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City of Gainesville Urban Forest Ecological Analysis 2016

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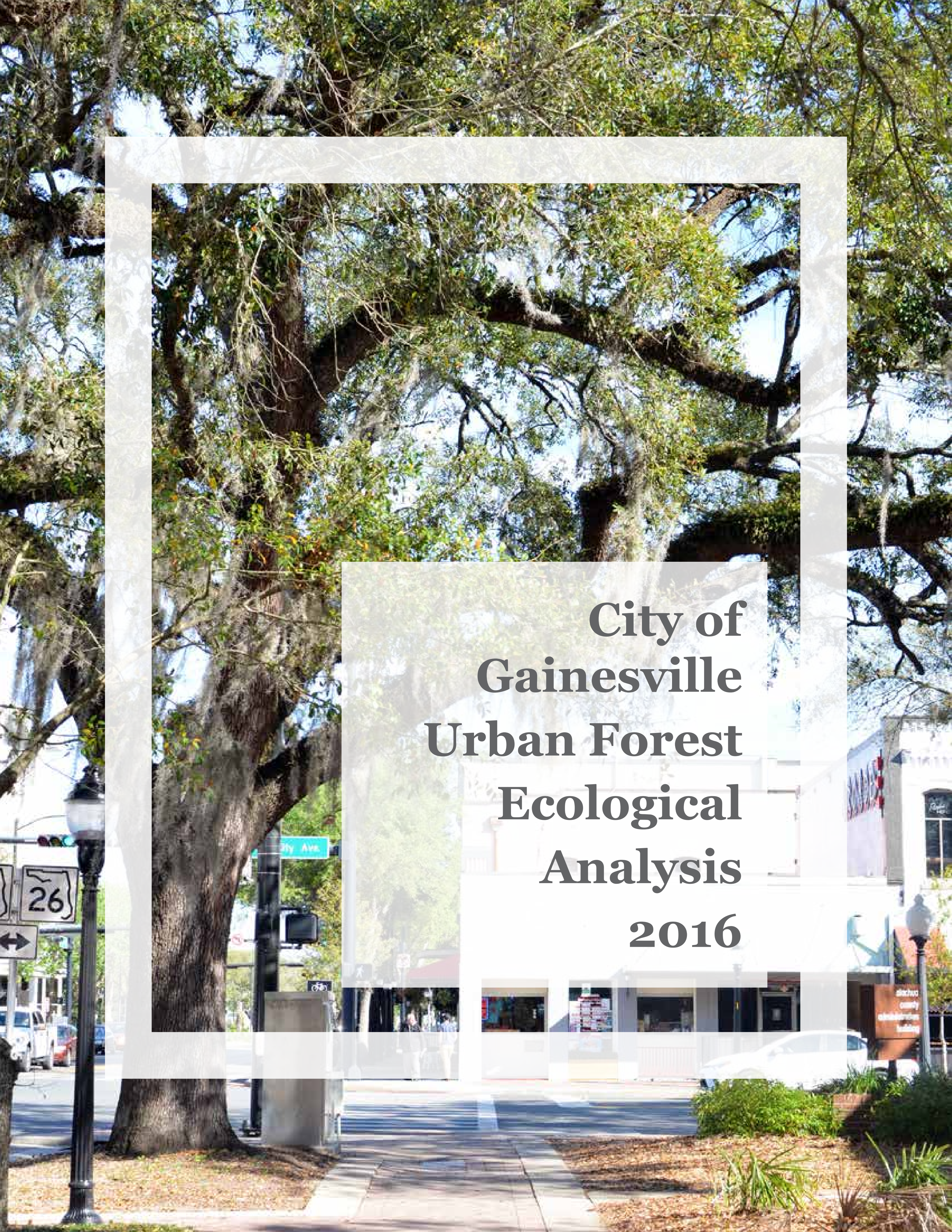

City of Gainesville Urban Forest Ecological Analysis 2016

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Final Report to the City of Gainesville

March 2017

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Special Thanks

Joe Wolf, Gainesville Regional Utilities

Geoff Parks, City of Gainesville PRCA

Landowners and residents of Gainesville

Citation for this report:

Andreu, M. G., Fox, D., Landry S., Northrop, R., and Hament, C. (2017). Urban Forest Ecological Analysis. Report to the City of Gainesville, March 2017. City of Gainesville, Florida.

Photos by Caroline Hament and David Fox

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Executive Summary

Economic Values:

- Compensatory value: $1.4 billion.
- Total savings from urban forest benefits: $24.4 million/year.
- Residential heating and cooling savings: $7.7 million/year.
- Avoided air pollution abatement value: $2.7 million/year.
- Public health savings: $2.66 million/year.
- Carbon sequestration: 44,200 tons of carbon per year ($5.88 million/year).
- Carbon storage: 746,000 tons of carbon ($99.2 million).
- Avoided stormwater costs: $3.8 million/year.

Ecological Structure:

- Number of trees*: 7.2 million.
- Tree canopy cover: 47%.
- Number of species identified: 173 (97 in tree stratum; 153 in shrub stratum).
- Loblolly pine, slash pine, laurel oak, water oak, and red maple make up over half of Gainesville's urban forest.
- Over 94% of tree species identified are native to Florida.
- Average density: 178 trees per acre.
- 60% of trees in Gainesville are less than 6 inches in diameter.
- 80% of trees are in excellent or good condition, 11% in fair health, and 9% in poor condition or dead.
- 30% of the city is covered by shrubs.
- 24% of the City is covered by impervious surfaces; 23% is covered by maintained grass.

*Trees in this study are woody stems ≥1" diameter at breast height (DBH).

Ecological Assessment

This ecological assessment provides a detailed look into some of the economic and ecological values of the City of Gainesville'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
- urban forest planning and management
- providing empirical data for the inclusion of trees within environmental regulations

During spring to early fall of 2016, one hundred and seventy-seven plots were sampled and analyzed to quantify the vegetation structure, functions, and values of the urban forest in Gainesville. This report documents the methods used and a discussion of results from these analyses.

Methods

In order to capture a representative sample of the urban forest across broad land use categories, a systematic random sampling design was used to achieve a geographic distribution of inventory plots throughout the city. Using geographic information system (GIS) tools, a hexagonal grid was projected onto a map of the city; each full hexagon represented approximately 200 acres (Figure 1). One sample point was randomly located within each hexagon. The latitude and longitude was acquired from the GIS for each point to aid in plot establishment and data collection. 177 plots were randomly sampled (Table 1). GIS land use and tax parcel data were acquired from the City (Appendix A). Broad land use categories were generalized from these spatial data sets (Table 1 and Figure 2).

With this systematic sampling, the percentage of plots that fall into each land use was similar to the percent of Gainesville in each land use (Table 1). A comparatively small area of the City has an agricultural land use (pasture and wholesale nursery), and no sample plots fell in these areas (Figure 2). Over one-quarter of Gainesville is covered by forestland, about half of which is composed of pine plantations along the northern City boundary. The large *Industrial* area in the NW corner of the City includes lands surrounding the Deerhaven power plant while the large *Transportation* area in the eastern part of the City is the Gainesville Regional Airport (Figure 2). The land use that occupies the most acreage in the city is Residential (29%) (Table 1).

Data collection in the 177 plots began May 9 and ended October 21, 2016. Using the latitude and longitude values from the GIS, a fixed radius 1/10th acre (r = 37.2 ft) sample area was established at each plot center location. Plot center was documented with distances and directions to reference objects, which can be used to facilitate future plot reestablishment.

Three vertical strata of the urban forest were quantified at every sample plot: tree, shrub, and ground cover (Table 2). The tree stratum includes woody stems greater than or equal to 1 inch in diameter at breast height (DBH), measured 4.5 feet from the

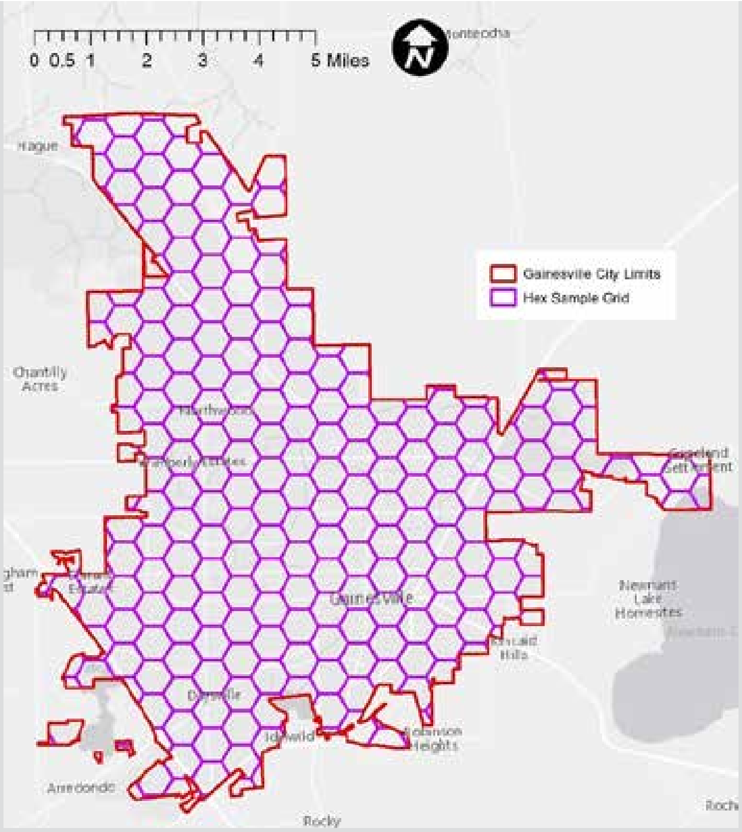


Figure 1. Study area map with sample grid overlay.

Land Use	Area (acres)	Percent of City	Number of Plots
Residential	11,792	28.9	48
Forested	11,098	27.2	35
Transportation	6,218	15.3	29
Public/Institutional	3,972	9.7	24
Industrial	2,973	7.3	13
Commercial	2,828	6.9	19
Open Space/Park	1,719	4.2	9
Agriculture	141	0.3	0
Gainesville	**40,740**	**100**	**177**

Table 1. Generalized land uses in the City of Gainesville, FL with number of sample plots per strata.

ground. The shrub stratum is made up of woody plants at least 1 foot tall but with stems less than 1 inch DBH. The ground cover stratum consists of woody or herbaceous vegetation less than 1 foot tall. Data was collected following the plot sampling protocol referenced in the 2017 i-Tree User's Manual (v6), Phase III found at www.itreetools.org.

Data collected also included the following:

- Percent cover of each stratum
- Identification of tree and shrub plant species
- Tree DBH
- Tree height
- Tree crown measurements
- Crown condition assessments
- Proximity of trees to buildings
- Tree crown light exposure index

Data was analyzed by the i-Tree Eco software tool (v6), formerly known as UFORE (Urban Forest Effects Model) (Nowak, Stevens, Sisinni, & Luley, 2002), which was created by the U.S. Forest Service. This tool is widely used throughout the U.S., Canada, Australia, and the U.K. Models within i-Tree Eco quantify the structure and following values of the urban forest:

- Compensatory value
- Residential heating and cooling savings
- Avoided air pollution abatement value
- Public health savings
- Carbon sequestration value
- Carbon storage value
- Avoided stormwater costs

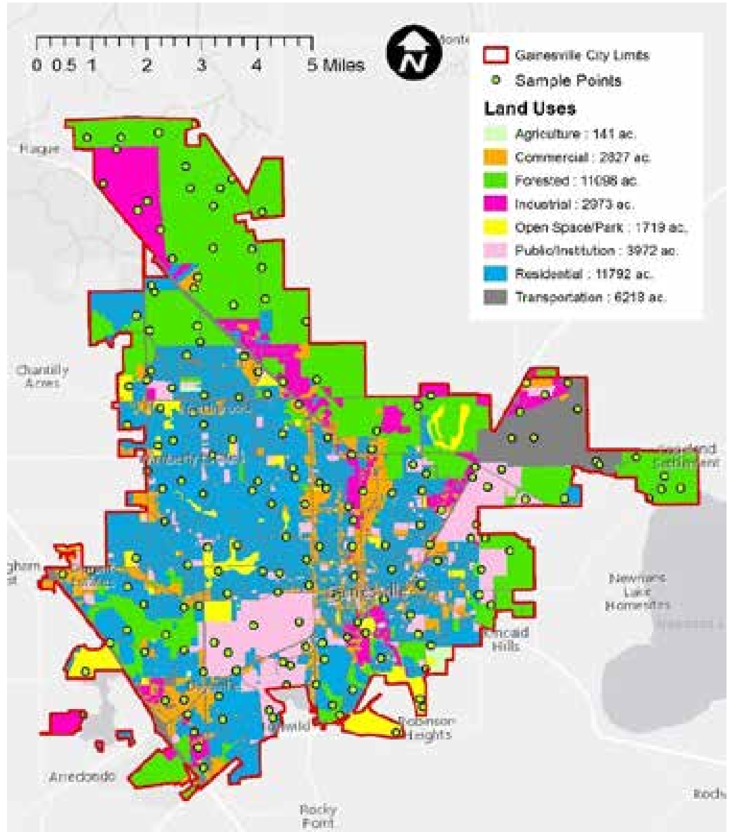


Figure 2. Generalized land use map of Gainesville, FL including sample plot locations.

Strata	Description
Tree	Woody stems ≥1" DBH
Shrub	Woody plants ≥1ft height; <1" DBH
Ground Cover	Woody or herbaceous vegetation <1ft height

Table 2. Description of each vertical stratum of the urban forest included in the i-Tree Eco sampling methodology.

Results

Gainesville is located in temperate north Florida. Many of the plant species found in Gainesville are specific to this climate zone (Plant Hardiness Zone 9a: average annual extreme minimum temperatures between 20-25° F) and are not found further south in the sub-tropical regions of the state. Typical forest types in this region include mixed pine and mixed hardwood uplands and cypress/gum wetlands. Remnants of these forest types were found within the city limits. Southern pine timber production is also common in northern Florida, and the City of Gainesville contains some active production forests.

Diversity

For the purpose of this study, species diversity is the number of species present. Diversity can be used as an indicator for vulnerability or resilience to natural disturbances such as insect and disease outbreaks. In this study, 173 species were identified in the City of Gainesville. Of these, 97 species were identified in the tree stratum (woody stems ≥1″ DBH) and 153 species in the shrub stratum (woody plants ≥ 1ft height; <1″ DBH) (Appendix B). The land use category with the greatest diversity is *Residential* (70 species), as homeowners typically plant a broader suite of tree species than may be found in other urban areas. The land use category with the lowest number of species is *Industrial* (21 species). By comparison, 42 tree species were identified in the *Forested* land use (Figure 3).

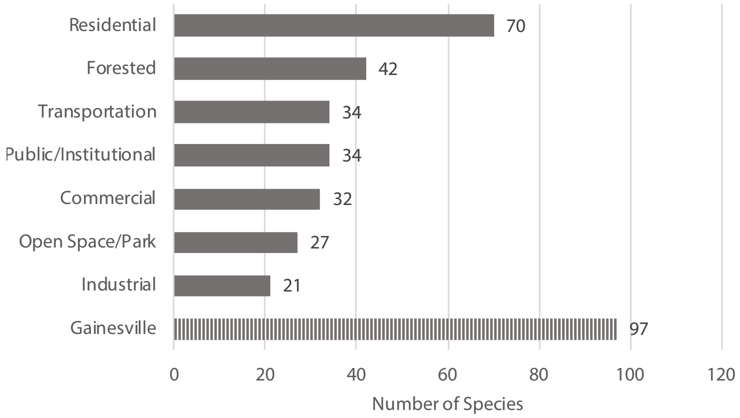


Figure 3. Comparison of the number of tree species by land use designation.

Tree Population

There are an estimated 7.2 million trees in the City of Gainesville, comprised of 97 species. The 10 most common tree species, representing 70% of the population are loblolly pine (*Pinus taeda*), slash pine (*Pinus elliottii*), laurel oak (*Quercus laurifolia*), water oak (*Quercus nigra*), red maple (*Acer rubrum*), Carolina laurel cherry (*Prunus caroliniana*), sweetgum (*Liquidambar styraciflua*), wax myrtle (*Morella cerifera*), swamp tupelo (*Nyssa biflora*), and sugarberry (*Celtis laevigata*) (Figures 4 and 5). All of these species are common in natural plant communities, described by the Florida Natural Areas Inventory (FNAI), found in this geographical region. Loblolly and slash pines represent 28% of the trees in this inventory due to the large acreage of pine plantations within the City. Relative to other cities in Florida, it is notable that Gainesville's urban forest is not dominated by any invasive tree species.

