Tampa Tree Growth Rate Analysis

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Executive Summary

- Species-specific, regional growth models were developed to assist the City of Tampa with its tree mitigation efforts.
- Two data sources were used to predict growth over time: 1.) the results of the repeated i-Tree inventories conducted every five years within the city; and 2.) the results of growth models conducted by the USDA Forest Service in Orlando using past planting records.
- The two methods garnered different annual growth rates with the USDA planting-record's based approach estimating annual growth rates of 0.2 to 1.2 inches per year (compared to 0 to .8 inches per year based on the i-Tree inventory data)
- Given limitations with using i-Tree data to model annual growth, we recommend using the values derived from the USDA Forest Service models and have created generalized growth rates for species not included in their data set.

The City of Tampa's urban forest provides many benefits to its citizens and surrounding region. For example, in 2016 Tampa's urban forest reduced 808 tons of air pollution each year and reduced residential building cooling and heating costs by $7 million. In their Urban Forest Management Plan, Tampa has created a series of goals for the urban forest to ensure that the city's trees are able to continue providing these benefits well into the future. The amount of benefits Tampa's urban forest can provide is proportional to the amount of tree cover in the city, the type of trees, and the care they receive.

One approach the City uses to meet these goals is through regulating tree removals on private property using a permitting system since approximately 50% of city tree canopy is located on privately owned land. When trees are removed in accordance with the permitting process, those trees must either be replaced with new trees on that property, or a fee must be paid into a mitigation fund. The current ratio for calculating the number of replacement trees was based on general growth rates observed in nursery settings for common tree species in Tampa. However, it is unclear how applicable growth rates from nursery settings are to Tampa's urban forest.

The goal of this report is to provide region-specific growth rates for common tree species found in Tampa. The report estimates growth rates for tree size data collected from the 2011, 2016, and 2021 i-Tree inventories. It also provides growth rate estimates based on urban tree growth data developed for Florida by the United States Forest Service.

Background and Related Research

Highlights:

- *There are many ways to measure urban tree growth.*
- *The change over time in tree trunk width, called diameter at breast height (DBH), is a common way to measure tree growth.*
- *A repeated measures inventory determines tree growth by measuring the same trees multiple times over the course of several years.*
- *There are many factors in the urban environment that can affect tree growth.*

The prediction of tree growth based on species and environmental conditions has been a long-standing practice in European and North American forestry (Weiskittel et al., 2011). Such growth models have been commonly used to estimate the quantity of timber produced by a stand of trees. Unfortunately, growth models developed for trees growing in forest settings have limited applicability to urban trees. In urban settings, trees may be growing in open environments, poor soil conditions, and in close proximity to infrastructure such as roads or overhead wires (Piana et al., 2021). Urban trees may also be managed by arborists or property owners. And even trees in remnant natural areas embedded within a city can experience growing environments that are unique from rural forests (Piana et al., 2021).

There are several approaches to measuring urban tree growth. One approach is dendrochronology, which determines tree age by extracting a narrow core of wood from a tree's trunk and counting the number of rings in the core (e.g., Shoda et al., 2020; Trlica et al., 2020). The tree's diameter at breast height (DBH) is then divided by the age indicated by the tree rings to produce a growth rate. The rings can also be used to determine the amount of growth in a particular year and assess the effects of weather on growth (Vaz Monteiro et al., 2017). A more recent modification of the dendrochronology approach is the use of a resistance drill to count tree rings in less invasive manner, though this method is still in development for urban trees (Leopold, 2022; Orozco-Aguilar et al., 2018).

Other studies have used records of time since planting to calculate the average growth rate for a particular species in a particular place (e.g., Berland, 2020; Peper et al., 2001). The Urban Tree Database (UTD), compiled by McPherson et al. (2016), used this approach and contains measurements of urban tree size and age from more than 14,000 trees across the conterminous United States. The tree data are grouped by geographic region and represent the most common species in each region. The researchers developed mathematical equations that use the database to predict tree size and growth for target species in each region. The Urban Tree Database equations for the Central Florida and Gulf Coast regions are used later in this report to provide context for the growth analysis of Tampa's inventory.

Another approach for assessing tree growth, called a repeated measures study, is the measurement of the same trees multiple times over the course of several years to document the change in size of individual trees (e.g., Boukili et al., 2017; Lawrence et al., 2012; Smith et al., 2019; Tucker Lima et al., 2013). In Gainesville, Florida, a repeated city tree inventory found that growth rates were affected by land use, the percent of grass underneath the tree, crown light exposure, and species (Lawrence et al., 2012). The repeated measures approach is the basis for the analysis of tree growth rates in Tampa since multiple inventories have been conducted using the same plots and trees in the city.

Urban tree growth is most commonly measured as the change in trunk diameter at breast height 4.5 feet above the ground surface (DBH). Though at times the growth of the rest of the tree may not be proportional to the growth of the trunk. For example, in Raleigh, North Carolina, irrigating street trees did not change trunk growth rates but did increase stem elongation. Urban tree height and crown growth can be challenging to assess overtime since tree height and crown shape can be changed by pruning or damage from wind (Rust, 2014). For these reasons, the growth analysis of Tampa's urban trees focuses on changes in DBH over time.

Many factors affect urban tree DBH growth. Research by Lawrence et al. (2012), Tucker Lima et al. (2013), Boukilie et al. (2017), and Vaz Monteiro et al. (2017) provide examples of such factors:

- Tree species and its native status to a region
- Land use
- Neighborhood characteristics
- DBH at the time of the initial inventory
- Ratio of the height of the crown base to total tree height
- Total height
- Percent grass coverage under the tree
- Percent leaf litter or mulch under the tree
- Crown light exposure
- Neighborhood demographic characteristics

Many of these factors and the extent of their influence on tree growth can vary among cities and geographic regions (Berland, 2020). Consequently, studying patterns and drivers of growth within a city's inventory allows us to develop more accurate predictions of urban tree growth.

