Development Practices and Ordinances as Predictors of Canopy Coverage in Florida (United States) Communities

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Abstract: This study compared the management practices and ordinances enacted by 43 Florida (United States) communities to assess their potential impact on tree canopy coverage. Dot-based canopy analysis was used to assess community level canopy coverage. This information was paired with each community's responses to a 2014 survey of municipal forestry management practices in the United States. Canopy coverage ranged between 17.6% and 63.3% among the communities assessed, with average of 33.7%. Two factors were significant when attempting to predict canopy coverage. Housing density had a negative impact on tree canopy (P-value = 0.0116). In contrast, ordinance designating and protecting heritage or other trees of significance resulted in a 6.7% increase in canopy coverage (P-value = 0.0476). Results of this research provide base-level data regarding urban forest cover in a range of Florida communities. More importantly, this research suggests the heritage tree protections afforded to old or large-stature urban trees has a measurable impact on tree canopy retention.

Keywords: ecosystem services; environmental policy; heritage trees; tree ordinance; urban forest management; urban tree canopy

1. Introduction

Research has demonstrated that trees in urban environments provide a variety of ecosystem services (e.g., creation of habitats) and other benefits (e.g., increased quality of life) (Roy et al., 2012). Many of these benefits are associated with the healthy leaf area of a tree (Nowak & Greenfield, 2012), making urban tree canopy cover an important measurement for estimating overall urban forest benefits. Nowak et al. (1996) defines an urban tree canopy (UTC) as the proportion of area, when viewed from above, occupied by tree crowns. Environmental benefits derived from an UTC include ecosystem services such as improved air and water quality (Nowak et al., 2007) and energy use reduction (Akbari, 2002). Economic benefits range from increased property value (Pandit et al., 2013) to reduced heating and cooling costs (Pandit & Laband, 2010). Management of urban trees can be conducted with specific UTC cover goals in mind in order to maximize benefits (Nowak & Crane, 2000; Hill et al., 2010; McPherson et al., 2011; Hauer & Peterson, 2016).

In contrast to these benefits, urban trees have costs associated with their installation, care, and eventual removal which are shared between residents, businesses, and municipalities (e.g., planting, maintenance, or infrastructure repair) (Koeser et al., 2016; Vogt et al., 2015). Furthermore, urban trees are considered public assets in many municipalities, making an UTC subject to municipal tree management practices and ordinances (e.g., pruning cycles, planting initiatives, preservation ordinances, etc.) created by municipal staff and external groups (Hauer & Peterson, 2016). Land use ordinances and the degree to which they are enforced will impact the UTC (Elmendorf et al. 2003; Hill et al., 2010). For instance, a study of the UTC and associated management practices in the Atlanta Metropolitan Area showed that planning and zoning regulations aimed at UTC protection and quality growth were associated with an increase in canopy cover over ten years (Hill et al., 2010). Hill et al. (2010) also point out that UTC management actions should also extend to private trees, which can make up a large portion of the urban forest. In Tampa, Florida, Landry and Pu (2010) found that tree canopy coverage was greater on private lots developed after the adoption of a 1974 tree protection ordinance compared to lots developed prior to the ordinance. However, regulations of private trees can cause political tensions. For example, a tree management bill was introduced to the Florida Senate in 2018 [Senate Bill (SB) 574: Tree and Vegetation Trimming and Removal] which, among other provisions, would roll back local governments' abilities to require permits for the trimming, pruning, removal, or harvesting of trees on private property in certain areas, and to require mitigation (i.e., replacement) of trees removed or harmed. This proposed bill concerned some individuals who were aware of the pattern of declining UTC across this United States (Nowak & Greenfield 2012).

A comprehensive understanding of a municipality's UTC can provide urban resource managers with baseline data to set goals, inform key stakeholders of the effects of certain management and development strategies, and subsequently improve various urban forest functions (Hill et al., 2010). In light of emerging research on management practices and the UTC, and legislation like the aforementioned Bill, we were motivated to investigate the effects Florida municipal management actions have on local UTC and how different municipalities compare. The objectives of this study were to 1. use dot-based spatial analysis to estimate canopy cover in Florida municipalities, and to 2. investigate the relationships between canopy cover and variables related to municipal development, tree management practices, and tree-related municipal ordinances gathered from a survey of municipal forestry managers.

2. Materials and methods

2.1. Study area

The study area consisted of 43 Florida (United States) communities who had returned a comprehensive survey on urban forest management (Hauer and Peterson, 2016). Locations of these communities are shown in Fig. 1.

