JACKSONVILLE I-TREE ECO SAMPLE INVENTORY

Prepared for:

City of Jacksonville, FL

Prepared by:

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PROJECT SUMMARY

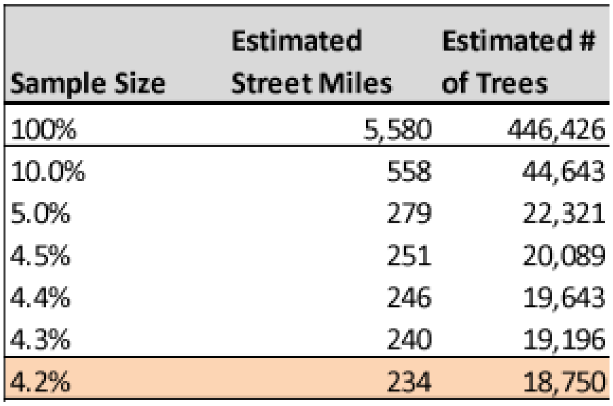
This project was designed and overseen by The City of Jacksonville Department of Public Works. All work was done under the supervision of ISA Certified arborists in compliance with the scope of services outlined in the bid specification. The three main goals of this project were as follows:

- Generate random sample of 5,249 segments of city road rights-of-way (10% of total segments)
- Assess each tree within the randomly selected road segments using data fields defined by the Department of Public Works
- Produce a final report summarizing findings

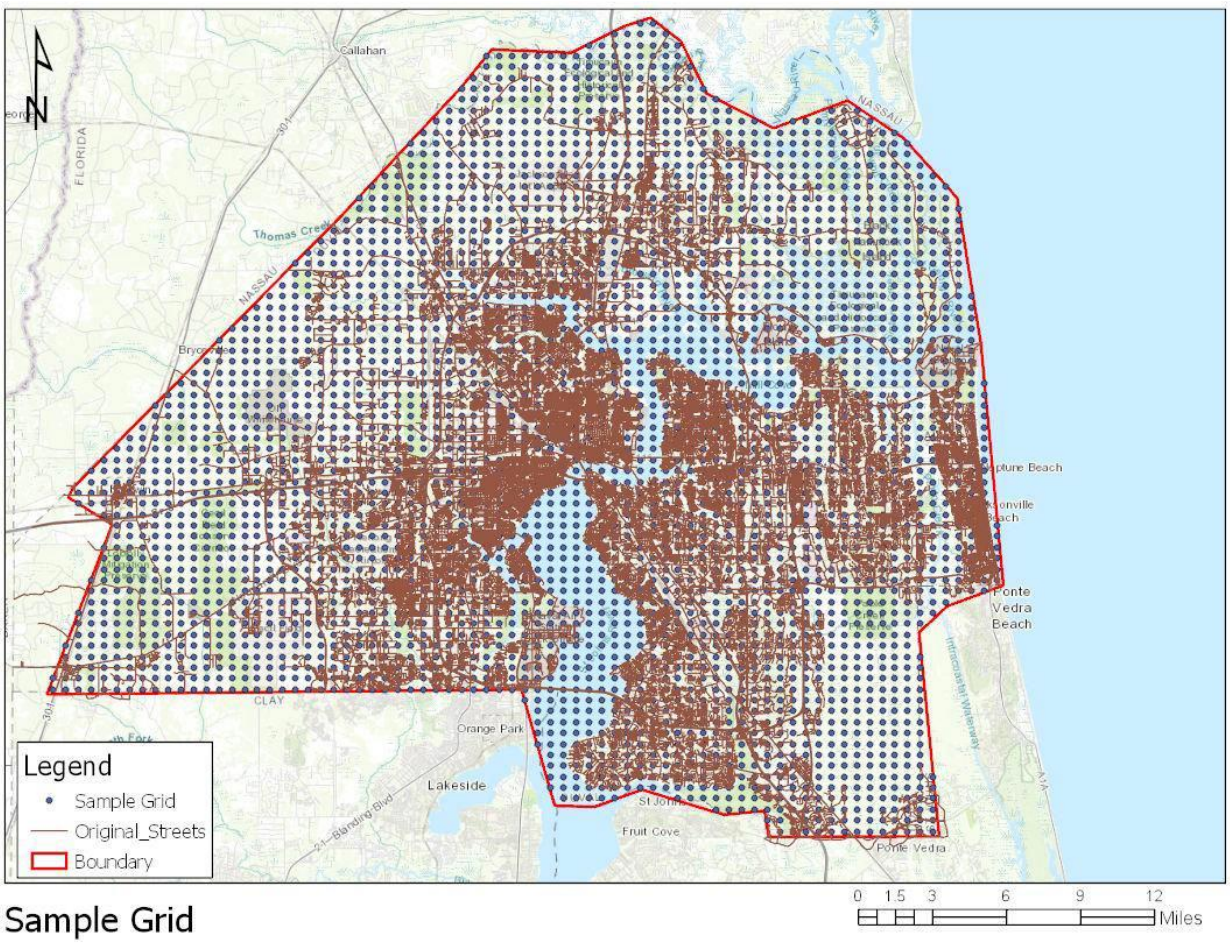
The purpose of this report is to summarize the findings of the inventory and extrapolate the results of random sampling. The extrapolated data is intended to estimate the resources needed to provide long-term maintenance of city street trees; and to quantify and monetize the annual ecosystem benefits provided by city street trees.

SAMPLING METHODOLOGY

The original goal of this project was to sample 5,249 street segments (10%) within the city. There are a total of 47,616 city-owned street segments within Jacksonville, covering 4,936.8 street miles. The working budget for this project allowed for 15,000 trees to be collected over the course of the inventory. When analyzing the initial sample, we assumed the average number of trees per mile (TPM) to be 80 based on experience and tree density of similar cities. A 10% sample would therefore yield 558 street miles and approximately 44,640 trees to be collected. This number was deemed too large to produce a true random sample within the allowable budget for data collection. Based on calculations, it was determined that a sample size of 233.6 street miles (2,240 individual segments) would allow for roughly 18,000 trees to be collected at the estimated 80 TPM. The chart below shows a matrix of different sample sizes and the resulting estimated number of trees to be collected.



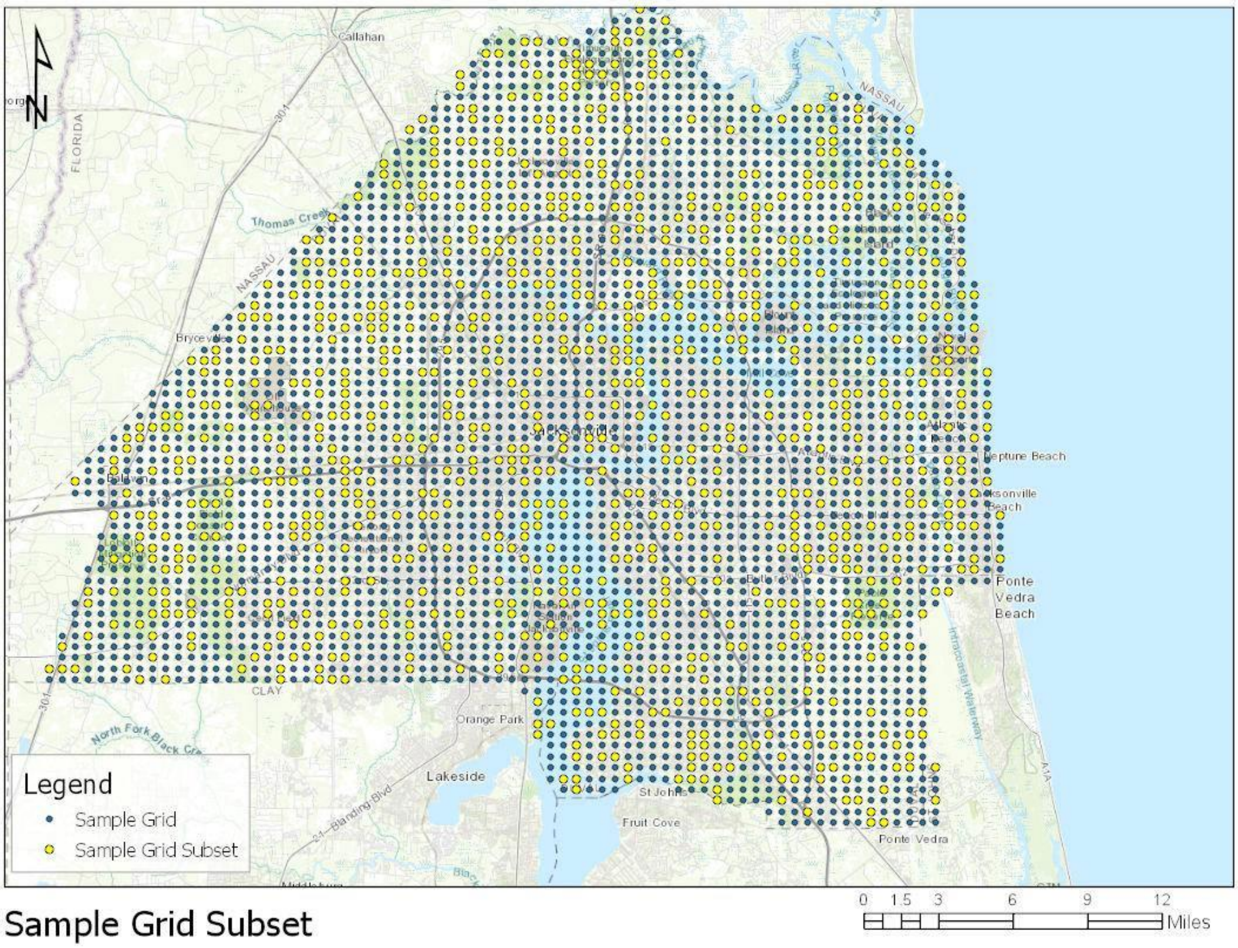
Sample Size	Estimated Street Miles	Estimated # of Trees
100%	5,580	446,426
10.0%	558	44,643
5.0%	279	22,321
4.5%	251	20,089
4.4%	246	19,643
4.3%	240	19,196
4.2%	234	18,750



Sample Grid

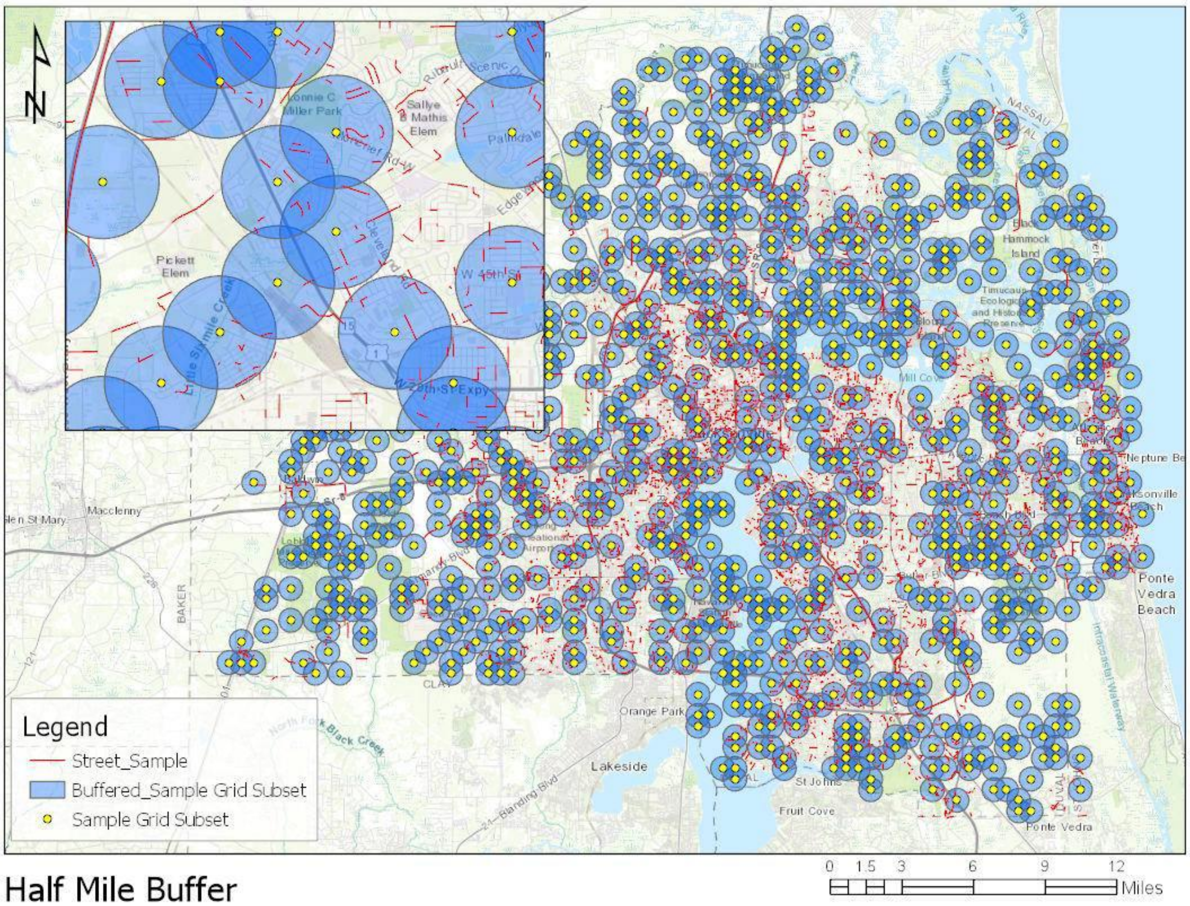
Once the desired number of street segments/street miles was determined, ArcGIS Pro was used to create a random sample that fit these parameters. The GIS shapefile for Jacksonville's streets and municipal boundary were provided by the city. These two layers were used to create the street sample in conjunction with known sampling methods and basic GIS operations. In order to create the street segment sample, a grid was created with 75 rows and 75 columns. This grid was clipped to the extent of the city boundary to served as the basis for generating the random sample.

