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Survival and Growth Factors Affecting Community-Planted Urban Street Trees

Emily J. Jack-Scott
Yale School of Forestry and Environmental Studies, emily.jackscott@gmail.com

Survival and Growth Factors Affecting Community-Planted Urban Street Trees

Urban street trees face adverse growing conditions: compacted soils, extreme heat, lack of nutrients, drought, car damage and vandalism. Limited funding, however, is cited by urban tree-planting organizations as their major obstacle. To maximize budgets, many organizations along the eastern United States have planted bare root trees as a less expensive alternative to balled-and-burlapped (B&B) trees. Existing research indicates equivalent survival rates between bare root and B&B trees; but no research has examined this in community group-planted urban street trees. Bare root trees are additionally advantageous in community-based plantings because they are much lighter and easier for volunteers to handle. This study evaluated the influence of stock and other site factors on street tree survival and growth measures (diameter at breast height, percent canopy cover, and percent live crown), while controlling for species and age. Site factors included street traffic intensity, site type (curbside, park, yard, or commercial corridor), wound presence, and sidewalk pit cut dimensions. 1159 trees (representing ten species) planted by Philadelphia community groups under the guidance of the Pennsylvania Horticultural Society from 2006-2009 were sampled. Overall, trees showed a high survival rate of 95%, with no significant difference between B&B and bare root trees. Species with the highest survival rates were *Prunus virginiana* (chokecherry), *Platanus x acerifolia* (London plane tree), and *Acer tataricum ssp. ginnala* (Amur maple). Heavily trafficked streets exhibited lower survival, percent canopy cover and percent live crown. Larger growth measures were expected and found in B&B trees, as they have historically been planted larger than their bare root counterparts. Findings support planting larger trees (such as B&B and/or larger bare root trees) along commercial corridors. Species in the Rosaceae family (*Amelanchier spp.*, *Malus spp*, and *Prunus virginiana*) exhibited lower percents canopy cover. Wound presence and pit cut size were not major factors affecting the 1-5 year old street trees sampled in this study. The major management implication of these findings is that bare root trees are a viable alternative to B&B trees in community-based urban forestry initiatives. Tree-planting campaigns with similar climactic conditions to Philadelphia can use this study to inform selection of stock and species.

Keywords

Urban forestry, harvesting method, bare root, balled-and-burlapped, B&B, Philadelphia, PHS, TreeVitalize, transplanting, street traffic, wound, pit cut, Acer tataricum ssp. ginnala, Acer rubrum, Amelanchier, Cercis canadensis, Cladrastis kentukea, Gleditsia triacanthos, Malus, Platanus x acerifolia, Prunus virginiana, Syringa reticulata, Amur maple, red maple, serviceberry, redbud, yellowwood, honey locust, crabapple, London plane tree, Japanese tree lilac

Acknowledgements

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INTRODUCTION

Urban forests have been recognized for their role in improving the standard of living for city residents across the country (Dwyer et al. 1992; Bolund & Hunhammer 1999; Sather et al. 2004). Street trees offer a wide array of services including improved air and water quality (Beckett et al. 2000; Nowak et al. 2007), property value (McPherson et al. 1997), human health (Coder 1996), energy conservation (Nowak 1995), wildlife habitat (Coder 1996), weather buffering and urban heat island amelioration (McPherson 1994), storm water catchment (McPherson et al. 1997), sense of community (Coder 1996), economic revitalization (Wolf 2003), and crime reduction (Kuo and Sullivan 2001). Crown fullness and size are often positively correlated with these benefits; larger, fuller trees generally produce greater effects (McPherson et al. 1999). While urban reforestation campaigns have gained popularity in recent years, urban street tree counts continue to decrease, and funding availability remains the greatest challenge facing tree planting efforts (Kielbaso 1990; Hauer and Johnson 2008). Government agencies, contractors, and non-governmental organizations across the country have thus been exploring alternative means of maximizing the number of trees they can plant.

Bare root trees are seen as a less expensive, more easily transported alternative to balled-and-burlapped (B&B) trees (Buckstrup & Bassuk 2003; Sather et al. 2004), and have been planted in many cities in the eastern United States. The bare root method of transplanting trees has a long-standing history in nurseries, dating back to the industry's origin in the U.S. in the eighteenth century (Davidson et al. 1999). Bare root trees are grown similarly to B&B trees but are transplanted in a way such that the soil the trees are grown in can be shaken away, leaving the roots exposed (Sather et al. 2004). In order to prevent the roots from desiccating, they are recommended to be dipped into a hydrogel polymer slurry and wrapped in a clear plastic bag (Buckstrup & Bassuk 2003; Harris et al. 2004). The roots are sensitive to changes in temperature, moisture, and planting conditions, and should therefore be transplanted while dormant during spring or fall, and within a week of shipping from the nursery (Sather et al. 2004). Bare root trees have many advantages as they are a fraction of the weight and cost of B&B trees, can be shipped more efficiently, and root pruned for visible defects prior to planting (Buckstrup and Bassuk 2003; Flott et al. 2008). In sum, bare root plantings allow more volunteers to plant more trees within the same constraints of community group capacity and funding availability.