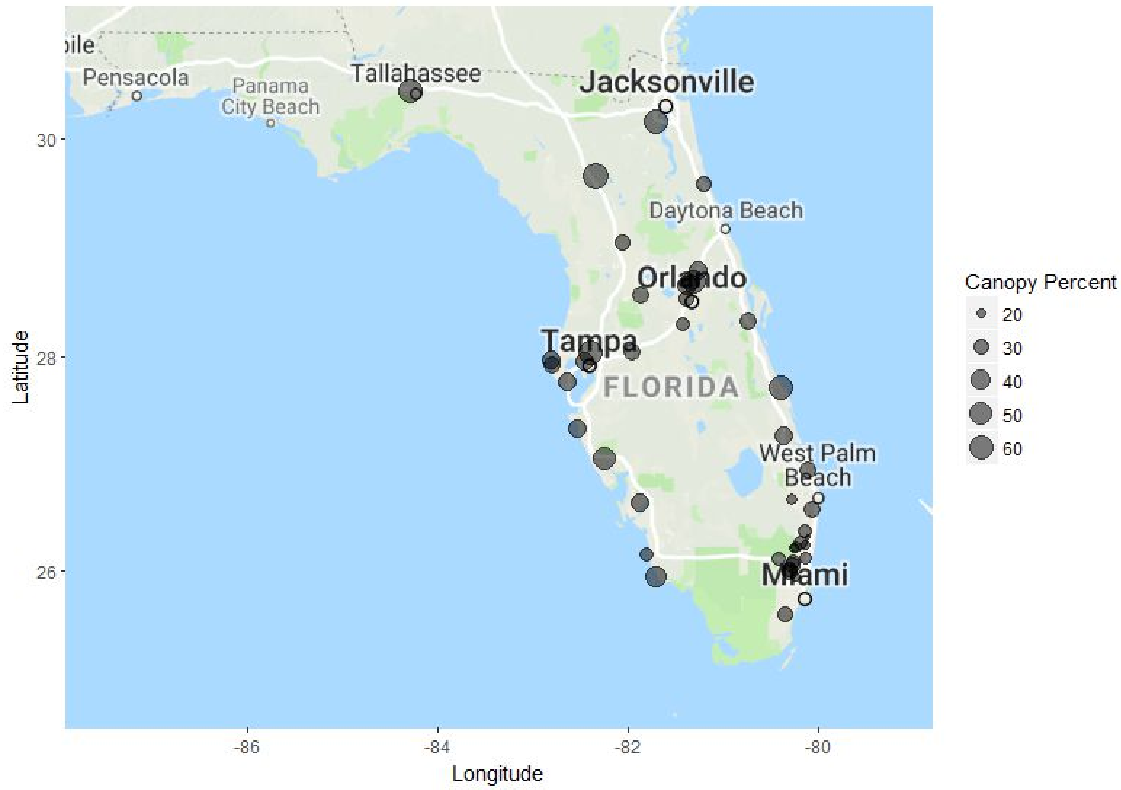

Figure 1. Locations of the 43 Florida (United States) communities included in this assessment of canopy coverage. The sizes of the points are scaled to reflect relative differences in canopy coverage.

2.2. Survey methodology

The predictor variables used to model percent canopy coverage were derived in part from the results of a 2014 survey of municipal forestry management practices in the United States (Hauer and Peterson, 2016). The comprehensive, 109-question survey was sent to a stratified sample of 1727 communities in all fifty states, of which 87 were sent to Florida communities. All communities with populations over 50,000 received the survey and a random sample was taken for cities with populations between 25,000 and 49,999 (50%) and between 2,500 and 24,999 (10%). More detailed information regarding the generation of the mailing list is available by referencing Koeser et al. (2016). The survey was approved through the [redacted] Institutional Review Board (IRB) prior to study recruitment.

Following the approach outlined by Dillman et al. (2014), all communities on our mailing list received a pre-notice followed by a printed copy of the survey (i.e., with a cover letter). Non-respondents were also sent a reminder postcard, followed by a second printed survey (i.e., with a cover letter). A final email reminder was sent to any remaining non-respondents.

A second round of surveying was conducted using a truncated, 53-question survey in an attempt to reach communities that did not complete the larger set of questions. This shortened questionnaire (with cover letter) was sent non-respondents to the long-form version. A single email reminder was sent to non-respondents of the truncated survey. In addition to the communities that responded to the survey in 2014, the authors reached out to the urban foresters from Fort Lauderdale, Naples, Pompano Beach, and Temple Terrace. The authors knew these individuals personally through their local professional society (though knew little of their respective programs) and used this connection to increase the sample size for the canopy analysis. Interviews occurred July of 2018. These four individuals referenced records from 2014 to answer the survey questions relevant to our canopy analysis.

2.3. Dot-based canopy analysis

The aerial imagery assessed in this study was accessed from the National Agricultural Imagery Program (NAIP; USDA, 2018). Specifically, imagery from 2015 was used to coincide with the timeframe of the survey mentioned above. Spatial resolution for the 2015 NAIP imagery was 1 m. A random point sampling method was conducted following the 'i-Tree Canopy' user guidelines (https://canopy.itreetools.org/) and Nowak and Greenfield (2012), which suggests the collection of 500-1,000 random survey points per community. In an effort to increase measurement confidence, we adopted the larger, 1,000 point sample size within this suggested range. Boundaries for each community assessed were provided by the American Community Survey (ACS; United States Census Bureau, 2015).

A geographic information system (ArcGIS 10; ESRI, Redlands, CA, United States) was used to import NAIP aerial imagery and generate the random points (at an average minimum distance of 5 meters). Urban tree canopy was assessed as either tree or non-tree. Each city was assessed at least two interpreters. Points where the interpreters disagreed were discarded prior to analysis, thus minimizing photointerpreter bias. Canopy percentage, agreement between/among interpreters, standard error (SE), and 95% confidence intervals were (Parmehr et al., 2016).

$$SE = \sqrt{p(1-p/N}$$

Where p = number of tree points (n)/the total number of sample points (N)

$$95\%\ CI = UTC \pm SE \times 1.96$$

2.4. Data analysis

A multiple linear regression model was fit using community-wide percent canopy coverage as the dependent variable of interest. This analysis was conducted using the lm() function in R (R Core Team, 2016). Initially, a maximal model was fit using the explanatory variables listed in Table 1.

Table 1. Initial set of variables assessed in modelling canopy coverage in Florida (United States) communities. Mean/counts include data from the survey and data acquired from other sources (U.S. Census Bureau, 2018; various municipal ordinance websites).

Variable	Definition	Mean (Std. Dev.) or Count
Canopy coverage[z]	Response variable, percent (%) of city covered by tree canopy	34.4% (11.7%)
Housing density[y]	Housing units per square kilometer	520.4 (294.6)
Median home value[y]	Median value of resident-owned housing units	$221,482 ($155,976)
House percent since 2010[y]	Percent of total housing units constructed after 2010	0.6% (0.6%)
House percent since 2000[y]	Percent of total housing units constructed after 2000	20.3% (14.1%)
House percent since 1990[y]	Percent of total housing units constructed after 1990	37.5% (18.7%)
Maintains Rights-of-ways (ROW)[x]	Who is responsible for maintaining trees in rights-of-way (e.g., street trees between sidewalk and curb/ alley trees)	Community - 23 Homeowner - 7 Joint ownership - 7 Other - 1
ISA Certified Arborist - yes[x]	Community employs at least one ISA Certified Arborist credential holder	Yes - 31 No - 9
Four year degree - yes[x]	Community employs at least one person with a four year degree related to tree care	Yes - 19 No - 21
Tree board - yes[x]	Community has a government-authorized board to help develop/administer tree management policy	Yes - 28 No - 11
Tree preservation ordinance[xw]	Community has an ordinance requiring the preservation of trees during development	Yes - 32 No - 8
Removal permit ordinacne[xw]	Community has an ordinance restricting tree cutting on private property	Yes - 23 No - 18
Heritage tree ordinance[xw]	Community identified and preserves heritage/significant trees	Yes - 26 No - 15

