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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Performance include irrigation (Gilman et al., 1998, 2013; Koeser et al., 2006). After planting, management factors that influence 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, underling 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 interchanges 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                                                                 | Notes                                                                 
|----------------------------------|-------------------------|---------------------|----------------------------------|------------------------------------------------------------------------|----------------------------------------------------------------------|
| Broschat and Donselman (1990)    | Field nursery/Fort Lauderdale, FL | 7 months            | P. roebelenii, C. elegans        | Biological age (G+, S+) Immature plants = 100% mortality               | G assessed using root biomass                                         |
|                                 |                         |                     |                                  |                                                                        | H observed using root biomass                                         |
| Broschat (1991)                  | Median/Miami, FL        | 8 months            | P. roebelenii                    | Transplanting (H-), Age (G-), Transplanting without fronds (G+, S+)    | G assessed using root biomass                                         |
|                                 |                         |                     |                                  |                                                                        | H assessed using root biomass                                         |
|                                 |                         |                     | P. roebelenii                    | Top-irrigation (H-), Leaf-tying (S-)                                   | G assessed using root biomass                                         |
|                                 |                         |                     |                                  |                                                                        | H assessed using root biomass                                         |
|                                 |                         |                     | P. roebelenii                    | Transplanting depth below original (G-, H-, S-)                       | G assessed using root biomass                                         |
|                                 |                         |                     |                                  |                                                                        | H assessed using root biomass                                         |
|                                 |                         |                     | P. roebelenii                    | Wet season planting (G+), rootball size (G+)                          | G, H assessed using root biomass                                       |
|                                 |                         |                     |                                  |                                                                        | S assessed using tissue analysis                                       |
|                                 |                         |                     | W. robusta, P. canariensis       | Leaf removal/tie (no effect G, H, or S)                               | G assessed using new leaf count                                       |
|                                 |                         |                     |                                  |                                                                        | H assessed visually                                                   |
|                                 |                         |                     | W. robusta, P. canariensis       | Leaf removal/tie (no effect G, H, or S)                               | G assessed using new leaf count                                       |
|                                 |                         |                     |                                  |                                                                        | H assessed visually                                                   |
|                                 |                         |                     | W. robusta, P. canariensis       | Above ground space (G-, H+, S-)                                      | G, H assessed using root biomass                                       |
|                                 |                         |                     |                                  |                                                                        | S assessed using tissue analysis                                       |
| Hodel et al. (2005)              | Field nursery/Rhodora, FL | 2 years             | C. fulviceps, C. canariensis     | Air/soil temperature (G+)                                            | G assessed with root/shoot elongation and (root biomass)             |
|                                 |                         |                     |                                  |                                                                        | H assessed visually                                                   |
|                                 |                         |                     |                                  |                                                                        | S assessed using tissue analysis                                       |
|                                 |                         |                     | C. fulviceps, C. canariensis     | Leaf removal/tie (no effect G, H, or S)                               | G assessed using new leaf count                                       |
|                                 |                         |                     |                                  |                                                                        | H assessed visually                                                   |
|                                 |                         |                     |                                  |                                                                        | S assessed using tissue analysis                                       |
|                                 |                         |                     | C. fulviceps, C. canariensis     | Leaf removal/tie (no effect G, H, or S)                               | G assessed using new leaf count                                       |
|                                 |                         |                     |                                  |                                                                        | H assessed visually                                                   |
|                                 |                         |                     |                                  |                                                                        | S assessed using tissue analysis                                       |
|                                 |                         |                     | C. fulviceps, C. canariensis     | Above ground space (G-, H+, S-)                                      | G, H assessed using root biomass                                       |
|                                 |                         |                     |                                  |                                                                        | S assessed using tissue analysis                                       |
|                                 |                         |                     | C. fulviceps, C. canariensis     | Leaf removal/tie (no effect G, H, or S)                               | G assessed using new leaf count                                       |
|                                 |                         |                     |                                  |                                                                        | H assessed visually                                                   |
|                                 |                         |                     |                                  |                                                                        | S assessed using tissue analysis                                       |
|                                 |                         |                     | C. fulviceps, C. canariensis     | Leaf removal/tie (no effect G, H, or S)                               | G assessed using new leaf count                                       |
|                                 |                         |                     |                                  |                                                                        | H assessed visually                                                   |
|                                 |                         |                     |                                  |                                                                        | S assessed using tissue analysis                                       |
