Final Report: Clear Recovery Zone Vegetation Requirements, and Review of Current Tree Pruning and Maintenance Practices for Landscape, Urban, and Rural Areas within the Right of Way

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16. Abstract
Though not its primary mission, the Florida Department of Transportation (FDOT) is one of the most significant tree planting organizations in the state. This research investigates the effectiveness of their existing contracts and tree planting management efforts. In an assessment of 2711 planted trees and palms, we found that 98.5% survived the transplanting process. Onsite irrigation (as compared to truck watering) generally did not impact tree survival. In contrast tree visual health ratings did detect a significant benefit associated with dedicated irrigation systems. Additionally, this research found that mower damage (the most common source of mechanical damage to the trees assessed) could be reduced if staking materials and mulch were used and if trees were spaced closely together (prohibiting the use of large, pull-behind mowers). Results of this research are incorporated into an assocatiate tree and shrub maintenance guide created for all FDOT landscape trees and palms.

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APPROXIMATE CONVERSIONS TO SI UNITS

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
LENGTH				
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
AREA				
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
VOLUME				
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: Volumes greater than 1000 L shall be shown in m^3.				
MASS				
oz	ounces	28.35	grams	G
lb	pounds	0.454	kilograms	Kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")

EXECUTIVE SUMMARY

- The Florida Department of Transportation (FDOT) is one of the most significant and successful planters of trees and palms in the state. With an establishment rate of 98.5%, the program is the most effective reported in the scientific record to date (both nationally and internationally).
- The addition of inground irrigation was significantly linked to higher assessed visual conditions, which can be a predictor of long-term health. Immediate survival rates, however, were generally the same for plantings irrigated by water truck (with the exception of planted *Sabal palmetto*).
- While mowing damage was not as significant as witnessed in other studies, 6% of trees inventoried had root or lower stem injuries consistent with those caused by lawn care activities. These can be avoided through a combination of mulching, staking for two years after planting (taking care to loosen straps after first growing season), and increasing planting density (to require the use of smaller, zero-turn mowing equipment).
- In addition to the core deliverables originally promised for this project, we developed an efficient, repeatable, and peer-reviewed means of assessing the health of palms for use in FDOT inspections.
- A completely updated, 103-page tree and palm maintenance guide was developed for FDOT. It includes all of the necessary pruning basics for FDOT staff and contractors. Additionally, it includes a contract specifications guide for 34 common pruning scenarios along publicly managed transportation corridors to aid FDOT in its contracting.
- Five face-to-face technology transfer events were conducted statewide, and videos of the presented modules were recorded for future FDOT use. Of those in attendance, 87.3% felt the content of the events was “Excellent” or “Above Average” in its usefulness related to their daily work activities.

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CHAPTER 1 - INTRODUCTION AND OVERVIEW OF PROJECT

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. As project size has been noted to influence tree survival (Ko et al., 2015a), the scale of this program warrants further investigation from the perspective of establishment performance. This monitoring, if incorporated into adaptive management efforts, can enhance the program's success and help ensure its projected 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 is 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 regarding the broader subject of tree growth and longevity research. In addition, the plantings assessed include a high percentage of palms (51.6%), which are often absent from similar works published in the past.

Findings from the research project are intended to guide future FDOT planting efforts and to craft revisions to the current tree maintenance guide. Additional field surveys and communications with FDOT are intended to shape best practices for tree trimming in rural areas. Finally, these findings will be communicated to FDOT staff during multiple technology transfer sessions to bring the department up to speed on the new guide, specification writing, and with findings from the field surveys.

CHAPTER 2 - HEALTH AND ESTABLISHMENT OF HIGHWAY PLANTINGS IN FLORIDA [1]

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 annual establishment (98.5%) across 21 planting projects ranging from nine to 58 months after installation, (n = 2711). For transplanted palm establishment, irrigation was significant (99.4% establishment for on-site irrigation; 96.2% for no on-site irrigation). 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 types given tree, management, and environmental factors.

[1] The pre-published version of the research is presented here. Links to the final version and an additional paper on palm health assessment are included in Chapter 5.

SECTION 1: INTRODUCTION TO URBAN TREE PERFORMANCE LITERATURE

While urban tree planting initiatives are often positively perceived, associated tree losses can reduce or negate the benefits that are often proudly touted. These initiatives can be volunteer or professionally driven, implemented out of “good will” or can result from mandate. Regardless of circumstance, the resources devoted to installation and maintenance are immense, partly due to the challenges of establishing trees in the urban landscape. The result is an area of active inquiry regarding the growth, health, and longevity of urban trees (Koeser et al., 2014; Leibowitz, 2012; Lu et al., 2010; Roman and Scatena, 2011; Vogt et al., 2015).

The importance of growth and longevity research has led to the formation of the Urban Tree Growth and Longevity Working Group (Scharenbroch et al., 2014), as well as extensive review of factors contributing to urban tree mortality (Hilbert et al., *submitted*). The complexity in which taxa respond to various site conditions and maintenance in different climates have created the need for region-specific research.

While growth and longevity studies are often “snapshots” in time, long-term studies are becoming increasingly valued by researchers (Ko et al., 2015a, 2015b; Koeser et al., 2013). In what may be perceived as a topic area with narrow focus, researchers explore a great variety of topics that aim to improve the management of urban trees for long-term survival, such as monitoring protocols (Boyer et al., 2016; Roman et al., 2013; Vogt and Fischer, 2014), population demographics (Roman et al., 2016), cost/benefit of tree maintenance (Widney et al., 2016), site assessments (Scharenbroch et al., 2017), biophysical and human factors (Hilbert et al., *submitted*), and more.

Ecosystem Services and Planting Initiatives

Numerous tree growth, health, and longevity studies develop from goals of assessing and increasing 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 (Van Treese II et al., 2017; Wolf, 2003), enhanced roadway definition (Van Treese II et al., 2017), and slowed asphalt degradation through shading (McPherson and Muchnik, 2005). Roadside vegetation has often been said to reduce roadside air and noise pollution (Islam et al., 2012), but recent findings contradict this idea, stating that trees can increase residence time of pollutants or increase concentrations downwind dependent upon spatial landscape characteristics (Tong et al., 2015).

In planting trees to increase these ecological services, 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 one considers the inputs associated with nursery operations, installation, and maintenance (Petri et al., 2016). To ensure urban plantings function as intended, factors related to establishment after planting must be identified regionally, within specific land use types, and mitigated through best management practices.

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, and (4) community-related factors.

Tree-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 (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). For example, poor condition ratings during initial inventories correlated with tree mortality in follow-up inventories (Koeser et al., 2013; Roman et al., 2014a). Similarly, van Doorn and McPherson (2018) found that trees demonstrate reduced diameter growth when in poor health. These findings indicate the usefulness of tree health metrics in urban forest management.

Environment-Related Factors

Environment-related factors include a range of conditions related to the climate (Koeser et al., 2014), microclimate (Martin et al., 2016; Whitlow and Bassuk, 1987), soil conditions, crown light exposure, and land use type. 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. With regards to land use, transportation corridors can be difficult sites for tree survival, with 20.2% average annual mortality reported (compared to an overall average mortality of 6.6%) in a study from Baltimore, Maryland (Nowak et al., 2004). In the same study, however, it was noted that mortality in the transportation land use class was attributed primarily to one species. 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 that finding (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).

