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Factors influencing urban tree planting program growth and survival in Florida, United States

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ABSTRACT

High levels of mortality after installation can limit the long-term benefits associated with urban tree planting initiatives. Past planting projects funded by the Florida Forest Service were revisited two to five years after installation to document tree survival and growth and assess program success. Additionally, various site (e.g., soil compaction, installed irrigation) and tree-related (e.g., species, nursery production method, initial size at planting) factors were noted to assess their impact on tree growth. Results show that the overall establishment rate for the 26 sites ($n = 2354$ trees) was high, with 93.6% of trees alive at the time of final inspection. On-site irrigation played a significant role in tree survival and growth, especially for *Magnolia grandiflora* (97.7% survival on irrigated sites; 73.8% survival on non-irrigated sites). Findings from this work validate the effectiveness of current program policies which include maintenance of tree quality within the first year after planting, and offer further insights regarding the impacts of season of planting and initial size of nursery stock on plant growth and development.

Introduction

Municipalities, non-profit groups, and state government agencies devote significant resources toward tree-planting initiatives intended to maximize and sustain the ecological services and health benefits associated with urban forests (Kendall and McPherson, 2012; Pincetl et al., 2013). In recent years, the scale and notoriety of these initiatives have increased, with numerous million-tree planting programs underway in major North American cities like Miami, Los Angeles, Denver, and New York (City and County of Denver, 2006; City of Los Angeles, 2006; Miami-Dade County, 2011; PlaNYC, 2013). While the number of trees planted can be an important factor in gauging the potential impact of these efforts (and is the primary metric tracked by each program), tree establishment in the landscape and longevity must ultimately be considered when assessing long-term program success.

Many of the benefits offered by urban trees increase as trees grow in size (Leibowitz, 2012; Maco and McPherson, 2003). Insufficient post-planting care (Beatty and Heckman, 1981; Gilman et al., 1998; Harris and Gilman, 1993), poor-quality nursery stock (McKay, 1996; Struve, 2009), limiting site conditions (Beatty and Heckman, 1981; Lemaire and Rossignol, 1999), and vandalism (Nowak et al., 1990; Jones et al., 1996; Impens, 1999; Nowak et al., 2004) can all contribute to the death of recently transplanted urban trees before they are able to make meaningful environmental and economic contributions to a community. In extreme cases of immediate or nearly complete post-transplant loss (Yang and McBride, 2003; Sklar and Ames, 1985; see Table 1), planting initiatives represent a wasted investment of human and financial capital, including materials and labor. Beyond economics, trees that die after transplanting do an ecological disservice considering the material inputs, energy inputs, and environmental impacts associated with tree production, transplanting, maintenance, removal, and disposal (Nowak et al., 2002; Kendall and McPherson, 2012; Ingram, 2012, 2013).

Urban tree mortality is generally greatest among the youngest trees, especially in the first two to three years following transplanting (Miller and Miller, 1991; Richards, 1979; Roman et al., 2013). In the past three decades, numerous researchers from North America and Europe have assessed post-transplanting establishment rates and growth during this tenuous period of an urban tree's life (Table 1). Many earlier works focused solely on gauging the level of planting survival in urban replanting efforts. However, more recent research has attempted to determine the biological,

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Table 1
Early (<10 years since planting) urban tree survival rates for past cited planting program studies.

