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Biological, Social, and Urban Design Factors Affecting Young Street Tree Mortality in New York City

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Abstract

In dense metropolitan areas, there are many factors including traffic congestion, building development and social organizations that may impact the health of street trees. The focus of this study is to better understand how social, biological and urban design factors affect the mortality rates of newly planted street trees. Prior analyses of street trees planted by the New York City Department of Parks & Recreation between 1999 and 2003 (n=45,094) found 91.3% of those trees were alive after two years and 8.7% were either standing dead or missing completely. Using a site assessment tool, a randomly selected sample of 13,405 of these trees was surveyed throughout the City of New York during the summers of 2006 and 2007. Overall, 74.3% of the sample trees were alive when surveyed and the remainder were either standing dead or missing. Results of our initial analyses reveal that highest mortality rates occur within the first few years after planting, and that land use has a significant effect on street tree mortality. Trees planted in one- and two-family residential areas had the highest survival rates (82.7%), while young street trees planted in industrial areas, open space and vacant land had the lowest rates of street tree survival (60.3% -62.9%). Also significant in predicting street tree success and failure are species type, tree pit enhancements, direct tree care/stewardship, and local traffic conditions. These results are intended to inform urban forest managers in making decisions about the best conditions for planting new street trees.

Keywords

Urban forestry; street trees; mortality; stewardship; urban design; planting

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INTRODUCTION

It is understood that the establishment period following planting of an urban street tree is crucial to its survival (Richards 1979; Gilbertson and Bradshaw 1990), yet little is known about the factors or relationships that ultimately contribute to tree mortality or survival. Improving the survival of young street trees can do more to reduce replacement needs than will investments to maintain older trees (Richards 1979). This study of young street trees planted throughout neighborhoods in New York City provides a context in which to understand how biological, social, and urban design factors impact the establishment of new street trees through a multi-disciplinary site assessment framework that examines the conditions of the urban street. In this study, we present our rationale, methods, and descriptive statistics on the subject in an effort to contribute to the literature on street tree health and as a means to inform similar practitioner-based efforts in other urban areas.

One of the fundamental challenges to city managers and civic groups is ensuring the survival of newly-planted street trees in places as dynamic, heterogeneous, and diverse as cities. Population growth, vehicular traffic, poor air quality, and building and sidewalk designs all present challenges to urban street trees, yet trees must reach maturity in order to maximize proven biophysical and social benefits (Dwyer et al. 1992). While there is much research on soil regimes, nursery stock, and species selection, survival rates still vary widely—from 34.7% to 99.7% according to a recent review of the literature (Roman 2006). As cities around the United States increase their investment in tree planting via programs such as MillionTreesNYC, Million Trees Los Angeles, and Keep Indianapolis Beautiful, urban forest managers must be able to ensure young trees' best chance of survival.

Other published work on tree mortality provides insight into factors impacting the life of an urban street tree. One early study analyzes street trees in three Boston neighborhoods that differ both socioeconomically and demographically and reports a 26% mortality rate of 136 trees planted two to four years prior on one commercial street (Foster and Blaine 1978). The authors also observed low rates of vandalism, high rates of automobile damage, and the potential for tree stakes to damage newly-planted trees. Localized effects could also be at play in the findings of an Oakland study that assesses street tree growth and mortality of 480 volunteer-planted trees along a 5.4-mile stretch of one boulevard; after two years, 34% of the trees were dead or removed (Nowak et al. 1990). Although the authors find differences in mortality related to adjacent land uses, it is uncertain if the mortality here is high overall due to conditions local to the boulevard; if the trees were planted incorrectly by the volunteers; or if the trees were too small to withstand minor stresses that may not affect trees of a larger caliper; or some other factor. Another study with a local focus reports on environmental factors influencing 1,000 urban street trees in New York City (Berrang et al. 1985). Because all of the trees in this study are sited directly around electrical power facilities, it is difficult to determine if their observations are a result of this adjacent land use or if they can be applied across the urban landscape. Observational studies such as these give insight into potential factors influencing the survival of newly-planted trees, but have yet to be tested on a city-wide scale. This study examines similarities and differences among a wide range of site conditions and neighborhoods.