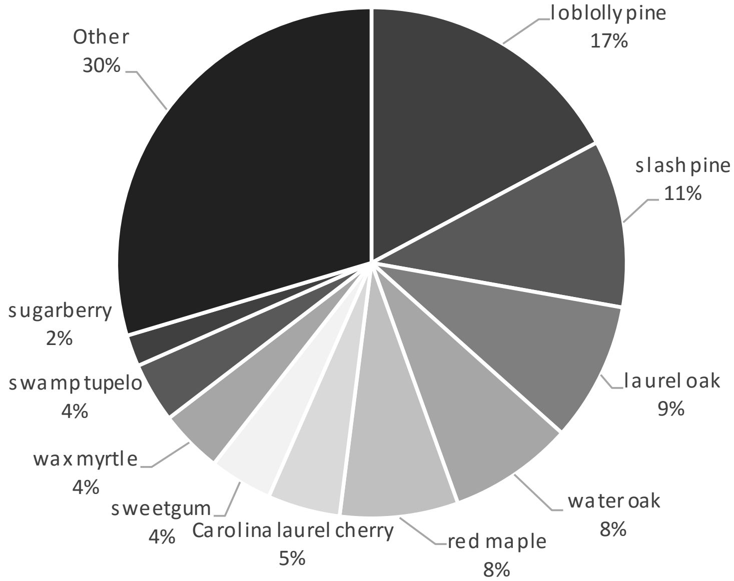


Figure 4. Top ten tree species as a percentage of the total tree population in Gainesville, FL.

Loblolly Pine *Pinus taeda*

Slash Pine *Pinus elliottii*

Laurel Oak *Quercus laurifolia*

Water Oak *Quercus nigra*

Red Maple *Acer rubrum*

Figure 5. Top ten tree species in the City of Gainesville.

Carolina Laurel Cherry
Prunus caroliniana

Sweetgum
Liquidambar styraciflua

Wax Myrtle
Morella cerifera

Swamp Tupelo
Nyssa biflora

Sugarberry
Celtis laevigata

Native and Non-Native Tree Species

Of the 97 tree species identified in the City, 65 are native to Florida, meaning they were found in Florida prior to European colonization in the 16th century. The remaining 32 species are non-native, meaning they were introduced outside of their native range. Of these non-native species, six were listed by the Florida Exotic Pest Plant Council (FLEPPC, 2016) as invasive (Table 3). Invasive species are those that spread into and dominate an area, and they negatively affect ecological functions of the forest. Five of these are considered Category I (CAT I) invasive species, which is a subset of the FLEPPC list indicating those species which have caused severe documented ecological damage.

Although other invasive species were found in the shrub and ground cover strata, the i-Tree sampling scheme does not capture the cover of these species.

Species	Common Name	Percent of Tree Population	Percent Leaf Area	Number of Plots Present
*Albizia julibrissin**	Mimosa	0.14	0.16	3
Broussonetia papyrifera	Paper mulberry	0.24	0.06	1
*Cinnamomum camphora**	Camphor tree	0.91	1.05	9
*Ligustrum lucidum**	Glossy privet	0.19	0.14	4
*Syzygium cumini**	Jambolan plum	0.02	<0.01	1
*Triadica sebifera**	Chinese tallow	0.16	0.06	5

Table 3. Invasive tree species found in the City of Gainesville as defined by FLEPPC.
*CAT I Invasive Species

Forest Structure

Forest structure is the distribution of vegetation both horizontally and vertically. The following sections review physical attributes of the forest that were measured and calculated to determine forest structure: tree density, diameter distribution, forest health, urban forest cover, and leaf area. These metrics were ultimately used to quantify the ecological functions of Gainesville's urban forest.

Tree Density

Tree density is the number of trees per acre (TPA). The higest TPA is found in the *Forested* land use, where loblolly and slash pine are often planted at densities between 500 and 700 TPA. The *Residential* land use, which represents the most acreage in the city (Table 1) and has the highest number of species (Figure 3), has far fewer TPA. The lowest TPA is found on *Commercial* and *Transportation* lands (Figure 6), which make up 22% of the City.

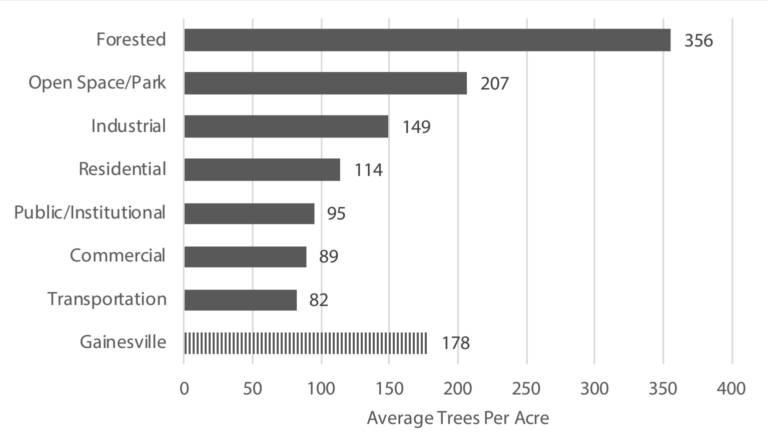


Figure 6. Comparison of average trees per acre (TPA) for each land use designation in Gainesville, Fl.

Diameter Distribution of Trees

The diameter distribution of live trees in Gainesville is skewed toward smaller diameter classes (Figure 7). However, species within each class grow at different rates and have different maximum size potentials. For example, wax myrtle (*Morella cerifera*), which makes up 10% of the 1-3" diameter class (Table 4), grows quickly, but has a small maximum diameter and is short-lived. Loblolly pine (*Pinus taeda*), however, grows quickly, but has a large maximum diameter and is longer-lived. By comparison, live oak (*Quercus virginiana*), which makes up 25% of the largest diameter class (Table 4), grows relatively slowly, has the potential to get large, and is very long-lived. Only four of the 97 species identified in the City make up the largest diameter class (>30"), and 3 of the 4 are not present in the species that make up the majority of the smallest diameter class (Table 4).

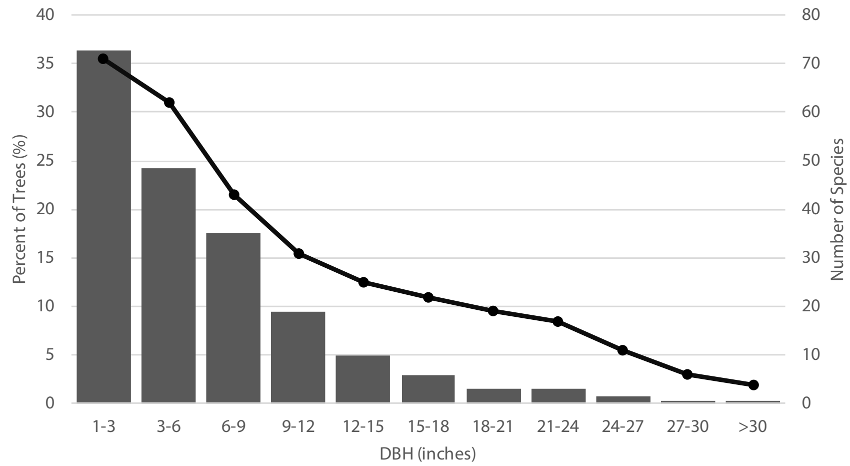


Figure 7. Comparison of diameter (DBH) distribution by diameter class (columns) with the number of species present in each diameter class (line).

Species	Percent of 1-3" DBH class	Species	Percent of >30" DBH class
Laurel oak	12%	Bald cypress	41%
Red maple	11%	Live oak	25%
Water oak	10%	Swamp tupelo	23%
Wax myrtle	10%	Sugarberry	11%
Carolina laurel cherry	9%	—	—
Loblolly pine	5%	—	—
Sweetgum	3%	—	—
Sugarberry	3%	—	—
Elderberry	2%	—	—
Dahoon	2%	—	—

Table 4. Ten species make up 68% of the 1-3" diameter class in Gainesville's urban forest. Four species make up the largest diameter class (>30").

Forest Health

The 2016 analysis indicates that approximately 80% of the trees are considered to be in excellent or good health, 11% are in fair health, and the remaining 9% are in poor condition or lower. Tree health was evaluated by land use. The i-Tree methodology to determine estimates of tree health is based on canopy condition assessments. These estimates of health do not reflect structural integrity.

The highest percentage of healthy trees (defined as excellent and good categories) in Gainesville are those in *Public/Institutional* (85%), *Industrial* (81%), and *Forested* (81%) land uses (Figure 8). Approximately 71-81% of trees in *Commercial*, *Transportation*, and *Residential* land uses were in excellent or good health. A greater percentage of trees in *Commercial* areas were in fair condition (15%) than those in *Transportation* and *Residential* areas (8% and 11%). The lowest percentage of healthy trees occurs on *Open Space/Park* lands and the highest percentage of unhealthy or recorded dead trees fell on *Transportation.*

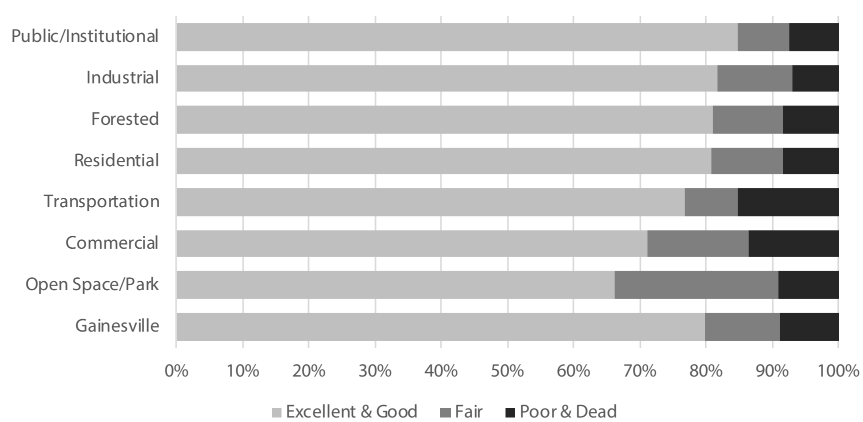


Figure 8. Condition of trees in Gainesville by land use designation.

Cover of Urban Forest Strata

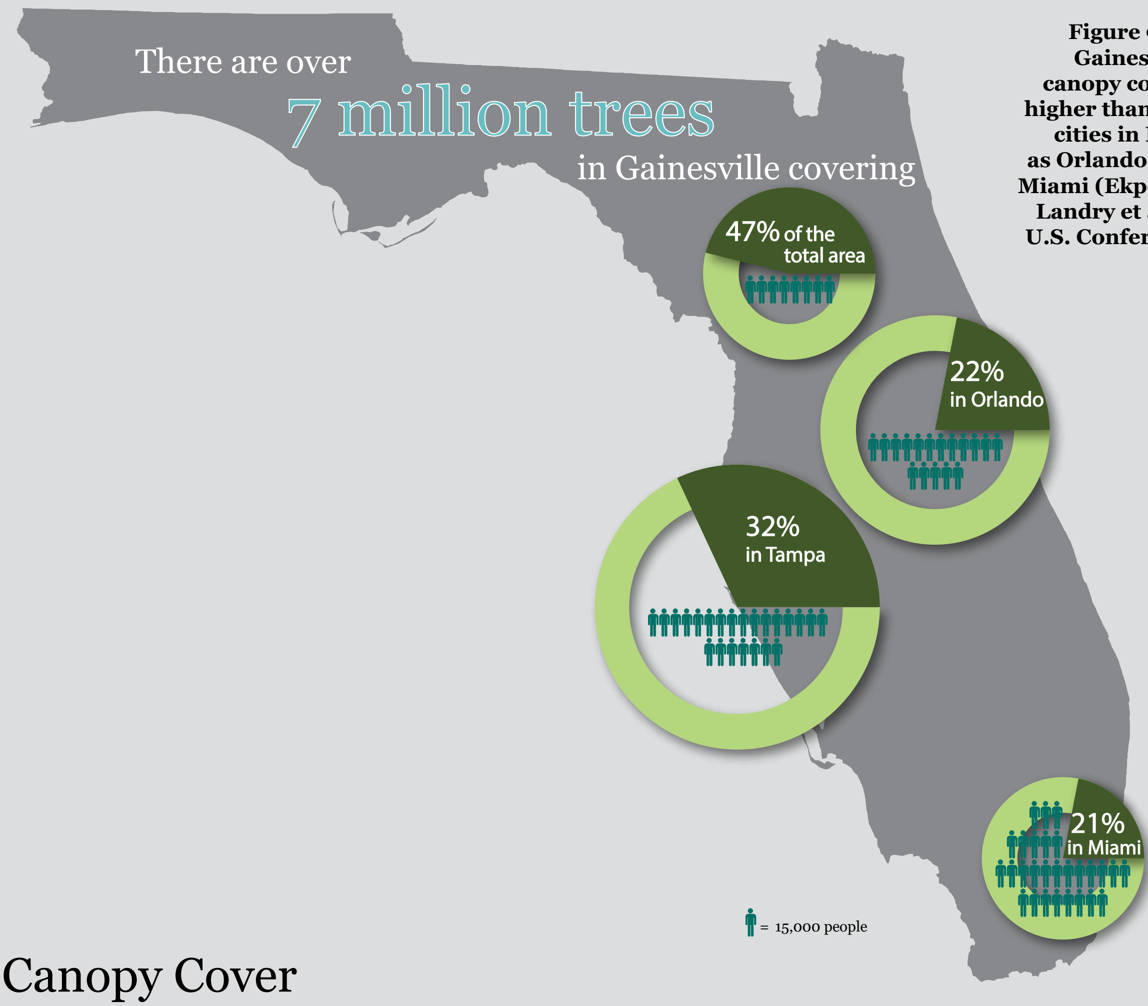


Figure 9. The City of Gainesville has 47% canopy cover, which is higher than other major cities in Florida, such as Orlando, Tampa, and Miami (Ekpe et al., 2012, Landry et al., 2011, and U.S. Conference of Mayors, 2008).

Tree Canopy Cover

Tree canopy cover is used to quantify the amount of land area under and around trees. Sometimes thought of as the "footprint" of the urban forest, ecologically, canopy cover influences microclimate (e.g. shade in parking lots and homes) as well as the interception of rainfall (stormwater flow) and air pollution abatement (Leff, 2016).

Based on Eco sample plot data collected, the estimated average tree canopy cover of Gainesville is 47% (Figure 9), but it is spatially variable across land uses (Figure 10). Tree cover is greatest in *Forested* areas (71%) and lowest in *Industrial* areas (25%). The *Residential* (44%) and *Open Space/Park* (44%) land uses were nearly at the Gainesville average (Figure 10) and together represent 33% of the City (Table 1).

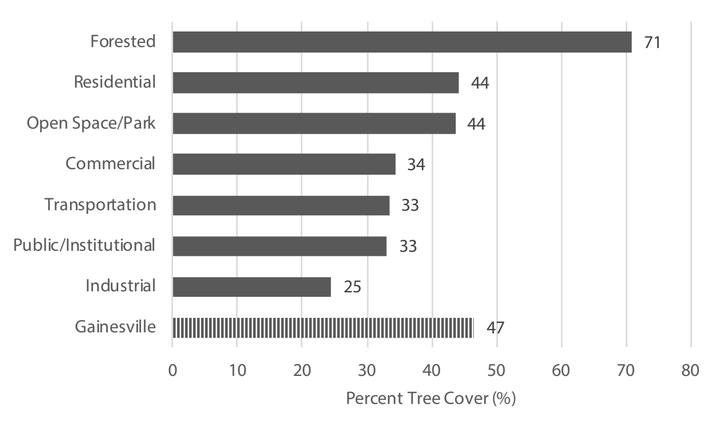


Figure 10. Percent tree cover by land use in the City of Gainesville.

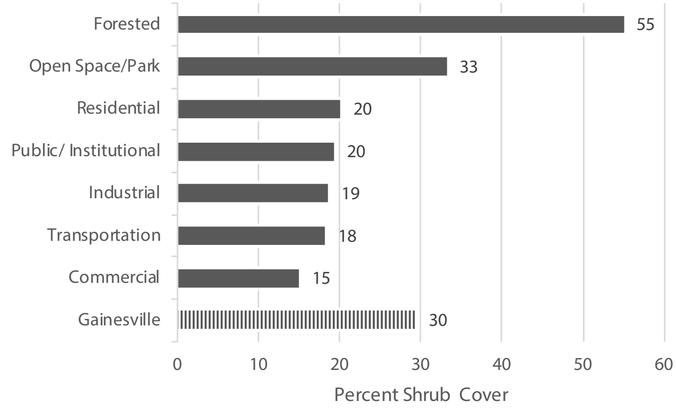


Figure 11. Percent shrub cover by land use designation in the City of Gainesville.