The first step in generating a random sample was to assign each street segment a sequential number. Once the segments were numbered, they could be chosen at random by using a python script to achieve the desired sample size. The picture below shows the subset of points selected within the sample grid (selected points are highlighted yellow).



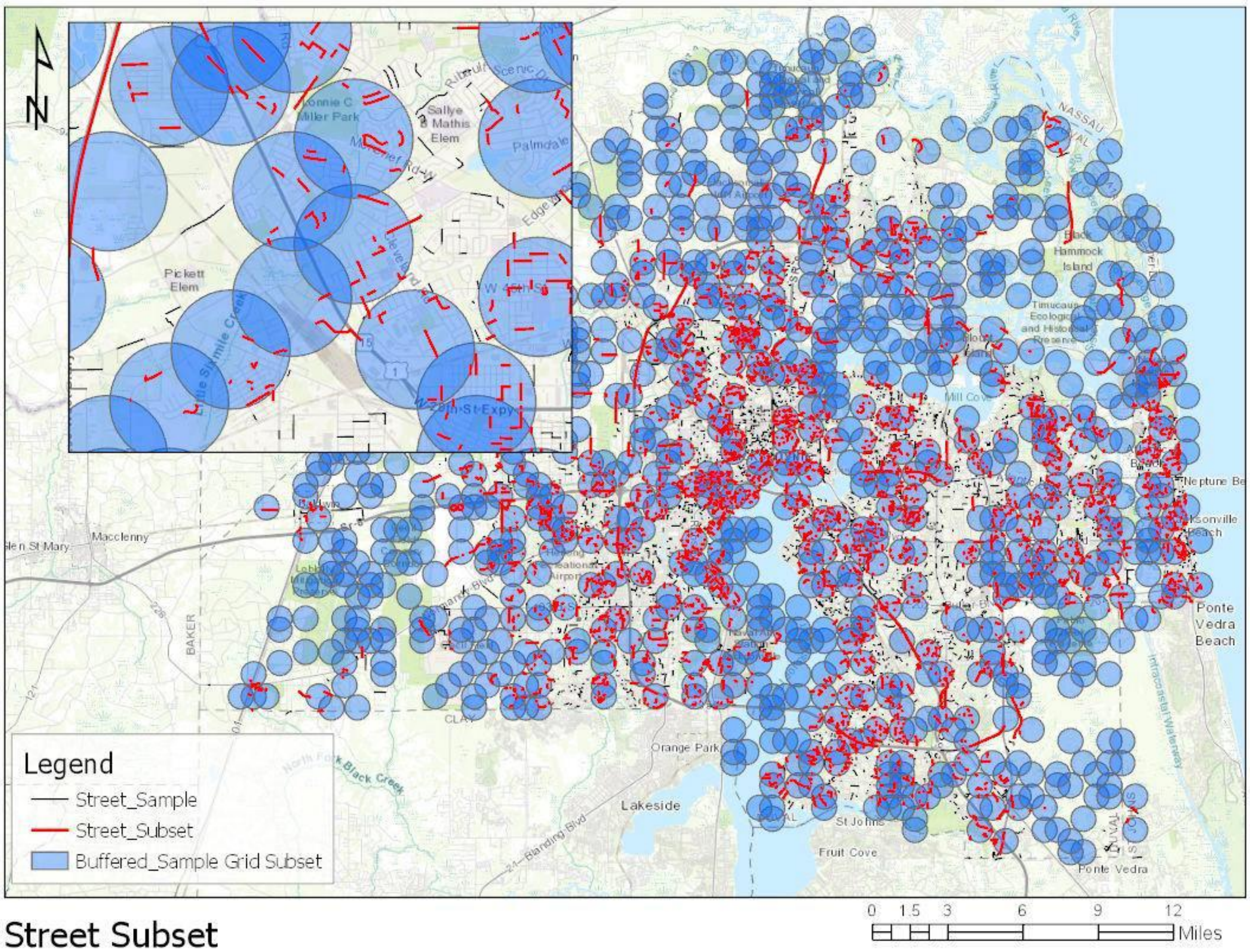
Sample Grid Subset

A new grid layer was created from the above selection, which would become the random sample used to select street segments. In order to capture nearby street segments, the sample grid point layer was buffered out a half mile.



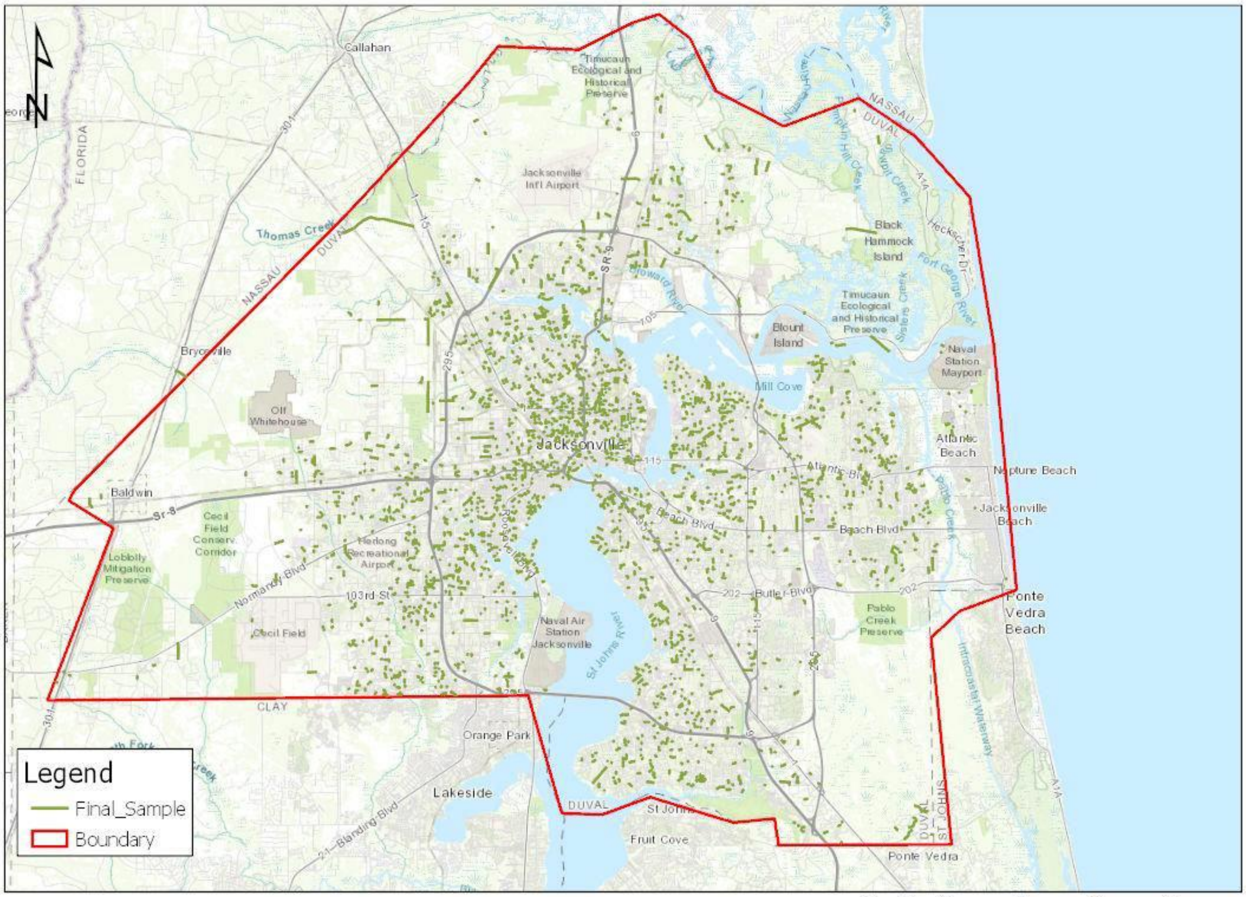
Half Mile Buffer

All streets that intersected the buffered grid were selected from the original street layer. Street segments were kept intact and not clipped to the extent of the buffered grid so they can be inventoried in complete segments.



Street Subset

Ultimately, a layer was created from the street segments that intersected the buffered sample grid in order to create a subset that accurately represents city-maintained roads and highways. Segments not maintained by the City were removed from the sample. The resulting street subset contains 2,420 street segments and a total of 233.6 street miles.



Final Sample

PROJECT METHODOLOGY

All data collection was completed by, or under the supervision of, ISA Certified Arborists. Data was collected on pen-based tablets using Plan-it Geo's software suite. Each tree recorded in the inventory was visually inspected on-site as part of a Level 2 assessment. Diameters were measured with D-Tapes and were recorded to the nearest inch. The following attributes were collected for each tree:

1. Road segment number
2. Road Name and the name of the crossing street at the beginning and end of each road segment
3. Tree located in median or along right-of-way
4. X and Y coordinates for each tree
5. Botanical and common name of species
6. Trunk diameter in inches at DBH
7. Crown spread in feet
8. Height of branch clearance over roadway, specifically noting trees with an overhead clearance of less than 14 feet
9. Condition
    a. Dead
    b. Dying
    c. Poor
    d. Fair
    e. Good
10. Distance and azimuth to building of three stories or less if the tree is 60 feet or less from the building when measured from the trunk surface to the building surface
11. Tree management recommendation
    a. Prune-Critical
    b. Prune
    c. Remove-Critical
    d. Remove
    e. No Trim

DATA COLLECTION RESULTS

A total of 1,878 street segments (3.94% of all segments) covering 169.6 street miles (3.44% of total miles) were inventoried for the City of Jacksonville in 2019 yielding 15,405 sites. 300 sites (19.1 miles) were void of City trees leaving a total of 1,578 street segments (150.5 miles) and 15,105 sites that contain City trees. Maps of treeless segments, unused sample segments, and the complete inventory can be found in Appendix V.

It is important to note that when analyzing the data, treeless street miles will be included in the extrapolation. This will account for additional treeless street miles throughout the city and will provide a more accurate estimate of the total population. Therefore, the percent sample of the inventory was determined by dividing the number of miles covered during the inventory by the total number of city-maintained street miles. Inversely, the extrapolation multiplier was determined by dividing the city street miles by the number of inventoried miles.

Inventoried Miles	/	City Street Miles	=	Percent Sample
169.6	/	4,936.8	=	3.435%
City street Miles	/	Inventoried Miles	=	Extrapolation Multiplier
4,936.8	/	169.6	=	29.11

SIGNIFICANT FINDINGS

Understanding an urban forest's structure, function and value can promote management decisions that will improve human health and environmental quality. An assessment of the vegetation structure, function, and value of the Jacksonville urban forest was conducted during 2019. Data from 15,105 trees located throughout Jacksonville were analyzed using the i-Tree Eco model developed by the U.S. Forest Service, Northern Research Station. Significant values from the inventoried street tree data are then applied using the Extrapolation Multiplier to evaluate the total tree benefits throughout Jacksonville (Table 1).

- Number of trees: 15,105
- Tree Cover: 139.4 acres
- Most common species of trees: Common crapemyrtle, Live oak, Cabbage palmetto
- Percentage of trees less than 6" (15.2 cm) diameter: 14.7%
- Pollution Removal: 4.696 tons/year ($13.8 thousand/year)
- Carbon Storage: 9.032 thousand tons ($1.54 million)
- Carbon Sequestration: 257.1 tons ($43.8 thousand/year)
- Oxygen Production: 685.6 tons/year
- Avoided Runoff: 431.4 thousand cubic feet/year ($28.8 thousand/year)
- Building energy savings: $43,600/year
- Carbon Avoided: 65.13 tons/year ($11100/year)
- Structural values: $20.7 million

Table 1. Extrapolated values of significant findings from the inventoried population

Significant Findings	Inventoried Population	Extrapolated Values
# of Trees	15,105	439,684
Tree Cover (acres)	139.4	4,058
Trees <6 inch diameter (%)	14.7%	14.7%
Pollution Removal (tons/yr)	4.696	136.7
Pollution Removal ($/yr)	$13,800	$401,697
Carbon Storage (tons)	9,032	262,908
Carbon Storage ($)	$1,540,000	$44,827,075
Carbon Sequestration (tons)	257.1	7,484
Carbon Sequestration ($/yr)	$43,800	$1,274,952
Oxygen Production (tons/yr)	685.6	19,957
Avoided Runoff (cubic ft/yr)	431,400	12,557,403
Avoided Runoff ($/yr)	$28,800	$838,325
Building Energy Savings ($/yr)	$43,600	$1,269,130
Carbon Avoided (tons/yr)	65.13	1,896
Carbon Avoided ($/yr)	$11,100	$323,104
Structural Values ($)	$20,700,000	$602,545,755

Ton: short ton (U.S.) (2,000 lbs)

Monetary values $ are reported in US Dollars throughout the report except where noted.