The published study with the largest sample size reports on observations of 10,000 newly-planted trees in northern England and finds 9.7% mortality after one year (Gilbertson and Bradshaw 1985). The researchers draw attention to the many factors potentially affecting mortality levels such as stock quality, planting technique, and maintenance regime, but do not attempt to directly link any of these phenomena to tree mortality rates. A similar study tracks four groups of newly-planted trees during their first year in urban Brussels (Impens and Delcarte 1979). The average mortality rate after one year is 11.3%, but detailed information that describes the size, species, or specific location of the trees is not addressed by the study.

A second study about the survival of newly-planted urban trees in Northern England reports on constant, in-situ monitoring of the study trees, which has the potential to provide more detailed information about precisely when and how the tree died (Gilbertson and Bradshaw 1990). The authors found 22.7% mortality after three growing seasons in the inner-city compared with 17% in greater Liverpool. Although the difference is assumed to be linked to the inhospitable environment of the study cohort, vandalism is not a primary cause of tree death in inner city Liverpool. Instead, biological factors such as species tolerance, transplant stress, water stress, and weed competition are deemed most crucial for urban tree establishment (Gilbertson and Bradshaw 1990).

The methods used in urban tree mortality research are broad and varied, making it difficult to compare rates of survival, but several key observations can be gleaned from these prior studies that likely have implications on mortality rates. Vandalism, as measured by the observation of broken branches in the canopy or a broken main stem, is an important factor in the mortality of urban trees (Gilbertson and Bradshaw 1985; Nowak et al. 1990; Pauleit et al. 2002; Roman 2006); adjacent land use can negatively affect street tree populations (Nowak et al. 2004; Roman 2006); and some species of trees fare much better than others as street trees (Gilbertson and Bradshaw 1990; Miller and Miller 1991; Sydnor et al. 1999; Pauleit et al. 2002). Few studies have analyzed the role of physical urban design factors such as traffic volume or the tree's location within the streetscape on mortality rates. Previous studies have not fully investigated the contribution of social or stewardship factors including sociability of the area proximate to the tree (e.g. seating, gardens, front yards) or signs of direct tree care and stewardship (e.g. weeding, mulching, gardening in tree bed), to young street tree success. The goal of this study is twofold, to develop an assessment tool that includes biological, social, and urban design factors and apply it across a wide range of land uses and neighborhood settings to gain insight into the multiple pathways and processes impacting the health of young street trees.

METHODOLOGY

Sampling Plan

The 13,405 trees analyzed in this study were pulled from a larger sample of 45,094 trees using a partial inventory technique based on stratified random sampling (Sun and Bassuk 1991; Jaenson et al. 1992). The sample was stratified by time in-ground and land use in order to get a random and comprehensive sample of trees in each of these groups. At the time of field survey, all trees had been in the ground between 3 and 9 years. For the stratified random sample, the trees planted from spring 1999 to fall 2003 were grouped into three planting periods. The sample was also stratified using aggregated land use classes from the New York City Primary Land Use Tax Lot Output (PLUTO) data set (NYC Department of City Planning 2005); the original land use types were grouped into One & Two Family Residential, Multi-family Residential; Mixed, Commercial and Public Institutions; Industrial, Utility & Parking; and Open Space & Vacant Land. During field surveys we found that the land use information in PLUTO was not up-to-date or accurate. Forty eight percent of the tree planting locations visited had actual land uses that differed from the PLUTO data. Because of issues encountered with the accuracy of the PLUTO database, we present our results using the land use types observed for the tree in the field. We also readjusted our stratified sample to account for the distribution of field-verified land use.

Field Methods

In order to efficiently visit and record data on 13,405 trees across all five boroughs of New York City, a grid map series at roughly 1:10,000 was produced using ArcGIS. A custom data collection form designed in Pendragon Forms allowed survey questions to be loaded on a Palm Pilot for mobile data collection. These field data were directly synchronized into Microsoft Excel. In this study, the data were collected at multiple scales - the tree level, then the building level, and at the block level. In order to facilitate easy repetition of data collection, all variables were optimized for simple field observation and require no laboratory analysis or precise measurements. The data are organized into the three groups of relevant information: biological factors that may affect young street trees, urban design factors, and sociability/stewardship factors. Some of the variables we collected can apply to more than one tier – for example, presence or absence of a tree guard can be both a physical design and a stewardship factor, depending on whether they are routinely installed as part of municipal tree planting.

