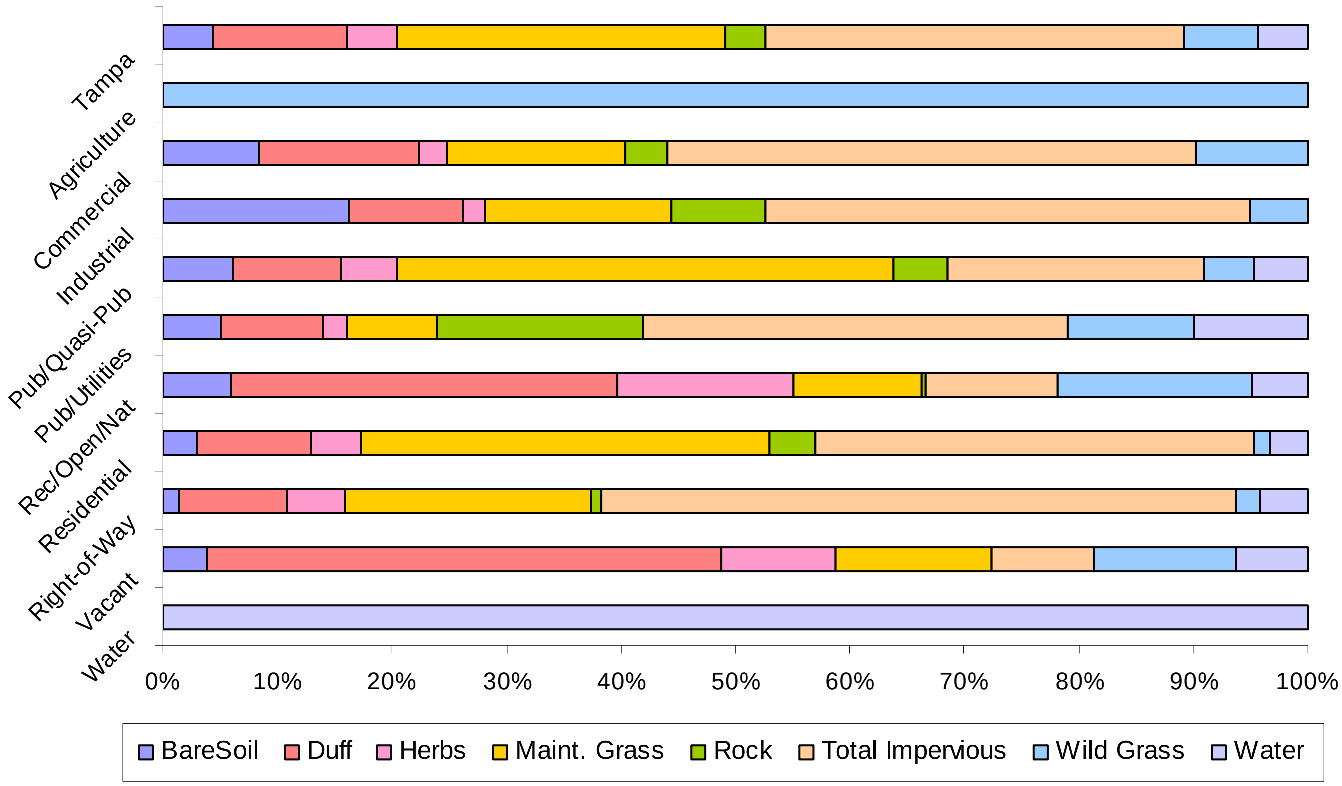
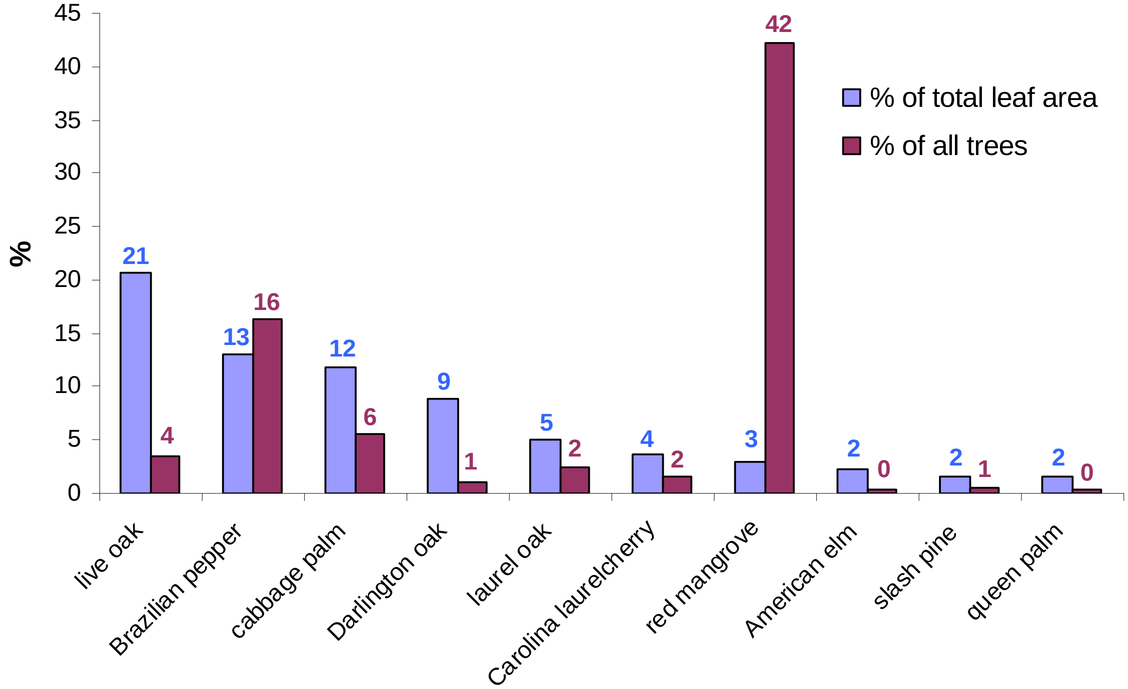


Figure 8. Proportional distribution of ground covers in Tampa by land use.

Leaf Area

Leaf area (LA) is a three-dimensional measure of the total green leaf surface area on a tree or shrub. This differs from canopy cover, a two dimensional measure, because it is calculated for each tree and shrub regardless of canopy position or overlap. Leaf area is another measure that is useful in quantifying some of the functions of the urban forest such as pollution removal. The tree species with the greatest LA is live oak (21%) but live oaks only represent 4% of the tree population in Tampa's urban forest (Figure 9).



*values of zero represent percents of less than 1

Figure 9. Percent leaf area by species (blue) and the percentage of total trees each species represents (red) (Darlington oak is also commonly known as laurel oak).

This demonstrates that although not abundant, live oak contributes greatly to the urban forests environmental services with its large sprawling crown. Brazilian pepper, the second largest contributor to leaf area (13%) in Tampa, is also plentiful with its number of stems (16%). As it has been discussed throughout this report, Brazilian pepper is a non-native invasive species. A great deal of money is being spent by federal, state, county, and municipal governments to eradicate this plant species due to its aggressive nature. Because leaf area is important to urban forest functions like pollution removal, managers will need to consider how to replace the leaf area lost when Brazilian pepper is controlled. Finally, the most dominant tree species in the urban forest based on the number of stems (42%) was red mangrove but it only represents 3% of the leaf area within the city.

Importance Values

It can be difficult to determine which trees are important contributors to the urban forest in Tampa. This is because some species have large numbers of stems but low leaf area and vice versa. Ecologists overcome this uncertainty by calculating an importance value (IV) for each species based upon its relative frequency (% of population) and relative leaf area. When these values are summed the IV can be used to rank all tree species.

Table 4. Importance value (IV) for top ten species; IV = %Pop + %LA.

Common Name	%Pop[a]	% LA[b]	IV[c]
red mangrove	42.2	3	45
Brazilian pepper	16.4	13	29
live oak	3.5	20.6	24
cabbage palmetto	5.6	11.8	17
Darlington oak	1.1	8.8	10
laurel oak	2.4	5.1	8
Black mangrove	5.6	1.2	7
Carolina laurelcherry	1.6	3.6	5
White lead tree	3.1	1.4	5
White mangrove	2.4	1.2	4

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

In this study the top three species, in terms of highest IV, are red mangrove, Brazilian pepper and live oak (Table 4). Mangroves are generally concentrated along Tampa's shoreline, Brazilian pepper is commonly found on disturbed sites throughout the city, and live oaks tend to occur in uplands on well drained sites. Two of these species are native to Florida and one is a non-native invasive species. The fact that Brazilian pepper is one of the top three species in terms of importance is both disturbing and challenging. While this species is deemed a noxious weed it represents a significant portion of the urban forest. It is challenging to control because it readily spreads by human activities (planted by unaware homeowners for landscaping) and animals (birds eat the fruit and excrete the seed elsewhere). Eradication of Brazilian pepper will leave a gap in the urban forest that will need to be replaced by other native tree species.

The Value of Tampa's Urban Forest

The urban forest is a valuable resource for many reasons. It is important for providing vegetative and wildlife biodiversity and habitat, and also performs many ecological functions. Some of these functions 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. As the average maximum temperature in Tampa in July 2007 was 90ºF and average winter temperatures ranged from 59ºF to 77ºF in December 2007 (NOAA 2008), reducing energy consumption to regulate building temperatures in Tampa is highly desirable. Unlike parts of the northeastern and northwestern US, air conditioning is commonly used in residential homes in west central Florida, making energy consumption high in the summer months. Trees near buildings can provide shade during the day, thereby helping to reduce temperatures of buildings and thus the energy required to cool them. In the winter months trees can either increase or decrease energy consumption depending on the tree species characteristics (deciduous or evergreen) and its location relative to a building. For example, an evergreen species that shades a building in the summer may reduce energy consumption, yet in the winter may increase the amount of energy required to heat that same building. However, if this tree were deciduous then the effects of shading during the winter would be less because the tree would shed its leaves. However, a tree with a dense canopy in the winter months (i.e. evergreen) can act as a windbreak, reducing heat loss and therefore reducing the amount of energy required to heat a building.

The energy conserved by trees in the urban forest of Tampa was calculated using the following criteria. 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. This data was input into the UFORE model to calculate an energy conservation estimate in megawatt hours (MWh) and million British thermal units (MBtu). Based on these calculations the total amount of carbon emissions avoided due to a decrease in energy production was estimated. Values for energy conservation estimates were calculated only for residential homes in the *Residential* land use category utilizing the average rate of energy consumed by residential buildings in Tampa, 2007 (McPherson and Simpson 1999). This rate was provided by Tampa Electric Company (TECO) and equaled $114.54/MWh and $33.56/MBtu.

Table 5. Energy conserved and associated dollar values due to the proximity of residential buildings to trees in 2007.

	Heating	**Cooling**	**Total**
Energy Conserved			
MBtu[a]	2,994	n/a	2,994
MWh[b]	106	34,637	34,743
Carbon avoided	68	6,117	6,185
US Dollars Saved			
MBtu	$100,479	n/a	$100,479
MWh	$12,141	$3,967,322	$3,979,463
Carbon avoided	$1,389	$124,292	$125,681

[a] Million British Thermal Unit
[b] Megawatt-hour

The total amount of energy conserved in cooling residential buildings was 34,743 MWh's with an associated value of $3.9 million dollars (Table 5). In addition, the amount of energy conserved by reducing the need to heat a building was approximately 2,994 MBtu's, saving Tampa's citizens $100,479. Finally, it was estimated that the total amount of carbon emissions avoided from energy production by power plants as a result of conserving energy was 6,185 tons with an associated value of $125,681. Therefore, in 2007 the total dollar amount trees saved residents in Tampa was $4.2 million dollars.

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), particulate matter (PM_{10}), 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 less than 10 micrometers are other pollutants that can cause serious respiratory issues. PM_{10} consists of suspended microscopic droplets (liquid or solid) that are small enough to be inhaled and eventually penetrate into the lungs. Fortunately, trees physically intercept particulate matter on their leaves (leaf area), thus improving air quality.

Trees also cleanse 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). These pollutants can have adverse affects on tree health, which varies by species.

Table 6. Tonnage and associated dollar values for pollutants removed by trees and shrubs in Tampa, 2007.

	Pollutant	**English (short) tons**	**US Dollars**
Trees	CO	66	$57,367
	NO_2	52	$318,661
	O_3	456	$2,796,010
	PM10	209	$855,141
	SO_2	111	$165,773
Shrubs	CO	32	$27,570
	NO_2	27	$167,738
	O_3	236	$1,446,730
	PM_{10}	115	$469,239
	SO_2	56	$84,366
Total		**1360**	**$6,388,595**

Not only do trees help improve the air quality in urban areas, they also do it in a cost effective manner. In 2007, the UFORE model estimated that Tampa's trees and shrubs removed 1,360 tons of pollution with an estimated value of $6.3 million dollars (Table 6). The UFORE 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 were calculated with guidelines suggested by Murray et al. (1994).

