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Research Paper

Development practices and ordinances predict inter-city variation in Florida urban tree canopy coverage

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ABSTRACT

Many cities around the world have set ambitious urban tree canopy cover goals, with the expectation that urban forests will provide ecosystem services as functional green infrastructure. Numerous studies have examined intra-city spatial patterns in urban tree canopy (UTC) and found that UTC relates to socioeconomic indicators and urban form. Additionally, a few studies have shown local regulations can be linked to increased tree cover. However, the relationship between UTC and governance across different cities has not been well-explored. To address this gap, we compared the management practices enacted by 43 municipalities in Florida (United States) to investigate their potential impact on tree canopy coverage. UTC was assessed through visual interpretation of aerial images. We used multiple linear regression to predict inter-city variation in UTC based on 1) municipal forestry management practices, including whether the municipality had an arborist, tree ordinances, a municipal tree inventory, and a canopy cover goal, and 2) community sociodemographic data. UTC ranged between 17.6% and 63.3% among the municipalities assessed, with an average UTC of 33.7%. Two factors significantly predicted canopy coverage. Housing density had a negative relationship with tree canopy (P-value = 0.0116). In contrast, municipalities with heritage tree protections had 6.7% more canopy coverage (P-value = 0.0476). Future research should continue to consider the potential impacts of governance structures on the spatio-temporal dynamics of inter- and intra-city UTC patterns.

1. Introduction

Urban trees can provide a variety of benefits, including increased quality of life, wildlife habitat, green stormwater infrastructure, increased property values, and energy savings from shade (Pandit & Laband, 2010; Roy, Byrne, & Pickering, 2012; Pandit, Polyakov, Tapsuwan, & Moran, 2013; Berland et al., 2017; Ko, 2018). 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. Urban tree canopy (UTC) is the proportion of land area, when viewed from above, occupied by tree crowns (Nowak et al., 1996). Many cities, particularly in the United States, Canada, Western Europe, and Australia, have set ambitious UTC cover goals to maximize tree benefits (Hill, Dorfman, & Kramer, 2010; Hauer & Peterson, 2016; Locke, Romolini, Galvin, O'Neil-Dunne, & Strass, 2017). Some US cities aim to increase UTC by 50–100% from current levels (Leff, 2016). These UTC goals are sometimes accompanied by specific implementation strategies, such as planting initiatives for private residential lands (Nguyen et al., 2017).

As municipalities have increasingly integrated UTC in their urban forest management, researchers have been examining UTC spatial patterns, temporal dynamics, and the human and biophysical mechanisms that explain these patterns. Such scholarship has highlighted several complimentary explanations for the heterogeneity in intra-city UTC patterns. Based on the suggestion that urbanization displaces forests and other ecosystems, population density is one factor that may explain UTC distributions. However, studies have shown both positive and negative associations between population density and UTC (e.g.,

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Troy, Grove, O'Neil-Dunne, Pickett, & Cadenasso, 2007; Pham, Apparicio, Séguin, Landry, & Gagnon, 2012; Bigsby, McHale, & Hess, 2014), suggesting that other explanations are needed.

Several explanations related to social stratification have been proposed. For instance, wealthier people are better able to afford to live in neighborhoods with desirable amenities such as UTC (e.g., Chowdhury et al., 2011). Socioeconomic groups with access to governance power might influence the location of public investments (Logan & Molotch, 1987), possibly including tree planting (Grove et al., 2006). Recent studies have linked education level, household income, and race to canopy cover differences within cities (Greene, Robinson, & Millward, 2018; Nesbitt, Meitner, Girling, Sheppard, & Lu, 2019; Schwarz et al., 2015). In recent meta-analyses covering several dozen studies (Gerrish & Watkins, 2018; Watkins & Gerrish, 2018), support for social stratification explanations is further evidenced by a strong relationship between income and race and UTC distributions within cities. A study of Milwaukee's urban forest found similar trends; however, the results point towards a complex situation involving race, income, cultural practices, and neighborhood-level disinvestment (Heynen, Perkins, & Roy, 2006). In addition to the population density and social stratification explanations, the lifestyle-based 'Ecology of Prestige' theory suggests that tree planting and other land management decisions are also influenced by neighborhood-scale social norms (Grove et al., 2006; Grove, Locke, & O'Neil-Dunne, 2014; Locke, Landry, Grove, & Chowdhury, 2016). In other words, residents want to show they belong to the neighborhood by maintaining similar types of landscapes, which can, in turn, impact the number, size, condition, and types of trees in different neighborhoods (Grove et al., 2014).