These methods were based upon social site assessment models used for natural resource management (Freudenburg 1986) with city foresters taking an active role in training and supervising researchers in the field. All fieldwork was conducted by 20 interns hired and trained by the New York City Department of Parks & Recreation (NYC Parks) and the USDA Forest Service Northern Research Station (NRS). Data collection took place over the summers of 2006 and 2007 in hundreds of New York City neighborhoods. Recording the presence or absence of observable phenomena, the team used a combined study approach and developed a data collection framework that resulted in the collection of over forty items of data at the location of each tree. Street tree locations varied widely, from high-rise areas, to low-rise brownstone neighborhoods, to single family structures in suburban settings. For the purposes of this analysis, missing trees were counted as dead, following the precedent of previous studies (Gilbertson and Bradshaw 1990; Miller and Miller 1991; Pauleit et al. 2002).

Biological Factors

Table 1 lists the biological factors that may have an effect on the success and failure of young street trees. If the tree cannot obtain its minimum biological requirements, it will not thrive, regardless of the urban context in which it was planted. This first layer of data collection provides important clues to the overall health of the tree. The data items listed below may indicate tree health, growth rates, damage and decay, or soil health or identify biological stressors affecting establishment. They are most useful in determining the overall health of a living street tree; if a tree is dead or missing from where it was planted, it is not possible to collect many of these data items. In light of the developing awareness in an objective methodology in appraising tree health (Bond 2010) and linking urban tree evaluations into the forest inventory analysis (FIA) through the ongoing International Union of Forest Research Organizations (IUFRO) Urban Forestry Data Standards effort, our approach is certainly subject to change as methods become standardized. Soil compaction was measured by applying pressure to the soil with a screwdriver tip; if the screwdriver easily entered the soil, the soil was said to be uncompacted.

Data Item	Response type
water pooling in tree pit	presence/absence
soil compaction	presence/absence
animal waste	presence/absence
sucker growth	presence/absence
evidence of leaf chlorosis	presence/absence
evidence of insect damage	presence/absence
evidence of dieback	presence/absence
guiding wires girdling tree	presence/absence
guard/grate girdling tree	presence/absence
broken branches	presence/absence
unnatural lean	presence/absence
trunk wound	presence/absence
pit soil level	categorical
planting depth	categorical
species	categorical
diameter at breast height	categorical

Table 1. Biological factors potentially affecting young street trees in NYC.

Sociability/stewardship Factors

The social factors which potentially influence young street tree mortality are listed in Table 2. Our data collection methodology includes recording direct signs of tree stewardship at the level of each tree (i.e. planting in tree pits, adding mulch), which are indicators that individuals or groups are caring for a tree. At the building and neighborhood level, we observed off-tree signs of stewardship such as the presence of home decorations, front yard gardens, and murals. These factors are considered "cues to care" that provide evidence that individual and/or community-level stewardship is taking place (Nassauer 1995). A well-cared for urban street tree and pit area is considered to be a sign of active local stewardship. We also collected data on practices that could have conflicting effects on a tree's health; for example, tree lights could retard tree growth by strangling the tree, but also could draw attention to the presence of a tree thereby triggering stewardship.

Table 2. Sociability/stewardship factors potentially affecting street trees in NYC

	Data Item	Response type
Tree/tree pit level	pit off curb (at least 12" away)	presence/absence
	curb intact	presence/absence
	tree grate	presence/absence
	block paving in tree pit	presence/absence
	tree guard*	presence/absence
	tree pit type	categorical
	presence/condition of block pavers	presence/absence; categorical
	tree pit size (square feet)	number
Building level	ground floor door	presence/absence
	awning on adjacent building	presence/absence
	scaffolding on adjacent building	presence/absence
	number of building stories	number
	land use classification	categorical
Streetscape level	median strip on street	presence/absence
	on-street parking	presence/absence
	bus stop nearby (< 5')	presence/absence
	driveway nearby (< 5')	presence/absence
	bike rack nearby	presence/absence
	sidewalk condition	categorical
	traffic volume	categorical
	tree placement in slope	categorical
	sidewalk width	number
	number of traffic lanes	number
	% pavement within drip line	number

* the variable presence of a tree guard can also apply to the sociability / stewardship category