An important concept to understand is that the structure of the forest affects the functions of the forest. In this case, because we have information about the vertical distribution of the vegetation (trees and shrubs), we can better estimate pollution reduced by the forest. Trees are attributed to removing two-thirds (894 tons) of the air pollution and the remaining one third (466 tons) is attributed to the shrub strata. This highlights the importance of the understory component of the urban forest, which is often overlooked.

Carbon Storage and Sequestration

Global climate change is a concern shared by scientists and government leaders throughout the world. On July 13, 2007 Florida Governor Charlie Crist signed three executive orders addressing global climate change by reducing greenhouse gas emissions, increasing energy efficiency, and pursuing more renewable energy sources. In February 2008 Tampa Mayor Pam

Iorio signed the U.S. Mayors Climate Protection Agreement to reduce greenhouse gas emissions. Urban forests can significantly contribute to all three of these policy goals and in particular can contribute to the sequestration and storage of atmospheric carbon.

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. This time span can be extended if the tree is harvested to make a product (i.e. furniture) thus sequestering the carbon for additional years. Carbon sequestration rates vary by species but in general healthier and more vigorous trees tend to sequester carbon at higher rates than unhealthy trees. Tree health can be maximized through proper management and maintenance (e.g. pruning).

In Tampa approximately 69% of the trees are considered to be in excellent or good health, 11% are in fair health, and the remaining 20% are in poor condition or lower. A natural forest tends to have trees that are classified in all of these health class conditions, each providing an array of wildlife habitat and ecosystem functions. Having a variety of tree health conditions in a forest represents its heterogeneity in age, species, resource availability, etc. In the urban forest maintaining tree health is a function of sound management practices and it will vary across the city depending on management intensity.

One way to understand the value of urban forest management is to look at tree health by land use. The highest percentage of healthy trees in Tampa are those that were under some degree of public management: *Public/Quasi-Public/Institutions* (96% healthy), *Right of Ways* (95% healthy), and *Public Communications/Utilities* (80.5%) (Figure 10). Trees in excellent or good health for both *Residential* and *Commercial* land uses average about 50% of their total trees, but the *Residential* areas have a larger percentage of trees in fair condition (31%) than *Commercial* areas (17%). The land use we consider a natural benchmark (*Recreational/Open/Natural*) has 41% of the trees classified in excellent or good health and 21% in fair condition. Lastly, the lowest percentage of healthy trees occurs on *Industrial* and *Vacant* lands.

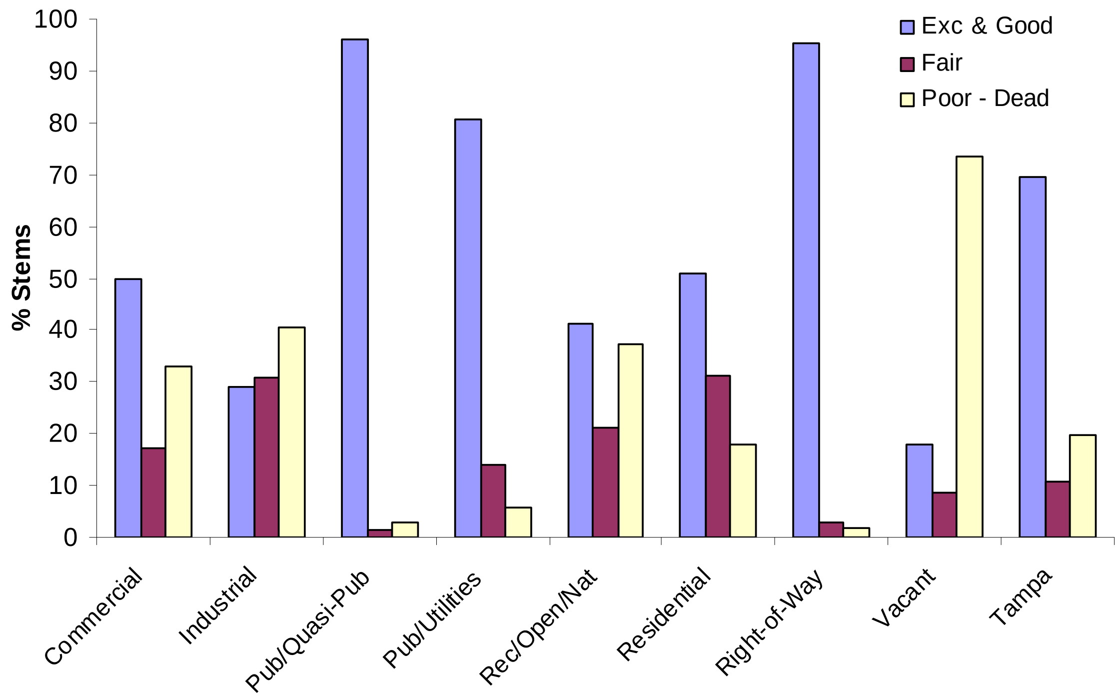


Figure 10. Relative tree health condition classes by land use in the city of Tampa.

The amount of carbon that a tree stores fluctuates as tree grows (increases), dies (ceases), or decays (decreases). The total amount of carbon currently stored by the trees of Tampa's urban forest is estimated to be 511,141 tons with a value of $10,386,389 (Figure 11). Since carbon is released back into the atmosphere after a tree dies and begins to decay, this value also represents the total amount of carbon that could be released if trees were no longer a part of the urban infrastructure. The value of carbon (stored and sequestered) is calculated using a conservative $20.32 per short ton of carbon (Frankhauser 1994). In Tampa 34% of the stored carbon is in live oaks, which are known to live up to 300 years. An additional 31% of carbon is stored in Darlington oak (*Quercus hemisphaerica*) and laurel oak (*Quercus laurifolia*) combined. These two tree species tend to have a shorter lifespan closer to 70 – 100 years and are known to be susceptible to fungal decay and damage during large storm events.

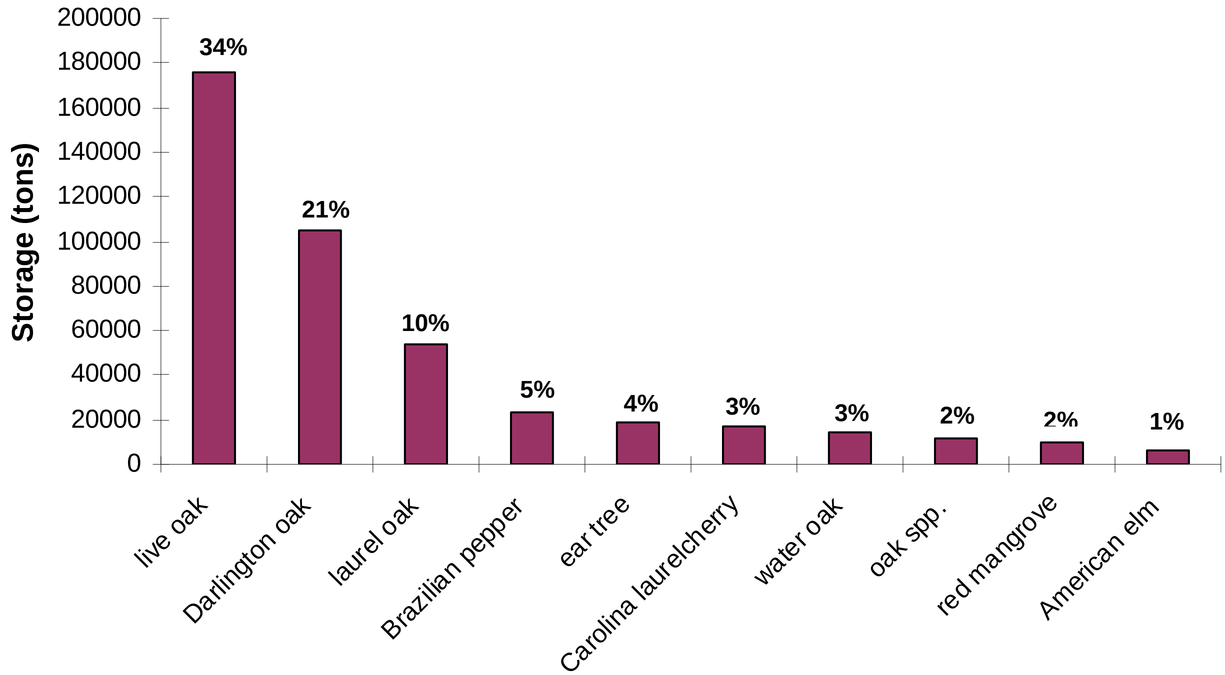


Figure 11. Carbon (C) stored and relative dollar value of ten tree species in Tampa, 2007.

The UFORE model estimates that the amount of carbon sequestered or removed from the atmosphere in 2007 was 46,525 tons with an associated value of $945,396. The total net carbon sequestered annually by Tampa's urban forest is about 40,955 tons. Net carbon sequestration is the amount of carbon sequestered *less* the estimated amount of carbon emitted as dead trees decay. In Tampa carbon is sequestered and emitted by forests and humans daily. Ideally the forest would be considered a carbon sink or emit less than it stores, and this is the case for the urban forest of Tampa. While the urban forest of Tampa is a carbon sink (stores more carbon than it emits) it is not able to offset all of the additional carbon emissions produced by the activities of the human population in the city. If we assume that the population in Tampa is approximately 332,888 (City-data.com 2008) and the average emission per capita in Tampa is similar to the average of all Floridians at 15.26 tons/yr (www.eredux.org 2008) then the urban forest only reduces citywide carbon emissions by approximately 1% per year. To put this into perspective the urban trees annually sequester the amount of carbon emitted in 3.6 days by the population of Tampa.

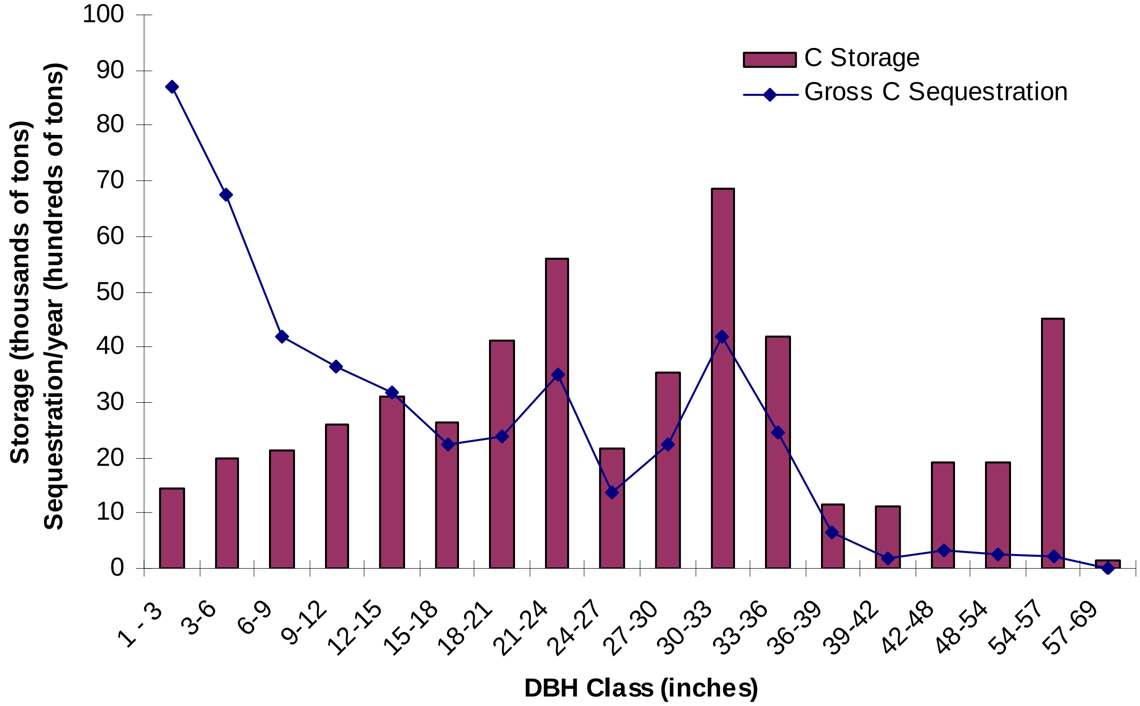


Figure 12. Carbon (C) stored and annual carbon sequestered by diameter class for trees in Tampa.