Urban tree canopy patterns reflect legacies of past events and human decisions and the growth rate and lifespan of trees (Boone, Cadenasso, Grove, Schwarz, & Buckley, 2010; Grove et al., 2018; Roman et al., 2018). Housing age, for instance, has consistently been associated with tree cover, suggesting a time-lagged effect. Older houses tend to have larger trees – a relationship that would reflect the time required for trees to grow to maturity, or alternatively, differences in urban development patterns across time (Troy et al., 2007; Landry & Chakraborty, 2009; Locke et al., 2016; Pham, Apparicio, Landry, & Lewnard, 2017). Residential development styles that allow more space for vegetation, such as single-family homes and larger building setbacks from the street, have also been associated with higher UTC (Troy et al., 2007; Pham et al., 2017). Redevelopment and renovation in residential neighborhoods have been correlated with overall decreases in tree numbers, although street-level analyses have found some positive associations with tree planting and development (Steenberg, Robinson, & Duinker, 2018). As such, the association between UTC and population or building density are often rooted in the legacies of urban development patterns.

Dozens of studies have investigated socioeconomic characteristics influencing UTC and a few studies have examined the influence of urban form; however, the role of local actors and government policies in influencing UTC has rarely been examined (Hill et al., 2010; Landry & Pu, 2010; Conway, Shakeel, & Atallah, 2011). Research on governance and its impact on UTC has been sparse in urban forestry literature (Konijnendijk van den Bosch et al., 2018; Mincey et al., 2013). Studies have mostly focused on planting initiatives and stewardship (Fisher, Campbell, & Svendsen, 2012), as opposed to how formal government policies influence UTC. Trees located along streets and in city parks are generally under direct municipal jurisdiction (Ricard, 2005; Fischer & Steed, 2008; Hauer & Peterson, 2016; Roy, 2017). Trees in residential yards, commercial parking lots, and other land uses are regulated through a variety of local ordinances and tree planting requirements (McPherson, 2001; Landry & Pu, 2010; Hauer & Peterson, 2016; Nguyen et al., 2017; Phelan, Hurley, & Bush, 2018). Tree ordinances that regulate the removal of trees during development, the replacement of removed trees with new plantings, and the preservation of heritage trees are more common today than in the past (Hauer & Peterson, 2016). UTC is therefore subject to municipal plans, planting initiatives, and local ordinances.

Land use ordinances, and the degree to which they are enforced, can impact UTC. For instance, a study of the UTC around Atlanta, Georgia (United States; US) showed that planning and zoning regulations aimed at UTC protection and sustainable development practices (e.g., conservation easements, park creation, heat island mitigation) were associated with an increase in canopy cover over ten years (Hill et al., 2010). In Tampa, Florida (US), Landry and Pu (2010) found that UTC was greater on private lots developed after the adoption of a 1974 tree protection ordinance compared to lots developed before the ordinance. Tree ordinances and other aspects of municipal tree management change over time and are not consistent across cities (Schmied & Pillman, 2003; Ricard, 2005; Zhang, Zheng, Allen, Letson, & Sibley, 2009; Rines, Kane, Kittredge, Ryan, & Butler, 2011; Steiner, 2016). Research examining how inter-city variation relates to differences in management and socioeconomic characteristics across municipalities can broaden our understanding of how UTC patterns emerge.

In light of emerging research on management interests surrounding UTC, we investigated the effects of municipal management actions on UTC across municipalities. We specifically examined communities in the state of Florida (US) because of recent interest in tree preservation ordinances there, as described further in the discussion. Our research objective was to investigate the relationship between inter-city UTC variation and 1) municipal forestry management practices, including whether the municipality had an arborist, tree ordinances, a municipal tree inventory, and a canopy cover goal, and 2) community sociodemographic data.

2. Methods

2.1. Study area

Florida is a peninsular state in the southeastern US. The north and central portions of Florida have a humid subtropical climate, while southern Florida has a tropical climate (Kottek, Grieser, Beck, Rudolf, & Rubel, 2006). The entire state has a distinct summer rainy season (May through October) and a winter dry season which can lead to severe drought. Florida's wet season coincides with a period of increased tropical storm and hurricane activity (Misra & Mishra, 2016). Florida's urban foresters and natural resource planners contend with these conditions at both the municipal and county level.