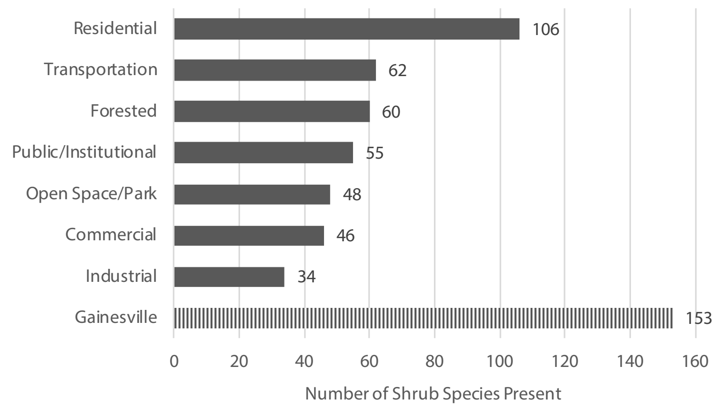


Figure 12. Number of shrub species present in each land use designation.

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 (comprised of woody plants at least 1 foot in height and less than 1 inch DBH). The shrub stratum provides additional leaf area and some of the same benefits as trees. Because the tree and shrub layers are in overlapping strata their cover estimates are not additive.

In Gainesville approximately 30% of the city is covered with shrubs (Figure 11), comprised of 153 species (Figure 12). The *Forested* land use has the greatest shrub cover (55%) and is comprised of 60 species. By comparison, the *Residential* land use has much less cover (20%), but has the highest number of species present (106 species).

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 used in quantifying pollution removal and avoided runoff, as leaves are responsible for wind, solar, and water interception. The i-Tree Eco model calculates leaf area of individual species using regression equations and takes into consideration tree condition.

The tree species with the greatest LA in Gainesville were loblolly pine (20%) and slash pine (15%), which were also the most dominant tree species in the urban forest based on the number of trees (Table 5). However, not all species followed this pattern. Live oak represented only 1% of the total tree population, yet 4% of the LA. Many of the species that make up majority of the City's LA are common in forested wetland plant communities described by FNAI.

Since leaf area is a crucial factor in quantifying the benefits of the urban forest, leaf area by land use was also considered. The land use with the highest percentage of the City's LA was *Forested* (44%) (Figure 13). The *Residential* land use, which takes up the greatest percentage of the City, had 26% of the City's LA. *Industrial*, *Open Space/Park,* and *Commercial* areas had the smallest proportion of the City's LA (3%, 4%, and 5%), but also account for the smallest portion of Gainesville's total acreage (Figure 13).

Species	Leaf Area (%)
Loblolly pine	20%
Slash pine	15%
Water oak	8%
Laurel oak	7%
Red maple	6%
Sweetgum	5%
Live oak	4%
Bald cypress	4%
Swamp tupelo	3%
Sugarberry	3%

Table 5. Species with the most leaf area (LA) in Gainesville.

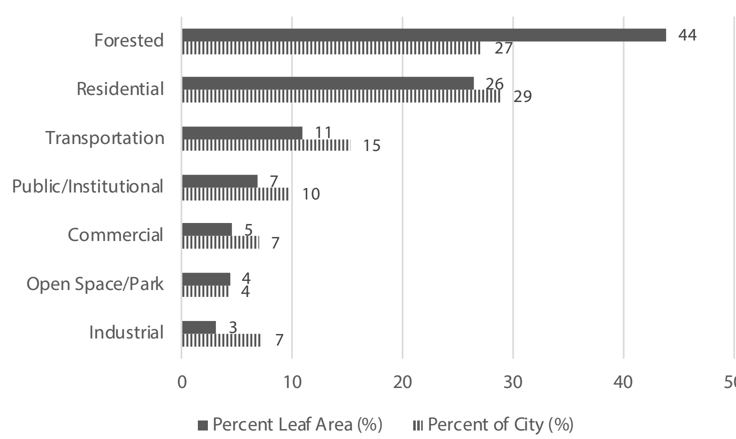


Figure 13. Distribution of leaf area by land use and the percentage of the City represented by each land use.

Ground Cover

The groundcover stratum is made up of the surfaces covering the ground including herbaceous and woody vegetation less than 1 foot tall. Ground cover is divided into two broad categories: impervious (e.g. roads, rooftops, and sidewalks) and pervious (e.g. lawns, gravel driveways, mulched beds, and ponds) surfaces. The groundcover type likely determines whether rainfall will seep into the ground or be diverted as stormwater runoff.

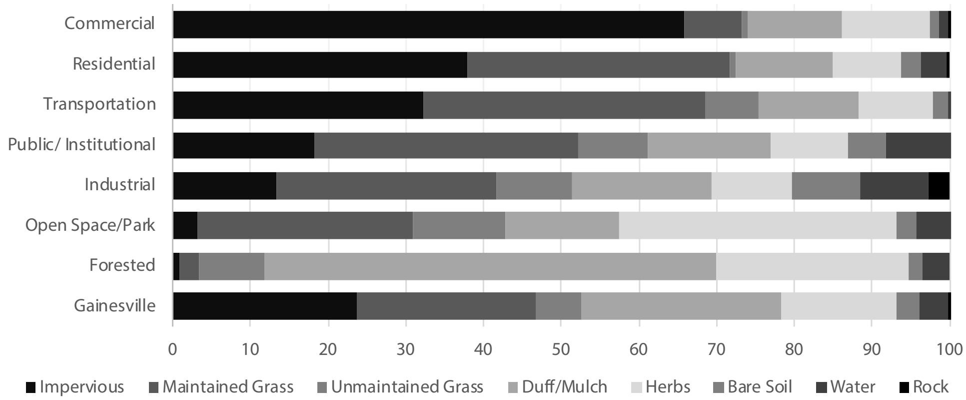


Figure 14. Proportional distribution of ground covers by land use in Gainesville.

Urbanization tends to increase the amount of impervious surface area in a city. In Gainesville, 23% percent of the ground cover in the city is impervious (Figures 14 and 15). The land use areas with the greatest amount of impervious surfaces are *Commercial* (66%), *Residential* (38%), and *Transportation* (32%) (Figure 14).

The land use categories with the greatest amount of pervious ground cover are *Forested* (99%) and *Open Space/ Park* (97%) (Figure 14). Pervious surfaces were divided into seven categories (maintained grass, unmaintained grass, duff/mulch, herbs, bare soil, water, and rock) as each have different hydrological impacts (Figure 15). Much of the pervious surfaces in Gainesville are classified as maintained grasses or lawns (23%). In Florida approximately "one-third of the freshwater use is for municipal use, half of which is used to water lawns (Cervone, 2003)." The land uses with the highest percentage of maintained grass are *Transportation* (36%), *Public/Institutional* (34%), and *Residential* (34%) (Figure 14).

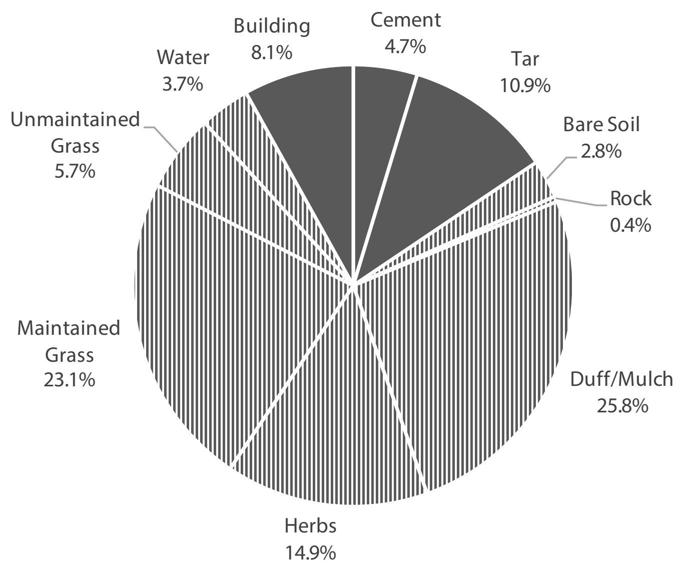


Figure 15. Distribution of ground cover types by percent in Gainesville.

Tree Cover Change

Independent of the i-Tree Eco plot-based analysis, an additional tree canopy analysis for the City of Gainesville was completed using remote sensing techniques. Landsat imagery and high-resolution aerial photography (NAIP) were used to examine tree canopy cover over the nineteen year period between 1996 and 2015 (see Appendix C for study methods). Landsat images are considered 'moderate resolution' having a 30-meter pixel size while the NAIP images are 'high resolution' having 1-meter pixels. While Landsat imagery was available for the entire study period, NAIP photography was only available between 2006 and 2015.

Landsat analysis results indicate a decrease in Gainesville tree canopy cover between 1996 and 2015. There was an overall net loss in tree canopy between 1996 and 2006 followed by a net gain from 2006 to 2015 (Table 6). The net gain was also indicated by the NAIP photography analysis. The distribution of canopy change from 1996 to 2015, from 1996 to 2006 and from 2006 to 2015 is shown in Figures 16, 17, and 18 respectively. Canopy gains and losses can be found throughout the City, and large concentrated areas of change can also be seen. From 1996 to 2006 large blocks of land in the northern portion of the city experienced losses and then showed canopy gains from 2006 to 2015. Much of this portion of the City is covered by production pine forests so the gains and losses can likely be attributed to timber harvest followed by reforestation activity.

Imagery Source	1996	2006	2015
Landsat	58%	46%	47%
NAIP	-	50%	54%

Table 6. Tree canopy cover by year for Gainesville measured using remote sensing.

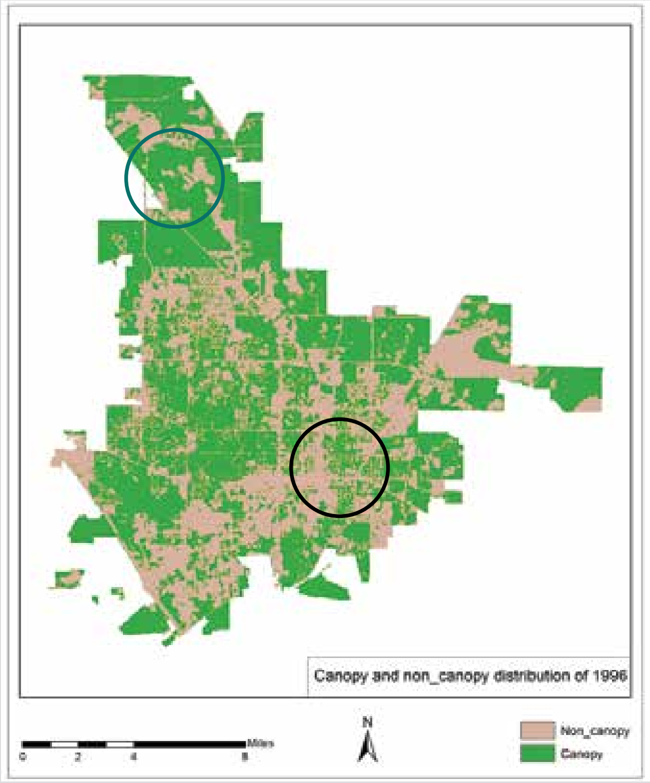


Figure 16. Canopy and non-canopy distribution of 1996 in the City of Gainesville.

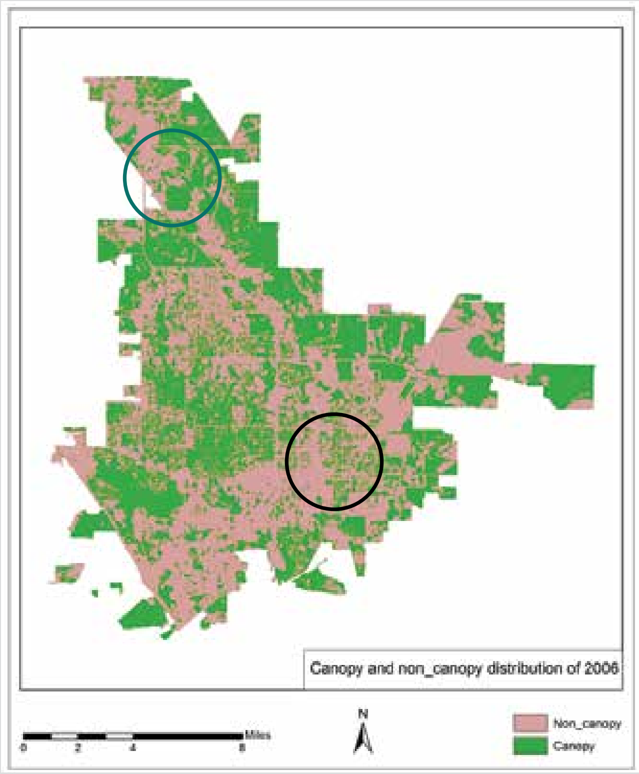
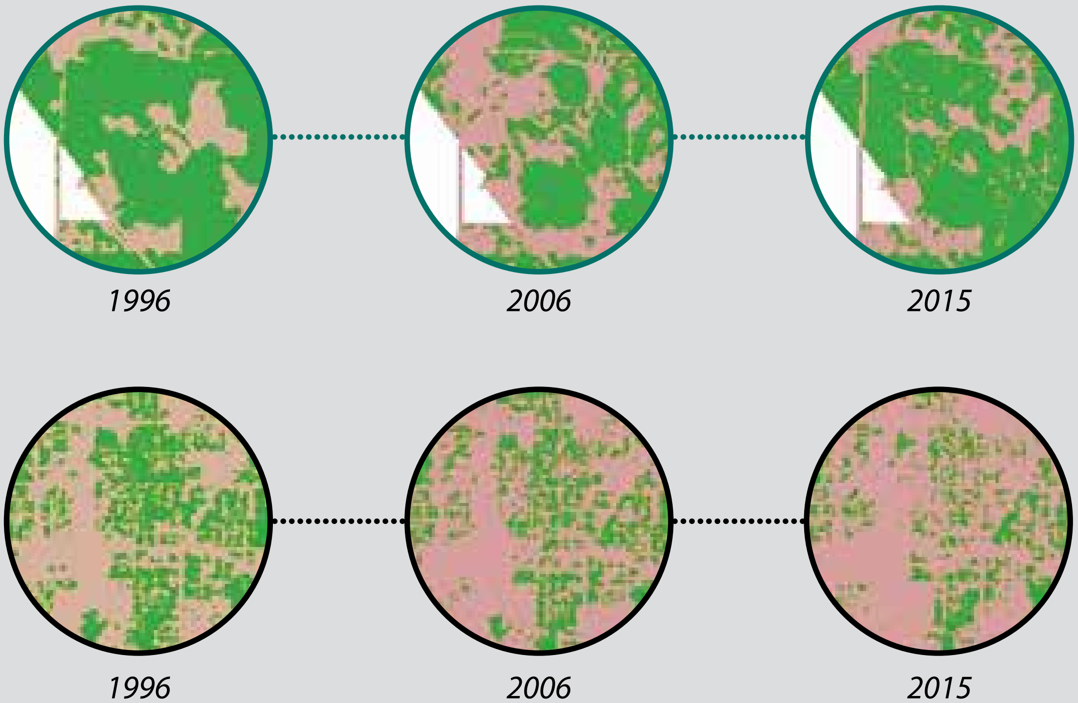


Figure 17.Canopy and non-canopy distribution of 2006 in the City of Gainesville.



Changes to Gainesville's canopy occurred between 1996 and 2015 (Figures 16, 17, 18). In some areas (top), canopy was lost then gained, likey due to timber harvest followed by reforestation. In other areas of the city (bottom), canopy has been lost over time without gains.

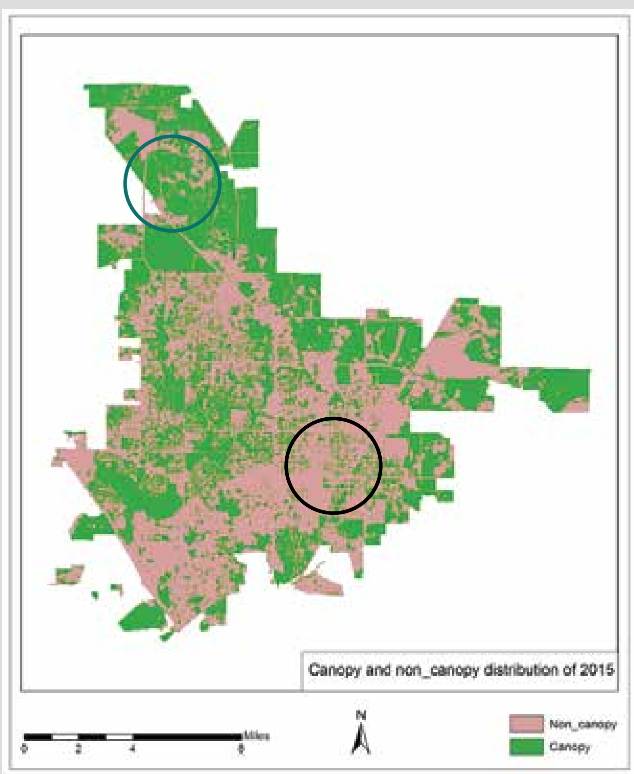


Figure 18. Canopy and non-canopy distribution of 2015 in the City of Gainesville.