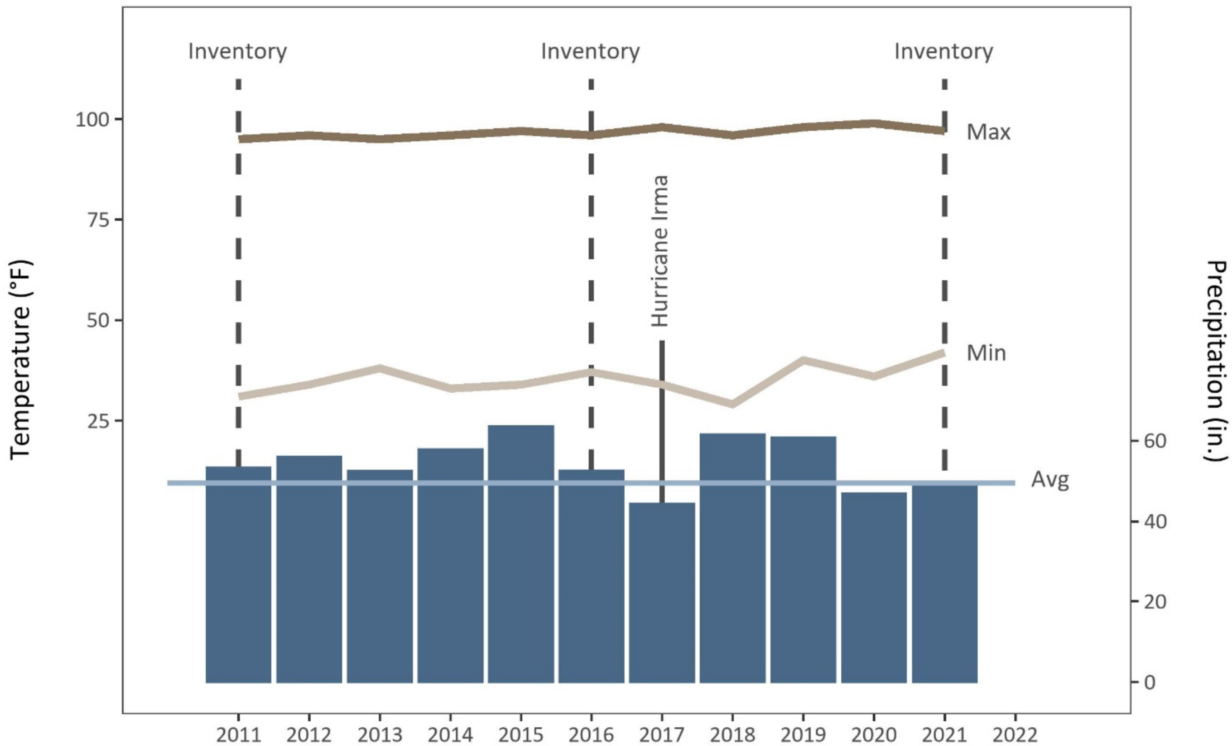
Previous Inventories

- *Three inventories were repeated in the same set of plots in Tampa in 2011, 2016, and 2021*

In 2006, 2011, 2016, and 2021 urban forest inventories of Tampa were conducted following i-Tree Eco protocols (www.itreetools.org/tools/i-tree-eco). The details of the inventory methodology can be found in the Tampa Tree Canopy and Urban Forest Analysis 2021 report. Unfortunately, data from the 2006 inventory was not configured in such a way that facilitated comparing individual trees with the other more recent inventories. Briefly, in 2011, 201 permanent plots were randomly located within the Tampa's political boundary. Within each of these plots 0.1 acre plots, survey crews measured the trunk diameter at breast height (4.5 feet above the ground; DBH), tree height, and crown width in two direction for all trees and shrubs with a DBH greater than 1 inch. The location of each tree within a plot was recorded based on the tree's compass bearing relative to and distance from the plot center. These 201 plots were revisited and remeasured in 2016 and 2021, though in 2016 only 193 of the original plots could be remeasured and in 2021 only 189 of the 2016 plots were remeasured.

Between 2011 and 2016 annual precipitation and temperatures were average and did not vary substantially between years (Figure 1). Hurricane Irma occurred in 2017 and passed near Tampa as a Category 1 hurricane. An assessment of 67 plots which had previously been evaluated in the 2016 i-Tree inventory found that 24% of surveyed trees had been damaged by the hurricane (Landry et al., 2021). In the period between the 2016 and 2021 inventories, there were two years of above average precipitation and two years below average.

Figure 1: Annual maximum and minimum temperatures and total precipitation in Tampa, Florida from 2011 to 2021. Dashed lines indicate the years when i-Tree inventories were conducted. The horizontal blue line indicates average annual precipitation.



Methods

Multiple Urban Forest Inventories

In an effort to create a Tampa-specific growth model, the last three inventories (i.e., 2011, 2016, and 2021) were merged into a single dataset using the tree location data recorded for each plot, following a protocol similar to Lawrence, et al. (2012) and Tucker Lima, et al. (2013). First, we removed all dead trees from the datasets. Then we removed multi-stemmed trees since it was not possible to match each individual stem between inventories. We also excluded palms from the analysis since they do not exhibit substantial trunk growth over time (Tucker Lima et al., 2013). Following i-Tree protocol, the location of each tree in the inventory was recorded based on its distance and angle from the plot center, a permanent point used to relocate plots from year to year. We matched trees from each dataset together if they shared similar location data (angle and distance from plot center) and were the same species.

The primary dataset for this report is based on data matched from the 2016 and 2021 inventories since they represent the most recent growth data. Trees that were not measured in 2021 but were matched between 2011 and 2016 were added to this dataset.

We calculated the annual DBH growth rate for a give tree as follows:

$$Annual\ DBH\ Growth\ = \frac{DBH_{2021} - DBH_{2016}}{Date_{2021} - Date_{2016}} \times 365$$

Where DBH_{2021} and DBH_{2016} are the DBH measurements from 2021 and 2016, and $Date_{2021}$ and $Date_{2016}$ are the days when measurements were made. The equation is then multiplied by 365 to convert growth per day to growth per year.

Urban Tree Database

We also extracted data and growth models from the Urban Tree Database (UTD) to provide additional context about urban tree growth in Florida. The UTD is an extensive collection of urban tree size and age data collected and analyzed by the United States Forest Service (McPherson et al., 2016). Data were collected across the United States, though we focused on tree data from the Central Florida and Gulf Coast regions. As explained in the Background section, the UTD created growth models by comparing tree age to tree size rather than using repeated inventories. These growth models are mathematical equations that use information such as the age of a tree to estimate its size.

We identified 19 species from the City of Tampa Tree Matrix (https://tampatreemap.org/tree-matrix) in the UTD which had data from the Central Florida and/or Gulf Coast regions. When a species had data for both Central Florida and Gulf Coast regions, we used data from Central Florida. For each of these species, we extracted two sets of growth model equations from the UTD. These models used 1) age to predict DBH, and 2) DBH to predict average crown diameter. Species' data could be fit with one of several types of equations, including linear, quadratic, cubic, and log-log. These equations are presented in Appendix 1 and were also used to create a set of graphs to visualize the relationship between age and size for the 19 species. While the UTD data and equations are presented in metric units, we converted units to feet and inches for ease of use and interpretation. We also used average crown diameter to calculate crown area by assuming the tree crown approximates a circle.

Results & Discussion

- *16% of trees measured in the 2021 Tampa i-Tree inventory were matched to tree measurements from the 2016 inventory and were used to calculate annual DBH growth rates.*
- *20% of the matched trees exhibited negative growth rates and were excluded from further analysis, likely resulting from measurement error.*
- *Average annual DBH growth rates across 29 species ranged from negligible to 2.1 inches per year.*
- *Approximately half of matched trees were located in natural/conservation lands.*
- *Annual growth rates estimated by models in the Urban Tree Database (UTD) tend to be higher than rates based on the re-inventory matched trees, likely since the UTD is based on measurements of park and street trees.*

Repeated Inventory Growth Rates

Of the 2,078 trees and palms that were measured during the 2021 i-Tree inventory, we were able to match 322 of them to the 2016 dataset with confidence. One additional tree was matched between the 2011 and 2016 dataset that had not been measured in 2021. The low percentage of matched trees can be attributed to several factors. First, relocating trees using the plot center angle and distance method is particularly challenging in the dense forest and mangrove stands common in Tampa. These forests contain a high density of small-stemmed trees and shrubs. Second, several species common in Tampa can be multi-stemmed and often had individuals which had to be excluded from the analysis.

