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Original article

Health and establishment of highway plantings in Florida (United States)

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ABSTRACT

Urban tree planting initiatives can experience high levels of mortality during establishment years. Mortality tied to the stresses of transplanting can be partially negated or exacerbated depending on the species selected, nursery materials used, site conditions present, and management practices employed. Past research has quantified post-planting survival, health, and growth. However, varying climates, species, land use types, and management practices warrant additional region-specific research. The purpose of this study is to assess the success of plantings along Florida highways and identify species, site, and management factors related to tree and palm health and establishment. Results show high establishment survival (98.5%) across 21 planting projects ranging from 9 to 58 months after installation (n = 2711). For transplanted palms, the presence of on-site irrigation significantly improved establishment from 96.2% to 99.4%. No establishment differences were detected with regard to irrigation treatment for small-stature trees, shade trees, and conifers. Additionally, there were significant differences in tree health response among tree groups given species, management, and site factors.

1. Introduction

Urban tree growth and longevity has gained greater attention from researchers and practitioners in recent years (Ko et al., 2015a; Koeser et al., 2014; Leibowitz, 2012; Lu et al., 2010; Roman and Scatena, 2011; Vogt et al., 2015), including those looking to increase long-term ecosystem services through planting initiatives (Ko et al., 2015a; McPherson, 2014; Widney et al., 2016). In addition to documented benefits like improved human health (Nesbitt et al., 2017), increased tourism (Deng et al., 2010), building energy conservation (Ko, 2018), and storm water management (Berland et al., 2017), urban trees provide transportation corridor-specific benefits such as improved driver mentality (Wolf, 2003), enhanced roadway definition (Van Treese et al., 2017), and slowed asphalt degradation through shading (McPherson and Muchnik, 2005).

In planting trees to increase these and other benefits, the first years after installation are often noted as the most difficult time of a tree's life (Miller and Miller, 1991; Roman et al., 2014a). Mortality during this establishment phase not only undermines future economic benefits (Widney et al., 2016), but can, in cases of extremely low survivorship, cause environmental harm when considering the material and energy inputs associated with nursery operations, installation, and maintenance (Petri et al., 2016). To ensure urban plantings function as intended, factors related to post-planting mortality must be identified regionally (i.e., between areas with differing climates and management activities) within specific land use types, and mitigated through best management practices.

1.1. Factors that influence planting success

Past research indicates that the survival or death of a newly-planted tree can be influenced by a range of factors. Vogt et al. (2015) noted four distinct categories that helped predict tree mortality in urban environments: (1) tree-related factors, (2) environment-related factors, (3) management-related factors, or (4) community-related factors.

Tree-related factors include species selection (Koeser et al., 2013; Lu et al., 2010; Miller and Miller, 1991), species water requirements (Roman et al., 2014b), size at planting (Watson, 2005), mature tree size

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(Ko et al., 2015a, 2015b; Roman et al., 2014a, 2014b), and tree age or time since planting (Koeser et al., 2014; Lu et al., 2010; Roman et al., 2014b). Additionally, tree health assessed at a given point in time has been cited as a factor for predicting future mortality (Martin et al., 2016) and growth (van Doorn and McPherson, 2018). For example, poor condition ratings during initial inventories correlated with tree mortality in follow-up inventories (Koeser et al., 2013; Roman et al., 2014a). This indicates the usefulness of tree health metrics in urban forest management.

Environment-related factors for tree success include a range of conditions related to the climate, soil conditions, and land use of a site. Regarding land use, transportation corridors can be difficult sites for tree survival. For example, a study from Baltimore, Maryland reported 20.2% average annual mortality in transportation corridors (compared to an overall average mortality of 6.6%) (Nowak et al., 2004). Similarly, Lu et al. (2010) found that median trees planted in New York City, New York demonstrated only 53.1% survival for trees ranging 3–9 years since planting. Mortality has been found to be positively correlated with increased traffic intensity and speed limits (Lu et al., 2010; Jack-Scott, 2012), but not all studies support such findings (Vogt et al., 2015). In a Florida tree establishment study, highway median tree growth was similar to that of parks and parking lot site types, while street trees demonstrated lower growth in two of three tested species (Koeser et al., 2014).

Beyond land use, urban soil conditions can have a significant impact on tree survival, growth, and health (Day et al., 2010; Scharenbroch and Catania, 2012). In an extreme case of low roadside planting survival, Jim (1993) attributed high first year mortality of trees (95%) and palms (63%) to poor soil conditions that included drainage, structure, pH, salinity, and elemental toxicities. In roadside environments, underlying and adjacent soils are typically modified to support load (Randrup et al., 2001). These modified soils are highly compacted and low in organic material (McGrath and Henry, 2016), reducing soil structure and aggregates suitable for tree growth (Jim, 1998a). Soil compaction limits root growth and root penetration into surrounding soil (Bary et al., 2016; Kristoffersen, 1999). In addition to altered soil structure, high alkalinity (especially near concrete roadways) ultimately limits nutrient availability and uptake (Jim, 1998b). Heavy metals and other contaminants from traffic exist in roadside soils but are unlikely to reach toxicity levels that effect plant growth (Jim, 1998b) and health (Morse et al., 2016).

Florida soils are generally sandy-textured, which can limit water and nutrient holding capacity (Harris et al., 2010). Additionally, highway interchange slopes and embankments can increase runoff and reduce infiltration. Without proper irrigation (and berms surrounding the transplanted root ball), trees may experience chronic drought conditions – especially during the winter dry period in peninsular Florida. Other site-related factors beyond soil include climate (Koeser et al., 2014), microclimate (Martin et al., 2016; Whitlow and Bassuk, 1987), and crown light exposure. Vogt et al. (2015) did not find crown light exposure to be a significant predictor of tree survival. However, Roman et al. (2015) noted that high levels of sunlight exposure paired with irrigation cessation resulted in increased tree mortality for trees planted along a highway in California.

Management-related factors that can influence tree performance include, among other things, the contractor hired (Foster and Blaine, 1978) and monitoring program employed (Roman et al., 2013). Regarding new plantings, nursery cultivation practices (Allen et al., 2017; Jack-Scott, 2012; Koeser et al., 2014), the presence of quality assurances/standards for nursery stock (Koeser et al., 2014; Roman et al., 2015), proper handling of plant materials (Koeser et al., 2009; Struve, 2009), planting season selection (Ko et al., 2015a; Koeser et al., 2014; Miller and Miller, 1991; Roman et al., 2014b; Vogt et al., 2015), and planting depth can impact survival (Gilman and Grabosky, 2004; Wells et al., 2006). After planting, management factors that influence tree performance include irrigation (Gilman et al., 1998, 2013; Koeser et al., 2014; Vogt et al., 2015; Roman et al., 2015), staking care (Foster and Blaine, 1978; Labrosse et al., 2011), mulching (Gilman et al., 2013; Scharenbroch, 2009), and site mowing practices (Morgenroth et al., 2015; Percival and Smiley, 2015).

Roman et al. (2015) reported a case study in California where high establishment survival (96.3% over six years) was observed along highway sound walls. The authors attributed this to regionally-appropriate species selection, as well as planting and stewardship practices that included continuous monitoring and maintenance by trained volunteers and youth interns. Use of high quality nursery stock, on-site irrigation, mulching, weed removal, and staking as needed were other indicators of a high level of care received. The primary cause of mortality in this case study, as well as a study by Foster and Blaine (1978), was vehicular strikes.

Multiple research efforts have explored relationships between community-related factors and tree survival and growth. Those factors include housing stability (Roman et al., 2014b), property value (Ko et al., 2015a), homeownership (Nowak et al., 1990; Vogt et al., 2015), volunteer commitment (Boyce, 2010), and unemployment (Nowak et al., 1990) with planting program success. More recently, Limoges et al. (2018) did not find significance between socioeconomic factors and tree growth. Most of the aforementioned citations involved street or yard trees that were planted and/or maintained by residents and/or volunteers. The extent to which community factors impact planting programs which are planned, installed, and maintained by professionally trained, well-funded organizations is unknown.