The Value of Gainesville's Urban Forest

The i-Tree Eco model uses the urban forest structure metrics discussed in the previous section to quantify and value the benefits of the urban forest. These benefits are considered ecosystem services because of their beneficial effects on the health and well-being of humans (Escobedo, Kroeger, and Wagner, 2011). These ecosystem services and their values (summarized in Table 7) are discussed in the following sections.

$24.4 million/year + $1.4 billion
Ecosystem Services *Compensatory Value*

Ecosystem Service	Annual Value (million $)
Tree shading energy savings	7.7
Avoided carbon emissions	1.7
Air pollution capture	2.7
Avoided health care costs	2.7
Avoided stormwater runoff costs	3.8
Carbon sequestration	5.9
Total Annual Urban Forest Benefits	**24.4**

Table 7. Summary of ecosystem services and annual values of Gainesville's urban forest.

In addition to its annual values, the urban forest has an overall estimated value referred to as its compensatory value. This value considers tree size, species, condition, and location. The compensatory value is an estimate of the cost to replace all trees in the city if they were removed (e.g. deliberately or due to a storm).

The compensatory value of trees in Gainesville's urban forest is over $1.4 billion dollars. This value was calculated by the ECO model using the industry standard methodology developed by the Council of Tree and Landscape Appraisers.

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, and decreases the demand for non-renewable fossil fuels, which is a global concern.

Trees that were 20 feet tall and less than 60 feet from a residential building that was 3 stories tall or less were considered to have an influence on energy consumption (increase or decrease) (McPherson & Simpson, 1999). Trees and residential buildings that met these criteria were located, identified, measured (height and crown area), and mapped on all inventory plots. The i-Tree Eco model estimated energy conservation utilizing the average amount of energy consumed by residential buildings in Gainesville (McPherson and Simpson 1999).

By reducing the amount of energy needed to heat or cool a building, trees also reduce the amount of carbon that would be released into the atmosphere during the production of electricity through burning of fossil fuels. Avoided carbon emissions were estimated based on modeled energy conservation due to tree shading. Energy savings were calculated using Florida state wide averages of $116.15/MWH and $17.30/MBtu. The carbon avoided value is based on $133.05 per ton.

Gainesville's urban forest resulted in an estimated reduction of residential energy use for cooling of 58,770 MWhs valued at $6.8 million dollars. The estimated reduction of carbon emissions due to reduced energy production by power plants was 12,900 tons with an associated value of about $1.7 million. In 2016, trees saved Gainesville residents an estimated $7.7 million dollars in total heating and cooling costs (Table 8).

Type	Heating	Cooling	Total	Price ($)	Value ($)
Natural Gas (MBTU)	38,130	0	38,130	$17.30	$659,600
Electricity (MWH)	1,570	58,770	60,340	$116.15	$7,008,400
Carbon Avoided (ton)	910	11,980	12,890	$133.05	$1,715,000

Table 8. Annual energy savings from residential trees.

Public Health: Air Pollution Removal

Air pollution in cities causes deleterious health impacts for residents. Some of the most serious air pollutants in urban environments are carbon monoxide (CO), nitrogen dioxide (NO_2), ground-level ozone (O_3), fine particulate matter ($PM_{2.5}$), and sulfur dioxide (SO_2). Carbon monoxide is a toxic gas that enters the atmosphere through the combustion of fossil fuels (e.g. vehicles and power plants). Nitrogen dioxide is a respiratory irritant, and it is an ingredient in the formation of ground-level ozone (O_3; 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, reducing the rate of ground-level ozone formation (Nowak & Dwyer, 2007).

Pollutant	Removal (short ton)	Value ($)
O_3	692	$1,310,010
NO_2	102	$22,930
SO_2	26	$2,090
$PM_{2.5}$	22	$1,324,400
CO	4	$6,176
Total	**846**	**$2,665,600**

Table 9. Annual pollution removal by the trees and shrubs in Gainesville.

Particulate matter less than 2.5 micrometers ($PM_{2.5}$) consists of suspended microscopic droplets (liquid or solid) that are small enough to be inhaled. $PM_{2.5}$ is associated with serious respiratory issues when it penetrates into the lungs. Trees improve air quality by intercepting PM2.5 on their leaves. They remove carbon monoxide (CO), nitrogen dioxide (NO_2), ozone (O_3), and sulfur dioxide (SO_2) from the atmosphere through uptake via their leaf stomata.

The i-Tree Eco model estimated that Gainesville's trees and shrubs remove 846 tons of pollution per year with a value of $2.67 million dollars (Table 9). The model calculates the amount of pollution eliminated from the atmosphere based on 2016 Environmental Protection Agency (EPA) air pollution and weather monitors in Gainesville and assumes pollution reduction does not happen during rain events. Value estimates for CO and $PM_{2.5}$ were calculated with guidelines suggested by Murray, Marsh, & Bradford (1994) and Ottinger, Wooley, Robinson, Hodas, & Babb (1990). Value estimates for O_3, SO_2, and NO_2 were calculated based on the EPA Benefits Mapping and Analysis Program (BenMAP) model (EPA, 2012).

	NO_2	O_3	$PM_{2.5}$	SO_2
Tree	$15,310	$861,200	$979,900	$1,360
Shrub	$7,620	$448,820	$344,500	$730
Subtotal	$22,930	$1,310,010	$1,324,400	$2,090
Total	**$2,659,430**			

Table 10. Estimated annual economic benefits of reduced health impacts from airborne pollutant reduction by trees and shrubs in the city of Gainesville (BenMAP).

The BenMAP model estimates the reduction in health impacts and the associated economic benefits derived from changes in air quality. Pollutant reduction estimates from i-Tree were used by the BenMAP model to produce estimates of potential savings in health care costs (e.g. reduced incidence of respiratory illness and related hospital visits or days lost from work/school). Gainesville's urban forest reduces air pollution levels resulting in an estimated $2.66 million savings on airborne pollutant related health care costs (Table 10).

Avoided Runoff

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). This analysis includes the savings in stormwater control costs associated with the estimated interception of precipitation by the trees of Gainesville's forest. In 2016, it is estimated that rainfall interception from trees in the Gainesville urban forest saved the City $3.8 million in stormwater control costs (Table 12).

Loblolly pines represent 18% of the overall estimated population and account for one fifth (20%) of the total estimated rainfall interception and savings in stormwater control costs (Figure 18). The top ten species having the greatest estimated leaf area accounts for 75% of all estimated interception and savings.

The land use with the greatest avoided runoff value is *Forested* ($1.7 million/year). The second greatest value is in *Residential* areas ($1.0 million/year), which occupies 29% of the city (Table 11).

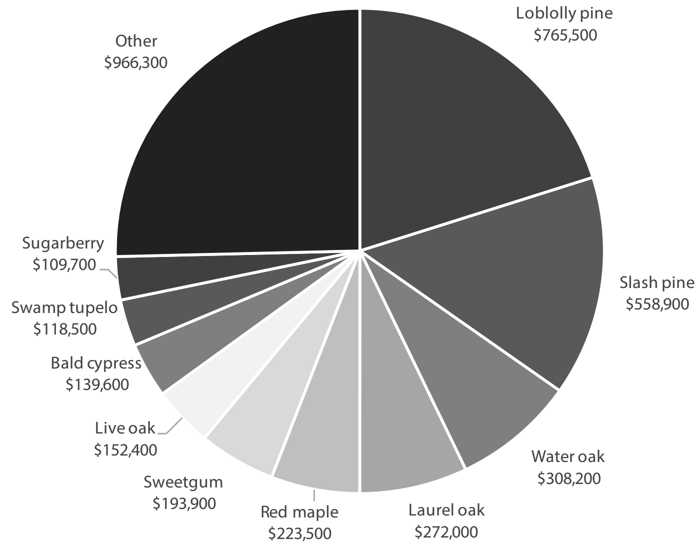


Figure 19. Savings in avoided runoff costs by species.

Strata	Avoided Runoff (mil ft³/yr)	Avoided Runoff Value ($/yr)	Percent of City (%)
Forested	25	$1,670,700	27.2
Residential	15	$1,006,700	28.9
Transportation	6	$415,900	15.3
Public / Institutional	4	$259,600	9.7
Commercial	3	$172,700	6.9
Open Space / Park	2	$165,600	4.2
Industrial	2	$117,400	7.3
Gainesville	**57**	**$3,808,500**	**100**

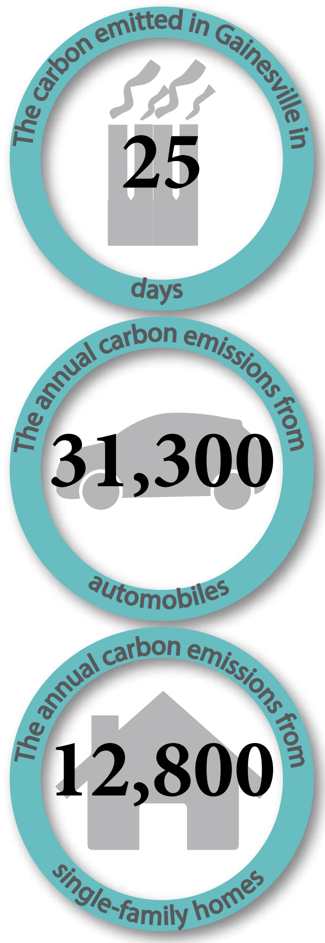
Table 11. Avoided runoff and associated savings in each land use designation in the City with the percent acreage of each land use.

Carbon Sequestration

Carbon dioxide (CO_2) is a greenhouse gas that contributes to climate change. During the process of photosynthesis, trees incorporate atmospheric carbon into the tissue in their new growth which is then considered to be sequestered or locked up for the life of the tree or plant part (leaves, branches, trunk, or roots) (Abdollahi, Ning, & Appeaning, 2000). Carbon sequestration rates vary by species, but healthier and more vigorous trees tend to sequester carbon at higher rates than unhealthy trees. The urban forest of Gainesville is a carbon sink, meaning it stores more carbon than it releases. Net carbon sequestration is the amount of carbon sequestered minus the estimated amount of carbon emitted as dead trees decay. The Eco model estimated that in 2016 Gainesville's urban forest sequestered or removed 44,200 gross tons of carbon from the atmosphere, valued at $5.88 million.

The rate of carbon sequestration by an individual tree is a function of the tree size, species, and condition. The tree species with the highest rate of carbon sequestration in Gainesville is loblolly pine, which is also the species that stores the greatest amount of carbon (Figure 20).

The carbon sequestered annually by Gainesville's urban forest is equivalent to...



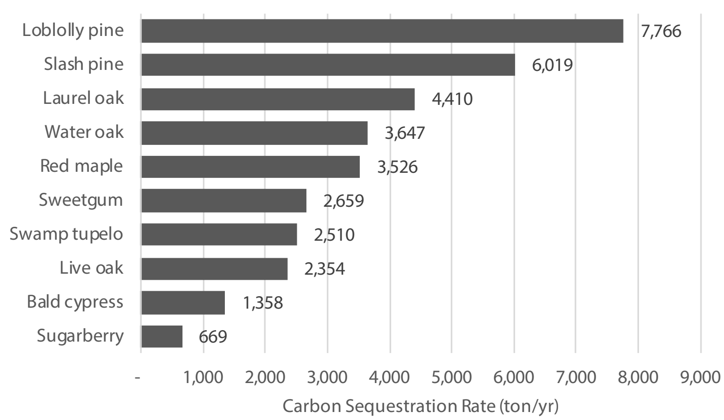


Figure 20. Carbon sequestration rates in Gainesville by species.

Carbon Storage

The amount of stored carbon in a tree fluctuates as it grows (increases), dies (ceases), or decays (decreases). To calculate current carbon storage, biomass for each tree was calculated using equations from the literature and measured tree data. Tree dry-weight biomass was converted to stored carbon by multiplying by 0.5. The total amount of carbon stored by the trees of Gainesville's urban forest is estimated to be 746,000 tons valued at $99.2 million. In Gainesville 27% of the stored carbon is in loblolly pines and slash pines combined. An additional 18% of carbon is stored in live oak and laurel oak combined (Figure 21).

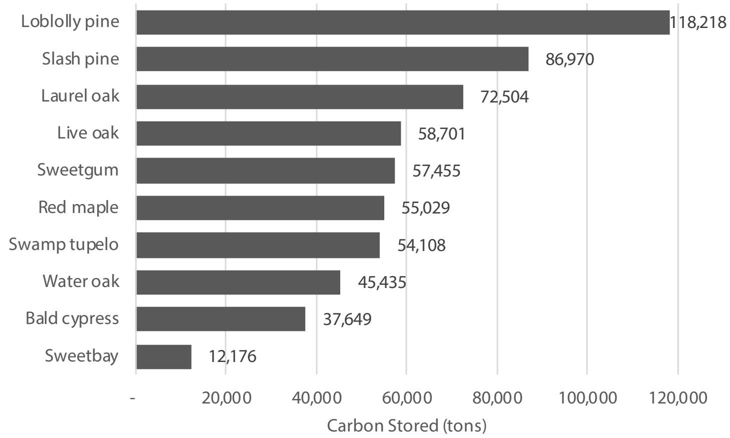


Figure 21. Carbon stored in Gainesville by species.

The land use storing the most carbon is *Forested* (44%), which represents 27% of the City (Table 12). The *Residential* land use represents 29% of the City, and it stores 25% of the carbon. The land use storing the least carbon is *Industrial* (3%), which represents 7% of the City.

Strata	Carbon Storage (tons)	Carbon Storage (%)	Percent of City (%)
Forested	331,400	44.4	27.2
Residential	184,200	24.7	28.9
Transportation	99,500	13.3	15.3
Public / Institutional	48,100	6.4	9.7
Commercial	34,000	4.6	6.9
Open Space / Park	27,700	3.7	4.2
Industrial	21,000	2.8	7.3
Gainesville	**745,800**	**100**	**100**

Table 12. Carbon storage by land use designation and percent acreage.

Appendices

Appendix A: Land Use

Land use categories were defined for use as strata by the i-Tree Eco model based on land uses and zoning provided by the City in geographic information (GIS) files. Classification of all parcels within the City was done according to the following Eco land use definitions:

ECO Land Use	Description
Agriculture	Pastures, row crops, or wholesale nurseries
Commercial	Retail and professional business uses
Forested	Upland and wetland forests, both natural and planted
Industrial	Industrial uses including municipal water, waste, and power facilities
Open Space / Park	Park and recreational lands, cemeteries, golf courses
Public / Institutional	Government offices, hospitals, schools, churches, & other municipal facilities
Residential	All forms of housing
Transportation	Roads, railroads, and airports

Certain City land use codes directly translated to Eco land uses while others did not. In the table below, blank Eco land uses indicate that more than one classification could have been applied to the City land use, depending on the specific parcel. Some individual parcels were manually classified using GIS layers and aerial photography to aid in the classification decision.