Out of the 323 matched trees, 256 had an annual DBH growth rate that was positive or zero (negligible annual growth). These 256 trees represent 29 species. Calculating negative DBH growth rates in repeated measures inventories is not uncommon (Lawrence et al., 2012). DBH growth in forest stands can be less than the precision of measuring equipment, especially when trees in forest stands grow taller faster to compete with other trees for sunlight. Measurement error can also be a source of negative growth rates if tree trunks are not measured at the exact same height from year to year. Additionally, some remeasured individuals could have been sprouts that grew from trees damaged by weather or other natural causes.

The average annual DBH growth rates for most of the species observed in the study was less than 1 in. per year, except for live oak and baldcypress (Table 1). Several species exhibited negligible DBH growth rates, including American elm, fetterbush lyonia, Japanese privet, swamp bay, and sweet viburnum. Baldcypress and laurel oak had the highest maximum annual growth rates, 8.5 and 4.9 inches per year, respectively.

Table 1: Average, median, and range of DBH growth rates calculated from comparing the Tampa 2011, 2016, and 2021 i-Tree inventories. Quantity indicates the number of trees matched for each species.

			DBH Growth Rate (in./year)		
Common Name	**Scientific Name**	**Quantity**	**Average**	**Median**	**Range**
American elm	*Ulmus americana*	6	0	0	0-0.1
American sycamore	*Platanus occidentalis*	2	0.2	0.2	0.1-0.2
Baldcypress	*Taxodium distichum*	6	2.1	0.8	0-8.5
Benjamin fig	*Ficus benjamina*	1	0.2	0.2	0.2-0.2
Black tupelo	*Nyssa sylvatica*	11	0.1	0.1	0-0.3
Button bush	*Cephalanthus occidentalis*	4	0.1	0	0-0.1
Carolina laurelcherry	*Prunus caroliniana*	1	0.4	0.4	0.4-0.4
Chinese elm	*Ulmus parvifolia*	1	0.1	0.1	0.1-0.1
Dahoon	*Ilex cassine*	11	0.1	0.1	0-0.1
Eastern red cedar	*Juniperus virginiana*	2	0.6	0.6	0.4-0.8
Fetterbush lyonia	*Lyonia lucida*	2	0	0	0-0
Japanese privet	*Ligustrum japonicum*	1	0	0	0-0
Laurel oak	*Quercus laurifolia*	43	0.4	0.1	0-4.9
Live oak	*Quercus virginiana*	27	0.4	0.3	0-1.3
Longleaf pine	*Pinus palustris*	5	0.1	0.1	0.1-0.1
Paper mulberry	*Broussonetia papyrifera*	1	0.2	0.2	0.2-0.2
Parsley hawthorn	*Crataegus marshallii*	1	0.2	0.2	0.2-0.2
Pond cypress	*Taxodium distichum v. imbricarium*	70	0.1	0.1	0-0.6
Red maple	*Acer rubrum*	9	0.1	0.1	0-0.3
Sand pine	*Pinus clausa*	2	0.4	0.4	0.4-0.5
Slash pine	*Pinus elliottii*	5	0.4	0.2	0.1-1.4
Sour orange	*Citrus aurantium*	1	0.1	0.1	0.1-0.1
Southern bayberry	*Morella cerifera*	13	0.1	0.1	0-0.2
Swamp bay	*Persea palustris*	5	0	0	0-0.1
Swamp tupelo	*Nyssa sylvatica v. biflora*	15	0.1	0.1	0-0.2
Sweet viburnum	*Viburnum odoratissimum*	1	0	0	0-0
Sweetgum	*Liquidambar styraciflua*	4	0.8	0.8	0-1.6
Water oak	*Quercus nigra*	6	0.1	0.1	0-0.4

Almost half of the matched trees were located in the Natural/Conservation land use category (Table 2). Single-Family Residential land use had the second highest number of matched trees while Public

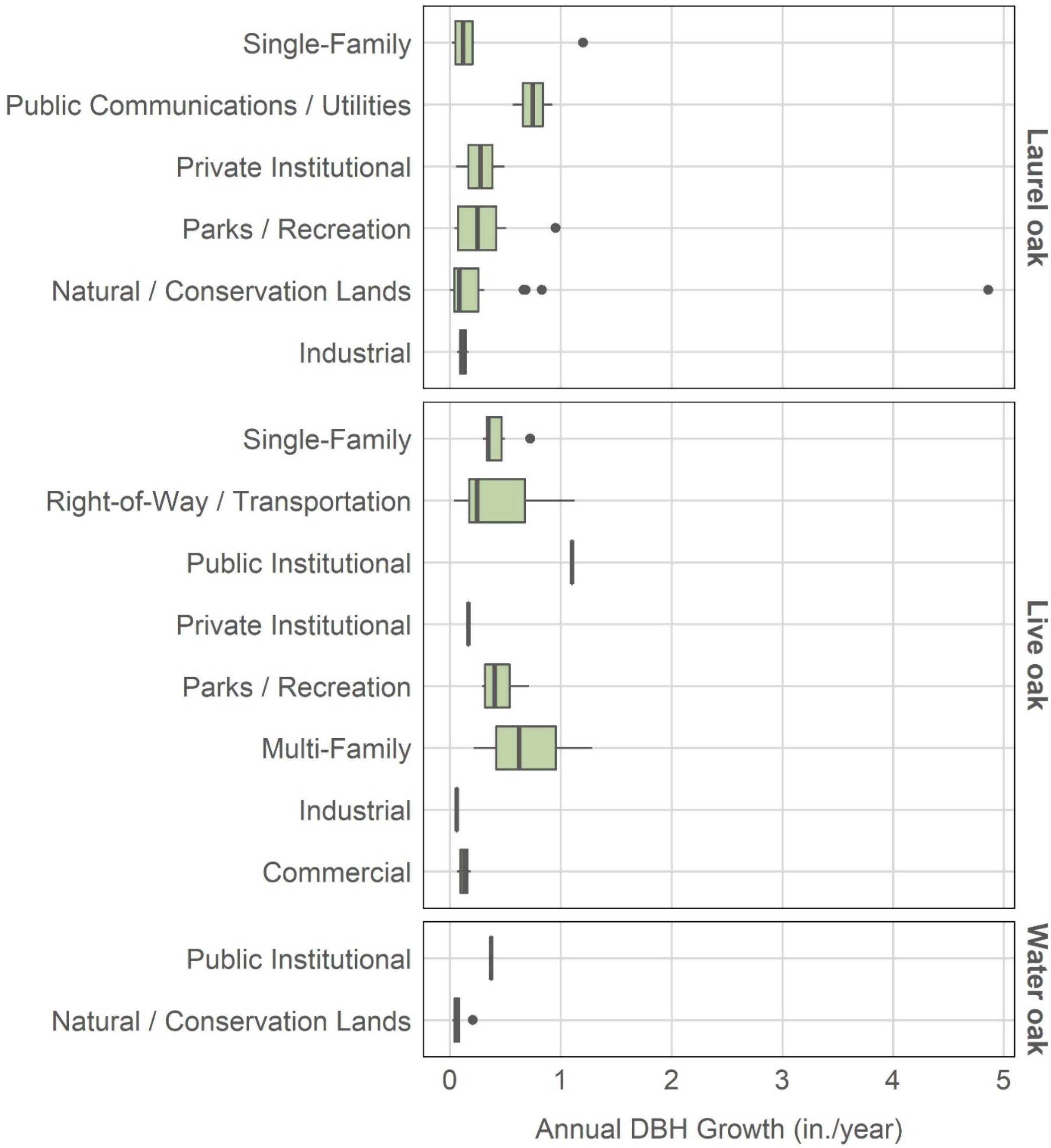
Institutional, Multi-Family, Commercial, and Public Communications/Utility land uses each had less than 10 matched trees.