1.2. Health and establishment of palms

While urban tree growth and longevity research is an active area of inquiry, most studies focus on trees in temperate climates (Lima et al., 2013). As such, palms have been researched less than other woody plants. The relatively small body of research that examines factors of palm establishment in both landscape and nursery settings is summarized in Table 1. For species like *Sabal palmetto* where roots die back to the trunk when severed for harvesting, removing all of the living fronds before transplant can improve survival from 64% to 95% by lessening transpiration until new roots are regenerated (Table 1) (Broschat, 1991). Most palm species, however, regrow roots from the point at which they are cut after digging. As such, pruning at transplanting may not be necessary to maintain a root/shoot balance for these species during the establishment phase. However, Broschat (1994) demonstrated that recently transplanted *Phoenix roebelenii*, only benefitted from pruning when exposed to soil water stress. In general, benefits associated with frond removal (and tying) are variable and species specific (Hodel et al., 2006).

Planting depth of palms is also a factor that can influence survival (Broschat, 1995). Hodel et al. (2005) found transplant season temperature and rootball size to be the most important factors related to establishment success for *Washingtonia robusta*, *Phoenix reclinata*, and *Phoenix canariensis*. However, Broschat (1998) observed that planting season in southern Florida may not be important as warm temperatures allow for near year-round root and shoot elongation. Hosek and Roloff (2016) assessed urban site factors (above-ground space and distance to roadway) but found weak or no correlation with palm health.

1.3. Project justification

The Florida Department of Transportation's (FDOT) "Bold Initiative" invests $40 million (USD) annually on highway beautification (Khatchatryan et al., 2014). Trees and palms serve as a key element of installations along the most travelled corridors (Ko et al., 2015a). The scale of this program warranted further investigation from the perspective of establishment performance. Tree establishment performance monitoring, if incorporated into adaptive management efforts, can enhance the program's future success and help ensure its projected

Table 1
Factors associated with palm growth, health, and transplant success.

Reference	Setting/ Location	Time Since Planting	Species	Factors[z]	Notes
Broschat and Donselman (1990)	Field nursery/Fort Lauderdale, FL	7 months	*P. roebelenii, C. elegans*	Biological age (G+, S+)	Immature plants = 100% mortality
Broschat (1991)	Median/Miami, FL	8 months	*S. palmetto*	Transplanting without fronds (G+, S+)	G assessed by canopy size
Broschat (1994)	Nursery Fort Lauderdale, FL	5 months	*P. roebelenii* (water stressed) *P. roebelenii* (non-water stressed)	Transplanting without fronds (G+, S+) Top-irrigation (H -)	G assessed using root dry-weight and live-frond count Leaf-tying showed no improvements
Broschat (1995)	Field nursery/Fort Lauderdale, FL	15 months	*P. roebelenii*	Transplanting depth below original (G -, H -, S -)	G assessed using frond count. H assessed using tissue analysis
Hodel et al. (2005)	Arboretum/Los Angeles, CA	3 years	*W. robusta, P. reclinata, P. canariensis*	Wet season planting (G+), rootball size (G+, S+)	G assessed using root biomass
Broschat (1998)	Rhizotron/Fort Lauderdale, FL	2 years	*R.regia, C. nucifera, S. romanzoffiana*	Air/soil temperature (G+)	G assessed with root/shoot elongation and frond count.
Hodel et al. (2006)	Field nursery/Borrego Springs, CA	5 months	*W. robusta*	Leaf removal/tie (no effect G, H, or S)	G assessed w/ new leaf count. H assessed visually (color)
Hosek and Roloff (2016)	Urban environments/Olhão, Portugal	Unknown	*C. humilis, W. robusta, P. canariensis*	Above ground space (H+), Distance to road (H+)	Weak correlations but sig. Health assessed visually.

[z] Growth, "G," health "H," and survival "S." "+" indicates positive associations between factors and responses, while "-" indicates negative associations.

economic impacts materialize (Khatchatryan et al., 2014). In addition to economics, successful establishment and long-term survival of these plantings has the potential to provide human health (e.g., traffic calming) and ecological services for decades to come.

The goal of this research was to assess the establishment and health of FDOT plantings installed along Florida's highway system between 2011 and 2016. This work provides insight into tree-specific responses given varying site conditions and management techniques, which may help to guide appropriate management strategies and work specifications. Examining roadside trees in a so far under-researched region of the United States provides valuable information in the broader subject of tree growth and longevity research. In addition, the plantings assessed included a high percentage of palms (51.6%), which are often absent from similar works published in the past.

2. Materials and methods

Between June 26, 2017 and October 12, 2017, twenty-one roadside tree planting projects were sampled across seven (of eight) FDOT districts (Fig. 1). District 6 (Miami), was excluded from inventory given the timing of the experiment and tree losses associated with Hurricane Irma (Mayer, 2017). Also excluded from data collection were *Phoenix* spp. due to the prevalence of lethal bronzing (formally Texas Phoenix palm decline or TPPD) in Florida, a phytoplasma pathogen that has been associated with catastrophic losses (Harrison and Elliott, 2016). These exclusions allow analyses of mortality and health in more typical circumstances, absent catastrophic loss (Lugo and Scatena, 1996). Within each district, planting project areas were randomly chosen from those installed between July 2012 and October 2015. Many of the FDOT planting initiatives are very large, with a single planting installment having several hundred trees planted along every side of a particular highway interchange or FDOT property. Therefore, one contiguous section of an interchange/site was sampled at random for inventory rather than a complete planting installment.

All trees were installed by professional contract labor. FDOT favors the installation of container-grown shade trees (species that reach at least 9.14 m at maturity), small-stature trees (species under 9.14 m at maturity), and conifers, while palms are generally field-grown. Contractors were responsible for the planting and maintenance of projects for a specified time after planting (12 or 24 months, dependent upon contract specifications), known as the "establishment" phase. This phase began at the completion of the installation process. During the establishment phase, monthly inspections were made by FDOT personnel or subcontractors to ensure all trees were alive and at the highest grade according to the Florida Grades and Standards for Nursery Plants (2015). If those criteria were not met and uncorrectable, the contractor was notified to replace the tree with the same size/species and would be charged for each day the tree was not replaced, at no cost to FDOT. Contracts specified irrigation, fertilization, staking, and mulching but details varied by planting project. For example, some contracts specified that staking and bracing material be removed at the end of the first year of establishment, while others specified removal at the end of the second year. Within a planting project, some trees received drip irrigation (1285 trees) while others were irrigated by truck or possibly non-irrigated (1241 trees), dependent upon vehicular access and access to an irrigation source.

After final inspection of the establishment phase, the planting project maintenance responsibility was passed on to the FDOT Office of Maintenance or, in some instances, the project was turned over the surrounding municipality. In either case, FDOT regularly inspected landscape areas to assess survival and tree pruning needs.