Ecosystem service estimates are reported for trees.

For an overview of i-Tree Eco methodology, see Appendix I. Data collection quality is dependent on the data collectors, over which i-Tree has no control.

INVENTORY STATISTICS

Species Distribution

The urban forest of Jacksonville has 15,105 trees of predominantly of Common crapemyrtle (24.1 percent), Live oak (11.5 percent), and Cabbage palmetto (9.6 percent). The top 10 most common species make up 71.1% of the population (Figure 1).

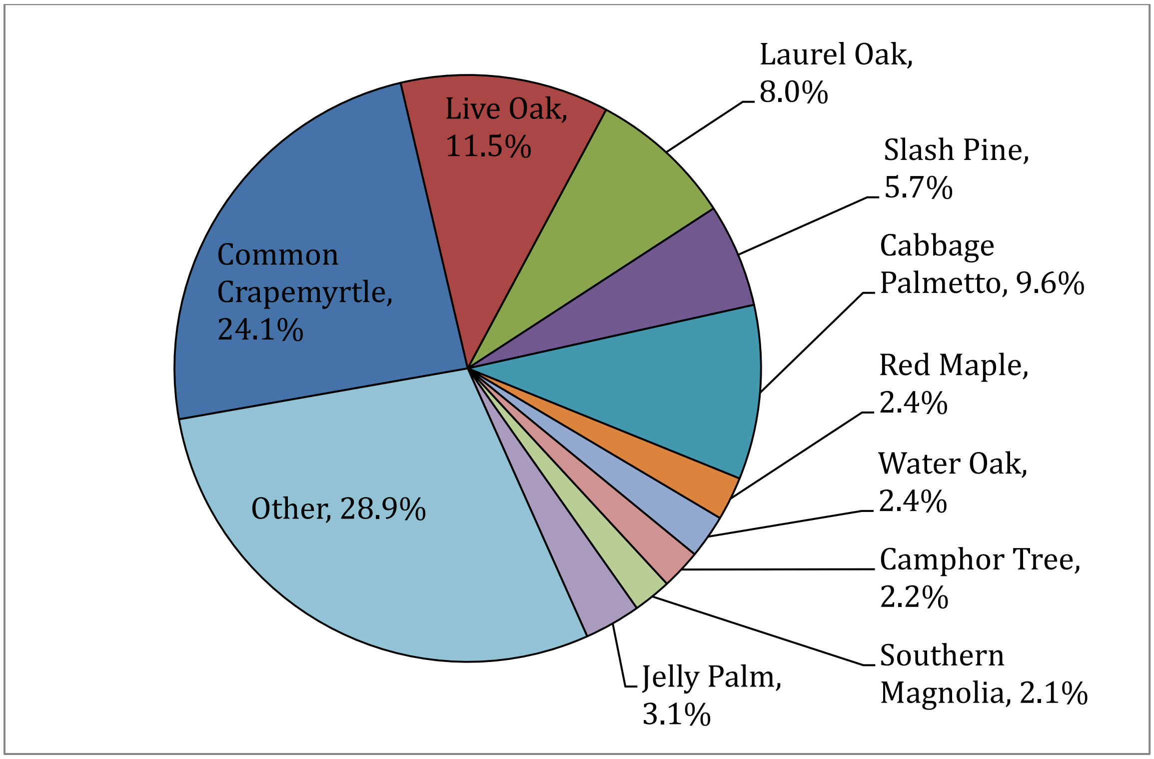


Figure 1. Tree species composition in Jacksonville

The inventoried trees cover about 139.4 acres and provide 530.2 acres of leaf area. When extrapolated, street trees in Jacksonville cover about 4058 acres of land and provide 15,433 acres of leaf area. The most dominant species in terms of leaf area are Live Oak, Laurel Oak, and Slash Pine. Leaf area varies depending on species canopy spread and density; therefore population percentage is not correlated with leaf area coverage. Importance values (IV) are calculated as the sum of percent population and percent leaf area to balance between population size and canopy cover. High importance values do not mean that these trees should necessarily be encouraged in the future; rather these species currently dominate the urban forest structure. The 10 species with the greatest importance values are listed in Table 2.

Table 2. Species with the greatest importance values (IV) in Jacksonville

Species	% Population	% Leaf Area	IV
Common Crapemyrtle	24.1	8.2	32.3
Live Oak	11.5	19.7	31.2
Laurel Oak	8.0	14.9	22.9
Slash Pine	5.7	9.3	15.1
Cabbage Palmetto	9.6	4.2	13.8
Red Maple	2.4	4.2	6.7
Water Oak	2.4	3.8	6.2
Camphor Tree	2.2	2.7	4.9
Southern Magnolia	2.1	2.7	4.8
Jelly Palm	3.1	1.3	4.3

Size Characteristics

The general size of a tree provides insight into the age and value of the tree as well as the overall age of the urban forest. There are two industry-wide recognized size characteristics, height and diameter at breast height. Diameter at breast height (DBH) is determined by the diameter of the tree at 4.5 feet above grade. DBH range distribution can be used to analyze the relative age distribution of an urban forest. This allows a city to adjust their planting plans to ensure that there are enough young trees to replace aging and over-mature trees. It is important that all age classes are adequately represented throughout the urban forest to ensure a healthy, vibrant tree canopy for future generations. Nearly 90% of the trees in Jacksonville are sized between 3 to 24 inch for diameter at breast height and over 50% within 6 to 12 inch DBH (Figure 2). The city has less than 5% of trees over 36 inch DBH suggesting the city forest is relatively young.

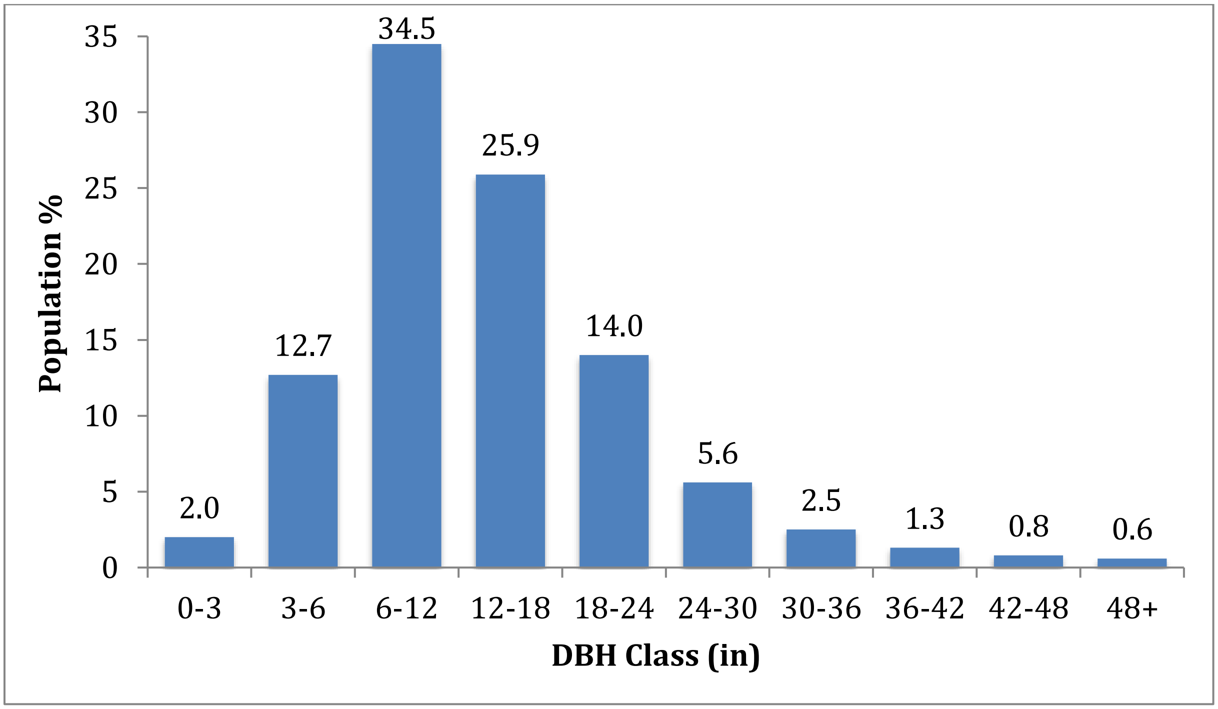


Figure 2. Percent of tree population by diameter class (DBH- stem diameter at 4.5 feet)

Tree Condition

Tree collected during the inventory process were assessed and assigned a health rating based on the following criteria:

> Good – The tree has no major structural problems; no significant damage from diseases or pests; no significant mechanical damage; a full, balanced crown, and normal twig condition and vigor for its species.
>
> Fair – The tree may exhibit the following characteristics: minor structural problems and/or mechanical damage; significant damage from non-fatal or disfiguring diseases; minor crown imbalance or thin crown; minor structural imbalance; or stunted growth compared to adjacent trees.
>
> Poor – The tree appears healthy but may have structural defects. This classification also includes healthy trees that have unbalanced structures or have been topped. Trees in this category may also have severe mechanical damage, decay, severe crown dieback, or poor vigor/failure to thrive.
>
> Dead –This category refers only to dead trees.

Count for each category of tree condition is then used to extrapolate the population amount and percentage (Table 3). Healthier trees have more cultural, social, biological, and economical benefits for the community and ecosystem than poor or dying trees. As illustrated in Figure 3, majority of the trees in Jacksonville are categorized as Fair and Good. Tree condition distribution can aid the city to gauge its street tree health and better approximate the tree maintenance budget for future upkeep.

Table 3. Tree count and population percentage for each tree condition

Tree Condition	Inventoried Count	Extrapolated Count	Population %
Good	4,681	136,257	30.99%
Fair	7,535	219,332	49.88%
Poor	2,724	79,292	18.03%
Dead	165	4,803	1.09%

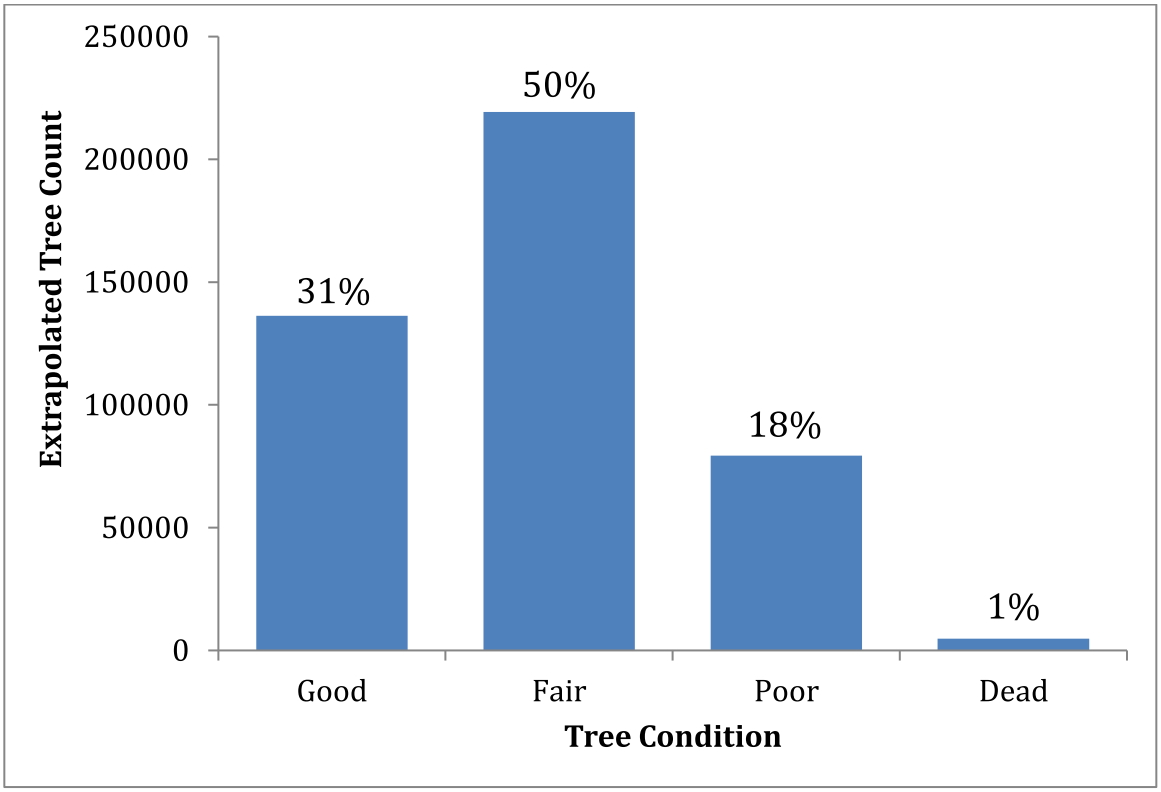


Figure 3. Extrapolated tree condition distribution

Recommended Maintenance

Tree collected during the inventory process were recommended to a following maintenance routine based on the health of each tree:

> Prune Critical - Trees that require critical pruning are recommended for trimming to remove hazardous deadwood, hangers, or broken branches. These trees have broken or hanging limbs, hazardous deadwood, and dead, dying, or diseased limbs or leaders greater than four inches in diameter.
>
> Remove Critical - Trees designated for critical removals have defects that cannot be cost-effectively or practically treated. Most of the trees in this category will have a large percentage of dead-crown and pose an elevated level of risk for failure. Any hazards that could be potential dangers to person(s) or property are seen as potential liabilities would be in this category. Large dead and dying trees that are high liability risks are included in this category.
>
> Prune - These trees require routine horticultural pruning to correct structural problems or growth patterns, which would eventually obstruct traffic or interfere with utility wires or buildings
>
> Remove - Trees that should be removed but do not pose a liability as great as the first priority will be identified here.
>
> No Trim - Trees that pose little to no risk and did not require corrective pruning at the time of the inventory.