Initial research directly comparing bare root and B&B trees by Cool (1976) found higher mortality in bare root trees than in B&B trees. A follow-up study by Vanstone and Ronald (1981) found that if transplanted correctly, no difference in mortality was evident between stocks by the second growing season. B&B trees did however rank higher in growth indices (shoot growth and leaf size). Buckstrup and Bassuk (2000) conducted a similar study directly comparing the mortality and growth rates of bare root trees to those of B&B trees over two growing seasons. Their mortality findings substantiated those put forth by Vanstone and Ronald (1981), but their data on growth indices indicated no differences across stock. Most recently, Anella et al. (2008) further corroborated Buckstrup & Bassuk's (2000) findings in the more drought-inclined environment of Oklahoma. All of these studies emphasized the importance of sampling across species and growing seasons. Despite these findings, popular belief still holds that B&B trees consistently have higher survival rates than their bare root counterparts (Sather et al. 2004). The body of research on urban bare root trees currently lacks any studies directly comparing bare root and B&B trees planted by volunteers.

The main objective of this study is to highlight the role stock (bare root vs. B&B) plays in the survival and growth of community-planted street trees. Primary test factors include species and age (accounting for multiple growing seasons). Secondary factors under consideration are street traffic intensity, site type (curbside, yard, park, and commercial corridor), wound presence, and dimensions of sidewalk pit cuts. Street traffic (both pedestrian and automobile) can in theory impact tree survival and growth because trees are at a higher risk of damage from cars and vandalism. Site type can impact a tree's access to water, as well as its exposure to traffic-related risks. Wounding opens a tree up to infection and can therefore impact a tree's survival and growth. Sidewalk pit cut size in theory acts as a proxy for access to rainwater as well as other constraints on root growth. The role of these factors has not been quantified in the existing body of published research on community urban forestry.

It is hypothesized that bare root and B&B trees will have equivalent survival rates. Across these two stocks, higher rates of mortality will be positively correlated with smaller pit cut size, wound presence and higher street traffic. Because bare root trees are often specified to be planted at smaller caliper size than B&B trees, it is expected that growth measures will be correspondingly larger in B&B trees. Higher growth measures are also expected along less heavily trafficked streets, in yard trees, in trees without wounding, and in larger pit cuts. Species-specific variability in DBH and crown fullness is also expected based on tree habit and form.

METHODS

Site Selection and Sampling Design

This study was conducted on trees planted in Philadelphia through the TreeVitalize campaign coordinated by the Pennsylvania Horticultural Society (PHS) in southeast Pennsylvania. Philadelphia is located at 39˚ 57' 8" N / 75˚ 9' 51" W along the mid-Atlantic border of the United States. The city covers 326.14 km^2 (80,589 acres or 126 mi^2) and is situated at an elevation of 11.89 m (39 ft) above mean sea level. It is home to 1.5 million people and 2.1 million trees. In 2003, an American Forests study found an average city-wide canopy cover of 15.7%, ranging from 1.8% to 38.3% by neighborhood. A more detailed UTC study in 2010 put the overall average canopy cover at 19.6%. More than half of the city's trees have diameter at breast height (DBH) sizes of less than 15.25 cm (6 in) (Nowak et al. 2007). Every year hundreds of trees are planted by the city government through the Department of Parks and Recreation (through a division formerly called the Fairmount Park Commission). Many hundreds, and in recent years thousands, more are planted by PHS through the TreeVitalize campaign.

TreeVitalize is a public-private partnership launched by the PA Department of Conservation and Natural Resources in 2004. In less than five years the program reached its initial goal of planting over 20,000 trees in and around Philadelphia through community members. The program continues to grow in southeast PA and has now been launched in all other metropolitan areas across the state. Tree-planting volunteers are led by community group leaders trained through the 9-hour Tree Tenders® course developed by PHS in collaboration with Penn State Cooperative Extension. The training program covers tree planting, identification, benefits, and maintenance. The fact that TreeVitalize represents both public and private organizations, as well as community groups makes it an ideal urban forestry program for study.

All bare root trees planted through the TreeVitalize program were ordered at 1-2" caliper, dipped in a hydrogel slurry and bagged at the nursery following uprooting, or upon their immediate arrival in Philadelphia. They were then consistently planted within a week of uprooting in accordance with transplanting guidelines (Buckstrup & Bassuk 2009). Through the Tree Tenders course and planting-day demonstrations, volunteers in community groups were instructed to plant B&B trees by placing them into tree pits, then cutting away as much of the wire baskets and burlap as possible before back-filling soil. No soil amendments (like BioPak™ or compost) were provided.