Soil-Related Factors

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 multiple poor soil factors, including drainage, structure, pH, salinity, and elemental toxicities. In roadside environments, the 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), which reduces 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 altering soil structure, soils near roadsides (especially concrete roadways) can have increased alkalinity, which 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 affect 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). When these soil conditions are combined with the steep slopes associated with highway interchanges and other roadside embankments, runoff increases, and infiltration is reduced. Without proper irrigation (and berms surrounding the transplanted rootball), trees may experience chronic drought conditions, especially during the winter dry period of peninsular Florida.

Management-Related Factors

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). With regard to 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 all 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 that have the potential to damage stems (Morgenroth et al., 2015; Percival and Smiley, 2015).

Roman et al. (2015) reported a case study in California where high establishment (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 in a study by Foster and Blaine (1978), was vehicular strikes.

Community-Related Factors

Multiple research efforts have explored the relationship between community-related factors and tree survival and growth. Past research has linked community factors such as 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.

Health and Establishment of Palms

While urban tree growth and longevity research is an active area of inquiry, the majority of 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 2-1. 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% over eight months by lessening transpiration until new roots are regenerated (Table 2-1; Broschat, 1991). Most palm species, however, regrow roots from the point at which they are cut after digging. Thus, pruning at transplanting may not be necessary to maintain a root/shoot balance for these species during the establishment phase (Broschat, 1994). Broschat (1994) demonstrated that recently transplanted *Phoenix roebelenii*, a species that does not experience the same root dieback as *S. palmetto*, only benefited from frond pruning when exposed to soil water stress. In general, the 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 (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 the season in which planting occurred in southern Florida may not be important, as conditions 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 that these factors were uncorrelated or weakly correlated with palm health.

Table 2-1. Factors associated with palm growth, health, and transplant success.

Reference	Setting/ Location	Study Period	Species	Factors[a]	Notes
Broschat and Donselman (1990a)	Field Nursery/ Fort Lauderdale, FL	7-month after planting	*P. roebelenii, C. elegans*	Biological age (G+, S+)	Immature plants = 100% mortality.
Broschat (1991)	Median/ Miami, FL	8-month after planting	*S. palmetto*	Transplanting without fronds (G+, S+)	G assessed by canopy size.
Broschat (1994)	Nursery/ Fort Lauderdale, FL	5-month after planting	*P. roebelenii* (water stressed)	Transplanting without fronds (G+, S+)	G assessed using root dry-weight and live-frond count.
			P. roebelenii (non-water stressed)	Top-irrigation (H -)	Leaf-tying showed no improvements.
Broschat (1995)	Field nursery/ Fort Lauderdale, FL	15-month after planting	*P. roebelenii*	Transplanting depth below original (G -, H -, S -)	G assessed by frond count. H assessed by tissue analysis.
Hodel (1995)	Arboretum/ Los Angeles, CA	3-year after root pruning	*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-year after planting	*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-month after planting	*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)	Entire palm population/ Olhão, Portugal	Unknown	*C. humilis, W. robusta, P. canariensis*	Above-ground space (H+), Distance to road (H+)	Weak correlations but sig. Health assessed visually.

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

SECTION 2: MATERIALS AND METHODS

Experimental Design

Between June 26, 2017, and October 12, 2017, twenty-one roadside tree planting projects were sampled across seven (of eight) FDOT districts (Figure 2-1). District 6 (Miami), was excluded from inventory given the timing of sampling and tree losses resulting from Hurricane Irma (Mayer, 2017). *Phoenix spp*. were also excluded due to the prevalence of Texas Phoenix palm decline (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 under 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. Given the scale of the FDOT planting areas (where single installations could have several hundred trees planted along every side of an interchange or FDOT property), one contiguous section of an interchange/site was selected at random for inventory.

Planting Project Contract Details

All trees were installed by professional contract labor. FDOT favors the installation of container-grown shade trees, small-stature trees, and conifers, while palms are generally field-grown. Contractors held responsibility for planting projects and tree maintenance 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 met the high-quality nursery standard of Florida #1 (*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 these 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 (1,285 trees) while others were irrigated by truck or possibly non-irrigated (1,241 trees), dependent upon vehicular access and access to an irrigation source.

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

Data Collection

At each planting project area, trees were inspected to assess establishment and health. For establishment, living trees were counted and compared to the total number of trees encountered. Standing dead trees, stumps, and missing trees were considered dead. Possible replacement trees were identified by visual cues that distinguished the tree from others in the planting project, such as new mulch, new staking material, recently pruned palm canopies, flagging tape, different bark texture, etc. True replacement status, however, could not be confirmed. Due to the replacement strategy employed in this planting program, this paper defines establishment as the proportion of trees alive at the time of inventory regardless of replacement status, as opposed to other standard definitions of establishment (Levinsson et al., 2017).

Establishment and health were evaluated relative to a range of tree-, site-, and maintenance-related factors (Table 2-2). Health was rated using the method outlined by Bond (2012) classifying growth, opacity, ratio, quality, and vitality into 20% scoring classes. 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 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 2-3).

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 (Husky THD9407, Home Depot, Atlanta, Georgia, United States) on two sides of the tree (in line with the predominant slope) and averaged. RUSI Parameters INFR, SURF, ERA, and EXP were recorded for each tree. For the TXT, STRC, pH, SOM, AHOR, and WAS RUSI variables, assessments were made for groups of trees planted in zones of similar soil characteristics that were stratified by visual cues (e.g., ground vegetation, slope, etc.) within a given planting area. Within each stratified zone, ten samples were collected with a soil core at a depth of 25.4 cm and aggregated for further analysis. Finally, the climatic ratings PPT and GDD were assessed at the project level (i.e., all trees at a given location had the same rating).

Data Analysis

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 ft) 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 for trees to be used in modeling). Attempts to rectify the issue by reducing predictor variables failed. Therefore, the prop.test() function in R, which uses Pearson's chi-square test, 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 versus absent). An experiment-wise error rate was controlled for using a Holm adjustment (Holm, 1979).

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 2-4). Of the five health ratings detailed by Bond (2012), quality and vitality were the most widely used among the species assessed and are reported in the results below. These two health responses were fit against the predictors noted in Tables 2-2 and 2-3 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 models using the anova() function in R (Crawley, 2013).

Due to the importance of maintenance practices in urban tree 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 lawncare damage to a tree. For all statistical tests, an alpha level of 0.05 was adopted as the threshold of significance.