2.2. Sampled municipalities and survey data

The sample of 43 Florida municipalities (Fig. 1) used in this study came from the results of a survey of urban forest management conducted by Hauer and Peterson (2016). Their 109-questionnaire was sent to a stratified sample (by population) of 1727 communities in all 50 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 communities with populations between 25,000 and 49,999 (50% sampled) and between 2500 and 24,999 (10% sampled). The mailing list was developed from community contact information provided by state urban and community forestry coordinators. This was supplemented with community government website contact lists and sent to a person most closely aligned with the municipal tree program (Hauer & Peterson, 2016; Koeser, Hauer, Miesbauer, & Peterson, 2016). The survey was approved through the University of Wisconsin-Stevens Point Institutional Review Board. Following the approach outlined by Dillman, Smyth, and Christian (2014), all communities in the study received a pre-notice followed by a printed copy of the survey with a cover letter. Non-respondents were also sent a reminder postcard, followed by a second printed survey with a cover letter. A final email reminder was sent to any remaining non-respondents.

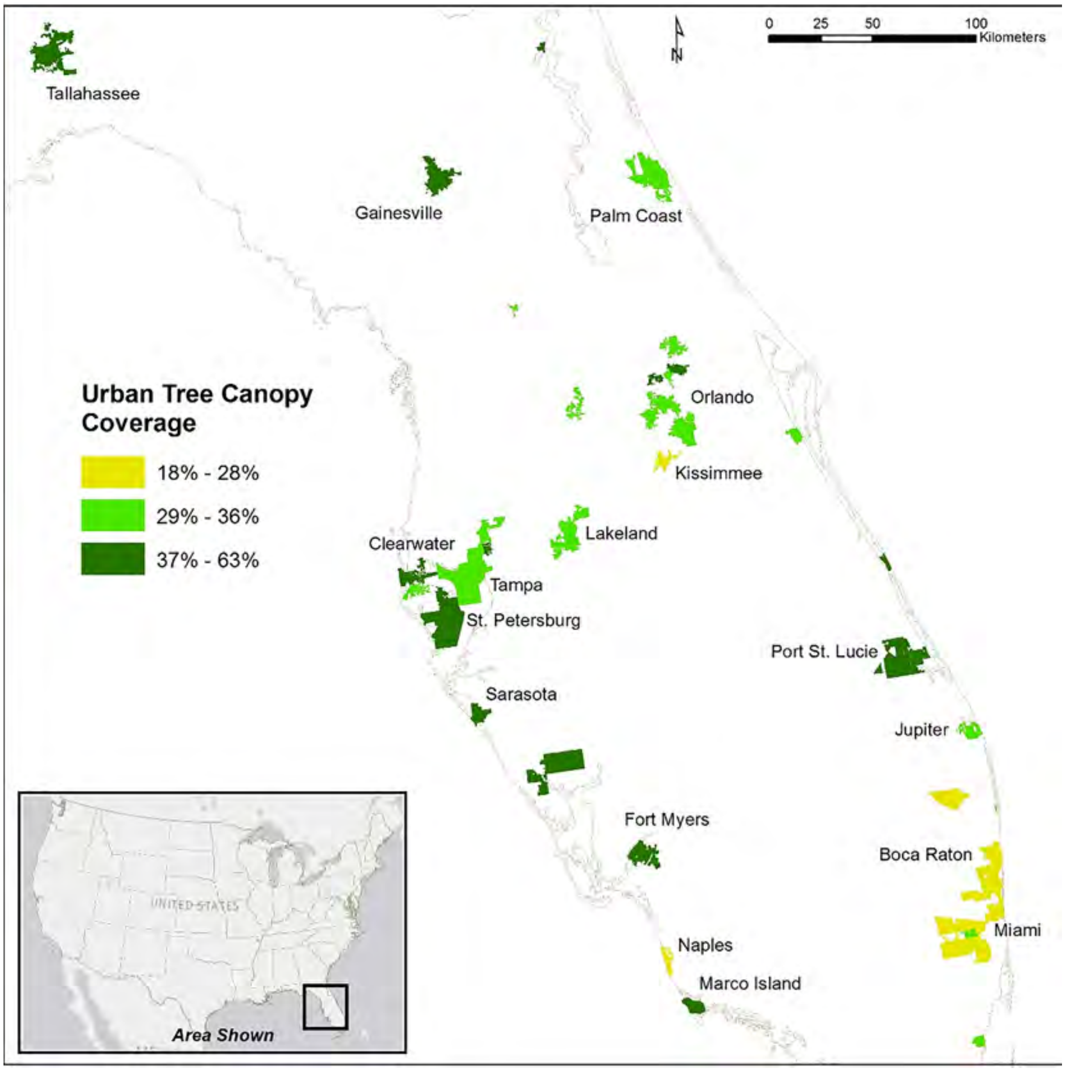

Fig. 1. Locations of the 43 Florida (US) communities included in this assessment of canopy coverage. The different colors represent the percent of the city covered by tree canopy. Larger cities are labeled for reference. The full list of cities included in this study is available in Table 2.