PHS has maintained records of every tree planted since 2004, including notes on species, planting address, stock (bare root vs. B&B), and the community group that planted it. An analysis of these records showed the most commonly planted species in both bare root and B&B stocks have been Amur maple (*Acer tataricum ssp. ginnala* Maxim., Sapindaceae), red maple (*Acer rubrum* L., Sapindaceae), serviceberry (*Amelanchier* Medik., Rosaceae), redbud (*Cercis canadensis* L., Rosaceae), yellowwood (*Cladrastis kentukea* (Dum. Cours.) Rudd, Fabaceae), honey locust (*Gleditsia triacanthos* L., Fabaceae), crabapple (*Malus* Mill., Rosaceae), London plane tree (*Platanus x acerifolia* Willd., Platanaceae), chokecherry (*Prunus virginiana* L., Rosaceae), and Japanese tree lilac (*Syringa reticulata* (Blume) H.Hara, Oleaceae). Cultivars for each of these species were unfortunately not always recorded, and therefore could not be accounted for in this analysis. Records for these ten species were sorted by stock and year planted, and then randomized. Up to 30 sites for each stock, of each species, from each planting year, were randomly selected (some groupings were limited to fewer than 30 sites). The sampling design was fully crossed, and blocked by planting year. Because some neighborhoods are more involved in TreeVitalize plantings than others, sites were not distributed evenly across the city. A total of 1411 sites were selected through this process and mapped using ArcGIS (Figure 1). Of the original 1411 trees sites, 644 (45%) were B&B trees, and 767 (55%) were bare root trees.

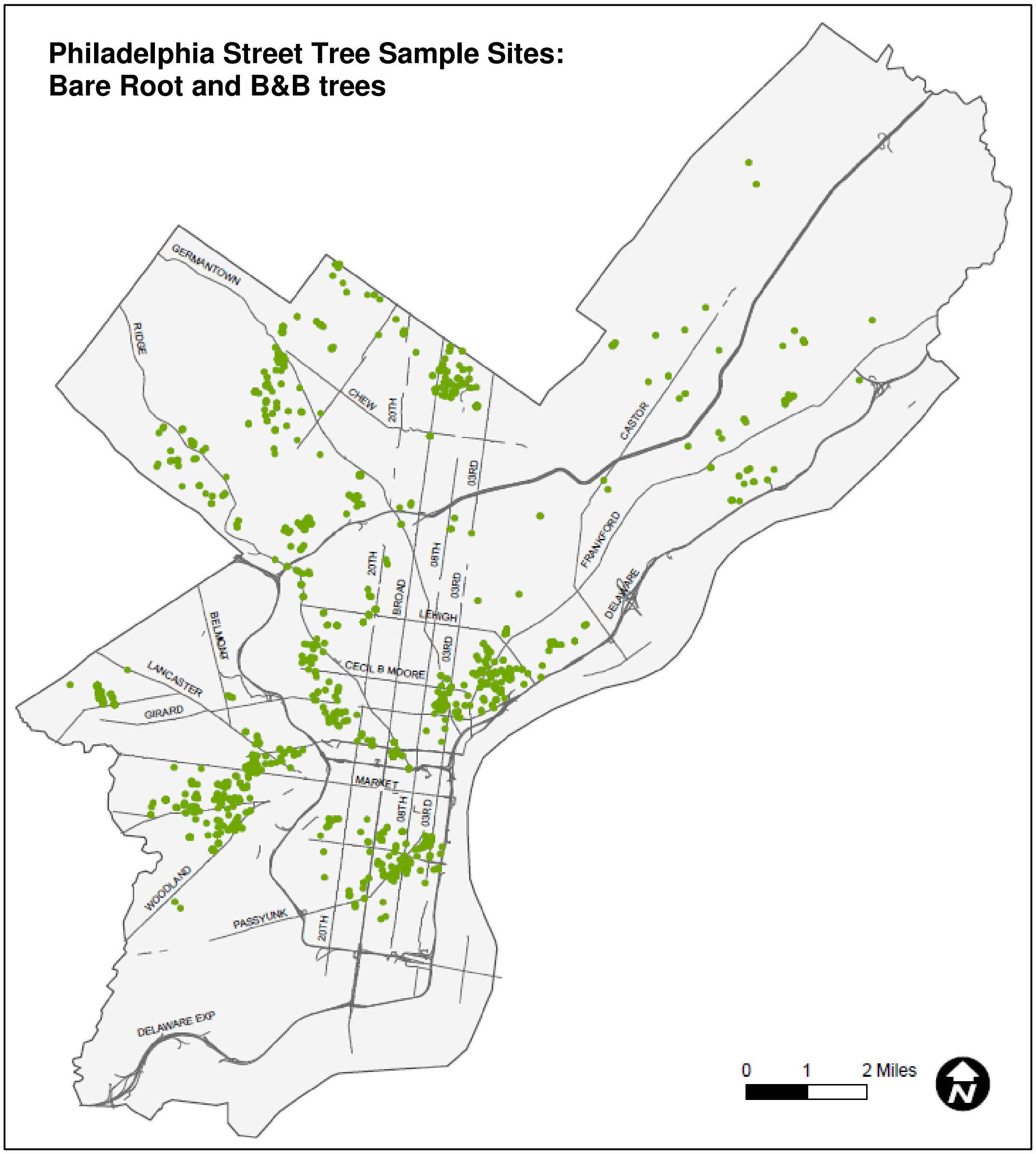


Figure 1: Based on records from the Pennsylvania Horticultural Society, 1411 bare root and balled-and-burlapped trees were randomly sampled for mortality and growth in metropolitan Philadelphia. Sites were chosen across ten species and four age classes planted 2006-2009.