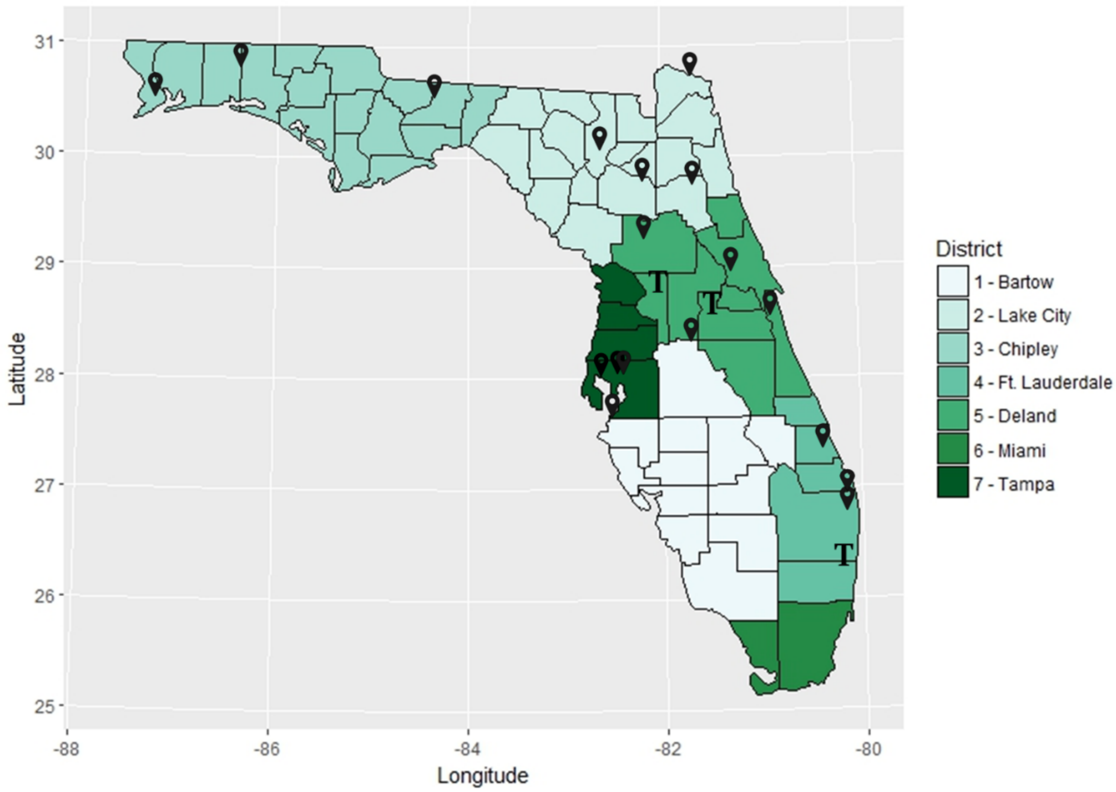

Figure 2-1. Florida Department of Transportation District Map (United States) with marked locations of planting projects sampled in this study. Turnpike District projects denoted with “T”.

Table 2-2. Overview of variables used in FDOT roadside tree planting analyses.

Variable	Description	Type	Collection Level[a]	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)	lawn care, stakes, other	binary	tree	
root flare (0/1)	visible without digging	binary	tree	
tree type[b]	small-stature, shade, conifer, palm	categorical	tree	
planting season	wet/dry	categorical	project	Misra and Mishra (2016)
yrs since plant	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)
branch structure (1-5)	poor – excellent	ordered	tree	
RUSI Scores	See Table 2-2	ordered	tree/zone/ project	Scharenbrock et al., (2017)

[a] Collection level indicates location within a planting project where 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. [b] Small-stature (<9.14m) and shade (>9.14m) were separated by species’ height at maturity.

Table 2-3. Scoring functions and adaptations of RUSI parameters (Scharenbroch et al., 2017) for use in FDOT roadside tree planting analyses.

RUSI Parameter	Units	Collection Level [a]	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[d]	n/a	Zone	M, SG, PL	ABK	SBK	GR
TXT[e]	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, 8.1-9	5-5.9, 6.6-8	6-6.5
EC	µS cm^{-1}	Zone	<50 or >3,000	50-100, 2,001-3,000	101-300, 1,001-2,000	301-1,000
SOM[c]	% 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 [b c]	mm•yr^{-1}	Project	<1290	1290-1372	1372-1585	>1585
GDD[c]	base 50	Tree	<6992	6992-7663	7663-8069	>8069
EXP	# sides	Tree	0	1-2	3-4	5

[a] "Collection level" indicates the location within a planting project where 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. [b] PPT score unaffected by on-site irrigation. [c] Some RUSI scores determined by breaking data in quantiles. [d] Soil structure abbreviations are M=massive; SG=single grained; PL=platy; ABK=angular blocky; SBK=subangular blocky; GR=granular. [e] Soil texture abbreviations are 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.

Table 2-4. Normalized descriptions of ordered health ratings used in ordinal logistic regression.

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

SECTION 3: RESULTS

Tree Establishment

Based on installation records, the time since installation for the sampled projects ranged from nine to 58 months. The average project age was 30 months. A total of 2,711 trees were assessed for survival. 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. Establishment over the study period for each tree type was 98.0% (palms), 99.4% (small-stature), 99.8% (shade), and 97.3% (conifer), contributing to an overall establishment of 98.5% (Table A-1). Of the total sample, 45 trees were noted as potential replacements, although unconfirmed.

When examining establishment, all tree types had higher establishment success when permanent irrigation was present; however, the impacts were only statistically significant for palms ($P = 0.006$) (Table 2-5). Within the palms, the establishment of the most common species, *S. palmetto*, 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 ($P = 0.015$).

Tree Health

Of 2,711 trees, 2,403 trees were visually rated for health using the methods outlined by Bond (2012). 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 a categorical variable (e.g., on-site irrigation). A summary of significant effects is given in Figure 2-2. Final health models for each health response and tree type are included in Appendix B.

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-value < 0.001) (Table B-1). Of the RUSI parameters, ERA had the highest odds ratio (odds ratio = 2.82; P-value = 0.0028) (Figure 2-2). 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-value = 0.0005) and 1.78 (P-value = 0.0022), respectively. An increase in RUSI scores for AHOR (A-horizon depth; odds ratio = 0.49; P-value = 0.0047), EC (electrical conductivity; odds ratio = 0.52; P-value = 0.0364), EXP (crown light exposure; odds ratio = 0.22; P-value = 0.0082), and pH (odds ratio = 0.31; P-value < 0.0001) were associated with a reduction in shade tree quality ratings (Figure 2-2). 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-value < 0.0001). The same held true in the absence of berms (odds ratio = 0.24; P-value < 0.0001) (Figure 2-2).

For the final shade tree vitality model, *L. styraciflua* (odds ratio = 4.85; P-value = 0.0460), *Magnolia grandiflora* (odds ratio = 21.05; P-value < 0.0001), *Peltophorum pterocarpum* (odds ratio = 24.04; P-value < 0.0001), and *Swietenia mahagoni* (odds ratio = 5.47x107; P-value <0.0001) had higher vitality ratings than the baseline of *D. regia* (Table B-2). Years since planting was also a significant predictor of vitality (odds ratio = 2.93, P-value <0.0001) (Figure 2-2). In the absence of on-site irrigation, shade trees were less likely to attain a higher vitality rating (odds ratio = 0.26, P-value = 0.0004). Counterintuitively, as the PPT (annual precipitation) RUSI score increased, the likelihood of attaining a higher vitality rating decreased (odds ratio = 0.65; P-value = 0.0009). Similar trends were noted with increased ratings for EXP (crown light exposure; odds ratio = 0.01; P-value = 0.0012), STRC (soil structure; odds ratio = 0.66; P-value = 0.0170), and TXT (soil texture; odds ratio = 0.23; P-value = 0.0042) (Figure 2-2).

Small-Stature Trees

In modeling 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-value = <0.0001) (Figure 2-2). As the ERA (estimated rooting area) score increased, the likelihood of attaining a higher quality rating decreased (P-value = 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-value < 0.0001).