Tree inventory - yes[x]	Community has a record of public trees within its jurisdiction	Yes - 25 No - 14
Canopy goal - yes[x]	Community has a goal for enhancing or maintaining % tree canopy coverage	Developing - 2 Yes - 14 No - 20

[z]Source: Dot-based canopy analysis
[y]Source: U.S. Census Bureau (2018)
[x]Source: Hauer and Peterson (2016)
[w]Source: Municipal websites

As missing data prevented the use of a stepwise deleting function, the regsubsets() function from the *leaps* package (Lumley and Miller, 2017) was used to run and plot (by R^2 value) the 20 best subsets of our predictor variables. This plot (Fig 1.) was used to identify which variables were most commonly associated with models having higher predictive power. A second, reduced model with housing density, house percent since 2010, maintains ROW, ISA Certified Arborist, tree board, and ordinance: heritage trees was run and non-significant explanatory variables were removed one-at-a-time based on P-value (highest first). Each reduced model was compared against its preceding model using the anova() function in R (R core team, 2016) to determine if there was a significant difference in fit between the two iterations (Crawley, 2013). All determinations of statistical significance were made at an α=0.05 level of Type 1 error. Diagnostic plots were referenced to confirm no underlying assumptions associated with the analysis were violated.

3. Results

3.1. Survey results for Florida cities

Overall, 667 communities responded to either the initial survey (n=513) or the truncated survey (n=154) for a total response rate of 38.6% in all 50 states. In Florida, 39 of the 87 communities surveyed responded leading to a statewide response rate of 44.8%, higher than that of the total survey population. The initial survey, combined with the four additional communities from this study, resulting in a 49.4% response rate. The survey results provided information on different aspects of urban forest management, including the community, staff, management practices, and inventorying activities. When asked who is legally responsible for trees in rights-of-way, 61% said the community was solely responsible. Over three-quarters of the respondents said they had at least one ISA Certified Arborist on the staff, and about half said they had at least one employee with a four-year degree. Over two-thirds of the responding communities reporting having a government-organized tree board, over three-quarters had tree preservation ordinances in place, and over half had ordinances that protect heritage or significant trees. About half of the respondents said they had permit requirements that restrict tree cutting on private property. A majority said they had a tree inventory, but only a third of those respondents said the inventory was up-to-date. Finally, less than half of the communities said they had canopy cover goals.