Data Collection

Site inspections were conducted between mid-June and early August 2009 to ensure that all trees were fully leafed-out upon time of inspection. At each site, address and species planted were verified or revised. Three growth/vigor measures were then taken: diameter at breast height (DBH), percent canopy cover, and percent live crown. DBH was measured in quarter-inch increments using calipers. Four measurements of percent canopy cover were taken using a densiometer (Doccola et al. 2009). The densiometer was constructed in-house following EPA guidelines (EPA 2007). These measurements were taken at curbside, left, right, and sidewalk-facing directional points, and then averaged to capture variability. In order to calculate percent live crown, trunk height and total height were measured in half-foot and foot increments, respectively. Height measurement standards followed Colorado State Forest Service guidelines (Schomaker 2004). Percent live crown was later calculated by dividing live crown height (total height less trunk height) by total height and multiplying by 100. Street traffic intensity (residential low traffic, residential high traffic, or commercial) was based on visual assessment of site land use and traffic intensity (both vehicular and pedestrian). Site type (commercial corridor, curbside, yard, park), tree trunk wound presence, and sidewalk pit cut dimensions were also recorded.

Statistical Analysis

Statistical analysis was done using R statistical software and language (Peters & McFadden 2010). DBH data was normalized using a log transformation, while percent canopy cover and percent live crown were normalized using an arcsin()^2 transformation. Logistic regression was done to analyze mortality data (Packer and Clay 2000), and multiple linear regressions in conjunction with regression trees were used to analyze growth measure data (DBH, percent canopy cover, percent live crown) (Gregg et al. 2003). Regression trees were used as a visual aid in determining significant interaction effects (De'ath and Fabricius 2000). Explanatory variables included stock, species, age, site traffic, site type, wound presence, and pit cut size. A forward selection procedure was used to retain only those factors that were significant in the model (Peña-Claros et al. 2008, De’ath and Fabricius 2000). A two-way ANOVA with an error term for years planted (age) was also done to test for an interaction between species and stock while accounting for the blocked sampling design (Peña-Claros et al. 2008).

RESULTS

A majority of the 1411 tree sites selected were found and inspected (1159, 82.6%). Those not found were presumably either, a) never planted, or b) planted, died and removed. 89% of the B&B sites and 77% of bare root sites were found. While this suggests a potentially higher rate of mortality in bare root trees, in reality this discrepancy is due to a higher rate of clerical mistakes in early bare root planting years. Sites not found were not included in statistical analysis.

Mortality

Both bare root and B&B stocks exhibited very high survival rates: 95% of bare root trees, and 96% of B&B trees after an average of 2.62 years since planting. The results of logistic regression analysis indicated no significant difference in survival rates between bare root and B&B trees (Figure 2).

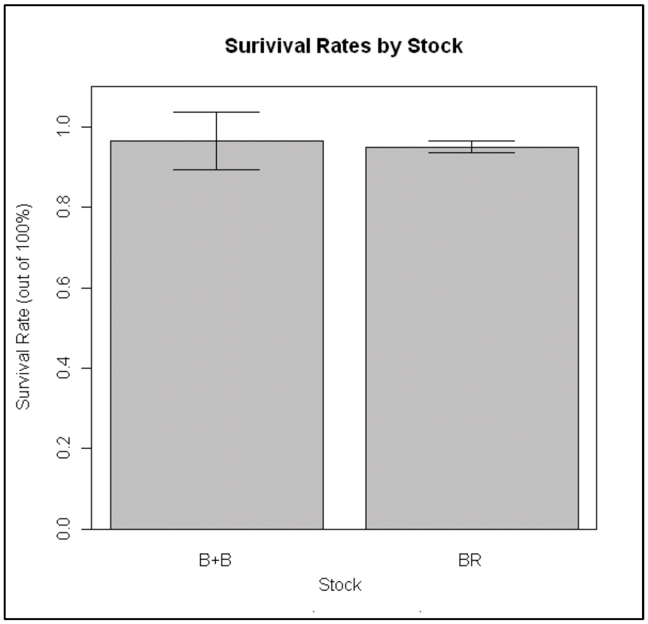


Figure 2 High rates of survival were found both stocks, with no significant difference in survival rates between B&B and bare root trees.