For the final small-stature tree vitality model, species was again a significant predictor. *Lagerstroemia spp*. (odds ratio = 0.18, P-value = 0.0016) had higher vitality ratings than *Ilex x attenuata* ‘Eagleston’ (Table B-4). 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-value = 0.1506). Years since planting improved the likelihood of attaining a higher vitality rating (odds ratio = 1.67; P-value < 0.0001), while the absence of on-site irrigation reduced the likelihood of attaining a higher vitality rating (odds ratio = 0.25; P-value < 0.0001) (Figure 2-2).

Conifers

Both final vitality and quality models for conifer health ratings yielded similar results. *P. palustris* and *Taxodium distichum* were both outperformed by *Pinus elliottii* (Table B-5; Table B-6). Similarly, absence of installed irrigation resulted in lower likelihoods of attaining higher quality (odds ratio = 0.13; P-value = <0.0001) and vitality ratings (odds ratio = 0.04; P-value = 0.0026) (Figure 2-2). 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-value = 0.0088) and vitality ratings (odds ratio = 16.72; P-value = 0.0010) (Figure 2-2). INFR (distance to infrastructure) rating had a positive relationship with quality rating (odds ratio = 2.13; P-value = 0.0007). As with the shade tree vitality model, the PPT (annual precipitation) score was associated with a reduced likelihood of attaining a higher vitality rating (odds ratio = 0.40; P-value = 0.0011) (Figure 2-2).

Palms

For the final palm quality model, species was again a significant predictor. When compared to the *Wodyetia bifurcata* baseline, all other species were more likely to have higher quality ratings (min. odds ratio = 16.45; all P-values < 0.0001) (Table B-7). Wet season plantings (odds ratio = 2.95; P-value < 0.0001), absence of berms (odds ratio = 1.65 ; P-value = 0.0293), staking for greater than one year (odds ratio = 2.86; P-value < 0.0001), EC (electrical conductivity; odds ratio = 1.74; P-value = 0.0008), INFR (distance to infrastructure; odds ratio = 1.30; P-value = 0.0077), and SOM (soil organic matter; odds ratio = 1.27; P-value = 0.0051) scores improved the likelihood of attaining a higher quality rating (Figure 2-2). In contrast, increased years since planting (odds ratio = 0.63; P-value = <0.0001), EXP (crown light exposure; odds ratio = 0.44; P-value = <0.0001), GDD (growing degree days; odd ratio = 0.80, P-value = 0.0204), and TXT (soil texture; odds ratio = 0.54; P-value = 0.0155) were associated with lower quality ratings (Figure 2-2).

Tree Maintenance

Results from logistic regression show that both staking and mulching protect trees from the lawn care damage (Table 2-6) 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.

Table 2-5. Establishment success for trees planted on sites with irrigation installed and for trees planted on sites lacking installed irrigation.

	On-site irrigation		Non-irrigated		P-value
Tree type	% establish	n	% establish	N	(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

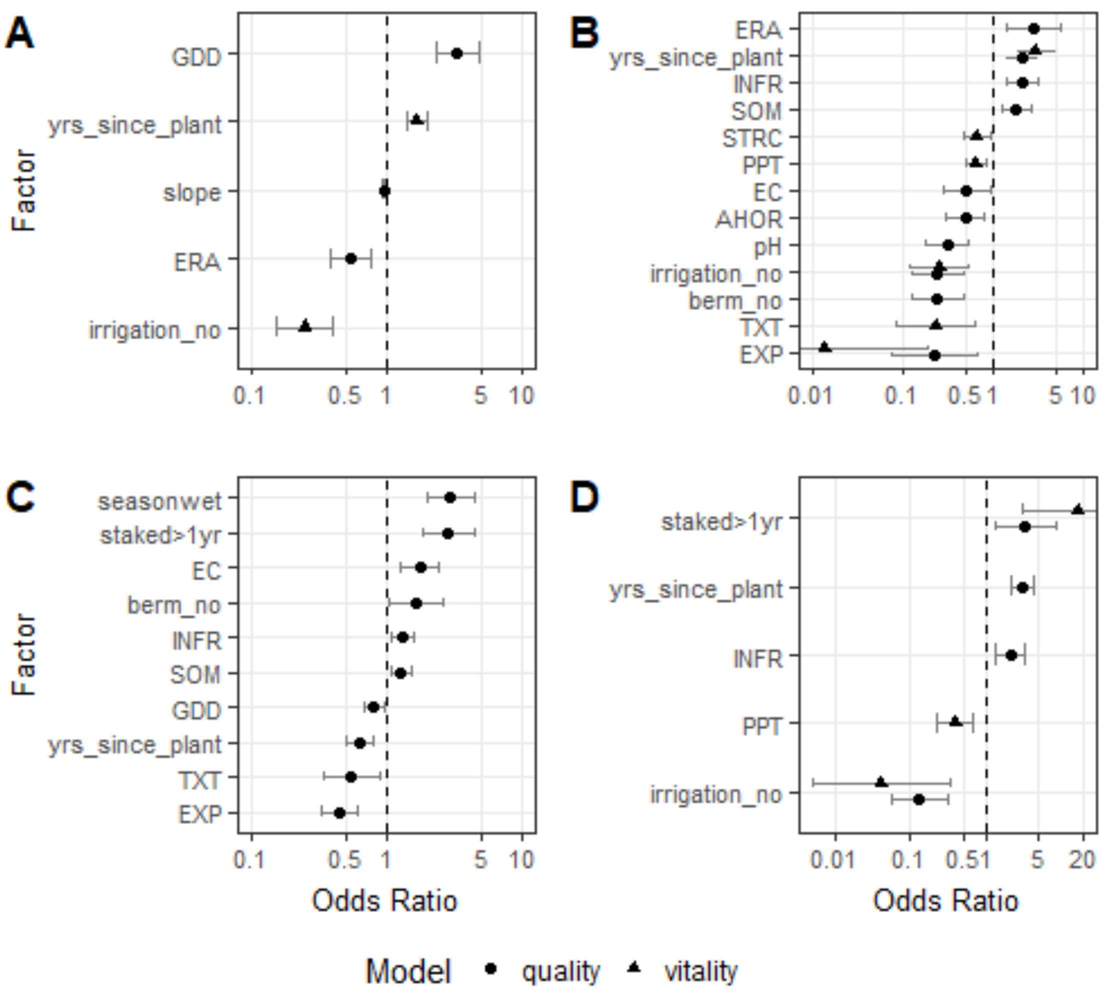

Figure 2-2. Odds ratios and corresponding 95% confidence intervals for significant factors (P = <0.05) from each of the seven final ordinal logistic regression models. Tree types are small-stature (A), shade (B), palm (C), conifer (D). Rapid Urban Site Index factors within the models include: growing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

Table 2-6. Odds ratios and corresponding 95% confidence intervals (calculated for the odds ratio) resulting from binary logistic regression for factors related to lawncare damage to trunks.

Factor	Coefficient	SE	P-value	OR[a]	95%CI
mulched	-1.2336	0.2413	<0.0001	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	0.8053	0.2305	0.0005	2.2373	[1.4240, 3.5153]

[a] An odds ratio greater than 1 indicates an increased likelihood of a tree being damaged by lawncare equipment per one unit increase in the predictor. Increases in estimated rooting area (ERA) result in an increased likelihood of lawn care damage.

