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Understanding why young urban trees die can improve future success

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ABSTRACT

The first several years after planting a tree, referred to as the establishment period, are recognized to have the highest annual mortality rates; determining those factors that influence survival of young trees should be considered paramount. This research examined several factors that influence young urban tree mortality: nursery production type (i.e. bare root, gravel bed bare root, container, or balled and burlapped), tree taxa, planting location type, and "planted by" (i.e. "who" planted the tree). The results from this study supported several relationships between project variables and young tree mortality, most notably that trees planted as containerized or balled-and-burlapped rootstock types in boulevards and parks had significantly higher survival rates than bare-root trees. Nursery production type, tree planting location, and tree taxa all had statistically significant impacts on young tree mortality, but "planted by" was not significant. The highest mortality rates were experienced by all trees planted in park/public spaces. The conclusions of this research will help to fill gaps and build upon the existing body of literature that practitioners may draw from to make informed planting and care decisions.

1. Introduction

The United States (US) Census Bureau in the 2016 American Communities Survey found that approximately 80 % of Americans live in urban areas (US Census Bureau, 2016). As such, they are impacted by the condition, quality, and management of urban forests, whether they are aware of it or not. People and communities value the trees that make up their urban forests for many reasons. To some, trees are important for aesthetics and placemaking; they can convey a sense of connection to history, provide inspiration, or a calming peaceful atmosphere in an otherwise turbulent, crowded city (Thompson et al., 1994; Kuo and Sullivan, 2001). To others, the value of urban trees comes from the individual benefits of lower home heating and cooling costs (Akbari et al., 2001), increased property values (Donovan et al., 2011), and lower summer ambient temperatures (Akbari and Taha, 1992; Bowler et al., 2010; US Environmental Protection Agency, 2019), which plays an important role in combating urban heat island effects. Still others value trees for the communal roles that urban trees provide in air and pollutant filtration (Nowak et al., 2006), reduced and intercepted stormwater runoff (Sanders, 1986; Berland et al., 2017; Kuehler et al., 2017), increased air quality and decreased asthma rates (McPherson, 2003; Lovasi et al., 2008), and their ability to sequester carbon from the atmosphere (Akbari et al., 2001; Nowak and Crane, 2002; McHale et al., 2007). The benefits that urban trees have are both wide ranging and well documented, and people who live in or visit these urban areas stand to gain much from the healthy trees that surround them.

Local units of government are most often responsible for planting trees in public spaces in urban areas, yet approximately 45 % identify their budget allocation as being below the identified need (Hauer and Peterson, 2016). Furthermore, communities reported that 14.3 percent of their tree care funding was spent on tree planting (Hauer and Peterson, 2016), the third most expensive tree care activity after tree pruning and tree removal (in terms of percentage of budget allocation). This figure is also important from a Midwestern U.S. perspective where tree removals exceed tree plantings, likely as a result of budgets being shifted towards tree removal in the wake of emerald ash borer (EAB), at the expense of tree planting (Hauer and Peterson, 2016). Additionally, there was no significant increase in total municipal budgets as a result of EAB infestations (Hauer and Peterson, 2017) suggesting that financial responses to controlling EAB do not follow the history of financial commitments made in the wake of Dutch elm disease (DED) in the 1970′s (French, 2013). Ultimately, any loss of newly planted trees represents wasted resources, both in terms of financial cost, as well as time lost during planting operations. By minimizing young tree mortality, local units of government are efficiently utilizing their often strained resources.

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The immediate years following planting are often the toughest, as newly planted trees are most susceptible to extreme environmental and physiological stresses. This general state of stress is referred to as transplant shock, and is in part the result of root loss following transplanting and/or insufficient post planting maintenance (Watson and Sydnor, 1987). Trees subject to transplant shock generally exhibit symptoms of impaired function including general decline in vitality, canopy thinning, dieback, and reduced winter hardiness among others (Fountain et al., 1998). If left unaddressed in a stressful environment, the tree may continue to decline and prematurely die. In cases of stress and mortality, inadequate root systems are often labeled as a common culprit. Because tree roots are lost prior to planting via harvesting or desiccation (Watson, 1996) they lack much of the initial capacity to take up water and necessary nutrients. During this time in a tree's life, water is usually considered to be the most limiting factor to growth and establishment (Gilbertson and Bradshaw, 1985; Miller and Miller, 1991; Watson, 1996; Pallardy, 2008). Both compaction and soil moisture stress can greatly impact a young tree's capacity for fibrous root growth and root elongation (Struve, 2009), which can greatly extend the period of time required for the tree's establishment period.