Years since planting (age) were also not a significant predictor of mortality (p=0.921). Species with the highest survival rates were *P. virginiana* and *Platanus x acerifolia,* with *A. tataricum ssp. ginnala*, *S. reticulata, Amelanchier spp.*, and *C. kentukea* close behind; *C. canadensis* had the lowest survival rate (Figure 3).

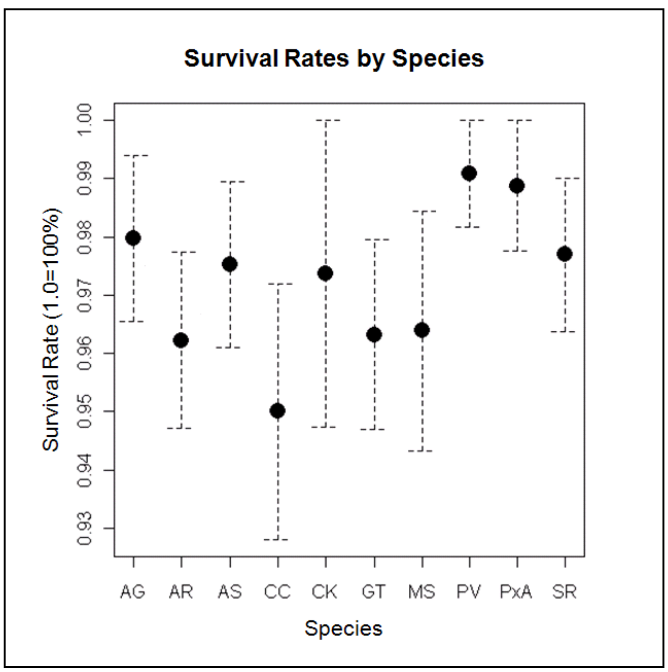


Figure 3 Species sampled were *Acer ginnala* (AG), *Acer rubrum* (AR), *Amelanchier spp.* (AS), *Cercis canadensis* (CC), *Cladrastis kentukea* (CK), *Gleditsia triacanthos* (GT), *Malus spp.* (MS), *Prunus virginiana* (PV), *Platanus x acerifolia* (PxA), and *Syringa reticulata* (SR). *Prunus virginiana* (chokecherry) and *Platanus x acerifolia* (London plane tree) had the highest survival, and *Cercis canadensis* (redbud) had the lowest.

Street traffic intensity was the only other significant factor to affect survival rates. Lower survival rates were observed along heavily trafficked commercial corridors (p=0.0056) (Table 1).

Table 1 –Higher mortality was found along commercial corridors (the highest traffic intensity). *Prunus virginiana* (chokecherry) exhibited the highest rate of survival, while *Cercis Canadensis* (redbud) exhibited the lowest, although all species showed very high rates of survival (>93%). Significant codes: 0 '***', 0.001 '**', 0.01 '*'.

Survival Coefficients (Equivalent R-squared = 0.124, AIC = 379.53)		
	Estimate	**P-value**
Commercial Traffic	-0.991	0.0056**
Acer ginnala	2.537	0.0009***
Acer rubrum	1.812	0.0002***
Amelanchier spp.	2.254	0.0004***
Cercis canadensis	1.481	0.0051**
Cladrastis kentukea	2.404	0.0225*
Gleditsia triacanthos	1.978	0.0002***
Malus spp.	1.859	0.0039**
Prunus virginiana	3.296	0.0015**
Platanus x acerifolia	3.065	0.0032**
Syringa reticulata	2.424	0.0002***

Growth

Growth was evaluated using three measures: diameter at breast height (DBH), percent canopy cover, and percent live crown. Due to discrepancies between recorded and actual species planted on sites, only *Acer rubrum* (red maple), *Amelanchier spp.* (serviceberry), and *Gleditsia triacanthos* (honey locust) were found in sufficient quantities to be included in two-way ANOVA analysis. Results indicated that DBH was significantly affected by stock ($p_{[1,15]}=0.020$) and species ($p_{[2,15]}=0.029$). Percent canopy cover was significantly affected by species ($p_{[2,15]}<0.0001$). Tukey tests indicated that with regard to DBH, *Amelanchier spp.* vs. *A. rubrum* (p<0.0001) as well as *G. triacanthos* vs. *Amelanchier* (p<0.0001) were significantly different; while *A. rubrum* and *G. triacanthos* were not (p=0.913). All three species pairings had significantly different percent canopy covers (all p<0.0001).

According to multiple regression analyses, older and B&B trees were found to have larger measures for all three growth indices (p<0.0001). This was expected as trees obviously grow larger with age, and because B&B trees are initially planted larger than bare root stock. Growth indices also varied significantly with species. *Platanus x acerifolia* (p<0.0001) had significantly higher DBH values, while *Amelanchier spp.* (p<0.0001), *Malus spp.* (p=0.0005), and *Syringa reticulata* (p=0.0003) had lower DBH measures. Pit cut size was surprisingly negatively correlated with DBH in *Platanus x acerifolia* trees (p=0.0070). Age, stock, species, and pit cut size accounted for 51.9% of the variability in DBH measures (Table 2).