SECTION 4: DISCUSSION

Tree Establishment

With establishment ranging from 97.3% (conifers) to 99.8% (shade tree), the program studied has one of the highest success rates in the growth and longevity literature. 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 six years after planting for highway trees in East Palo Alto, California. 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 irrigated and non-irrigated sites for shade, small-stature, and conifer tree types (Table A-1). A statistically significant difference did exist for palms, however. This appeared to be driven by differences in establishment for

S. palmetto (Table A-1). For this species, severed roots die back to the trunk during harvest, increasing the potential for post-planting water stress (Broschat, 1991).

Tree Health

Although each of the seven health models developed for this study offered slightly different results given the rating and tree type assessed (Figure 2-2; 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 (Figure 3-1).

The absence of on-site irrigation repeatedly resulted in visual 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 the 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 were also associated with 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 scoring 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.

In our study sites, another factor related to water management was planting season (i.e., wet versus dry). We found wet season plantings yielded higher quality ratings overall 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 (Hodel, 2005; Broschat, 1998). However, the other tree types included 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 tree planting, 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 (Figure 2-2). 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 with a new tree) has weeded out the poorly performing trees, what remains are the healthier individuals. In contrast, we noted that palm health declined with age. Palms not adapted to Florida’s sandy soils can develop nutrient deficiencies which 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 ill-suited for a site, in the absence of supplemental fertilization, symptoms will manifest over time as new fronds begin to grow.

INFR (distance to infrastructure) showed up in three models and had a positive association with health, corroborating past findings by Koeser et al. (2013) in which expanding the width from sidewalk to curb improved tree condition, and research by Sanders and Grabosky (2014) in which 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 original RUSI model (Scharenbroch et al., 2017). One possible explanation is that the trees in this study are still in the younger stages of the urban tree 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 on the sites inventoried.

Staking longer than one year improved visual health ratings. For palms, Broschat et al. (2000) recommend bracing materials be removed six to eight months after planting, although retaining bracing materials will not girdle palm trunks as they will broadleaf and coniferous trees. Although it initially seemed 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 of the underlying cause, these findings indicate that retaining stakes for more than one growing season may not cause harm if monitored and adjusted to prevent girdling.

Tree Maintenance

Several visual cues associated with tree maintenance and stewardship were recorded and allow for comparison with other studies (Table 2-7). 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 adhered to at higher rates compared to other assessments of early tree growth and longevity (Table 2-7). 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 2-7). 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 by Morgenroth et al. (2015) in Christchurch, New Zealand. However, trees ranged from 3 cm to 253 cm in DBH in the Morgenroth et al. (2015) study. As stem diameter relates to tree age, the population of trees assessed in Christchurch included older trees that had had many more years to be damaged and re-damaged by lawn mowing equipment than the trees in our study.

Within our sampled trees, we did find some of the plantings had care measures 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 signs of mechanical stem wounding than non-mulched trees (Table 2-6). Similarly, staked trees were half as likely to show signs of lawn care damage as trees without staking (Table 2-6). 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 and crews use larger equipment when trees are spaced farther apart. Large tractor-pulled brush mowing attachments are more difficult 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 of the health ratings we employed. Percival and Smiley (2015) attribute timing, species-specific ability to compartmentalize decay, and extent of stem wounding to be determinants 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 street trees in Boston, Massachusetts (United States), 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 2-7). 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 2-7.

Table 2-7. 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[a])	62.9% (1018) 7.2% (291)	Morgenroth et al. (2015) Roman et al. (2014b)
Total trunk damage	8% (1202[a])	47.4% (656)	Vogt et al. (2015)
Staking damage	1% (1202[a])	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. (2015)
Mulched	76.5% (2491)	7.2% (13405) 38.5% (291) 10.5% (658[c])	Lu et al. (2010) Roman et al. (2014b) Vogt et al. (2015)
Root flare visible	50.1% (2495)	27.4% (658)	Vogt et al. (2015)
Girdling roots	1.25% (1116[a])	n/a	n/a
Poor branch structure	3% (969[ab])	n/a	n/a

[a] Palms were excluded. [b] Small-stature trees were excluded. [c] Study examined proper versus improper mulching.

SECTION 5: CONCLUSIONS AND RECOMMENDATIONS

This research investigated a multitude of factors to quantify how they relate to both the establishment 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 versus 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.

This Florida highway planting study demonstrates that replacement strategy in planting initiatives can ensure high levels of establishment in young trees. Recent research has analyzed the influence of replacement tree strategy on the overall structure of a municipal forest (van Doorn and McPherson, 2018). While same species and size replacements (an FDOT practice) have been cautioned against (ibid.), the long-term effects regarding planting initiatives are unknown, indicating the need for longitudinal studies that consider replacement policy as apart of the experimental design. To do so, measures should be taken by planting-initiative management to track and record species, size, and timing of replacement trees.

FDOT “Bold Initiative” plantings also provide evidence that tree stewardship is essential to planting-initiative success. Indicators of care were abundant, supporting findings that at-planting (e.g., depth) and post-planting (e.g., trunk protection with mulch, stakes, etc.) care is critical to establishment survival (Roman et al., 2014b). Future research should examine motivators as well as associated hurdles for government agencies to embrace large-scale tree planting initiatives, thus helping other agencies improve their planting efforts.

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 used as 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 unknown. Moreover, visual aesthetics are generally prioritized over growth once trees leave the nursery for the landscape. This work also demonstrates the potential of incorporating an urban site index to assess the suitability of planting locations, although some counterintuitive findings signal for the need of collective, regional efforts to better define scoring functions for site factors.

Additionally, this study was not without limitations. Baseline growth data was not available for growth analyses. With regard to analyses, the inclusion of replacement trees may add noise to statistical tests and modeling. Also, some factors of tree performance from previously published growth and longevity research were unavailable for consideration in this study. Those factors include but are not limited to diameter growth, nursery stock size, contractor, plant material handling practices, and the effects of other maintenance practices, such as pruning and fertilization. Nevertheless, the methods employed in this study are well suited for gauging the effectiveness of past management efforts and assessing contributing factors of tree establishment and health.

APPENDIX A: ESTABLISHMENT BY TREE TYPE AND SPECIES

Table A-1. Establishment by tree type and species. Data was collected along Florida Department of Transportation corridors as part of a statewide “Bold Landscaping Initiative.”