|                                 |                         |                     | C. fulviceps, C. canariensis     | Leaf removal/tie (no effect G, H, or S)                               | G assessed using new leaf count                                       |
|                                 |                         |                     |                                  |                                                                        | H assessed visually                                                   |
|                                 |                         |                     |                                  |                                                                        | S assessed using tissue analysis                                       |
|                                 |                         |                     | C. fulviceps, C. canariensis     | Leaf removal/tie (no effect G, H, or S)                               | G assessed using new leaf count                                       |
|                                 |                         |                     |                                  |                                                                        | H assessed visually                                                   |
|                                 |                         |                     |                                  |                                                                        | S assessed using tissue analysis                                       |
|                                 |                         |                     | C. fulviceps, C. canariensis     | Leaf removal/tie (no effect G, H, or S)                               | G assessed using new leaf count                                       |
|                                 |                         |                     |                                  |                                                                        | H assessed visually                                                   |
|                                 |                         |                     |                                  |                                                                        | S assessed using tissue analysis                                       |
|                                 |                         |                     | C. fulviceps, C. canariensis     | Leaf removal/tie (no effect G, H, or S)                               | G assessed using new leaf count                                       |
|                                 |                         |                     |                                  |                                                                        | H assessed visually                                                   |
|                                 |                         |                     |                                  |                                                                        | S assessed using tissue analysis                                       |
|                                 |                         |                     | C. fulviceps, C. canariensis     | Leaf removal/tie (no effect G, H, or S)                               | G assessed using new leaf count                                       |
|                                 |                         |                     |                                  |                                                                        | H assessed visually                                                   |
|                                 |                         |                     |                                  |                                                                        | S assessed using tissue analysis                                       |
|                                 |                         |                     | C. fulviceps, C. canariensis     | Leaf removal/tie (no effect G, H, or S)                               | G assessed using new leaf count                                       |
|                                 |                         |                     |                                  |                                                                        | H assessed visually                                                   |
|                                 |                         |                     |                                  | G assessed using new leaf count                                       |
|                                 |                         |                     |                                  | H assessed visually                                                   |
|                                 |                         |                     |                                  | S assessed using tissue analysis                                       |
|                                 |                         |                     |                                  | G assessed using new leaf count                                       |
|                                 |                         |                     |                                  | H assessed visually                                                   |
|                                 |                         |                     |                                  | S assessed using tissue analysis                                       |
|                                 |                         |                     |                                  | G assessed using new leaf count                                       |
|                                 |                         |                     |                                  | H assessed visually                                                   |
|                                 |                         |                     |                                  | S assessed using tissue analysis                                       |
|                                 |                         |                     |                                  | G assessed using new leaf count                                       |
|                                 |                         |                     |                                  | H assessed visually                                                   |
|                                 |                         |                     |                                  | S assessed using tissue analysis                                       |
|                                 |                         |                     |                                  | G assessed using new leaf count                                       |
|                                 |                         |                     |                                  | H assessed visually                                                   |
|                                 |                         |                     |                                  | S assessed using tissue analysis                                       |
|                                 |                         |                     |                                  | G assessed using new leaf count                                       |
|                                 |                         |                     |                                  | H assessed visually                                                   |
|                                 |                         |                     |                                  | S assessed using tissue analysis                                       |
|                                 |                         |                     |                                  | G assessed using new leaf count                                       |
|                                 |                         |                     |                                  | H assessed visually                                                   |
|                                 |                         |                     |                                  | S assessed using tissue analysis                                       |
|                                 |                         |                     |                                  | G assessed using new leaf count                                       |
|                                 |                         |                     |                                  | H assessed visually                                                   |
|                                 |                         |                     |                                  | S assessed using tissue analysis                                       |
|                                 |                         |                     |                                  | G assessed using new leaf count                                       |
|                                 |                         |                     |                                  | H assessed visually                                                   |
|                                 |                         |                     |                                  | S assessed using tissue analysis                                       |