ECO LAND USE	City LANDUSE DESCR	LANDUSE CODE
Agriculture	Acrg Not Znd Ag	9900
Transportation	Airport	2000
Commercial	Auto Sales	2700
Industrial	Bottler	4500
Commercial	Bowling Alley	3400
Public/Institutional	Churches	7100
Commercial	Clb/Ldg/Un Hall	7700
Public/Institutional	College-Wtr Mgt Dist	8400
Residential	Common Area	900
Residential	Condominium	400
	County Vacant/Xfeatures	8010
Public/Institutional	County-Sch Brd Vacant/Xf	8011
	Cty Inc Nonmuni	8600
	Cultural	7900
Commercial	Dept Store	1300
	Federal	8800
	Federal Vacant/Xfeatures	8040
Commercial	Financial	2300
Commercial	Florist	3000
Commercial	Food Processing	4600
Open Space/Park	Forest/Pk/Rec-Wtr Mgt Dst	8200
Open Space/Park	Golf Course	3800
Agriculture	Grzgsoil Class2	6100
Industrial	Heavy Mfg	4200
Public/Institutional	Hospital	8500
Commercial	Insurance	2400

ECO LAND USE	City LANDUSE DESCR	LANDUSE CODE
Industrial	Light Mfg	4100
Industrial	Lumber Yd/Mill	4300
Residential	MFR <10 Units	800
Industrial	Min Processing	4700
Industrial	Ming/Pet/GasInd	9200
Residential	Misc. Residence	700
Residential	Mobile Home	200
Open Space/Park	Mort/Cemetary	7600
Commercial	Motel	3900
Residential	Multifamily	300
	Municipal	8900
	Municipal Vacant/Xfeature	8050
Commercial	Night Clubs	3300
Public/Institutional	Nursing Home	7400
Commercial	Off Multistory	1800
Commercial	Office 1 Story	1700
Commercial	Open Storage	4900
Agriculture	Orn/Misc Agri	6900
Commercial	Orphng/Non-Prof	7500
	Other Public Vac/Xfeature	8090
Open Space/Park	Outdr Rec/Pk Ld	9700
Commercial	Pkg Lot (Comm)	2800
Commercial	Post Office	1701
Commercial	Prof Offices	1900
Public/Institutional	Prv Hospital	7300
Public/Institutional	Prv Schl/Coll	7200
Public/Institutional	Pub Cty School	8300
Transportation	Railroad Owned-Local Assd	9110
Commercial	Rest, Drive-in	2200
Commercial	Restaurant	2100
Residential	Retirement	600
Transportation	Right-Of-Way	9400
Residential	Sani/ Rest Home	7800
Commercial	Serv Stations	2600
Commercial	Service Shops	2500
Industrial	Sewg/Waste Land	9600
Commercial	Sh Ctr Cmmity	1600
Commercial	Sh Ctr Nbhd	1601
Commercial	Sh Ctr Regional	1500
Residential	Single Family	100
	State Of Fla - TIITF	8701
	State(Not TIITF)Vac/Xf	8020
	State(TIITF) Vacant/Xf	8030
	State-Not TIITF	8700
Commercial	Store/Off/Res	1200

ECO LAND USE	City LANDUSE DESCR	LANDUSE CODE
Commercial	Stores	1100
Commercial	Supermarket	1400
Commercial	Theater	3200
Forested	Tmbr Not Clssfd	5900
Forested	Tmbr Si 80-89	5500
Forested	Tmbr Si 90+	5400
Commercial	Tourist Attraction	3500
Industrial	Utility	9100
	Vacant	0
	Vacant Comm	1000
	Vacant Industrial	4000
	Vacant Institutional	7000
Industrial	Wareh/Dist Term	4800
Forested	Water Mgt Dist Vac/Xfeat	8000
Industrial	Wholesaler	2900

Appendix B: Ecological Assessment Species Level Results

Tree species identified in Gainesville's urban forest:

a Tree, Shrub strata

b Native, Exotic (non-native), and Invasive status

*Category I Invasive Species

Species	Common Name	T, S[a]	% Tree	N, E, I[b]
Abelia chinensis	Abelia	S	-	E
Acca sellowiana	Feijoa	S	-	E
Acer floridanum	Florida maple	T, S	0.1%	N
Acer negundo	Boxelder	T, S	0.7%	N
Acer rubrum	Red maple	T, S	7.5%	N
Acoelorrhaphe wrightii	Paurotis palm	T, S	<0.1%	N
Aesculus pavia	Red buckeye	T, S	<0.1%	N
Albizia julibrissin	Mimosa	T, S	0.1%	E, I*
Aralia spinosa	Devils walking stick	T, S	0.1%	N
Ardisia crenata	Coral ardisia	S	-	E, I*
Asimina angustifolia	Slimleaf pawpaw	S	-	N
Asimina parviflora	Smallflower pawpaw	S	-	N
Asimina reticulata	Netted pawpaw	S	-	N
Asimina triloba	Common pawpaw	S	-	N
Baccharis halimifolia	Saltbush	T, S	<0.1%	N
Bambusa spp.	Bamboo	S	-	E
Betula nigra	River birch	T	<0.1%	N
Bismarckia nobilis	Bismarck palm	T	<0.1%	E
Broussonetia papyrifera	Paper mulberry	T, S	0.2%	E, I
Bumelia spp.	Bumelia	T, S	<0.1%	N
Bumelia lanuginosa	Chittamwood	S	-	N
Butia capitata	Jelly palm	T, S	<0.1%	E
Buxus microphyllus	Boxwood	S	-	E
Cajanus spp.	Pigeon pea	S	-	E
Callicarpa americana	American beautyberry	S	-	N
Camellia japonica	Camellia	T, S	0.1%	E
Camellia sasanqua	Sasanqua camellia	S	-	E
Carpinus caroliniana	American hornbeam	T, S	0.9%	N
Carya glabra	Pignut hickory	T, S	0.3%	N
Carya illinoinensis	Pecan	T, S	0.9%	N
Carya tomentosa	Mockernut hickory	T, S	<0.1%	N
Celtis laevigata	Sugarberry	T, S	2.0%	N
Cephalanthus occidentalis	Button bush	T, S	0.3%	N
Cercis canadensis	Eastern redbud	T, S	0.2%	N
Chamaerops humilis	European fan palm	S	-	E
Chionanthus virginicus	Fringe tree	T, S	<0.1%	N
Cinnamomum camphora	Camphor tree	T, S	0.9%	E, I*

Species	Common Name	T, S[a]	% Tree	N, E, I[b]
Citrus spp.	Citrus	T, S	<0.1%	E
Citrus aurantium	Sour orange	S	-	E
Citrus limon	Lemon	S	-	E
Clerodendrum spp.	Glorybower	S	-	E
Cornus florida	Flowering dogwood	T, S	0.1%	N
Cornus foemina	Swamp dogwood	T, S	0.1%	N
Crataegus spp.	Hawthorn	T, S	<0.1%	N
Crataegus marshallii	Parsley hawthorn	T, S	0.2%	N
Cycas revoluta	Sago palm	S	-	E
Cyrilla racemiflora	Swamp titi	S	-	N
Diospyros spp.	Persimmon	S	-	E
Diospyros virginiana	Common persimmon	T, S	<0.1%	N
Duranta erecta	Golden dewdrop	S	-	E
Dypsis lutescens	Areca palm	S	-	E
Elaeagnus pungens	Thorny elaeagnus	S	-	E, I
Eriobotrya japonica	Loquat tree	T, S	<0.1%	E
Euonymus americanus	American strawberry bush	S	-	N
Ficus carica	Common fig	S	-	E
Ficus pumila	Climbing fig	S	-	E
Fraxinus americana	White ash	T	0.5%	N
Fraxinus pennsylvanica	Green ash	T, S	0.7%	N
Gardenia jasminoides	Cape jasmine	S	-	E
Gaylussacia dumosa	Dwarf huckleberry	S	-	N
Gaylussacia frondosa	Blue huckleberry	S	-	N
Gordonia lasianthus	Loblolly bay	T, S	0.7%	N
Hamelia patens	Firebush	S	-	N
Hibiscus rosa-sinensis	Chinese hibiscus	S	-	E
Hypericum spp.	St. John's wort	S	-	N
Ilex cassine	Dahoon	T, S	1.7%	N
Ilex cornuta	Chinese holly	S	-	E
Ilex glabra	Gallberry	S	-	N
Ilex myrtifolia	Myrtle dahoon	T	<0.1%	N
Ilex opaca	American holly	T, S	<0.1%	N
Ilex ×attenuata 'Savannah'	Savannah holly	T	<0.1%	N
Ilex vomitoria	Yaupon holly	T, S	0.4%	N
Ilex ×attenuata 'Fosteri'	Foster's holly	S	-	N
Illicium parviflorum	Yellow anise	S	-	N
Itea virginica	Virginia sweetspire	S	-	N
Ixora coccinea	Ixora	S	-	E
Juniperus spp.	Juniper	S	-	E
Juniperus chinensis	Chinese juniper	S	-	E
Juniperus chinensis 'Torulosa'	Hollywood juniper	T	<0.1%	E
Juniperus conferta 'Blue Pacific'	Shore juniper	S	-	E
Juniperus virginiana	Eastern red cedar	T, S	0.3%	N

Species	Common Name	T, S[a]	% Tree	N, E, I[b]
Koelreuteria paniculata	Golden rain tree	T, S	<0.1%	E, I
Lagerstroemia indica	Crape myrtle	T, S	0.7%	E
Lantana camara	Lantana	S	-	E, I*
Ligustrum japonicum	Ligustro	T, S	0.2%	E
Ligustrum lucidum	Glossy privet	T, S	0.2%	E, I*
Liquidambar styraciflua	Sweetgum	T, S	4.0%	N
Loropetalum chinense	Chinese fringe flower	S	-	E
Lyonia ferruginea	Rusty lyonia	T, S	<0.1%	N
Lyonia lucida	Fetterbush	T, S	0.4%	E
Magnolia grandiflora	Southern magnolia	T, S	1.2%	N
Magnolia virginiana	Sweetbay	T, S	0.8%	N
Magnolia x soulangeana	Saucer magnolia	T	<0.1%	E
Manihot spp.	Manihot	S	-	E
Morella cerifera	Wax myrtle	T, S	4.0%	N
Moringa oleifera	Horseradish tree	T, S	<0.1%	E
Morus rubra	Red mulberry	T	0.3%	N
Musa spp.	Banana	S	-	E
Nandina domestica	Heavenly bamboo	S	-	E, I*
Nyssa biflora	Swamp tupelo	T, S	3.8%	N
Osmanthus fragrans	Tea olive	S	-	E
Ostrya virginiana	Eastern hophornbeam	T, S	0.9%	N
Persea americana	Avocado	T	<0.1%	E
Persea borbonia	Redbay	T, S	1.0%	N
Persea palustris	Swamp bay	T, S	0.1%	N
Photinia × fraseri	Fraser photinia	S	-	E
Pinus elliottii	Slash pine	T, S	10.6%	N
Pinus glabra	Spruce pine	T, S	0.2%	N
Pinus palustris	Longleaf pine	T, S	0.6%	N
Pinus taeda	Loblolly pine	T, S	17.2%	N
Pittosporum tobira	Pittosporum	S	-	E
Platanus occidentalis	Sycamore	T	0.1%	N
Platycladus orientalis	Arborvitae	T, S	<0.1%	E
Podocarpus macrophyllus	Podocarpus	T, S	0.1%	E
Populus deltoides	Eastern cottonwood	T	<0.1%	N
Prunus spp.	Plum	S	-	N
Prunus angustifolia	Chickasaw plum	T, S	<0.1%	N
Prunus caroliniana	Carolina laurel cherry	T, S	4.6%	N
Prunus persica	Peach	S	-	E
Prunus serotina	Black cherry	T, S	0.7%	N
Prunus umbellata	Flatwoods plum	T, S	0.3%	N
Prunus virginiana	Common chokecherry	S	-	E
Punica granatum	Pomegranate	S	-	E
Pyrus spp.	Pear	S	-	E
Pyrus calleryana 'bradford'	Bradford pear	T	0.1%	E

Species	Common Name	T, S[a]	% Tree	N, E, I[b]
Quercus alba	White oak	T	<0.1%	N
Quercus austrina	Bluff oak	T	<0.1%	N
Quercus falcata	Southern red oak	T	<0.1%	N
Quercus geminata	Sand live oak	T, S	<0.1%	N
Quercus hemisphaerica	Darlington oak	T, S	0.5%	N
Quercus laurifolia	Laurel oak	T, S	8.8%	N
Quercus michauxii	Swamp chestnut oak	T, S	0.3%	N
Quercus nigra	Water oak	T, S	7.9%	N
Quercus shumardii	Shumard oak	T	0.1%	N
Quercus virginiana	Live oak	T, S	0.8%	N
Rhaphiolepis indica	Indian hawthorn	S	-	E
Rhapidophyllum hystrix	Needle palm	S	-	N
Rhapis excelsa	Lady palm	T, S	0.1%	E
Rhododendron ×obtusum	Kurume azalea	S	-	E
Rhododendron canescens	Pinxter azalea	S	-	N
Rhododendron simsii	Indian azalea	S	-	E
Rhus copallinum	Winged sumac	S	-	N
Rosa spp.	Rose	S	-	E
Rubus spp.	Blackberry	S	-	N
Sabal minor	Dwarf palmetto	S	-	N
Sabal palmetto	Cabbage palm	T, S	0.6%	N
Salix caroliniana	Carolina willow	S	-	N
Sambucus canadensis	Elderberry	T, S	0.9%	N
Senna bicapsularis	Butterfly bush	S	-	E
Serenoa repens	Saw palmetto	S	-	N
Spiraea spp.	Spiraea	S	-	E
Syzygium cumini	Jambolan plum	T, S	<0.1%	E, I*
Taxodium ascendens	Pond cypress	T	1.0%	N
Taxodium distichum	Bald cypress	T, S	1.8%	N
Ternstroemia gymanthera	Cleyera	S	-	E
Tilia americana	American basswood	T, S	0.2%	N
Trachycarpus fortunei	Windmill palm	T	<0.1%	E
Triadica sebifera	Chinese tallow	T, S	0.2%	E, I*
Ulmus alata	Winged elm	T, S	0.5%	N
Ulmus americana	American elm	T, S	0.2%	N
Ulmus parvifolia	Chinese elm	T	<0.1%	E
Vaccinium arboreum	Sparkleberry	S	-	N
Vaccinium corymbosum	Highbush blueberry	S	-	N
Vaccinium myrsinites	Shiny blueberry	S	-	N
Vaccinium stamineum	Deerberry	T, S	0.2%	N
Viburnum suspensum	Sandankwa viburnum	S	-	E
Viburnum dentatum	Arrowwood	S	-	N
Viburnum obovatum	Small-leaf arrowwood	T, S	<0.1%	N
Viburnum odoratissimum	Sweet viburnum	T, S	0.2%	E

Species	Common Name	T, S[a]	% Tree	N, E, I[b]
Viburnum rufidulum	Rusty blackhaw	T, S	0.1%	N
Yucca aloifolia	Spanish bayonet	S	-	N
Zanthoxylum americanum	Hercules' club	S	-	N
Ziziphus mauritiana	Indian jujube	S	-	E

Appendix C: Gainesville Tree Canopy Assessment Using Remote Sensing Methods

Authors: Shawn Landry and Qiuyan Yu, University of South Florida

Introduction

The purpose of this project was to utilize relatively low-cost remote sensing methods to quantify tree canopy coverage and change in Gainesville. Through the acquisition and analysis of moderate-resolution Landsat imagery, urban forest canopy coverage was mapped for 1996, 2006 and 2015 and also reported as canopy change over these time periods. The original intent was to use 1995, 2005 and 2015 time periods, but cloud-free Landsat imagery was unavailable for the 1995 and 2006 (see below). Since Landsat imagery is known to underestimate tree canopy cover, very-high resolution aerial imagery from the National Agriculture Imagery Program (NAIP) was utilized with a dot-based method to develop accurate estimates citywide tree canopy cover for 2016 and 2015. Future work efforts, with additional funding, could utilize the very-high resolution aerial imagery to develop detailed land cover maps for exploration of tree cover and change at the resolution of the property parcel.

Accurate Estimate of Citywide Tree Canopy Cover

Citywide tree canopy in the City of Gainesville was accurately estimated using a dot-based sampling approach with NAIP aerial photographic imagery from 2006 and 2015 (Figure 1). This approach to estimate citywide tree canopy cover followed the "dot-based" estimation methods described by David Nowak and colleagues from the U.S. Forest Service (Nowak et al. 1996, Nowak and Greenfield 2012). The dot-based approach has been shown to be a very accurate and consistent method of characterizing canopy cover and change (Landry et al. 2013) A total of 1500 dots were randomly placed within the Gainesville boundary. At each location, a dot was photo-interpreted as "canopy" or "not canopy" by a trained photo-interpreter using 2006 NAIP and separately with 2015 NAIP. A subsample of 500 dots were independently classified a second time as a method to test the verification error. Dots located within the tree canopy were classified as canopy, while dots located on other vegetation or other surfaces were classified as no canopy.

	2006 NAIP	2015 NAIP
Canopy	748 (49.9% +/- 1.3%)	808 (53.9% +/- 1.3%))
Non-Canopy	752 (50.1%)	692 (46.1%)
Total	1500	1500

Table 1. Count of canopy and non-canopy of both 2006 and 2015.

In 2006, 748 out of 1500 dots were classified as canopy, while 808 out of 1500 dots were canopy in 2015 (Table 1). The standard error is 1.3% for both 2006 and 2015 dot methods. Citywide tree canopy coverage was thus 49.9% +/- 1.3% (48.6 – 51.2%) in 2006 and 53.9% +/- 1.3% (52.6 – 55.2%) in 2015. These results suggest a small increase in tree canopy cover within the City of Gainesville between 2006 and 2015.