Data were collected about neighborhood sociability to ascertain whether the tree is incorporated into active street life. For example, benches are built into tree pits, seating is arranged under trees' canopies, or play equipment is often proximate to the tree. At the neighborhood level, signs of sociability indicate more "eyes upon the street" (Jacobs 1961) or the orientation of urban space to enhance community awareness and engagement. This sociability can influence tree survival via multiple pathways, such as through prevention of tree vandalism. Moreover, these signs of sociability can be considered indicators of community street life and may relate to stewardship over time. Given a study that collects observational data at one moment in time, it is important to use these proximate measures of social life as indicators that stewardship may have occurred historically. Areas of community street activity include facilities such as places of worship and schools, which are known to sponsor local stewardship activities. Drawing upon the work of Wilson and Kelling (1982), negative indicators were also observed, such as the presence of broken windows, vacant lots and buildings, and (non-mural) graffiti. Known as the "broken-window theory," the presence of vacant buildings and lots strewn with garbage tend to attract more visible disorder on and around neighborhood streets. Researchers documented the presence and absence of disorder around each street tree.

One difference in this section of data is that it is possible for some items to have two response types. For example, if a front yard is present (presence/absence), it may be valuable to note what type of yard (categorical; i.e. paved, grass). The same can be said for gardens, building security, murals, and public facilities. Collecting this second tier of data gives researchers the ability to strengthen an analysis of the dynamic social factors affecting street tree mortality.

Urban Design Factors

This study suggests that physical urban design factors influence the success of young street trees; this category includes information at three different levels: tree/tree pit, building, and streetscape (listed in Table 3). The factors measured at the level of the tree and tree pit itself are more directly connected with the tree success or failure, while others, such as the presence of a bike rack nearby and the width of the sidewalk, are more exploratory in nature and may only provide insights into potential influences. All factors comprise the physical urban context into which the tree has been planted. They are the result of urban design, zoning practices, or unplanned piecemeal development and they affect the flow of pedestrians, bicycles, and motor vehicles through the environment surrounding the tree. At the same time, these factors also affect airflow, sunlight, and wind speed that can impact the growing conditions of trees (McGrath et al. 2007).

Most of these data are collected in the presence/absence format, but some other responses are categorical in nature. For example, pit type could be characterized as a sidewalk cutout or tree lawn; block paving status can range from good to raised or altogether missing; traffic volume could be low, medium, or high; and sidewalk condition could be good, cracked, poor condition, etc.

Table 3. Urban design factors potentially affecting street trees in NYC.

	Data Item	Response type
Tree/tree pit level	tree care-related signage	presence/absence
	stakes present, but no wires	presence/absence
	walled tree well	presence/absence
	tree pit plantings	presence/absence
	tree guard*	presence/absence
	tree pit paved to tree trunk	presence/absence
	mulch in tree pit	presence/absence
	gravel in tree pit	presence/absence
	bench near/around pit	presence/absence
	bird feeder in tree or tree pit	presence/absence
	irrigation bag	presence/absence
	evidence of weeding of tree pit	presence/absence
	litter in tree pit	presence/absence
	evidence of pruning	presence/absence
	debris in canopy of tree	presence/absence
	electrical outlet in tree pit	presence/absence
	lights in or around tree	presence/absence
Building level	seating area associated with building	presence/absence
	play equipment in yard of building	presence/absence
	flag on building	presence/absence
	decorations on door of building	presence/absence
	flower planters	presence/absence
	building has front yard (type)	presence/absence; categorical
	building has garden (type)	presence/absence; categorical
	building security (type)	presence/absence; categorical
Streetscape	graffiti on adjacent buildings	presence/absence
	broken/missing windows	presence/absence
	mural on adjacent building (type)	presence/absence; categorical
	public facilities on block (type)	presence/absence; categorical
	block-level vacancies	categorical

* the variable presence of a tree guard can also apply to the urban design category

FINDINGS FROM DESCRIPTIVE STATISTICS

The following descriptive statistical analyses examine the effects of time since planting, land use, and selected biological, social, and urban design factors on urban young street tree mortality. Contingency tables and chi-square analyses were used to assess the effect of each variable, with the simplifying assumption that variables are independent and do not interact with each other. Although in reality our dataset contains many nested, correlated and confounding variables, as practitioners we are interested in evaluating the contributions of each variable from a management perspective and for refining planting policies and site selection procedures. Formal analysis incorporating combinations of and interactions between these factors is ongoing and will be treated in future manuscripts.