Table 2: The quantity of matched trees within each land use category.

Land Use	Quantity Matched Trees
Natural / Conservation Lands	110
Single-Family	71
Private Institutional	20
Parks / Recreation	16
Industrial	11
Right-of-Way / Transportation	11
Public Institutional	8
Multi-Family	4
Commercial	3
Public Communications / Utilities	2

For many species, annual DBH growth rates were similar between land use categories (Figures 2-5). Some exceptions include bald cypress, sweetgum, and laurel oak. It is reasonable to expect trees in different land uses to exhibit different growth rates (Tucker Lima et al., 2013). However, it is difficult to draw conclusions about the effects of land use on the growth of individual species in Tampa because many combinations of species and land use categories have a very small number of observations.

Figure 2: The distribution of annual DBH growth rates for oak species in different land use categories illustrated by a box and whisker plot*.



* Box and whisker plot interpretation: Box and whisker plots represent the range and distribution of data. The line in the center of the box represents the median annual growth rate for a species. The left edge of the box represents the lower quartile – 25% of the data are less than that value. The right edge of the box represents the upper quartile – 75% of the data are less than that value. The left edge of the whisker (line) represents the minimum value of data, excluding any outliers which are shown as circles. The right edge of the whisker (line) represents the maximum value of the data excluding any outliers.

Figure 3: The distribution of annual DBH growth rates for shrub species in different land use categories illustrated by a box and whisker plot (see Figure 2 for explanation).

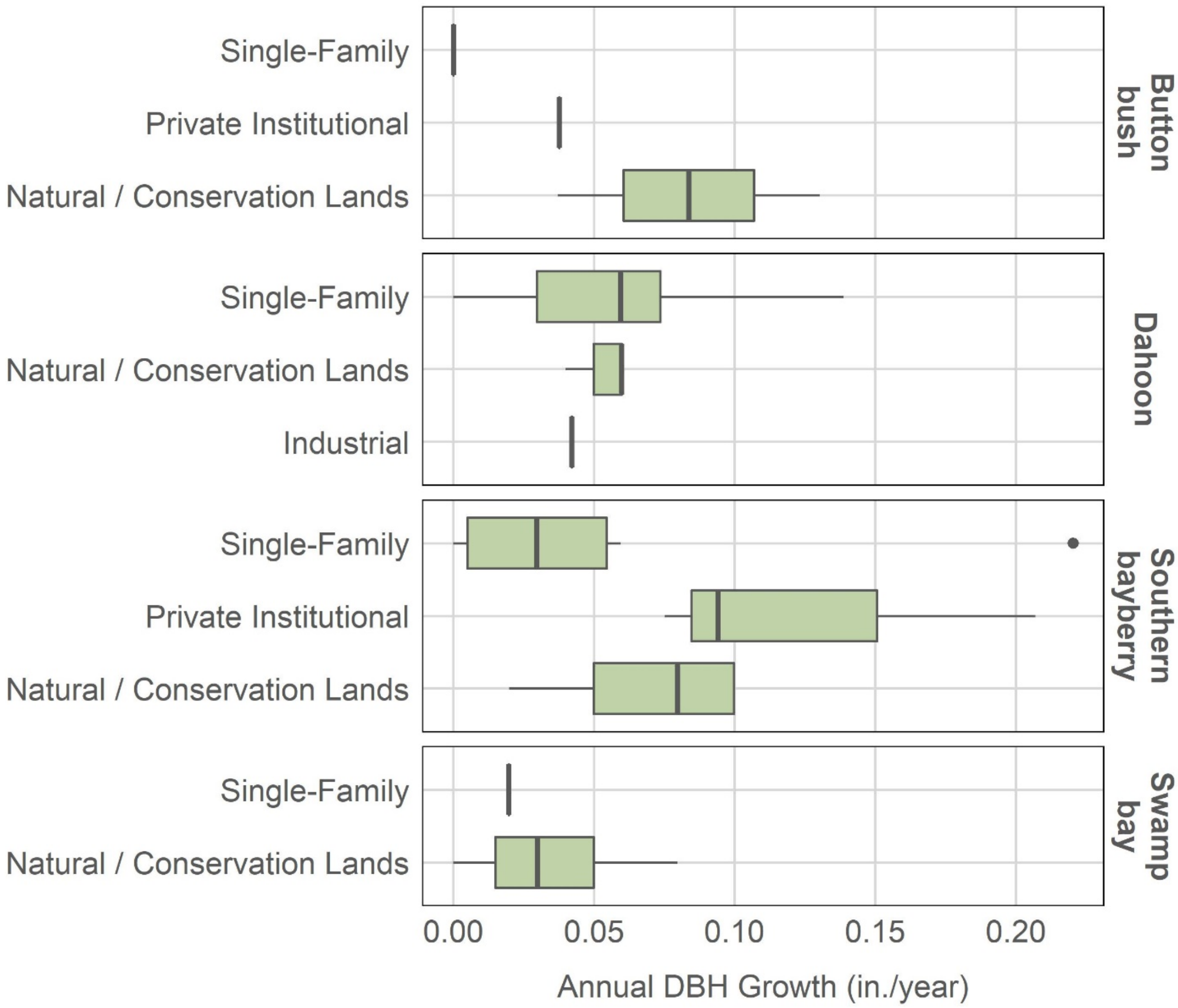


Figure 4: The distribution of annual DBH growth rates for conifer species in different land use categories illustrated by a box and whisker plot (see Figure 2 for explanation).