Nationally, 667 municipalities responded to the survey for a total response rate of 38.6%. A total of 39 Florida communities responded to the 2015 survey request, and four additional communities responded to a follow-up request in 2018, leading to a statewide response rate of 49.4%. In all cases, the responses reflect the program state in 2014. A test for non-respondent bias was conducted to detect differences between responding and non-responding communities using the USDA-Forest Service Community Accomplishment Reporting System (CARS) dataset. The CARS data for each state are compiled by the State Urban & Community Forestry Coordinator who determines if a community has staff, ordinance, advisory groups, or management plans. No difference between responding and non-responding communities was found using a chi-square ($p > 0.05$ all cases Fisher Protected) and a *t*-test ($p = 0.183$) for the sum of having none to all of the four CARS categories.

2.3. UTC analysis

We acquired aerial imagery from the National Agricultural Imagery Program (NAIP; USDA, 2018), and used leaf on imagery from 2015 to coincide with the timeframe of the survey mentioned above. Spatial resolution 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 suggest the collection of 500–1000 random survey points per municipality. To increase measurement confidence, we adopted the larger, 1000 point sample size. Boundary shapefiles for each municipality assessed were obtained from the American Community Survey (ACS; United States Census Bureau, 2015).

A geographic information system (ArcGIS v. 10.2.2; ESRI, Redlands, CA, United States) was used to import NAIP aerial imagery and generate random points. UTC was assessed as either tree or non-tree. Each city was assessed by at least two interpreters. Points where the interpreters disagreed were discarded before analysis, thus minimizing photointerpreter bias. Canopy percentage and agreement between interpreters were noted for each municipality.

2.4. Data analysis

A multiple linear regression model was fit using municipality 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. In addition to governance-related variables obtained from the surveys, we considered municipal-scale data from the ACS related to sociodemographics and urban form: housing density, housing age (% built since 1990, 2000, and 2010), and median home value.

As missing data prevented the use of a stepwise deleting function,

Table 1
The initial set of variables assessed in modeling urban tree canopy (UTC) in Florida municipalities (n = 43). 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 (%)
UTC[z]	Percent (%) of the city covered by tree canopy	34.4 (11.7)
Housing density[y]	Housing units per square km	520.4 (294.6)
Median home value[y]	Median value ($ USD) 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 the sidewalk and curb/alley trees)	Community – 23 (61%) Homeowner – 7 (18%) Joint ownership – 7 (18%) Other – 1 (3%)
ISA Certified Arborist[x]	Community employs at least one International Society of Arboriculture (ISA) Certified Arborist credential holder	Yes – 31 (78%) No – 9 (22%)
Four-year degree[x]	Community employs at least one person with a four-year degree related to urban forestry	Yes – 19 (48%) No – 21 (52%)
Tree board[x]	Community has a government-authorized board to help develop/administer tree management policy	Yes – 28 (72%) No – 11 (28%)
Tree preservation ordinance[x w]	Community has an ordinance requiring the preservation of trees during development	Yes – 32 (80%) No – 8 (20%)
Removal permit ordinance[x w]	Community has an ordinance restricting tree cutting on private property	Yes – 23 (56%) No – 18 (44%)
Heritage tree ordinance[x w]	Community identified and preserves heritage/significant trees	Yes – 26 (63%) No – 15 (37%)
Tree inventorys[x]	Community has a record of public trees within its jurisdiction	Yes – 25 (64%) No – 14 (36%)
Canopy goal[x]	Community has a goal for enhancing or maintaining % tree canopy coverage	Developing – 2 (6%) Yes – 14 (39%) No – 20 (55%)

[z] Source: Aerial imagery UTC analysis.
[y] Source: U.S. Census Bureau (2018).
[x] Source: Hauer and Peterson (2016).
[w] Source: Municipal ordinance publishing websites: American Legal Publishing Corporation (2018),Municode (2018).

the regsubsets() function from the *leaps* package (Lumley & Miller, 2017) was used to run and plot (by R^2 value) the 20 best subsets of our predictor variables. This plot 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 $\alpha = 0.05$ 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

Florida survey responses used in our analysis are listed in Table 1. When asked who is legally responsible for trees in rights-of-way (Table 1), 61% of these Florida communities said the municipality was solely responsible. Over three-quarters of the respondents said they had at least one Certified Arborist on their staff and about half said they had at least one employee with a four-year degree related to urban forestry. Over two-thirds of the responding communities reported 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 reported having a tree inventory, but only a third of those respondents said the inventory was up-to-date. Finally, less than half of the communities reported having canopy cover goals (Table 1).