Time Since Planting

As previously mentioned, it is widely assumed in the literature that there is some time after planting in which the mortality rates of street tree populations stabilize. In order to determine if and possibly when this is occurring in New York City, we performed a preliminary analysis to determine if time since planting is related to street tree mortality. Our data do in fact suggest this type of trend, as the rate of tree loss for trees inspected 6-8 and 8-9 years after planting are nearly identical. Contingency table analysis found years since planting to have a significant influence on tree survival (Pearson's X^2=24.65, df=2, p<0.001). The decrease in survival rate between the first two time periods is the most marked, which reflects the immediate difficulty that young street trees face after being transplanted into the urban landscape. The two-year survival rate for these young street trees was calculated using operational contract data.

Table 4. Young street tree survival by years since planting.

Years since planting	Alive		Not Alive		Total sample size
	No. of trees	%	No. of trees	%	
*2 years after planting**	*41,169*	*91.3%*	*3,925*	*8.7%*	*45,094*
3-6 years after planting	1,891	78.2%	526	21.8%	2,417
6-8 years after planting	3,690	73.0%	1,363	27.0%	5,053
8-9 years after planting	4,381	73.8%	1,554	26.2%	5,935
Total	9,962	74.3%	3,443	25.7%	13,405

* 2 year survival rate is based on contractual guarantee inspection data and is only provided for reference.

Land Use

Because previous research highlighted the importance of adjacent land use in young street tree mortality, we performed an additional analysis examining this phenomenon in New York City. For this analysis, observed land uses were grouped into five categories: one/two family residential; multi-family residential; mixed, commercial, and public institutions; industrial, utility, and parking; and open space/vacant land.

In New York City, young street trees in one and two family residential areas have the highest survival rate (Table 5), while industrial areas and open space/vacant land had the lowest rates of street tree survival (ranging from 60.3% to 62.9%). Pearson's chi-square test found land use group to have a significant influence on tree survival (X^2=455.432, df=4,p<0.001). This data suggests that neighboring human activities do have an effect on young street tree survival and our results are similar to those found in other studies (e.g. Nowak et al. 1990; Nowak et al. 2004).

Table 5. Young street tree survival by land use group

Land Use Group	Alive		Not Alive		Total sample size
	No. of trees	%	No. of trees	%	
One/Two Family Residential	4,821	82.7%	1,009	17.3%	5,830
Multi-Family Residential	2,232	72.3%	856	27.7%	3,088
Mixed, Commercial and Public Institutions	388	62.9%	229	37.1%	617
Industrial, Utility and Parking	1,903	66.2%	972	33.8%	2,875
Open Space and Vacant Land	545	60.3%	359	39.7%	904
Total	9,889	74.3%	3,425	25.7%	13,314

Biological, Sociability/Stewardship, And Urban Design Factors

As mentioned previously, we looked at how individual or groups of variables affected survival rates through a series of two-way contingency tables. The results presented here begin to lay out the type of processes at work in the urban forest. Our initial results are summarized in Tables 6 through 8.

Biological Factors

Previous research has shown that species does matter with respect to the mortality of urban street trees, and this study reinforces that idea that there are significant differences in survival rates between species (Table 6). Of the trees planted that comprise greater than one percent of the total, callery pear (*Pyrus calleryana*) is the most successful. Although the entire suite of species that NYC Parks plants are known to be tolerant of urban conditions, some have higher tolerances than others. Anecdotally, one of the most common stressors that an urban street tree faces believed to face is deposition of animal waste in the tree pit, yet in our results the presence of scat was unexpectedly associated with higher survival, underscoring how these simplistic analyses based on one-time observations should be interpreted with caution.