The first few years of a tree's life is referred to as the establishment period, which is broadly defined as the period of time required for a plant to regrow a characteristic root system for the species, capable of supporting aboveground growth (Miller and Miller, 1991; Watson, 1996). Typically, this is indicated by a resumption of an equal "root to shoot ratio" whereby the tree's root system resumes a pre-transplant size and function relative to the tree's canopy. Transplanted trees are not considered established until primary and secondary roots expand into native surrounding soil, branch out, and produce sufficient fibrous roots to support the tree's above ground biomass (Fountain et al., 1998). Broadly speaking, tree roots grow at similar rates regardless of tree size; however, the roots of a larger tree must grow over a longer distance to redevelop sufficient root spread post transplanting (Watson and Himelick, 2013). While the length of the establishment period is affected by many environmental and cultural factors, research estimates there is approximately one year of "establishment" per one caliper inch (e.g. a two inch caliper tree would have a roughly two year establishment period) (Watson, 1996). Existing literature supports the claim that the establishment period of young trees is generally between 1–5 years post-planting planting (Miller, 1996; Roman et al., 2014; Hilbert et al., 2019) after which trees were considered past the establishment phase of their development.

Previous studies indicate the highest likelihood of mortality in young trees occurs during the first one to five years after planting (Miller and Miller, 1991; Nowak et al., 2004; Roman et al., 2014) which coincides with the projected establishment period. Tree death linked to transplant failure tends to taper off after year five (Koeser et al., 2013). There is strong evidence to suggest that the first year of a tree's life post planting is when they experience the highest level of mortality (Miller and Miller, 1991; Roman et al., 2014.) In a study of recently planted tree cohorts in Belgium, first year mortality figures ranged from 6.5 % on the low end to 19.7 % mortality on the high end (Average = 11.3 % mortality) (Impens and Delcarte, 1979). Furthermore in an examination of trees in Sacramento, CA, the first year post planting was observed to have the highest mortality at 12.2 %, essentially double that of the following years (6.2 %, 6%, 4.7 %, 3.4 % respectively for the next four years) (Roman et al., 2016).

In the succeeding years after the first-year post planting, young tree mortality remains relatively high for the duration of the establishment period. Hilbert et al. (2019) found in an examination of previous young tree mortality studies (n = 21), that among all the studies, the median annual mortality rate ranged from 6.6–7.0%. Mortality rates decline after the establishment phase to a median annual mortality rate of between 2.8–3.8%. (Hilbert et al., 2019). In terms of tree benefits and costs, the costs of planting a tree exceed the benefits of planted trees for the first five years, but over the next 25 years, benefits increasingly exceed costs to at an eventual ratio of 3-to-1 or greater (McPherson, 1992).

Recognizing and addressing the variables linked to young tree mortality is crucial in determining best practices for tree planting. Minimizing those factors that increase mortality rates allows newly planted trees to survive at higher rates through the establishment period into maturity, where they provide the greatest benefit. The primary objective of this research was to identify and examine the relationship between who planted the tree, tree taxa, nursery production type, and planting location and young tree mortality rates. This research hopes to better inform practitioners and positively influence tree planting outcomes as a way to increase overall tree survival past establishment period.

2. Methods

The research was executed by assessing historical records of tree plantings on publicly owned properties in a diverse range of Minnesota and Wisconsin communities that were participating in either of two ongoing studies: a Great Lakes Restoration Initiative (GLRI), or the University of Minnesota (UMN) Department of Forest Resources' Urban Forestry Outreach Research and Extension lab (UMN UFORE) cost-benefit analysis of tree planting projects. Communities selected for inclusion represented a range of urban, suburban, and rural areas that agreed to participate and share their tree planting data. Trees included in this study were planted in spring and fall between the years of 2014–2018 were annually surveyed after the completion of the growing season (between August and May) to determine first year mortality rates. When possible, data were collected by UMN researchers, though in the absence of UMN staff, data were self-reported by communities' urban forestry technical staff.

Data was collected on a total of 6055 individual trees in the United States from the following communities, political boundaries, agencies, or organizations in the state of Minnesota: Arlington, Fridley, Hennepin County, Mississippi Park Connection, New Ulm, North St. Paul, Robbinsdale, Rochester, Shakopee, Sherburne County Soil and Water Conservation District, St. James, and St. Paul. One community from the state of Wisconsin was included in the study: Racine. The climate of this region is a typical continental climate consisting of frigid cold winters, and hot humid summers. All trees were planted within USDA plant hardiness zones 4a-5b.

Tree mortality, the response variable, was collected as a binary option; alive or dead. Trees were determined to be functionally dead when the tree appeared to be dead in a visual inspection as per mortality criteria. Criteria for determining a tree as functionally dead included; complete lack of leaves, 99 % or greater necrotic stem tissue, stem failure (critically damaged or broken tree trunk), missing tree, failure of "scratch test" (Davey Tree Company, 2017) in canopy branches, or the tree had been removed. Mortality rates in this study are defined as one-year post planting mortality aka first year mortality. Time was measured as a function of growing season rather than calendar year (i.e. one full and complete growing season equates to one year). Mortality rates are displayed here as percent probability of mortality.

