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Trends in street tree survival, Philadelphia, PA

Lara Roman
University of Pennsylvania

Presented to the Faculties of the University of Pennsylvania in Partial Fulfillment of the Requirements for the Degree of Master of Environmental Studies 2006.
Advisor: Professor Fred Scatena

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Street tree survival in Philadelphia was assessed for comparison to published literature. Select street trees species planted in the years 1995-2003 in North Philadelphia were surveyed to assess survival rates, and to identify trends in mortality and tree size. These trees were planted by the Philadelphia Green program of the Pennsylvania Horticultural Society. The overall survival of street trees 8-10 years after planting is 57%. Planting year specific survival rates for 8, 9, and 10 years after planting are 44%, 58%, and 63%, respectively. These values are comparable to those predicted by the analysis of previously published studies. Survival of trees 8-10 years after planting varies significantly by species, zip code, and U.S. Census indicators. Current tree size varied significantly by exposed soil area and sidewalk condition. One select species, hedge maple, was chosen for additional study to assess temporal trends in street tree mortality. Hedge maples 2-10 years after planting in North Philadelphia were surveyed. Time period since planting was significantly correlated to survival (estimated $r^2 = 0.75$, estimated annual survival 95.5%). Conclusions about the causes of mortality in the study area are suggestive, but limited. Power analysis of tree diameter and site vehicular disturbance indicates that a sample size upwards of 1000 would be needed to detect difference. Recommendations are made for future data collection of street tree studies in Philadelphia and elsewhere.

Disciplines
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Introduction

Urban forests may be defined as "the trees and forests found in urbanized settings" (Clark et al. 2004). The urban forest encompasses parks and other open space, as well as street trees and trees on private land. Urban forests have a multitude of environmental benefits, including improved air and water quality, changes to urban hydrology, mitigation of the urban heat island, noise reduction, and ecological stability (Dwyer et al. 1992). Additionally, urban forests provide energy savings, increase real estate values, and improve quality of life. Urban forests provide quality of life and societal benefits by promoting strong community identities and cohesive neighborhoods, providing opportunities for recreation, making people healthier through physical exercise and psychological well-being, providing aesthetically pleasing surroundings, combating suburban sprawl, attracting and maintaining economic development, and increasing and stabilizing real estate values (Dwyer et al. 1992, Martin et al. 1989, Sherer 2003, TPL 2005, Wachter 2004). The costs of the urban forest include planting and maintenance costs for residents, governments, and community groups, conflicts with utility wires and sidewalks, and fear of the forest (D'Amato et al. 2001, Dwyer et al. 1991, Templeton and Goldman 1996).

The Philadelphia Green program of the Pennsylvania Horticultural Society (PHS) supports the development and care of community gardens, neighborhood parks, and public green spaces. One of the main areas of emphasis for this program is the planting and maintenance of street trees. Philadelphia Green has maintained a database of their street tree planting projects since 1992. In order to measure the success of street tree planting projects, and to strategize for the coming years, the author has analyzed and compared Philadelphia Green planting records with current street tree conditions.

This study addresses trends in street tree mortality by analyzing the available literature and by surveying street trees 2-10 years after planting in Philadelphia. The topics investigated in this project are: 1) trends in street tree mortality rates and variation in annual mortality over time; 2) relationship between site conditions and mortality, and size of trees; and 3) determining the sample size and data records required to determine mortality, causes of decline, and growth rates in future studies.

Street tree lifespans and survival rates

The sustainable management of urban forests is an ongoing challenge. Street trees in particular can be costly to plant and maintain, and have notoriously high mortality rates. Many authors have asserted that the high mortality and short lifespans of urban trees are due to harsh urban conditions. Previous research has addressed longevity, mortality rates, and causes of death and disease. However, statistically analyzed and scientifically reported data on these topics are lacking. There is an oft-heard claim that street trees live on average only seven to ten years (Moll 1989, NJTF 2005, Taylor 1993). However, this claim is unsubstantiated by most data (Foster and Blaine 1978, Nowak et al. 2004, Polanin 1991, Richards 1979). Describing the harsh conditions of trees planted with the Philadelphia Green program, Taylor (1993) claims that, "[for] every tree planted in this city, seven die". The New Jersey Tree Foundation, in explaining the need for street tree planting programs, states that, "[trees] in our cities and towns are only averaging a lifespan of seven years" (NJTF 2005). Moll (1989) reports that downtown trees have an average lifespan of 7 years, compared to 32 years for suburban trees. No location is specified as the basis for these values. Skiera and Moll (1992) estimated average lifespan of trees in different land uses based on surveys of managers in 20 United States cities. They report an average lifespan of 13 years for downtown street trees, compared with 37 years for residential sites, 60 years for the best city sites, and 150 years for rural sites. The figures from these publications are not supported by clearly defined methods and statistical analysis.