Source	Location	Species	% survival (*n*)	Yrs since planting	Notes
Impens and Delcarte (1979)	Brussels, Belgium	Numerous	88.7 (2905)	1	Average survival and number planted for 4 assessment periods
Sklar and Ames (1985)	Oakland, CA, United States	Numerous	0.5 (2000)	<10	Federal inner-city planting program
			60–70 (1500)	<10	Community-based inner-city planting program; includes replacements
Gilbertson and Bradshaw (1990)	Liverpool, United Kingdom	Numerous	77.3(401)	3	
Nowak et al. (1990)	Oakland/Berkley, CA, United States	*Robinia pseudoacacia*	65.4 (254)	2	
		Magnolia grandiflora	63.8 (199)	2	
		Platanus × *acerifolia*	81.5 (27)	2	
Miller and Miller (1991)	Wisconsin, United States	Numerous	67.5 (2048)	4	Average survival across 10 species and 3 cities
Gerhold et al. (1994)	Pennsylvania and Maryland, United States	*Malus* spp.	94–100 (unknown)	3	Range of survival for 10 cultivars planted in 12 communities
Yang and McBride (2003)	Beijing, China	*Sophora japonica*	83.1 (450)	<1 (11 wks)	Large trees planted bare root with the majority of main structural roots/scaffold branches removed
		Fraxinus chinensis	62.7 (300)		
Thompson et al. (2004)	Iowa, United States	Numerous	91 (932)	4	Average for 21 cities/towns
Lu et al. (2010)	New York, NY, United States	Numerous	91.3 (45,094)	2	
Jack-Scott (2011)	Philadelphia, PA, United States	Numerous	95 (590)	1–5	Bare root stock; excludes missing/removed trees
			96 (573)	1–5	Balled-and-burlapped stock; excludes missing/removed trees
Roman and Scatena (2011)	Philadelphia, PA, United States	*Acer campestre*	78.8 (151)	2–10	
Jack-Scott et al. (2013)	New Haven, Connecticut, United States	Numerous	73.8 (1393)	4–16	
Roman et al. (2013)	Oakland, CA, United States	Numerous	80.3 (unknown)	1–4	

and in some cases, social factors contributing to young tree survival and mortality (Lu et al., 2010). In identifying the conditions associated with elevated planting mortality, urban forest managers can potentially eliminate or at least partially mitigate those conditions consistently linked to low rates of survival and establishment.

In this study, past planting projects funded by the Florida Forest Services from 2004 to 2008 were revisited to assess installed urban trees and identify conditions that contributed to enhanced or reduced survival and growth rates. This time frame includes data from a period of more intensive post-hurricane recovery planting following the 2004 and 2005 hurricane seasons (where seven named storms impacted parts of Florida). This work provides information about species tolerance to specific urban conditions in Florida, as well as key information regarding the appropriateness of stock type, tree size, and other factors under these conditions.

Materials and methods

Project selection

Records from the Florida Forest Service (FFS; formerly Florida Division of Forestry) headquarters in Tallahassee, FL (United States) were accessed in March 2010 to evaluate the success of past state urban forestry tree planting grants. Records were available for approximately 150 grants funded from 2004 to 2008. Only projects with an available project manager or contact person and mapped locations were included in the study data set. The trees in this study were installed in public spaces by volunteers, contractors, and staff through numerous organizations under a variety of urban conditions, nursery production systems, and hardiness zones. Prior to assessment, projects were stratified by geographic region (North/Temperate, Central/Transition, South/Sub-tropical; Fig. 1) site type, and presence or absence of irrigation. When available, at least three different projects were randomly chosen from the resulting groupings for on-site data collection. *Quercus virginiana* was the most commonly planted tree during the time period assessed and thus makes up the largest component of the study sample ($n = 1197$).

Trees were planted between March 2005 and March 2009. Each site was inspected by FFS personnel in the weeks following planting, and then again one year later, to ensure all trees were present, alive, met the Florida #1 grade (i.e., single trunk, full crown, minor/no trunk injuries, and only easily-corrected structural defects present) in accordance with Florida Grades and