For the site type category, trees were divided into one of two categories: boulevard or park/public space. Trees were considered boulevard trees if they were in an area less than 10 feet (US) from a roadway or street. For the purpose of this study, trees in right of way (ROW) areas less than 10 feet from a roadway or street were included under the label "boulevard" even if no sidewalk was present. Conversely, trees were considered to be park/ public space trees if they were equal to or greater than 10 feet from a roadway or street. Distance was also measured from the inside of the curb to the street side of the tree trunk while sampling.

Tree taxa was also chosen for analysis. The trees were identified and coded by the U.S. Forest Service (i-Tree) species code, scientific name, and common name in order to reduce misinterpretation that can come with the sole use of common names. Because data were sourced from a variety of communities and programs, tree taxa was self-reported by some communities and was subject to community capacity for accurate identification. Tree taxa was identified to the species level wherever possible, though some were only possible to confidently identify to genus. Initial data collection identified 115 unique species codes, which included codes that could only be classified to genus (e.g. *Acer spp*., *Quercus spp*.). Trees that lacked an appropriate code for species were classified according to their genus code. Due to the prominence of Asiatic elm cultivars (e.g. Accolade, 'Discovery', Triumph) all Japanese, Chinese, and Siberian elm (*Ulmus davidiana* var. *japonica (*Rehder) Nakai*, U. parvifolia* Jacq, and *U. pumila* L. respectively) hybrids were classified into one category as "Asiatic Elms".

Taxa correlation analysis was not completed on trees that could only be classified to genus due to the consideration that any outcomes of analysis wouldn't accurately describe the potential variety of species within those component trees. The exception was *Malus* spp, which was used to classify crabapple. Additionally, two tree species (*Acer ginnala* Maxim. and *Elaeagnus angustifolia* L.) classified as invasive by the Minnesota DNR (MNDNR, 2019) were discarded as well as one species on the invasive species "watch list" (*Pyrus calleryana* Decne.). These species plus tree species that had less than 75 observations and were deemed to have a statistically low sample size (Sernaker, 2019) were reclassified into the "Other" category (n = 1627) in order to not to lose their data. "Other" tree data was included in the data analysis for all variables but taxa. Ultimately, this left 4428 trees in 25 confirmed taxa for full analysis.

Another variable for analysis was the different nursery production type available for young tree plantings. Each tree in the survey was categorized into one of four nursery production types: balled and burlapped (B&B), container, gravel bed bare root, and bare root. The classification of bare root versus gravel bed bare root was made on the day of planting, with bare root trees planted prior to August 1 classified as bare root trees even if they had spent some time in a community gravel bed. Trees held in gravel beds past August 1 were deemed to have fully benefited from the enhanced root growth associated with sufficient time in a gravel bed and were classified as gravel bed bare root trees (Busiahn and Peterson, 2013). Regardless of when they were planted in the landscapes, bare root or gravel bed bare root trees were all purchased from wholesale nurseries that harvested the trees bare root via U-blades (small trees) or inverted moldboard plows the previous autumn and stored in controlled atmosphere facilities (1.11–3.33 degrees C [34–38 degrees F]; 90–95 % humidity) during the months prior to shipping to the various communities or agencies. All bare root nursery grown trees were received by the various communities and agencies during the months of April and May. Due to the reality that autumn harvesting of these trees took place over a period of two to three months, and the delivery dates data of specific trees were not recorded by the communities or agencies, the amount of time a bare root tree potentially spent in controlled atmosphere storage was not included for analysis.

Size data of nursery production type (i.e. stem caliper, diameter of bare root systems, container size, B&B root ball dimensions) provided by the various communities and agencies varied among and within all types. For bare root trees, caliper measurements (i.e., stem diameters measured at 15.24 cm above the first main order root) ranged between 6.35 and 38 mm (0.25–1.5 inches). Container trees ranged between number 10 and number 20 container sizes (container trees are graded as the size of container they were grown in rather than height or stem caliper), with no caliper measurements reported. For balled and burlapped trees, calipers ranged between 44.45 and 63.5 mm (1.75–2.50 inches). Because no individual tree to caliper data were provided, tree size at planting was not included in the analyses for this study.

The variable "planted by" describes who planted the tree. This category was broken into three classifications: contractors, organization staff, and volunteers. Contractors were classified as an entity hired and paid to plant trees. This included any paid tree planting organization that was not the "host organization". Organization staff consisted of paid employees of the sponsoring municipality, county or organization. Finally, volunteers were non-paid participants in tree plantings. Volunteers were recruited by the host organization. All volunteers used in this study were required to attend a best planting practices presentation or workshop and were supervised during the actual tree planting. Best planting practices presentations or workshops for volunteers varied as they were given by the host organization, except in the case of the cost-benefit study communities, where the presentations were provided by UMN-UFORE staff. Due to the wide variety of supervising entities, planting sites, planting dates, number of trees to be planted, and the ratio of supervisors to volunteers, it is reasonable to assume that there was some degree of variation in the level of supervision of each volunteer group.

Balled and burlapped trees, container trees, and non-gravel bed bare root trees were planted in the period loosely defined as spring. No specific data was provided for the exact period during spring when they were planted, so for that reason, time of year (with the exception of bare root trees held in gravel beds) was not included in any analysis.