Trees in Boston, MA sidewalks were estimated to have an average lifespan of about 10 years (Foster and Blaine 1978), although the procedure to estimate lifespan from Boston mortality data is unclear. Nowak et al. (2004) estimate the average lifespan for urban trees in Baltimore, MD to be 15 years, with 30% of trees living past 15 years. These estimates are based on variable mortality rates for different tree size classes. The authors graphically demonstrate that the "average lifespan of trees drops significantly as annual mortality rates increase, particularly over the first 10-20 percent" (Nowak et al. 2004). In Jersey City, NJ, Polanin (1991) found that Norway maple (*Acer platanoides*) had an average site age of 48 years, and London plane (*Platanus acerifolia*) had an average age of 39 years. Based on complaint and removal records, Polanin (1991) explains that Norway maple was removed most often because it had "succumb to urban stress", or was in poor condition. London plane was removed most often due to sidewalk upheaval. Richards (1979) modeled losses for four street tree species in Syracuse, NY to determine average years of service per tree as follows: honey locust (*Gleditsia triacanthos*) 30 years, Norway maple 55 years, sugar maple (*Acer saccharum*) 57 years, and silver maple (*Acer saccharinum*) 73 years. The Polanin (1991) and Richards (1979) studies report the age of trees existing several decades after planting, without including initial mortality.

Although different species and different locations may be expected to have a range of street tree lifespans, this enormous range of reported street tree lifespans speaks more to the variety of methods used to assess mortality. Furthermore, even if we assume that street trees have relatively low average lifespans, the average lifespan may not be the best indicator of street tree survival and replacement needs. Annual mortality of a planting cohort may not remain constant year after year. It has been suggested that the first four years after planting, referred to as the establishment period, have the highest annual mortality rates (Richards 1979, Miller and Miller 1991).

Nowak et al. (2004) found that trees with smaller diameters have significantly higher mortality than larger trees. The authors suggest that reducing mortality in smaller trees will greatly increase average lifespan. A comparison of annual mortality rates of newly planted trees one year after planting (6.5-19.7% dead) vs. mortality rates of already existing trees (1.9-3.3% dead, unspecified number of years since planting) in Brussels, Belgium (Impens and Delcarte 1979) also supports the hypothesis that younger trees have higher mortality rates than established trees. Young trees may be unable to tolerate environmental stresses and minor human disturbances (Richards 1979). Additionally, the shock of transplantation and improper planting techniques may lead to high first year mortality (Ferrini et al. 2000). Quality of tree stock at planting and post-planting maintenance are important to the survival and growth of amenity trees (Insley 1980). Land use and socioeconomic factors may also play an important role in street tree survival during the establishment period (Nowak et al. 1990, Nowak et al. 2004, Skiera and Moll 1992).

A review of available street tree survival data from thirteen studies from temperate regions (Table 1) illustrates that reported survival rates vary greatly. However, these studies also varied greatly in their methodologies, especially in what types of trees were measured and over what length of time. Trees described as street, sidewalk, or streetside were measured exclusively in most studies. In contrast, Nowak et al. (2004) measured a variety of urban locations, including urban areas with street trees, and SMUD (2003) measured shade trees planted in residential areas. Some studies followed a cohort of newly planted trees (Foster and Blaine 1978 [Boylston St. only], Gerhold et al. 1994, Gilbertson and Bradshaw 1985, Impens and Delcarte 1979, Nowak et al. 1990, Sklar and Ames 1985, SMUD 2003, Snydor et al. 1999). Some surveyed annual mortality rates in already established street trees (Impens and Delcarts 1979, Nowak et al. 2004). Others relied on historical records which were sometimes compared to recent surveys (Dawson and Khawaja 1985, Foster and Blaine 1978, Hauer et al. 1994, Miller and Miller 1991, Richards 1979, Snydor et al. 1999).

Within these broad methodology categories, other factors also render comparison between studies challenging. For example, Sklar and Ames (1985) report survival rates of street trees planted beginning in 1978 through the early 1980s, including replacement trees. This procedure does not represent a true cohort study that follows a group planted in the same year. Another study with urban mortality data was not included because urban trees were grouped with trees in rural and agricultural areas (Ip 1996).

Causes of street tree mortality and decline

The conceptual framework for tree decline of Sinclair and Hudler (1988) provides a starting point for the discussion of causes of street tree mortality. Decline is defined as "premature progressive loss of health", and is distinguished from the normal occurrence of senescence by premature debilitation. The authors suggest four concepts for tree decline: 1) chronic irritation by a single agent, 2) damage by secondary agent after injurious event, 3) chronic irritation by one or more agents that reduce tolerance of other agents that then lead to decline, and 4) synchronous cohort senescence, which is an extension of the third concept. A plethora of causes for street tree death and disease have been proposed, and the above mentioned framework explains how the agents may complement and supplement one another.