For this study, establishment is defined as the proportion of trees alive compared to the number of trees encountered at the time of sampling. Numerous other methods are used to assess establishment, such as tissue growth rates, physiological processes, or combinations of both (Levinsson et al., 2017). Standing dead trees, stumps, and missing

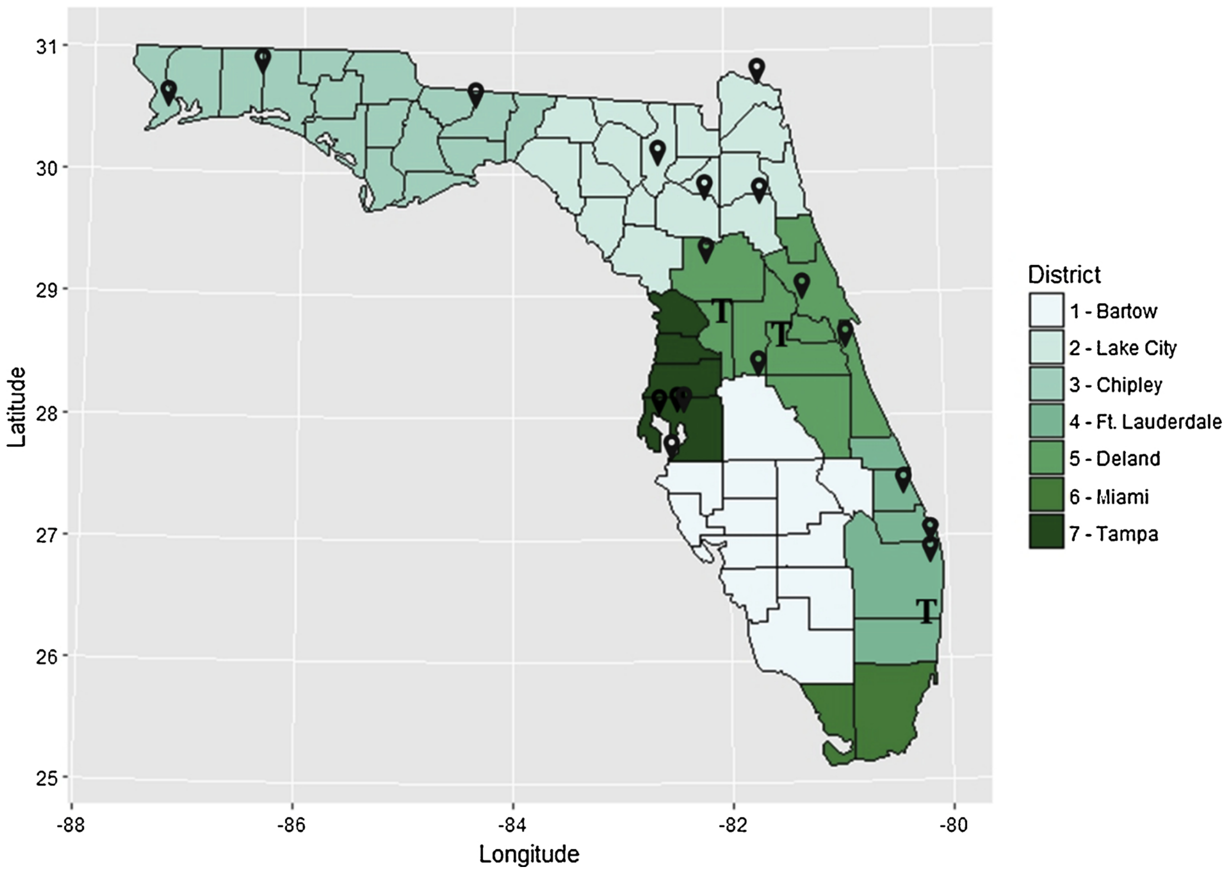

Fig. 1. Florida Department of Transportation District Map (United States) with marked locations of planting projects sampled in this study. Turnpike District projects denoted with “T”.

trees were all included when assessing trees that failed to fully establish in the landscape. Trees that appeared to be replacements were identified using visual cues that distinguished the tree from others in the planting project such as new mulch, new staking material, recently pruned canopy on palms, flagging tape, or different bark texture. However, true replacement status could not be confirmed.

Establishment and health were evaluated relative to a range of tree-, site-, and maintenance-related factors (Table 2). Health was rated using the method outlined by Bond (2012) – classifying growth, opacity, ratio, quality, and vitality into 20% scoring classes. The presence or absence of trunk damage, the presence or absence of a visible trunk flare, tree type (e.g., conifer, palm, shade, and small-stature), time since planting, site slope, presence or absence of installed irrigation, and the duration of staking were all assessed visually. For trunk damage, notes were made regarding the likely cause (e.g. mowing, sunscald, staking, etc.). This differentiation was used to facilitate further analysis on factors associated with mower damage.

Among the site-related predictor variables assessed in this study were those detailed by Scharenbroch et al. (2017) in their creation of the Rapid Urban Site Index (RUSI). The index was modified for this

Table 2
Overview of variables used in Florida Department of Transportation roadside tree planting analyses.

Variable	Description	Type	Collection Level[x]	Source
Response				
alive (0/1)	any living foliage, present	binary	tree	
quality (0-5)	% upper canopy free of chlorosis, necrosis, stunting	ordered	tree	Bond (2012)
vitality (0-5)	% upper canopy free of dieback	ordered	tree	Bond (2012)
Explanatory				
trunk damage (0/1)	Presence/absence with notes regarding likely source (e.g. lawn care, staking, sunscald, other)	binary	tree	
root flare (0/1)	visible without digging	binary	tree	
tree type[y]	small-stature, shade, conifer, palm	categorical	tree	
planting season	wet/dry	categorical	project	Misra and Mishra (2016)
years since planting	since beginning of establishment phase	numeric	project	
slope	median of 5% increments	numeric	tree	
irrigation (0/1)	installed at tree	binary	tree	
stake duration	> or < one year	categorical	tree	Koeser et al. (2014)
RUSI Scores	see Table 3	ordered	tree/zone/project	Scharenbroch et al. (2017)

[x] Collection level indicates the location within a planting project data was collected, where “tree” indicates an individual observation. Data collected within a “zone” or “project” was applied to each observation within that specified area.

[y] Small-stature (< 9.14 m) and shade (> 9.14 m) were designated by maximum heights at maturity.

Table 3
Scoring functions and adaptations of Rapid Urban Site Index (RUSI) parameters (Scharenbroch et al., 2017) for use in Florida Department of Transportation roadside tree planting analyses. RUSI parameters are explained in the Methods section.

RUSI Parameter	Units	Collection Level[v]	RUSI Score			
			0	1	2	3
INFR	m	tree	< 1	1-5	6-10	> 10
TRAF	n/a	n/a	excluded due to lack of site variation			
SURF	n/a	tree	bare soil	patchy veg	thick veg	mulch
PEN	lbs/sq in	tree	300+	201-300	101-200	0-100
STRC[y]	n/a	zone	M, SG, PL	ABK	SBK	GR
TXT[z]	n/a	zone	no soil; CF > 75%	S, SI, C; CF = 50-75%	LS, SCL, SICL, CL, SC, SIC; CF = 25-49%	SL, SIL, L; CF < 25%
pH	pH	zone	< 4 or > 9	4-4.9 or 8.1-9	5-5.9 or 6.6-8	6-6.5
EC	$\mu S\ cm^{-1}$	zone	< 50 or > 3,000	50-100 or 2,001-3,000	101-300 or 1,001-2,000	301 to 1,000
SOM[x]	% OM	zone	< 1.08	1.08-1.60	1.60-2.17	> 2.17
AHOR	cm	zone	< 1	1-5	6-15	> 15
ERA	m^2	tree	< 5	5-25	26-50	> 50
WAS	%	zone	no aggregate	< 50% post soak	< 50% post swirl	> 50% post swirl
PPT[w,x]	$mm\cdot yr^{-1}$	project	< 1290	1290-1372	1372-1585	> 1585
GDD[x]	days, base 50	tree	< 6992	6992-7663	7663-8069	> 8069
EXP	# sides	tree	0	1-2	3-4	5

[v] Collection level indicates the location within a planting project data was collected, where "tree" indicates an individual observation. Data collected within a "zone" or "project" was applied to each observation within that specified area.
[w] scoring function unaffected by onsite irrigation.
[x] scoring functions determined by breaking data into quantiles.
[y] M = massive; SG = single grained; PL = platy; ABK = angular blocky; SBK = subangular blocky; GR = granular.
[z] CF = coarse fragments; C = clay; S = sand; S = silt; SIC = silty clay; SICL = silty clay loam; CL,=clay loam; SC = sandy clay; SIL = silt loam; L = loam; SCL = sandy clay loam; SL = sandy loam; LS = loamy sand.

study, though the following factors were replicated exactly as detailed: distance to infrastructure (INFR), estimated rooting area (ERA), soil texture (TXT), soil structure (STRC), surface (SURF), wet aggregate stability (WAS), crown light exposure (EXP), A-horizon depth (AHOR), and electrical conductivity (EC). Modifications were made to penetration (PEN), growing degree days (GDD), precipitation (PPT), soil organic matter (SOM), pH (pH), and traffic (TRAF) factors and are listed in Table 3. In general, changes to the index were made to accommodate available equipment or to account for regional differences (Table 3).