3.2. UTC in Florida municipalities

UTC ranged from 17.6% in Deerfield Beach to 63.3% in Gainesville (Table 2). Average UTC for the 43 assessed communities was 33.7% (std. dev. = 11.7). Agreement among our interpreters ranged from 94.9% to 99.5%. Average agreement for the 43 cities was 97% (Table 2).

3.3. Predictors of UTC

In conducting the model simplification process, two predictors of UTC beyond the intercept term were significant (Fig. 2). The first significant predictor was housing density ($P < 0.0116$) which had a negative relationship with UTC (Table 3). With a coefficient of -0.0021, a 1.1% decrease in UTC would be predicted for an increase of 500 housing units per km^2. The second predictor in our model was the presence of 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 UTC (Table 3). Housing density and heritage tree ordinance accounted for approximately a quarter of the inter-city UTC variability (adjusted $R^2 = 0.24$).

4. Discussion

Our analysis of UTC in Florida municipalities shows that development practices manifested as urban form (specifically, housing density) and the presence of heritage tree protection ordinances partially explain inter-city UTC variation. Our study advances burgeoning UTC research by demonstrating linkages between governance practices and tree cover levels. Below, we discuss the urban forestry governance context related to UTC, predictors of inter-city UTC patterns, and

Table 2
Population, percent urban tree canopy (UTC), standard error, 95% confidence intervals, number of interpreters, and percent agreement associated with the dot-based aerial imagery UTC analysis of 43 Florida municipalities. Canopy estimations based on 2015 leaf-on imagery from National Agricultural Imagery Program (NAIP; USDA, 2018).

Municipality	2014 Population	UTC (%)	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	4070	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	8412	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	2588	32.2	1.5	29.3	35.1	2	97.4
Groveland	8729	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	4492	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

robustness of the aerial imagery interpretation method.

4.1. Urban forestry governance related to UTC

While most previous UTC studies have focused on intra-city UTC variation related to sociodemographic differences (e.g., see meta-analyses by Gerrish & Watkins, 2018; Watkins & Gerrish, 2018), with some papers also highlighting the importance of urban form (e.g., Troy et al., 2007; Pham et al., 2012; Bigsby et al., 2014), the governance context across different municipalities has been under-explored. Both formal municipal ordinance and programs, as well as informal approaches through stewardship networks and financial incentives, can impact UTC (Hill et al., 2010; Landry & Pu, 2010; Romolini, Grove, & Locke, 2013). Indeed, many cities are actively trying to increase their UTC levels with 25% of communities either having a goal (17%) or developing a goal (8%; Hauer & Peterson, 2016).

Communities use a variety of urban forestry management practices to promote UTC. In Florida, a majority of surveyed municipalities had tree inventories, yet a minority had tree canopy goals. Both of these tools tell users what they have and may be used to promote planning. Many respondents said they had measures in place (e.g., permit requirements) for removing trees on private property and most did have a tree preservation ordinance to regulate trees during construction. None of these factors significantly explained UTC in Florida.

Heritage tree preservation ordinances specifically protect trees with large stem diameters. Large trees have greater canopy areas that provide more benefits than smaller trees (Maco & McPherson, 2003). For example, on a college campus in Philadelphia, Pennsylvania (US), six large *Platanus* × *acerifolia* trees (approximately 80 years old and 24 m tall) that were saved during a construction project were estimated to provide ecosystem services equivalent to over one thousand small trees that were between one and four inches in stem diameter (Bassett, 2015). Thus, large tree retention provides a greater potential impact on canopy retention and supports the importance of management priorities for tree preservation during construction and development rather than removal and replanting.

Construction and development activities are also predictors of urban forest change over time. In urban areas ranging from Christchurch (New Zealand) to Toronto, Ontario (Canada) and Worcester, Massachusetts (US), housing renovation, demolition, and urban development were significant predictors of canopy loss and tree mortality (Hostetler, Rogan, Martin, Delauer, & O'Neil-Dunne, 2013; Morgenroth, O'Neil-Dunne, & Apiolaza, 2017; Steenberg et al., 2018). Our findings from municipalities across Florida, combined with findings specific to Tampa (Landry & Pu, 2010), suggest that tree protection and preservation ordinances can have measurable impacts on UTC levels.