Moderate Resolution Tree Cover Mapping

Measurements of tree canopy cover over time can provide an indicator of the geographic distribution of urban forest benefits within different areas of the city and how it has changed over time. The use of moderate-resolution satellite imagery such as Landsat have been shown to underestimate urban tree canopy cover (i.e., 30 meter pixels compared to 1 meter pixels for the NAIP imagery). However, the use of Landsat provides a consistent long-term measurement of change for several decades prior to the availability of high-resolution mapping techniques.

Landsat Data download

Landsat data were acquired from United States Geological Survey (http://earthexplorer.usgs.gov/) for 5/6/1996, 5/2/2006 and 5/11/2015 as shown in Figure 2. Although the original intent was to focus on 1995 and 2005, Landsat scenes acquired in summer of 1995 and 2005 were covered by clouds over the study area as shown in the Appendix.

Figure 1. City of Gainesville with NAIP images.

Landsat image processing

Image processing followed standard accepted remote sensing techniques and utilized ENVI software. Calibration is to calibrate original DN to radiance, reflectance or brightness temperature. Top of atmospheric reflectance and surface reflectance were achieved using ENVI 5.2 classic and ENVI 4.8. ToA (top of atmosphere) Reflectance used ENVI 5.2 classic > Basic Tools > Preprocessing > Calibration Utilities > Landsat Calibration, select Reflectance. Surface Reflectance used the FLAASH model in ENVI 4.8.

Normalization was used to minimize the differences caused by atmospheric or solar conditions between images so that the tree canopy mapping method would be consistent through time (1996, 2006 and 2015). The data of 2006 was employed as the standard image, based on which other two images (1996, 2015) were normalized. Linear model is generated for each band with corresponding band of 2006. The general model is as shown in in Equation 1:

$$y = x + b \tag{1}$$

where y is band reflectance of 2006, and x stands for corresponding band reflectance of 1996 or 2015. The linear models of normalization for each band based on the image of 2006 are as shown in Table 2. The R squares are higher than 75%, except band 2 of Landsat image of 2015 with R square 74.89%, pretty close to 75%. Therefore, all the regression models are acceptable.

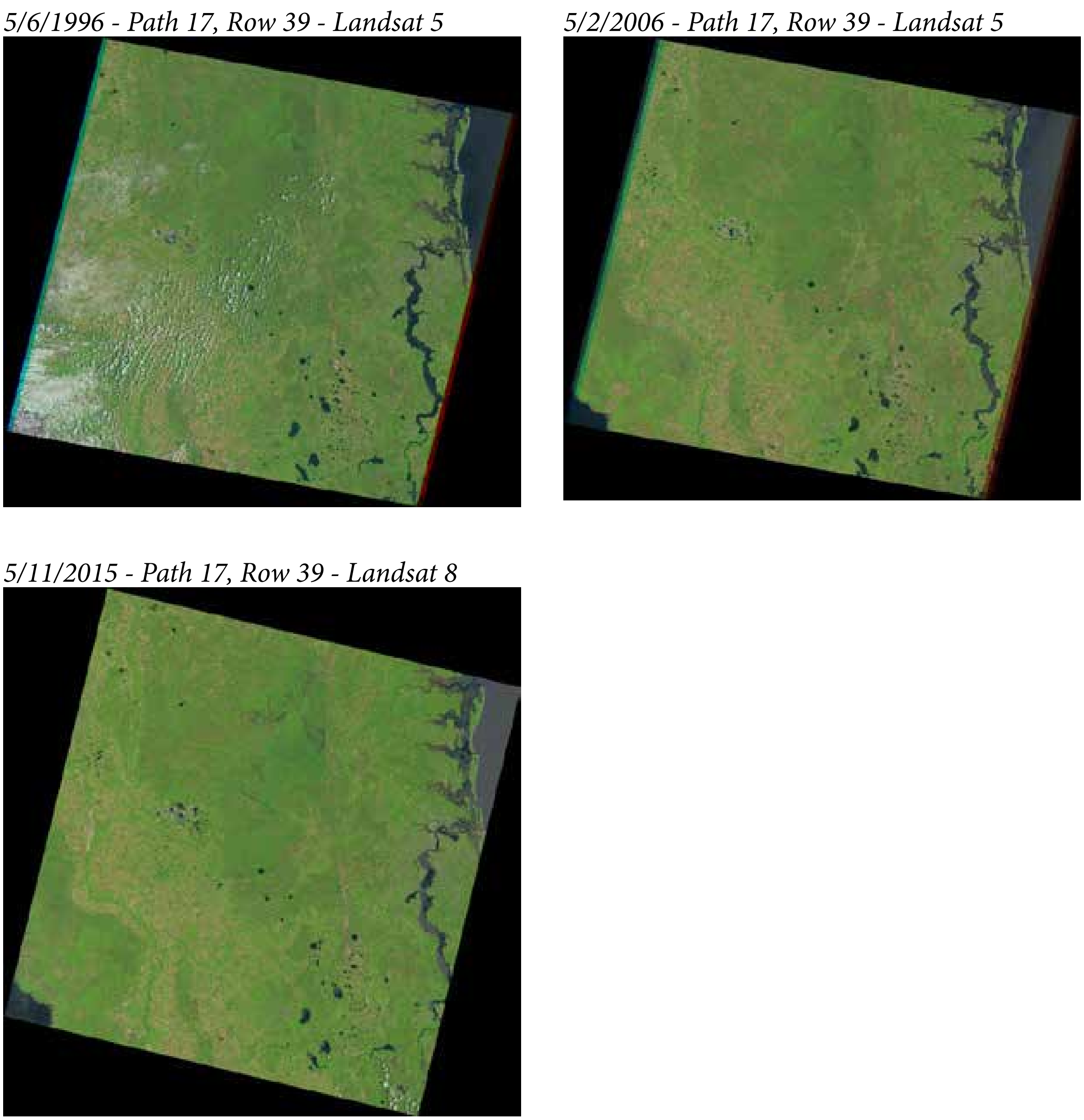


Figure 2. Natural color preview images of Landsat TM data used.

		2006_B1	2006_B2	2006_B3	2006_B4	2006_B5	2006_B7
1996	a	1.0539	1.1205	1.0471	0.97	0.9227	0.9328
	b	-80.955	-91.335	-63.242	-100.18	66.302	82.921
	R^2	0.966	0.9516	0.9294	0.9705	0.9776	0.9765
2015	a	0.6439	0.7459	0.7622	0.8081	0.8215	0.8808
	b	214.43	217.66	184.37	186.99	50.946	137.04
	R^2	0.7872	0.7489	0.822	0.9325	0.9746	0.8808

Table 2. Linear models of normalization for each band, image of 2006 as standard image.

Tree Canopy Classification Using Decision tree

To achieve the amount and distribution of canopy and non-canopy from Landsat image, decision tree with biophysical composition index (BCI) and normalized difference vegetation index (NDVI) was applied to classify canopy and no-canopy from Landsat images. The decision tree classifier is generated using Landsat image of 2006 based on the verification data from NAIP image (Canopy and Non_canopy), then it is tested using image of 2015, lastly, it is applied to extract canopy from image of 1996. Decision tree classification is popular in remote seeing community to classify land cover types. It is defined as a classification procedure that recursively partitions a data set into smaller subdivisions on the basis of a set of tests defined at each branch in the tree (Friedl and Brodley 1997). BCI is a quantitative spectral indicator designed for characterizing major urban land cover compositions following Ridd's conceptual vegetation–impervious surface–soil (V–I–S) triangle model. It could be derived with the help of the normalized Tasseled Cap (TC) spectral, as shown in Eqs 2-5. TC transformation for Landsat data, which could transform spectral reflectance to brightness, greenness and wetness (the first three components), is able to highlight relevant vegetation variance (Healey, Cohen et al. 2005). The combination of BCI and NDVI is able to reduce within-class variation and enhance between-class variation among various urban compositions. This method was successfully used to extract endmembers of urban land cover types in urban areas of Franklin County, Ohio (Deng and Wu 2013).

$$BCI = \frac{(H + L)/2 - V}{(H + L)/2 + V} \quad (2)$$

$$H = \frac{TC1 - TC1_{min}}{TC1_{max} - TC1_{min}} \quad (3)$$

$$V = \frac{TC2 - TC2_{min}}{TC2_{max} - TC2_{min}} \quad (4)$$

$$L = \frac{TC3 - TC3_{min}}{TC3_{max} - 3} \quad (5)$$

where H, V, and L are the normalized TC components 1, 2 and 3, indicating "high albedo material", "vegetation", and "low albedo material", respectively; TCi (i = 1, 2, 3) are the first three original TC spectra; TCimax and TCimin are the maximum and minimum values of the ith TC component, respectively.

The extraction rule for canopy and non_canopy from decision tree applied for 2006 and 2015 is achieved using decision tree classification in Rstudio programming software. According to the decision rule (Figure 3), pixels with NDVI equal and larger than 0.7286 or pixels with NDVI larger than 0.6617 and BCI larger than -0.2913 were considered as canopy, otherwise as non_canopy. Confusion matrices were computed to compare the pixels classified using Landsat to the 1500 dots classified from NAIP images, as shown in Table 3-4. Of the 1500 Landsat pixels that correspond with the NAIP dots, 77.94% of the 2006 pixels classified as canopy were correctly classified, while 86.04% of pixels classified as non-canopy were correctly classified. In 2015, 75.53% of canopy pixels and 83.82% of non-canopy pixels were correctly classified.

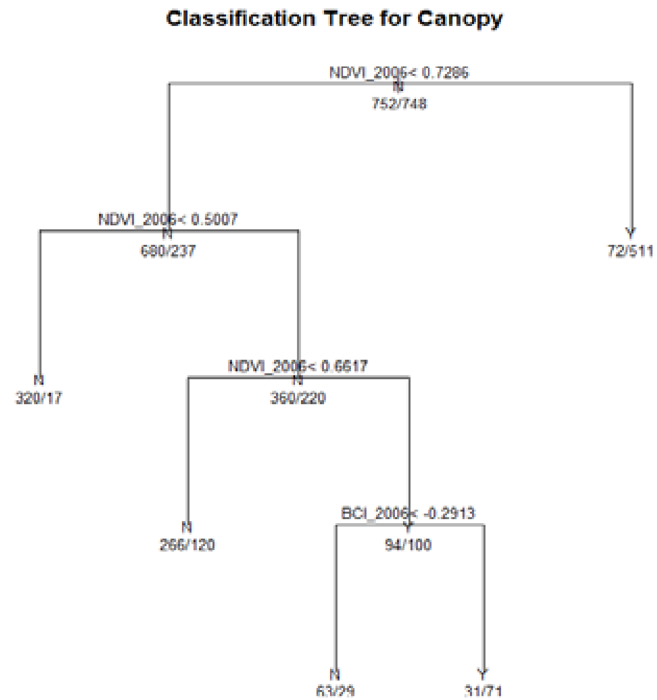


Figure 3. Decision tree rule for 2006

n=1500		True 2006			True 2015		
Class		Canopy	Non_canopy	Total	Canopy	Non_canopy	Total
Predicted Using Landsat	Canopy	583	105	688	565	112	677
	Non_canopy	165	647	812	243	580	823
	Total	748	752	1500	808	692	1500

Table 3. Classification confusion matrix on pixel.

n=1500		True 2006 (Percent)			True 2015 (Percent)		
Class		Canopy	Non-Canopy	Total	Canopy	Non_canopy	Total
Predict-ed using Landsat (Percent)	Canopy	77.94	14.04	45.87	75.53	14.97	45.13
	Non-canopy	22.06	86.04	54.13	30.07	83.82	54.87
	Total	100	100	100	100	100	100

Table 4. Classification confusion matrix on percent.

Tree Cover Results

The decision tree classifier was applied to whole study area (City of Gainesville) for 1996, 2006 and 2015. The distribution of canopy and non-canopy in 1996, 2006 and 2015 is shown in Figure 4-6. The amount of canopy from 1996 to 2006 was decreased and then increased a small portion from 2006 to 2015 (Table 5). Total area in the City of Gainesville as of 2016 is approximately 165 Km2. Because of the lower accuracy of Landsat-based results, all numbers are rounded to the nearest percent or nearest square kilometer.

	Landsat 1996	Landsat 2006	Landsat 2015
Canopy (%)	58 % (96 Km^2)	46 % (76 Km^2)	47 % (78 Km^2)
Non-canopy (%)	42 % (69 Km^2)	54 % (89 Km^2)	53 % (87 Km^2)

Table 5. Classification result from Landsat images for the City of Gainesville using decision tree.

The results of the Landsat classification results, as expected, show less canopy than the dot-based analysis that used the higher resolution NAIP imagery. Results for the 2006 NAIP showed 49.9% +/- 1.3% canopy, compared to 46% canopy estimated from 2006 Landsat; and 53.9% +/- 1.3% canopy from the 2015 NAIP compared to 47% canopy estimated from 2015 Landsat. A comparison of the image resolution as shown in Figure 4 illustrated how Landsat results underestimate tree canopy within highly heterogeneous areas of the City. As previously discussed, despite the underestimation of canopy from the Landsat images, the temporal trend results are valuable. A full land cover classification from the NAIP imagery would be necessary to estimate canopy with greater accuracy for individual neighborhoods in the City.

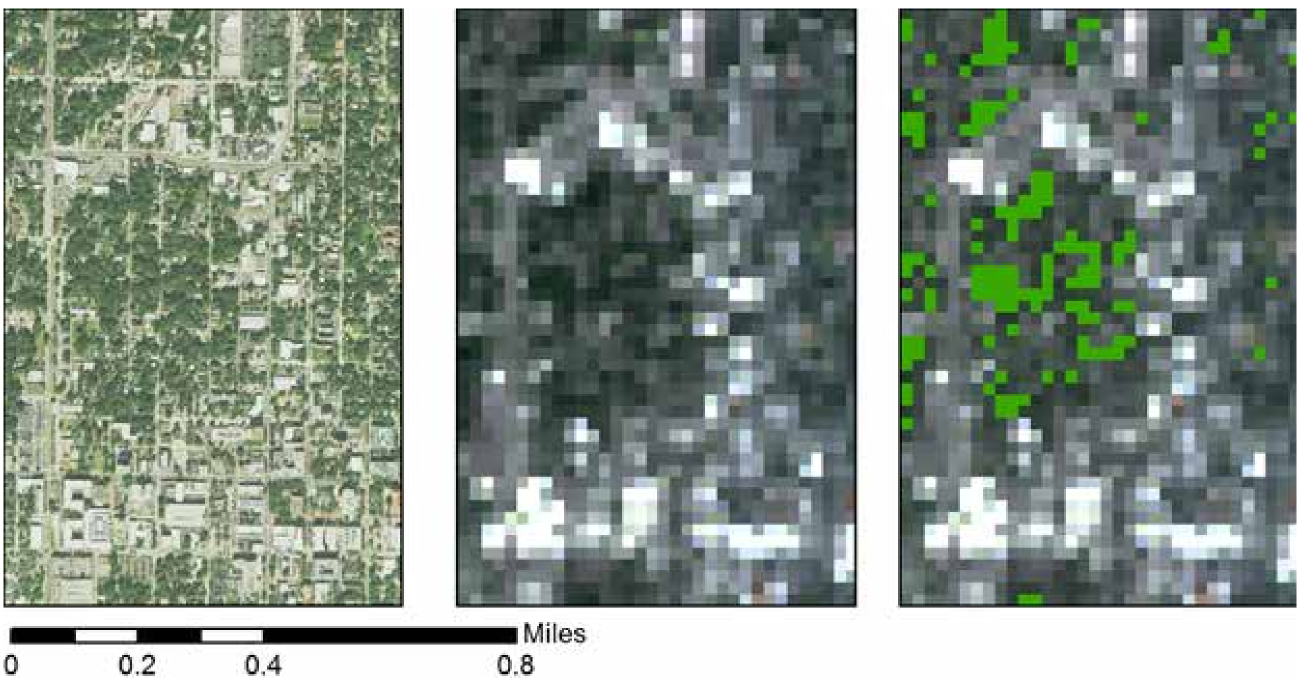


Figure 4. 2015 NAIP imagery (left), 2015 Landsat (middle) and mapped canopy from Landsat.