Maintenance routine for Jacksonville is extrapolated from the inventoried results (Table 4). Majority of the inventoried trees required no trim at the time of collection (Figure 4). The inventory collected is helpful in locating trees that that require maintenance. Moving forward, the city can utilize the extrapolated street tree health to better plan/budget for its urban forest management and maximize tree benefits.

Table 4. Tree count and population percentage for each required maintenance

Recommended Maintenance	Inventoried Count	Extrapolated Count	Population %
Prune Critical	111	3,231	0.73%
Remove Critical	148	4,308	0.98%
Prune	2,987	86,947	19.77%
Remove	631	18,367	4.18%
No Trim	11,228	326,830	74.33%

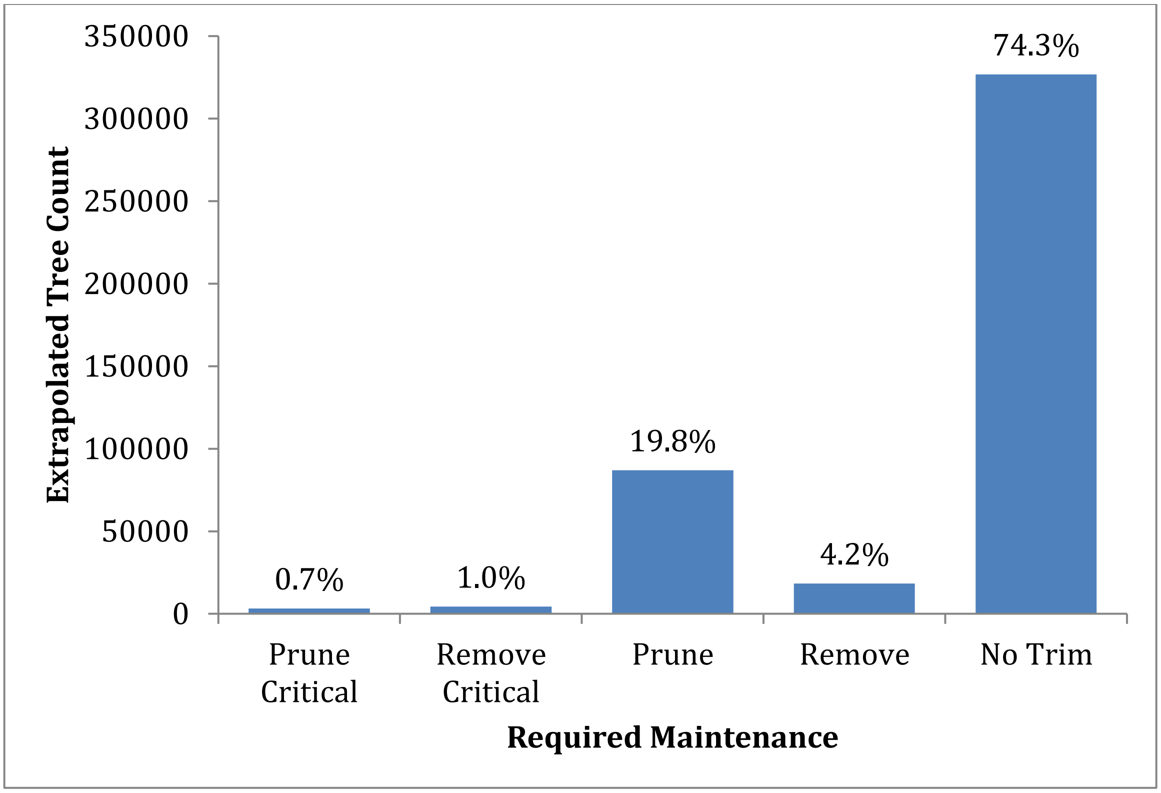


Figure 4. Extrapolated tree maintenance distribution

ECOSYSTEM BENEFITS

Air Pollution Removal

Poor air quality is a common problem in many urban areas. It can lead to decreased human health, damage to landscape materials and ecosystem processes, and reduced visibility. The urban forest can help improve air quality by reducing air temperature, directly removing pollutants from the air, and reducing energy consumption in buildings, which consequently reduces air pollutant emissions from the power sources. Trees also emit volatile organic compounds that can contribute to ozone formation. However, integrative studies have revealed that an increase in tree cover leads to reduced ozone formation (Nowak and Dwyer 2000).

Pollution removal by trees in Jacksonville was estimated using field data and recent available pollution and weather data. Citywide data is then calculated using the Extrapolation Multiplier (Table 5). The inventoried tree population is estimated to remove 4.696 tons of air pollution (ozone (O_3), carbon monoxide (CO), nitrogen dioxide (NO_2), particulate matter less than 2.5 microns ($PM_{2.5}$), and sulfur dioxide (SO_2)) per year with an associated value of $13.8 thousand (see Appendix I for more details). The extrapolated tree population for the City of Jacksonville is estimated to remove 136.69 tons of air pollution per year with an associated value of $401.5 thousand. Pollution removal was greatest for ozone; however $PM_{2.5}$ was the most valuable pollutant removed, almost doubling the value of ozone (Figure 5).

Table 5. Inventoried and extrapolated average annual pollution removal and removal value by trees in Jacksonville

	Inventoried Data		Extrapolated Data	
Pollutant	Pollution Removal (lbs)	Removal Value ($)	Pollution Removal (lbs)	Removal Value ($)
CO	258.516	178.340	7,525.011	5,191.208
O3	7,558.206	4,312.750	220,007.968	125,537.643
NO2	1,053.947	72.260	30,678.806	2,103.380
SO2	161.872	5.260	4,711.850	153.111
PM2.5	358.904	9,226.010	10,447.154	268,555.225
Total	9,391.445	13,794.620	273,370.788	401,540.566

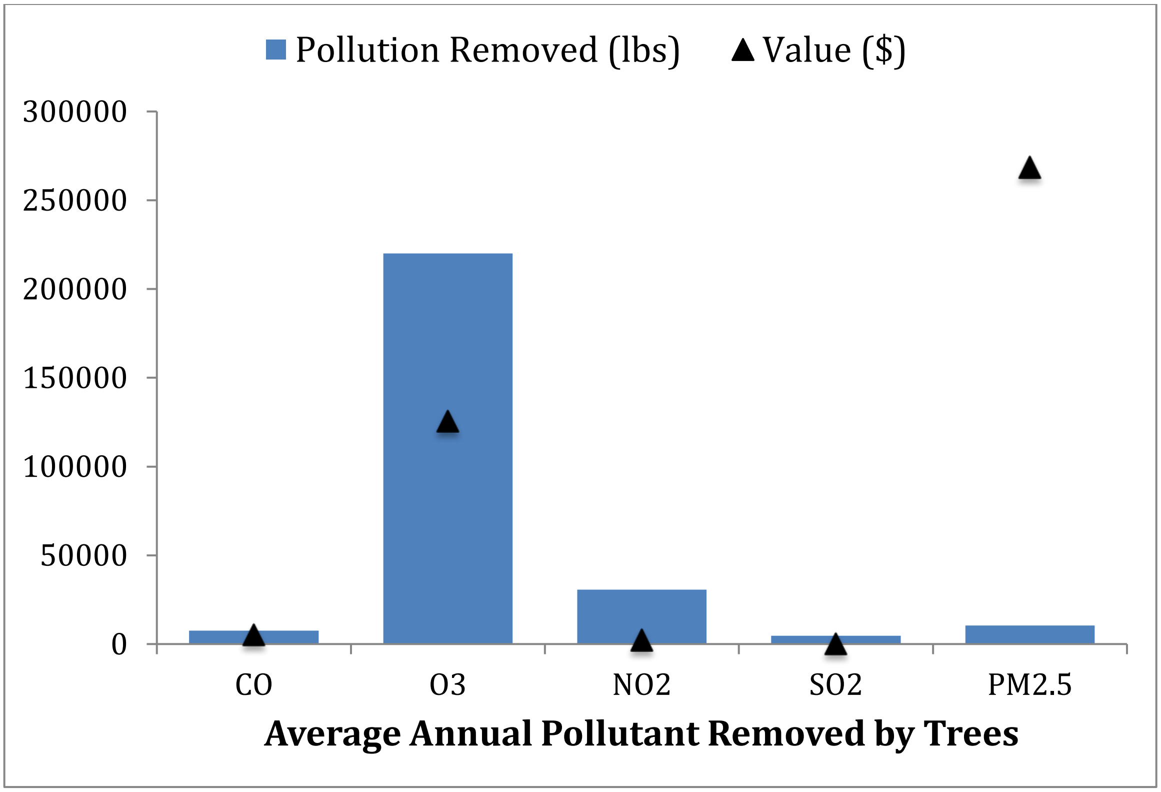


Figure 5. Average annual pollution removal and value for trees in Jacksonville

Carbon Storage and Sequestration

Climate change is an issue of global concern. Urban trees can help mitigate climate change by sequestering atmospheric carbon (from carbon dioxide) in tissue and by altering energy use in buildings, and consequently altering carbon dioxide emissions from fossil-fuel based power sources (Abdollahi et al 2000).

Trees reduce the amount of carbon in the atmosphere by sequestering carbon in new growth every year. The amount of carbon annually sequestered is increased with the size and health of the trees. The gross sequestration of inventoried trees is about 257.09 tons of carbon per year with an associated value of $43.85 thousand. The extrapolated tree population for the City of Jacksonville is estimated to sequester 7,483.5 tons of carbon per year with an associated value of $1.276 million. Species with greatest carbon sequestration are listed in Table 6 and the amount and value sequestered displayed in Figure 6. See Appendix I for more details on methods.