Growth, “G,” health, “H,” and survival “S.” “+” indicates positive associations between factors and responses, while “−” indicates negative associations.
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 | Source                  |
|-------------------------|--------------------------------------------------|---------|------------------|-------------------------|
| Response                | alive (0/1) any living foliage, present          | binary  | tree             | Bond (2012)             |
|                         | 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             | Bond (2012)             |
|                         | root flare (0/1) visible without digging         | binary  | tree             | Bond (2012)             |
|                         | tree type small-stature, shade, conifer, palm    | categorical | tree           | Misra and Mishra (2016) |
|                         | planting season wet/dry                          | categorical | project      | Misra and Mishra (2016) |
|                         | years since planting since beginning of establishment phase | numeric  | project         | Misra and Mishra (2016) |
|                         | slope median of 5% increments                    | numeric  | project         | Misra and Mishra (2016) |
|                         | irrigation (0/1) installed at tree               | binary  | tree             | Keeser et al. (2014)    |
|                         | stake duration > or < one year                   | categorical | tree           | Keeser et al. (2014)    |
|                         | RUSI Scores see Table 3                         | ordered  | tree/zone/project | Scharenbroch et al. (2017) |

* 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.

* Small-stature (< 9.14 m) and shade (> 9.14 m) were designated by maximum heights at maturity.
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 (TRAFF) 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, 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 outlined 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

| RUSI Parameter | Units | Collection Level | RUSI Score |
|---------------|-------|-----------------|------------|
| INFR          | m     | tree            | 0 1 2 3    |
| TRAF          | n/a   | n/a            | < 1 1-5 6-10 > 10 |
| SURF          | n/a   | tree            | excluded due to lack of site variation thick veg much |
| PEN           | lbs/sq in | tree | 300+ 201i 00 to 1 00 101-200 0-100 |
| STRC          | n/a   | zone            | M, SG, PL, ABBK, SKB GR |
| TXT           | n/a   | zone            | no soil, CF > 75% S, SI, C, CF = 50-75% 4.4-9 or 8.1-9 5-9 or 6.6-8 |
| pH            | µS cm⁻¹ | zone | < 50 or > 3000 50-100 or 2001-3000 101-300 or 1001-2000 301 to 1000 |
| SOM           | %     | zone            | < 1.08 1.08-1.60 1.60-2.17 > 2.17 |
| AHOR          | cm    | zone            | < 1 1-5 6-15 > 15 |
| ERA           | m²    | tree            | < 5 5-25 26-50 > 50 |
| WAS           | %     | zone            | no aggregate < 50% post soak < 50% post swirl > 50% post swirl |
| PPT²,³       | mm-yr⁻¹ | project | < 1290 1290-1372 1372-1585 > 1585 |
| GDD²          | days, base 50 | tree | < 6992 6992-7663 7663-8069 > 8069 |
| EXP           | # sides | tree | 0 1-2 3-4 5 |

* 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.

• scoring function unaffected by onsite irrigation.

• scoring functions determined by breaking data into quantiles.

• CF = coarse fragments; C = clay; S = sand; S = silt; SIC = silt clay; SICL = silty clay loam; CL = clay loam; SC = sandy clay; SIL = silty clay; L = loam; SCL = sandy clay loam; SL = sandy loam; LS = loamy sand.

| 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 |
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 B).

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 *Flex* 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 (odds 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; P < 0.0001), and pH (odds ratio = 0.31; P < 0.0001) were associated with a reduced likelihood of attaining a higher quality rating (odds ratio = 0.22; P < 0.0001) (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 difference 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).

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 6

| 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 | 0.0000  | 1.2096 | 0.9601 | 1.5240  |
| ERA*                    | 0.8053      | 0.2305 | 0.0005  | 2.2373 | 1.4240 | 3.5153  |

* Estimated rooting area.
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).

Another 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.