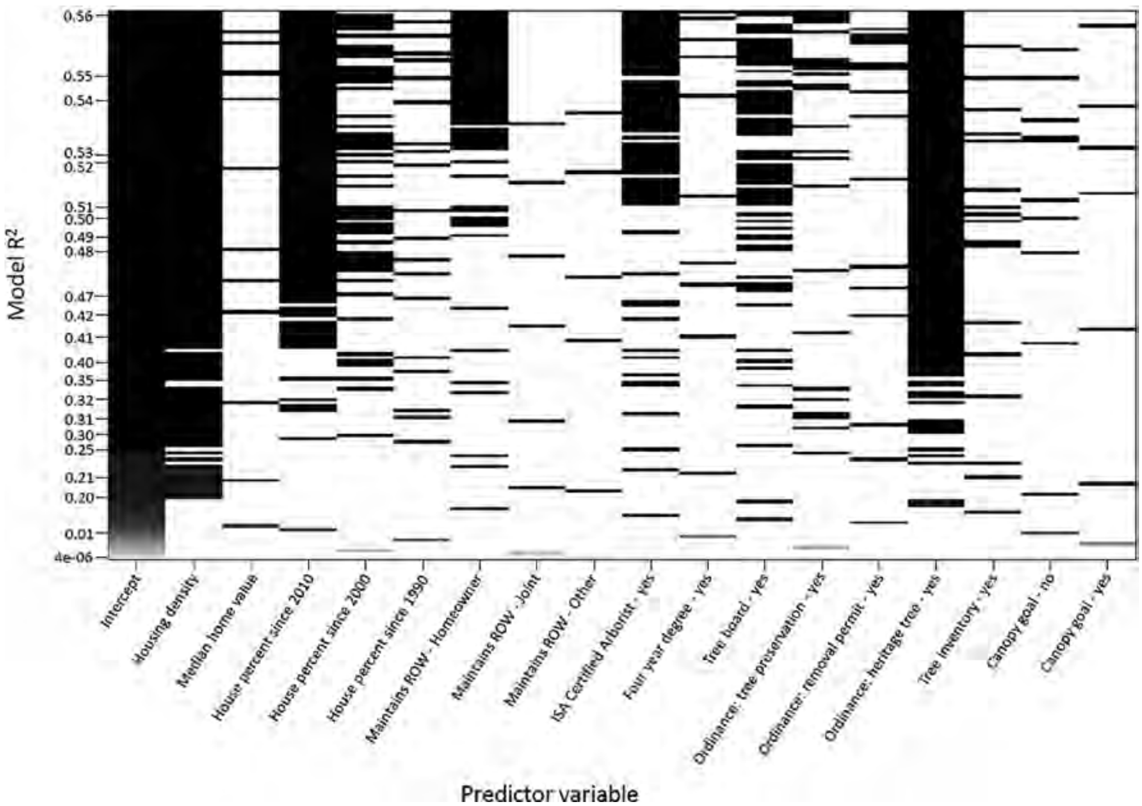

Fig. 2. Coefficient of determination (R^2) values for the various combinations of predictor variables selected for initial testing. Variables most commonly associated with the highest predictive power (shown as black bands) were selected for initial model simplification. Figure generated using the leaps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

Table 3
Final model and regression results in predicting urban tree canopy (UTC) for 43 Florida communities with a range of urban forest management strategies and ordinances (adjusted $R^2 = 0.24$).

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

Tree preservation requirements are used in the United Kingdom and Germany to restrict tree removal by requiring permission to remove trees or setting aside natural areas that are restricted from development through a formal constraint permanently attached to the land title (Miller, Hauer, & Werner, 2015). The State of Maryland (US) Forest Conservation Act has been used to retain forest and promote forestation resulting in 120% more forest (retained and planted) than cleared for development (Galvin, Wilson, & Honeczy, 2000). Thus, properly implemented policies are an effective way to promote retention of tree canopy.