Table 6. Estimated annual gross carbon sequestration and value for Jacksonville urban tree species with the greatest sequestration

	Inventoried Data		Extrapolated Data	
Species	Carbon Sequestered (tons)	Sequestered Value (thousands $/yr)	Carbon Sequestered (tons)	Sequestered Value (thousands $/yr)
Live Oak	59.65	10.17	1,736.32	296.13
Common Crapemyrtle	57.48	9.80	1,673.16	285.36
Laurel Oak	41.91	7.15	1,219.94	208.06
Water Oak	11.00	1.88	320.19	54.61
Camphor Tree	9.28	1.58	270.13	46.07
Red Maple	8.87	1.51	258.19	44.03
Slash Pine	8.53	1.45	248.30	42.35
Southern Magnolia	7.27	1.24	211.62	36.09
American Sycamore	3.72	0.63	108.28	18.47
Japanese Privet	2.80	0.48	81.50	13.90

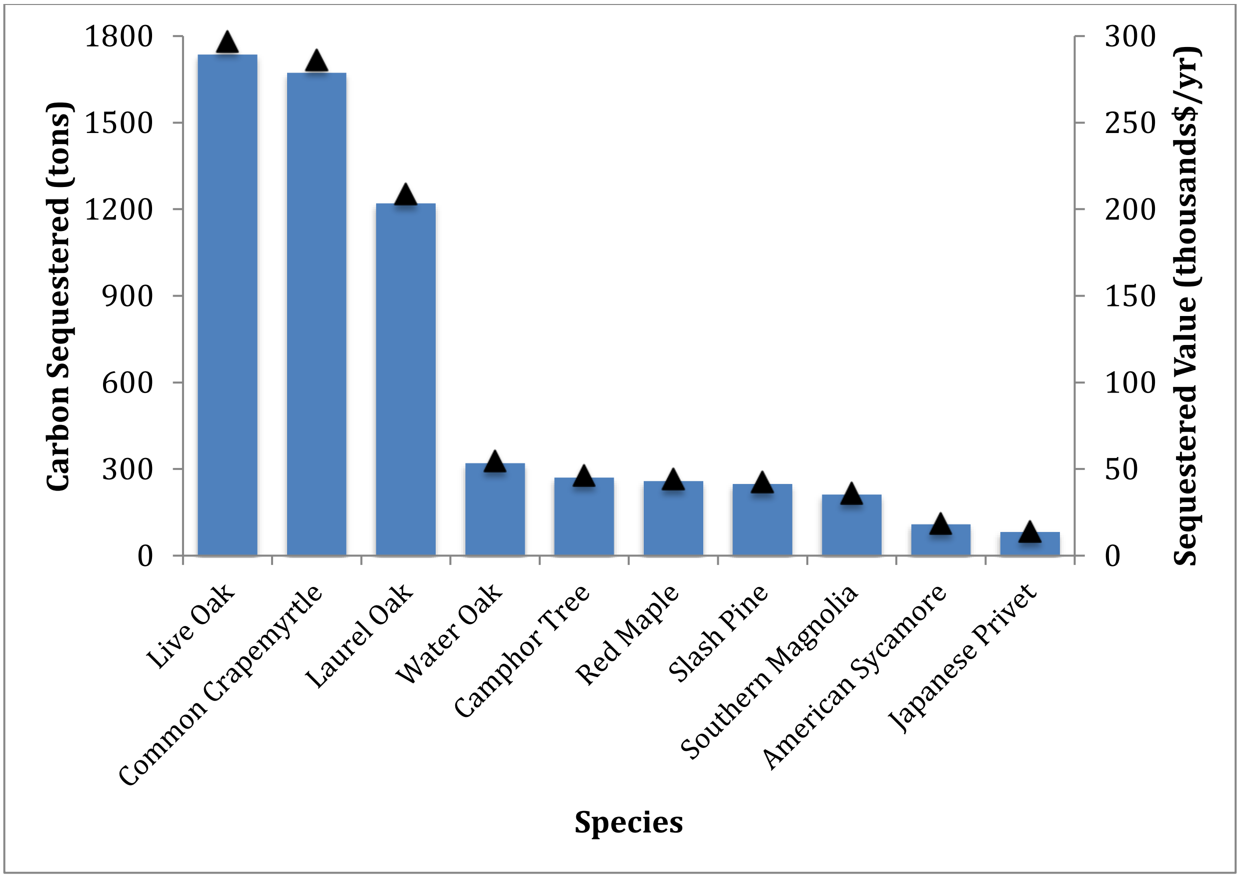


Figure 6. Carbon sequestration (bar) and its value (dot) for extrapolated species population in Jacksonville

Carbon storage is another way trees can influence global climate change. As a tree grows, it stores more carbon by holding it in its accumulated tissue. As a tree dies and decays, much of its stored carbon is released back into the atmosphere. Thus, carbon storage is an indication of the amount of carbon that can be released if trees are allowed to die and decompose. Maintaining healthy trees will keep the carbon stored in trees, but tree maintenance can contribute to carbon emissions (Nowak et al 2002c). When a tree dies, using the wood in long-term wood products, to heat buildings, or to produce energy will help reduce carbon emissions from wood decomposition or from fossil fuel or wood-based power plants.

The inventoried tree population is estimated to store 9030 tons of carbon ($1.54 million). Of the species sampled, Live oak stores and sequesters the most carbon (Table 7), with approximately 31% of the total carbon stored and 23.2% of all sequestered carbon (Figure 7). The extrapolated tree population for the City of Jacksonville is estimated to store 262,920 tons of carbon per year with an associated value of $44.8 million.

Table 7. Estimated carbon storage and values for Jacksonville urban tree species with the greatest storage

	Inventoried Data		Extrapolated Data	
Species	Carbon Storage (tons)	Storage Value (thousands $/yr)	Carbon Storage (tons)	Storage Value (thousands $/yr)
Live Oak	2,802.30	477.93	81,570.72	13,911.89
Laurel Oak	1,822.40	310.81	53,047.31	9,047.22
Common Crapemyrtle	1,180.50	201.33	34,362.57	5,860.54
Water Oak	466.90	79.63	13,590.75	2,317.90
Camphor Tree	419.60	71.56	12,213.92	2,083.08
Red Maple	301.90	51.49	8,787.85	1,498.77
Slash Pine	272.50	46.47	7,932.06	1,352.81
Southern Magnolia	259.10	44.19	7,542.01	1,286.29
American Sycamore	130.50	22.26	3,798.66	647.86
Sand Live Oak	96.50	16.46	2,808.97	479.07

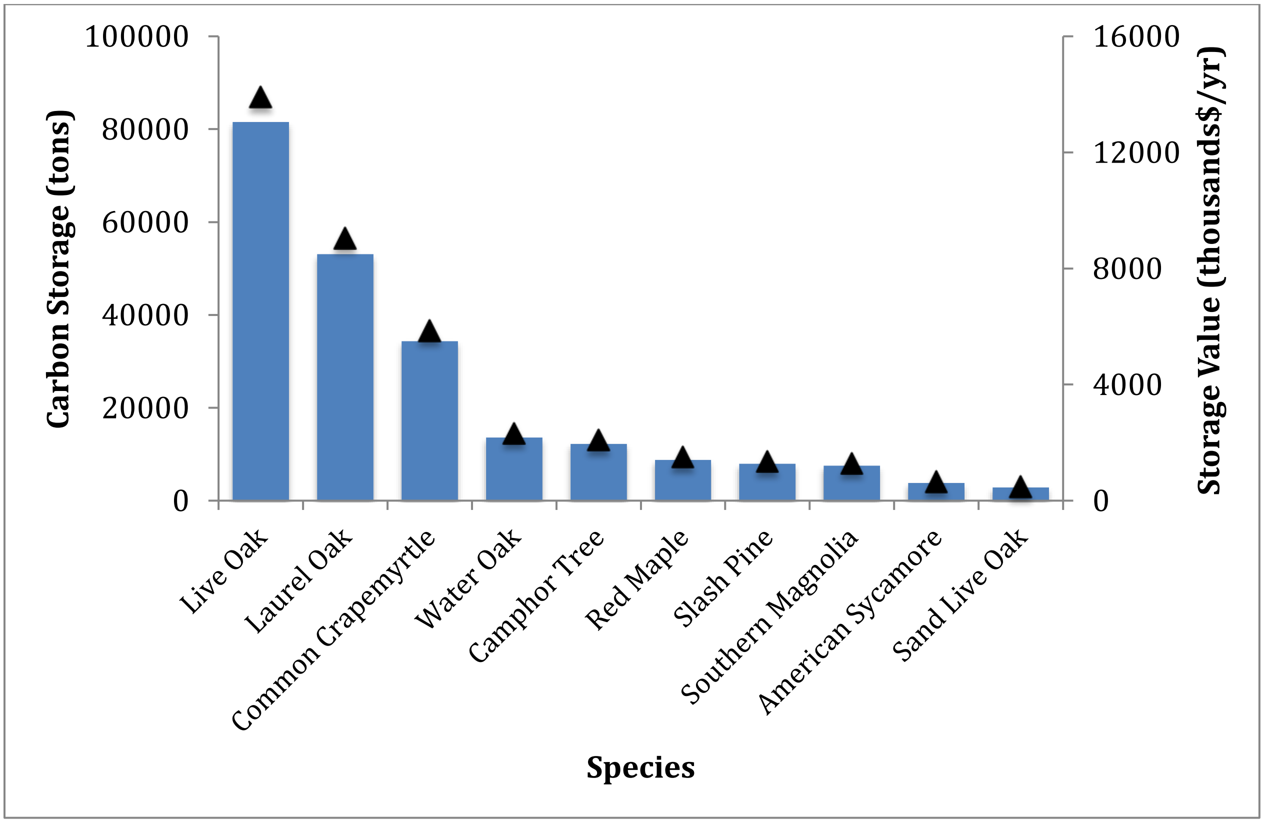


Figure 7. Carbon storage (bar) and its value (dot) for extrapolated species population in Jacksonville

Oxygen Production

Oxygen production is one of the most commonly cited benefits of urban trees. The annual oxygen production of a tree is directly related to the amount of carbon sequestered by the tree, which is tied to the accumulation of tree biomass (Figure 8).

The inventoried trees in Jacksonville are estimated to produce 685.6 tons of oxygen per year while the entire population is estimated to produce 19,956.8 tons per year. Top 10 oxygen producing species and the corresponding gross carbon sequestration is listed in Table 8. However, this tree benefit is relatively insignificant because of the large and relatively stable amount of oxygen in the atmosphere and extensive production by aquatic systems. Our atmosphere has an enormous reserve of oxygen. If all fossil fuel reserves, all trees, and all organic matter in soils were burned, atmospheric oxygen would only drop a few percent (Broecker 1970).

Table 8. Top oxygen producing species in Jacksonville based on the inventoried trees

Species	Oxygen (tons)	Gross Carbon Sequestration (ton/yr)
Live Oak	4,629.71	1,736.32
Common Crapemyrtle	4,461.75	1,673.16
Laurel Oak	3,253.46	1,219.94
Water Oak	853.75	320.19
Camphor Tree	719.85	270.13
Red Maple	688.12	258.19
Slash Pine	662.51	248.30
Southern Magnolia	564.70	211.62
American Sycamore	288.47	108.28
Japanese Privet	217.15	81.50

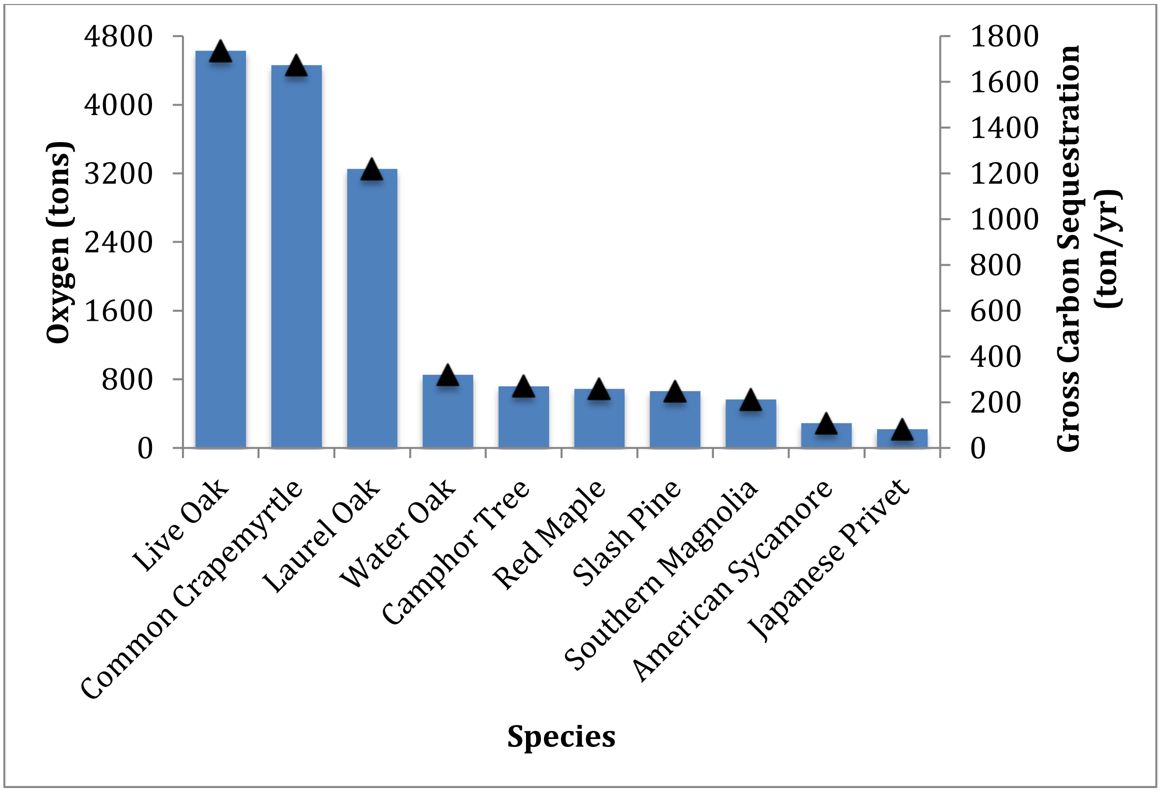


Figure 8. Oxygen production (bar) and gross carbon sequestration (dot) by the top oxygen producing species in Jacksonville

Avoided Runoff

Surface runoff can be a cause for concern in many urban areas as it can contribute pollution to streams, wetlands, rivers, lakes, and oceans. During precipitation events, some portion of the precipitation is intercepted by vegetation (trees and shrubs) while the other portion reaches the ground. The portion of the precipitation that reaches the ground and does not infiltrate into the soil becomes surface runoff (Hirabayashi 2012). In urban areas, the large extent of impervious surfaces increases the amount of surface runoff.