INFRA (distance to infrastructure) showed up in three models and had a positive association with health, corroborating past findings by Kooser 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 (La 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

### 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) | Citation |
|--------------------|------------|------------------|----------|
| Lawn care damage   | 6% (1202)  | 62.9% (1018) 0.0% (568) 7.2% (291) | Morgenroth et al. (2015); Roman et al. (2015b); Roman et al. (2014b) |
| Total trunk damage | 8% (1202)  | 47.4 (656)     | Vogt et al. (2015) |
| Staking damage     | 1% (1202)  | 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) | 2.9% (2354)    | Kooser et al. (2014) |
| Mulched            | 76.5% (2491) | 7.2% (13,405) 100.0% (568) 38.5% (291) 10.5% (658) | Lu et al. (2010); Roman et al. (2015a); Roman et al. (2014b); Vogt et al. (2015) |
| Root flare visible | 50.1% (2495) | 27.4% (658)    | n/a      |
| Girdling roots     | 1.25% (1116) | n/a             | n/a      |
| Poor branch structure | 3% (969) | n/a             | n/a      |

* palms excluded.

† small-stature trees excluded.

‡ trees that were mulched properly.

§ data from East Palo Alto, California case study.
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 show 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 Theftord: Methodology, Supervision, Writing - review & editing. Deborah R. Hilbert: Writing - review & editing.

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Table A1

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

| Tree Type       | Species                        | Common name           | n  | Establishment (%) |
|-----------------|--------------------------------|-----------------------|----|-------------------|
| Shade trees     | 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               |
|                 | Eleocarpus decipiens            | Japanese blueberry    | 23 | 100               |
|                 | Ilex x attenuata                | 'East Palatka' holly  | 10 | 100               |
|                 | Liquidambar formosissimo        | sweet gum             | 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               |
| Coicodoba orbicula|                            | 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 (%) |
|-----------------|--------------------------------|---------------------|----|-------------------|
| Small-stature   | Lagerstroemia spp.             | crapemyrtle         | 330| 99.7              |
| 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   | Juniperus virginiana           | redbud              | 499| 99.4              |
| tree totals     |                                |                     |    |                   |
| 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              |
| Palms           | Livistonia chinesis            | Chinese fan palm    | 99 | 98.0              |
|                 | Psychosperma 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                 | −0.7154     | 0.2531| 0.0001  | 0.4890| 0.2978 | 0.8031  |
| EC                   | −0.6609     | 0.3158| 0.0364  | 0.5164| 0.2781 | 0.9589  |
| ERA                  | 1.0382      | 0.3472| 0.0001  | 2.8242| 1.4299 | 5.5779  |
| EXP                  | −1.4974     | 0.5662| 0.0002  | 0.2237| 0.0738 | 0.6786  |
| INFIR                | 0.7424      | 0.2121| 0.0005  | 2.1009| 1.3864 | 3.1857  |
| pPH                  | −1.1679     | 0.2868| < 0.0001| 0.3110| 0.1773 | 0.5456  |
| SOM                  | 0.5782      | 0.1890| 0.0002  | 1.7829| 1.2310 | 2.5822  |
| E. decipiensa       | 3.5221      | 0.8682| < 0.0001| 33.8554| 6.1740 | 185.6470|
| L. styraciflua      | 5.9546      | 0.8364| < 0.0001| 385.5352| 74.8366| 1986.1603|
| M. grandiflora      | 1.4140      | 0.5046| 0.0051  | 4.1124| 1.5297 | 11.0557 |
| P. pericarpum       | 1.2911      | 0.5420| 0.0172  | 3.6369| 1.2572 | 10.5213 |
| Q. virginiana       | 2.2992      | 0.4938| < 0.0001| 9.9661| 3.7860 | 26.2538 |
| S. mahagoni         | 2.9213      | 0.8551| 0.0006  | 18.5648| 3.4740 | 99.2078 |

* 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.