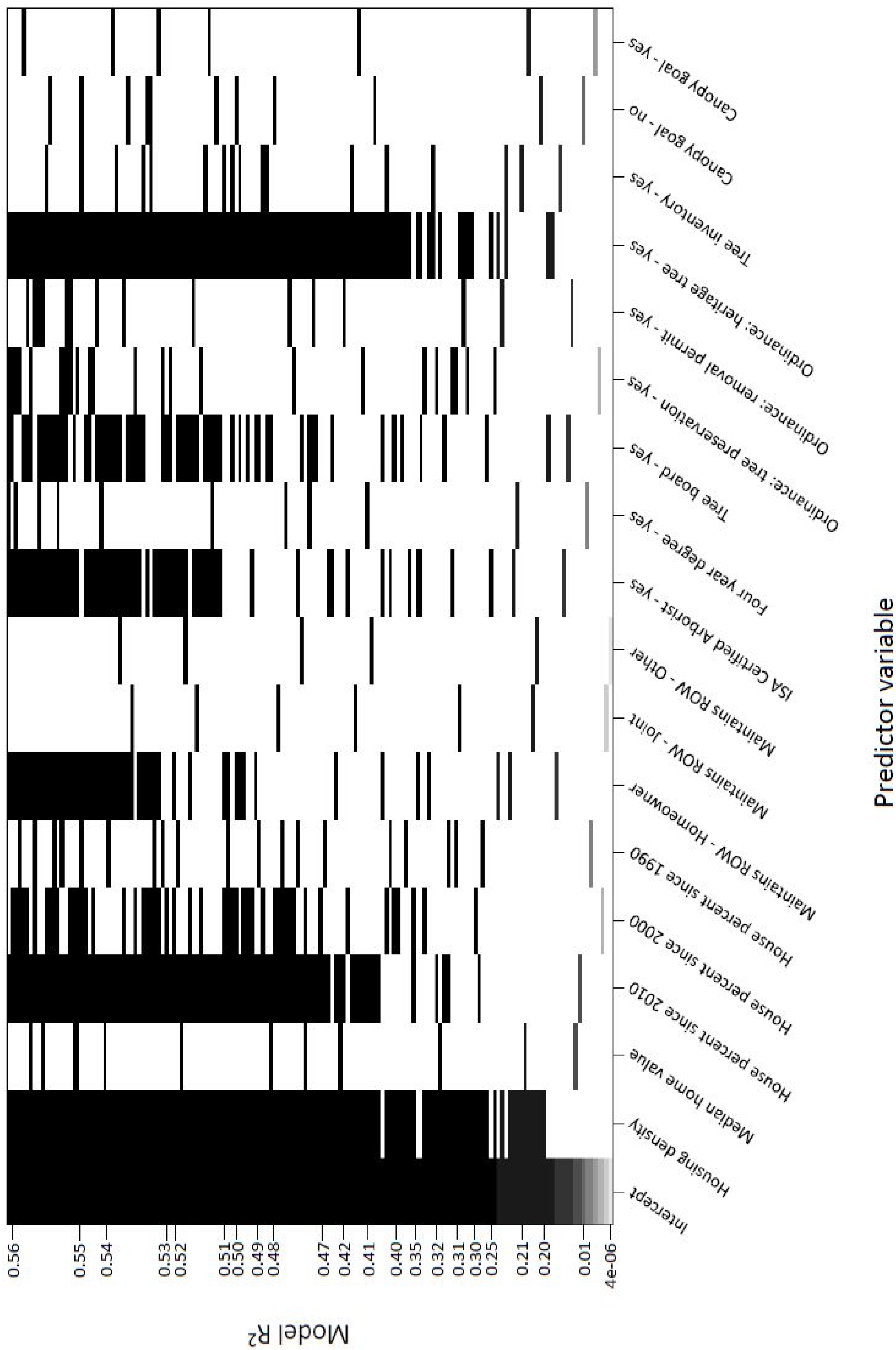

Figure 2. Coefficient of determination (R^2) values for the various combinations of predictor variables selected for initial testing. Variables most commonly associated with the highest predictive power were selected for initial model simplification. Figure generated using the leaps package in R (Lumley and Miller, 2017).

3.2. Canopy coverage in Florida cities

Canopy coverage ranged from 17.6% in Deerfield Beach to 63.3% in Gainesville Florida (Table 2). Average canopy coverage for the 43 assessed communities was 33.7% (±1.5%). Agreement among our interpreters ranged from 94.9% to 99.5%. Average agreement for the 43 cities was 97% (Table 2).

Table 2. Population, percent canopy coverage, standard error, 95% confidence intervals, number of interpreters, and percent agreement associated with the dot-based canopy analysis of 43 Florida (United States) communities.

Community Name	2014 Population	Canopy Coverage (%)	SE (%)	95% CI Lower (%)	95% CI Upper (%)	Interpreters	Agreement (%)
Gainesville	124,354	63.3	1.5	60.4	66.2	2	99.3
Tallahassee	181,376	58.7	1.6	55.6	61.8	2	99.0
Indian River Shores	4,070	57.9	1.6	54.8	61.0	2	99.4
Temple Terrace	25,495	55.6	1.6	52.5	58.7	2	98.8
Orange Park	8,412	55.0	1.6	51.9	58.1	2	97.8
Winter Springs	33,282	54.4	1.6	51.3	57.5	2	96.1
North Port	57,357	51.5	1.6	48.4	54.6	2	98.7
Marco Island	16,413	48.5	1.6	45.4	51.6	2	98.2
Altamonte Springs	42,215	40.2	1.6	37.1	43.3	2	97.2
Clearwater	107,685	37.2	1.6	34.1	40.3	3	95.6
St. Petersburg	244,769	36.9	1.5	34.0	39.8	2	97.5
Fort Myers	62,298	36.1	1.5	33.2	39.0	3	97.4
Port St. Lucie	164,603	36.1	1.5	33.2	39.0	2	97.7
Sarasota	51,917	35.8	1.5	32.9	38.7	2	97.6
Tampa	335,709	35.7	1.5	32.8	38.6	2	98.4
Sanford	53,570	35.1	1.5	32.2	38.0	2	99.1
Casselberry	26,241	34.7	1.5	31.8	37.6	3	97.2
Jupiter	55,156	34.4	1.5	31.5	37.3	2	98.4
Largo	77,648	34.2	1.5	31.3	37.1	2	97.5
Lakeland	97,422	34.0	1.5	31.1	36.9	2	97.4
Rockledge	24,926	32.9	1.5	30.0	35.8	2	98.1
Hypoluxo	2,588	32.2	1.5	29.3	35.1	2	97.4
Groveland	8,729	32.1	1.5	29.2	35.0	2	96.7
Cutler Bay	40,286	30.1	1.5	27.2	33.0	3	96.2
Cooper City	28,547	29.8	1.5	26.9	32.7	2	96.9

Palm Coast	75,180	29.7	1.5	26.8	32.6	2	98.8
Belleview	4,492	29.4	1.5	26.5	32.3	3	98.5
Orlando	238,300	29.4	1.4	26.7	32.1	2	99.3
Miramar	122,041	28.1	1.4	25.4	30.8	2	99.3
Pembroke Pines	154,750	28	1.4	25.3	30.7	2	96.8
Coconut Creek	52,909	26.9	1.4	24.2	29.6	3	94.9
Kissimmee	59,682	26.3	1.4	23.6	29.0	2	98.4
Boca Raton	84,392	26.2	1.4	23.5	28.9	3	95.5
Weston	65,333	25.6	1.4	22.9	28.3	2	97.7
Naples	20,913	25.3	1.4	22.6	28.0	2	98.0
Davie	91,992	25.1	1.4	22.4	27.8	3	97.3
Fort Lauderdale	175,599	24.5	1.4	21.8	27.2	2	99.5
North Lauderdale	41,023	22.6	1.3	20.1	25.1	2	96.8
Wellington	56,508	21.6	1.3	19.1	24.1	2	96.9
Pompano Beach	105,851	20.6	1.3	18.1	23.1	2	98.9
Tamarac	60,427	20.4	1.3	17.9	22.9	2	97.4
Miami Gardens	107,167	19.4	1.3	16.9	21.9	2	99.4
Deerfield Beach	75,018	17.6	1.2	15.2	20.0	3	98.8

3.3. Predictors of canopy coverage

In conducting the model simplification process, two significant predictors of canopy coverage beyond the intercept term were significant. The first significant predictor was *housing density* (P<0.0116) which had a negative relationship with canopy coverage (Table 3). A 1.1% decrease in UTC would occur for each 500 housing units per km^2 compared to a situation with no housing units. The second predictor in our model was having a *heritage tree ordinance* (P<0.0476*).* For this variable, having some form of heritage or significant tree designation was associated with a 6.7% increase in canopy coverage (Table 3). *Housing density* and *heritage tree ordinance* accounted for approximately a quarter of the variability seen with regard to community canopy coverage (adjusted R^2 = 0.24).

Table 3. Final model and regression results in predicting canopy coverage for 43 Florida (United States) communities with a range of urban forest management strategies and ordinances.