Once data were collected from participating organizations, they were organized into a usable form using Microsoft Excel Spreadsheet software. Location data of trees was verified using ESRI Arcmap Collector or Treekeeper 7 where applicable. Statistical analysis was completed in collaboration with the University of Minnesota Statistical Consulting Center using logistic regression modeling in R and RStudio analysis software.

3. Results

Data analysis was conducted on the relationship of the four variables to young tree health: "planted by," site type, species, and nursery production type (Table 1). A linear model (ANOVA) was applied to the aforementioned variables.

3.1. "Planted by"

The far right column in Table 1 displays p-values that indicate whether the effect of a variable was significant. A significant p value was defined as equal to or less than 0.05. The "planted by" variable is 0.835, indicating that the effect of this variable was not significant when predicting tree mortality. Organization staff planted 3816 trees, contractors planted 684 trees, and volunteers 1555 trees. The percentages of trees that died for each group are displayed in Table 2. Of the trees that contractors planted, 5.7 % died, the lowest percentage of the different types of planting entities. The highest percentage of trees that died were those planted by volunteers, at 12.2 % mortality.

Table 3 illustrates the relationship of the sub-variables. The last column displays the p-values of the difference in odds. All of the p-values are larger than 0.90 indicating that there is no significant difference in tree mortality among the categories of "planted by."

3.2. Site type

Site type was a significant variable in predicting tree mortality (Table 1). There were 4294 trees that were classified as "boulevard" trees and 1761 trees classified as "park/ public area". Holding the rest of

Table 1
ANOVA table for statistical significance of variables.

Variable	Df	Sum Sq	Mean sq	F value	Pr(>f) (P value)
"Planted By"	2	0.0	0.015	0.180	0.835
Site Type	1	3.7	3.711	43.634	4.31e-11
Taxa	25	18.8	0.753	8.856	<2e-16
Nursery Production Type	3	7.5	2.499	29.382	<2e-16

Table 2
Tree Mortality by "Planted By".

"Planted By"	Contractor	Staff	Volunteers
Number of trees planted	684	3816	1555
Percentage of trees that died	5.7 %	9.9 %	12.2 %

Table 3
Comparison of "Planted By" groups (with P-values).

Linear Hypothesis	Pr(>|z|) (P value)
Staff - Contractor == 0	0.96
Volunteer - Contractor == 0	0.91
Volunteer - Staff == 0	0.96

the variables constant, the likelihood of a tree dying if it were in a park/public space was 1.4 times (Sernaker, 2019) higher than a tree dying on a boulevard, a statistically significant difference (Table 4). A significant p value was defined as equal to or less than 0.05.

3.3. Nursery production type

By holding the rest of the variables constant, the difference in the likelihood of first year mortality among the four different nursery production types was calculated (Table 5). Bare root trees died more frequently than B&B trees by a factor of 2.86. Gravel bed bare root trees died more frequently than B&B trees by a factor of 2.54. Bare root trees died more frequently than container trees by a factor of 5.56. Bare root trees also died more frequently than gravel bed bare root trees by a factor of 1.31. Finally, gravel bed bare root trees died more frequently than container trees by a factor of 4.24. There was no significant difference in the mortality rates for container trees and B&B trees. A total of 566 B&B trees, 698 container trees, 2645 bare root trees, and 2146 gravel bed bare root trees were included in the study and analysis.

3.4. Taxa

Results based on represented species (n = 4428) were highly variable when examining the intersection of species with nursery production type and planting location (Table 6). Altogether, there were ten species whose adjusted[1] average was less than 10 % probability of mortality. *Catalpa speciosa* displayed the lowest probability of mortality across all conditions. In descending order, the next trees with the lowest probabilities of mortality were *Amelanchier x grandiflora* 'Autumn Brilliance', *Aesculus glabra, Ulmus spp.* (Asiatic Elms), *Ulmus americana, Gymnocladus dioicus, Malus spp., Acer x freemanii, Syringa reticulata, and Celtis occidentalis.* The lowest relative performers were *Taxodium distichum* and *Nyssa sylvatica.*

3.5. Combined variables

Combining the variables into a matrix based on species produced

Table 4
Comparison of site types (with P-value).

Linear Hypothesis	Pr(>|z|) (P value)
Park/Public Space - Boulevard == 0	6e-04

[1] Taxa averages were adjusted based on the the number of each tree in each variable combination for each species, due to the high degree of variation in the number of instances per variable combination (e.g. # of bare root northern catalpa planted in parks).

Table 5
Comparison of mortality rates by nursery production types* (With P-Values).

Rootstock Type A	Mortality Ratio of Stock Type A: Stock Type B	Rootstock Type B	Pr(>|z|)
Bare Root	2.86	B&B	<0.001
Bare Root	5.56	Container	<0.001
Bare Root	1.31	Gravel Bed Bare Root	0.04
Gravel Bed Bare Root	2.54	B&B	<0.001
Gravel Bed Bare Root	4.24	Container	<0.001
Container	no statistically significant	B&B	0.30

B&B n = 566. Container n = 698. Bare Root n = 2,645. Gravel Bed Bare Root n = 2,146.