Penetration (PEN) was measured using a soil cone penetrometer (Soil Compaction Tester, Dickey-John Corporation, Auburn, Illinois, United States) 15.3 cm below ground at the outer periphery of the root ball. Two measurements were made per tree and the average readings were recorded. Additionally, percent slope was measured using a digital level (THD9407, Husky, Atlanta, Georgia, United States) on two sides of the tree (in line with the predominant slope) and averaged. The RUSI factors TRAF, INFR, ERA, SURF, and EXP were also recorded for each tree. Several RUSI variables (i.e., TXT, STRC, pH, EC, OM, AHOR, and WAS), were assessed for groups of trees planted in zones of similar soil characteristics that were stratified by visual cues (e.g. ground vegetation, slope, distance to hardscape, etc.,) within a given planting area. Within each stratified zone, ten samples were collected with a soil core and used to create an aggregate soil sample. Finally, the climatic ratings PPT and GDD were assessed at the site level (i.e., all trees at a given location had the same rating).

Trees were classified and analyzed by tree type (shade, small-stature, conifer, and palm). Shade trees are those species that reach at least 9.14 m (30 feet) at maturity while small-stature trees do not reach that threshold. Species with fewer than twenty observations were excluded from establishment and health analyses. Within tree type, species that did not experience any mortality (i.e., 0% missing, stumps, or standing dead) were excluded from establishment analysis. Given regional differences across Florida, planting season was determined based on the project location's wet season onset and demise observation dates (Misra and Mishra, 2016). Potential replacement trees were included in all analyses. All statistical analysis was performed using R version 3.3.2 (R Core Team, 2016). Attempts at modeling establishment success using logistic regression were unsuccessful given the high success rate (some cases had 100% establishment). Attempts to rectify the issue by reducing predictor variables failed. Therefore, the prop.test() function in R was utilized to test the null hypothesis that probabilities of tree establishment were not different when considering different treatments for on-site irrigation (i.e., present vs. absent) which uses Pearson's chi-square test. An experiment-wise error rate was controlled for using a Holm adjustment (Holm, 1979).

Of the 2711 relocated trees, 2403 trees were visually rated for health using the methods outline by Bond (2012). Prior to analysis, health ratings were normalized based on the mode rating observed within each species (Bond, 2012). Differences in health were normalized as deviations from the most common rating for each species (Table 4). Of the five health ratings detailed by Bond (Bond, 2012), quality and vitality were the most widely used among the species assessed and are reported in the results below. In modeling tree-, site-, and maintenance-related factors associated with increased or decreased health ratings, odds ratios were calculated to quantify the likelihood of a rating change given a one-unit change in an ordinal predictor variable (e.g. RUSI pH score increasing by one) or the presence/absence of categorical variable (e.g., on-site irrigation). These two health responses were fit against the predictors noted in Table 2 using ordinal logistic regression. Modeling was conducted using the polr() function from the MASS package in R (Venables and Ripley, 2002). Full models were simplified to the final models reported below by removing non-significant predictors in a one-at-a-time manner and assessing whether the fit differed between the original and reduced model using the anova() function in R (Crawley, 2013).

Due to the importance of maintenance practices in urban tree

Table 4
Normalized health rating descriptions.

Health Rating	Description
Dead	Dead, missing, or removed observation
Critical	3 or more deviations below the new normalized value
Poor	2 deviations below the new normalized value
Fair	1 deviation below the new normalized value
Normal	0 deviations below the new normalized value
Excellent	1 deviation above the new normalized value

Table 5
Establishment success for trees planted on sites with drip irrigation installed and for trees planted on sites lacking permanent irrigation. Data only includes trees with more than 20 replications which were assessed for health (n = 1999).

Group	Permanent irrigation present		No permanent irrigation		
	% established	n	% established	n	P-value (Holm)
Conifer	98.3	115	95.1	102	0.356
Palm	99.4	601	96.1	625	0.006
Shade	100	155	96.1	26	n/a
Small-stature	99.6	285	97.8	90	0.290

planting initiatives, a binomial logistic regression was used to test the effects of mulching, staking, ERA (estimated rooting area), and years since planting on the presence or absence of lawn care damage on a tree. For all statistical tests, an alpha level of 0.05 was adopted as the threshold for significance.

3. Results

3.1. Tree establishment

Based on installation records, the time since installation for the sampled projects ranged from 9 to 58 months. The average project age was 30 months. A total of 2711 trees were located and assessed. Of the trees sampled, 51.5% were palms, 18.4% were small-stature trees, 17.6% were shade trees, and 12.4% were coniferous trees (Appendix A).

When examining establishment, all tree groups had higher establishment success when permanent drip irrigation was present; however, the impacts were only statistically significant for palms (P = 0.006) (Table 5). Within the palms, the most common species, *S. palmetto* establishment decreased from 99.4% to 95.8% when planted on non-irrigated sites (P = 0.006). Non-irrigated *W. robusta* had a similar establishment (95.3%) to non-irrigated *S. palmetto* (95.8%), though the former species was not located on irrigated sites in the projects visited. While overall establishment did not differ for the conifers between irrigated and non-irrigated sites (P = 0.356), *Pinus palustris* had significantly higher establishment success when planted on sites with irrigation installed (P = 0.015).

3.2. Tree health

A summary of significant effects is given in Fig. 2. Individual models for each of the health response variables separated by tree type are included in Appendix B.

3.3. Small-stature trees

In modelling quality ratings for small-stature trees, GDD (growing degree days) was the only significant factor to positively impact quality ratings with an odds ratio of 3.32 (P = < 0.0001). As ERA (estimated rooting area) score increased, the likelihood of attaining a higher quality rating decreased (P = 0.0004). Finally, the small tree quality model was the only model to have slope as a significant factor, in that it had a negative, albeit slight, association with quality rating (odds ratio = 0.9575; P < 0.0001).

For the final small-stature tree vitality model, species was again a significant predictor. *Lagerstroemia spp*. (odds ratio = 0.18, P = 0.0016) had higher vitality ratings than *Ilex x attenuata* 'Eagleston'. In contrast, there was no difference in the vitality ratings for the *Ligustrum japonicum* as compared to the *Ilex* base-level (odds ratio = 0.43; P = 0.1506); Years since planting improved the likelihood of attaining a higher vitality rating (odds ratio = 1.67; P < 0.0001) while the absence of on-site irrigation reduced the likelihood of attaining a higher vitality rating (odds ratio = 0.25; P < 0.0001) (Fig. 2).

3.4. Shade trees

For shade trees, species had a significant impact on the quality health rating. In the most extreme comparison, *Liquidambar styraciflua* was 385 times more likely to receive a higher quality rating than the baseline of *Delonix regia* (P < 0.001). Of the RUSI parameters, ERA had the highest odds ratio (odd ratio = 2.82; P = 0.0028) (Fig. 2). Other factors with positive impacts on shade tree quality included INFR (distance to infrastructure) and SOM (soil organic matter), with odds ratios of 2.10 (P = 0.0005) and 1.78 (P = 0.0022), respectively. An increase in RUSI scores for AHOR (A-horizon depth; odds ratio = 0.49; P = 0.0047), EC (electrical conductivity; odds ratio = 0.52; P = 0.0364), EXP (crown light exposure; odds ratio = 0.22; P = 0.0082), and pH (odds ratio = 0.31; P < 0.0001) were associated with a reduction in shade tree quality ratings (Fig. 2). Additionally, shade trees without on-site irrigation were less likely to attain a higher quality rating than those with irrigation installed (odds ratio = 0.24; P < 0.0001). The same held true in the absence of berms (odds ratio = 0.24; P < 0.0001) (Fig. 2).