Variable	Coefficient	Standard Error	*P* value	95% CI Lower	95% CI Upper
Intercept	37.2696	4.1194	<0.0001	28.9303	45.6089
Housing density	-0.0021	0.0008	0.0116	-0.0038	-0.0005
Heritage tree ordinance	6.7207	3.2827	0.0476	0.0751	13.3664

4. Discussion

4.1. Survey results for Florida cities

The information gleaned from this study creates a picture of urban forest management in Florida. Most surveyed communities had tree inventories, despite this very few had tree canopy goals. This might be due in part to the fact that most UTC typically falls on private property, complicating a municipality's ability to maintain a specific amount of canopy cover (Miller at al., 2015). However, many respondents said they had measures in place (i.e., permit requirements) for cutting trees on private property. Additionally, a majority of the Florida communities had tree preservation and heritage tree ordinances protecting their public and (in some instances) private trees. Preservation ordinances that protect trees during development activities can be significant management practices in rapidly-urbanizing areas such as Florida. This is also true of heritage tree preservation ordinances, which protect trees with large stem diameters. These significantly-sized trees would likely have greater canopy areas that provide more benefits and ecosystem services than smaller trees of the same species (Maco and McPherson, 2003; Leibowitz, 2012). Extra attention should be paid to these large trees when examining UTC and creating canopy goals.

4.2. Canopy coverage in Florida cities

Dot-based canopy assessment is a proven, albeit somewhat labor-intensive, method of conducting land classification (Walton et al., 2008; Jackson et al. 2010). In urban forestry research, dot-based interpretation is often considered that standard to compare against other manual or more automated approaches for identifying canopy coverage (Nowak and Greenfield, 2010; Nowak and Greenfield, 2012; Parmehr et al., 2016). In testing the repeatability of dot-based canopy assessment, Jackson et al (2010), compared canopy classifications for five locations (e.g., Georgia, Kansas, Michigan, Oregon, and Utah) across the United States. The authors had two to five assessors interpret a total 208 plots (with 105 dots per plot) and reported how many plots from each location met a 90% threshold for agreement. With over 70% meeting or surpassing this threshold for all but the Georgia location (which had an errant interpreter), the authors concluded that the method offered a high level of agreement (Jackson et al., 2010). In comparison, 100% of the cities assessed by our interpreters met or surpassed the 90% agreement threshold used by Jackson et al. (2010; Table 2) using the same imagery source, (National Agriculture Imagery Program or NAIP).

Canopy coverage for the Florida communities included in this study ranged from 17.6% in Deerfield Beach to 63.3% in Gainesville. The latter value for percent canopy coverage is among the highest reported in the literature. In looking at 29 Chicago-area communities, Iverson and Cook (2000) estimated 62.7% canopy coverage in North Barrington, Illinois, United States. Heynen and Lindsey (2003) observed a maximum canopy coverage of 55.7% in their assessment of 60 central Indiana communities. At 55% canopy coverage, Nowak et al (1996) identified Baton Rouge, Louisiana as the most treed city in their aggregation of 68 canopy analyses conducted in the United States.

Several of the communities assessed for this study had previous assessments of canopy coverage to draw on for comparison. In 2016, one year after our referenced imagery, researchers estimated Tampa had a total canopy coverage of 32.3% (Landry et al., 2018). In comparing 95% confidence intervals, the lower bound for our study's estimate of canopy coverage (32.8%) overlapped with the upper bound for the estimate (33.7%) calculated by Landry et al. (2018). Even greater overlap was noted with canopy coverage estimates calculated by the City of Fort Lauderdale. The urban forester for this community related that he had estimated canopy coverage in 2018 at 25.9% with a 95% confidence interval between 23.2 and 28.6 (Mark Williams, personal communication; Table 2). Despite differences in methodology, canopy estimates from Orlando's 2012 i-Tree Eco analysis (31.4 %; Epke et al., 2012) also fell within our 95% confidence intervals (Table 2).

Our canopy estimates were less consistent with past estimates when looking at our two most treed communities - Gainesville and Tallahassee. Using 2013 imagery, Ucer et al. (2016) compared two different sampling techniques for estimating canopy coverage in Tallahassee. While both methods tested garnered similar results in their study (44.5% to 49.1% depending on imagery source), their results were well below our canopy estimate of 58.7% (Table 2). That said, our estimates did align with a 55% canopy coverage estimate obtained by the City of Tallahassee as part of efforts to develop an Urban Forest Master Plan (City of Tallahassee, 2018). Similarly, our estimate of tree canopy coverage in Gainesville (63.3%) was higher than independent estimates (54%) derived from the same 2015 imagery (Andreu et al., 2017). That noted, our estimate was in line with historic estimates of canopy coverage (59% to 67%) for the community calculated by Szantoi et al. (2008).

4.3. Predictors of canopy coverage

While our two-variable reduced model may appear somewhat simplistic compared to other attempts at predicting canopy coverage (Hill et al., 2010; Landry and Pu, 2010; Kendal et al., 2012; Conway and Bourne, 2013), it is appropriate for our sample size of 43 communities and likely avoids the generation of misleading coefficients, P-values, and coefficient of determination values associated with overfitting

(Minitab Blog Editor, 2015). The negative relationship between housing density and canopy coverage is both intuitive and in line with findings from past research (Iverson and Cook, 2000; Conway and Bourne, 2013). The importance of housing density also supports the "population density" explanation of tree canopy distribution (i.e., that people displace trees; Locke et al, 2016). In plotting canopy coverage values by location (Fig. 1), the relationship is particularly noticeable in the densely populated, Southeastern portion of the state (e.g., Palm Beach, Broward, and Miami-Dade counties).

More interesting with regard to our original research questions is the significance of having heritage tree designations and protections. A 6.7% increase in canopy coverage represents anywhere from 10.5% to 38.1% of the total canopy coverage depending on the community investigated (Table 2). While the other ordinances noted in our survey did not remain in our reduced model as predictors of canopy coverage, their absence cannot be taken as evidence that they are not effective. For example, nearly every city surveyed had ordinances in place requiring the planting of trees for new developments (n=39) and new parking lots (n=39). As such these were not used as predictors for canopy coverage in any of our models.