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

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S.A. Blair, et al.  
Urban Forestry & Urban Greening 43 (2019) 126384
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                 | −4.2947     | 1.3283| 0.0012  | 0.0136| 0.0010 | 0.1843  |
| PPT                 | −0.4334     | 0.1305| 0.0009  | 0.6483| 0.5020 | 0.8572  |
| STRC                | −0.4154     | 0.1741| 0.0170  | 0.6601| 0.4692 | 0.9285  |
| TXT                 | −1.4615     | 0.5112| 0.0042  | 0.2319| 0.0851 | 0.6315  |
| E. decipiens       | −0.1652     | 0.6020| 0.7838  | 0.8477| 0.2605 | 2.7584  |
| L. styraciflua     | 1.5780      | 0.7909| 0.0460  | 4.8455| 1.0283 | 22.8317 |
| M. grandiflora     | 3.0471      | 0.5441| < 0.0001| 21.0537| 7.2468 | 61.1660 |
| P. pterocarpum     | 3.1798      | 0.7273| < 0.0001| 24.0420| 5.7792 | 100.0180|
| Q. virginiana      | 0.6310      | 0.3923| 0.1078  | 1.8794| 0.8711 | 4.0548  |
| S. mahagoni        | 17.8176     | < 0.0001| < 0.0001| 54712190.3018| 54712036.3316| 54712344.2724|

* 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.

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

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                 | −0.6061     | 0.1711| 0.0004  | 0.5455| 0.3901 | 0.7628  |
| GDD                 | 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  |

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

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.  | −1.6871     | 0.5353| 0.0016  | 0.1851| 0.0648 | 0.5285  |
| L. japonicum       | −0.8372     | 0.5824| 0.1506  | 0.4329| 0.1382 | 1.3558  |

* For species comparisons, L. japonicum was 0.19 times more likely to have a higher vitality rating when compared to the I. attenuata ‘Eagleston’ baseline.

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

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| < 0.0001| 3.3739| 1.3583 | 8.3804  |
| Years since planting| 1.1141      | 0.1708| < 0.0001| 3.0467| 2.1800 | 4.2581  |
| INFRI               | 0.7569      | 0.2232| 0.0007  | 2.1316| 1.3763 | 3.3016  |
| P. palustris        | −3.8261     | 0.6478| < 0.0001| 0.0218| 0.0061 | 0.0776  |
| T. distichum        | −2.8425     | 0.4522| < 0.0001| 0.0583| 0.0240 | 0.1414  |

* 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 (INFRI).
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                        | -0.9136     | 0.2808| 0.0011  | 0.4011     | 0.2313 | 0.6955  |
| P. palustris                | -3.2312     | 0.9802| 0.0010  | 0.0395     | 0.0058 | 0.2698  |
| T. distichum                | -2.3588     | 0.7508| 0.0017  | 0.0945     | 0.0217 | 0.4118  |

* For species comparisons, P. elliotii 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. elliotii baseline.
* 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 | 4.8463  |
| Years since planting        | -0.4642     | 0.1122| <0.0001 | 0.6286     | 0.5045 | 0.7833  |
| EC                          | 0.5548      | 0.1647| 0.0008  | 1.7416     | 1.2612 | 2.4050  |
| EXP                        | 0.8154      | 0.1560| <0.0001 | 0.4425     | 0.3259 | 0.6008  |
| GDD                        | -0.2188     | 0.0943| 0.0204  | 0.8035     | 0.6678 | 0.9666  |
| INFR                       | 0.2637      | 0.0989| 0.0077  | 1.3017     | 1.0724 | 1.5802  |
| SOM                        | 0.2420      | 0.0865| 0.0051  | 1.2738     | 1.0752 | 1.5091  |
| TXT                        | 0.5982      | 0.2471| <0.0001 | 0.5498     | 0.3388 | 0.8923  |
| A. alexandra               | 2.8005      | 0.6212| <0.0001 | 16.4521    | 4.8691 | 55.5900 |
| B. nobilis                 | 4.6915      | 0.5041| <0.0001 | 109.0165   | 40.5889| 292.8040|
| L. chinensis               | 3.9869      | 0.5294| <0.0001 | 53.8849    | 19.9017| 152.0862|
| P. elegans                 | 4.3032      | 0.7648| <0.0001 | 73.9360    | 16.5150| 331.0054|
| R. regia                   | 3.5801      | 0.5049| <0.0001 | 35.8774    | 13.3359| 96.5205 |
| S. palmeto                 | 3.7465      | 0.4559| <0.0001 | 42.3719    | 17.3375| 103.5544|
| W. robusta                 | 5.8769      | 0.5246| <0.0001 | 356.7006   | 127.5596| 997.4583|

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

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