Table 2 – Age, stock, species, and pit cut size were significant explanatory variables affecting DBH. Higher DBH measures were recorded in older, B&B, and *Platanus x acerifolia* (London plane tree) trees. Lower measures were recorded in trees that were younger, bare root, *Amelanchier* (serviceberry), *Malus spp.* (crabapple), and *Syringa reticulata* (Japanese tree lilac). Significant codes: 0 '***', 0.001 '**', 0.01 '*'.

DBH Regression Coefficients (Adjusted R-squared = 0.519)		
	Estimate	**P-value**
Age	0.1856	<0.0001***
Stock	-0.1418	<0.0001***
Amelanchier spp.	-0.2718	<0.0001***
Age:*Malus spp.*	-0.0339	0.0005***
Age:*Platanus x acerifolia*	0.1636	<0.0001***
Age:*Syringa reticulata*	-0.0429	0.0003***
Age:*Platanus x acerifolia*:Pit Cut Size	-0.0029	0.0070**

Percent canopy cover was significantly correlated with species, street traffic intensity and wound presence. *A. tataricum ssp. ginnala* (p<0.0001), *Amelanchier spp.* (p<0.0001), *G. triacanthos* (p<0.0001), *Malus spp.* (p<0.0001), and *P. virginiana* (p<0.0001) had significantly lower percent canopy cover measures than other species. *G. triacanthos* trees with bole wounds also had lower percent canopy cover (p=0.0416). Trees on low traffic residential streets had higher percents canopy cover (p=0.0011) than those on high traffic residential streets and commercial corridors. These factors accounted for 40.6% of variance in percent canopy cover data (Table 3).

Table 3– Higher percent canopy cover measures were recorded in trees that were older, B&B, and along low traffic residential streets. Lower measures were recorded in trees that were younger, bare root, *Acer ginnala* (Amur maple), *Amelanchier* (serviceberry), *Gleditsia triacanthos* (honey locust), *Malus spp.* (crabapple), and *Prunus virginiana* (crabapple). Significant codes: 0 '***', 0.001 '**', 0.01 '*'.

Percent Canopy Cover Coefficients (Adjusted R-squared=0.406)		
	Estimate (x10^-5)	**P-value**
Age	0.916	<0.0001***
Stock	-0.635	<0.0001***
Acer ginnala	-1.288	<0.0001***
Amelanchier spp.	-3.185	<0.0001***
Gleditsia triacanthos	-2.206	<0.0001***
Malus spp.	-1.844	<0.0001***
Prunus virginiana	-1.063	<0.0001***
Low Residential traffic	0.446	0.0011**
***G. triacanthos*:Wound Presence**	-1.019	0.0416*