Urban trees and shrubs, however, are beneficial in reducing surface runoff. Trees and shrubs intercept precipitation, while their root systems promote infiltration and storage in the soil. Avoided runoff is estimated based on local weather from the user-designated weather station. In Jacksonville, the total annual precipitation in 2015 was 34.8 inches. Avoided runoff value is calculated based on the price of $0.067 per cubic feet. The inventoried trees and shrubs of Jacksonville help to reduce runoff by an estimated 431 thousand cubic feet a year with an associated value of $29 thousand (see Appendix I for more details). The extrapolated tree population for the City of Jacksonville is estimated to reduce runoff by 12,556 thousand cubic feet a year with an associated value of $840 thousand.

Table 9 shows the amount of runoff avoided by the top runoff diverting species and the corresponding value saved and tree leaf area. Trees with greater leaf area are better able to intercept precipitation, thus species leaf area parallels with runoff avoided (Figure 9).

Table 9. Volume and money conserved by Jacksonville top runoff diverting tree species extrapolated from the inventoried data

	Extrapolated Data		
Species	Avoided Runoff (1000 cubic ft/yr)	Avoided Runoff Value (1000 $/yr)	Leaf Area (acre)
Live Oak	2,479.77	165.76	3,047.95
Laurel Oak	1,870.89	125.06	2,299.57
Slash Pine	1,171.06	78.28	1,439.41
Common Crapemyrtle	1,029.41	68.81	1,265.35
Cabbage Palmetto	531.89	35.55	653.78
Red Maple	530.02	35.43	651.45
Water Oak	479.63	32.06	589.45
Camphor Tree	342.23	22.88	420.62
Southern Magnolia	336.29	22.48	413.34
American Sycamore	322.62	21.57	396.46

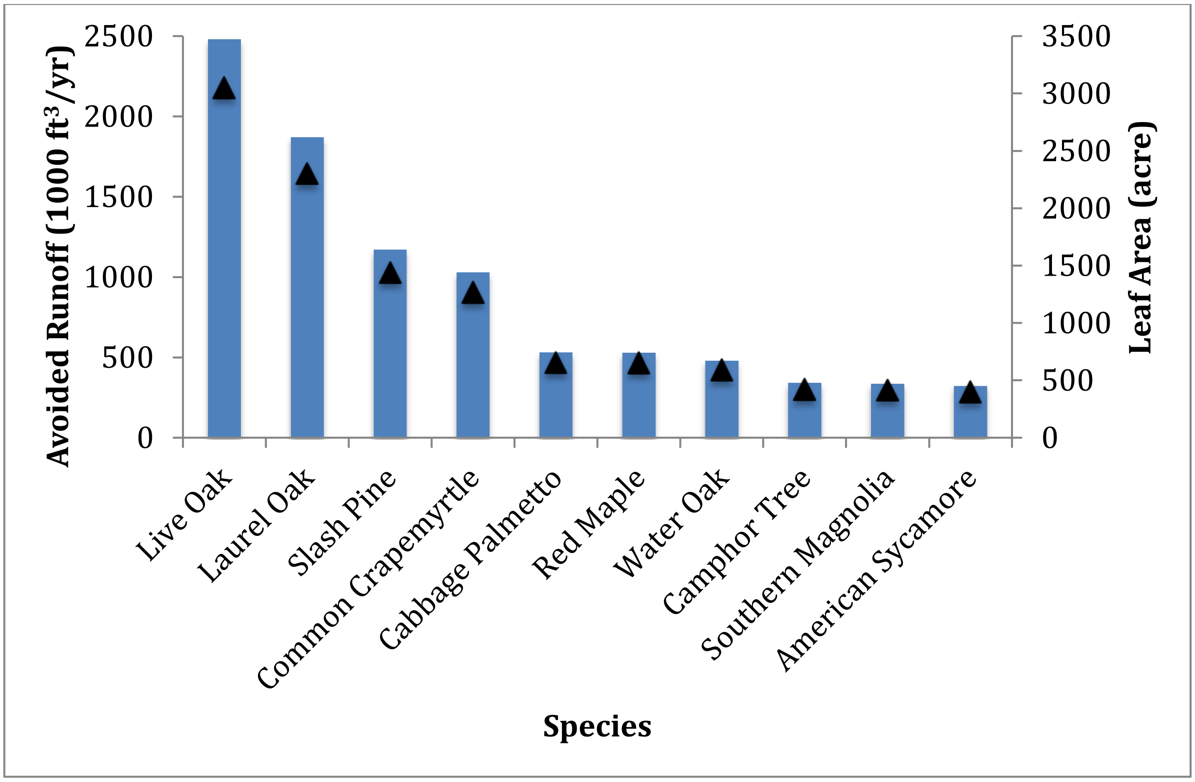


Figure 9. Runoff avoided (bar) and leaf area (dot) by top runoff diverting species for extrapolated population in Jacksonville

Trees and Building Energy Use

Trees affect energy consumption by shading buildings, providing evaporative cooling, and blocking winter winds. Trees tend to reduce building energy consumption in the summer months and can either increase or decrease building energy use in the winter months, depending on the location of trees around the building. Estimates of tree effects on energy use are based on field measurements of tree distance and direction to space conditioned residential buildings (McPherson and Simpson 1999).

The inventoried trees in Jacksonville are estimated to reduce energy-related costs from residential buildings by $43,600 annually (Table 10). Trees also provide an additional $11,100 in value by reducing the amount of carbon released by fossil fuel based power plants (a reduction of 65.1 tons of carbon emissions; Table 11). The extrapolated tree population is estimated to reduce energy-related costs from residential buildings citywide by $1,269,130 annually. The extrapolated population is also estimated to provide an additional $323,104 in value by reducing the amount of carbon released by fossil fuel based power plants (a reduction of 1,894.9 tons of carbon emissions).

Table 10. Annual energy savings due to trees near residential buildings

Amounts						
	Inventoried Data			Extrapolated Data		
Type	Heating	Cooling	Total	Heating	Cooling	Total
MBTU	272.337	N/A	272.337	7,927.3	N/A	7,927.3
MWH	11.176	323.832	335.008	325.3	9,426.3	9,751.6
Carbon Avoided (ton)	7.678	57.448	65.126	223.5	1,672.2	1,895.7

MBTU - one million British Thermal Units

MWH - megawatt-hour

Table 11. Annual savings ($) in residential energy expenditure during heating and cooling seasons

Energy Values ($)						
	Inventoried Data			Extrapolated Data		
Type	Heating	Cooling	Total	Heating	Cooling	Total
MBTU	4,712	N/A	4,712	137,159	N/A	137,159
MWH	1,298	37,613	38,911	37,783	1,094,858	1,132,640
Carbon Avoided	1,310	9,798	11,108	38,132	285,205	323,337

Based on the prices of $116.15 per MWH and $17.302566801612 per MBTU (see Appendix I for more details)

MBTU - one million British Thermal Units

MWH - megawatt-hour

Structural and Functional Values

Urban forests have a structural value based on the trees themselves (e.g., the cost of having to replace a tree with a similar tree); they also have functional values (either positive or negative) based on the functions the trees perform.

The structural value of an urban forest tends to increase with a rise in the number and size of healthy trees (Nowak et al 2002a). Annual functional values also tend to increase with increased number and size of healthy trees. Through proper management, urban forest values can be increased; however, the values and benefits also can decrease as the amount of healthy tree cover declines.

Inventoried Urban trees in Jacksonville have the following structural values:

- Structural value: $20.7 million
- Carbon storage: $1.54 million

Inventoried Urban trees in Jacksonville have the following annual functional values:

- Carbon sequestration: $43.8 thousand
- Avoided runoff: $28.8 thousand
- Pollution removal: $8.56 thousand
- Energy costs and carbon emission values: $54.7 thousand

Extrapolated Urban trees in Jacksonville have the following structural values:

- Structural value: $602.5 million
- Carbon storage: $44.8 million

Extrapolated Urban trees in Jacksonville have the following annual functional values:

- Carbon sequestration: $1.27 million
- Avoided runoff: $838.3 thousand
- Pollution removal: $249.2 thousand
- Energy costs and carbon emission values: $1.59 million

Total Annual Benefits

The inventoried tree population provides $130 thousand in total annual benefits while the citywide extrapolated tree population provides a total of 3.79 million in annual benefits (Table 12). Over 50% of benefits come from carbon sequestration and energy reduction savings (Figure 10).

Table 12. Total annual benefits for trees in the City of Jacksonville

Benefits	Total Inventoried $ (USD)	Total Extrapolated $ (USD)
Energy	$43,623.31	$1,269,808.71
Gross Carbon Sequestration	$43,847.06	$1,276,321.73
Pollution Removal	$13,794.62	$401,540.57
Avoided Runoff	$28,834.58	$839,331.10
Total Benefits	$130,099.57	$3,787,002.11

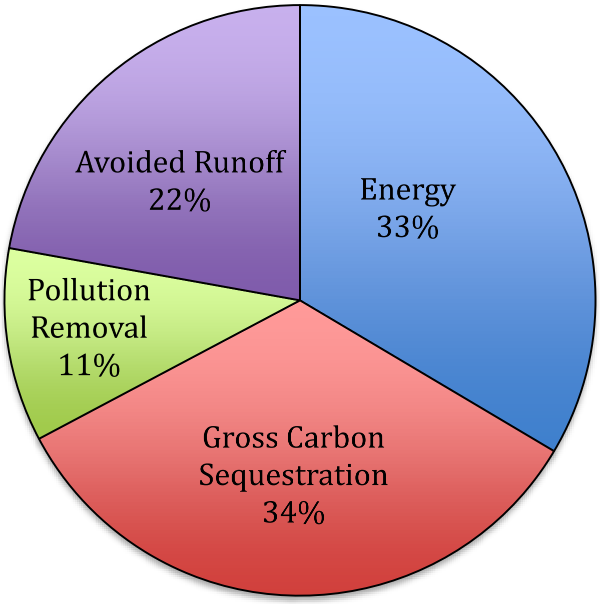


Figure 10. Percentage of total annual benefits

APPENDIX I. i-Tree Eco Model and Field Measurements

i-Tree Eco is designed to use standardized field data and local hourly air pollution and meteorological data to quantify urban forest structure and its numerous effects (Nowak and Crane 2000), including:

- Urban forest structure (e.g., species composition, tree health, leaf area, etc.).
- Amount of pollution removed hourly by the urban forest, and its associated percent air quality improvement throughout a year.
- Total carbon stored and net carbon annually sequestered by the urban forest.
- Effects of trees on building energy use and consequent effects on carbon dioxide emissions from power sources.
- Structural value of the forest, as well as the value for air pollution removal and carbon storage and sequestration.
- Potential impact of infestations by pests, such as Asian long-horned beetle, emerald ash borer, gypsy moth, and Dutch elm disease.

Typically, all field data are collected during the leaf-on season to properly assess tree canopies. Typical data collection (actual data collection may vary depending upon the user) includes land use, ground and tree cover, individual tree attributes of species, stem diameter, height, crown width, crown canopy missing and dieback, and distance and direction to residential buildings (Nowak et al 2005; Nowak et al 2008).

During data collection, trees are identified to the most specific taxonomic classification possible. Trees that are not classified to the species level may be classified by genus (e.g., ash) or species groups (e.g., hardwood). In this report, tree species, genera, or species groups are collectively referred to as tree species.

Tree Characteristics:

Leaf area of trees was assessed using measurements of crown dimensions and percentage of crown canopy missing. In the event that these data variables were not collected, they are estimated by the model. An analysis of invasive species is not available for studies outside of the United States. For the U.S., invasive species are identified using an invasive species list (Florida Exotic Pest Plant Council 2007) for the state in which the urban forest is located. These lists are not exhaustive and they cover invasive species of varying degrees of invasiveness and distribution. In instances where a state did not have an invasive species list, a list was created based on the lists of the adjacent states. Tree species that are identified as invasive by the state invasive species list are cross-referenced with native range data. This helps eliminate species that are on the state invasive species list, but are native to the study area.

Air Pollution Removal:

Pollution removal is calculated for ozone, sulfur dioxide, nitrogen dioxide, carbon monoxide and particulate matter less than 2.5 microns. Particulate matter less than 10 microns (PM_{10}) is another significant air pollutant. Given that i-Tree Eco analyzes particulate matter less than 2.5 microns ($PM_{2.5}$), which is a subset of PM_{10}, PM_{10} has not been included in this analysis. $PM_{2.5}$ is generally more relevant in discussions concerning air pollution effects on human health.