For the final shade tree vitality model, *L. styraciflua* (odds ratio = 4.85; P = 0.0460), *Magnolia grandiflora* (odds ratio = 21.05; P < 0.0001), *Peltophorum pterocarpum* (odds ratio = 24.04; P < 0.0001), and *Swietenia mahagoni* (odds ratio = 5.47 × 107; P < 0.0001) had higher vitality ratings than the baseline of *D. regia*. Years since planting was also a significant predictor of vitality (odds ratio = 2.93, P < 0.0001) (Fig. 2). In the absence of on-site irrigation, shade trees were less likely to attain a higher vitality rating (odds ratio = 0.26, P = 0.0004). Counterintuitively, as PPT (annual precipitation) RUSI score increased, the likelihood of attaining a higher vitality rating decreased (odds ratio = 0.65; P = 0.0009). Similar trends were noted with increased ratings for EXP (crown light exposure; odds ratio = 0.01; P = 0.0012), STRC (soil structure; odds ratio = 0.66; P = 0.0170), and TXT (soil texture; odds ratio = 0.23; P = 0.0042) (Fig. 2).

3.5. Conifers

Both final vitality and quality models for conifer health ratings yielded similar results. *Pinus palustris* and *Taxodium distichum* were both outperformed by *Pinus elliottii* (Appendix B). Similarly, absence of installed irrigation resulted in lower likelihoods of attaining higher quality (odds ratio = 0.13; P = < 0.0001) and vitality ratings (odds ratio = 0.04; P = 0.0026) (Fig. 2). In contrast, being staked for greater than one year had the opposite effect – improving the likelihood of attaining a higher visual quality (odds ratio = 3.37; P = 0.0088) and vitality ratings (odds ratio = 16.72; P = 0.0010) (Fig. 2). INFR (distance to infrastructure) rating had a positive relationship with quality rating (odds ratio = 2.13; P = 0.0007). As with the shade tree vitality model, PPT (annual precipitation) score was associated with a reduced likelihood of attaining a higher vitality rating (odds ratio = 0.40; P = 0.0011) (Fig. 2).

3.6. Palms

For the final palm quality model, again species was a significant predictor. When compared to the *Wodyetia bifurcata* base level, all other species were more likely to have higher quality ratings (min. odds ratio = 16.45; all P < 0.0001) (Appendix B). Wet season plantings (odds ratio = 2.95; P < 0.0001), absence of berms (odds ratio = 1.65 ; P = 0.0293), staking for greater than one year (odds ratio = 2.86; P < 0.0001), EC (electrical conductivity; odds ratio = 1.74;

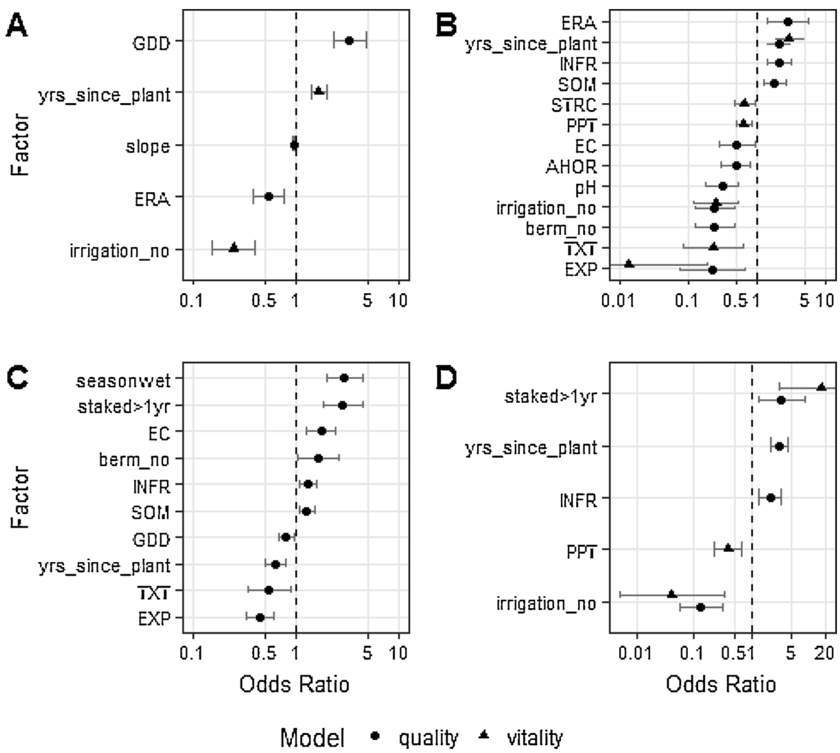

Fig. 2. Odds ratios and corresponding 95% confidence intervals for significant factors (P = < 0.05) from each of the seven final ordinal logistic regression models. Species groups are small-stature (A), shade (B), palm (C), and conifer (D). Rapid Urban Site Index factor abbreviations from the models include: A-horizon depth (AHOR), electrical conductivity (EC), estimated rooting area (ERA), crownlight exposure (EXP), growing degree days (GDD), distance to infrastructure (INFR), pH (pH), annual precipitation (PPT), soil organic matter (SOM), soil structure (STRC), and soil texture (TXT).

P = 0.0008), INFR (distance to infrastructure; odds ratio = 1.30; P = 0.0077), and SOM (soil organic matter; odds ratio = 1.27 ; P = 0.0051) scores improved the likelihood of attaining a higher quality rating (Fig. 2). In contrast, increased years since planting (odds ratio = 0.63; P = < 0.0001), EXP (crown light exposure; odds ratio = 0.44; P = < 0.0001), GDD (growing degree days; odd ratio = 0.80, P = 0.0204), and TXT (soil texture; odds ratio = 0.54; P = 0.0155) were associated with lower quality ratings (Fig. 2).

3.7. Maintenance practices

Results from logistic regression show that both staking and mulching protect trees from the lawn care damage (Table 6) while a one unit score increase in ERA (estimated rooting area) makes a tree 2.24 times more likely to be damaged with lawn care equipment.

4. Discussion

4.1. Tree establishment

With establishment ranging from 97.3% (conifers) to 99.8% (shade tree) (Appendix A), the program studied has one of the highest success rates in the growth and longevity literature. However, it is important to note that these plantings do include replacement trees as part of the installation and maintenance contract. As such, we have taken care throughout this manuscript to describe planting success in terms of establishment in the landscape (as opposed to mortality). As replacement trees are included in our models, the most comparable study to this work is the assessment of Florida Forest Service funded planting initiatives conducted by Koeser et al. (2014). In this study of 26 planting projects (n = 2354), an establishment rate of 93.6% two to five years after planting was observed.

This important caveat noted, our findings are in line with a recent case study documented by Roman et al. (2015) who observed a 96.3% establishment survival 6 years after planting for highway trees in East Palo Alto, California (United States). While key differences exist between these two planting programs (notably, the East Palo Alto location was maintained by volunteers and youth interns and the trees were not covered with a replacement policy) there were similarities in the care given related to nursery stock quality assurance, irrigation and mulch to maintain soil moisture, and the use of staking materials to support and protect recently-planted trees.

Establishment did not vary between sites with permanent drip irrigation and no permanent drip irrigation for shade, small-stature, and conifer tree groups (Table 5). A statistically significant differenced did exist for palms, however. This appeared to be driven by differences in establishment for *S. palmetto* (Appendix A). For this species, severed roots die back to the trunk during harvest, increasing the potential for post-planting water stress (Broschat, 1991).