Table 6. Young street tree survival and select contributing biological factors

Independent Variable	Alive	Not Alive	% Survival	X^2 value	*df*	*p*-value
Tree species (>1% of all planted trees)						
Pyrus calleryana	1,863	381	83.0%	178.611	18	<0.001
Gleditsia triacanthos	1,274	332	79.3%			
Tilia cordata	617	168	78.6%			
Quercus palustris	639	177	78.3%			
Zelkova serrata	537	149	78.3%			
Tilia tomentosa	143	41	77.7%			
Quercus rubra	145	42	77.5%			
Fraxinus pennsylvanica	268	85	75.9%			
Prunus cerasifera (Purpleleaf plum)	113	37	75.3%			
Acer rubrum	245	81	75.2%			
Prunus serotina (Kwanzan cherry)	266	88	75.1%			
Japanese pagoda tree	310	109	74.0%			
Prunus virginiana (Shubert cherry)	452	184	71.1%			
Tilia tomentosa	477	204	70.0%			
Acer campestre	170	73	70.0%			
Liquidambar styraciflua	171	77	69.0%			
Prunus spp.	210	107	66.2%			
Gingko biloba	370	189	66.2%			
Plantanus acerifolia	112	68	62.2%			
Presence of animal scat in tree pit or near tree						
Present	627	139	81.9%	24.19	1	<0.001
Not present	9,335	3,301	73.9%			

Sociability/ Stewardship Factors

These variables can help to elucidate the level of engagement that an individual or local community group has with trees in the urban landscape. In terms of sociability, trees with adjacent seating or an adjacent front yard were all more likely to survive in the urban environment (Table 7). Our data also show that a tree is more likely to survive if the building in front of which it is planted has a garden or planters/window boxes. If a garden is present, though, the type or visible level of garden care does not have any bearing on young street tree survival. Our interpretation of these results is that either (1) the mere presence of adjacent stewardship of other natural amenities (lawns, gardens) is adequate to engage local residents in the care of maintenance of their street trees; or (2) presence of signs of off-tree stewardship may be an indicator of on-tree stewardship that has occurred historically.

A stewardship index was constructed from factors that directly affect the area in and around the tree pit, including: presence of signage, plantings in pits, mulch, and evidence of weeding. This stewardship index is significantly correlated with tree survival. Planting in the tree pit was the most often observed stewardship behavior (1,039 trees), followed by mulch (962 trees), weeding (317 trees), and signage (232 trees). Evidence of active, direct tree stewardship is a positive indicator or predictor of street tree survival.

Table 7. Young street tree survival and select sociability/stewardship factors

Independent Variable	Alive	Not Alive	% Survival	X^2 value	*df*	*p*-value
Presence of seating near tree						
With seating	694	135	83.7%	28.44	1	<0.001
No seating	8,719	2,824	75.5%			
Presence of front yard near tree						
Yard present	5,246	1,170	81.8%	236.40	1	<0.001
No yard	4,167	1,789	70.0%			
Presence of a garden near tree						
Garden present	3,266	607	84.3%	210.59	1	<0.001
No garden	6,147	2,352	72.3%			
Garden type (if present)						
Natural	3,345	623	84.3%	1.04	1	0.308
Plastic	12	4	75.0%			
Garden care (if present)						
Good	3,201	580	84.7%	4.40	1	0.036
Poor	155	41	79.1%			
Presence of planters or window boxes						
Present	1,623	244	86.9%	142.19	1	<0.001
Not present	7,790	2,715	74.2%			
Presence of stewardship signs*						
4 signs	20	0	100.0%			
3 signs	112	3	97.4%			
2 signs	328	11	96.8%	412.36	4	<0.001
1 sign	1,325	122	91.6%			
None	8,177	3,307	71.2%			

* signs of stewardship include presence of signage on or near the tree; plantings in street tree pits; mulch placed in pit; and evidence of weeding

Urban Design Factors

Our research indicates that the urban context into which street trees are planted is an important factor in their success and failure (Table 8). Street trees have a greater chance at survival when planted in lawn strips rather than sidewalk cutouts. In our data the size of sidewalk cut out pits does not have a significant influence on the survival of young street trees. Given that larger tree pits yield greater volumes of uncompacted soil for the roots to grow and greater surface area for water to enter the tree pit, one would expect that street trees would fare much better in large tree pits. One possible interpretation of this result is that tree pit size is not as important in the early life of a young street tree, but will become a limiting factor as the tree begins to grow out of its spot in the sidewalk.