Species	Common name	n	Establishment (%)
Shade trees			
Ilex x attenuata	‘East Palatka’ holly	10	100
Chionanthus virginicus	fringe tree	9	100
Senna surattensis	glossy shower	4	100
Elaeocarpus decipiens	Japanese blueberry	23	100
Swietenia mahagoni	mahogany	23	100
Carya glabra	pignut hickory	3	100
Acer rubrum	red maple	10	100
Delonix regia	royal poinciana	42	100
Chorisia speciosa	silk-floss tree	12	100
Magnolia grandiflora	southern magnolia	115	100
Liquidambar styraciflua	sweetgum	33	100
Ulmus alata	winged elm	1	100
Peltophorum pterocarpum	yellow poinciana	35	100
Quercus virginiana	southern live oak	159	99.4
Shade tree totals		*479*	*99.8*
Small-stature trees			
Ilex x attenuata	‘Eagleston’ holly	29	100
Cercis canadensis	eastern redbud	19	100
Prunus umbellata	flatwoods plum	12	100
Olea europaea	olive	7	100
Tabebuia aurea	Caribbean trumpet	3	100
Tabebuia heptaphylla	pink trumpet tree	11	100
Coccoloba uvifera	sea grape	20	100
Lagerstroemia spp.	crapemyrtle	330	99.7
Ligustrum japonicum	Japanese privet	68	97.1
Small-stature tree totals		*499*	*99.4*
Conifers			
Pinus taeda	loblolly pine	9	100
Juniperus virginiana	redcedar	8	100
Pinus elliottii	slash pine	95	100
Taxodium distichum	baldcypress	112	97.3
Pinus palustris	longleaf pine	110	95.5
Taxodium ascendens	pondcypress	1	100
Conifer totals		*335*	*97.3*
Palms			
Bismarckia nobilis	Bismarck palm	156	100
Hyophorbe lagenicaulis	bottle palm	19	100
Wodyetia bifurcata	foxtail palm	21	100
Butia odorata	mule palm	5	100
Roystonea regia	royal palm	104	100
Ptychosperma elegans	solitaire palm	44	100
Trachycarpus fortunei	windmill palm	19	100

Table A-1. Continued

Species	Common name	n	Establishment (%)
Livistionia chinensis	Chinese fan palm	99	98.0
Sabal palmetto	sabal palm	667	97.9
Archontophoenix alexandrae	Alexander palm	32	96.9
Washingtonia robusta	Mexican fan palm	232	95.3
Palm totals		*1398*	*98.0*

APPENDIX B: FINAL ORDINAL LOGISTIC REGRESSION HEALTH MODELS

Table B-1. Final ordinal logistic regression model for shade tree quality. Data was collected at Florida Department of Transportation “Bold Landscaping” areas.

Factor	Coefficient	SE	P-value	OR	95%CI
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]
yrs_since_plant	0.7326	0.1863	0.0001	2.0805	[1.4439, 2.9977]
AHOR[b]	-0.7154	-0.2531	0.0047	0.4890	[0.2978, 0.8031]
EC[b]	-0.6609	-0.3158	0.0364	0.5164	[0.2781, 0.9589]
ERA[b]	1.0382	0.3472	0.0028	2.8242	[1.4299, 5.5779]
EXP[b]	-1.4974	0.5662	0.0082	0.2237	[0.0738, 0.6786]
INFR[b]	0.7424	0.2121	0.0005	2.1009	[1.3864, 3.1837]
pH[b]	-1.1679	0.2868	<0.0001	0.3110	[0.1773, 0.5456]
SOM[b]	0.5782	0.1890	0.0022	1.7829	[1.2310, 2.5822]
E. decipiens[a]	3.5221	0.8682	<0.0001	33.8554	[6.1740, 185.6470]
L. styraciflua[a]	5.9546	0.8364	<0.0001	385.5352	[74.8366,1986.1603]
M. grandiflora[a]	1.4140	0.5046	0.0051	4.1124	[1.5297,11.0557]
P. pterocarpum[a]	1.2911	0.5420	0.0172	3.6369	[1.2572, 10.5213]
Q. virginiana[a]	2.2992	0.4938	<0.0001	9.9661	[3.7860, 26.2338]
S. mahagoni[a]	2.9213	0.8551	0.0006	18.5648	[3.4740, 99.2078]

[a] 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. [b] 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 B-2. Final ordinal logistic regression model for shade tree vitality. Data was collected at Florida Department of Transportation “Bold Landscaping” areas.

Factor	Coefficient	SE	P-value	OR	95%CI
irrigation_no	-1.3557	0.3837	0.0004	0.2578	[0.1215, 0.5468]
yrs_since_plant	1.0734	0.2399	<0.0001	2.9254	[1.8280, 4.6814]
EXP[b]	-4.2947	1.3283	0.0012	0.0136	[0.0010, 0.1843]
PPT[b]	-0.4334	0.1305	0.0009	0.6483	[0.5020, 0.8372]
STRC[b]	-0.4154	0.1741	0.0170	0.6601	[0.4692, 0.9285]
TXT[b]	-1.4615	0.5112	0.0042	0.2319	[0.0851, 0.6315]
E. decipiens[a]	-0.1652	0.6020	0.7838	0.8477	[0.2605, 2.7584]
L. styraciflua[a]	1.5780	0.7909	0.0460	4.8455	[1.0283, 22.8317]
M. grandiflora[a]	3.0471	0.5441	<0.0001	21.0537	[7.2468, 61.1660]
P. pterocarpum[a]	3.1798	0.7273	<0.0001	24.0420	[5.7792, 100.0180]
Q. virginiana[a]	0.6310	0.3923	0.1078	1.8794	[0.8711, 4.0548]
S. mahagoni[a]	17.8176	<0.0001	<0.0001	54712190.3018	[54712036.3316, 54712344.2724]

[a] 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. [b] Rapid Urban Site Index factors within the model include crownlight exposure (EXP), annual precipitation (PPT), soil structure (STRC), and soil texture (TXT).

Table B-3. Final ordinal logistic regression model for small-stature tree quality. Data was collected at Florida Department of Transportation "Bold Landscaping" areas.

Factor	Coefficient	SE	P-value	OR	95% CI
ERA[a]	-0.6061	0.1711	0.0004	0.5455	[0.3901, 0.7628]
GDD[a]	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]

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

Table B-4. Final ordinal logistic regression model for small-stature tree vitality. Data was collected at Florida Department of Transportation "Bold Landscaping" areas.

Factor	Coefficient	SE	P-value	OR	95%CI
yrs_since_plant	0.5122	0.0831	<0.0001	1.6689	[1.4181, 1.9640]
Lagerstroemia spp. [a]	-1.6871	0.5353	0.0016	0.1851	[0.0648, 0.5285]
L. japonicum[a]	-0.8372	0.5824	0.1506	0.4329	[0.1382, 1.3558]
irrigation_no	-1.3960	0.2415	<0.0001	0.2476	[0.1542, 0.3975]

[a] 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 B-5. Final ordinal logistic regression model for conifer quality. Data was collected at Florida Department of Transportation "Bold Landscaping" areas.

Factor	Coefficient	SE	P-value	OR	95%CI
irrigation_no	-2.0275	0.4393	<0.0001	0.1317	[0.0557, 0.3115]
staked>1yr	1.2161	0.4642	0.0088	3.3739	[1.3583, 8.3804]
yrs_since_plant	1.1141	0.1708	<0.0001	3.0467	[2.1800, 4.2581]
INFR[b]	0.7569	0.2232	0.0007	2.1316	[1.3763, 3.3016]
P. palustris[a]	-3.8261	0.6478	<0.0001	0.0218	[0.0061, 0.0776]
T. distichum[a]	-2.8425	0.4522	<0.0001	0.0583	[0.0240, 0.1414]

[a] 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. [b] Rapid Urban Site Index factors within the model include distance to infrastructure (INFR).

Table B-6. Final ordinal logistic regression model for conifer vitality. Data was collected at Florida Department of Transportation "Bold Landscaping" areas.