The rate of carbon sequestration by an individual tree is a function of the tree age (vigor) and species. Trees greater than 27 inches in DBH account for approximately 50% of the carbon stored but the rate at which carbon is stored happens faster in the smaller diameter trees of 1-12 inches DBH (Figure 12). Thus, carbon is stored in the larger trees for the longest periods of time and the smaller diameter trees (in general the younger trees) more actively sequester carbon due to their increased vigor. The tree species with the highest rate of carbon sequestration in Tampa is live oak, which coincidentally is also the species that stores the greatest amount of carbon (Figure 13).

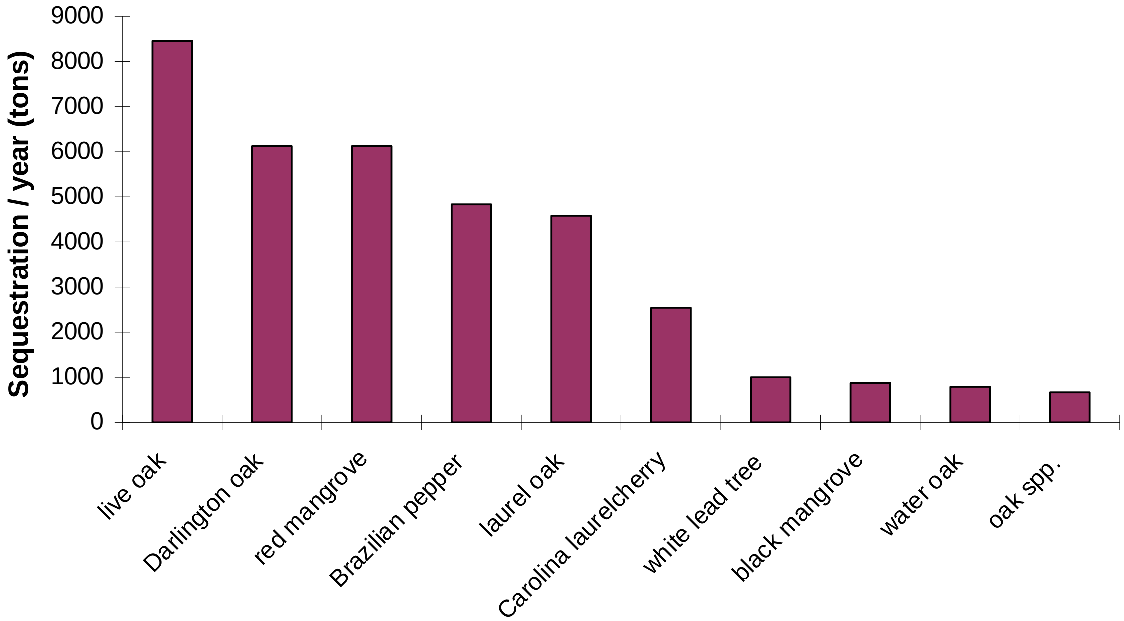


Figure 13. Top ten species that sequestered the most carbon in 2007 in Tampa.

Compensatory Value

Trees in Tampa's urban forest have an overall estimated value referred to as its compensatory value. This value takes into consideration the size, species, condition, and location of each tree. Furthermore, the compensatory value is also an estimate of the amount of money it would cost to replace a tree with a similar species if that one were to be removed (Nowak et al. 2002).

Tree removal in Tampa is the result of anthropogenic influences (e.g. development, safety, preference, etc.) and natural disturbances (e.g. storms, lightening, disease, etc.). Though we can somewhat control human influence on tree removal it is more challenging to determine or predict the quantity and quality of trees that will be removed by environmentally stochastic events such as hurricanes. The amount of damage to the urban forest following a natural disturbance has been difficult to assess on a broad scale and is often a “best guess” estimate. The data from this assessment provides us with a more robust estimate of the value of the urban forest in Tampa to date based on empirical data collected in the process of completing this inventory.

The estimated compensatory value of trees in Tampa's urban forest is approximately $1.47 billion dollars. This value was calculated using the most up to date information from the Council of Tree and Landscape Appraisers. A compensatory value was estimated for all tree species that occurred in the 2007 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 (stems) inventoried in this study.

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. To summarize, in 2007 this forest had an economic value (albeit unrealized) in excess of $1.48 billion dollars (Table 6). While this dollar value will fluctuate annually some of these figures are relatively fixed (e.g. compensatory value and carbon stored) and some of these figures are generated annually (e.g. pollution removal, carbon sequestration, and energy savings). The relatively fixed value of the forest is $1.48 billion dollars and the annual value for 2007 is $11.5 million dollars. The urban forest is an asset that is part of the city's infrastructure and is providing many services to the city at a relatively low investment and maintenance cost. In this report we have only quantified a few of the services that the urban forest provides. When science is able to fully quantify the economic value of other services and functions of the urban forest we are likely to increase our appreciation for this asset that is important to the ecological, economic, and social well being of the city and its citizens.

Table 6. Summary of Tampa's Urban Forest and associated functional values.

Feature	**Measure**
Number of Trees	7,817,408
Tree Cover	28.1%
Pollution Removal	1,360 tons/year ($6.3 million/year)
Carbon Storage	511,141 tons ($10,386,389)
Gross Carbon Sequestration	46,525 tons/year ($945,396/year)
Compensatory Value	$1,465,600,097
Value of Energy Conservation	$4,205,623

Additional Values of Urban Forests

Trees and natural areas within the city bring both benefits and costs. The costs are easier to quantify and are more often well known to city managers working within a given budget and who must address the complaints of citizens. The benefits can often appear nebulous and difficult to quantify. Nevertheless, a considerable and expanding body of research exists on the economic, social, and public/environmental health benefits that the urban forest brings.

Economic: A study by the University of Washington reported a willingness by consumers to pay up to 12% more for goods in landscaped business districts (Wolf 2003). Several studies have analyzed the effect of tree cover on the price of residential house sales, finding that values of properties in tree lined areas may be up to 6% higher and that properties adjacent to parks and greenways typically have 8 - 20% higher appraised values. These values are capitalized by city governments when property taxes are assessed, or when taxes are paid on property sale.

Economic: Transportation engineers and homeowners are well aware of the detrimental effects of trees on sidewalks and roads through direct damage caused by root growth. A less well known fact is that shade from urban trees can increase the life of roads surfaces by reducing pavement temperatures during the long summer months (McPherson and Muchnik 2005).

Social: The conventional wisdom has been that trees and other vegetation can foster criminal behavior because they provide cover for criminals and reduce opportunities for casual surveillance. Urban social research now indicates that this is not true. In fact, trees and grass provide a greater sense of safety, lead to stronger ties among neighbors, lead to more supervision of children in outdoor spaces, with fewer incivilities, fewer property crimes, and fewer violent crimes (Kuo and Sullivan 2001).

Public Health: Contact with nature has been shown to have a positive effect on children with Attention Deficit Disorder (ADD). Individuals whose workspace allow them to see nature experience 23% less time off sick and report higher levels of job satisfaction (Wolf 2003). Patients in hospitals with views of trees have been reported to recover significantly faster.

Environmental Health: Trees influence urban hydrology by improving water quality through the interception of pollution and reduction of stormwater flows. One study found that for each 5% increase in tree cover, stormwater flow is reduced by 2% (Coder 1996).

Economic and Environmental Health: Trees in the wildland urban interface are increasingly being viewed as potential resources of biomass for bio-fuel production (Andreu et al. 2005). As the rice of oil increases and carbon markets develop, opportunities to utilize urban woody biomass as a feedstock for green energy production will likely emerge. The production of a carbon neutral fuel from urban woody biomass has environmental health benefits and creates a stream of revenue for a product otherwise deemed as waste.

Focus Areas of Tampa's Urban Forest

Mangrove Forest

Mangrove forests are a rare ecological community within North America. Because of their sensitivity to sub-freezing temperatures the distribution of mangrove forests in the continental United States is limited to the southern coast of Florida and Texas. Within Florida, their distribution has been further restricted due to changes in land use as metropolitan regions have attempted to accommodate the influx of 15 million new residents since 1960 (Figure 14). In Tampa Bay, almost 50% of the mangrove forest has been lost in the past 100 years (U.S. Geological Survey 1996).

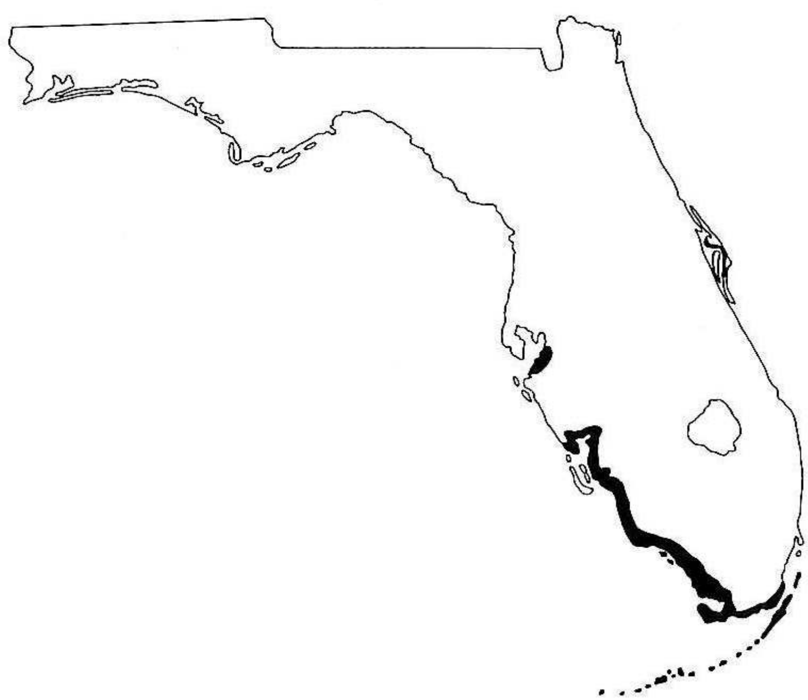


Figure 14. Geographical range of mangroves in Florida Odum and McIvor 1990.

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.

The mangrove forest includes three tree species collectively called mangroves, red (*Rhizophora mangle*), black (*Avicennia germinans*) and white (*Laguncularі racemosa*) mangrove. The three are found in overlapping ecological zones. These three species make up approximately 50% (3,920,196 trees) of the total number of trees (stems >1 inch diameter) in Tampa's urban forest. Red mangrove accounts for 42% of the trees, black mangrove 6% of the trees, and white mangrove 2% of the trees in the city of Tampa. Within the mangrove forest red mangroves dominate, accounting for 84% of the total number of trees while black and white mangroves represent the remaining 16% (Figure 15).

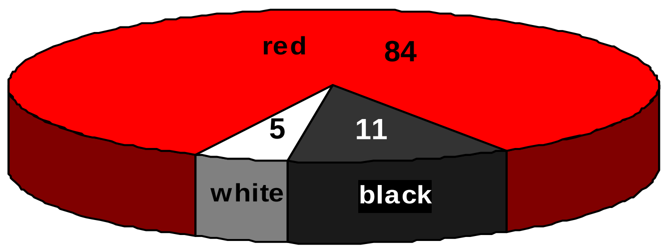


Figure 15. Proportion of mangrove species (# of stems) in Tampa.

The mangrove forest contributes a total of $221 million to the structural value of Tampa's urban forest (Figure 16). This does not account for the economic value of the sport and commercial fisheries industries or the value of their ecological services.

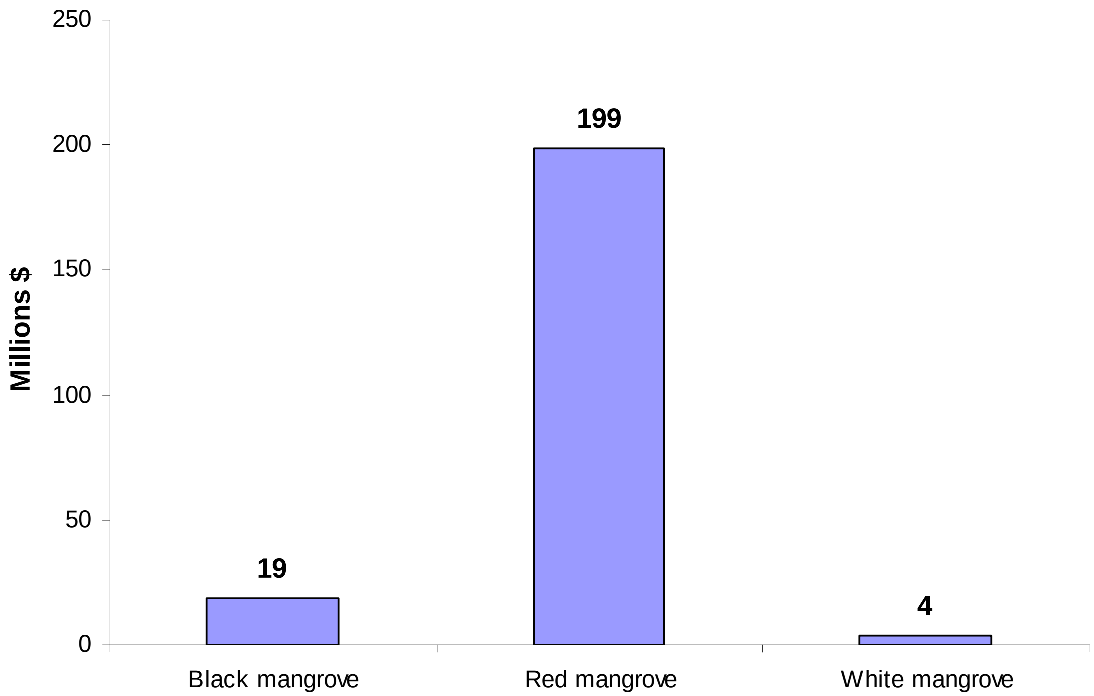


Figure 16. Compensatory value of mangroves in Tampa's urban forest.