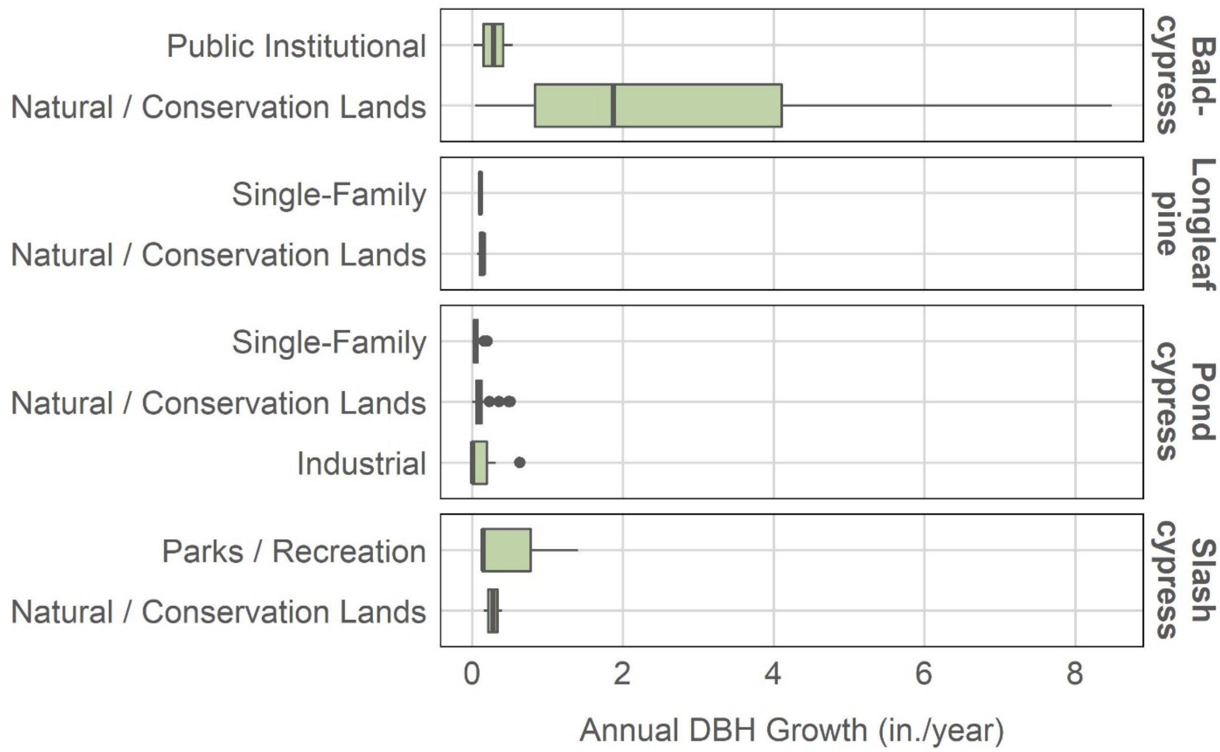
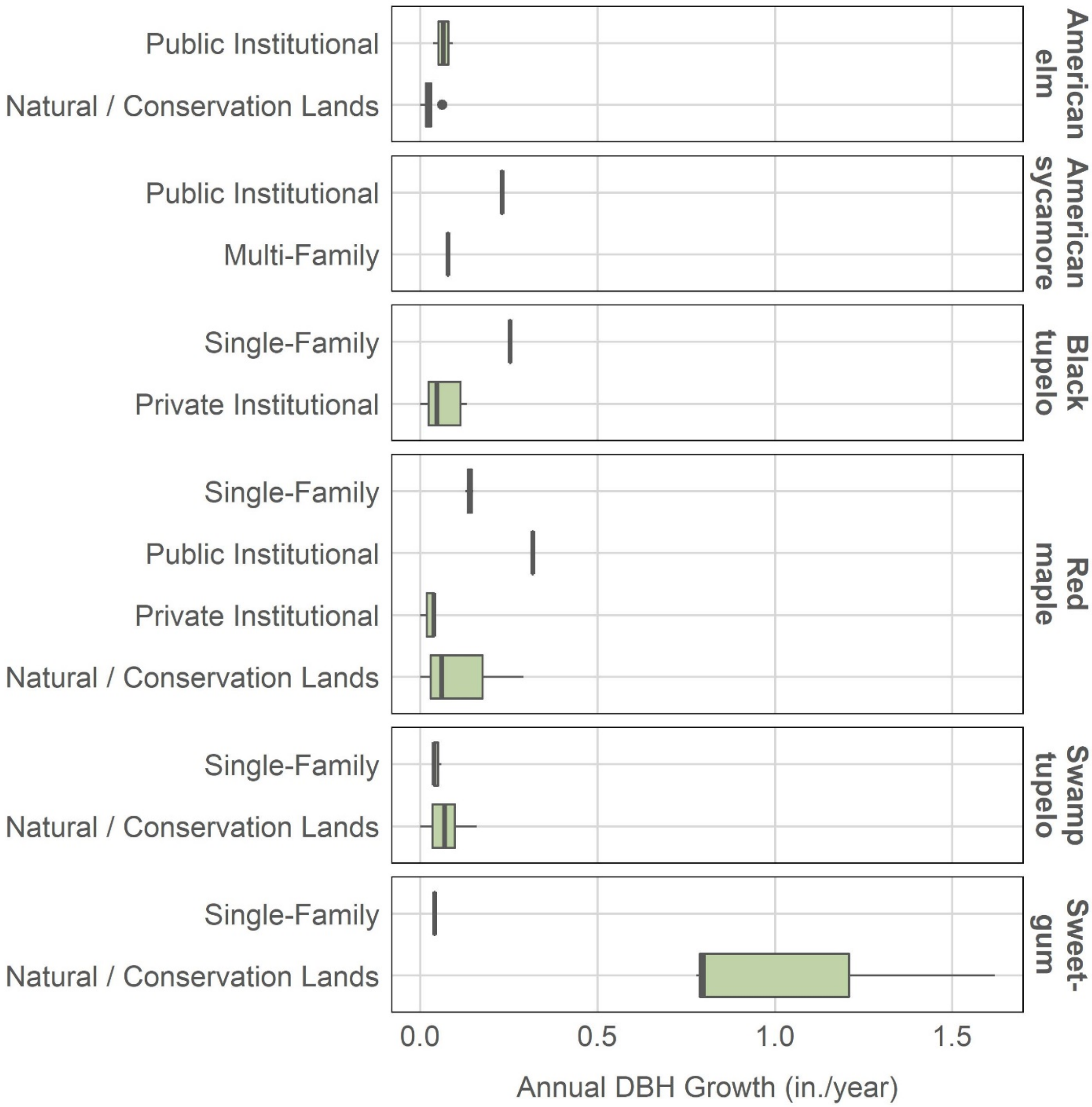


Figure 5: The distribution of annual DBH growth rates for other species in different land use categories illustrated by a box and whisker plot (see Figure 2 for explanation).



Urban Tree Database Models

Estimated growth rates based on the Urban Tree Database (UTD) models tend to be greater compared to the multiple inventory-based growth rates (Table 3). For example, the UTD estimates annual DBH growth rate for red maple should be 1.1 inches per year for a 5-year-old tree, however the average re-inventory growth rate is 0.1 inches per year. Similarly, water oak's UTD-based growth rate is 0.6 inches per year compared to the average 0.1 inches per year derived from the re-inventory.

A potential explanation for the discrepancy between the UTD and Tampa re-inventory growth rates is that the UTD is based on measurements of urban street and park trees, that is, trees growing in more open conditions compared to a natural forest area (McPherson et al., 2016). Approximately half of of the re-inventory trees were located in natural/conservation areas. When trees are not growing in close competition with one another, which is presumably the case for the UTD trees, they can allocate more resources to growing wider rather than taller (Rhoades and Stipes, 1999). The UTD models are most applicable to trees planted in parks, residential and commercial developments, and other open landscapes.

One advantage of the UTD growth models is that for many species the growth rate can vary with tree age (Table 3, Figure 6). Since these models were based on measurements from trees with a wide range of ages, they better reflect the ways a tree's growth patterns can change over time. Flowering dogwood's growth rate tends to slow over time as the tree reaches maturity near 25 years. By contrast, in its first 25 years of growth red maple's growth rate is consistent over time.