Factor	Coefficient	SE	P-value	OR	95%CI
irrigation_no	-3.1787	1.0567	0.0026	0.0416	[0.0052, 0.3303]
staked>1yr	2.8169	0.8545	0.0010	16.7252	[3.1334, 89.2748]
PPT[b]	-0.9136	0.2808	0.0011	0.4011	[0.2313, 0.6955]
P. palustris[a]	-3.2312	0.9802	0.0010	0.0395	[0.0058, 0.2698]
T. distichum[a]	-2.3588	0.7508	0.0017	0.0945	[0.0217, 0.4118]

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

Table B-7. Final ordinal logistic regression model for palm quality. Data was collected at Florida Department of Transportation “Bold Landscaping” areas.

Factor	Coefficient	SE	P-value	OR	95%CI
berm_no	0.5059	0.2321	0.0293	1.6584	[1.0522, 2.6139]
seasonwet	1.0829	0.2077	<0.0001	2.9533	[1.9658, 4.4368]
staked>1yr	1.0503	0.2299	<0.0001	2.8586	[1.8215, 4.4863]
yrs_since_plant	-0.4642	0.1122	<0.0001	0.6286	[0.5045, 0.7833]
EC[b]	0.5548	0.1647	0.0008	1.7416	[1.2612, 2.4050]
EXP[b]	-0.8154	0.1560	<0.0001	0.4425	[0.3259, 0.6008]
GDD[b]	-0.2188	0.0943	0.0204	0.8035	[0.6678, 0.9666]
INFR[b]	0.2637	0.0989	0.0077	1.3017	[1.0724, 1.5802]
SOM[b]	0.2420	0.0865	0.0051	1.2738	[1.0752, 1.5091]
TXT[b]	-0.5982	0.2471	0.0155	0.5498	[0.3388, 0.8923]
A. alexandrae[a]	2.8005	0.6212	<0.0001	16.4521	[4.8691, 55.5900]
B. nobilis[a]	4.6915	0.5041	<0.0001	109.0165	[40.5889, 292.8040]
L. chinensis[a]	3.9869	0.5294	<0.0001	53.8849	[19.0917, 152.0862]
P. elegans[a]	4.3032	0.7648	<0.0001	73.9360	[16.5150, 331.0054]
R. regia[a]	3.5801	0.5049	<0.0001	35.8774	[13.3359, 96.5205]
S. palmetto[a]	3.7465	0.4559	<0.0001	42.3719	[17.3375, 103.5544]
W. robusta[a]	5.8769	0.5246	<0.0001	356.7006	[127.559, 6997.4583]

[a] 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. [b] 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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CHAPTER 3 - SUMMARY OF CHANGES TO MAINTENANCE GUIDE

Revisions were made to FDOT Document – *A Guide for Tree and Palm Maintenance for Urban Roadsides and Landscape Areas*.

In June 2018, the Principal Investigator and Graduate Student met with the Project Manager to visit landscaping sites that had been previously surveyed. At this time, discussions were held regarding rural tree pruning practices. Additionally, the Graduate Student emailed with Tim Allen regarding rural tree maintenance practices. These steps ensured the completion of *Task 2, Subtask 2*.

Due to revisions to the current guidebook, we propose a new title: *A Guide for Tree and Palm Maintenance along Florida Roadsides*.

Beyond the scope of the grant, multiple sections have been added that aim to improve tree maintenance practices for the department. Those sections include:

- Rural Tree Pruning (as indicated in grant)
    - This covers proper tools, best management practices, site selection, debris management, equipment sanitation, and working adjacent to sensitive areas.
- Restoration Pruning
    - During *Deliverable 1*, it was noted that some trees in north Florida had been damaged by Hurricane Irma. Also, District 6 was excluded from the study due to losses associated with Hurricane Irma. This sparked an idea to include a detailed process for storm response as well as restoring or replacing damaged or fallen trees.
- Tree Risk Mitigation
    - This section is intended to give guidance for identifying and managing dead trees, trees with defects, etc. that may influence roadside safety. The idea for this addition developed when considering rural tree pruning. Because rural areas are adjacent to natural forest stands that regularly experience tree mortality, whole-tree failures should be a very important consideration.

The Appendices have multiple additions. Those additions include:

- Pruning Specifications developed by Dr. Ed Gilman.
- A section on chemical side-trimming that is referenced by the Rural Tree Pruning chapter.
- A summary of soil conditions found along state roadsides during *Deliverable 1* methods.
- An overview of pests and diseases found along state roads during *Deliverable 1* methods.

The new guidebook also has a glossary of terms used.

CHAPTER 4 - SUMMARY OF TECHNOLOGY TRANSFER SERIES

SECTION 1: Technology Transfer Schedule

Face-to-face technology transfer sessions were held at five FDOT regional headquarters (Districts 1,3,5,6, and 7). A sixth event was scheduled for District 2 but was cancelled given the uncertainty surrounding the COVID-19 pandemic.

The dates for the training sessions were as follows:
- DeLand – December 17, 2019 (27 attendees)
- Tampa – January 16, 2020 (31 attendees)
- Chipley – February 10, 2020 (16 attendees)
- North Miami – February 12, 2020 (50 attendees)
- Bradenton – March 9, 2020 (38 attendees)
- Lake City – March 16, 2020 (Canceled given COVID-19)

Initially, the training had four modules arranged according to the following schedule:

FDOT Tech Transfer Training Session: Roll Out of a Guide For Tree and Palm Maintenance Along Florida Roadsides

9:00 am to 9:45 am - Bold Initiative; Big Results - Findings from an Assessment of Recent Tree Installations (45 mins)
The Florida Department of Transportation has made significant investments in tree plantings along interchanges, bridges, rest areas, and other high-traffic areas. The University of Florida recently surveyed past planting initiatives to assess what tree-, site- and care-related factors contributed to planting success. The results of this research and management implications are discussed.

9:45 am to 10:15 am - Visual Assessment of Tree and Palm Condition (30 mins)
Assessments of tree condition provide the most details recorded when surveying trees and palms. Tree condition factors into acceptance of nursery stock, post-care inspection of plantings, assessments of future maintenance and care demands, and determinations of tree risk. This presentation will highlight five reproducible, visual measures of tree condition while highlighting two approaches developed for FDOT in assessing palm health.

10:15 am to 10:30 am - Break (15 mins)

10:30 am to 11:30 am - Proper Pruning of Shade Trees, Palms, and Crepe Myrtle (60 mins)
Trees are living structures. As such, pruning must consider the biology and natural structure of a tree, as well as the desired pruning objectives. In this presentation, we highlight proper pruning practices for three of the most common tree types found on

FDOT installations. Additionally, we will examine several examples of improper pruning that are still prevalent in Floridian landscapes.

11:30 am to 12:00 pm - Pruning Specifications: Why and How to Write Them (30 mins) *How can trained FDOT staff accurately convey proper pruning practices to contractors and field crews? How can site managers hold tree crews accountable for not delivering the services requested? The answer to both of these questions is the creation of clear and concise pruning specifications using standard language from the ANSI - A300 Pruning standards. Participants will be given a brief overview of the pruning specifications developed by Dr. Edward Gilman as part of this project.*

In completing the first training session in Bartow, the FDOT project manager suggested dropping the fourth presentation on pruning specifications as it was most relevant to only a few attendees in each district. The presentation has been recorded for the benefit of those who work in contracting for FDOT.