4.2. Predictors of canopy coverage

While our two-variable reduced model may appear somewhat simplistic compared to other attempts at predicting UTC (Hill et al., 2010; Landry & Pu, 2010; Kendal, Williams, & Williams, 2012; Conway & Bourne, 2013; Locke et al., 2016), 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). Furthermore, in contrast to studies that examined the explanations for intra-city UTC heterogeneity, the scale of our analysis was the municipality as a whole. At this highly aggregated spatial scale, our study compared factors related to population density and social stratification (e.g., median home value) between municipalities. The negative relationship between housing density and UTC is both intuitive and in line with findings from past research (Iverson & Cook, 2000; Troy et al., 2007; Conway & Bourne, 2013). The importance of housing density supports the "population density" explanation of tree canopy distribution (i.e., that people displace trees; Locke et al., 2016). Spatial scale matters when considering explanations of UTC (Chowdhury et al., 2011; Locke et al., 2016). Given the scale of our study (i.e., the municipality), our results suggest that the population density explanation of UTC could be more relevant for explaining differences between cities, while social stratification and lifestyle-based explanations could be more important drivers within a city (Grove et al., 2006, 2014; Locke et al., 2016; Gerrish & Watkins, 2018; Watkins & Gerrish, 2018). That said, Nesbitt et al. (2019) did find that per capita income and the proportion of the population with higher education were significantly correlated with vegetation coverage in a comparison of ten cities. Mapping UTC values by location in Florida (Fig. 1), the influence of housing density 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 objective is the significance of having heritage tree designations and protections. A 6.7% increase in UTC represents a substantial gain for municipalities that have a heritage tree ordinance (Hauer & Peterson, 2016; Leff, 2016; Locke et al., 2017). While cities enact planting programs to meet their tree cover goals (Nguyen et al., 2017), tree protection ordinances may be just as important. Though the other ordinances noted in our survey did not remain in our reduced model as predictors of UTC, 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, those ordinances were not used as predictors for UTC in any of our models as a result of common implementation. They could be important in inter-city analyses in other regions, as they are not uniformly adopted across the US (Hauer & Peterson, 2016). Enforcement of ordinances is also an important part of regulation and achieving the intended governance goal. Finally, the year an ordinance is first enacted is likely important as it may take decades for even the most stringent protections and replanting requirements to make a noticeable impact.

Even though the presence of heritage tree ordinances was significant in our final model, it is possible that UTC impacts may ultimately be the combined influence of all ordinances and special protections communities afford for their large-stature trees. Alternatively, the statistical significance of heritage tree ordinances may reflect the stricter protections afforded to trees of noteworthy stature or historical notoriety. Further research into the local context of urban tree ordinances is needed to illuminate this relationship. While other research has shown that the presence of municipal tree ordinances relates to community socioeconomic status (Dickerson, Groninger, & Mangun, 2001), housing value was not significant in our final model, suggesting that other sociopolitical processes may be at play.

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). There could be several reasons we did not see a relationship with tree preservation ordinances and UTC. Tree preservation ordinances do allow the removal of trees to permit the development of a forested site. To offset these removals, new trees (likely smaller in size) 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 (Miller et al., 2015). 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 and other stressors that afflict younger trees could limit canopy replacement efforts – especially if adequate early care is not provided (Koeser, Gilman, Paz, & Harchick, 2014; Roman et al., 2015).

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 property rights (Conway & Lue, 2018). In contrast to the findings of Landry and Pu (2010), our data did not indicate that private tree protections (in the form of removal permitting) had any association with UTC across the state. Effective private tree protection depends on enforcement and public knowledge of permitting requirements – both of which could vary by municipality (Conway & 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 & Lue, 2018). Ideally, an enforcement program is preventative of a violation with fines and punishments serving as a deterrent for future unauthorized tree removal. Finally, permitting generally does not restrict the removal of trees for development or to manage the risk of injury to people and property.

Our findings are timely as tree care professionals in Florida have recently become concerned (Lemongello, 2017) about a tree management bill that was introduced to the Florida Senate in 2018 [Senate Bill (SB) 574: Tree and Vegetation Trimming and Removal] and reintroduced in 2019 [SB 1400: Private Property Rights]. The first bill, while ultimately unsuccessful, eliminated local governments' abilities to require permits for the trimming, pruning, removal, or harvesting of trees on private property in certain areas. It also would have prevented local governments from being able to require mitigation (i.e., replacement) of trees removed or harmed. The second bill was successful and (at the time of writing) awaits approval from the governor of Florida. If signed, the new law would prohibit local governments from protecting trees on residential properties in the three months proceeding the hurricane season if the property owner has documentation from an International Society of Arboriculture Certified Arborist stating the trees in question are a danger to people or property. The bill prohibits any requirement of replacements for trees removed during this timeframe.

Tree ordinances that regulate tree removal are not new, with a history of several hundred years in the US and Canada (Dickerson et al., 2001; McPherson, 2001; Zhang et al., 2009; Conway & Lue, 2018). The findings for this study demonstrate the potential for ordinances to directly impact municipal UTC goals and other management priorities. Additional studies are needed to understand the impacts of ordinances across cities in other regions. Although our model suggests that the presence of heritage tree ordinances is associated with greater UTC at the municipal scale in Florida, there could also be variation in the ordinance-UTC relationship within a given city based on differing levels of enforcement or resident awareness (Hauer & Peterson, 2016; Conway & Lue, 2018).