Additionally, the UTD database also includes models that can estimate crown area from tree age or DBH (Figure 7). These estimates can be useful for predicting changes in canopy area as new trees are added to the city's urban forest. We also aggregated the individual species DBH growth rates from UTD into slow, moderate, and fast growing species as identified by the Tampa Tree matrix (Table 4).

Table 3: Estimated annual DBH growth rates for 5- and 20-year-old trees using equations developed by the Urban Tree Database project.

		Annual DBH Growth Rate (in./year)	
Common Name	**Scientific Name**	**5-year-old tree**	**20-year-old tree**
American Holly	*Ilex opaca*	0.4	0.6
Chinese Elm	*Ulmus parvifolia*	0.7	0.5
Crapemyrtle	*Lagerstroemia indica*	0.8	0.8
Flowering Dogwood	*Cornus florida*	0.5	0.2
Laurel Oak	*Quercus laurifolia*	0.7	1.0
Loblolly Pine	*Pinus taeda*	0.7	0.6
Loquat	*Eriobotrya japonica*	0.7	0.7
Pecan	*Carya illinoinensis*	0.5	0.5
Red Cedar	*Juniperus virginiana var. silicicola*	0.7	0.8
Red Maple	*Acer rubrum*	1.1	0.8
Shumard Oak	*Quercus shumardii*	0.7	1.0

Slash pine	*Pinus elliottii*	0.9	0.8
Southern Live Oak	*Quercus virginiana*	1.2	0.9
Southern Magnolia	*Magnolia grandiflora*	0.9	0.7
Sugarberry	*Celtis laevigata*	0.6	0.8
Sweetgum	*Liquidambar styraciflua*	1.0	0.7
Sycamore	*Platanus occidentalis*	0.8	0.8
Water Oak	*Quercus nigra*	0.5	0.6
Willow Oak	*Quercus phellos*	0.6	0.6

Figure 6: The relationship between tree age and DBH for 19 species included in the Urban Tree Data base for the central Florida and Gulf Coast regions (McPherson et al., 2016). The circles indicate the size and age of individual trees used in the database. The solid green line indicates the estimated average tree size based on UTD equations developed for each species.

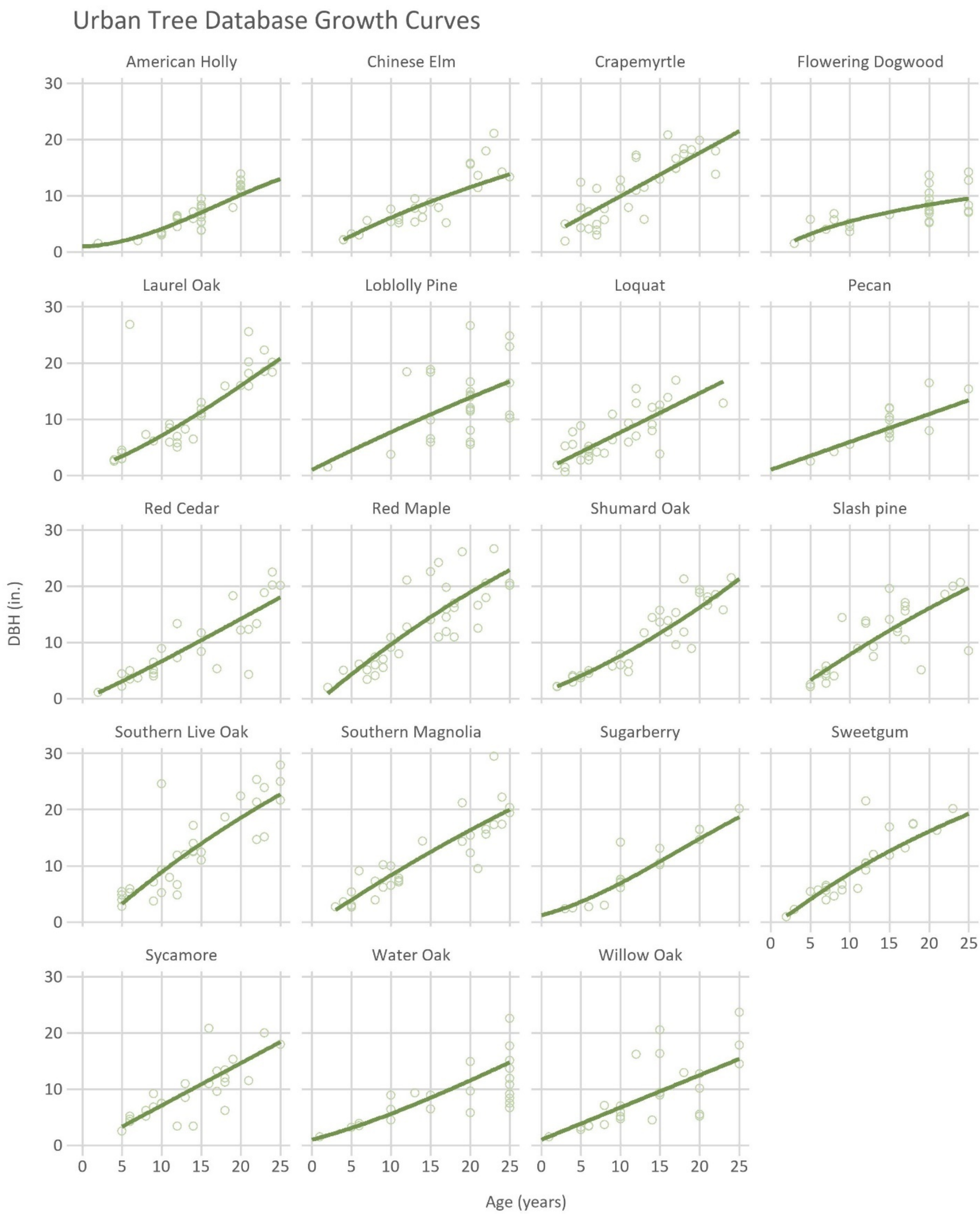


Figure 7: The relationship between tree age and crown area for 19 species included in the Urban Tree Data base for the central Florida and Gulf Coast regions. The circles indicate the size and age of individual trees used in the database. The solid green line indicates the estimated average tree size based on UTD equations developed for each species.