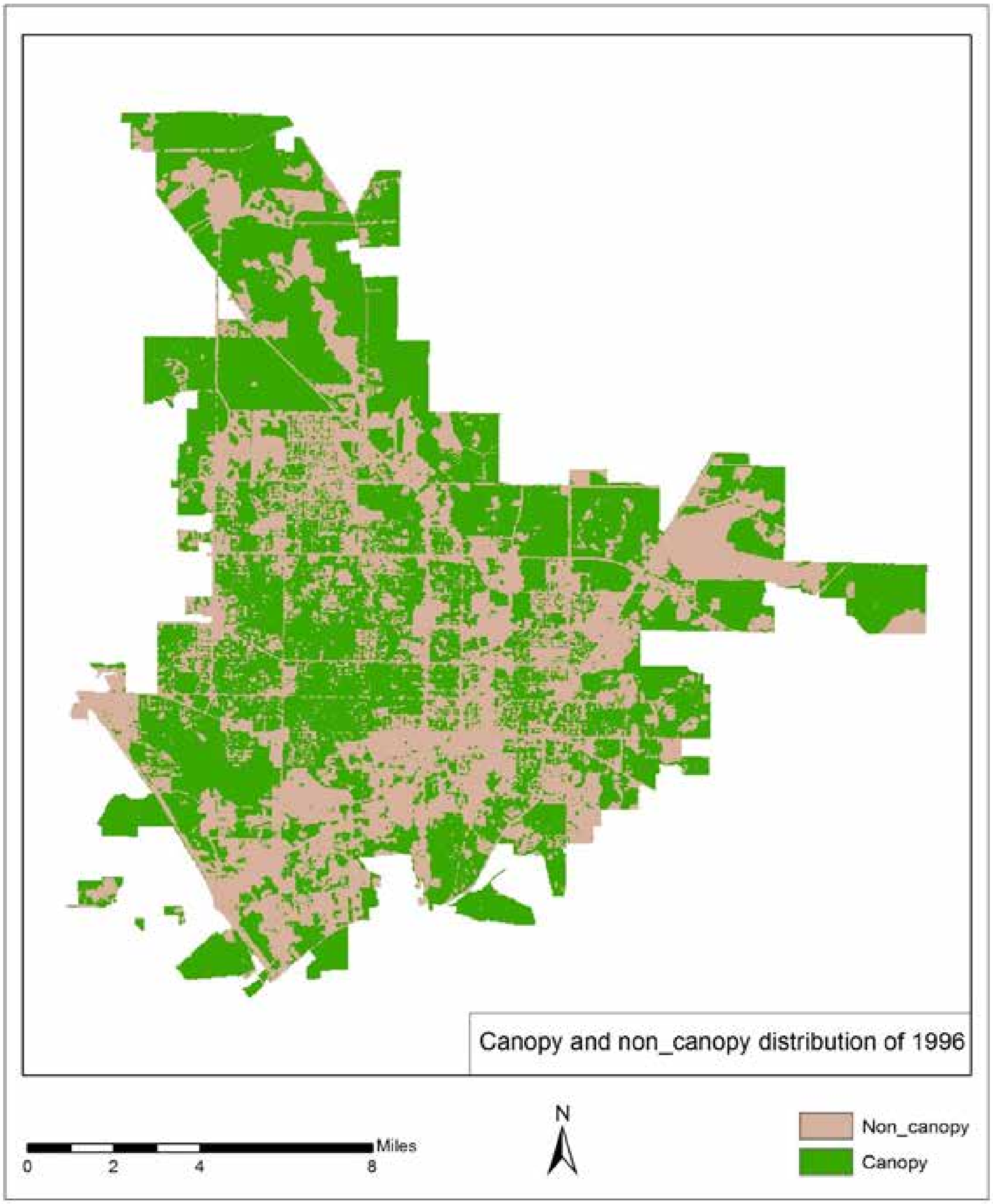


Figure 5. Canopy and non-canopy distribution of 1996 in the City of Gainesville.

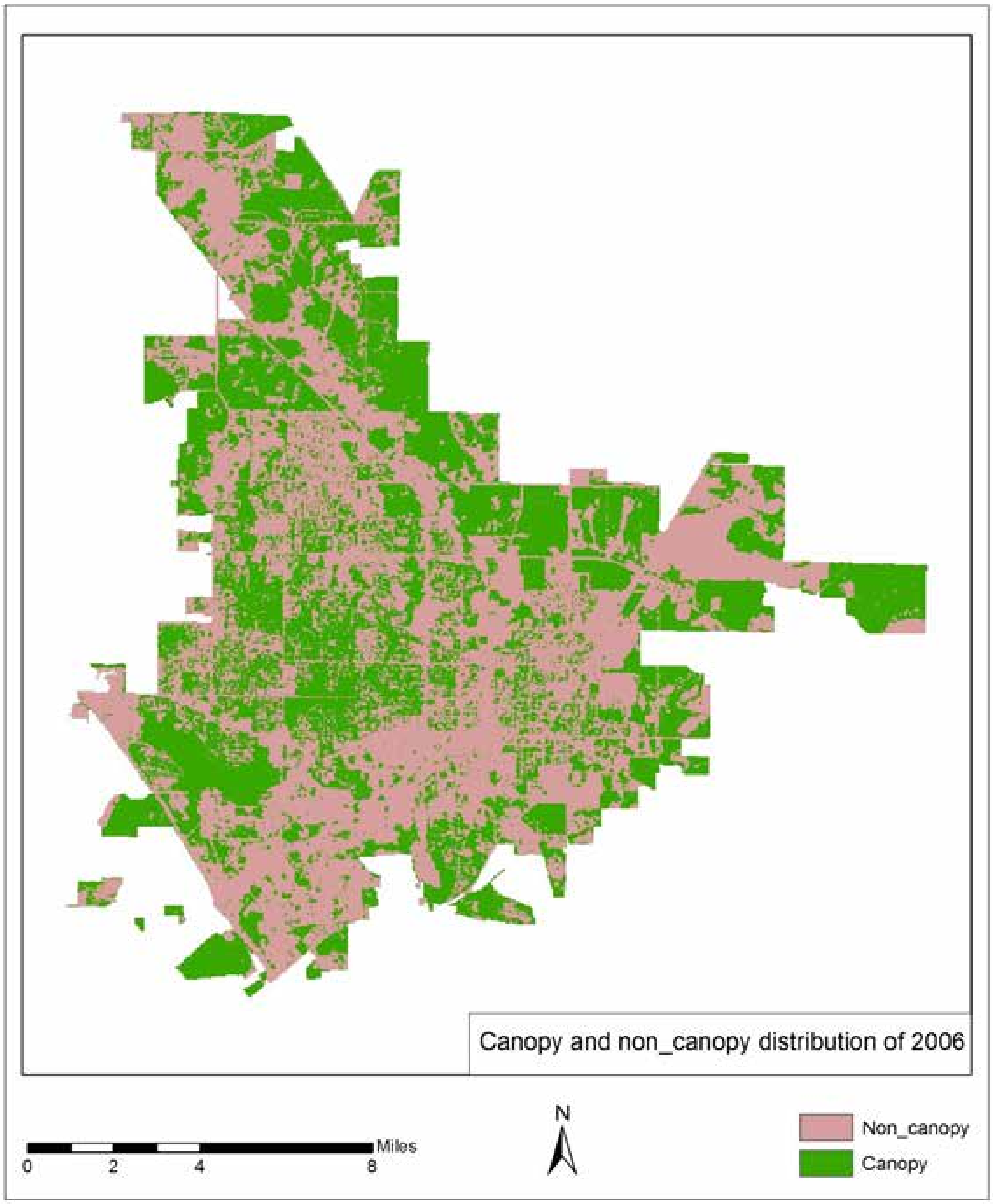


Figure 6. Canopy and non-canopy distribution of 2006 in the City of Gainesville.

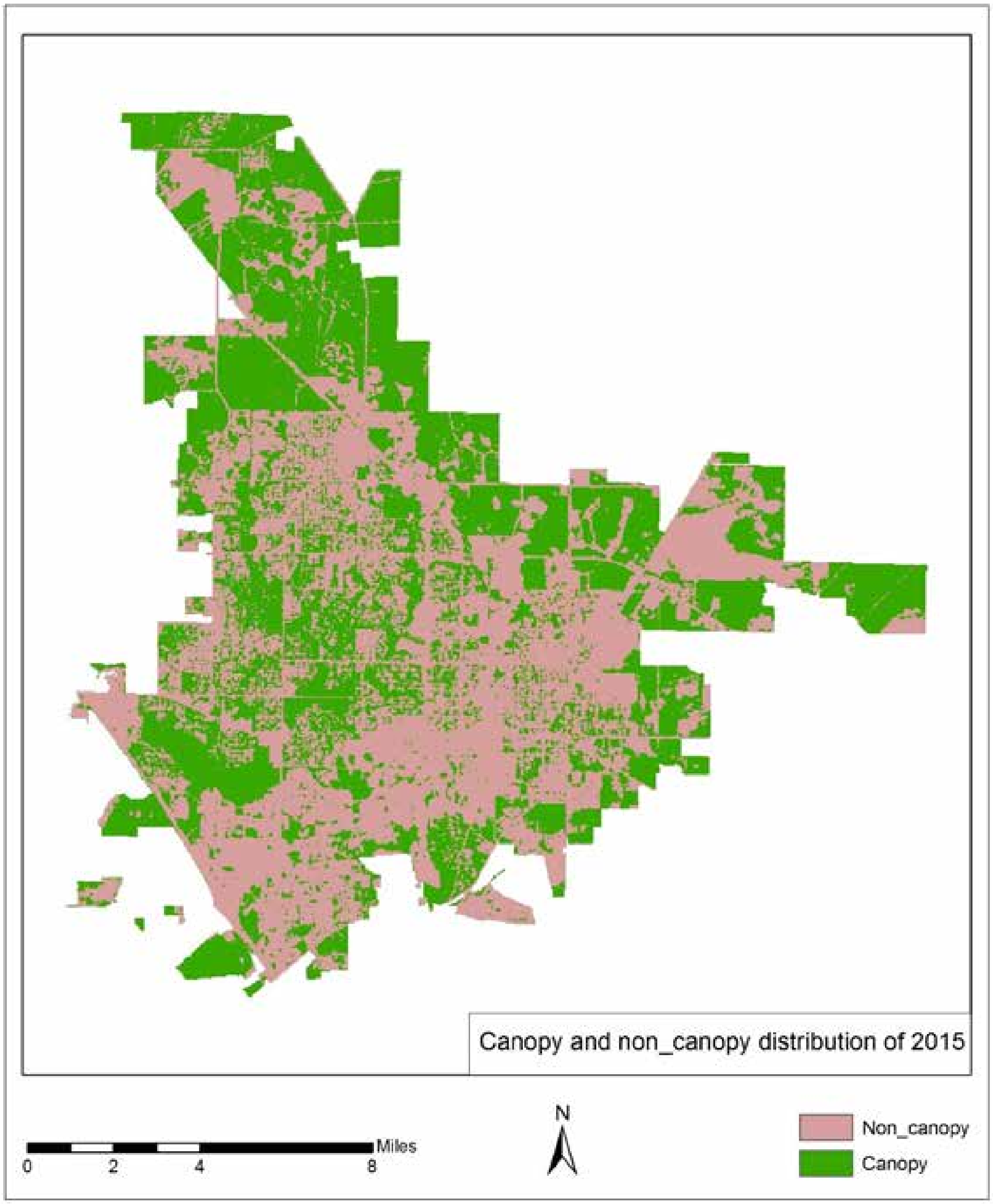


Figure 7. Canopy and non-canopy distribution of 2015 in the City of Gainesville.

Tree Cover Change

The canopy in the City of Gainesville decreased from 1996 to 2015. There was an overall net loss in tree canopy from 1996 to 2006, and then a net gain in tree canopy from 2006 to 2015 (Table 6). The distribution of canopy change from 1996 to 2015, from 1996-2015 and from 2006 to 2015 is shown in Figures 7, 8 and 9, respectively.

	Canopy gain km2(%)	Canopy loss km2(%)	No change km2(%)
1996 to 2015	8 (5%)	25 (15%)	132 (80%)
1996 to 2006	8 (5%)	27 (16%)	130 (79%)
2006 to 2015	15 (9%)	13 (8%)	137 (83%)

Table 6. Canopy change in the City of Gainesville.

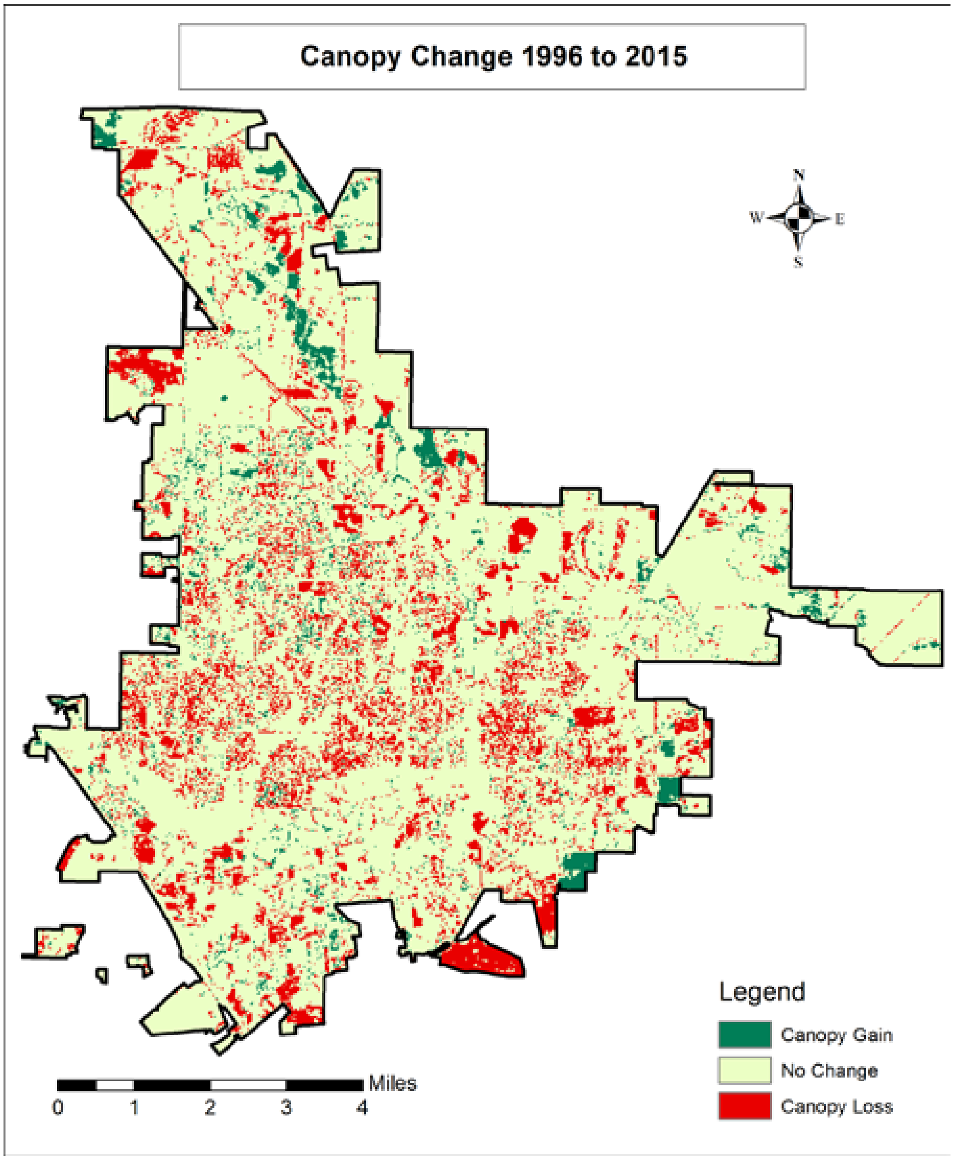


Figure 8. Canopy change distribution from 1996 to 2015 in the City of Gainesville.