Table 6
Results of binary logistic regression of tree damage by lawn care equipment. This includes odds ratios and corresponding 95% confidence intervals (calculated for the odds ratio) resulting from binary logistic regression. An odds ratio greater than 1 indicates an increased likelihood of a tree be damaged by lawncare equipment per one unit increase in the predictor.

Factor	Coefficient	SE	p-value	OR	CI low	CI high
Mulched	−1.2336	0.2413	0.0000	0.2912	0.1815	0.4674
Staked	−1.4842	0.5277	0.0049	0.2267	0.0806	0.6378
yrs_since_planting	0.1903	0.1179	0.1064	1.2096	0.9601	1.5240
ERA[x]	0.8053	0.2305	0.0005	2.2373	1.4240	3.5153

[x] Estimated rooting area.

4.2. Tree health

Although each of the seven health models developed for this study offered slightly different results given the rating and group assessed (Fig. 2; Appendix B), certain themes arose in the data. Specifically, irrigation, years since planting, INFR (distance to infrastructure), EXP (crown light exposure), and stake duration were significant predictors of quality and/or vitality ratings that appeared in at least three models (Fig. 2).

The absence of on-site drip irrigation repeatedly resulted in visual

Table 7
Summary of maintenance practices observed on FDOT planted trees in comparison with past observations of landscape trees in other studies.

Maintenance Factor	FDOT % (n)	Previous Work(s) % (n)	Citation
Lawn care damage	6% (1202[z])	62.9% (1018) 0.0% (568) 7.2% (291)	Morgenroth et al. (2015); Roman et al. (2015)[w];Roman et al. (2014b)
Total trunk damage	8% (1202[z])	47.4 (656)	Vogt et al. (2015)
Staking damage	1% (1202[z])	50-84% (unknown) 17% (488) 37.5% (291)	Foster and Blaine (1978); Labrosse et al. (2011); Roman et al. (2014b)
Staking > 1 year	11.5% (2135)	2.5% (2354)	Koeser et al. (2014)
Mulched	76.5% (2491)	7.2% (13,405) 100.0% (568) 38.5% (291) 10.5% (658 [x])	Lu et al. (2010); Roman et al. (2015)[w];Roman et al. (2014b); Vogt et al. (2015)[x]
Root flare visible	50.1% (2495)	27.4% (658)	Vogt et al. (2015)
Girdling roots	1.25% (1116[z])	n/a	n/a
Poor branch structure	3% (969[z,y])	n/a	n/a

[z] palms excluded.
[y] small-stature trees excluded.
[x] trees that were mulched properly.
[w] data from East Palo Alto, California case study.

health reductions. This finding is supported by past research in Florida demonstrating higher survival and increased growth in recently-installed trees under irrigation (Gilman, 2004). Counterintuitively, increases in PPT (annual precipitation) score had the opposite effect of on-site irrigation on shade tree vitality and conifer vitality ratings. It should be noted that PPT is a rather coarse metric for characterizing potentially complex weather patterns. Rains in Florida can be quite sporadic. The state can endure several months of drought and make up its year-to-date rain deficit in a single rain event such as a tropical storm (Putterman, 2017).

Also related to water availability is the construction of soil berms intended to help retain water near the rootball and improve infiltration, especially when slopes increase potential runoff. Berms improved shade tree quality but reduced palm quality. Further research investigating the effectiveness of berms in improving tree performance is warranted. Interestingly, increased EXP (crown light exposure) reduced ratings for palm quality, as well as shade tree quality and vitality. In the RUSI system, increases in exposure are associated with higher (more beneficial) scores (Scharenbroch et al., 2017). However, Roman et al. (2015) attributed excessive sun exposure paired with irrigation cessation several years after planting as a potential factor of tree death in East Palo Alto, California. If trees were drought stressed in our study population, full sun exposure may have exacerbated these water-limiting conditions.

Another factor related to water management was planting season (i.e., wet vs. dry). We found wet season plantings yielded higher quality ratings for palms. This relationship supports findings by Roman et al. (2014b) and previous palm-specific research that found wet and warm season plantings improve establishment (Broschat, 1998; Hodel et al., 2005). Other tree types in this study were uninfluenced by season. Vogt et al. (2015) acknowledges the existence of a complex relationship among planting season, watering strategy, and precipitation. Moreover, other researchers have had conflicting findings regarding planting season. In their assessment of Sacramento, California tree plantings, Ko et al. (2015a) noted less mortality for trees installed during the dry season.

Small-stature trees, shade trees, and conifers generally exhibited greater health with age (Fig. 2). Vogt et al. (2015) explained this when they noted that older plantings have had more time to experience losses associated with transplant shock. Once this attrition (or in our case, replacement) has weeded out poorer performing trees, what remains are healthier individuals. In contrast, palm health declined with age. While palm health decline over time was not examined in this study, there are some potential reasons for this trend. Palms not adapted to Florida's sandy soils can develop nutrient deficiencies which would impact quality ratings. These deficiencies can take years to correct once visible (Broschat, 2009). While fertilization from the nursery may be enough to initially sustain a transplanted species, the absence of supplemental fertilization may manifest as deficiency symptoms as new fronds develop over time.

INFR (distance to infrastructure) showed up in three models and had a positive association with health, corroborating past findings by Koeser et al. (2013), where expanding widths from sidewalk to curb improved tree condition; and research by Sanders and Grabosky (2014), where tree growth increased in wider parking lot cut-outs. In contrast, ERA (estimated rooting area) yielded mixed results in our health analysis, after being the most strongly correlated-to-tree health variable in the RUSI model (Scharenbroch et al., 2017). One possible explanation is that trees in this study are still in the younger stages of their life cycle, and rooting area may be less limiting at their current size (Lu et al., 2010). Also, roots were rarely restricted by infrastructure on more than one side in our sample.

Staking longer than one year improved visual health ratings. For palms, Broschat et al. (2000) recommends bracing materials be removed 6–8 months after planting, although retaining bracing materials will not girdle palm trunks as with broadleaf and coniferous trees. Although it was initially viewed that retaining stakes for more than one year may be an indicator of reduced care, contractual requirements in some cases call for two-year staking. Trees staked beyond that timeframe may have been under additional care resulting from late-establishment-phase replacements. Moreover, trees with staking materials had lower incidence of lawn mowing damage (see below). Regardless, these findings indicate that retaining stakes for more than one growing season may not cause harm if monitored and adjusted to prevent girdling, which is discussed further in the next section.

4.3. Tree maintenance

Several indicators of tree maintenance and stewardship were recorded to allow for comparison among other studies (Table 7). Past research has used visual cues related to care at-planting (e.g., planting depth) and post-planting (e.g., trunk protection with mulch, stakes, etc.) to assess differences in establishment and survival (Roman et al., 2014b). In assessing these FDOT plantings, we found evidence that follow-up maintenance practices were being followed at high rates compared to other assessments of early tree growth and longevity (Table 7). For example, Vogt et al. (2015) found trunk damage on 47.4% of recently established trees (average age of 4.47 years after planting) (Table 7). In contrast, we found 8.1% of trees to have trunk damage (average age of 2.4 years after planting).

Similarly, lawn care damage in the FDOT plantings assessed was notably lower than reported in by Morgenroth et al. (2015) in Christchurch, New Zealand. However, trees ranged from 3 cm to 253 cm in DBH in the aforementioned study, making it plausible that older (and larger) trees had more years to receive lawn care damage.

Within our sampled trees, we found measures of care in place which reduced the likelihood of injuries related to lawn care activities. For example, mulched trees were nearly three times less likely to have lawn care damage than non-mulched trees (Table 6). Similarly, staked trees were half has likely to shown signs of lawn care damage as trees without staking (Table 6). Less intuitively, we found that lawn care damage increased as estimated rooting area (ERA) scores increased. In talking with FDOT staff, they predicted this even before our analysis as contractors use larger equipment when trees are spaced farther apart. Large tractor-pulled brush mowing attachments are harder to maneuver around trees than the smaller zero-turn mowers used in close quarters.