SECTION 2: Technology Transfer Evaluations

Table 4-1. Program evaluations received at the five technology transfer events held in Districts 1,3,5,6, and 7.

Question	Excellent	Above Average	Average	Below Average	Poor	N/A
How would you rate the amount of new information you learned? (104 responses)	60.6%	33.7%	5.7%	0%	0%	0%
How would you rate the usefulness of this information to your job? (102 responses)	65.7%	21.6%	10.7%	1.1%	0%	0.9%
How would rate the session in terms of meeting your expectations? (103 response)	62.1%	22.3%	15.6%	0%	0%	0%
How would you rate the materials/slides presented? (102 responses)	61.7%	27.4%	10.9%	0%	0%	0%
How would you rate the speaker's knowledge of the course material? (103 responses)	80.6%	16.5%	2.9%	0%	0%	0%
How would rate the speaker's presentation skills? (102 response)	68.7%	24.5%	6.8%	0%	0%	0%

Additionally, we asked which training modules were most and least relevant to the attendees' work. Of the 73 respondents who opted to answer this question, two-thirds (67.1%) felt the pruning module was most relevant to their work. The module on visual inspection of tree condition was viewed as the second most relevant offering (favored by 24.7%).

Finally, the evaluation forms included an open comment section. Comments from the training are as follows:

- Good!
- Good job.
- Thank you. Very useful!

- Very good class. I learned a lot.
- Well-needed information.
- Great work.
- I really loved it.
- Excellent teacher.
- Have more classes.
- The presenter made the assumption the group understood “tree lingo” Suggest he drop back to educate on basics.
- Good information to know.
- Good Class
- Training very informative.
- First time taking the class. I can use it at home and work.
- All topics very informative.
- Thanks you. Consider continuing training every two years for districts.
- Power points are good.
- Very Interesting and knowledgeable info. I will use in the field and future.

SECTION 3: Pre- and Post-Test Results

Identical pre- and post-tests were distributed at the start and conclusion of the technology transfer training sessions. The following 10 questions were posed to attendees:

1. **Which are the following are effective strategies for reducing mower damage on recently planted trees?**
   A. Mulching trees
   B. Staking trees
   C. Reducing the space between trees
   D. All of the above

2. **Which of the following palms are susceptible to lethal bronzing (formally TPPD)?**
   A. *Phoenix* spp. (the date palms)
   B. *Sabal palmetto* (cabbage palm), *Cocos nucifera* (coconut palm), and Sy*agrus romanzoffiana* (queen palm)
   C. *Bismarkia nobilis* (Bismarck palm), *Butia capitata* (pindo palm), and *Livistona chinensis* (Chinese fan palm)
   D. All of the above

3. **A tree's health impacts its ability to resist which of the following?**
   A. Pests and diseases
   B. Wind storm damage
   C. Branch loss in ice storms
   D. All of the above

4. **"Tree condition" is the combination of a tree's:**
   A. Health and reproductive potential
   B. Structural integrity and ability to compartmentalize
   C. Health and structural integrity
   D. Reproductive potential and ability to compartmentalize

5. **Number the following steps associated with making a three-point cut in their appropriate order (i.e., 1, 2, and 3).**

   _____ Remove the branch stub at the branch collar
   _____ Undercut the branch beyond the branch collar
   _____ Remove the branch beyond the undercut

6. **Which of the following are recommended pruning practices?**
   A. Flush cutting branches along the trunk to promote rapid wound closure

B. Retaining a branch stub to avoid accidentally cutting into the branch collar
C. Removing all the interior branches (leaving the outer canopy intact) to reduce wind loading
D. None of the above

7. **When pruning palms, what fronds can be removed without unduly impeding plant health?**
   A. All fronds that have naturally senesced (fronds that are brown in appearance in the lower canopy)
   B. Wind-damaged fronds
   C. Fronds in the lower canopy (below 9 o'clock and 3 o'clock)
   D. All of the above

8. **"Crepe murder" is a colorful term frequently used to describe what ill-advised pruning activity on crepe myrtle?**
   A. The removal of sprouts at the base of the tree
   B. Severe heading cuts made to reduce tree size and promote regrowth
   C. Reduction cuts made to enhance flower production
   D. All of the above

9. **When communicating with contractors and work crews about future pruning operations, referring them to the ANSI A300 Pruning Standards will effectively convey the work that is expected to be completed.**
   A. True
   B. False

10. **"Reduction" and "removal" are examples of what component of a pruning specification?**
    A. System
    B. Objective
    C. Cut location
    D. Cut type

The last two questions pertained specifically to the fourth training module, which was not presented beyond the first event in DeLand. As such, these questions were excluded from grading and reporting.

In grading the evaluations, it became obvious that the questions were more difficult and nuanced than expected. If these events were ever repeated, a revision of the questions would be in order. Despite this, median scores increased from 50% to 63% after training. In assessing this change with a one-sided T-test, we found the increase was statistically significant (*P*-value = 0.0076).

CHAPTER 5 – PROJECT DELIVERABLES

Tree and Palm Maintenance Guide:

Blair, S., D.C. McLean, D.R. Hilbert†, A.K. Koeser, E.F. Gilman, and B. Kempf. 2019. *A Guide for Tree and Palm Maintenance Along Florida Roadsides.* University of Florida IFAS/Extension, Wimauma, Florida 122pp.
https://www.dropbox.com/s/rqufq37r4llwjfv/FDOT%20Handbook%20V1.docx?dl=0

Peer-reviewed Journal Articles:

Blair, S.A., A.K. Koeser, L.A. Roman, G.W. Knox, and M. Thetford. 2019. Health and establishment of highway plantings in Florida (United States). *Urban Forestry & Urban Greening*. 43:126384.
https://www.fs.fed.us/nrs/pubs/jrnl/2019/nrs_2019_blair_001.pdf

Blair, S.A., A.K. Koeser, G.W. Knox, L.A. Roman, and M. Thetford. 2019. Visual health assessments for palms. *Urban Forestry & Urban Greening.* 41:195-200.
https://www.fs.fed.us/nrs/pubs/jrnl/2019/nrs_2019_blair_002.pdf

Slide Presentations:

Bold Initiative; Big Results - Findings from an Assessment of Recent Tree Installations
https://www.dropbox.com/s/h7x0rriakr0hoi8/Research%20Findings%20and%20Observations%20-%20FDOT%20Bold%20Initiative.pptx?dl=0

Visual Assessment of Tree and Palm Condition
https://www.dropbox.com/s/z3cl777qj9r1v68/FDOT%20-%20Visual%20Health%20Assessment.pptx?dl=0

Proper Pruning of Shade Trees, Palms, and Crepe Myrtle
https://www.dropbox.com/s/yof1u0camuw9swt/FDOT%20Pruning%20-%20Guide%20Rollout.pptx?dl=0

Pruning Specifications: Why and How to Write Them
https://www.dropbox.com/s/dsqb19btcun1dlm/Pruning%20Specifications.pptx?dl=0

Pre- and Post-Tests:

Pretest
https://www.dropbox.com/s/1z3ailolihep9uf/Pre%20Test.docx?dl=0

Post-test
https://www.dropbox.com/s/hi1uskdgr7t6t3i/Post%20Test.docx?dl=0

Evaluation Form:
https://www.dropbox.com/s/tm3gubibqes3c0g/Program%20Evaluation.docx?dl=0