* First year mortality rates by nursery production type were B&B @ 4.0 %; Container @ 8%; Bare Root @ 13 %; Gravel Bed Bare Root @ 10 %.

Table 6
Adjusted average percent probability of mortality by tree taxa.

Taxa	Adjusted Average Percent Probability of Mortality
Catalpa speciosa (Warder) Warder ex Engelm.	2.03
Amelanchier x grandiflora Rehder 'Autumn Brilliance'	2.74
Aesculus glabra Willd.	3.33
Ulmus spp. (Asiatic Elms)	4.71
Ulmus americana L.	5.71
Gymnocladus dioicus (L.) K. Koch	6.27
Malus spp.	6.48
Acer x freemanii A.E. Murray	7.53
Syringa reticulata (Blume) H. Hara	7.88
Celtis occidentalis L.	9.33
Ostrya virginiana (Mill.) K. Koch	10.63
Maclura pomifera (Raf.) Schneid.	11.37
Tilia americana L.	12.68
Platanus × acerifolia (Alton) Willd.	12.76
Ginkgo biloba L.	13.02
Zelkova serrata (Thunb.) Makino	13.30
Amelanchier laevis Wiegand	13.54
Carpinus betulus L.	14.22
Quercus bicolor Willd.	14.31
Cladrastis kentukea (Dum. Cours.) Rudd	16.41
Quercus rubra L.	17.17
Quercus macrocarpa Michx.	17.32
Gleditsia triacanthos (L.) forma *inermis* Schneid.	17.50
Taxodium distichum (L.) Rich.	20.34
Nyssa sylvatica Marshall	45.76
Average	**12.25**

consistent outcomes in terms of percent probability of mortality (Table 7). Within each species, probability of mortality relative to nursery production type was consistently lowest with container trees, followed by B&B, gravel bed bare root, and bare root. Probability of mortality by site type was lower for trees planted in boulevards than on park/public space. Species percent probability of mortality performance relative to the combined variables of nursery production type and site type were lowest for container trees planted on boulevards, followed by container trees in park/public space, B&B trees in Boulevards, B&B trees in park/public spaces, gravel bed bare root trees in boulevards, gravel bed bare root trees in park/public space, and bare root trees in boulevards. Bare root trees in park/public spaces consistently produced the highest mortality rates.

Table 7
Combined variable percent probability of mortality.

Species	B&B (Boulevard)	B&B (Parks)	Container (Boulevard)	Container (Parks)	Gravel Bed Bare Root (Boulevard)	Gravel Bed Bare Root (Parks)	Bare Root (Boulevard)	Bare Root (Parks)	Adjusted Average
Catalpa speciosa	0.51	0.73	0.3	0.44	1.28	1.84	1.67	2.4	2.03
Amelanchier x grandiflora	1.06	1.54	0.66	0.96	2.65	3.81	3.41	4.89	2.74
Aesculus glabra	1	1.45	0.6	0.87	2.51	3.6	3.27	4.67	3.33
Ulmus spp.	1.41	2.03	0.85	1.23	3.51	5.01	4.56	6.47	4.71
Ulmus americana	1.68	2.4	1	1.42	4.09	5.77	5.31	7.44	5.71
Gymnocladus dioicus	2.2	3.16	1.33	1.92	5.42	7.66	6.99	9.82	6.27
Malus spp.	2.09	3	1.26	1.82	5.15	7.29	6.65	9.35	6.48
Acer freemanii	1.81	2.6	1.1	1.58	4.49	6.37	5.8	8.19	7.53
Syringa reticulata	2.53	3.62	1.53	2.2	6.19	8.72	7.96	11.14	7.88
Celtis occidentalis	3.52	5.01	2.14	3.07	8.48	11.84	10.84	14.98	9.33
Ostrya virginiana	3.1	4.43	1.88	2.71	7.53	10.55	9.65	13.4	10.63
Maclura pomifera	3.11	4.44	1.89	2.71	7.55	10.57	9.67	13.43	11.37
Tilia americana	3.95	5.62	2.41	3.45	9.47	13.16	12.06	16.58	12.68
Platanus x acerifolia	3.69	5.26	2.25	3.22	8.89	12.38	11.34	15.38	12.76
Ginkgo biloba	4.39	6.23	2.68	3.83	10.45	14.46	13.28	18.15	13.02
Zelkova serrata	3.48	4.96	2.12	3.04	8.4	11.72	10.73	14.84	13.3
Amelanchier laevis	4.28	6.09	2.61	3.74	10.22	14.16	12.99	17.79	13.54
Carpinus betulus	4.02	5.72	2.45	3.51	9.63	13.37	12.26	16.84	14.22
Quercus bicolor	4.73	6.66	2.84	4.02	11.03	15.1	14	18.93	14.31
Cladrastis kentukea	4.65	6.47	2.78	3.98	10.83	14.97	13.74	18.76	16.41
Quercus rubra	4.49	6.31	2.69	3.81	10.49	14.39	13.33	18.07	17.17
Quercus macrocarpa	8.04	11.15	4.89	6.87	17.91	23.84	22.26	29.12	17.32
Gleditsia triacanthos	6.96	9.69	4.21	5.93	15.72	21.11	19.66	25.99	17.5
Taxodium distichum	3.88	5.53	2.36	3.39	9.31	12.95	11.87	16.33	20.34
Nyssa sylvatica	14.98	20.33	9.56	13.28	30.95	39.37	37.03	46	45.76
Average	**3.82**	**5.38**	**2.34**	**3.32**	**8.89**	**12.16**	**11.21**	**15.16**	**12.25**