Mangrove trimming and alteration are regulated through the Florida 'Mangrove Trimming and Preservation Act' as amended by the 1999 Florida Legislature. The intent of the legislature is to protect and preserve mangrove resources valuable to our environment and economy from unregulated removal, defoliation, and destruction. Specific rules are in place that ensure riparian area property owners right to a view, while requiring the use of licensed and trained mangrove trimmers for trimming mangroves greater than 10 feet in total height.

Inland Urban 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 (the non-coastal areas) of the urban forest contains 3,897,000 trees (Table 7) representing 90 tree species.

Table 7. The number of stems in the inland urban forest with and without mangroves and Brazilian pepper.

	Total Stems	**Proportion of Total Stems**
Urban Forest	7,817,408	100
Without Mangroves	3,897,212	50
Without Mangroves & Brazilian Pepper	2,646,215	34

Within the inland portion of the urban forest Brazilian pepper is the dominant species (33%) followed by cabbage palm (11%) and live oak (7%) (Figure 17). The top ten species make up nearly three quarters (73%) of the total number of trees in Tampa for the inland urban forest.

Each of the 80 species, that make up the remaining twenty-seven percent of the urban forest, contribute less than one percent each to the total inland urban forest.

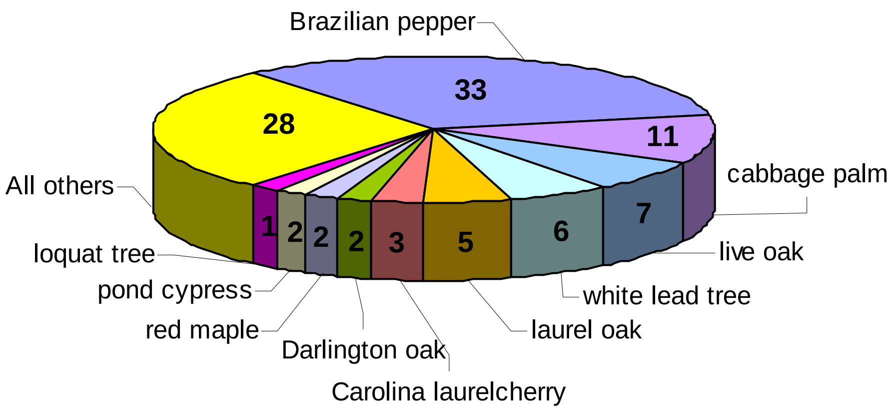


Figure 17. Top ten tree species of Tampa's inland urban forest and their associated percentages. .

The *Residential* land use had the greatest number of trees (Figure 18). This is due to the large portion of residential land within the city. *Vacant* lands had a large number of trees as well but this is primarily a function of the density of small diameter Brazilian pepper trees (1,250,785 trees). The total number of trees within the inland urban forest excluding Brazilian pepper and mangroves is 2,646,215 (Table 7).

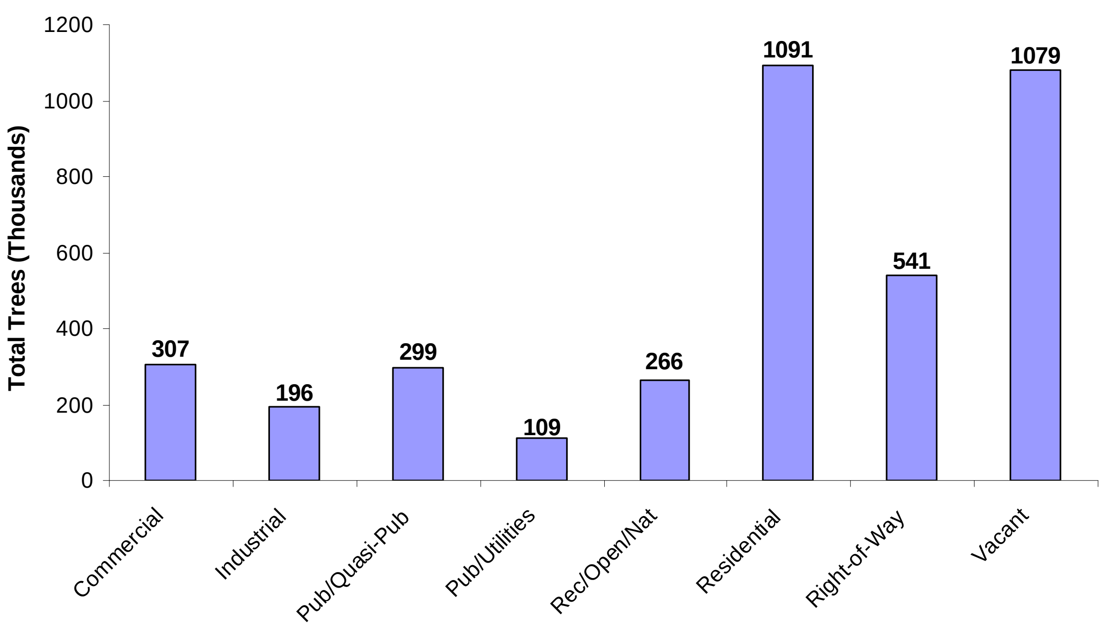


Figure 18. Number of trees by land use for the inland urban forest of Tampa.

Approximately 63% of the city's inland trees are in the smaller (1 - 6 inches) diameter classes (Figure 19). In the 1-3 inch diameter class, 20% is made up of Brazilian pepper, 17% are oak spp., while cypress spp. and wax myrtle contribute approximately 10% each. In the 3-6 inch diameter class cypress spp. and oak spp. each contribute 21% and 9% is made up of Brazilian pepper. In the larger diameter class of 36+, 67% of the trees are oak spp. while bald cypress and ear tree each make up 17%.

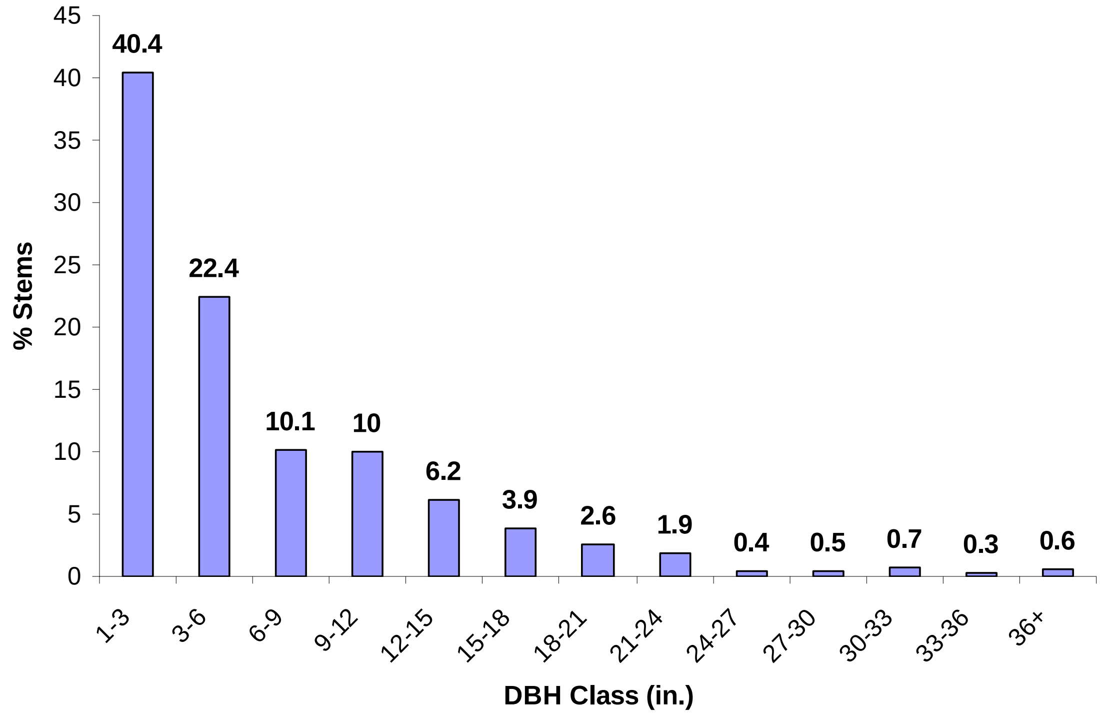


Figure 19. Diameter class distribution of the trees in Tampa's inland urban forest.

Palms

Palms are a distinct structural element of the city's landscape. Palm species have been consistently used on residential sites and public rights-of-way to accent the city's sub-tropical climate. While not truly trees (palms are monocots), they function as trees and represent a significant portion of Tampa's urban forest (7%). Their physical structure and metabolism differ from flowering and coniferous trees and as a result the functional and economic values of palms were assessed using an alternative methodology within the UFORE model. The economic and 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 584,658. The *Residential* and *Public/Quasi-Public/Institutions (PQI)* land uses had the greatest number of palms. While the *PQI* lands contained primarily cabbage palm, the *Residential* land use had the greatest diversity with 11 different palm species (Figure 20).

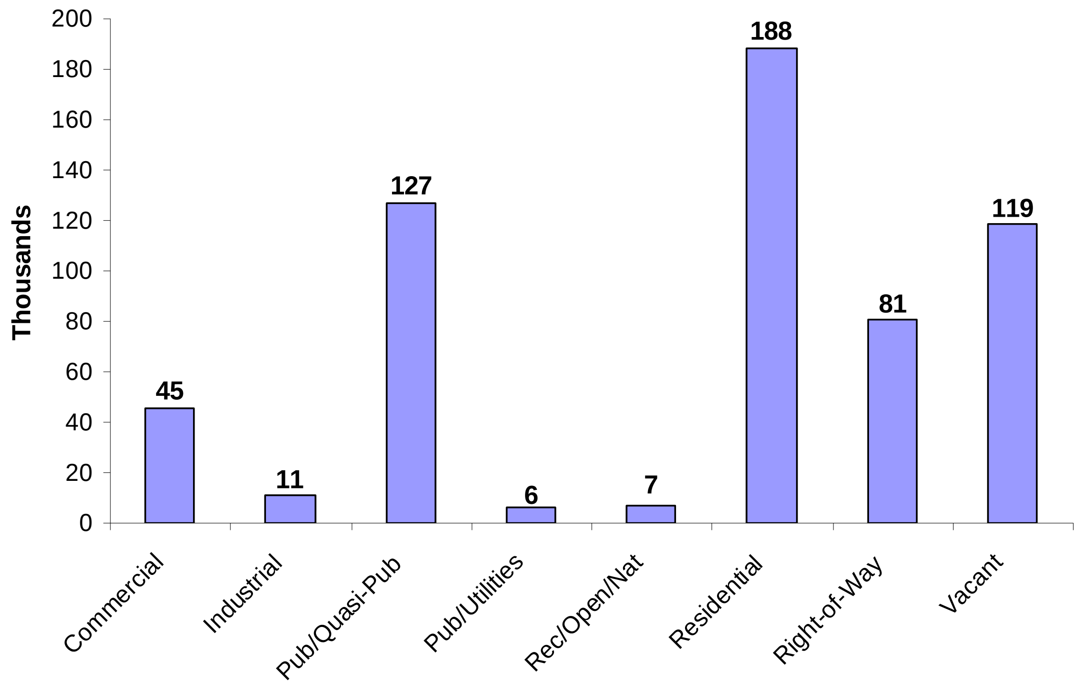


Figure 20. Number of palms by land use in Tampa.

Florida's state tree, the cabbage palm (*Sabal palmetto*) is the only native palm of large stature found in the city. It is one of the top-ten dominant species found in the urban forest canopy (6%) and the most common of the palms (75%). Cabbage palm is tolerant of both drought and high water tables, therefore it can exist across a broad spectrum of growing conditions. Within the urban environment it is found in parks and other natural areas as well as within the tight confines of buildings, streets and sidewalks. Its high level of wind resistance makes it an ideal palm for planting near buildings and in public areas.