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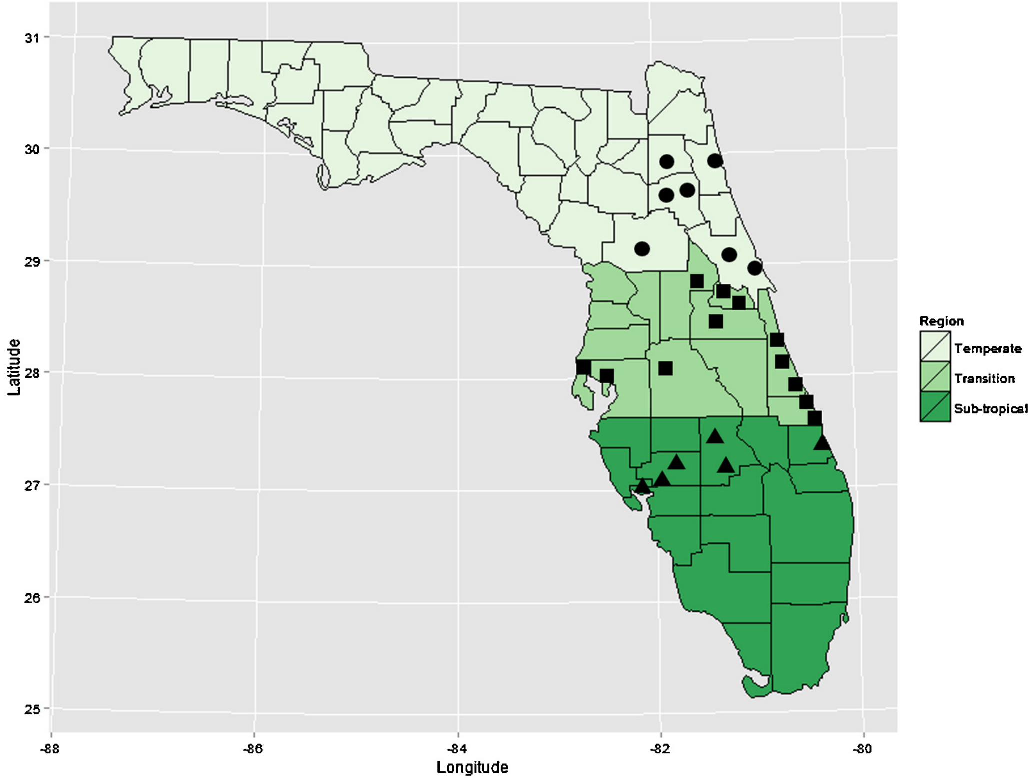

Fig. 1. Northern, central, and southern Florida (United States) planting sites evaluated in this study.

Standards for Nursery Plants (Florida Department of Agriculture and Consumer Services, 1998), and were planted at the proper depth with no soil covering the root ball surface.

Project managers for the selected grants were contacted in May 2010 to make arrangements for site visits and data collection. Site visits for data collection started on July 7, 2010 and ended on August 26, 2010. Data was collected for 26 projects located in 17 counties and 24 cities or towns in Florida, United States. On average, planting projects were assessed 38 months after installation. Time since installation ranged from 20 to 64 months.

Measurements

At each site, the number of living trees was counted and compared to the number originally planted to determine percentage survival for that project. Trees with at least some foliage were considered living. Trunk diameter (caliper) was measured with a diameter tape 15.3 cm from the ground. This value was compared to the caliper listed in the tree specifications contained in the project grant application. Crown condition (i.e., poor, fair, good, or excellent) and percentage of crown with live foliage were rated visually. Visible leans were noted (i.e., presence or absence of) and the structural quality of the tree was rated on a 5-point scale (i.e., 1: poor form with several codominant stems to 5: excellent form with one dominant leader to the top of the crown).

Tree firmness in the ground was assessed by grasping the trunk 1.2 m from the ground and rocking the tree back and forth. Trees were rated from one (i.e., loose) to five (i.e., firm). To evaluate soil compaction, mulch was removed from a small soil section 30.5 cm beyond the periphery of the original root ball in the north and south directions. A 1.9-cm tip diameter soil penetrometer (Soil Compaction Tester, Model 15585as1, DICKEY-john® Corporation, Auburn, IL, United States) was inserted 15.3 cm below the soil surface at each location. The highest reading was recorded for each tree.

Site type was noted for each planting project as one of five site types: parking lot, highway median (i.e., soil space between two opposing lanes of traffic), street tree (i.e., planted in a space between a sidewalk and a street curb), open lawn, or park tree. Additionally, the presence or absence of tree stabilization devices and in-ground irrigation was noted. All qualitative ratings above (e.g., crown condition, structural condition, firmness) were conducted by the same individual.