Of the tree ordinance types used to predict canopy coverage (i.e., *tree preservation ordinance, removal permit ordinance;* and *heritage tree ordinance*), only *heritage tree ordinance* was significant (Table 3). However, 92.3% of the cities that reported having protections enacted for heritage trees also reported having ordinances regarding the preservation of existing trees during development. Similarly, 69.2% of cities with heritage tree designations also had ordinances restricting tree cutting on private property. As such it is not clear if heritage tree protections alone are responsible for the measured increase in canopy. The increase in canopy may ultimately be the combined impact of all the ordinances in addition to any special protections communities afford for their large stature trees.

That noted, *heritage tree ordinance* did play a role in many of the models with the highest predictive ability derived from our initial set or variable (Fig. 2). Its statistical significance could reflect the stricter protections afforded to trees of noteworthy stature or historical notoriety. Large stature trees in both forest and urban environments are the genetic and environmental lottery winners of the plant world - defying odds that weeded out hundreds, if not thousands, of peer trees over the decades (i.e., other trees that did not reach maturity). While this is the case even in hospitable locales, urban sites can be especially challenging as the conditions (e.g., adequate space, native soils, protection from neighboring trees) which allowed heritage trees to grow to their fullest potential may no longer exist in a post-development environment. Despite their relative rareness, large stature trees provide a disproportionate amount of environmental and economic benefit. Benefits like shading, air pollution capture, stormwater control, and carbon sequestration are all tied to tree size and canopy area. Factoring in growth and attrition rates, it could take decades, dozens of replacement trees, or both to mitigate the loss associated with a single large stature heritage tree.

While tree preservation ordinances and removal permits are intended, in part, to reduce canopy loss, neither *tree preservation ordinance* nor *removal permit ordinance* made it into our final reduced model (Table 3). With regard to tree preservation ordinances, there could be several reasons we did not see a relationship with canopy coverage (beyond the overlap in ordinances noted above). Tree preservation ordinances do allow the removal of trees to permit the development of a forested site. To offset these removals, new trees can be planted elsewhere on the property or in the community. Alternatively, developers are often given the option of paying into a tree mitigation fund if they prefer or if suitable planting sites are not available. Depending on how the number of replacement trees is calculated, it could take several decades to regain the canopy lost to development. Additionally, if mitigation funds are not actively spent to replant trees within a community, the canopy linked to these funds is essentially lost without replacement. Even with an active replanting program, transplant losses, vandalism, and other stressors that afflict younger trees could limit canopy replacement efforts - especially if adequate early care is not provided.

Research by Landry and Pu (2010) in the Tampa Bay area suggests that protections for trees of a certain size regardless of ownership (public or private) can lead to higher canopy area. However, tree removal permits on private land are a potentially contentious issue which residents may see as being at odds with their individual property rights (Conway and Lue, 2018). In contrast to the findings of Landry and Pu (2010), our data did not indicate private tree protections had any influence on canopy coverage when assessment was expanded beyond the City of Tampa, Temple Terrace, and the surrounding county. Effective private tree protection depends on enforcement and public knowledge of permitting requirements - both of which may could vary by community (Conway and Lue, 2018). Moreover, enforcement occurs only after a tree has been cut down and often only after a member of the public has reported the removal (Conway and Lue, 2018). Finally, permitting generally does not restrict the removal of trees for development or to reduce tree risk, which likely account for the majority of tree removals (even unpermitted).

4.4. Policy implications

As noted, urban canopy coverage directly affects many ecological and economic benefits. However, maintaining, protecting, and expanding urban tree canopy requires an investment of resources by communities. Moreover, trees, buildings, and urban infrastructure all compete for limited space - potentially putting canopy goals at odds with development efforts. Ultimately, it is up to community leaders and their constituents to decide where this balance best fits their needs and values.

That noted, this work provides evidence that at least some protection measures currently used in Florida communities are associated with increases in urban tree canopy. For those questioning the validity of current ordinances, the data provided for this work hopefully alleviates some of the concerns that existing regulations are not serving their intended function. Additional work looking at the impacts of urban forest management over time is the next logical step in this line of inquiry. Additionally, the impacts of urban forest management efforts on storm resiliency (specifically canopy loss) would be a very relevant question for hurricane-prone areas like Florida.

5. Conclusion

Many of the ecosystem services urban tree managers calculate when assessing the value of their urban forest are directly linked to canopy coverage. Large trees contribute more canopy than smaller-sized trees, but must compete with other aspects of urban infrastructure for above and belowground space. This can lead to conflict, tree injury, and even tree death if care is not taken during the development and redevelopment of sites.

Communities enact ordinances to reduce damage to trees given development efforts and restrict the removal of healthy, stable trees as a public good. These efforts can be somewhat controversial, especially when they interfere with private property owner rights. Regardless of one's opinion on this matter, there appears to be some measurable benefit associated with some tree protection ordinances. In particular, we observed a significant increase in canopy associated with communities that designated and protected heritage trees. These findings add much needed empirical evidence to a debate which is playing out in the study area and beyond.

Authors' contributions

[redacted]

Conflicts of interest

The authors declare no conflict of interest

References

1. Akbari, H. (2002). Shade trees reduce building energy use and CO_2 emissions from power plants. *Environmental Pollution*, 116, Supplement 1, S119-S126. https://doi.org/10.1016/S0269-7491(01)00264-0.

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

3. City of Tallahassee. Urban Forest Master Plan (2018). http://www.talgov.com/place/pln-urbanforestry.aspx Accessed 28 August 2018.

4. Conway, T.M. & Bourne, K.S. (2013). A comparison of neighborhood characteristics related to canopy cover, stem density, and species richness in an urban forest. *Landscape and Urban Planning*, 113,10-18.

5. Elmendorf, W. F., Cotrone, V. J., & Mullen, J. T. (2003). Trends in urban forestry practices, programs, and sustainability: Contrasting a pennsylvania, U.S., study. *Journal of Arboriculture*, *29*, 237-247.