4.3. UTC from aerial imagery

While visual interpretation of aerial photos to classify land cover is widespread in urban forestry, landscape ecology, and geography (e.g., Gerard et al., 2010; Morgan, Gergel, & Coops, 2010; Garzon-Lopez, Bohlman, Olff, & Jansen, 2013; See et al., 2013; Díaz-Porras, Gaston, & Evans, 2014; Carta, Taboada, & Müller, 2018), the application of this method to UTC has been criticized recently, particularly in comparison to modern LiDAR-derived spatially explicit UTC mapping technologies (O'Neil-Dunne, MacFaden, & Royar, 2014; Locke et al., 2017). Dot-based UTC assessment is a proven, albeit labor-intensive, method of conducting land cover classification (Nowak et al., 1996; Walton, Nowak, & Greenfield, 2008; Jackson, Moisen, Patterson, & Tipton, 2010; Morgan et al., 2010). In urban forestry research, dot-based interpretation has often been considered the standard to compare against other manual or more automated approaches for identifying canopy coverage (Nowak & Greenfield, 2010; Nowak & Greenfield, 2012; Parmehr, Amati, Taylor, & Livesley, 2016). Even LiDAR-derived land cover mapping involves manual corrections by technicians and accuracy assessments determined by visually examining random points (Congalton, 1991; O'Neil-Dunne et al., 2014). Accuracy assessments comparing LiDAR to visual interpretation indicate agreements generally above 97% (O'Neil-Dunne et al., 2014). For the Florida cities we studied, interpreter agreement averaged 97% (Table 2).

In testing the repeatability of dot-based canopy assessment, Jackson et al. (2010), compared canopy classifications for five locations across the United States. The authors 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) using the same imagery source (NAIP).

Several of the communities assessed for this study had previous assessments of UTC to draw on for comparison. In 2016, one year after our referenced imagery, researchers estimated Tampa had a total UTC of 32.3% (Landry et al., 2018). The 95% confidence intervals slightly overlap between that study and ours. 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 UTC 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, UTC estimates from Orlando's 2012 i-Tree Eco analysis (31.4%; Ekpe, Becker, Lab, Hinkle, & Escobedo, 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, Ucar, Bettinger, Merry, Siry, and Bowker (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, Fox, Landry, Northrop, & Hament, 2017). That noted, our estimate was in line with historic estimates of canopy coverage (59% to 67%) for Gainesville calculated by Szantoi, Escobedo, Dobbs, and Smith (2008). When municipal foresters seek to evaluate UTC change towards meeting goals, it will be important to utilize the same methods over time, and if aerial image interpretation is used, then the same set of points should be employed. While LiDAR-derived urban land cover maps provide complete mapping of tree cover within a city, not all cities can afford this technology, and visual interpretation of aerial photographs remains a viable option.

5. Conclusion

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). UTC directly affects many ecosystem services. 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.

This work provides evidence that at least some protection measures currently used in Florida communities are associated with greater UTC than in communities lacking the measure. In particular, we observed significantly greater UTC associated with communities that designated and protected heritage trees. These findings add much needed empirical evidence to debates surrounding urban forest management (Lemongello, 2017) which are playing out in Florida and beyond.

Additional research to investigate the associations between UTC and ordinances over time is the next logical step in this line of inquiry. Additionally, research concerning the relationships between urban forest management efforts and storm resiliency (specifically canopy loss and renewal) would be very relevant for hurricane-prone areas such as Florida. Development, redevelopment, and construction are ongoing processes in urban areas (Morgenroth et al., 2017; Steenberg et al., 2018), and there remains much to learn about interactions between these urban change processes, local urban forest management practices, and UTC spatiotemporal dynamics.

Authors' contributions

AKK, SL, and RJH conceived the experiment. RJH designed and implemented the survey. DRH, AKK, SL, and RJH adapted the canopy coverage assessment methodology used. KH, DRH, HC, and DL collected and maintained data under the supervision of DRH. DRH, AKK, LAR, SL, and KH led the writing effort. DRH, AKK, HP, RJH, MA contributed to initial drafting, internal review, and revisions of the first submission, as well as, subsequent revisions made after peer review.

Declaration of Competing Interest

The authors declare no conflict of interest.

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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
Section II – Budget
Section III – Tree Management Profile
Section IV – Volunteers/Partnerships
Section V – Contractors
Section VI – Inventory
Section VII – Operations Profile
Section VIII – Assistance Programs

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 h 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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