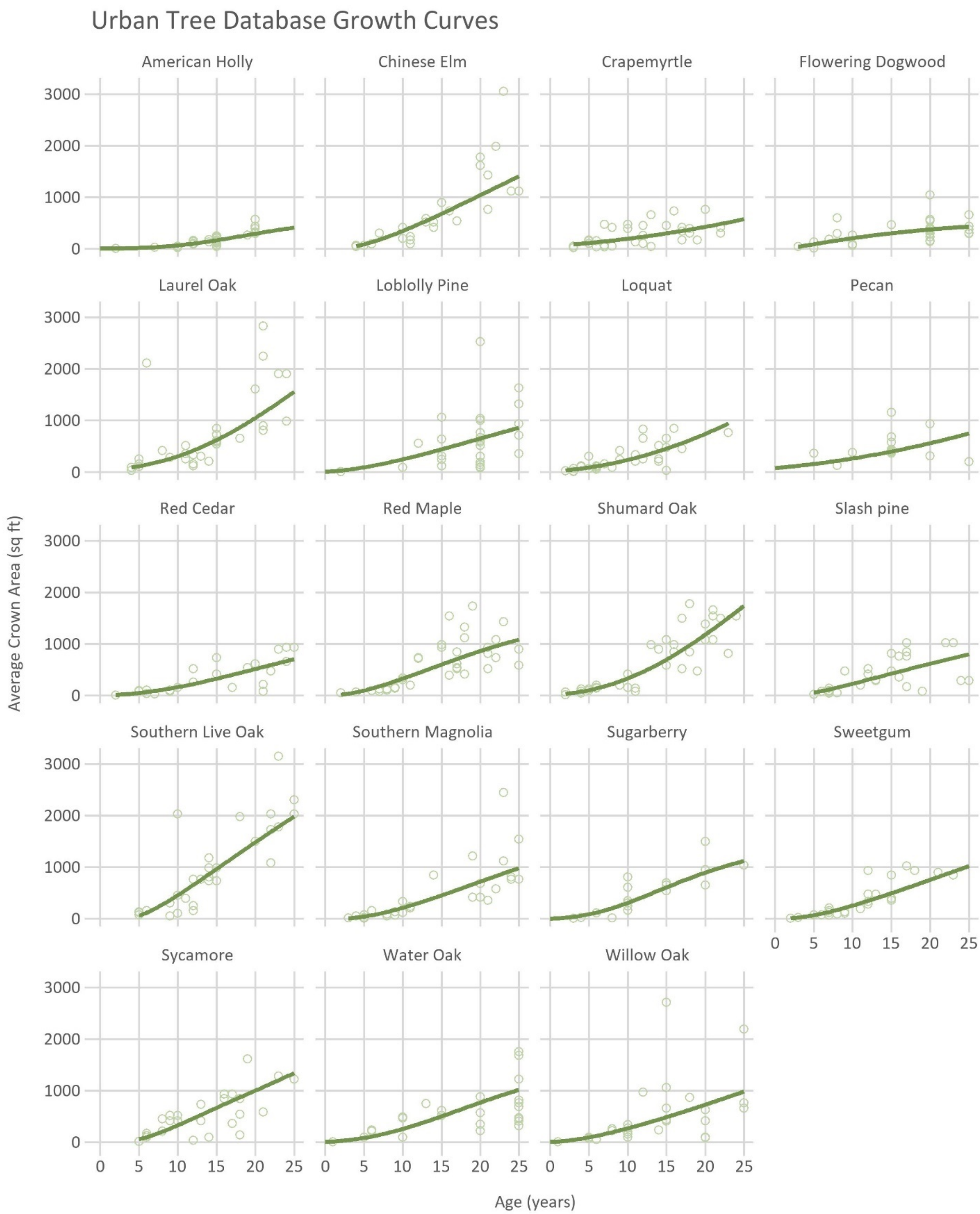


Table 4. Generalized diameter growth estimates for *Slow Growing, Moderate Growing,* and *Fast Growing* trees as defined by the Tampa Tree Matrix (estimates based on findings from the U.S. Forest Service Urban Tree Database project; McPherson et al., 2016).

Tree Matrix Growth Rating	5-year-old Tree	20-year-old Tree
Slow Growth Rate	0.4	0.6
Moderate Growth Rate	0.8	0.7
Fast Growth Rate	0.8	0.8

Conclusions

Developing accurate estimates of tree growth in urban environments is necessary to plan for the replacement of trees so cities such as Tampa can maintain and increase urban forest cover. Tree growth can be challenging to measure in sub-tropical environments where tree species may not produce annual growth rings. Instead, measurement techniques such as re-inventorying tree populations or comparing size across trees of multiple known ages are needed to generate estimates of urban tree growth.

We calculated the growth rates of trees from 29 species found in Tampa by comparing tree size among repeated inventories of Tampa's urban forest. We found a low percentage of matched trees between the 2016 and 2021 inventories and we found that 20% of matched trees had measurements that were smaller in 2021 compared to 2016. This suggests the re-inventory technique using angle and distance data to relocate trees may be limited in its effectiveness for urban natural areas with high tree density such as those found in Tampa.

Tree growth models for central Florida developed by the Urban Tree Database (UTD) project (McPherson et al., 2016) produced higher annual DBH growth rates compared calculations based on the Tampa inventories. Since the UTD focused on street and park trees, its models are more appropriate for estimating the growth of urban trees in open settings. Since most of the re-inventory trees were located in natural/conservation areas, the re-inventory-based estimates are most applicable to those settings.

Using the UTD Central Florida growth models for planning purposes with urban trees planted in open environments offers two main benefits. First, the UTD models are based on a sufficiently large sample size that they account for variability in tree growth rates as trees age. Second, the UTD models can also predict crown size which can then be used to connect tree growth to city-wide canopy goals. The UTD equations for the 19 species identified in the database are included as an Appendix to this report.

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Appendix 1: Urban Tree Database Growth Equations

Table A1-1: Equations developed by the Urban Tree Data project to predict DBH and crown diameter. The DBH equations contain a factor (2.54) to convert the estimate from centimeters to inches. The crown area equations contain factors to convert the original estimate of crown diameter from meters to feet (3.28084), then diameter to radius (0.5) then from radius to crown area. The units for age are years.

Common Name	Scientific Name	Equation
American Holly	*Ilex opaca*	DBH (in.) = [2.53924 + 0.07682*age + 0.08877*(age^2) - 0.00172*(age^3)]/2.54
		Crown Area (ft2) = {[2.53924 + 0.07682*age + 0.08877*(age^2) - 0.00172*(age^3)]/3.28084*0.5}^2 * pi
Chinese Elm	*Ulmus parvifolia*	DBH (in.) = [exp(0.493515 + 2.550672*log(log(age+1 + 1)) + age * (0.004334/2))]/2.54
		Crown Area (ft2) = {[exp(0.493515 + 2.550672*log(log(age+1 + 1)) + age * (0.004334/2))]/3.28084*0.5}^2 * pi
Crapemyrtle	*Lagerstroemia indica*	DBH (in.) = [5.70526 + 1.95628*age]/2.54
		Crown Area (ft2) = {[5.70526 + 1.95628*age]/3.28084*0.5}^2 * pi
Flowering Dogwood	*Cornus florida*	DBH (in.) = [exp(0.96778 + 1.85836*log(log(age+1) + (0.08767/2)))]/2.54
		Crown Area (ft2) = {[exp(0.96778 + 1.85836*log(log(age+1) + (0.08767/2)))]/3.28084*0.5}^2 * pi
Laurel Oak	*Quercus laurifolia*	DBH (in.) = [1.30621 + 1.23988*age + 0.04912*(age^2) - 0.00065*(age^3)]/2.54
		Crown Area (ft2) = {[1.30621 + 1.23988*age + 0.04912*(age^2) - 0.00065*(age^3)]/3.28084*0.5}^2 * pi
Loblolly Pine	*Pinus taeda*	DBH (in.) = [2.50889 + 1.77264*(age) - 0.00698*(age)^2]/2.54
		Crown Area (ft2) = {[2.50889 + 1.77264*(age) - 0.00698*(age)^2]/3.28084*0.5}^2 * pi
Loquat	*Eriobotrya japonica*	DBH (in.) = [1.72609 + 1.77157*age]/2.54
		Crown Area (ft2) = {[1.72609 + 1.77157*age]/3.28084*0.5}^2 * pi
Pecan	*Carya illinoinensis*	DBH (in.) = [2.527411 + 1.258243*age]/2.54
		Crown Area (ft2) = {[2.527411 + 1.258243*age]/3.28084*0.5}^2 * pi
Red Cedar	*Juniperus virginiana var. silicicola*	DBH (in.) = [(-0.6109) + 1.63311*age + 0.0145*(age^2) - 0.00022*(age^3)]/2.54
		Crown Area (ft2) = {[(-0.6109) + 1.63311*age + 0.0145*(age^2) - 0.00022*(age^3)]/3.28084*0.5}^2 * pi
Red Maple	*Acer rubrum*	DBH (in.) = [(-3.6811) + 3.0548*(age) - 0.02326*(age)^2]/2.54