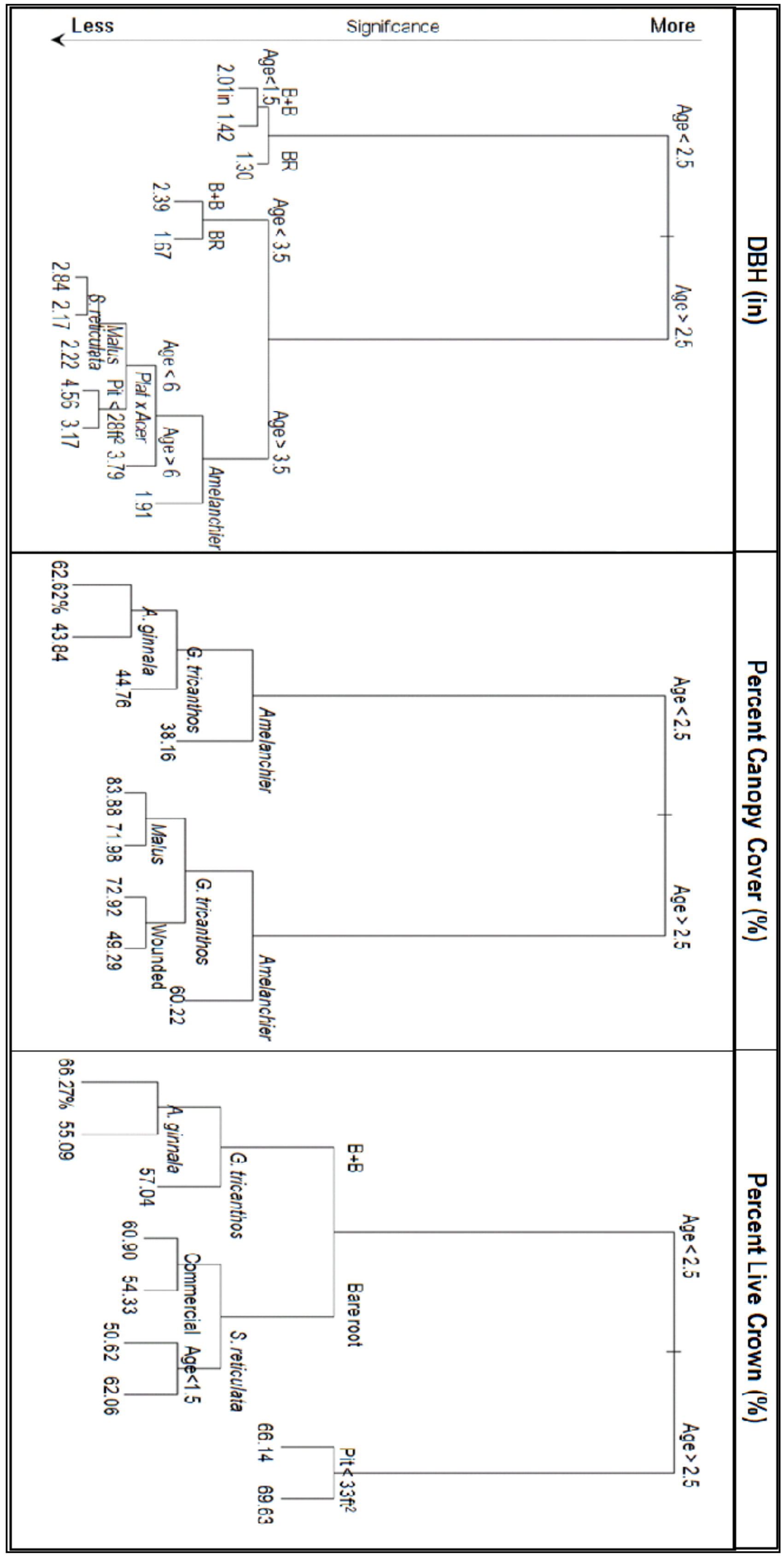
Higher percent live crown was found in curbside (p=0.0271), yard (p=0.0017), *P. virginiana* (p=0.0026) and *Platanus x acerifolia* (p=0.0397) trees. Lower percents live crown were observed in *A. tataricum ssp. ginnala* (p=0.018), *C. kentukea* (p<0.0001), *G. triacanthos* (p=0.0002), and *S. reticulata* (p<0.0001). Younger bare root trees (except *S. reticulata*) along commercial corridors had lower percents live crown (p=0.0003), though this trend diminished with age. Older trees in smaller sidewalk pit cuts (p=0.0049), and wounded *G. triacanthos* trees (p=0.022) also had lower percents live crown. Age, stock, species, pit cut size, wound presence, site type and street traffic accounted for 25% of variance in percent live crown (Table 4).

Table 4–Higher measures were recorded in older, B&B, street, yard, *Platanus x acerifolia* (London plane tree) and *Prunus virginiana* (chokecherry) trees. Lower measures were recorded in trees that were younger, bare root, in smaller pits, with wounds, and along commercial corridors. Significant codes: 0 '***', 0.001 '**', 0.01 '*'.

Percent Live Crown Coefficients (Adjusted R-squared=0.2505)		
	Estimate (x10^-6)	**P-value**
Age	2.628	<0.0001***
Stock	-2.331	<0.0001***
Pit Cut Size	0.089	0.0049**
Wound Presence	-1.949	0.022*
Acer ginnala	-4.098	0.018*
Cladrastis kentukea	-4.998	<0.0001***
Gleditsia triacanthos	-3.722	0.0002***
Prunus virginiana	3.253	0.0026**
Platanus x acerifolia	2.467	0.0397*
Syringa reticulata	-5.234	<0.0001***
Street/Curbside Site Type	1.734	0.0271*
Yard Site Type	4.218	0.0017**
Stock:Commercial Traffic	-6.235	0.0003***

The visual interactions of significant factors affecting all growth measures are well illustrated through regression trees (Figure 4). Regression trees display significance from the top down, with longer branches indicating higher significance.

Figure 4 – Regression trees illustrate significant interactions between factors affecting growth measures. They can be read from the top down; longer branches indicate more significant trends. For example, regarding percent live crown, trees under the age of 2.5 years, that are bare root, a species other than *Syringa reticulata* (Japanese tree lilac), and located along a commercial corridor have average percent live crown of 54.33%. This is significantly lower than trees that meet the same criteria but are not located along commercial corridors (60.90%).



DISCUSSION

The main objective of this study was to investigate the influence of stock (B&B vs. bare root) on survival and growth of urban street trees planted by community groups. Both bare root and B&B displayed very high survival rates, with no significant difference across stock. This substantiates findings by Vanstone and Ronald (1981), Buckstrup and Bassuk (2000), and Anella (2008) within the context of community-based plantings.

With regard to growth measures, B&B trees were found consistently to have higher DBH, percent canopy cover, and percent live crown values. This was expected because B&B trees are regularly planted larger than their bare root counterparts. Because this study was based on previously planted trees, size at which they were planted was not standardized across stocks. This study cannot provide insight into the comparative rates of growth; however, it does highlight that B&B trees currently have larger DBH measures and fuller crowns on average. Significance of stock on DBH dissipates with age, such that DBH of older trees becomes more correlated with species (Figure 4). This supports Buckstrup and Bassuk's (2000) finding that it may take multiple growing seasons for size differences between stocks to level out.