Although trunk wounding can lead to long term issues with health and stability, the presence of trunk wounds was not a significant predictor in our health models. Percival and Smiley (2015) attribute timing, species-specific ability to compartmentalize decay, and extent of stem wounding to be a determinant of the tree response. As a simple yes or no predictor variable, our data on trunk damage did not capture variability in wounding intensity which may have limited our ability to detect differences in visual health ratings.

Comparisons can also be made regarding tree staking practices. In an assessment of 488 trees in Guelph, Ontario (Canada), Labrosse et al. (2011), observed that 17% of trees were girdled to some degree by staking materials. Prior to this study, Foster and Blaine (1978), observed 81% of Boston, Massachusetts (United States) street trees had been damaged by staking materials. In our assessment of FDOT initiatives, only 1% of trees showed visible damage from stabilization measures. While damage was minimal, a greater proportion of trees planted by FDOT were staked longer than one year (11.5%) than was observed by Koeser et al. (2014) in Florida Forest Service funded planting initiatives (2.5%; Table 7). From a project stewardship perspective, Roman et al. (2014b) recommend the use of an overall combined maintenance rating in order to guide future tree maintenance. The FDOT currently conducts a multipoint inspection of its plantings, which may explain the care noted in Table 7.

5. Conclusions and recommendations

This research investigated a multitude of factors to quantify how they relate to both establishment (i.e., survival past the maintenance contract period) and health of recently installed trees along Florida transportation corridors. Overall, we found a high level of establishment success for these plantings. In looking at establishment success with regard to irrigation, the two methods of irrigation (e.g., water truck vs installed system) employed seemed equally effective for most of the tree types assessed. In particular, palms (specifically *S. palmetto*) appeared to benefit from a dedicated irrigation system.

In addition to high establishment rates, the FDOT "Bold Initiative" plantings assessed for this study yielded high visual health ratings, despite any site challenges associated with their proximity to roadways. While growth is often a measure of urban tree health, this work shows the potential of visual health ratings in assessing factors that influence tree performance – especially when initial size at planting is not known. This work also demonstrates the potential of incorporating an urban site index to assess planting location suitability, although some counterintuitive findings signal for the need of collective, regional efforts to better define scoring functions for site factors. As such, the methods employed in this study are well suited for the gauging the effectiveness of past management efforts.

CRediT authorship contribution statement

Seth A. Blair: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Software, Visualization, Writing - original draft. **Andrew K. Koeser:** Conceptualization, Data curation, Formal analysis, Funding acquisition, Methodology, Project administration, Resources, Software, Supervision, Writing - review & editing. **Gary W. Knox:** Methodology, Supervision, Writing - review & editing. **Lara A. Roman:** Methodology, Supervision, Writing - review & editing. **Mack Thetford:** Methodology, Supervision, Writing - review & editing. **Deborah R. Hilbert:** Writing - review & editing.

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Appendix A

See Table A1

Table A1
Percent establishment of observed tree species planted along Florida roadsides from July 2012 - October 2015.

Tree Type	Species	Common name	n	Establishment (%)
	Acer rubrum	red maple	10	100
	Carya glabra	pignut hickory	3	100
	Chionanthus virginicus	fringe tree	9	100
	Chorisia speciosa	silk-floss tree	12	100
	Delonix regia	royal poinciana	42	100
	Elaeocarpus decipiens	Japanese blueberry	23	100
	Ilex x attenuata	'East Palatka' holly	10	100
Shade trees	*Liquidambar styraciflua*	sweetgum	33	100
	Magnolia grandiflora	Southern magnolia	115	100
	Peltophorum pterocarpum	yellow poinciana	35	100
	Quercus virginiana	southern live oak	159	99.4
	Senna surattensis	glossy shower	4	100
	Swietenia mahagoni	mahagony	23	100
	Ulmus alata	winged elm	1	100
	Shade tree totals		479	99.8
	Cercis canadensis	eastern redbud	19	100
	Coccoloba uvifera	sea grape	20	100
	Ilex x attenuata	'Eagleston' holly	29	100

(*continued on next page*)

Table A1 (*continued*)

Tree Type	Species	Common name	n	Establishment (%)
	Lagerstroemia spp.	crapemyrtle	330	99.7
Small-stature trees	*Ligustrum japonicum*	Japanese privet	68	97.1
	Olea europaea	olive	7	100
	Prunus umbellata	flatwoods plum	12	100
	Tabebuia aurea	Caribbean trumpet	3	100
	Tabebuia heptaphylla	pink trumpet tree	11	100
	Small-stature tree totals		499	99.4
	Juniperus virginiana	redcedar	8	100
	Pinus elliottii	slash pine	95	100
	Pinus palustris	longleaf pine	110	95.5
Conifers	*Pinus taeda*	loblolly pine	9	100
	Taxodium ascendens	pondcypress	1	100
	Taxodium distichum	baldcypress	112	97.3
	Conifer totals		335	97.3
	Archontophoenix alexandrae	Alexander palm	32	96.9
	Bismarckia nobilis	Bismarck palm	156	100
	Butia odorata	mule palm	5	100
	Hyophorbe lagenicaulis	bottle palm	19	100
Palms	*Livistionia chinensis*	Chinese fan palm	99	98.0
	Ptychosperma elegans	solitaire palm	44	100
	Roystonea regia	royal palm	104	100
	Sabal palmetto	sabal palm	667	97.9
	Trachycarpus fortunei	windmill palm	19	100
	Washingtonia robusta	Mexican fan palm	232	95.3
	Wodyetia bifurcata	foxtail palm	21	100
	Palm totals		1398	98.0

Appendix B

See Tables B1–B7

Table B1
Final model and ordinal logistic regression results for shade tree quality. Data was collected along Florida Department of Transportation corridors as part of a statewide "Bold Landscaping Initiative.".

Factor	Coefficient	SE	P-value	OR	CL low	CL high
Berm – no	−1.4231	0.3336	< 0.0001	0.2410	0.1253	0.4634
Irrigation – no	−1.4082	0.3466	< 0.0001	0.2446	0.1240	0.4825
Years since planting	0.7326	0.1863	0.0001	2.0805	1.4439	2.9977
AHOR[y]	−0.7154	−0.2531	0.0047	0.4890	0.2978	0.8031
EC[y]	−0.6609	−0.3158	0.0364	0.5164	0.2781	0.9589
ERA[y]	1.0382	0.3472	0.0028	2.8242	1.4299	5.5779
EXP[y]	−1.4974	0.5662	0.0082	0.2237	0.0738	0.6786
INFR[y]	0.7424	0.2121	0.0005	2.1009	1.3864	3.1837
pH[y]	−1.1679	0.2868	< 0.0001	0.3110	0.1773	0.5456
SOM[y]	0.5782	0.1890	0.0022	1.7829	1.2310	2.5822
E. decipiens[x]	3.5221	0.8682	< 0.0001	33.8554	6.1740	185.6470
L. styraciflua[x]	5.9546	0.8364	< 0.0001	385.5352	74.8366	1986.1603
M. grandiflora[x]	1.4140	0.5046	0.0051	4.1124	1.5297	11.0557
P. pterocarpum[x]	1.2911	0.5420	0.0172	3.6369	1.2572	10.5213
Q. virginiana[x]	2.2992	0.4938	< 0.0001	9.9661	3.7860	26.2338
S. mahagoni[x]	2.9213	0.8551	0.0006	18.5648	3.4740	99.2078

[x] For species comparisons, *D. regia* was used as the baseline. For example, *M. grandiflora* was 4.1 times more likely to have a higher quality rating when compared to *D. regia* baseline.