In addition to assessing survivorship, a total of 1197 *Q. virginiana*, 240 baldcypress (*Taxodium distichum*), and 154 southern magnolia (*Magnolia grandiflora*) were measured for this study. Growth models were developed separately for each species, accounting for geographic region, site type (open lawn, park, street, highway median or parking lot), season planted, firmness rating, measured soil compaction, initial caliper, and the presence/absence of irrigation. For *Q. virginiana* only, nursery production method (container- or field-grown) was also compared. Both the *T. distichum* and *M. grandiflora* were primarily container-grown.

Data analysis

Initial attempts to model survival using logistic regression were unsuccessful as the residuals were heavily over-dispersed. Specifying a quasi-binomial distribution failed to fully rectify this issue. As such, tree survival was compared among species (separating out irrigated and non-irrigated trees) using the prop.test ( ) function in R (R Core Team, 2013). The *Q. virginiana* were subject to additional testing to assess differences in survival among irrigated and non-irrigated trees for the two nursery stock types. The experiment-wise error rate for this series of tests was controlled using a Holm adjustment (Holm, 1979) calculated via the p.adjust ( ) function in R (R Core Team, 2013).

Final caliper growth was initially fit with the predictors and all two-way interactions using the lm( ) function in R (R Core Team, 2013). Each species was analyzed separately given the noted

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Table 2
Percentage of *Quercus virginiana*, *Taxodium distichum*, and *Magnolia grandiflora* surviving under irrigated and non-irrigated conditions in selected urban tree planting programs funded by the state of Florida, United States from 2005 to 2009. On average, planting projects were in the ground 38 months at the time of inspection.

Species	Irrigated		Non-irrigated		Significant difference[z]
	% survival	*n*	% survival	*n*	
Q. virginiana	97.5	717	94.2a[y]	1017	**
T. distichum	94.1	135	86.0b	250	.
M. grandiflora	97.7	132	73.8c	103	***

[z] Testing irrigated vs. non-irrigated within each species. Significance codes: "***": 0.001; "**": 0.01; ".": 0.10.
[y] Means in a column followed by different letters are significantly different at $P = 0.05$ (averaged across 26 planting sites in Florida, United States).

differences in production method, as well as, differences in the timing of planting (e.g., the *M. grandiflora* were not planted in summer). Initial diagnostic plots of residuals revealed issues with normality and heteroscedasticity. Both issues were corrected by log-transforming the final caliper response variable. A back and forth Akaike information criterion-based (AIC-based) stepwise deletion function was run as a coarse filter to remove non-significant factors and interactions. Further model simplification was conducted to remove any remaining non-significant factors and combine dummy variables for the categorical variables that were not significantly different from the base level (Crawley, 2013). This process was conducted one change at a time. Each new model was compared against its predecessor with an *F*-test to confirm the change in residual sums of squares was not significant ($P = 0.05$). Generalized variance inflation factors (GVIFs) for the terms in the resulting reduced models indicated there were issues with multicollinearity (Sheather, 2010). To allow for coefficient interpretation, we addressed this concern by removing interactions in an iterative manner and reassessing the remaining GVIFs. This process was used to identify the final reduced models.

Results

Survival

On sites where in-ground irrigation was present, survival rates were high and did not vary by species ($P = 0.0873$; Table 2). In contrast, survival rates did vary by species in non-irrigated locations ($P < 0.0001$). While the difference in survival rates for irrigated and non-irrigated *T. distichum* was marginally significant ($P = 0.0514$), the impact of irrigation was more pronounced in the *Q. virginiana* ($P = 0.0064$) and *M. grandiflora* ($P < 0.0001$).

The proportion of *Q. virginiana* trees surviving was not impacted by production method ($P = 0.1020$; Table 3). Similarly, survival rates for field-grown *Q. virginiana* planted in irrigated locations were not statistically different from field-grown trees planted in non-irrigated locations ($P = 0.1650$). In contrast, the proportion of irrigated container-grown trees that survived was greater than was observed in the non-irrigated container-grown trees ($P = 0.0361$).