Findings confirmed variability across species. For example, *Amelanchier spp.* was consistently smaller than the other species, while *Platanus x acerifolia* was much larger. Species-specific variability is seen as a reflection of variance in habit and form rather that performance. All species sampled from the Rosaceae family (*Amelanchier spp., Malus spp.,* and *Prunus virginiana*) had lower percent canopy cover measures. This may have implications for species selection as percent canopy cover is often used by organizations in setting tree cover goals.

Explanatory variables accounted for the most variance in DBH (51.9%), with lesser impact on percent canopy cover (40.6%) and percent live crown (25%). Among those variables, street traffic intensity was the most significant factor after age, stock, and species. Given that wound presence was significant in percent live crown, it may be that with greater street traffic more passersby are breaking off branches, or creating other sources of stress. Under stress, the tree may not be able to allocate as many resources towards crown fullness.

While only 25% of the variance in percent live crown was explained through the statistical model used, the trends it exhibits are nonetheless insightful. High percent live crown was seen in yard trees – higher than in park, curbside, or corridor trees. Yard trees may have greater resource availability, and ability to allocate carbohydrates towards secondary growth. Species-specific form was also underlined by findings, with large live crowns in *Platanus x acerifolia* and *Prunus virginiana*.

Pit cut size had a much smaller influence on mortality and growth measures than was hypothesized. Pit cut size was positively correlated only with percent live crown in trees 2.5 years after planting. Further investigation into pit cut dimension influence on street trees with time would show whether this trend becomes more pronounced in more mature trees as root growth becomes more constricted. It should be noted that this study was conducted on ten commonly planted street tree species, so results for species less well-suited to the urban environment may vary in terms of survival and growth rates. Furthermore, all species sampled (excepting *A. tataricum ssp. ginnala* and *C. canadensis*) have been listed as 'easy to transplant' as bare root trees according to Buckstrup and Bassuk (2009). *C. canadensis* is listed as 'moderately difficult to transplant' as a bare root. This may account for the slightly lower survival rate observed in *C. canadensis* sampled in this study (though that lower survival rate was not statistically significant). Research on less commonly-planted urban tree species should also be pursued in the future.

Other limitations of these findings should also be addressed. Soil type and characteristics were not measured in this study. Planting seasons (fall vs spring) were not standardized across years (in some years, bare root trees were planted only in the spring), and therefore could not be compared statistically over planting seasons. Literature indicates transplanting season as a substantial factor affecting survival (Buckstrup & Bassuk 2000), especially in bare root trees; so it may well be that this additional factor accounts for additional variability in survival and growth rates across species. Lastly, watering regiments could not be evaluated across individual trees, as these varied depending on homeowner involvement. These limitations prevented thorough evaluation of major factors that affect survival and growth of urban street trees. However, the objective of this study was to evaluate the performance of street trees under the highly variable conditions associated with community plantings, and therefore should not negate the findings presented as they relate to large scale community plantings in the mid-Atlantic. Rather, factors like soil type, planting season, and watering regiments and how they affect community-planted street trees should be prioritized in future research within the urban forestry field. Additionally, this study should be replicated in five years to follow growth and mortality on a longer basis, since long-term survival of urban street trees is a major challenge.

MANAGEMENT IMPLICATIONS

Tree-planting campaigns in greater Philadelphia, and other areas with similar planting conditions, can use this study in decision-making when selecting street tree stock and species. This study's primary management implication is that if done correctly (following appropriate transplanting guidelines), bare root tree plantings can be carried out without concern for higher mortality within the first few years of transplanting. This has potentially huge implications not only for community organizations hoping to maximize tree-planting budgets and volunteer involvement, but also for nurseries in the area. This study may help to ameliorate concerns held by local nurseries that bare root trees do not survive as well as B&B trees in the urban environment. Additional follow-up studies should be conducted to see that these results hold true past the first few planting seasons, as it may take ten or so years for stressed trees to exhibit mortality or decreased growth vigor.

Higher DBH, percent canopy cover and percent live crown are useful to think about in terms of maximizing the benefits garnered from planting street trees. For example, air quality filtration and storm water catchment are notably improved in larger trees, with fuller crowns (McPherson et al. 1999). Findings from this study therefore uphold *Platanus x acerifolia* as a highly beneficial street tree. This study indicates that larger trees performed well along heavily trafficked streets, and because high traffic intensity affects survival, a concerted effort should be made to plant either B&B or larger bare root trees along those corridors.

Lastly, this study emphasizes the importance of conducting urban forestry research in street trees planted by community groups. This research model can provide insight into trends for urban tree-planting organizations elsewhere. Accurate, comprehensive record-keeping is highly encouraged in order to support future research. A follow-up study on the same trees measured for this study would generate valuable information about growth and survival over time.

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