4. Discussion

4.1. "Planted by"

Among paid contractors, organization staff, and trained volunteers, there was no statistically significant impact on tree mortality based on who planted the tree. While there appeared to be a high degree of variation in the percentage of trees that died for each category (Table 2), the variation is likely due in part to the notable difference in the number of trees planted by each planting entity. Furthermore, contractors were more likely to be planting nursery production types with higher survival rates (B&B) than volunteers who were primarily utilized to plant bare root and gravel bed bare root trees which had lower survival rates. In this case, the appearance of substantial variation of tree mortality for a variable that is otherwise considered not statistically significant is better explained by nursery production type and high variation in planting numbers than by whom the trees were planted.

It should be noted again that the volunteers examined in this study were subject to best tree planting practices presentations and were supervised during the actual planting time. Given that these volunteers had received some degree of training and were supervised, this is a likely explanation for their ability to plant trees with similar rates of effectiveness as contracted professionals and organization staff. This finding is in agreement with previous research (Foster-Smith and Evans, 2003; Gillett et al., 2011; Bancks et al., 2018), that found evidence to support the claim that the outcomes of volunteer engagement in projects can have comparable success to the outcomes of professionals when provided with an adequate amount of instruction and supervision.

The implications of this finding are important for potentially reducing costs associated with urban tree planting. Because communities and organizations utilize contractors at a higher rate than volunteers, and contractor costs are significantly higher than volunteer costs (Hauer and Peterson, 2016), given equal effectiveness, volunteers could be utilized to reduce planting costs with no significant reduction in survival rate. In communities where budgets are already being stretched due to pressures like managing emerald ash borer infestations which tie up organization staff with advanced technical work unsuitable for volunteers, an urban forestry volunteer program could be effective in reducing costs and augmenting capacity.

Perhaps as or more important than the potential cost savings is the potential for greater community engagement with planting programs. Again, if planting survival rates are similar among contracted professionals, community staff, and trained volunteers, the reservations that a community may have to engage its constituency for fear of unacceptable mortality rates becomes a moot issue. Volunteers may not always save money, but they may be more inclined to support and save planting programs that they are vested in (Hauer et al., 2018).

4.2. Site type

Site type, or planting location, was found to be a statistically significant variable. Whether a tree was planted in a road adjacent area (<10 feet from street or roadway) or in a park/public space (>10 feet from a roadway) had a large impact on tree mortality. Trees planted in park/public space exhibited a 1.4 times greater likelihood for mortality than trees planted in road adjacent areas. While this finding seems to run contrary with the common belief that street trees have higher mortality rates due to road pressures like salt and air pollution, the results of this project are broadly supported by existing literature that also found higher mortality in non-street trees (Nowak et al., 1990; Nowak et al., 2004; Lu et al., 2010). However, there have also been a few studies suggesting the converse, that park trees have higher survival rates than street trees. One such study determined that stewardship by park-oriented groups played a large role in the high survival rates seen in park trees (Jack-Scott et al., 2013). This theory that stewardship has an impact on survival may be an explanation for higher survival rates of public street-adjacent trees found in this study, where there is more stewardship in the form of municipal or county organizations (rather than park-oriented groups) conducting post planting maintenance.

Many of the organizations included in this study conducted post planting watering practices with a truck mounted watering tank, which has little capacity to stray from a roadway or path. This could mean that street trees are simply receiving more watering relative to park/public space trees due to convenience, thus contributing to their higher survival rates. Survival then would be better explained by post planting maintenance quality, which is a function of location, rather than the merit of the location itself. Given the body of research on the needs of recently planted tree root systems, aggressive post planting maintenance may have contributed more to lower tree mortality than geographic location.

Another possible explanation for the lower likelihood of mortality of street adjacent trees may lie in the construction of adjacent impervious infrastructure. Depending on the orientation of nearby sidewalks and pavement, it is possible that impervious infrastructure around the tree serves to direct water to the tree during rain events which would increase soil moisture in well drained or structural soils. Increased soil moisture would benefit root growth and thus tree survival. Information on maintenance watering and rainfall totals would be useful in interpreting these results and providing context to findings, but data on watering frequency and rainfall was not collected as a part of this study. Another theory relating to infrastructure is that certain sidewalk construction materials, namely concrete, may promote root growth by acting as a barrier against soil moisture loss that reduces evaporation, effectively acting as a mulch, and also as a small source of water via condensation on the underside of the sidewalk caused by the temperature differential between a cool sidewalk and relatively warm soil (Randrup et al., 2001).