Tree growth

For *Q. virginiana*, geographic region, season planted, months since planting, production method, presence/absence of irrigation, firmness rating, initial caliper, site type, and the interaction between production method and irrigation availability were all significant predictors of caliper growth when combined in the final, reduced model (Table 4). The final model yielded an adjusted R^2 value of 0.68. Caliper growth for *Q. virginiana* was significantly reduced in the transition region (the base level) as compared to both temperate and subtropical regions. Predicted caliper for spring-planted trees was larger than predicted caliper growth for the fall base level (Table 4). In contrast, both summer and winter planting were associated with reduced caliper growth (as compared to fall planting). Given our model, less caliper growth was predicted for both open lawn and street trees compared to the site base level (a combination of highway median, park, and parking lot trees; Table 4).

Presence of installed irrigation increased predicted caliper growth, with the interaction term indicating that container-grown *Q. virginiana* were more responsive to this site factor due primarily to slower growth without irrigation (Table 4). Also, increasing initial caliper (i.e., size of nursery stock at planting) increased predicted final caliper (Table 4). Finally, trees grew larger when firmly rooted in the ground (i.e., higher firmness rating) and when in the ground for a longer period of time (months planted, Table 4).

For *T. distichum*, geographic region, months since planting, tree looseness rating, initial caliper, and site type were all significant predictors of caliper growth in the final combined model (Table 4). This combination of factors yielded an adjusted R^2 of 0.73. Caliper growth was greatest in the temperate and least in the sub-tropical region, with the base level of "transition region" falling between the two dummy variables. Both open lawn and park sites had reduced caliper growth when compared to a combined base level that included highway median, parking lot, and street sites (Table 4). As with *Q. virginiana*, predicted caliper growth for *T. distichum* increased with initial nursery stock size (initial caliper) at planting (Table 4). Similarly, predicted growth increased as the months since planting and firmness rating increased.

Finally, geographic region, season of planting, presence/absence of irrigation, firmness rating, initial caliper, and site type were all significant predictors of *M. grandiflora* caliper growth (Table 4). The adjusted R^2 for the final model was 0.77. Predicted growth in the temperate region was significantly greater than the combined baseline level of transition and sub-tropical. Additionally, trees planted in spring grew larger than trees planted in fall (Table 4). In contrast, winter-planted trees grew slower than fall-planted trees (there were no summer-planted trees in the data set). Predicted growth for street trees was lower than in the other four site types. As with the other two species, predicted growth increased for sites with irrigation, nursery stock caliper, and firmness rating (Table 4).

Discussion

The overall establishment rate across the three species and 26 projects supported by the FFS Urban and Community Forestry Grant program was 93.6% at 20–64 months after planting ($n = 2354$). As noted earlier, this level of successful establishment may be partially inflated by the replacement of trees that died within a year of planting. In comparison to our findings, Thompson et al. (2004; Table 1) reported a survival rate of 91% for utility tree-planting programs in Iowa that did not have a similar inspection and replacement policy. Similarly, Gilbertson and Bradshaw (1985) reported a survival rate of 90.3% for planted urban trees in Britain with no early replacement.

Beyond the replacement policy, the relative success of the FFS sponsored planting projects may be at least partially attributable to rigorous nursery stock quality requirements (Florida #1 or

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Table 3
Percentage of balled and burlapped and container-grown *Quercus virginiana* surviving under irrigated and non-irrigated conditions in selected urban tree planting programs funded by the state of Florida, United States from 2005 to 2009. On average, planting projects were in the ground 38 months at the time of inspection.

Production method	Irrigated		Non-irrigated		Significant difference[a]
	% survival	*n*	% survival	*n*	
Container-grown	97.1	717	93.9	1017	*
Field-grown	98.5	135	95.7	250	NS

[a] Testing irrigated vs. non-irrigated within each production method. Significance codes: "*": 0.05; "NS": non-significant.

better) and on-sight inspections that required all trees to be alive and in conformance with the nursery stock quality requirements one year after planting. Trees missing or dead within several months of the initial planting were certified as having been replaced by further on-sight inspection. Another indicator of good follow-up management was that only 2.5% of all trees measured still had staking materials present beyond the first year (failure to remove in a timely manner can lead to trunk girdling).