Location	Study groups (sample size)		Survival rate (%, overall survival over time period)	Time period (yrs)	Estimated annual survival (%)	Source and Methods
Oakland, CA	all species				90.29	Sklar & Ames (1985)
	w/ community participation	(1500)	60-70	~5 (planted 1978-83)		
	w/out community participation	(2000)	0.5	~5-10 yrs (planted late 1960s/ early 70s -78)	34.66	ST, C
Oakland, CA	all species	(480)	66	2 (1985-87)	81.24	Nowak et al. (1990) ST, C
Sacremento, CA	all species	(280-602)	71-97	0.25-0.58 (various times, 1996-2003)	44.24-88.53	SMUD (2003) C (see appendix A)
Urbana, IL	all species	(1768)	4.4	50 (1932-82)	93.94	Dawson & Khawaja (1985) ST, H, E
Boston, MA						Foster & Blaine (1978)
Beacon Hill, existing trees	all species	(215)	39	10 (1966-76)	91.01	ST, H, E
Beacon St.	linden	(350)	23	66 (1910-76)	97.80	ST, H, C
Boylston St.	all species	(136)	74	2-4 (1972 & 74-76)	86.02	ST, C
Baltimore, MD				2 (1999-2001)		Nowak et al. (2004)
different areas	transportation	(33)	79.8	(avg. annual survival*)	79.80	
	commercial/indust.	(15)	89.4		89.40	
	high dens. residential	(77)	94		94.00	
	low-med. dens. resid.	(136)	97.8		97.80	E
Syracuse, NY	Norway maple	(unk.)	75	27 (1951-78)	98.94	Richards (1979)
	silver maple		75		98.94	
	sugar maple		47		97.24	
	honeylocust		30		95.64	ST, H, E
OH						Snydor et al. (1999)**
Cleveland	sweetgum	(68)	64.7	45 (1952-97)	99.04	
Cleveland	sycamore maple	(65)	29.2	42 (1955-97)	97.11	
Cleveland Area	Japanese cherry	(50)	0	41 (1956-97)	-	
Cleveland Area	Euro. white birch	(53)	0	40 (1957-97)	-	
Cleveland	red maple	(57)	87.7	39 (1958-97)	99.66	
Cleveland Area	Wash. hawthorne	(50)	2.0	38 (1959-97)	90.22	
Columbus	Norway maple	(84)	46.4	38 (1959-97)	98.00	
Toledo	Norway maple	(80)	56.3	34 (1963-97)	98.32	
Toledo	Norway maple	(71)	15.5	32 (1965-97)	94.34	

Cleveland Area	honeylocust	(76)	92.1	30 (1967-97)	99.73	ST, H, C
PA & MD small towns	crabapple spp.	(unk.)	94-100	3 (planted 1987-92)	97.96	Gerhold et al. (1994) ST, C
Milwaukee, WI	all species	(1,003)	58.8	4-6 (1980/82-86)	87.57	Miller & Miller (1991)
Waukesha, WI		(677)	76.5		93.52	
Stevens Point, WI		(368)	74.9	4-9 yrs (1975/82-86)	93.03	ST, H
Milwaukee, WI	all species			10 yrs (1979-89)		Hauer et al. (1994)
	damaged by constr.	(432)	77.3		97.46	
	undamaged	(413)	81.4		97.96	ST, H
Brussels,	all species	(2,300)	93.5	1 yr (1973-4)	93.50	Impens & Delcarte
Belgium		(3,710)	89.7	(1974-5)	89.70	(1979)
		(3,148)	80.3	(1975-6)	80.30	
		(2,463)	91.3	(1976-7)	91.30	ST, H
11 cities in Northern England	all species and towns	(10,000)	90.3	1 yr (1982-83)	90.30	Gilbertson & Bradshaw (1985) ST, C

Table 1. Summary of street tree survival rates from available literature. Only studies that report cumulative mortality or survival rates and which specify the time period were included. Locations are in temperate climates. Time period begins with year(s) planted or initially surveyed. Method abbreviations indicate: ST measured only street trees, C followed cohort of newly planted trees, E measured mortality of already established trees, and H compared historical records to recent surveys. See methods for annual survival estimation procedures. *For Nowak et al. (2004), time period entered as 1 in statistical analysis. ** For Snydor et al. (1999), only planting cohorts with ≥ 50 trees were included.