6. Ekpe, E.K., Becker, E., Lab, J., Hinkle, R. & Escobedo, F. 2012. Orlando, Florida's Urban and Community Forests and their Ecosystem Services. *EDIS Factsheet FOR290* (10 pp.). Gainesville Florida: Institute of Food and Agricultural Science, University of Florida.

7. Hauer R. J. & Peterson W. D. 2016. Municipal Tree Care and Management in the
8. United States: A 2014 Urban & Community Forestry Census of Tree Activities. Special Publication 16-1, College of Natural Resources, University of Wisconsin – Stevens Point. 71 pp.

9. Heynen, N.C. & Lindsey, G. (2003). Correlates of urban forest canopy cover: Implications for local public works. *Public Works Management & Policy*, 8, 33-47.

10. Hill, E., Dorfman, J.H., & Kramer, E. (2010). Evaluation the impact of government land use policies on tree canopy coverage. *Land Use Policy,* 27, 407-414.

11. Iverson, L.R. & Cook, E.A. (2000). Urban forest cover of the Chicago region and its relation to house density and income. *Urban Ecosystems*, 4, 105-124.

12. Jackson, T.A., Moisen, G.G., Patterson, P.L. & Tipton, J. (2010). Repeatability in photo-interpretation of tree canopy cover and its effect on predictive mapping. Paper at the 2010 Join Meeting of the Forest Inventory and Analysis (FIA) Symposium and the Southern Mensurationists, Knoxville, TN.

13. Kendal, D., Williams, N.S.G., & Williams, K.J.H. (2012). Drivers of diversity and tree cover in gardens, parks, and streetscapes in an Australian city. *Urban Forestry & Urban Greening*, 11, 257-265.

14. Koeser, A.K., Vogt, J.M., Hauer, R.J., Northrop, R.J., & Peterson, W. (2016). The Cost of Not Maintaining Trees: Findings and Recommendations from an International Symposium and Summit. *Arboriculture & Urban Forestry*, 42, 377-388.

15. Landry S., Koeser, A., Northrop, R., McLean, D., Donovan, G., Andreu, M. & Hilbert, D. (2018). City of Tampa Tree Canopy and Urban Forest Analysis 2016. Tampa, FL: City of Tampa, Florida

16. Landry, S.M. & Pu, R. (2010). The impact of land development regulation on residential tree cover: An empirical evaluation using high-resolution IKONOS imagery. *Landscape and Urban Planning*, 94, 94-104.

17. Leibowitz, R. (2012). Urban tree growth and longevity: An international meeting and research symposium white paper. *Arboriculture & Urban Forestry,* 38, 237-241.

18. Locke, D.H., Landry, S.M., Grove, J.M., & Chowdhury, R.R. (2016). What's scale got to do with it? Models for urban tree canopy. *Journal of Urban Ecology* 2,16pp.

19. Lumley, T & Miller, A. (2017). Leaps: Regression Subset Selection. URL https://CRAN.Rproject.org/package=leaps.

20. Maco, S.E. & McPherson, E.G. (2003). A practical approach to assessing structure, function, and value of street tree populations in small communities. Journal of Arboriculture 29,84-97.
21. McPherson, E.G., Simpson, J.R., Xiao, Q., and Wu, C. (2011). Million trees Los Angeles canopy cover benefit assessment. *Landscape and Urban Planning*, 99(1), 40-50.

22. Miller, R.W., Hauer, R,J., & Werner, L.P. (2015). *Urban Forestry Planning and Managing Urban Greenspaces (3rd Edition)*. Waveland Press. Long Grove, IL.

23. Minitab Blog Editor. The Danger of Overfitting Regression Models. (2015). http://blog.minitab.com/blog/adventures-in-statistics-2/the-danger-of-overfitting-regression-models Accessed 28 August 2018.

24. Nowak, D.J., & Crane, D.E. (2000). The Urban Forest Effects (UFORE) Model: Quantifying urban forest structure and functions. In Integrated tools for natural resources inventories in the 21st century, ed. M. Hansenand T. Burk. USDA Forest Service General Technical Report NC-212. St. Paul, MN: U.S. Department of Agriculture, 714–720.

25. Nowak, D.J. & Greenfield, E.J. (2010). Evaluating the national land cover database tree canopy and impervious cover estimates across the conterminous United States: A comparison with photo-interpreted estimates. *Environmental Management*, 46, 378-390.

26. Nowak, D.J. & Greenfield, E.J. (2012). Tree and impervious cover in the United States. *Landscape and Urban Planning,* 107, 21-30.

27. Nowak, D.J., Rowntree, R.A. McPherson, E.G., Sisinni, S.M., Kerkmann, E.R., & Stevens, J.C. (1996). Measuring and analyzing urban tree cover. *Landscape and Urban Planning*, 36, 49-57.

28. Nowak, D.J., Wang, J. & Endreny, T. (2007). Environmental and Economic Benefits of Preserving Forests Within Urban Areas: Air and Water Quality. CH. 4, USDA, U.S. Forest Service.

29. Pandit, R. & Laband, D.N. (2010). Energy savings from tree shade. *Ecological Economics*, 69, 1324-1329.

30. Pandit, R., Polyakov, M., Tapsuwan, S., & Moran, T. (2013). The effect of street trees on property value in Perth, Western Australia. *Landscape and Urban Planning,* 110, 134-142.

31. Parmehr, E.G., Amati, M., Taylor, E.J., & Livesley, S.J. (2016). Estimation of urban tree canopy using random point sampling and remote sensing methods. *Urban Forestry & Urban Greening,* 20, 160-171.

32. R Core Team. R: A language and environment for statistical computing. (2016). https://www.R-project.org/. Accessed 28 August 2018.

33. Roy, S., Byrne, J., & Pickering, C. (2012). A systematic quantitative review of urban tree benefits, costs, and assessment methods across cities in different climatic zones. *Urban Forestry & Urban Greening,* 11, 351-363.