Common Name	Scientific Name	Equation
Red Maple	*Acer rubrum*	Crown Area (ft2) = {[(-3.6811) + 3.0548*(age) - 0.02326*(age)^2]/3.28084*0.5}^2 * pi
Shumard Oak	*Quercus shumardii*	DBH (in.) = [2.54333 + 1.42769*(age) + 0.02543*(age)^2]/2.54
		Crown Area (ft2) = {[2.54333 + 1.42769*(age) + 0.02543*(age)^2]/3.28084*0.5}^2 * pi
Slash pine	*Pinus elliottii*	DBH (in.) = [exp(0.23241 + 3.06738*log(log(age+1) + (0.12536/2)))]/2.54
		Crown Area (ft2) = {[exp(0.23241 + 3.06738*log(log(age+1) + (0.12536/2)))]/3.28084*0.5}^2 * pi
Southern Live Oak	*Quercus virginiana*	DBH (in.) = [(-7.62777) + 3.34615*age - 0.03523*(age^2) + 0.00024*(age^3)]/2.54
		Crown Area (ft2) = {[(-7.62777) + 3.34615*age - 0.03523*(age^2) + 0.00024*(age^3)]/3.28084*0.5}^2 * pi
Southern Magnolia	*Magnolia grandiflora*	DBH (in.) = [(-1.74323) + 2.41888*(age) - 0.01267*(age)^2]/2.54
		Crown Area (ft2) = {[(-1.74323) + 2.41888*(age) - 0.01267*(age)^2]/3.28084*0.5}^2 * pi
Sugarberry	*Celtis laevigata*	DBH (in.) = [3.03874 + 0.92424*age + 0.06529*(age^2) - 0.00125*(age^3)]/2.54
		Crown Area (ft2) = {[3.03874 + 0.92424*age + 0.06529*(age^2) - 0.00125*(age^3)]/3.28084*0.5}^2 * pi
Sweetgum	*Liquidambar styraciflua*	DBH (in.) = [exp(0.76105 + 2.6362*log(log(age+1) + (0.03839/2)))]/2.54
		Crown Area (ft2) = {[exp(0.76105 + 2.6362*log(log(age+1) + (0.03839/2)))]/3.28084*0.5}^2 * pi
Sycamore	*Platanus occidentalis*	DBH (in.) = [(-1.10175) + 1.91487*age]/2.54
		Crown Area (ft2) = {[(-1.10175) + 1.91487*age]/3.28084*0.5}^2 * pi
Water Oak	*Quercus nigra*	DBH (in.) = [2.53058 + 0.94546*age + 0.0262*(age^2) - 0.00032*(age^3)]/2.54
		Crown Area (ft2) = {[2.53058 + 0.94546*age + 0.0262*(age^2) - 0.00032*(age^3)]/3.28084*0.5}^2 * pi
Willow Oak	*Quercus phellos*	DBH (in.) = [2.52535 + 1.46083*age]/2.54
		Crown Area (ft2) = {[2.52535 + 1.46083*age]/3.28084*0.5}^2 * pi

Appendix 2: Urban Tree Database Tree Size Predictions

Table A2-1: Urban Tree Database predictions for tree DBH at multiple ages based on observations of common species found in central Florida and the Gulf Coast regions.

		Predicted DBH (in.) at a given age (years)				
Common Name	**Scientific Name**	**5**	**10**	**15**	**20**	**25**
American Holly	*Ilex opaca*	2	4	7	10	13
Chinese Elm	*Ulmus parvifolia*	4	7	9	12	14
Crapemyrtle	*Lagerstroemia indica*	6	10	14	18	22
Flowering Dogwood	*Cornus florida*	3	5	7	8	10
Laurel Oak	*Quercus laurifolia*	3	7	11	16	21
Loblolly Pine	*Pinus taeda*	4	8	11	14	17
Loquat	*Eriobotrya japonica*	4	8	11	15	18
Pecan	*Carya illinoinensis*	3	6	8	11	13
Red Cedar	*Juniperus virginiana var. silicicola*	3	7	10	14	18
Red Maple	*Acer rubrum*	4	10	15	19	23
Shumard Oak	*Quercus shumardii*	4	8	12	16	21
Slash pine	*Pinus elliottii*	3	8	12	16	20
Southern Live Oak	*Quercus virginiana*	3	9	14	19	23
Southern Magnolia	*Magnolia grandiflora*	4	8	12	16	20
Sugarberry	*Celtis laevigata*	4	7	11	15	19
Sweetgum	*Liquidambar styraciflua*	4	9	13	16	19
Sycamore	*Platanus occidentalis*	3	7	11	15	18
Water Oak	*Quercus nigra*	3	6	8	12	15
Willow Oak	*Quercus phellos*	4	7	10	12	15

Table A2-2: Urban Tree Database predictions for crown area at multiple ages based on observations of common species found in central Florida and the Gulf Coast regions.

		Predicted crown area (ft^2) at a given age (years)				
Common Name	**Scientific Name**	**5**	**10**	**15**	**20**	**25**
American Holly	*Ilex opaca*	17	61	167	295	409
Chinese Elm	*Ulmus parvifolia*	127	404	742	1083	1459
Crapemyrtle	*Lagerstroemia indica*	109	192	298	427	579
Flowering Dogwood	*Cornus florida*	86	210	300	366	426
Laurel Oak	*Quercus laurifolia*	121	309	630	1067	1566
Loblolly Pine	*Pinus taeda*	89	257	453	646	847
Loquat	*Eriobotrya japonica*	95	228	445	735	1096
Pecan	*Carya illinoinensis*	161	262	389	569	750
Red Cedar	*Juniperus virginiana var. silicicola*	49	163	317	511	704
Red Maple	*Acer rubrum*	96	335	601	857	1080
Shumard Oak	*Quercus shumardii*	97	318	705	1164	1729
Slash pine	*Pinus elliottii*	51	227	425	618	797
Southern Live Oak	*Quercus virginiana*	56	474	946	1477	1993
Southern Magnolia	*Magnolia grandiflora*	43	210	462	732	988
Sugarberry	*Celtis laevigata*	84	322	598	903	1110
Sweetgum	*Liquidambar styraciflua*	67	257	494	757	1025
Sycamore	*Platanus occidentalis*	46	325	679	993	1349
Water Oak	*Quercus nigra*	85	247	516	755	1026
Willow Oak	*Quercus phellos*	96	263	470	734	979