Air pollution removal estimates are derived from calculated hourly tree-canopy resistances for ozone, and sulfur and nitrogen dioxides based on a hybrid of big-leaf and multi-layer canopy deposition models (Baldocchi 1988; Baldocchi et al 1987). As the removal of carbon monoxide and particulate matter by vegetation is not directly related to transpiration, removal rates (deposition velocities) for these pollutants were based on average measured values from the literature (Bidwell and Fraser 1972; Lovett 1994) that were adjusted depending on leaf phenology and leaf area. Particulate removal incorporated a 50 percent resuspension rate of particles back to the atmosphere (Zinke 1967). Recent updates (2011) to air quality modeling are based on improved leaf area index simulations, weather and pollution processing and interpolation, and updated pollutant monetary values (Hirabayashi et al 2011; Hirabayashi et al 2012; Hirabayashi 2011).

Trees remove $PM_{2.5}$ when particulate matter is deposited on leaf surfaces (Nowak et al 2013). This deposited $PM_{2.5}$ can be resuspended to the atmosphere or removed during rain events and dissolved or transferred to the soil. This combination of events can lead to positive or negative pollution removal and value depending on various atmospheric factors. Generally, $PM_{2.5}$ removal is positive with positive benefits. However, there are some cases when net removal is negative or resuspended particles lead to increased pollution concentrations and negative values. During some months (e.g., with no rain), trees resuspend more particles than they remove. Resuspension can also lead to increased overall $PM_{2.5}$ concentrations if the boundary layer conditions are lower during net resuspension periods than during net removal periods. Since the pollution removal value is based on the change in pollution concentration, it is possible to have situations when trees remove $PM_{2.5}$ but increase concentrations and thus have negative values during periods of positive overall removal. These events are not common, but can happen.

For reports in the United States, default air pollution removal value is calculated based on local incidence of adverse health effects and national median externality costs. The number of adverse health effects and associated economic value is calculated for ozone, sulfur dioxide, nitrogen dioxide, and particulate matter less than 2.5 microns using data from the U.S. Environmental Protection Agency's Environmental Benefits Mapping and Analysis Program (BenMAP) (Nowak et al 2014). The model uses a damage-function approach that is based on the local change in pollution concentration and population. National median externality costs were used to calculate the value of carbon monoxide removal (Murray et al 1994).

For international reports, user-defined local pollution values are used. For international reports that do not have local values, estimates are based on either European median externality values (van Essen et al 2011) or BenMAP regression equations (Nowak et al 2014) that incorporate user-defined population estimates. Values are then converted to local currency with user-defined exchange rates.

For this analysis, pollution removal value is calculated based on the prices of $1,380 per ton (carbon monoxide), $1,141 per ton (ozone), $137 per ton (nitrogen dioxide), $65 per ton (sulfur dioxide), $51,412 per ton (particulate matter less than 2.5 microns).

Carbon Storage and Sequestration:

Carbon storage is the amount of carbon bound up in the above-ground and below-ground parts of woody vegetation. To calculate current carbon storage, biomass for each tree was calculated using equations from the literature and measured tree data. Open-grown, maintained trees tend to have less biomass than predicted by forest-derived biomass equations (Nowak 1994). To adjust for this difference, biomass results for open-grown urban trees were multiplied by 0.8. No adjustment was made for trees found in natural stand conditions. Tree dry-weight biomass was converted to stored carbon by multiplying by 0.5.

Carbon sequestration is the removal of carbon dioxide from the air by plants. To estimate the gross amount of carbon sequestered annually, average diameter growth from the appropriate genera and diameter class and tree condition was added to the existing tree diameter (year x) to estimate tree diameter and carbon storage in year x+1.

Carbon storage and carbon sequestration values are based on estimated or customized local carbon values. For international reports that do not have local values, estimates are based on the carbon value for the United States (U.S. Environmental Protection Agency 2015, Interagency Working Group on Social Cost of Carbon 2015) and converted to local currency with user-defined exchange rates.

For this analysis, carbon storage and carbon sequestration values are calculated based on $171 per ton.

Oxygen Production:

The amount of oxygen produced is estimated from carbon sequestration based on atomic weights: net O2 release (kg/yr) = net C sequestration (kg/yr) × 32/12. To estimate the net carbon sequestration rate, the amount of carbon sequestered as a result of tree growth is reduced by the amount lost resulting from tree mortality. Thus, net carbon sequestration and net annual oxygen production of the urban forest account for decomposition (Nowak et al 2007). For complete inventory projects, oxygen production is estimated from gross carbon sequestration and does not account for decomposition.

Avoided Runoff:

Annual avoided surface runoff is calculated based on rainfall interception by vegetation, specifically the difference between annual runoff with and without vegetation. Although tree leaves, branches, and bark may intercept precipitation and thus mitigate surface runoff, only the precipitation intercepted by leaves is accounted for in this analysis.

The value of avoided runoff is based on estimated or user-defined local values. For international reports that do not have local values, the national average value for the United States is utilized and converted to local currency with user-defined exchange rates. The U.S. value of avoided runoff is based on the U.S. Forest Service's Community Tree Guide Series (McPherson et al 1999; 2000; 2001; 2002; 2003; 2004; 2006a; 2006b; 2006c; 2007; 2010; Peper et al 2009; 2010; Vargas et al 2007a; 2007b; 2008).

For this analysis, avoided runoff value is calculated based on the price of \$0.07 per ft^3.

Building Energy Use:

If appropriate field data were collected, seasonal effects of trees on residential building energy use were calculated based on procedures described in the literature (McPherson and Simpson 1999) using distance and direction of trees from residential structures, tree height and tree condition data. To calculate the monetary value of energy savings, local or custom prices per MWH or MBTU are utilized.

For this analysis, energy saving value is calculated based on the prices of \$116.15 per MWH and \$17.30 per MBTU.

Structural Values:

Structural value is the value of a tree based on the physical resource itself (e.g., the cost of having to replace a tree with a similar tree). Structural values were based on valuation procedures of the Council of Tree and Landscape Appraisers, which uses tree species, diameter, condition, and location information (Nowak et al 2002a; 2002b).
Structural value may not be included for international projects if there is insufficient local data to complete the valuation procedures.

Potential Pest Impacts:

The complete potential pest risk analysis is not available for studies outside of the United States. The number of trees at risk to the pests analyzed is reported, though the list of pests is based on known insects and disease in the United States.

For the U.S., potential pest risk is based on pest range maps and the known pest host species that are likely to experience mortality. Pest range maps for 2012 from the Forest Health Technology Enterprise Team (FHTET) (Forest Health Technology Enterprise Team 2014) were used to determine the proximity of each pest to the county in which the urban forest is located. For the county, it was established whether the insect/disease occurs within the county, is within 250 miles of the county edge, is between 250 and 750 miles away, or is greater than 750 miles away. FHTET did not have pest range maps for Dutch elm disease and chestnut blight. The range of these pests was based on known occurrence and the host range, respectively (Eastern Forest Environmental Threat Assessment Center; Worrall 2007).

Relative Tree Effects:

The relative value of tree benefits reported in Appendix II is calculated to show what carbon storage and sequestration, and air pollutant removal equate to in amounts of municipal carbon emissions, passenger automobile emissions, and house emissions.

Municipal carbon emissions are based on 2010 U.S. per capita carbon emissions (Carbon Dioxide Information Analysis Center 2010). Per capita emissions were multiplied by city population to estimate total city carbon emissions.

Light duty vehicle emission rates (g/mi) for CO, NOx, VOCs, PM_{10}, SO2 for 2010 (Bureau of Transportation Statistics 2010; Heirigs et al 2004), PM2.5 for 2011-2015 (California Air Resources Board 2013), and CO2 for 2011 (U.S. Environmental Protection Agency 2010) were multiplied by average miles driven per vehicle in 2011 (Federal Highway Administration 2013) to determine average emissions per vehicle.

Household emissions are based on average electricity kWh usage, natural gas Btu usage, fuel oil Btu usage, kerosene Btu usage, LPG Btu usage, and wood Btu usage per household in 2009 (Energy Information Administration 2013; Energy Information Administration 2014)

- CO_2, SO_2, and NOx power plant emission per KWh are from Leonardo Academy 2011. CO emission per kWh assumes 1/3 of one percent of C emissions is CO based on Energy Information Administration 1994. PM_{10} emission per kWh from Layton 2004.
- CO_2, NOx, SO_2, and CO emission per Btu for natural gas, propane and butane (average used to represent LPG), Fuel #4 and #6 (average used to represent fuel oil and kerosene) from Leonardo Academy 2011.
- CO_2 emissions per Btu of wood from Energy Information Administration 2014.
- CO, NOx and SOx emission per Btu based on total emissions and wood burning (tons) from (British Columbia Ministry 2005; Georgia Forestry Commission 2009).

APPENDIX II. Relative Tree Effects

The urban forest in Jacksonville provides benefits that include carbon storage and sequestration, and air pollutant removal. To estimate the relative value of these benefits, tree benefits were compared to estimates of average municipal carbon emissions, average passenger automobile emissions, and average household emissions. See Appendix I for methodology.

Carbon storage is equivalent to:

- Amount of carbon emitted in Jacksonville in 1 days
- Annual carbon (C) emissions from 6,390 automobiles
- Annual C emissions from 2,620 single-family houses

Carbon monoxide removal is equivalent to:

- Annual carbon monoxide emissions from 1 automobiles
- Annual carbon monoxide emissions from 3 single-family houses

Nitrogen dioxide removal is equivalent to:

- Annual nitrogen dioxide emissions from 75 automobiles
- Annual nitrogen dioxide emissions from 34 single-family houses

Sulfur dioxide removal is equivalent to:

- Annual sulfur dioxide emissions from 870 automobiles
- Annual sulfur dioxide emissions from 2 single-family houses

Annual carbon sequestration is equivalent to:

- Amount of carbon emitted in Jacksonville in 0.0 days
- Annual C emissions from 200 automobiles
- Annual C emissions from 100 single-family houses

APPENDIX III. Comparison of Urban Forests

A common question asked is, "How does this city compare to other cities?" Although comparison among cities should be made with caution as there are many attributes of a city that affect urban forest structure and functions, summary data are provided from other cities analyzed using the i-Tree Eco model.

I. City totals for trees

City	% of Tree Cover	# of Trees	Carbon Storage *(tons)*	*Carbon Sequestration (tons/yr)*	*Pollution Removal (tons/yr)*
Toronto, ON, Canada	26.6	10,220,000	1,221,000	51,500	2,099
Atlanta, GA	36.7	9,415,000	1,344,000	46,400	1,663
Los Angeles, CA	11.1	5,993,000	1,269,000	77,000	1,975
New York, NY	20.9	5,212,000	1,350,000	42,300	1,676
London, ON, Canada	24.7	4,376,000	396,000	13,700	408
Chicago, IL	17.2	3,585,000	716,000	25,200	888
Baltimore, MD	21	2,479,000	570,000	18,400	430
Philadelphia, PA	15.7	2,113,000	530,000	16,100	575
Washington, DC	28.6	1,928,000	525,000	16,200	418
Oakville, ON , Canada	29.1	1,908,000	147,000	6,600	190
Boston, MA	22.3	1,183,000	319,000	10,500	283
Syracuse, NY	26.9	1,088,000	183,000	5,900	109
Woodbridge, NJ	29.5	986,000	160,000	5,600	210
Minneapolis, MN	26.4	979,000	250,000	8,900	305
San Francisco, CA	11.9	668,000	194,000	5,100	141
Morgantown, WV	35.5	658,000	93,000	2,900	72
Moorestown, NJ	28	583,000	117,000	3,800	118
Hartford, CT	25.9	568,000	143,000	4,300	58
Jersey City, NJ	11.5	136,000	21,000	890	41
Casper, WY	8.9	123,000	37,000	1,200	37
Freehold, NJ	34.4	48,000	20,000	540	22

II. Totals per acre of land area

City	# of Trees/ac	Carbon Storage (tons/ac)	Carbon Sequestration (tons/ac/yr)	Pollution Removal (lb/ac/yr)
Toronto, ON, Canada	64.9	7.8	0.33	26.7
Atlanta, GA	111.6	15.9	0.55	39.4
Los Angeles, CA	19.6	4.2	0.16	13.1
New York, NY	26.4	6.8	0.21	17
London, ON, Canada	75.1	6.8	0.24	14
Chicago, IL	24.2	4.8	0.17	12
Baltimore, MD	48	11.1	0.36	16.6
Philadelphia, PA	25.1	6.3	0.19	13.6
Washington, DC	49	13.3	0.41	21.2
Oakville, ON , Canada	78.1	6	0.27	11
Boston, MA	33.5	9.1	0.3	16.1
Syracuse, NY	67.7	10.3	0.34	13.6
Woodbridge, NJ	66.5	10.8	0.38	28.4
Minneapolis, MN	26.2	6.7	0.24	16.3
San Francisco, CA	22.5	6.6	0.17	9.5
Morgantown, WV	119.2	16.8	0.52	26
Moorestown, NJ	62.1	12.4	0.4	25.1
Hartford, CT	50.4	12.7	0.38	10.2
Jersey City, NJ	14.4	2.2	0.09	8.6
Casper, WY	9.1	2.8	0.09	5.5
Freehold, NJ	38.3	16	0.44	35.3