Proposed causes of mortality and decline in street trees are: 1) poor soil conditions due to a) alkalinity, b) toxics and pollutants, c) high temperature, d) lack of physical space in soil pit, and e) compaction of soil which leads to f) nutrient stress, g) lower oxygen diffusion rate, and h) water stress; 2) poor atmospheric conditions due to a) high temperature, b) toxics and pollutants, and c) high potential evapotranspiration; 3) large-scale natural disturbances such as a) hurricanes, b) ice storms, and c) invasive pests; and 4) direct and current human actions such as a) vandalism, b) construction and demolition, c) sidewalk conflicts, d) utility wire conflicts, e) lack of maintenance, and f) inadequate transplanting techniques or nursery care. Discerning the relative importance of each of these twenty agents, and possibly even more factors, is an ongoing challenge. Many of these agents are related and the contribution of each agent likely varies by species, region, and site conditions. Some authors have attempted to estimate the relative contribution of a particular agent using anecdotal observations. For example, Patterson et al. (1980) propose that 80% of all problems with urban vegetation can be attributed to soil conditions. While the authors comprehensively explain the chemical and physical characteristics of urban soils that cause stressful environments, there was no statistical analysis to support the 80% claim. Two of the broad causes of street tree mortality and decline, soil conditions and direct human actions, are discussed in more detail below.

Urban soil conditions are often viewed as a primary contributor to street tree mortality and health. Urban soils are intensely managed and disturbed, with high spatial heterogeneity from previous uses, making their classification difficult (De Kimpe and Morel 2000). Urban soil chemical properties differ from rural areas, including differences in both essential plant nutrients and pollutants (Pouyat et al. 1995). Unhealthy street trees may manifest as observable leaf yellowing, or chlorosis. Causes of chlorosis include deficiencies of nitrogen (Scharenbroch and

Lloyd 2004) and other nutrients, which may be induced by soil alkalinity (Ware 1990), and compaction and poor drainage. Soil compaction results from both active and passive pedestrian and vehicular traffic, and causes crusting, decreased infiltration, increased density, reduced waterholding capacity, reduced aeration, and increased root impedance (Craul 1994). Oxygen diffusion rate, as an indicator of soil aeration, was critical to the vigor of landscape oak trees in California (MacDonald et al. 1993). With lower infiltration capacity and waterholding capacity, compacted soils and less available soil volume contribute to water deficits. Soil water reservoir limitations can cause tree water deficits, although the relative importance of the soil water reservoir versus atmospheric factors that regulate water demand is unresolved (Clark and Kjelgren 1990). Graves (1994) reviews the evidence that high soil temperature is detrimental to tree growth and health, and lists direct solar radiation, asphalt and concrete surfaces, and underground utilities as the causes of high urban soil temperatures. Lastly, the amount of physical soil space afforded to street trees is related to many of these soil conditions. Kopinga (1991) explains how restricted soil volume in street trees can result in nutrient and water deficits. Grabosky and Bassuk (1995) propose using a soil medium with a stone matrix that is capable of withstanding pressures, thus avoiding compaction and its detrimental effects.

While many of the abovementioned soil conditions are influenced by historic and continuing human activities, such indirect causes are distinguished from direct and current human actions in the list of agents. Site and species selection, site preparation, and maintenance may each affect the long-term health and survival of urban trees (Ware 1994). The considerably lower survival rate for trees planted without community participation in Oakland, CA supports the claim that human maintenance and vandalism affect street tree survival (Sklar and Ames 1985). Ferrini et al. (2000) found that shoot growth of trees in Florence, Italy was statistically different for varying nursery production methods and planting techniques. Damage from construction and sidewalk replacement negatively affected tree condition and survival in Milwaukee, WI (Hauer et al. 1994).

Study area and methods

Selection of Philadelphia street trees based on location, species, and year planted

The methodology involved comparing historical records to recent tree surveys, similar to some of the street tree studies reviewed (Table 1). The PHS database has entries for project identification number, address, species, cultivar, date, caliper, work history (new PHS planting, replacement of previous PHS planting, or existing non-PHS tree), pit size, and presence of overhead wires. Entries may lack pieces of this information. To minimize complicating uncontrolled variables, the street trees analyzed in this study were limited by geographic area, species, and year planted. Geographic area was limited by zip code, and only trees in 19122, 19125, and 19133 were included. These zip codes represent the neighborhoods of Fairhill, Fishtown, Harrowgate, Hartranft, Kensington, and West Kensington. The neighborhoods under analysis may be collectively referred to as North Philadelphia. Demographic information for North Philadelphia is shown in Table 2.

Selected tree species were hedge maple (*Acer campestre*), red maple (*Acer rubrum*), ginkgo (*Ginkgo biloba*), sawtooth oak (*Quercus acutissima*), and Japanese zelkova (*Zelkova serrata*, including the green vase cultivar). Of these species, only red maple is native to the northeastern United States. Japanese zelkova, gingko, and sawtooth oak are native to Asia. Hedge maple is native to Europe. Trees of these five species planted in the years 1995-97 were included. These species were selected because they were the most represented in the selected neighborhoods, and also because they had fairly complete data from the time of planting. Additional hedge maples planted in the years 1998-2003 were included for a more detailed analysis of survival rate variation over time.