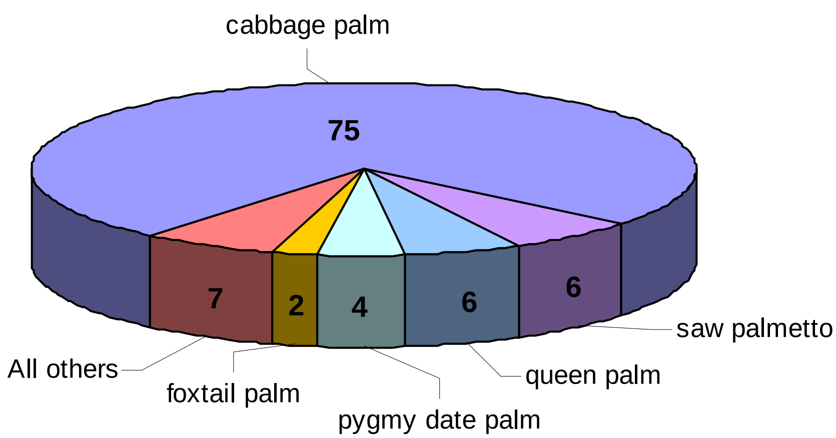


Figure 21. Relative number of the top five palm species based on the number of stems.

Saw-palmetto *(Serenoa repens)*, the second most prolific of all palms in the city (6.5 percent), is also native to Florida. Typically, the stems lie prostrate at the soil surface, but occasionally they grow upright and reach heights of 15 to 20ft. In the region's less urbanized native forest, saw-palmetto is often seen as the thick palm ground cover beneath the open pine woodland. As the use of native plant species for landscaping has increased in popularity, saw-palmetto has become one of the plants increasingly used. Saw-palmetto is naturally drought and insect resistant, requires no fertilizer, and is an ideal plant for enviroscaping.

Significant Diseases Affecting Palms in the City

Queen palm (*Syagrus romanozoffiana*), the third most common palm in the city (5.8%), is an inexpensive large palm commonly used for landscaping. In 2005 a pathogen, *Fusarium oxysporum*, was identified as the causal agent in the rapid decline and death of Queen palms in the Tampa Bay region. In 2007, the same pathogen was identified in the rapid decline and death of Mexican fan palms (*Washingtonia robusta*), another of the more common (1.7%) large stature palms 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.

The loss of these two palm species coupled with the added inability to replant palms at infected sites will likely decrease the diversity of palms in the urban forest in the near future, and impose economic costs for property owners and government agencies that will need to remove and destroy infected palms. Based upon labor and planting material cost estimates from the City of Tampa Parks and Recreation Department, the estimated replacement value for the calculated population of Queen and Mexican fan palms (palms and labor) in Tampa, using a smaller stature planting stock is $4,720,620.00.

A new disease for Florida palms, Texas Phoenix palm decline, was identified in Hillsborough County during 2006. The disease causes the decline and death of Canary Island date palm (*Phoenix canariensis),* edible date palm (*Phoenix dactylifera*) and wild date palm (*Phoenix sylvestris).* 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. These palms are found along major entrances to the city, boulevards and around formal and prominent municipal buildings. How far and how quickly Texas Phoenix palm decline will spread is unknown. Observations by professionals throughout the Tampa Bay region suggest that this disease is moving rapidly. Therefore, Tampa may soon face replacement costs of these palms as well.

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Appendices

Appendix A: Conversion of DOR Codes to Generalized Land Use Categories

The following information has been provided to document the conversion of Florida Department of Revenue land use codes to generalized land use categories. Four digit and two digit DOR codes were provided for each parcel by the Hillsborough County Property Appraiser Office (HCPA 2007); two digit DOR codes were provided by the Pasco County Property Appraiser Office (PCPA 2007). An original conversion of DOR code to existing land use code was provided by the Hillsborough County-City Planning Commission (Hillsborough County-City Planning Commission 2007) and modified by the Florida Center for Community Design and Research (USF 2007a).

Field Definitions:
Landuse Generalized: generalized land use category used for the project.
DOR CODE: four digit land use code used by Hillsborough County.
DOR DESC: abbreviated description used for the 4-digit DOR code
ELU4: generalized existing land used as classified by the Hillsborough County-City Planning Commission.
DOR2 CODE: two digit land use code used by Pasco County.
DOR2 DESC: abbreviated description used for the 2-digit DOR code
ELU2: generalized existing land use based on the 2-digit DOR code as classified by the Hillsborough County-City Planning Commission.

Table 10. DOR Code to Generalized Land Use Category crosswalk.

LANDUSE GENERALIZED	DOR CODE	DOR DESC	ELU4	DOR2 CODE	DOR2 DESC	ELU2
Agricultural	6300	PASTURE LAND 4	AG	63	PASTURE LAND 4	AG
Agricultural	6900	ORN/MISC AGRI	AG	69	ORN/MISC AGRI	AG
Agricultural	6800	DAIRIES/FEEDLTS	AG	68	DAIRIES/FEEDLTS	AG
Agricultural	6700	POUL/BEES/FISH	AG	67	POUL/BEES/FISH	AG
Agricultural	6600	ORCHARD GROVES	AG	66	ORCHARD GROVES	AG
Agricultural	6400	PASTURE LAND 5	AG	64	PASTURE LAND 5	AG
Agricultural	6200	PASTURE LAND 3	AG	62	PASTURE LAND 3	AG
Agricultural	6100	PASTURE LAND 2	AG	61	PASTURE LAND 2	AG
Agricultural	6000	PASTURE LAND 1	AG	60	PASTURE LAND 1	AG
Agricultural	5300	CROPSOIL CLASS3	AG	53	CROPSOIL CLASS3	AG
Agricultural	5200	CROPSOIL CLASS2	AG	52	CROPSOIL CLASS2	AG
Agricultural	5100	CROPSOIL CLASS1	AG	51	CROPSOIL CLASS1	AG
Agricultural	5000	IMPROVED AGRI	AG	50	IMPROVED AGRI	AG
Agricultural	6500	PASTURE LAND 6	AG	65	PASTURE LAND 6	AG
Commercial	2703	AUTO SALES C	HC	27	AUTO SALE/RPAIR	HC
Commercial	2900	WHOLESALER	HC	29	WHOLESALER	HC
Commercial	2800	PKG LOT (COMM)	LC	28	PKG LOT (COMM)	MHP
Commercial	2755	AUTO SALVAGE	HC	27	AUTO SALE/RPAIR	HC
Commercial	2754	AUTO REPAIR D	HC	27	AUTO SALE/RPAIR	HC
Commercial	2753	AUTO REPAIR C	HC	27	AUTO SALE/RPAIR	HC
Commercial	2752	AUTO REPAIR B	HC	27	AUTO SALE/RPAIR	HC
Commercial	2751	AUTO REPAIR A	HC	27	AUTO SALE/RPAIR	HC
Commercial	2720	SELF SERVICE CAR WASH	LC	27	CAR WASH	LC
Commercial	3100	DRV-IN THEATER	LC	31	DRV-IN THEATER	LC

LANDUSE GENERALIZED	DOR CODE	DOR DESC	ELU4	DOR2 CODE	DOR2 DESC	ELU2
Commercial	2704	AUTO SALES D	HC	27	AUTO SALE/RPAIR	HC
Commercial	3200	THEATER	LC	32	THEATER	LC
Commercial	2702	AUTO SALES B	HC	27	AUTO SALE/RPAIR	HC
Commercial	2701	AUTO DEALERSHIP	HC	27	AUTO SALE/RPAIR	HC
Commercial	2700	AUTO SALE/REPAIR	HC	27	AUTO SALE/RPAIR	HC
Commercial	2600	SERV STATIONS	LC	26	SERV STATIONS	LC
Commercial	2504	SERV SHOP D	LC	25	REPAIR SER SHOP	LC
Commercial	2503	SERV SHOP C	LC	25	REPAIR SER SHOP	LC
Commercial	2502	SERV SHOP B	LC	25	REPAIR SER SHOP	LC
Commercial	2501	SERV SHOP A	LC	25	REPAIR SER SHOP	LC
Commercial	2500	REPAIR SER SHOP	LC	25	REPAIR SER SHOP	LC
Commercial	2710	FULL SERVICE CAR WASH	LC	27	CAR WASH	LC
Commercial	3922	LMTD SERV B	LC	39	HOTELS/MOTELS	LC
Commercial	3911	FULL SERV A	LC	39	HOTELS/MOTELS	LC
Commercial	11CO	1 STY STORE CONDO	LC	11	STORE	LC
Commercial	3913	FULL SERV C	LC	39	HOTELS/MOTELS	LC
Commercial	3914	FULL SERV D	LC	39	HOTELS/MOTELS	LC
Commercial	3902	LUXURY B	LC	39	HOTELS/MOTELS	LC
Commercial	3901	LUXURY A	LC	39	HOTELS/MOTELS	LC
Commercial	3900	HOTELS/MOTELS	LC	39	HOTELS/MOTELS	LC
Commercial	3600	CAMPS	LC	36	CAMPS	LC
Commercial	3500	TOURIST ATTRAC	LC	35	TOURIST ATTRAC	LC
Commercial	3000	FLORIST	LC	30	FLORIST	LC
Commercial	3921	LMTD SERV A	LC	39	HOTELS/MOTELS	LC
Commercial	3903	LUXURY C	LC	39	HOTELS/MOTELS	LC
Commercial	3923	LMTD SERV C	LC	39	HOTELS/MOTELS	LC
Commercial	2204	FAST FOOD D	LC	22	FAST FOOD/LOW COST	LC
Commercial	3924	LMTD SERV D	LC	39	HOTELS/MOTELS	LC
Commercial	4300	LUMBER YD/MILL	HC	43	LUMBER YD/MILL	HC
Commercial	3931	EXTEND STAY A	LC	39	HOTELS/MOTELS	LC
Commercial	3932	EXTENDSTAY B	LC	39	HOTELS/MOTELS	LC
Commercial	3933	EXTEND STAY C	LC	39	HOTELS/MOTELS	LC
Commercial	3934	EXTENDSTAY D	LC	39	HOTELS/MOTELS	LC
Commercial	3300	NIGHT CLUBS	LC	33	NIGHT CLUBS	LC
Commercial	3400	BOWLING ALLEY	LC	34	BOWLING ALLEY	LC
Commercial	1239	MIXED USE MOTEL	MUN	12	MIXED USE	LC
Commercial	1630	STRIP CENTER	LC	16	SH CTR CMMITY	LC
Commercial	1620	SH CTR CMMITY B	LC	16	SH CTR CMMITY	LC
Commercial	1610	SH CTR CMMITY A	LC	16	SH CTR CMMITY	LC
Commercial	1600	SH CTR CMMITY	LC	16	SH CTR CMMITY	LC
Commercial	1510	REGIONAL MALL	LC	15	SH CTR REGIONAL	LC
Commercial	1500	SH CTR REGIONAL	LC	15	SH CTR REGIONAL	LC
Commercial	1420	CONV STORE/GAS	LC	14	SUPERMARKET	LC
Commercial	1410	CONV STORE	LC	14	SUPERMARKET	LC
Commercial	1400	SUPERMARKET	LC	14	SUPERMARKET	LC
Commercial	1320	WAREHSE DEPT STORE	LC	13	DEPT STORE	LC
Commercial	1310	DISCOUNT DEPT STORE	LC	13	DEPT STORE	LC
Commercial	1305	MALL ANCHORS	LC	13	DEPT STORE	LC
Commercial	2400	INSURANCE	LC	24	INSURANCE	LC
Commercial	1248	MIXED USE WAREHSE	MUN	12	MIXED USE	LC
Commercial	1720	OFFICE 1 STY B	LC	17	OFFICE 1 STORY	LC
Commercial	1228	MIXED USE MH	MUR	12	MIXED USE	LC