Installing a perimeter tree pit guard prevents vandalism and vehicular damage, prevents animal waste deposition, and is visually representative of a tree that is being cared for by someone. It is likely because of a combination these factors that trees in pits with perimeter guards have a greater chance at success than trees in unprotected pits. The presence/absence of tree guards can also be considered as a sociability/stewardship factor, not just a physical design variable. This is because while the mechanism for reduced mortality for street trees with tree guards are physical (by preventing soil compaction or inadvertent contact to the tree by cars), tree guards are typically installed privately and not by NYC Parks, and therefore also represents an act of stewardship. This may vary in other urban areas.

Table 8. Young street tree survival and select urban design factors

Independent Variable		Alive	Not Alive	% Survival	X^2 value	*df*	*p*-value
Pit type							
	Lawn	3,548	992	78.1%			
	Sidewalk	5,917	2,196	72.9%	58.43	2	<0.001
	Continuous	397	193	67.3%			
Presence of perimeter tree guard							
	With guard	1,121	83	93.1%	116.42	1	<0.001
	No guard	8,841	2,150	80.4%			
Tree Pit Size (sidewalk trees only)							
	55+ sq. ft	42	7	85.7%			
	45 to <55 sq. ft	160	29	84.7%			
	15 to <25 sq. ft	3,066	570	84.3%			
	05 to <15 sq. ft	336	70	82.8%	7.48	5	0.188
	35 to <45 sq. ft	266	58	82.1%			
	25 to <35 sq. ft	2,007	446	81.8%			
Tree location							
	Located on curb	9,413	2,959	76.1%	262.78	1	<0.001
	Located on median	549	484	53.1%			
Observed traffic volume							
	Light	6,785	1,842	78.6%			
	Moderate	2,224	1,026	68.4%	280.49	2	<0.001
	Heavy	806	530	60.3%			

The physical location of the tree within the urban streetscape is also significant. Trees planted in street medians have a poor chance at survival when compared to trees planted at the curbside. Traffic volume also has an effect on young street tree mortality, with trees in low traffic areas faring better than those planted in moderate or high traffic thoroughfares.

Another finding not explored here but worthy of discussion is that of missing trees. Of the over 13,000 trees visited in this study, nearly twenty percent of them were not present from their planted location while only six percent were standing dead. Although these two groups were collapsed for the purpose of discussing overall mortality, their large number warranted further analysis. We looked at whether or not the populations of standing and dead trees were significantly different with respect to some of our variables and found the following: trash in the tree pit is more common with dead trees than missing; missing trees are more likely when a sidewalk is less than five feet wide; trees are more likely to be missing than standing dead in a lawn strip than any other pit type. Missing trees are not statistically linked to the following: street slope, presence of street parking, sidewalk condition, or traffic volume. Urban forest managers in New York City agree that there are several possibilities of the fate of those missing trees: vandalism, vehicular collision, or tree removal without subsequent replacement but, regardless of the pathway, these missing trees are dead.

DISCUSSION

The highly local and specific nature of other published street tree mortality studies inspired this study to examine which factors may affect mortality in New York City. New York City's street tree planting mortality rates are lower than those published for other cities (see Figure 1). Some possible reasons for this distinction are: trees planted in New York City are planted by experienced contractors working under the supervision of trained foresters, while other tree planting programs frequently use volunteers with little or no planting experience (e.g. Nowak et al. 1990) or aren't working with strict contract specifications; and larger caliper trees (2.5-3") are planted in New York City, while smaller stock was planted in other locations (Nowak et al. 1990; Gilbertson and Bradshaw 1990).