Zip code	Median household income	Percent White	Percent African-American	Percent Asian	Percent Hispanic (of any race)
19122	$18,395	23.2	48.3	1.9	33.8
19125	$28,679	81.3	4.2	5.3	10.8
19133	$13,828	15.0	43.0	0.5	56.8

Table 2. Demographic information for North Philadelphia zip codes (U.S. Census 2000).

Tree and site data collected

Field work for this study was conducted June-September 2005. Information recorded was based on the PHS and other planting databases in Philadelphia. The presence or absence of the tree was recorded. If absent, the missing tree pit was noted as an empty pit, new paving, or no pit evidence. If present, the species and correct address were confirmed. Diameter at breast height (DBH, diameter at 1.3m from ground), width of walkable sidewalk (i.e., distance to house steps), pit area, and exposed soil area were measured. The latter two measurements often differed because of soil pit decorative and protective borders. Visible pedestrian stresses (e.g., litter, graffiti), vehicular stresses (e.g., parking), maintenance (e.g., pit border, planted flowers), width of road in lanes, road limitations (e.g., high traffic), and presence or absence of overhead wires were also noted.

The census tract for each address was determined using the U.S. Census American FactFinder (U.S. Census 2006). Select Census data acquired through the University of Pennsylvania Cartographic Modeling Lab (US Census Bureau 2006) was included in statistical analysis for alive or dead status in 2006 (see Appendix 2).

Statistical analysis

Regression analysis was used to analyze survival rates vs. time period for published data. Regression was log transformed, weighted by sample size, and the y-intercept was constrained to 100% survival rate at the time of planting. When the reported survival rate was zero (Snydor et al. 1999), log transformation was entered as -1. Two studies that did not report sample size were excluded. For the eleven remaining studies, all data points were used (i.e., multiple values from the same location or study were permitted), and conservative estimates were taken when a range of survival or time period was reported (e.g., 60-70% survival becomes 60%, 5-10 years becomes 5 years).

Annual survival s_a for the literature review data was estimated by

$$s_t = s_a^{\ t}, \text{ or } s_a = s_t^{\ 1/t}$$

where s_t is cumulative survival t years after planting, assuming constant annual survival. Conservative estimates were again used when a range of survival or time period was reported. Average lifespan l is estimated by

$$l = \frac{\sum_{i=1}^{x}((s_{i-1} - s_i)\ i)}{100}$$

where i is the number of years since planting and s_i is cumulative survival at year i. Year x is the time at which cumulative survival has reached nearly zero, the maximum lifespan, estimated by $x = log\ (0.01,\ s_a)$. Similarly, the median lifespan, when 50% of the planting cohort is still alive, is estimated by $log\ (0.5,\ s_a)$. Estimated annual survival for reviewed literature is given in Table 1. The uses and limitations of estimated lifespan are discussed. Estimations for North Philadelphia street trees are given in Table 4.

Street trees planted in North Philadelphia 8-10 years ago were analyzed using chi-square for the bivariate factor of alive or dead status in 2005. ANOVA was used to analyze for the continuous factor of current DBH. Hedge maples planted 2-10 years ago were studied with regression analysis, plotting survival rates and DBH vs. time since planting. Regression analysis of survival rate was log transformed, weighted by sample size, and the y-intercept was constrained to 100% survival at the time of planting. Regression analysis of DBH was weighted by sample size.

Sample sizes appropriate for future experiments were determined using power analysis in JMP for data suitable for ANOVA.

Results

Analysis of street tree literature review

Survival rate is linearly correlated with time period since planting. Estimated annual survival is 94.2% (Figure 1). Polynomial regressions were also significant, but had lower r^2 vales. Estimated annual survival rates for each study are provided in Table 1.

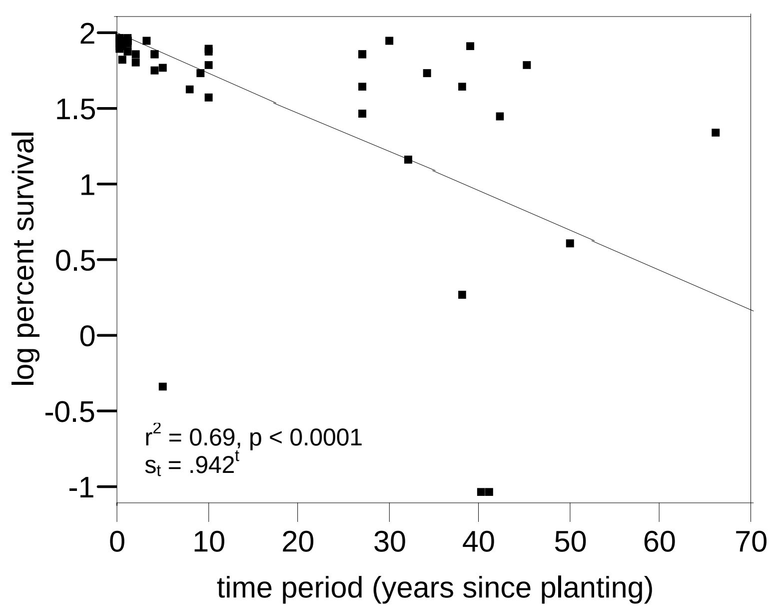

Figure 1. Street tree cumulative survival at varying time periods after planting in temperate locations.