4.3. Nursery production type

Holding all other variables constant, a tree's nursery production type was found to be a statistically significant factor in determining its survival. Even when other variables were considered such as taxa and site type, container trees (followed closely by B&B trees) consistently produced lower mortality rates than other production types.

The primary difference between the two production types with the lowest overall mortality rates (container and B&B) and the highest rates of mortality (bare root and gravel bed bare root) is the level of exposure to drying air and warmer temperatures by their root systems. At the point of harvesting bare root trees, which is often in late fall, trees can lose up to 95 percent of their roots, which dramatically reduces their capacity to uptake water (Watson, 1996). From there, with now-exposed roots, they are stored under cool climate-controlled conditions for the duration of the winter until they are sold in spring. From the time these bare root trees are harvested from the field, transported to the cooler for storage, removed from storage and transported to the buyer, and then transported by the buyer to the final planting location, the vulnerable bare root systems can be exposed to a variety of temperature and moisture fluctuations, which can be detrimental to root health, establishment success, and survival rates (Watson and Himelick, 1997; (Koeser et al., 2009); Goyette et al., 2014). This fluctuation of temperatures and moisture logically would contribute to the low survival rates.

While gravel bed bare root trees have had the same harvesting, storage, and transportation experiences as bare root trees, they have the benefit of having developed an enhanced fibrous root system while being held in the gravel for weeks, which may serve to buffer the negative impacts of fluctuating temperature and/ or moisture conditions, and poor transportation practices. This would result in more fibrous roots at the time of planting, which benefit water uptake, promoting establishment. Furthermore, given that gravel bed bare root trees are planted in late summer through autumn, they have the benefit of being placed into warmer soils which are conducive to fine root development, and ambient temperatures that, along with lowered photosynthetic demand, reduce net moisture loss. When these elements are coupled with the normal reduction in the consumption of water by trees and shrubs in autumn months (Akhmatov and Salaš, 2005), autumn planting may also help to explain the marginally higher survival rates of gravel bed bare root trees over bare root trees.

Balled and burlaped (B&B) and container trees, by contrast, always have a core of their roots protected by soil. This may serve to insulate the roots from temperature and moisture swings and buffer what roots they have left from moisture losses during storage and transit, increasing their likelihood for survival. What may set container trees apart from B&B trees is the amount of roots retained by the tree until the time of planting. Container trees, especially those grown in their containers long-term, retain nearly all of their roots into planting, compared to B&B trees that may have as little as 5% of their original roots (Watson, 1996). Container trees also may have been subject to root pruning at planting time, a method of reducing the negative impacts of encircling root systems, which has a secondary benefit of stimulating new root growth from the severed roots (Watson and Sydnor, 1987). Because this new root growth is taking place right as the tree is being planted, the stimulation of new roots into the surrounding soil would be very beneficial to water uptake and would theoretically lead to better establishment. These combined factors would help to explain the low rate of mortality of container trees relative to B&B trees.

4.4. Taxa

Information on which species are most successful in the urban environment is highly sought after by urban foresters who are always searching for ways to make their forests more diverse and resilient. However, choosing the best urban trees remains a difficult task in an era of increasing climate change, insect and pest, and urban pressures. The species of a tree was a statistically significant factor related to the likelihood of mortality. There were ten tree species present in this study whose adjusted average mortality remained under 10 % (*Catalpa speciosa, Amelanchier spp*. (*Amelanchier x grandiflora* 'Autumn Brilliance'), *Aesculus glabra, Ulmus spp*. (Asiatic Elms), U*lmus americana, Gymnocladus dioicus, Malus spp., Acer x freemanii, Syringa reticulata*, and *Celtis occidentalis*). Unsurprisingly, these trees appear to be some of the most commonly planted trees in the Twin Cities metro area, perhaps largely due to their high rates of survival. These trees tolerate a wide range of soil moisture types. Like most other plants, these trees prefer moist, well drained soils; however, they are also tolerant of both drier soils as well as occasionally flooded soils. Of the top performing trees, none were obligate wetland or obligate upland species, and almost all were classified as FAC[2] or FACU[3] in terms of their wetland indicator status (Lichvar et al., 2016), further indicating a preference for neutral to dryer soils. Because urban soils tend to be hotter than their rural counterparts (Pickett et al., 2011), trees that tolerate hotter, drier soils would likely be more successful.

Soil pH tolerance may also serve to play a role in why certain tree may be more successful than others. Urban environments are often composed of soils that exhibit higher pH, due to additions of calcareous building materials and other waste materials (Schleuß et al., 1998; Zhao et al., 2007). Furthermore, many critical nutrients such as iron and manganese, are only available for plant uptake at lower soil pH, limiting the degree to which trees can uptake them in the more alkaline urban

[2] FAC- Facultative: Equally likely to occur in wetlands and non-wetlands (estimated probability 34% – 66%).