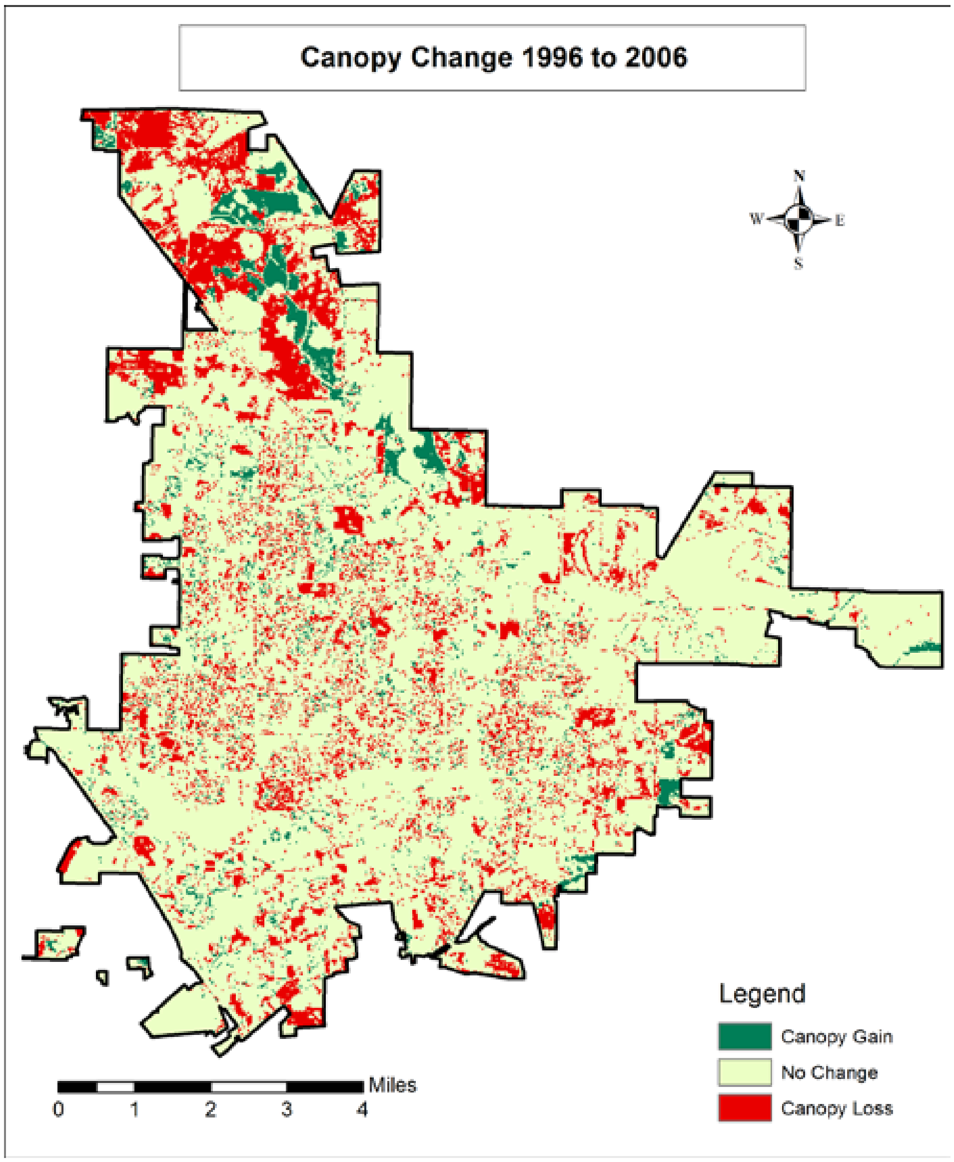


Figure 9. Canopy change distribution from 1996 to 2006 in the City of Gainesville.

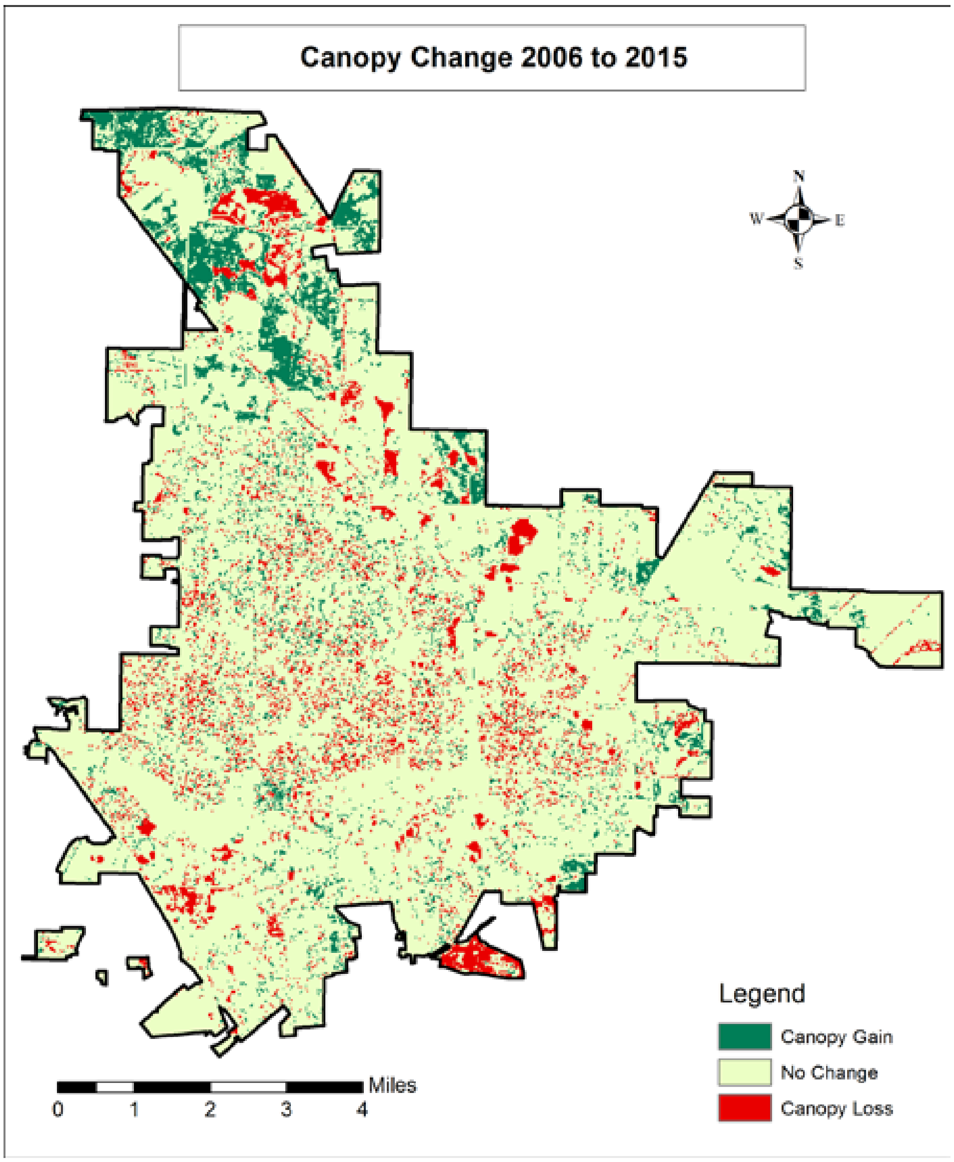


Figure 10. Canopy change distribution from 2006 to 2015 in the City of Gainesville.

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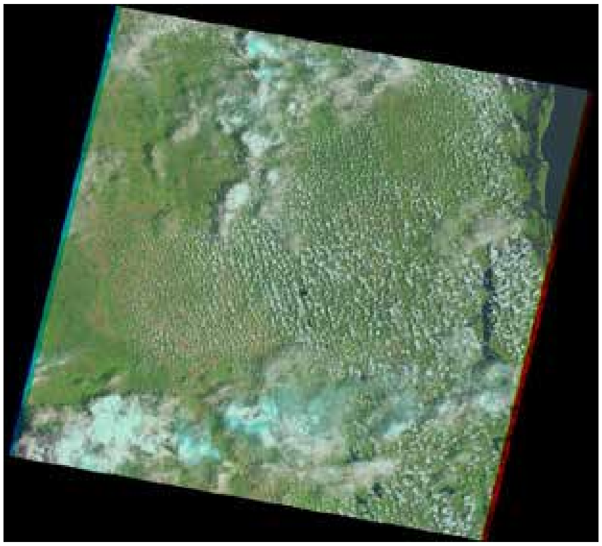
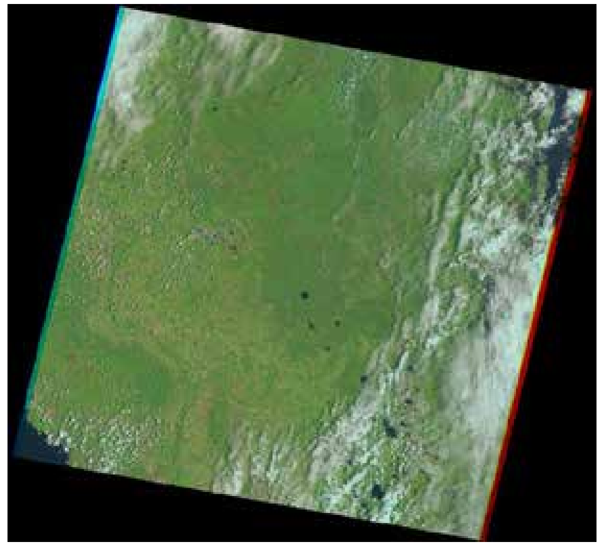
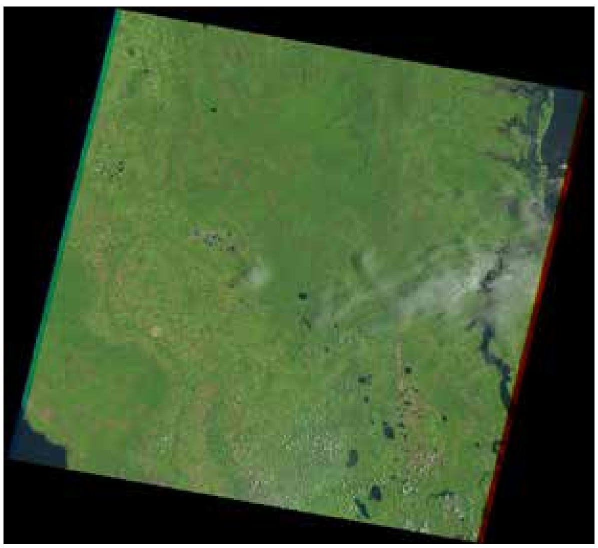
Remote Sensing Analysis Appendix: Landsat images with cloud cover in 1995 and 2005



5/4/1995



6/21/1995



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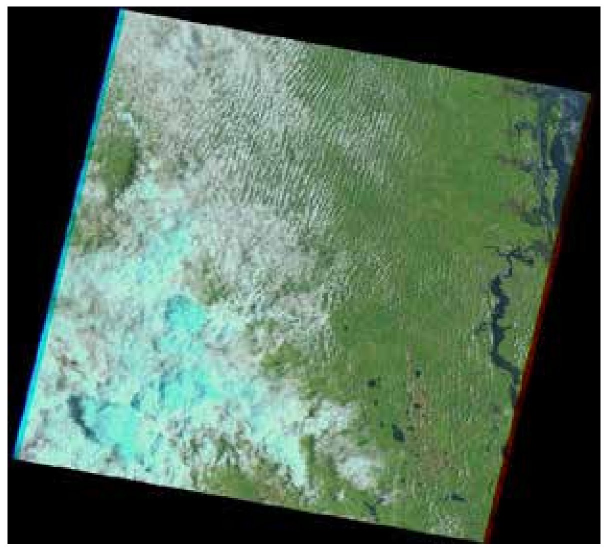

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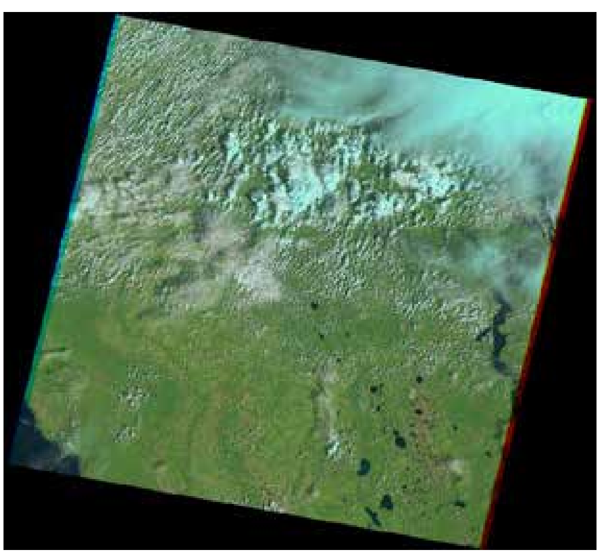
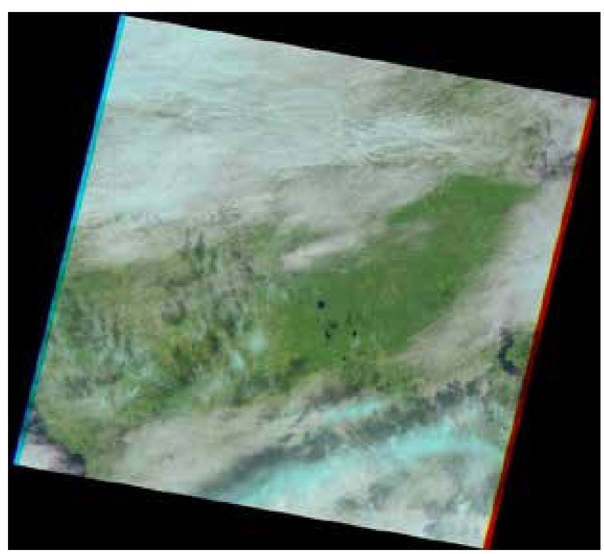


9/9/1995



9/25/1995

Figure 1. Landsat TM data acquired in summer of 1995 covered by clouds.

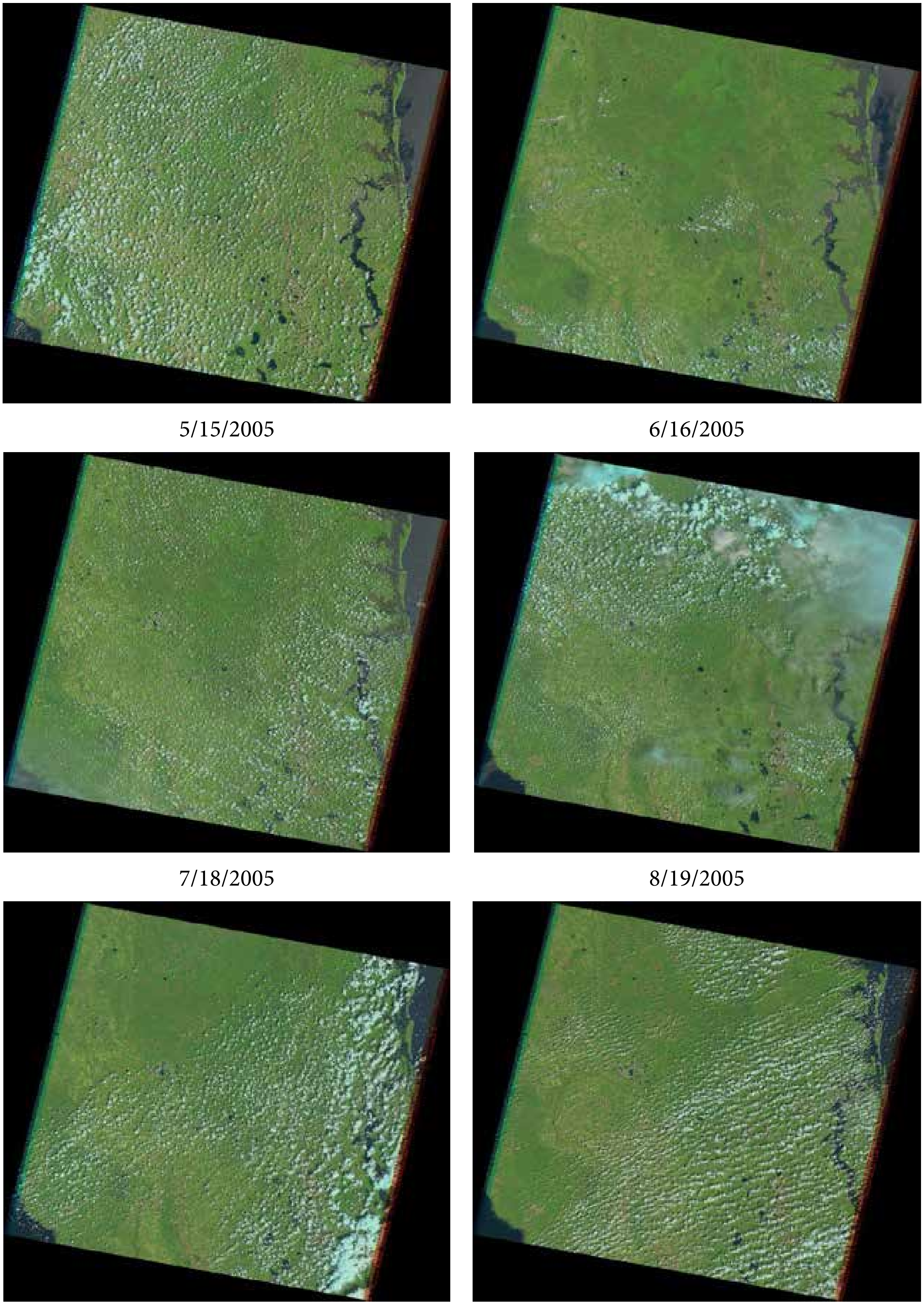


Figure 2. Landsat TM data acquired in summer of 2005 covered by clouds.

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