Select street tree species North Philadelphia, 8-10 years since planting

From the original PHS database, 154 street trees were selected. Of these, 147 remained after trees were disqualified for reasons such as assumed database error and improper location (i.e., in a park lawn instead of a sidewalk tree pit). In 2005, 84 trees were alive, thus the overall survival rate of selected species planted 8-10 years ago was 57.1%. The 63 dead trees consisted of 2 trees that were dead but still present, and 61 that had been removed. Of the removed trees, 7 were the result of a recent demolition, empty soil pits remained at 8 sites, and 15 of the sites had new paving over previous soil pits. The remaining 31 removed trees had no discernable soil pit evidence. Cause of death was not determined for the latter three scenarios.

Survival rates for each species ranged from 26.1% to 68.8% (Table 3). Survival rates for each planting year are given in Table 4, along with estimated annual survival and estimated median, average, and maximum lifespan. Using the equation determined from the literature review data, estimated cumulative survival rates for trees planted 8-10 years ago is 55-62%.

Species	Total # planted 1995-97	# Alive in 2005	Survival (%)	Avg. DBH of surviving trees in 2005 (cm)
Japanese zelkova	44	30	68.2	20.4
Hedge maple	32	19	59.4	16.4
Red maple	16	11	68.8	15.3
Gingko	32	18	56.3	18.2
Sawtooth oak	23	6	26.1	20.0
Total	147	84	57.1	-

Table 3. Survival rates of select street trees in North Philadelphia planted 8-10 years ago, and average DBH of surviving trees in 2005.

Planting year (time period)	Total # planted	# Alive in 2005	Cumulative survival (%)	Estimated annual survival (%)	Estimated median lifespan	Estimated average lifespan	Estimated maximum lifespan
1995 (10)	24	16	66.7	96.03	17	22	114
1996 (9)	100	58	58.0	94.13	11	16	76
1997 (8)	23	10	43.5	90.12	7	10	44

Table 4. Survival rates of all select street trees in North Philadelphia planted 8-10 years ago, by year planted. See methods for annual survival and lifespan estimation procedures.

Chi-square analysis of alive or dead status in 2005 reveals that species (chi-sq < 0.05), zip code (chi-sq < 0.05), and project identification number (chi-sq < 0.01) are significantly related to mortality. Census indicators were also found to be related to alive or dead status in 2005 (Table 5). For example, trees alive in 2005 were more likely to be located in census tracts with a lower US Postal Service vacancy rate, and a lower percent of industrial properties. Many of these factors relate to the built environment.

Census data	Average value for trees alive in 2005	Average value for trees dead in 2005	chi-square
USPS vacancy rate 2004	6.5	7.4	0.0003
USPS vacancy rate 2003	6.4	7.2	0.0022
Percent with bachelor's degree	3.2	2.0	0.0015
Percent Asian	6.1	8.4	0.0320
Percent multifamily properties	0.9	1.1	0.0202
Percent industrial	2.2	2.7	0.0127
Percent residential detached housing	0.9	0.5	0.0182
Percent L&I demolished	6.6	7.9	0.0375
Percent L&I demolition pending	4.2	4.8	0.0038
Percent L&I sealed properties	19.5	22.4	0.0258
Percent L&I vacant buildings	9.4	12.2	0.0002
Percent L&I vacant residential	7.3	9.1	0.0004

Table 5. Chi-square analysis of alive vs. dead status in 2005 for U.S. Census data for trees 8-10 years after planting in North Philadelphia.

ANOVA of DBH for trees alive in 2005 shows significant relationships with sidewalk condition ($p = 0.0002$) and exposed soil area ($p = 0.0150$). With regards to sidewalk condition, of the 84 trees alive in 2005, 1 was classified as damaged (DBH 20.0cm), 13 as shifting (average DBH 24.6cm, range 15.0 to 43.6cm), and 70 as undisturbed (average DBH 17.1cm, range 5.0 to 26.7cm).

Hedge maple street trees in North Philadelphia, 2-10 years since planting

Hedge maples planted 1995-2003 were analyzed for trends in survival over time. Survival rate of hedge maples in North Philadelphia (Table 6) is linearly correlated with time period since planting (estimated r^2 = 0.75, p = 0.0026, estimated annual survival 95.5%). Survival rate is also significantly correlated to time period since planting for polynomial regressions, but the estimated r^2 values are low.

Linear regression analysis of DBH for each planting year and time since planting reveals a positive correlation (r^2 = 0.97, p = 0.0004). Slope of the line, which is the annual growth rate, is 1.35cm/yr.