[3] FACU- Facultative upland: Usually occurs in non-wetlands (estimated probability 67% – 99%), but occasionally found in wetlands (estimated probability 1% – 33%).

soils (Cregg, 2014). Nutrient deficiencies may result in increased stress, dieback, and higher vulnerability to pests and disease. Of the top ten performing trees, all tolerated soil pH between 7 and 8.5 in the upper ranges of their pH tolerance (Minnesota Pollution Control Agency, 2021). However, many lower performing trees also had high pH tolerances, so while it may be a contributing factor, pH is not a singular explanation for differences in mortality. Additionally, since mortality data was only collected for 1 year post planting, it is unlikely that soil pH would have a demonstrable negative impact on mortality. Data regarding soil pH for trees included in this study was unavailable.

Cold hardiness appeared to play a minor role in tree survival rates, given that only trees with tolerances for cold hardiness zones 4 or colder (4a, 3, 2) were associated with higher survival rates. However, it may be that in trees with marginal zone 4 tolerance, knowledge of provenance would be important. For example, *Nyssa sylvatica*, which was observed to have low survival rates, is classified as a reliable zone 4 tree, but all seed sources were from New York or Washington State (confirmed by principal investigator). *Nyssa sylvatica* propagation seed from those two states could have been sourced from zones ranging from 4a to 9a.

Sweating trees, which is a process that essentially forces bud break and active growth (Halcomb and Fulcher, 2003), may also play a role in species success, depending on the individual species requirements. While it is unclear how many communities sweat bare root trees, failing to do so may partially explain high mortality rate trees like *Gleditsia triacanthos* forma *inermis, Quercus macrocarpa, Quercus bicolor, Taxodium distichum*, and *Nyssa sylvatica*, all species that benefit from sweating before planting. If sweating is skipped for those trees that need it, the result can be a shorter growing season for the tree for the first year, less root growth, and lower energy reserves upon entering winter, which may result in damage or mortality to the tree (Johnson, 2017). Additionally, *Catalpa speciosa* and *Aesculus glabra* were high performing species, and do not require sweating, meaning that if an organization decided not to sweat their trees, these species would suffer no ill effect. There did not appear to be any connection between native and non-native species status and mortality rate.

Altogether, the cause of the lower mortality rates found among the species examined in this study didn't appear to be due to any one particular factor. Tolerance of a wide range of soil moisture conditions seemed to be beneficial to tree survival, however some trees with high tolerance ranges were also found to have high rates of mortality. Similarly, while a tolerance for higher and wider range of soil pH seemed to benefit tree survival, there were also several exceptions where poor performing trees also had a wide range of soil pH tolerance. While there were certainly tree species with remarkably low mortality rates, those tree species seemed to have arrived at their high performance courtesy of different combination of beneficial traits for establishment.

4.5. Other potential variables

Although there were other variables that could have influenced the survival rates of the planted trees, a lack of detailed data made it unreasonable to assess their influence in this study. For instance, the size range of the trees at planting time was broad, from very small calipered bare root trees to large calipered B&B specimens. Larger trees logically would require more moisture to survive; smaller trees would logically be more vulnerable to unintentional physical damage. However, without data that linked the exact sizes to survival rates, those conclusions could not be substantiated. In future studies, it would be a worthy effort to develop a protocol to collect that data and hopefully any correlations.

Likewise, managers from some of the communities indicated that the roots of bare root trees were dipped in a hydrogel solution prior to planting, a commonly recommended practice that in theory reduces the potential of water loss in root tissues (Buckstrupp and Bassuk, 2009), while others simply placed the tree roots in water containers. However, in practice, the benefits of root dipping in hydrogel on post-transplant survival are unclear. Both Landis and Littaase (2012) and Bates et al. (2004) found no advantage of hydrogel root dips over water root dips in terms of post planting survival rates. Again, this variable deserves more attention in future similar studies since it is a commonly recommended practice, and assessments of hydrogel dips versus other treatments and controls would be best served by carefully linking the practices to exact trees being planted and evaluated one year later.

5. Conclusion

This study aimed to broaden the understanding of some human and biotic factors that influence young tree success. It sought to examine four variables for their potential impact on young tree mortality: tree species, nursery production type, planting location, and "planted by." The general recommendations that could be concluded or inferred from this study would include: 1) select "proven" regional tree species for higher survival rates; 2) for all nursery production types, container and/or B&B had the highest survival rates; 3) trees planted by volunteers can have survival rates comparable to contracted or employed personnel when sufficient training and supervision is provided; 4) the use of bare rooted trees needs to be accompanied by sufficient preparation when required (sweating) and accommodations to keep the roots consistently moist prior to planting; 5) post-planting care, in particular regular watering, may be the most influential survival tactic, especially for trees planted in parks or public spaces.

Author statement

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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