Several key patterns emerge in the analyses, offering a relatively straightforward interpretation of the factors contributing to tree growth and longevity. With the *Q. virginiana*, the proportion of container-grown trees surviving on sites with an irrigation system present was significantly greater than the proportion of container trees planted at sites without irrigation systems (Table 4). With field-grown stock, the benefit of an onsite irrigation system was less pronounced and not statistically significant. This is because the survival of field grown trees was higher than container-grown trees at sites lacking an irrigation system. A similar pattern was seen with caliper growth models. Dummy variables in regression have a simple additive effect on the predicted response. For our *Q. virginiana* model, the final predicted caliper growth was increased for trees at sites with irrigation systems (Table 4). For container-grown stock, the container produced × irrigation system present interaction showed that the container trees response to onsite irrigation was greater than the balled and burlapped response – partially negating the growth reductions seen with the former production method. In addition to benefits noted with the *Q. virginiana*, irrigation significantly increased survival and was associated with

Table 4
Final models and regression results for urban tree (log-transformed) caliper growth. Data for the three species (i.e., *Quercus virginiana*, *Taxodium distichum*, and *Magnolia grandiflora*) were collected an average of 38 months after planting in selected north (temperate zone), central (transition zone), and south (sub-tropical zone) Florida, United States.

Species	Factor	Coefficient	Standard error	*P* value	95% CI lower	95% CI upper
Q. virginiana	Intercept	0.909	0.074	<0.0001	0.7651	1.0535
	Geographic region – north[a]	0.215	0.018	<0.0001	0.1798	0.2507
	Geographic region – south[a]	0.212	0.017	<0.0001	0.1778	0.2456
	Planting season – spring[b]	0.078	0.023	0.0008	0.0326	0.1243
	Planting season – summer[b]	−0.051	0.025	0.0441	−0.1014	−0.0014
	Planting season – winter[b]	−0.053	0.028	0.0533	−0.1074	0.0008
	Months since planting	0.005	0.001	0.0006	0.0020	0.0072
	Container-produced[c]	−0.192	0.022	<0.0001	−0.2341	−0.1490
	Irrigation installed	0.070	0.023	0.0024	0.0250	0.1152
	Firmness rating[d]	0.171	0.007	<0.0001	0.1570	0.1854
	Initial caliper	0.092	0.005	<0.0001	0.0823	0.1024
	Site type – open lawn[e]	−0.076	0.015	<0.0001	−0.1051	−0.0460
	Site type – street[e]	−0.153	0.023	<0.0001	−0.1977	−0.1082
	Container produced × irrigation present (interaction)	0.098	0.027	0.0004	0.0435	0.1522
					Adjusted R^2	0.68
T. distichum	Intercept	−0.4838	0.3495	0.1676	−1.1723	0.2047
	Geographic region – north[a]	0.2402	0.0461	<0.0001	0.1493	0.3311
	Geographic region – south[a]	−0.2337	0.0936	0.0132	−0.4181	−0.0493
	Months since planting	0.0452	0.0096	<0.0001	0.0262	0.0642
	Firmness rating[b]	0.1382	0.0242	<0.0001	0.0906	0.1858
	Initial caliper	0.1353	0.0110	<0.0001	0.1136	0.1569
	Site type – open lawn[f]	−0.3027	0.0555	<0.0001	−0.4121	−0.1933
	Site type – park[f]	−0.5222	0.0826	<0.0001	−0.6849	−0.3595
					Adjusted R^2	0.73
M. grandiflora	Intercept	1.0877	0.0992	<0.0001	0.8916	1.2836
	Geographic region – north[g]	0.4023	0.0649	<0.0001	0.2741	0.5305
	Planting season – spring[b]	0.1689	0.0481	0.0006	0.0737	0.2640
	Planting season – winter[b]	−0.2184	0.0506	<0.0001	−0.3182	−0.1184
	Irrigation present	0.4348	0.0552	<0.0001	0.3257	0.5437
	Firmness rating[d]	0.1160	0.0154	<0.0001	0.0855	0.1465
	Initial caliper	0.0621	0.0188	0.0012	0.0249	0.0991
	Site type – street[h]	−0.3246	0.0775	<0.0001	−0.4777	−0.1713
					Adjusted R^2	0.77