LANDUSE GENERALIZED	DOR CODE	DOR DESC	ELU4	DOR2 CODE	DOR2 DESC	ELU2
		PARK				
Commercial	1227	MIXED USE AUTO	MUN	12	MIXED USE	LC
Commercial	1217	MIXED USE OFFICE	MUN	12	MIXED USE	LC
Commercial	1211	MIXED USE RETAIL	MUN	12	MIXED USE	LC
Commercial	1203	MIXED USE MULTI FAM	MUR	12	MIXED USE	LC
Commercial	1201	MIXED USE RES	MUR	12	MIXED USE	LC
Commercial	1200	MIXED USE	MUR	12	MIXED USE	LC
Commercial	1130	1 STY STORE C	LC	11	STORE	LC
Commercial	1120	1STY STORE B	LC	11	STORE	LC
Commercial	1110	1 STY STORE A	LC	11	STORE	LC
Commercial	1105	DRUGSTORE	LC	11	STORE	LC
Commercial	1100	"""STORE"	LC	11	STORE	LC
Commercial	1300	DEPT STORE	LC	13	DEPT STORE	LC
Commercial	1940	PROF OFF D	LC	19	PROF OFFICES	LC
Commercial	3912	FULL SERV B	LC	39	HOTELS/MOTELS	LC
Commercial	2203	FAST FOOD C	LC	22	FAST FOOD/LOW COST	LC
Commercial	2202	FAST FOOD B	LC	22	FAST FOOD/LOW COST	LC
Commercial	2201	FAST FOOD A	LC	22	FAST FOOD/LOW COST	LC
Commercial	2200	FAST FOOD	LC	22	FAST FOOD/LOW COST	LC
Commercial	2104	RESTAURANT D	LC	21	RESTAURANT	LC
Commercial	2103	RESTAURANT C	LC	21	RESTAURANT	LC
Commercial	2102	RESTAURANT B	LC	21	RESTAURANT	LC
Commercial	2101	RESTAURANT A	LC	21	RESTAURANT	LC
Commercial	2100	RESTAURANT	LC	21	RESTAURANT	LC
Commercial	1954	MEDICAL OFF D	LC	19	PROF OFFICES	LC
Commercial	1953	MEDICAL OFF C	LC	19	PROF OFFICES	LC
Commercial	1700	OFFICE 1 STORY	LC	17	OFFICE 1 STORY	LC
Commercial	1951	MEDICAL OFF A	LC	19	PROF OFFICES	LC
Commercial	1710	OFFICE 1 STY A	LC	17	OFFICE 1 STORY	LC
Commercial	1930	PROF OFF C	LC	19	PROF OFFICES	LC
Commercial	1920	PROF OFF B	LC	19	PROF OFFICES	LC
Commercial	1910	PROF OFF A	LC	19	PROF OFFICES	LC
Commercial	1900	PROF OFFICES	LC	19	PROF OFFICES	LC
Commercial	1850	BROADCASTING FACILITY	LC	18	OFF MULTISTORY	LC
Commercial	1840	OFF MULT-STY D	LC	18	OFF MULTISTORY	LC
Commercial	1830	OFF MULT-STY C	LC	18	OFF MULTISTORY	LC
Commercial	1820	OFF MULT-STY B	LC	18	OFF MULTISTORY	LC
Commercial	1810	OFF MULT-STY A	LC	18	OFF MULTISTORY	LC
Commercial	1800	OFF MULTISTORY	LC	18	OFF MULTISTORY	LC
Commercial	1740	OFFICE 1 STY D	LC	17	OFFICE 1 STORY	LC
Commercial	1730	OFFICE 1 STY C	LC	17	OFFICE 1 STORY	LC
Commercial	2300	FINANCIAL	LC	23	FINANCIAL	LC
Commercial	1952	MEDICAL OFF B	LC	19	PROF OFFICES	LC
Commercial	18CO	OFF MULT-STY CONDO	LC	18	OFF MULTISTORY	LC
Commercial	3904	LUXURY D	LC	39	HOTELS/MOTELS	LC
Commercial	12CO	MIXED USE CONDO		12	MIXED USE	LC
Commercial	13CO	DEPT STORE CONDO	LC	13	DEPT STORE	LC
Commercial	16CO	SH CTR CONDO	LC	16	SH CTR CMMITY	LC
Commercial	17CO	OFFICE 1 STY CONDO	LC	17	OFFICE 1 STORY	LC

LANDUSE GENERALIZED	DOR CODE	DOR DESC	ELU4	DOR2 CODE	DOR2 DESC	ELU2
Commercial	19CO	MEDICAL OFF CONDO	LC	19	PROF OFFICES	LC
Industrial	4860	FLEX SERV B	LI	48	WAREH/DIST TERM	LI
Industrial	4870	FLEX SERV C	LI	48	WAREH/DIST TERM	LI
Industrial	4880	FLEX SERV D	LI	48	WAREH/DIST TERM	LI
Industrial	4891	MINI WARE A	LI	48	WAREH/DIST TERM	LI
Industrial	4892	MINI WARE B	LI	48	WAREH/DIST TERM	LI
Industrial	4893	MINI WARE C	LI	48	WAREH/DIST TERM	LI
Industrial	4850	FLEX SERV A	LI	48	WAREH/DIST TERM	LI
Industrial	4900	OPEN STORAGE	HI	49	OPEN STORAGE	HI
Industrial	9300	SUBSURF RIGHTS	MIN	93	SUBSURF RIGHTS	MIN
Industrial	4950	RES/STG - MISC. RES	HI	49	OPEN STORAGE	HI
Industrial	9200	MING/PET/GASLND	MIN	92	MING/PET/GASLND	MIN
Industrial	4813	TRKG TERM C	LI	48	WAREH/DIST TERM	LI
Industrial	4894	MINI WARE D	LI	48	WAREH/DIST TERM	LI
Industrial	4600	FOOD PROCESSING	LI	46	FOOD PROCESSING	LI
Industrial	3700	RACETRACK	HI	37	RACETRACK	HI
Industrial	4811	TRKG TERM A	LI	48	WAREH/DIST TERM	LI
Industrial	4812	TRKG TERM B	LI	48	WAREH/DIST TERM	LI
Industrial	4840	WAREHOUSE D	LI	48	WAREH/DIST TERM	LI
Industrial	4700	MIN PROCESSING	HI	47	MIN PROCESSING	HI
Industrial	4810	WAREHOUSE A	LI	48	WAREH/DIST TERM	LI
Industrial	4500	BOTTLER/CANNERY	HI	45	BOTTLER/CANNERY	HI
Industrial	4400	PACKING PLANTS	HI	44	PACKING PLANTS	AG
Industrial	4200	HEAVY MFG	HI	42	HEAVY MFG	HI
Industrial	4104	LIGHT MFG D	LI	41	LIGHT MFG	LI
Industrial	4103	LIGHT MFG C	LI	41	LIGHT MFG	LI
Industrial	4102	LIGHT MFG B	LI	41	LIGHT MFG	LI
Industrial	4101	LIGHT MFG A	LI	41	LIGHT MFG	LI
Industrial	4814	TRKG TERM D	LI	48	WAREH/DIST TERM	LI
Industrial	4830	WAREHOUSE C	LI	48	WAREH/DIST TERM	LI
Industrial	4800	WAREH/DIST TERM	LI	48	WAREH/DIST TERM	LI
Industrial	4100	LIGHT MFG	LI	41	LIGHT MFG	LI
Industrial	4820	WAREHOUSE B	LI	48	WAREH/DIST TERM	LI
Public / Quasi-Public / Institutions	8620	COUNTY FIRE STATION	PI	86	COUNTY	PI
Public / Quasi-Public / Institutions	8540	HOSPITAL/TPA	PI	85	HOSPITAL	PI
Public / Quasi-Public / Institutions	8550	HOSPITAL/PC	PI	85	HOSPITAL	PI
Public / Quasi-Public / Institutions	8560	HOSPITAL/TT	PI	85	HOSPITAL	PI
Public / Quasi-Public / Institutions	8610	PUBLIC LIBRARY	PI	86	COUNTY	PI
Public / Quasi-Public / Institutions	8630	COUNTY OWNED	PI	86	COUNTY	PI
Public / Quasi-Public / Institutions	8600	COUNTY	PI	86	COUNTY	PI
Public / Quasi-Public / Institutions	8530	HOSPITAL/CNTY	PI	85	HOSPITAL	PI
Public / Quasi-Public / Institutions	8520	HOSPITAL/STATE	PI	85	HOSPITAL	PI
Public / Quasi-Public / Institutions	8510	HOSPITAL/FEDRL	PI	85	HOSPITAL	PI
Public / Quasi-Public / Institutions	8400	COLLEGE	SCH	84	COLLEGE	SCH

LANDUSE GENERALIZED	DOR CODE	DOR DESC	ELU4	DOR2 CODE	DOR2 DESC	ELU2
Public / Quasi-Public / Institutions	8670	PORT AUTHORITY	PI	86	COUNTY	PI
Public / Quasi-Public / Institutions	8310	PUBLIC ELEMENTARY	SCH	83	PUB CTY SCHOOL	SCH
Public / Quasi-Public / Institutions	9030	LEASED/COUNTY	PI	90	LEASED	PI
Public / Quasi-Public / Institutions	8300	PUBLIC SCHOOLS	SCH	83	PUB CTY SCHOOL	SCH
Public / Quasi-Public / Institutions	8320	PUBLIC MIDDLE	SCH	83	PUB CTY SCHOOL	SCH
Public / Quasi-Public / Institutions	9040	LEASED/TPA	PI	90	LEASED	PI
Public / Quasi-Public / Institutions	8330	PUBLIC HIGH SCHOOL	SCH	83	PUB CTY SCHOOL	SCH
Public / Quasi-Public / Institutions	8100	MILITARY	PI	81	MILITARY	PI
Public / Quasi-Public / Institutions	9090	LEASED/SPORTS	PI	90	LEASED	PI
Public / Quasi-Public / Institutions	9085	LEASED/HOSPITAL	PI	90	LEASED	PI
Public / Quasi-Public / Institutions	9080	LEASED/AVIATION	PI	90	LEASED	PI
Public / Quasi-Public / Institutions	9070	LEASED/PORT	PI	90	LEASED	PI
Public / Quasi-Public / Institutions	9010	LEASED/FEDERAL	PI	90	LEASED	PI
Public / Quasi-Public / Institutions	9050	LEASED/PC	PI	90	LEASED	PI
Public / Quasi-Public / Institutions	8680	AVIATION AUTH	PI	86	COUNTY	PI
Public / Quasi-Public / Institutions	9020	LEASED/STATE	PI	90	LEASED	PI
Public / Quasi-Public / Institutions	9000	LEASED	PI	90	LEASED	PI
Public / Quasi-Public / Institutions	8910	MUNICIPAL FIRE STATION	PI	89	MUNICIPAL	PI
Public / Quasi-Public / Institutions	8900	MUNICIPAL	PI	89	MUNICIPAL	PI
Public / Quasi-Public / Institutions	8800	FEDERAL	PI	88	FEDERAL	PI
Public / Quasi-Public / Institutions	8700	STATE	PI	87	STATE	PI
Public / Quasi-Public / Institutions	8690	SPORTS AUTH	PI	86	COUNTY	PI
Public / Quasi-Public / Institutions	9060	LEASED/TT	PI	90	LEASED	PI
Public / Quasi-Public / Institutions	7700	CLB/LDG/UN HALL	PI	77	CLB/LDG/UN HALL	PI
Public / Quasi-Public / Institutions	7200	PRV SCHL/COLL	SCH	72	PRV SCHL/COLL	SCH
Public / Quasi-Public / Institutions	7100	CHURCHES	PI	71	CHURCH OWNED	PI
Public / Quasi-Public / Institutions	7220	GOOD PRV SCHL	SCH	72	PRV SCHL/COLL	SCH
Public / Quasi-Public / Institutions	7600	MORT/CEMETERY	PI	76	MORT/CEMETERY	PI
Public / Quasi-Public / Institutions	7310	REHAB HOSPITAL	PI	73	PRV HOSPITAL	PI
Public / Quasi-Public /	7710	FITNESS CENTER	PI	77	CLB/LDG/UN HALL	PI