Year planted (time period)	Total # planted	# Alive in 2005	Survival (%)	Average DBH (cm)
1995 (10)	2	2	100.0	-
1996 (9)	30	19	63.3	16
1998 (7)	17	10	58.8	12.7
1999 (6)	10	10	100.0	9.6
2000 (5)	22	21	95.5	10.2
2001 (4)	45	35	77.8	9.1
2002 (3)	2	1	50.0	-
2003 (2)	23	23	100.0	6.3
Total	151	119	78.8	-

Table 6. Survival rates and average DBH of hedge maples in North Philadelphia planted 2-10 years ago, by year planted.

Discussion

Analysis of street tree mortality from previous studies (Figure 1) reveals an annual survival rate of 94.2%. Average lifespan is estimated at 16 years, and median lifespan at 12 years. These lifespan estimations contest the claim that street trees live on average only 7-10 years. Survival rates of North Philadelphia street trees are similar to other urban areas. Hedge maples in North Philadelphia also show a statistically significant relationship between time period since planting and survival, with an annual survival rate of 95.5%. Average lifespan for hedge maples in North Philadelphia is estimated at 21 years, and median lifespan at 15 years. Cumulative survival rates of several species in North Philadelphia at 8, 9, and 10 years after planting are similar to rates predicted by analysis of other studies.

Street tree lifespan information from previous studies ranges widely, and some authors assert average lifespan estimates with little supportive analysis. The relationship between annual survival and average lifespan has been discussed by others (Nowak et al. 2004), but it is not addressed in most studies of street tree mortality. Additionally, average lifespan may not be the most useful variable to understand mortality and replacement trends. The more useful variable for predicting replacement needs may be the median lifespan, or the time period after which 50% of trees are still alive. With very low (<5%) annual mortality rates, estimated average lifespan may reach the hundreds or thousands, because of the asymptotic relationship between annual mortality and average lifespan (Nowak et al. 2004). The estimated median lifespans for North Philadelphia trees are lower than the estimated average lifespans (Table 4). The average lifespans are higher because of the inclusion of high estimated maximum lifespans.

The relationship between survival and time since planting is strongest with a linear regression, for both the literature review and the North Philadelphia data. This indicates constant annual survival, and does not support the concept of an establishment period during which annual mortality is higher. However, the present retrospective analysis may not be the best suited for detecting temporal patterns.

If the first few years after planting are indeed crucial to long-term street tree survival, then performing basic maintenance during the first several years after planting may increase the likelihood of survival. Furthermore, assessing the health of recently planted trees and carrying out maintenance would facilitate community outreach to residents. In North Philadelphia, many residents expressed an interest in learning to care for their trees, but they had not communicated with representatives from greening programs since the original planting. Lack of community involvement (Sklar and Ames 1985) and adjacent land use, as indicators of human actions like maintenance and vandalism (Nowak et al. 2004), have been shown to negatively affect survival. Austin (2002) asserts that sustained community outreach benefits neighborhood development and public relations, as well as tree survival.

The North Philadelphia study addressed the question: under what conditions are street trees most likely to live? Results indicate that species, location, planting conditions (as they relate to project identification number), and U.S. Census indicators affect tree survival. There is a relationship between survival and Census indicators that deal with the built environment, notably property type and vacancy. Census tracts with more vacant properties and Licenses & Inspections marked properties are likely to have higher mortality. While these results are statistically significant, the magnitude of difference in the variables between dead and live trees may be less meaningful. For example, the difference in Postal Service vacancy rates for dead vs. live trees is less than 1%. Deductions based on these results are therefore preliminary, requiring further research to confirm these initial findings.

Tree size was significantly related to sidewalk condition, with larger trees more frequently next to sidewalks classified as damaged or shifting. The causal factors behind this association are unclear. D'Amato et al. (2002) found that street trees have a small impact on newer (<20 years old) sidewalks. Sidewalk cracks arise as a normal part of sidewalk aging, independent of pressure from tree roots (Snydor et al. 2000). Tree size was also significantly related to exposed soil area in the soil pit, with smaller trees in smaller pits. Again, the magnitude of difference was small. Smaller surface soil area may detrimentally affect tree growth, due to issues such as available soil nutrients and water infiltration, as many other authors have explained.

Conclusions about the causes of mortality and factors affecting tree growth were limited due to the retrospective nature of this study and small sample size. Surveying a cohort of trees from the time of planting, and continuing with annual surveys for 10 years, may prove more informative. This study is also limited by having few continuous variables for robust statistical analysis. Measuring variables such as sidewalk condition and tree health condition with more precision would strengthen investigations of street tree mortality. Methodology for such measurements with sidewalks has been developed by D'Amato et al. (2002), and considerations for tree health ratings have been discussed by Hickman et al. (1995). Lab analysis of soil and leaf chemical properties would also aid in quantifying environmental factors and resulting effects in trees.