[a] Compared to based level "geographic region – central".
[b] Compared to based level "planting season – fall".
[c] Compared to based level "balled and burlapped".
[d] Loosely anchored trees = 1; firmly anchored trees = 5.
[e] Compared to combined based level of "site type – highway median", "site type – park", and "site type – parking lot".
[f] Compared to combined based level of "site type – highway median", "site type – parking lot", and "site type – street".
[g] Compared to combined based level "geographic region – central" and "geographic region – south".
[h] Compared to combined based level of "site type – highway median", "site type – park", "site type – parking lot", and "site type – open lawn".

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increased caliper growth for both the *T. distichum* and the *M. grandiflora* (Tables 2 and 4).

The significance of irrigation is in line with past findings by Clark and Kjelgren (1990), who observed that even small amounts of water clearly improved survival and net productivity of urban trees in the Seattle area. One irrigation event in an extended dry period 14 months after planting *Q. virginiana* from 45 gallon containers in Florida made the difference between life and death (Gilman and Masters, 2010). Scientists and urban foresters have ranked water stress as one of the major problems encountered by urban trees (Whitlow and Bassuk, 1987). In a comparison of street side and natural habitat sugar maples (*Acer saccharum*), Close et al. (1996) determined that water stress was the factor most adversely influencing the growth of street trees.

Interestingly *Q. virginiana* planted in open lawn sites and *T. destichum* planted in open lawn and park sites experienced reduced caliper growth. These results are counter-intuitive given past work which found that trees growing in more open spaces, and thus with more rootable soil area, had better growth than trees growing in more restricted sites (Berrang et al., 1985; Vrecenak et al., 1989; Kjelgren and Clark, 1992; Flückiger and Braun, 1999; Grabosky and Gilman, 2004).

Q. virginiana planted in the landscape from field nurseries performed better overall in the landscape when compared to container-grown trees (Table 4). This has also been shown for *Q. virginiana* and other species in several other studies under much more controlled conditions (Gilman and Masters, 2010). Field-grown trees consistently produce more roots out into the landscape soils which translate into better tree survival and growth. However, survival rate was not affected by tree production method (Table 4).

Finally, past research in a colder climate has suggested that smaller nursery stock establishes faster and grow more quickly than larger trees planted at the same time (Watson, 1985, 2005). As Gilman et al. (2013) showed for *Acer rubrum* L. in Florida, we did not see this trend in our data. Compared to past works (Watson, 2005), the initial differences in caliper seen with our trees were much less dramatic and were based on planting records, not direct measurement. Similarly, the time frame for assessing growth and establishment was shorter than assessed by Watson (2005).

Conclusions and recommendations

Through extensive data collection at 26 sites across the state, we conclude that the FFS Urban and Community Forestry Grants Program is an effective model for urban replanting efforts. Survival rates for the species assessed were high in comparison to the documented experiences of other states and communities in the United States, Canada, and United Kingdom (Table 1) with the notable exception of non-irrigated *M. grandiflora*. This low mortality is at least partially attributable to the planting specifications calling for Florida # 1 (or better) nursery stock, industry-accepted planting practices, inspection one year after planting by FFS personnel, and the required replacement of missing or dead trees by the communities and organizations receiving grants.

This work shows that plant growth can be maximized by accounting for factors such as season of planting, site selection, and irrigation. All government agencies funding tree planting projects should continually assess the implications of their policies in the urban landscape. Doing so will increase the environmental and economic impacts of funds invested in replanting efforts.

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