LANDUSE GENERALIZED	DOR CODE	DOR DESC	ELU4	DOR2 CODE	DOR2 DESC	ELU2
Institutions						
Public / Quasi-Public / Institutions	7900	CULTURAL	PI	79	CULTURAL	PI
Public / Quasi-Public / Institutions	7300	PRV HOSPITAL	PI	73	PRV HOSPITAL	PI
Public / Quasi-Public / Institutions	8500	HOSPITAL	PI	85	HOSPITAL	PI
Public / Quasi-Public / Institutions	7250	PRIVATE COLLEGE	SCH	72	PRV SCHL/COLL	SCH
Public / Quasi-Public / Institutions	7240	FAIR PRV SCHL	SCH	72	PRV SCHL/COLL	SCH
Public / Quasi-Public / Institutions	7230	AVG PRV SCHL	SCH	72	PRV SCHL/COLL	SCH
Public / Quasi-Public / Institutions	7210	EXCELL PRV SCHL	SCH	72	PRV SCHL/COLL	SCH
Public Communications / Utilities	9100	UTILITY	PU	91	UTILITY	PU
Public Communications / Utilities	9600	SEWG/WASTE LAND	PU	96	SEWG/WASTE LAND	PU
Recreational / Open Space / Natural	5700	TMBR SI 60-69	UNK	57	TMBR SI 60-69	NAT
Recreational / Open Space / Natural	5800	TMBR SI 50-59	UNK	58	TMBR SI 50-59	NAT
Recreational / Open Space / Natural	3800	REG GOLF COURSE	ROS	38	GOLF COURSE	ROS
Recreational / Open Space / Natural	3820	EXEC GOLF COURSE	ROS	38	GOLF COURSE	ROS
Recreational / Open Space / Natural	9700	OUTDR REC/PK LD	ROS	97	OUTDR REC/PK LD	ROS
Recreational / Open Space / Natural	3830	PRACTICE GOLF FACILITY	ROS	38	GOLF COURSE	ROS
Recreational / Open Space / Natural	5600	TMBR SI 70-79	UNK	56	TMBR SI 70-79	NAT
Recreational / Open Space / Natural	5500	TMBR SI 80-89	UNK	55	TMBR SI 80-89	NAT
Recreational / Open Space / Natural	5400	TMBR SI 90+	UNK	54	TMBR SI 90+	NAT
Recreational / Open Space / Natural	5900	TMBR NOT CLSSFD	NAT	59	TMBR NOT CLSSFD	NAT
Recreational / Open Space / Natural	8260	PARKS&REC/TT	ROS	82	FOREST/PK/REC	ROS
Recreational / Open Space / Natural	8200	FOREST/PK/REC	ROS	82	FOREST/PK/REC	ROS
Recreational / Open Space / Natural	8210	PARKS&REC/FEDRL	ROS	82	FOREST/PK/REC	ROS
Recreational / Open Space / Natural	8220	PARKS&REC/STATE	ROS	82	FOREST/PK/REC	ROS
Recreational / Open Space / Natural	8230	PARKS&REC/CNTY	ROS	82	FOREST/PK/REC	ROS
Recreational / Open Space / Natural	8250	PARKS&REC/PC	ROS	82	FOREST/PK/REC	ROS
Recreational / Open Space / Natural	8240	PARKS&REC/TPA	ROS	82	FOREST/PK/REC	ROS
Residential	7408	CCRC	PI	74	HOME FOR AGED	PI
Residential	7409	REF CCRC	PI	74	HOME FOR AGED	PI
Residential	7406	EXHOME FOR AGED	PI	74	HOME FOR AGED	PI
Residential	7407	REFHOME FOR AGE	PI	74	HOME FOR AGED	PI
Residential	7800	SANI/ REST HOME	PI	78	SANI/ REST HOME	PI

LANDUSE GENERALIZED	DOR CODE	DOR DESC	ELU4	DOR2 CODE	DOR2 DESC	ELU2
Residential	7400	HOME FOR AGED	PI	74	HOME FOR AGED	PI
Residential	0508	MH CO-OP	MH	05	COOPERATIVE	MF
Residential	0106	TOWNHOUSE	SF	01	SINGLE FAMILY R	SF
Residential	0100	SINGLE FAMILY R	SF	01	SINGLE FAMILY R	SF
Residential	0411	NON-PROFIT EX CONDO	MF	04	CONDOMINIUM	MF
Residential	0418	OFFICE CONDO	LC	04	CONDOMINIUM	MF
Residential	0111	NEW RES PERMIT	SF	01	SINGLE FAMILY R	SF
Residential	0507	CO-OP REFERENCE	MF	05	COOPERATIVE	MF
Residential	0410	GOVT EX CONDO	MF	04	CONDOMINIUM	MF
Residential	0600	RETIREMENT	GQ	06	RETIREMENT	MF
Residential	0610	ALF A	GQ	06	RETIREMENT	MF
Residential	0611	ILF A	GQ	06	RETIREMENT	MF
Residential	0620	ALF B	GQ	06	RETIREMENT	MF
Residential	0621	ILF B	GQ	06	RETIREMENT	MF
Residential	0630	ALF C	GQ	06	RETIREMENT	MF
Residential	0500	COOPERATIVE	MF	05	COOPERATIVE	MF
Residential	0398	HUD	MF	03	MFR >9 UNITS	MF
Residential	0310	MFR CLASS A	MF	03	MFR >9 UNITS	MF
Residential	0320	MFR CLASS B	MF	03	MFR >9 UNITS	MF
Residential	0330	MFR CLASS C	MF	03	MFR >9 UNITS	MF
Residential	0340	MFR CLASS D	MF	03	MFR >9 UNITS	MF
Residential	0350	MFR CLASS E	MF	03	MFR >9 UNITS	MF
Residential	0107	GOVT EXEMPT TH	SF	01	SINGLE FAMILY R	SF
Residential	0397	RURAL DEVELOPMENT	MF	03	MFR >9 UNITS	MF
Residential	0300	MFR >9 UNITS	MF	03	MFR >9 UNITS	MF
Residential	0399	LIHTC	MF	03	MFR >9 UNITS	MF
Residential	0400	CONDOMINIUM	MF	04	CONDOMINIUM	MF
Residential	0408	MH CONDOMINIUM	MH	04	CONDOMINIUM	MF
Residential	0660	NURSING B	GQ	06	RETIREMENT	MF
Residential	0200	MH	MH	02	MOBILE HOME	SF
Residential	0631	ILF C	GQ	06	RETIREMENT	MF
Residential	0396	STUDENT HOUSING	GQ	03	MFR >9 UNITS	MF
Residential	2814	MHP D	MHP	28	PKG LOT (COMM)	MHP
Residential	7510	RESIDENTIAL HOA	SF	75	NON-PROFIT SERV	MF
Residential	7520	CONDO HOA	MF	75	NON-PROFIT SERV	MF
Residential	7530	TOWNHSE HOA	T+F	75	NON-PROFIT SERV	MF
Residential	7540	COMMERCIAL HOA	LC	75	NON-PROFIT SERV	MF
Residential	0645	ALF - RESIDENTIAL	GQ	06	RETIREMENT	MF
Residential	7500	NON-PROFIT SERV	PI	75	NON-PROFIT SERV	MF
Residential	0640	ALF D	GQ	06	RETIREMENT	MF
Residential	2810	MH PARK	MHP	28	PKG LOT (COMM)	MHP
Residential	2811	MHP A	MHP	28	PKG LOT (COMM)	MHP
Residential	7503	NON-PROFIT APTS.	MF	75	NON-PROFIT SERV	MF
Residential	2815	MHP E	MHP	28	PKG LOT (COMM)	MHP
Residential	0810	MFR - VALUE BY CAMA	T+F	08	MFR <10 UNITS	TF
Residential	0800	MFR <10 UNITS	T+F	08	MFR <10 UNITS	TF
Residential	0700	MISC RESIDENTIA	MF	07	MISC RESIDENTIA	MF
Residential	0680	NURSING D	GQ	06	RETIREMENT	MF
Residential	0670	NURSING C	GQ	06	RETIREMENT	MF
Residential	2812	MHP B	MHP	28	PKG LOT (COMM)	MHP
Residential	0650	NURSING A	GQ	06	RETIREMENT	MF
Residential	2813	MHP C	MHP	28	PKG LOT (COMM)	MHP
Residential	0641	ILF D	GQ	06	RETIREMENT	MF
Residential	2820	RV PARK	MHP	28	PKG LOT (COMM)	MHP

LANDUSE GENERALIZED	DOR CODE	DOR DESC	ELU4	DOR2 CODE	DOR2 DESC	ELU2
Right of Way / Transportation	9400	RIGHT-OF-WAY	R/W	94	RIGHT-OF-WAY	R/W
Right of Way / Transportation	2020	MARINAS/BOAT SLIPS	LC	20	MARINAS/BOAT SLIPS	LC
Right of Way / Transportation	9800	CENTRALLY ASSD	R/W	98	CENTRALLY ASSD	R/W
Right of Way / Transportation	2000	TRANSIT TERMINALS	PU	20	TRANSIT TERMINALS	PU
Unknown	NN	NOTE	UNK	NN	NOTE	UNK
Unknown	HH	HEADER	UNK	HH	HEADER	UNK
Vacant	7000	VACANT INSTIT	VAN	70	VACANT INSTIT	VAC
Vacant	9900	ACRG NOT ZND AG	VAC	99	ACRG NOT ZND AG	VAC
Vacant	0000	VACANT	VAR	00	VACANT	VAC
Vacant	4000	VACANT INDUS	VAN	40	VACANT INDUS	VAC
Vacant	1000	VACANT COMM	VAN	10	VACANT COMM	VAC
Vacant	0099	VAC UNPLAT <5AC	VAR	00	VACANT	VAC
Water	9500	RIVERS/LAKES	WAT	95	RIVERS/LAKES	WAT

Appendix B: Landsat TM Atmospheric Correction Parameters

Radiometric calibration was performed using the ENVI software Landsat TM Calibration tool to convert Landsat digital numbers to at-sensor reflectance values. Atmospheric correction was performed by deducting atmospheric path radiance estimated at pseudo-invariant dark water locations. At-surface reflectance values were first measured using a field spectrometer (ASD, Inc. FieldSpec3 Spectroradiometer, www.asdi.com) on several dark water locations on the Hillsborough River. Measurements were taken one-year later at approximately the same time of year as the IKONOS imagery (i.e. April 2). At-sensor reflectance was measured for each image at dark water locations on the Hillsborough River and Alafia River. Atmospheric path radiance was estimated by subtracting measured at-surface reflectance from at-sensor reflectance for the mid-point wavelength of each image band (i.e. 485nm, 560nm, 660nm, 830nm, 1650nm and 2215nm). Path radiance values were then subtracted from at-sensor calibrated values of each pixel of the 2006 image data.

Band	mid-point wavelength (nm)	At-Sensor Reflectance at Dark Water Locations			Measured At-Surface Reflectance at Dark Water Location	Estimated Atmospheric Path Radiance		
		scene 17/41	scene 17/40	scene 16/41		scene 17/41	scene 17/40	scene 16/41
1	485	0.083	0.083	0.103	0.0125	0.0705	0.0705	0.0905
2	560	0.058	0.056	0.07	0.0148	0.0432	0.0412	0.0552
3	660	0.039	0.039	0.049	0.0101	0.0289	0.0289	0.0389
4	830	0.033	0.03	0.036	0.0058	0.0272	0.0242	0.0302
5	1650	0.022	0.023	0.013	0.0041	0.0179	0.0189	0.0089
7	2215	0.005	0.011	0.011	0.0036	0.0014	0.0074	0.0074

Dark Water Locations
Scenes 17/41 and 17/40: Hillsborough River near the City of Tampa Dam. Approximate location in decimal degrees latitude/longitude: -82.422, 28.027).
Scene 16/41: Alafia River in the deep shipping channel near the mouth of the river. Approximate location in decimal degrees latitude/longitude: -82.391, 27.856.

Appendix C: Accuracy Assessment Results of Ikonos Classification

Overall Accuracy = (1445171/1511313) 95.6235%
Kappa Coefficient = 0.9423

Class	Ground Truth (Pixels) tree_v	veg_v	water_v	sand_v	impervious_v
Unclassified	0	1	0	0	0
Tree Canopy	256377	11282	60	0	97
Other Vegetat	3116	456035	1352	1324	2414
Water	63	0	372997	0	1864
Bare Sand/Soi	2	938	71	40297	25242
Impervious	299	6014	1996	10007	319465
Total	259857	474270	376476	51628	349082

Class	Ground Truth (Pixels) Total
Unclassified	1
Tree Canopy	267816
Other Vegetat	464241
Water	374924
Bare Sand/Soi	66550
Impervious	337781
Total	1511313

Class	Ground Truth (Percent) tree_v	veg_v	water_v	sand_v	impervious_v
Unclassified	0.00	0.00	0.00	0.00	0.00
Tree Canopy	98.66	2.38	0.02	0.00	0.03
Other Vegetat	1.20	96.16	0.36	2.56	0.69
Water	0.02	0.00	99.08	0.00	0.53
Bare Sand/Soi	0.00	0.20	0.02	78.05	7.23
Impervious	0.12	1.27	0.53	19.38	91.52
Total	100.00	100.00	100.00	100.00	100.00

Class	Ground Truth (Percent) Total
Unclassified	0.00
Tree Canopy	17.72
Other Vegetat	30.72
Water	24.81
Bare Sand/Soi	4.40
Impervious	22.35
Total	100.00

Class	Commission (Percent)	Omission (Percent)	Commission (Pixels)	Omission (Pixels)
Tree Canopy	4.27	1.34	11439/267816	3480/259857
Other Vegetat	1.77	3.84	8206/464241	18235/474270
Water	0.51	0.92	1927/374924	3479/376476
Bare Sand/Soi	39.45	21.95	26253/66550	11331/51628
Impervious	5.42	8.48	18316/337781	29617/349082

Class	Prod. Acc. (Percent)	User Acc. (Percent)	Prod. Acc. (Pixels)	User Acc. (Pixels)
Tree Canopy	98.66	95.73	256377/259857	256377/267816
Other Vegetat	96.16	98.23	456035/474270	456035/464241
Water	99.08	99.49	372997/376476	372997/374924
Bare Sand/Soi	78.05	60.55	40297/51628	40297/66550
Impervious	91.52	94.58	319465/349082	319465/337781

APPENDIX D: LIMITATIONS OF THE LAND COVER ANALYSES

As with most scientific research, there were limitations in the methods used for the land cover analysis, including the analysis of tree canopy change and the classification of existing tree canopy. These limitations should affect the confidence one should place in the results and any related interpretation. The reader is advised to carefully consider the implications these limitations may have on the appropriate use and application of the results from this study.