[y] Rapid Urban Site Index factors include A-horizon depth (AHOR), electrical conductivity (EC), estimated rooting area (ERA), crownlight exposure (EXP), distance to infrastructure (INFR), pH (pH), and soil organic matter (SOM).

Table B2
Final model and ordinal logistic regression results for shade tree vitality. Data was collected along Florida Department of Transportation corridors as part of a statewide "Bold Landscaping Initiative.".

Factor	Coefficient	SE	P-value	OR	CL low	CL high
Irrigation - no	−1.3557	0.3837	0.0004	0.2578	0.1215	0.5468
Years since planting	1.0734	0.2399	< 0.0001	2.9254	1.8280	4.6814
EXP[y]	−4.2947	1.3283	0.0012	0.0136	0.0010	0.1843
PPT[y]	−0.4334	0.1305	0.0009	0.6483	0.5020	0.8372
STRC[y]	−0.4154	0.1741	0.0170	0.6601	0.4692	0.9285
TXT[y]	−1.4615	0.5112	0.0042	0.2319	0.0851	0.6315
E. decipiens[x]	−0.1652	0.6020	0.7838	0.8477	0.2605	2.7584
L. styraciflua[x]	1.5780	0.7909	0.0460	4.8455	1.0283	22.8317
M. grandiflora[x]	3.0471	0.5441	< 0.0001	21.0537	7.2468	61.1660
P. pterocarpum[x]	3.1798	0.7273	< 0.0001	24.0420	5.7792	100.0180
Q. virginiana[x]	0.6310	0.3923	0.1078	1.8794	0.8711	4.0548
S. mahagoni[x]	17.8176	< 0.0001	< 0.0001	54712190.3018	54712036.3316	54712344.2724

[x] For species comparisons, D. regia was used as the baseline. For example, Q. virginiana was 1.87 times more likely to have a higher vitality rating when compared to D. regia baseline.
[y] Rapid Urban Site Index factors within the model include crownlight exposure (EXP), annual precipitation (PPT), soil structure (STRC), and soil texture (TXT).

Table B3
Final model and ordinal logistic regression results for small-stature tree quality. Data was collected along Florida Department of Transportation corridors as part of a statewide "Bold Landscaping Initiative.".

Factor	Coefficient	SE	P-value	OR	CL low	CL high
ERA[x]	−0.6061	0.1711	0.0004	0.5455	0.3901	0.7628
GDD[x]	1.2026	0.1852	< 0.0001	3.3288	2.3153	4.7858
Slope	−0.0434	0.0090	< 0.0001	0.9575	0.9408	0.9745

[x] Rapid Urban Site Index factors within the model include estimated rooting area (ERA) and growing degree days (GDD).

Table B4
Final model and ordinal logistic regression results for small-stature tree vitality. Data was collected along Florida Department of Transportation corridors as part of a statewide "Bold Landscaping Initiative.".

Factor	Coefficient	SE	P-value	OR	CL low	CL high
Irrigation - no	−1.3960	0.2415	< 0.0001	0.2476	0.1542	0.3975
Years since planting	0.5122	0.0831	< 0.0001	1.6689	1.4181	1.9640
Lagerstroemia spp.[x]	−1.6871	0.5353	0.0016	0.1851	0.0648	0.5285
L. japonicum[x]	−0.8372	0.5824	0.1506	0.4329	0.1382	1.3558

[x] For species comparisons, *Ilex* x *attenuata* 'Eagleston' was used as the baseline. For example, *Lagerstroemia* spp. were 0.19 times more likely to have a higher vitality rating when compared to the *I.* x *attenuata* 'Eagleston' baseline.

Table B5
Final model and ordinal logistic regression results for conifer quality. Data was collected along Florida Department of Transportation corridors as part of a statewide "Bold Landscaping Initiative.".

Factor	Coefficient	SE	P-value	OR	CL low	CL high
Irrigation – no	−2.0275	0.4393	< 0.0001	0.1317	0.0557	0.3115
Staked > 1 year	1.2161	0.4642	0.0088	3.3739	1.3583	8.3804
Years since planting	1.1141	0.1708	< 0.0001	3.0467	2.1800	4.2581
INFR[y]	0.7569	0.2232	0.0007	2.1316	1.3763	3.3016
P. palustris[x]	−3.8261	0.6478	< 0.0001	0.0218	0.0061	0.0776
T. distichum[x]	−2.8425	0.4522	< 0.0001	0.0583	0.0240	0.1414

[x] For species comparisons, *P. elliottii* was used as the baseline. For example, *P. palustris* was 0.05 times more likely to have a higher quality rating when compared to the *P. elliottii* baseline.
[y] Rapid Urban Site Index factors within the model include distance to infrastructure (INFR).

Table B6
Final model and ordinal logistic regression results for conifer vitality. Data was collected along Florida Department of Transportation corridors as part of a statewide "Bold Landscaping Initiative.".

Factor	Coefficient	SE	P-value	OR	CL low	CL high
Irrigation – no	−3.1787	1.0567	0.0026	0.0416	0.0052	0.3303
Staked > 1 year	2.8169	0.8545	0.0010	16.7252	3.1334	89.2748
PPT[y]	−0.9136	0.2808	0.0011	0.4011	0.2313	0.6955
P. palustris[x]	−3.2312	0.9802	0.0010	0.0395	0.0058	0.2698
T. distichum[x]	−2.3588	0.7508	0.0017	0.0945	0.0217	0.4118

[x] For species comparisons, *P. elliottii* was used as the baseline. For example, *P. palustris* was 0.04 times more likely to have a higher vitality rating when compared to the *P. elliottii* baseline.

[y] Rapid Urban Site Index factors within the model include annual precipitation (PPT).

Table B7
Final model and ordinal logistic regression results for palm quality. Data was collected along Florida Department of Transportation corridors as part of a statewide "Bold Landscaping Initiative.".

Factor	Coefficient	SE	P-value	OR	CL low	CL high
Berm - no	0.5059	0.2321	0.0293	1.6584	1.0522	2.6139
Season – wet	1.0829	0.2077	< 0.0001	2.9533	1.9658	4.4368
Staked > 1 year	1.0503	0.2299	< 0.0001	2.8586	1.8215	4.4863
Years since planting	−0.4642	0.1122	< 0.0001	0.6286	0.5045	0.7833
EC[y]	0.5548	0.1647	0.0008	1.7416	1.2612	2.4050
EXP[y]	−0.8154	0.1560	< 0.0001	0.4425	0.3259	0.6008
GDD[y]	−0.2188	0.0943	0.0204	0.8035	0.6678	0.9666
INFR[y]	0.2637	0.0989	0.0077	1.3017	1.0724	1.5802
SOM[y]	0.2420	0.0865	0.0051	1.2738	1.0752	1.5091
TXT[y]	−0.5982	0.2471	0.0155	0.5498	0.3388	0.8923
A. alexandrae[x]	2.8005	0.6212	< 0.0001	16.4521	4.8691	55.5900
B. nobilis[x]	4.6915	0.5041	< 0.0001	109.0165	40.5889	292.8040
L. chinensis[x]	3.9869	0.5294	< 0.0001	53.8849	19.0917	152.0862
P. elegans[x]	4.3032	0.7648	< 0.0001	73.9360	16.5150	331.0054
R. regia[x]	3.5801	0.5049	< 0.0001	35.8774	13.3359	96.5205
S. palmetto[x]	3.7465	0.4559	< 0.0001	42.3719	17.3375	103.5544
W. robusta[x]	5.8769	0.5246	< 0.0001	356.7006	127.5596	997.4583

[x] For species comparisons, *W. bifurcata* was used as the baseline. For example, *A. alexandrae* was 16.5 times more likely to have a higher quality rating when compared to the *W. bifurcata* baseline.

[y] Rapid Urban Site Index factors within the model include electrical conductivity (EC), crownlight exposure (EXP), growing degree days (GDD), distance to infrastructure (INFR), soil organic matter (SOM), and soil texture (TXT).

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