34. Szantoi, Z., Escobedo, F., Dobbs, C., & Smith, S. (2008). Rapid methods for estimating and monitoring tree cover change in Florida urban forests: The role of hurricanes and urbanization. In P. Bettinger, K. Merry, S. Fei, J. Drake, N. Nibbelink, and J. Hepinstall (Eds.), *Proceedings of the 6th Southern Forestry and Natural Resources GIS Conference.* (pp. 281-304). Athens, GA: Warnell School of Forestry and Natural Resources, University of Georgia.

35. Ucar, Z., Bettinger, P. Merry, K. Siry, J. & Bowker, J.M. (2016). A comparison of two sampling approaches for assessing the urban forest canopy cover from aerial photography. *Urban Forestry & Urban Greening,* 16, 221-230.

36. United States Department of Agriculture (USDA). National Agriculture Imagery Program (2018). https://www.fsa.usda.gov/programs-and-services/aerial-photography/imagery-programs/naip-imagery/ Accessed 28 August 2018.

37. Vogt J.M., Hauer R.J., & Fischer B.C. (2015). The Costs of Maintaining and Not Maintaining the Urban Forest: A Review of the Urban Forestry and Arboriculture Literature. *Arboriculture & Urban Forestry,* 41, 293-323.

38. Walton, J.T., Nowak, D.J., & Greenfield, E.J. (2008). Assessing urban forest canopy cover using airborne or satellite imagery. *Arboriculture & Urban Forestry,* 34, 334-340.

Appendix A:

Select Survey Questions and Summary of Responses

Municipal Tree Care and Management in Florida: *A 2014 Urban & Community Forestry Census of Tree Activities*. The survey was conducted for several municipalities (n=87) in the State of Florida. In looking at the returned survey results, questions with 7 or more non-responses (16.3%) were not considered for inclusion in the regression model.

Section I -- Community and Staff

Did your community conduct any kind of shade tree/urban & community forestry activities in 2014?

Yes
No
Don't know

Who in your community is primarily (legally) responsible for maintaining trees in municipal rights-of-way, for example street trees between sidewalk and curb or alley trees?

Municipality responsible
Abutting property owner responsible
Jointly responsible (municipality and abutting owner)
Other (*please specify:* ______________________)

Does someone in your community (i.e., employee, volunteer, consultant, etc.) oversee the care of municipal street trees, park trees or other public trees?

Yes
No
Don't Know

How many years has your community had a person responsible for the management of trees?

_________ Number of Years

What training and/or credentials are collectively held by the staff responsible for tree activities and/or management of trees?

No specific training or workshops	Yes	No
In-house and/or on-the-job-training	Yes	No
Attend tree care/management workshops	Yes	No
ISA Certified Arborist	Yes	No
ISA Certified Municipal Specialist	Yes	No
Two year degree	Yes	No
Four year degree	Yes	No
Graduate degree	Yes	No

How many public employees, including managers, are involved with the municipal tree management program?

_________ # of Total Employees

_________ # of Full Time Equivalents (2080 hour base year)

Section II -- Budget

What is the total municipal budget (excluding school budget) for 2014? (Please include entire amount for all governmental functions, activities, etc.)

____________________ $ Total 2014 Municipal Budget

What is the total annual budget of your municipality funded tree care activities and management from all municipal sources? (Include all tree activity expenses; include personnel, overhead, equipment, supplies, tree care and contract payments.)

______________________ $ Total 2014 Tree Budget

Is your budget adequate to meet current needs as defined in your work plan or your identified annual urban forestry budget needs? (This includes planting, maintenance, removal, inventory, education, etc.)

Yes
No → If no, _______% below identified need

What percent of the total tree management budget from all sources is used for the following activities?

Tree Removal __________

Section III -- Tree Management Profile

Does your community have a government-authorized tree board, parks board, city department, commission, or similar group that helps develop and/or administer tree management policy?

Yes
No

Does your municipality have one or more municipal ordinances that pertain to trees?

Yes
No
Developing

What topics do your community tree ordinances include?

Requires tree planting in new developments	Yes
Requires tree planting around new parking lots	Yes
Requires preservation of trees during development	Yes
Restricts tree cutting on private property	Yes
Identifies preservation of heritage or significant trees	Yes

Does your community have a written strategic plan for urban forestry, tree management, open space, green infrastructure, or land use management that includes trees?

Yes
No
Don't Know

Section IV -- Volunteers/ Partnerships

Does your community work with partners and/or volunteers (individuals or groups not paid for providing services) for tree planting, tree care, or other tree activities on public property?

Yes
No

Section V-- Contractors

Does your community use paid contractors for any of your tree care activities?

Yes
No

Section VI -- Inventory

Does your community have a tree inventory? (An inventory is any record of public trees in your community.)

Yes
No

What is the state of your tree inventory? (current = up to date) (CHECK ONE CHOICE)

Current (reflects tree population)
Developing (in process of making current)
Not current (missing tree population information)

Does your municipality have a tree canopy goal? (check one)

Yes
No → (PLEASE GO TO QUESTION 18, PAGE 18)
Developing → (PLEASE GO TO QUESTION 18, PAGE 18)

What is the total number of publicly owned trees in your community?

_________________ # of Publicly Owned Trees

Section VII -- Operations Profile

Please fill in the number of trees by tree care activity on all municipal properties in 2014 in the appropriate column. (Please enter 0 if no activity type was performed last year.)

# of Trees removed__________

# of Trees planted_____________

What percent of tree care (pruning, pest control, etc.) is done on a systematic (regularly scheduled) cycle and what percent on demand as reactive (complaints, hazardous situations, crisis, post storm etc.)? (Total = 100%)

______ % Systematic (Scheduled)

______% Reactive (on Demand)

Does your community conduct any of the following urban activities? (Check yes or no for each activity)

Provide technical assistance (information) for tree maintenance on private property?

Yes
No

Provide financial assistance for specific insect or diseased tree removal on private property?

Yes
No

Does your community regularly conduct tree risk management (hazard tree identification)?

Yes
No

Does your community have a written tree risk management policy?

Yes
No

Does your community have an emergency response system which includes trees?

Yes
No

Section VIII -- Assistance Programs

Do municipal staff provide educational presentations to city residents in regard to tree care?

Yes
No

Is your community currently a Tree City USA?

Yes
No

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