Arguably the most important limitation of any land cover analysis based upon remotely sensed data was that these classification methods could only classify what was visible from above (i.e. earth's orbit). These methods were not designed to detect smaller trees, other vegetation, impervious surface, water or bare sand/soil underneath a tree canopy. Therefore, while the land cover analysis was an invaluable tool to determine the extent of the urban forest, it was much less useful in characterizing the structure or function of the forest. For example, the ecological role of the forest (and the provision of ecosystem services) would likely be very different on area of land with 50% tree canopy and an undergrowth of vegetation than it would be with the same tree canopy above a parking lot.

It was important to maintain a consistent study area despite the long temporal period of the tree canopy change analysis. The study area boundary used in this study was defined by the 1996 City of Tampa political boundary (Tampa 1996) for the simple reason that all prior year results had already been defined by this boundary. The latest City of Tampa study area includes 6,979 acres (9%) additional area compared to the 1996 boundary. Existing citywide tree canopy based upon the Ikonos analysis remained the same for both the 1996 and latest boundary. However, it is possible that the inclusion of these additional areas would have produced different results for the New Tampa area (see results for the New Tampa neighborhood association in Table 8).

The dramatic difference between landsat (22%) and ikonos (29%) can be partially explained due to the inherent limitations in the hard classification methods, the limitations of the NDVI vegetation index, and the much higher resolution of Ikonos data. Conventional hard classification techniques such as those used in this study classify each pixel of an image according to a single land cover class. In other words, each 30x30 meter (pixel) area in the Landsat image was given the binary classification as either tree canopy present or absent. In reality, especially within the heterogeneous environment of an urban area, each 30x30 meter area of the city is likely a mixture of multiple land cover types. A pixel with a small proportion of tree canopy could be labeled as tree canopy absent, while a pixel with only a slightly larger proportion of tree canopy could be labeled as tree canopy present.

This study classified Landsat imagery using the normalized difference vegetation index. Vegetation indices such as NDVI suffer from the inability to reliably separate trees from other vegetation, and results are affected by the specific threshold value used to determine the presence or absence of tree canopy from the index value (Nichol and Wong 2007). This study used a high NDVI threshold value to improve the ability to reliably separate tree canopy from grass. Qualitative data analysis indicated that tree canopy coverage of 75% was generally required in order to detect the presence of tree canopy on a Landsat pixel. An obvious limitation was that relatively high amounts of tree canopy coverage (e.g. 0-74%) could have escaped detection. Despite this limitation, methods were applied consistently to all Landsat image analysis to ensure comparability between 1975 and 2006. The classification methods used for Ikonos imagery were considered much more sensitive to detection of smaller levels of tree canopy.

Arguably the most important difference between the Landsat and Ikonos classification methods was a result of the difference in image resolution. The resolution of the pan-sharpened Ikonos (1-meter pixel) imagery was 900 times greater than the Landsat (30-meter pixel) imagery. The higher resolution Ikonos imagery facilitated the detection of small patches of individual trees within a larger matrix of other land cover. These same patches would have escaped detection using the lower resolution Landsat image. For example, a $900m^2$ Landsat pixel with 25% tree canopy would have been labeled as $0m^2$ tree canopy, while this same area could have been labeled as $250m^2$ tree canopy using the Ikonos imagery. Interestingly, the detection of tree canopy was similar in the area of New Tampa. This area of the city contains a large extent of conservation forest lands with a high level of continuous canopy cover. It is likely that the similarity was because both methods were equally sensitive to detecting areas with high levels of tree canopy.

The limitations and issues discussed above have been provided in order to promote the responsible use of the results from this study in management, policy, research and other applications. However, it is also acknowledge that the authors of this study remain powerless to prevent the inappropriate use of these results.

APPENDIX E: LAND USE RELATED TO ECOLOGICAL ASSESSMENT

I. Land use category descriptions for all plots in the City of Tampa UFORE study.

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 described in these descriptions
Vacant	Abandoned/unused commercial, institutional, and industrial lands, and non-agricultural acreage
Water	An area that permanently holds water

In an effort to represent the cities land use categories accurately, the UFORE model was run with the field confirmed land uses.

II. A comparison between field determined land use and parcel based land use categorization for each plot.

Land Use Category	Parcel	Field
Agricultural	4	2
Commercial	12	22
Industrial	9	8
Public / Quasi-Public / Institutions	65	29
Public Communications / Utilities	3	5
Recreational / Open Space / Natural	1	35
Residential	63	69
Right of Way / Transportation	30	24
*Unknown**	1	0
Vacant	10	4
Water	3	3
Total	**201**	**201**

*Since field data collection did not categorize any plot in the ‘unknown’ land use, the area for this land use category (231 acres) was proportionally distributed across all other land uses in order for the model to account for the total area of the city (Table 1).

I. Tree species identified in Tampa's urban forest.

Common Name	Scientific Name	% Trees	% LA[a]	IV[b]	N, E, I[c]
American elm	*Ulmus americana*	0.3	2.3	3	N
American sycamore	*Platanus occidentalis*	0.1	0.2	0	N
arborvitae	*Thuja occidentalis*	0.2	0.2	0	E
areca palm	*Dypsis lutescens*	0	0.2	0	E
avacado	*Persea americana*	0.1	0.1	0	E
bald cypress	*Taxodium distichum*	0.2	0.3	1	N
bay sp.	*Persea sp.*	0	0.1	0	N
Bejamin fig	*Ficus benjamina*	0.1	0	0	E
bismarck palm	*Bismarckia nobilis*	0	0.3	0	E
black cherry	*Prunus serotina*	0	0	0	N
black mangrove	*Avicennia germinans*	5.6	1.2	7	N
black tupelo	*Nyssa sylvatica*	0.1	0.3	0	N
Brazilian pepper	*Schinus terebinthifolius*	16.4	13	29	E,I
buttonbush	*Cephalanthus occidentalis*	0	0	0	N
cabbage palm	*Sabal palmetto*	5.6	11.8	17	N
camphor tree	*Cinnamomum camphora*	0	0.1	0	E,I
Carolina laurelcherry	*Prunus caroliniana*	1.6	3.6	5	N
Carolina willow	*Salix caroliniana*	0.2	0.1	0	N
cassia	*Cinnamomum aromaticum*	0	0.1	0	E
chinaberry	*Melia azedarach*	0.2	0.5	1	E,I
Chinese elm	*Ulmus parvifolia*	0.3	1.4	2	E
Christmas palm	*Adonidia merrilli*	0	0.1	0	E
common fig	*Ficus carica*	0	0	0	E
common pear	*Pyrus communis*	0	0	0	E
common persimmon	*Diospyros virginiana*	0.1	0	0	N
crapemyrtle	*Lagerstroemia indica*	0.2	0.1	0	E
dahoon holly	*Ilex cassine*	0.2	0.3	1	N
Darlington oak	*Quercus hemisphaerica*	1.1	8.8	10	N
ear tree	*Enterolobium cyclocarpum*	0	1.6	2	E
eastern redbud	*Cercis canadensis*	0.1	0.1	0	N
fetterbush	*Lyonia lucida*	0	0	0	N
fiddle-leaf fig	*Ficus lyrata*	0.1	0.1	0	E
Florida royal palm	*Roystonea elata*	0	0.2	0	N
Florida strangler fig	*Ficus aurea*	0	0.1	0	N
flowering dogwood	*Cornus florida*	0	0	0	N
foxtail palm	*Wodyetia bifurcata*	0.2	0.5	1	E
golden rain tree	*Koelreuteria paniculata*	0.3	0.1	0	E
grapefruit	*Citrus x paradisi*	0.2	0.6	1	E
green ash	*Fraxinus pennsylvanica*	0.1	0.2	0	N

[a] Percent of leaf area
[b] Percent of tree population + percent of leaf area
[c] **N**ative, **E**xotic (non-native), and **I**nvasive status of tree species

Common Name	Scientific Name	% Trees	% LA[a]	IV[b]	N, E, I[c]
hibiscus	*Hibiscus rosa-sinensis*	0	0	0	E
jacaranda	*Jacaranda mimosifolia*	0	0	0	E
Japanese privit	*Ligustrum japonicum*	0.5	0.4	1	E
laurel oak	*Quercus laurifolia*	2.4	5.1	8	N
lemon	*Citrus limon*	0	0	0	E
lime	*Citrus aurantifolia*	0.3	0.2	1	E
live oak	*Quercus virginiana*	3.5	20.6	24	N
longleaf pine	*Pinus palustris*	0.5	1.5	2	N
loquat tree	*Eriobotrya japonica*	0.8	0.3	1	E
mango	*Mangifera indica*	0.2	0.2	0	E
Mexican fan palm	*Washingtonia robusta*	0.1	0.3	0	E
Norfolk island pine	*Araucaria heterophylla*	0.1	0.8	1	E
oak sp.	*Quercus sp.*	0.1	1.2	1	N
oleander	*Nerium oleander*	0.4	0.3	1	E
orange	*Citrus sinensis*	0.5	0.9	1	E
orchid tree	*Bauhinia variegata*	0	0	0	E,I
parsley hawthorn	*Crataegus marshallii*	0	0	0	N
pond cypress	*Taxodium ascendens*	0.9	0.8	2	N
pygmy date palm	*Phoenix roebelenii*	0.3	0.2	1	E
queen palm	*Syagrus romanzoffiana*	0.4	1.6	2	E
red mangrove	*Rhizophora mangle*	42.2	3	45	N
red maple	*Acer rubrum*	0.9	1.3	2	N
red mulberry	*Morus rubra*	0.1	0.5	1	N
red top photinia	*Photinia x fraseri*	0.1	0.1	0	E
redbay	*Persea borbonia*	0.2	0.2	0	N
rubber plant	*Ficus elastica*	0	0	0	E
sago palm	*Cycas revoluta*	0.1	0	0	E
salt bush	*Baccharis halimifolia*	0.1	0.1	0	N
sand live oak	*Quercus geminata*	0.7	0.7	1	N
saw palmetto	*Serenoa repens*	0.5	0.5	1	N
sea grape	*Coccoloba uvifera*	0.1	0.2	0	N
Senegal date palm	*Phoenix reclinata*	0.1	0.7	1	E
silk-oak	*Grevillea robusta*	0	0.2	0	E
slash pine	*Pinus elliottii*	0.5	1.6	2	N
sour orange	*Citrus aurantium*	0.6	0.5	1	E
Southern magnolia	*Magnolia grandiflora*	0.2	0.7	1	N
Southern redcedar	*Juniperus virginiana. var silicicola*	0.1	0.1	0	N
sparkleberry	*Vaccinium arboreum*	0	0	0	N
swamp bay	*Persea palustris*	0.1	0	0	N

[a] Percent of leaf area
[b] Percent of tree population + percent of leaf area
[c] **N**ative, **E**xotic (non-native), and **I**nvasive status of tree species

Common Name	Scientific Name	% Trees	% LA[a]	IV[b]	N, E, I[c]
sweetbay	*Magnolia virginiana*	0.1	0.1	0	N
sweetgum	*Liquidambar styraciflua*	0.1	0.1	0	N
tangerine	*Citrus reticulata*	0.1	0.3	0	E
turkey oak	*Quercus laevis*	0	0.1	0	N
viburnum	*Viburnum odoratissimum*	0.3	0.1	0	N
Walter's viburnum	*Viburnum obovatum*	0	0	0	N
water hickory	*Carya aquatica*	0	0	0	N
water oak	*Quercus nigra*	0.8	1.3	2	N
wax myrtle	*Morella cerifera*	0.6	0.4	1	N
weeping bottlebrush	*Callistemon viminalis*	0.1	1	1	E
white leadtree	*Leucaena leucocephala*	3.1	1.4	5	E,I
white mangrove	*Laguncularia racemosa*	2.4	1.2	4	N
white mulberry	*Morus alba*	0.2	0.3	1	E
winged elm	*Ulmus alata*	0	0	0	N
yew podocarpus	*Podocarpus macrophyllus*	0	0	0	E

[a] Percent of **l**eaf area
[b] Percent of tree population + percent of **l**eaf area
[c] **N**ative, **E**xotic (non-native), and **I**nvasive status of tree species