Sample sizes for future studies may be estimated using power analysis. For the analysis of sidewalk conditions and DBH, the following values were entered: $\alpha = 0.05$, $\sigma = 5.633097$, $\delta = 7.40814$, and power = 0.95. Sample size needed for such parameters is 10. The sample size of the present study already exceeds this amount, and indeed, DBH varied significantly by sidewalk condition. For the analysis of vehicular stress (presence or absence) and DBH, the following values were entered: $\alpha = 0.5$, $\sigma = 6.188535$, $\delta = 0.66072$, and power = 0.95. Sample size needed for such parameters is 1142; for power = 0.90, sample size needed is 924. This indicates that in order to increase the likelihood that vehicular stress would be detected as a significant, sample size must be dramatically increased. The feasibility of having such a large sample size is questionable. In the present study, vehicular stress was not significantly related to DBH.

Detecting a relationship is also limited by field observations of vehicular stress from parking; a single observation cannot capture years of vehicular hazards to the trees.

Future studies of street tree mortality and growth in Philadelphia and elsewhere should focus on following a cohort of trees in one geographic area, starting at the time of planting. Variables to consider include tree size, tree health, soil pit size, soil chemical and physical characteristics, adjacent land use, and socioeconomic indicators from sources such as the U.S. Census. Discerning the relative contribution of various factors on street tree health and mortality is an on-going challenge. As Gregg et al. (2003) explain, "[given] the potential for interactions among all factors and the relative absence of studies examining more than two or three factors in combination, understanding the net effect of multiple anthropogenic environmental changes in an urban environment and the relative importance of the individual factors remains a major challenge." Researchers should coordinate with local tree planting programs to record such information, which would benefit both parties with an improved understanding of the factors that influence street tree health and mortality.

Conclusion

Analysis of reported street tree survival rates revealed an estimated annual survival rate of 94.2%. Street trees in North Philadelphia 8-10 years after planting had a 57.1% cumulative survival rate, and planting-year specific survival rates were comparable to rates predicted from literature review analysis. Factors influencing health and mortality in street trees are numerous and often difficult to differentiate experimentally. Mortality varies significantly by species, zip code, and U.S. Census indicators related to the built environment. Current tree size varies significantly by exposed soil area and sidewalk condition. Analysis of survival over time in hedge maples 2-10 years after planting shows an estimated 95.5% annual survival. Future street tree studies would benefit from larger sample sizes, additional continuous variables for quantitative analysis, and annual surveys that follow a cohort of trees beginning at the time of planting.

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Appendix 1

Location	Study groups (sample size)		Survival rate (%, overall survival over time period)	Time period (yrs)	Estimated annual survival (%)	Source and Methods
Sacremento, CA	all species	(407)	88	0.5 (Jan-Jun 2003)	77.44	SMUD (2003)
		(367)	93	0.5 (Jul-Dec. 2002)	86.49	
		(379)	90	0.5 (Jan-Jun 2002)	81.00	
		(455)	94	0.33 (Sep-Dec 2001)	82.90	
		(327)	88	0.33 (May-Aug 2001)	67.88	
		(301)	95	0.25 (Feb-Apr 2001)	81.45	
		(280)	97	0.25 (Nov-Jan 01)	88.53	
		(383)	96	0.25 (Aug-Oct 2000)	84.93	
		(295)	88	0.25 (May-Jul 2000)	59.97	
		(423)	71	0.42 (Jan-May 1999)	44.24	
		(518)	93	0.33 (Jul-Oct 1998)	80.26	
		(414)	89	0.25 (Feb-Apr 1998)	62.74	
		(471)	90	0.33 (Sep-Dec 1997)	72.67	
		(410)	88	0.58 (Feb-Aug 1997)	80.22	
		(602)	82	0.25 (Nov-Jan 1997)	45.21	
		(476)	91	0.25 (Aug-Oct 1996)	68.57	C

Table 7. Supplement to Table 1. Summary of street tree survival rates in Sacremento, CA.

Appendix 2

Select Census data acquired through the University of Pennsylvania Cartographic Modeling Lab (US Census Bureau 2006) included in statistical analysis for alive or dead status in 2006 (Table 5).

- Information from 2000: % African-American, Asian, Hispanic, White, and Other Races; % children under 18; 2000 median income; % income below 100% poverty level; % income below 200% poverty level; % over 25 with high school education; %

over 25 with bachelor's degree; % housing owner occupied, and renter occupied; % L&I vacant properties; % L&I vacant buildings; % L&I vacant residential; % L&I vacant commercial; % L&I vacant land.

- Information from 2004: % residential detached housing; % residential semi-detached housing; % residential rowhouse; % L&I pending demolition; % L&I code violation; % L&I demolished; % L&I sealed properties; % USPS vacancy.
- Information from 2003: % USPS vacancy.