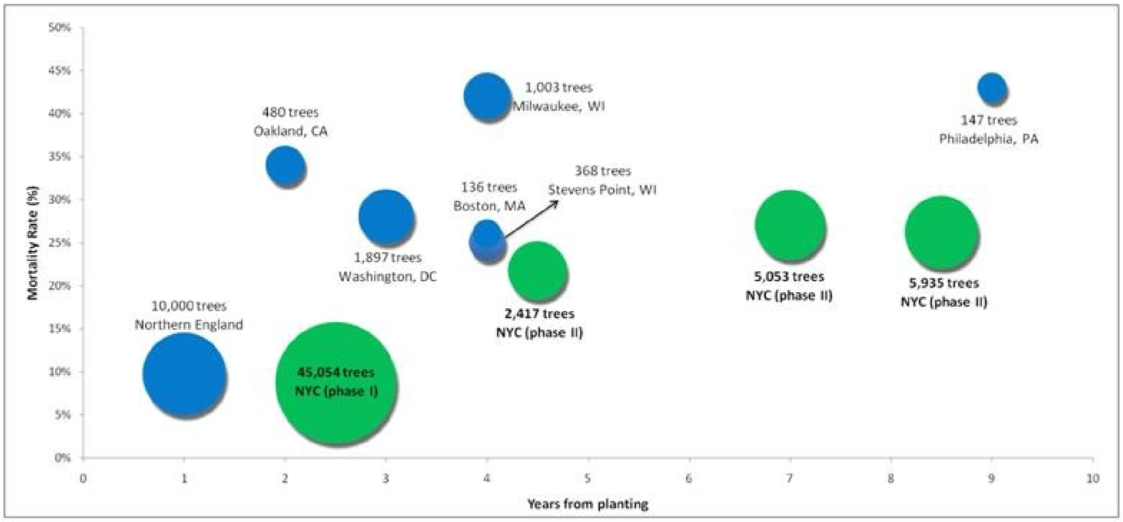

Figure 1. Other newly-planted street tree mortality studies (Aggregated from Roman, 2006), including the results from New York City.

In this manuscript we present a socio-ecological-design framework for future young street tree mortality research, with the intention of facilitating the replication of this type of study in other urban areas. Based on this work we have developed a Site Assessment Tools Description (available at http://www.nyc.gov/parks/ystm), a step-by-step guide for city managers and researchers on how to assess early street tree survival and mortality. Our hope is that other cities will replicate at least part of this study and over time build up data sets which will allow for cross-city comparisons.

These preliminary results provide an initial understanding of some of the factors that are important in the success and failure of young street trees planted in New York City, and provides direct feedback that managers can use to refine NYC Parks' planting practices and policies. Variation in planting survival rates by species has important implications for the long-term dynamics of New York City's street tree population. In terms of a tree's urban design and neighborhood context, this study confirms the observations of many urban foresters that curbside trees planted in lawn strips and in low-vehicular traffic areas are more likely to survive. This study also quantifies the disproportionately high mortality rates of trees that are planted in street medians compared to trees located on the curb. Based on this result, NYC Parks has already changed their planting policies for median trees, and is planting trees in only the widest street medians, where adverse factors like collisions, salt exposure, and minimal soil volume are less likely. Similarly, our observation of the effectiveness of tree guards in protecting young street trees is corroborated by the experiences of NYC's practicing urban foresters. Such demonstrated effectiveness may justify the expense of securing street tree guards at the time of planting.

Our results suggest that civic stewardship and neighborhood sociability is a critical complement to municipal management and investment in new street tree plantings. However, we have only started to explore how the data we collected could be used to develop more comprehensive indices representing stewardship or neighborhood sociability. The mechanisms that relate the signs of neighborhood sociability – or even of other non-tree signs of stewardship – to improved tree survival cannot be revealed through this study. While we hypothesize that active presence of residents on the street can serve to help ensure that vandalism of trees does not occur, other qualitative methods such as interviews and repeated social observational studies would be required to evaluate this hypothesis. Moreover, this study cannot determine directionality of observed relationships. For example, the presence of stewardship activities in nearby lawns and gardens may either inspire the care of street trees, or the presence of the new tree itself may encourage other acts of local stewardship along the street.

The initial results presented here offer an important basis for urban planning programs as well as for researchers interested in further exploring factors affecting tree canopy restoration efforts in the urban environment. This is just the beginning of what we will be able to learn from the data we collected using this integrated socio-ecological framework. The current MillionTreesNYC campaign aims to plant street trees in every available and feasible sidewalk location across a wide range of site types in New York City, but at other times and in other places, difficult choices must be made in terms of street tree planting locations. Taken together, these biological, social, and urban design factors can be weighed by urban foresters when designing and selecting the locations for street tree plantings and developing community stewardship programs. Further analysis of our data set will assess the relative importance of these and the remaining data variables that were collected during the field survey of these trees. As cities such as New York continue to develop and implement comprehensive tree planting campaigns, these findings provide insight in the field of natural resource management on the relationship between locations and vulnerability; stewardship and sustainability.

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