APPENDIX IV. General Recommendations for Air Quality Improvement

Urban vegetation can directly and indirectly affect local and regional air quality by altering the urban atmosphere environment. Four main ways that urban trees affect air quality are (Nowak 1995):

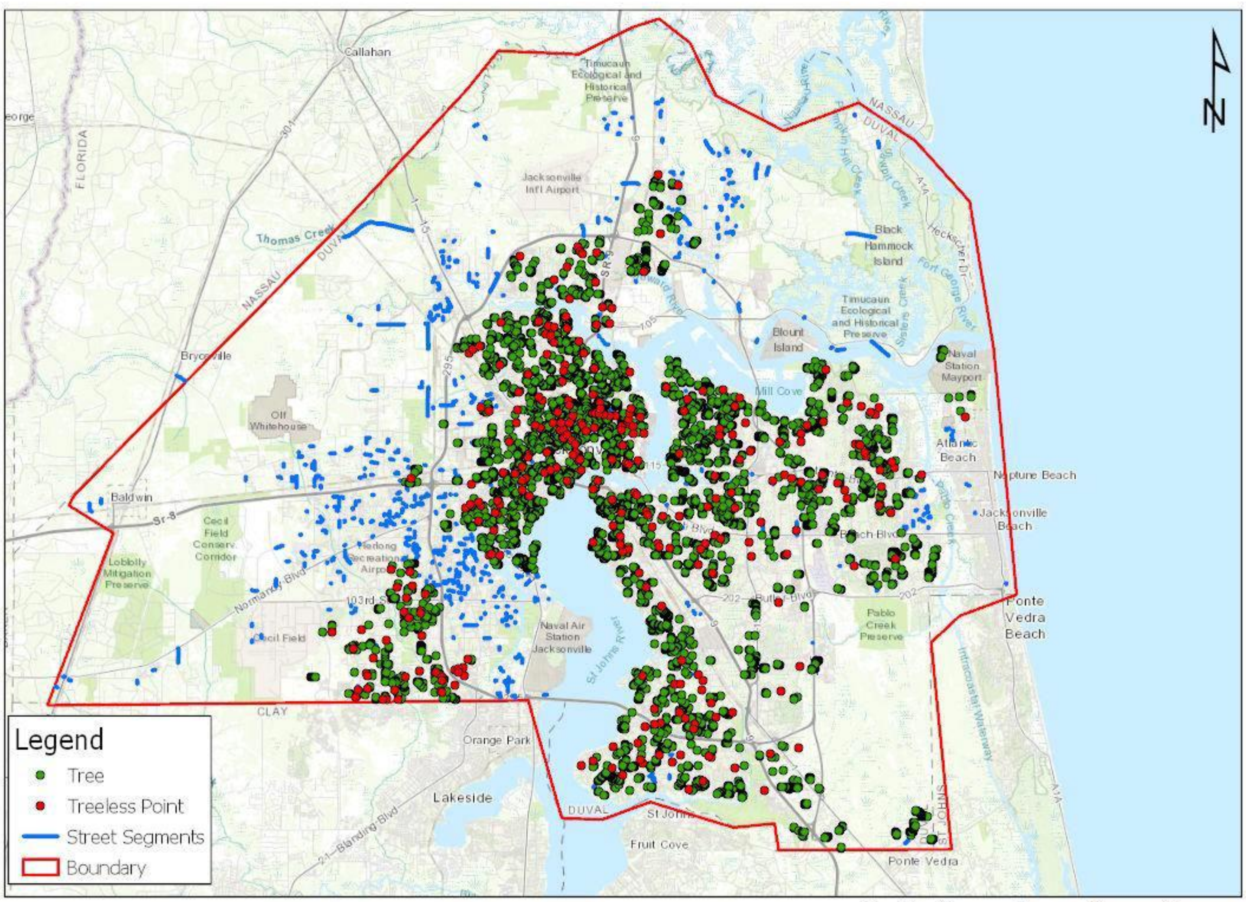
- Temperature reduction and other microclimate effects
- Removal of air pollutants
- Emission of volatile organic compounds (VOC) and tree maintenance emissions
- Energy effects on buildings

The cumulative and interactive effects of trees on climate, pollution removal, and VOC and power plant emissions determine the impact of trees on air pollution. Cumulative studies involving urban tree impacts on ozone have revealed that increased urban canopy cover, particularly with low VOC emitting species, leads to reduced ozone concentrations in cities (Nowak 2000). Local urban management decisions also can help improve air quality.

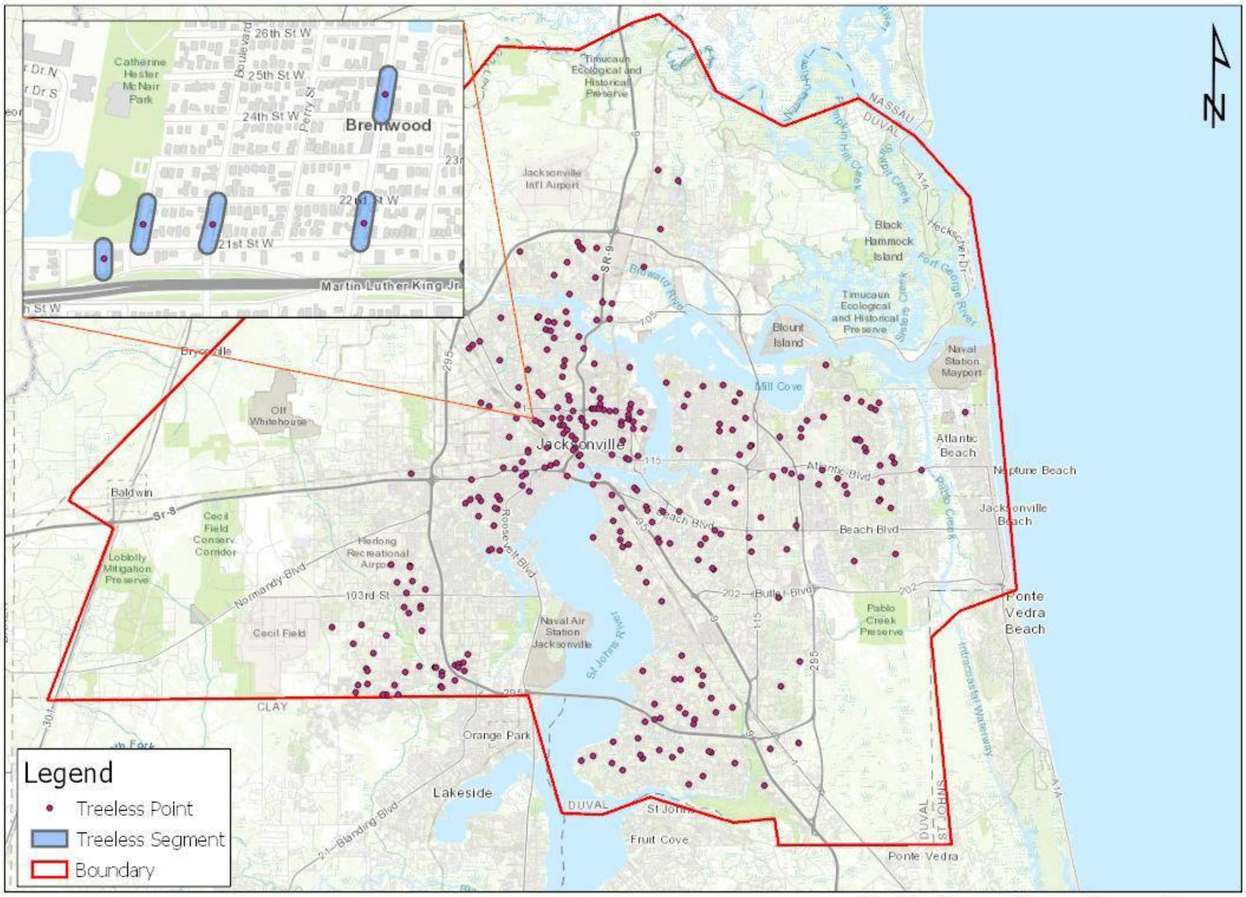
Urban forest management strategies to help improve air quality include (Nowak 2000):

Strategy	*Result*
Increase the number of healthy trees	Increase pollution removal
Sustain existing tree cover	Maintain pollution removal levels
Maximize use of low VOC-emitting trees	Reduces ozone and carbon monoxide formation
Sustain large, healthy trees	Large trees have greatest per-tree effects
Use long-lived trees	Reduce long-term pollutant emissions from planting and removal
Use low maintenance trees	Reduce pollutants emissions from maintenance activities
Reduce fossil fuel use in maintaining vegetation	Reduce pollutant emissions
Plant trees in energy conserving locations	Reduce pollutant emissions from power plants
Plant trees to shade parked cars	Reduce vehicular VOC emissions
Supply ample water to vegetation	Enhance pollution removal and temperature reduction
Plant trees in polluted or heavily populated areas	Maximizes tree air quality benefits
Avoid pollutant-sensitive species	Improve tree health
Utilize evergreen trees for particulate matter	Year-round removal of particles

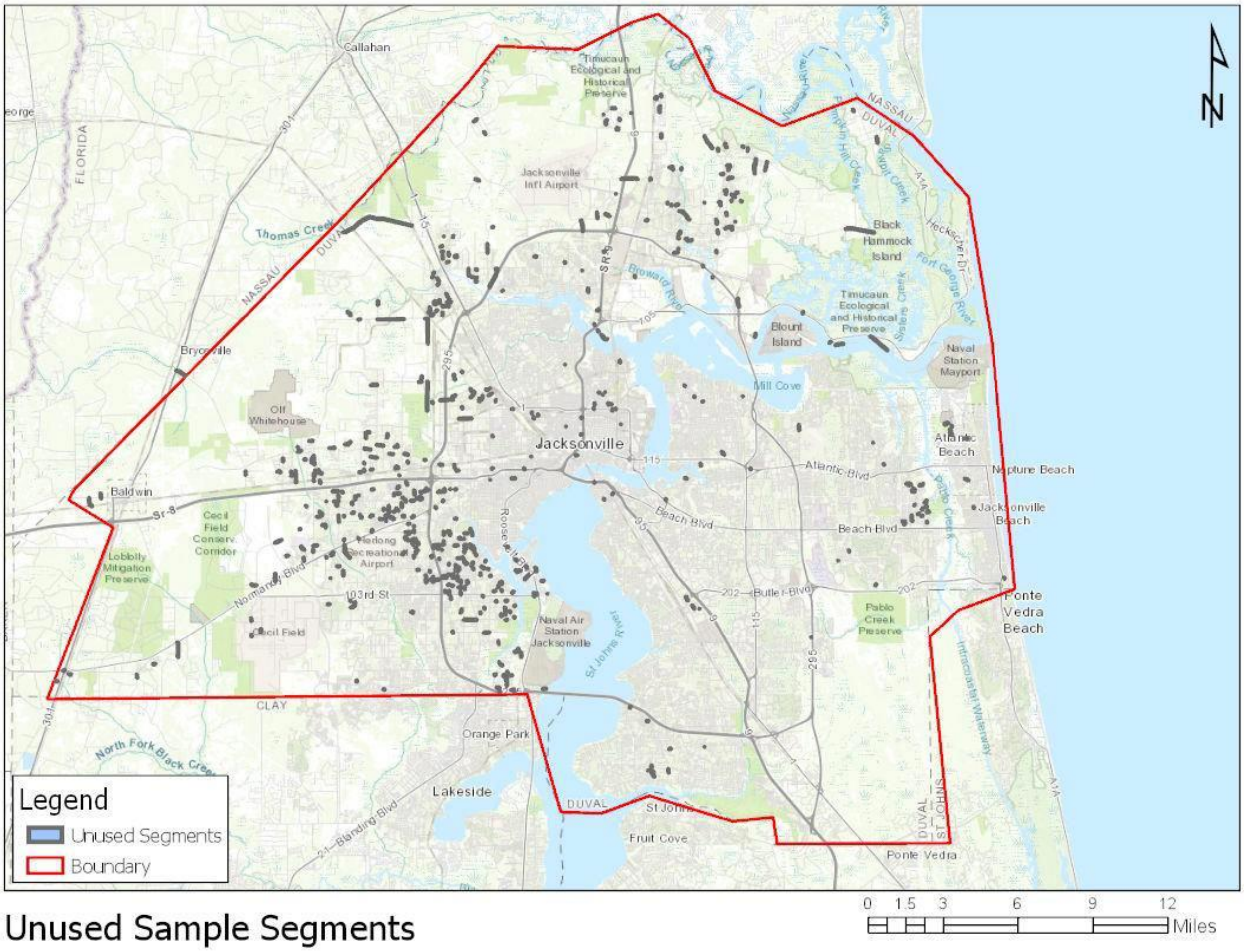
APPENDIX V. Maps



Tree Inventory



Treeless Segments



Unused Sample Segments