NEWLY PLANTED STREET TREE GROWTH AND MORTALITY

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Abstract. Two-year growth and mortality rates were analyzed for 254 black locust, 199 southern magnolia and 27 London plane trees planted along a major boulevard extending from southern Berkeley through western inner-city Oakland, California. After the first two years, 34% of these newly planted trees were either dead or removed. The average annual mortality rate was 19% with no significant difference in mortality among the species or between years. Areas of lower socio-economic status exhibited the most tree mortality with pecent mortality most strongly correlated with percent unemployment (r=0.78). Trees with adjacent land uses of apartments and public greenspaces had significantly high mortality while trees next to single family houses and rapid transit stations exhibited low mortality.

Résumé. Deux ans de taux de croissance et de mortalité ont été analysés chez 254 robiniers faux-acacia, 199 magnolias à grandes fleurs et 27 platanes de Londres plantés le long d'un boulevard principal qui s'étend du sud de Berkeley jusqu'à l'ouest de la ville d'Oakland, Californie. Après les deux premières années, 34% de ces arbres nouvellement plantés étaient morts ou abattus. Le taux moyen de mortalité annuel était de 19% sans différence significative avec la mortalité parmi les espèces ou entre les années, Les zones de faible statut socio-économique démontraient le plus de mortalité d'arbres, avec un pourcentage de mortalité plus fortement correlé au pourcentage de chômage (r=0,78). Les arbres avec des terrains adjacents à des édifices à appartements et des espaces verts publics avaient une mortalité significativement élevée alors que ceux près de maisons unifamiliales et des endroits de passages rapides démontraient une faible mortalité.

It is considered common knowledge that many street trees are killed within the first few years after planting, but few studies have actually measured new planting mortality rates (Table 1). Various factors of the street tree environment can also greatly influence early tree mortality rates.

Beatty and Heckman (1), in a survey of urban tree managers in the United States, found an inverse relationship between city size and the rate of tree survival. Survival rates were also higher in regions which had milder climates, with western cities reporting the greatest success in newly planted tree survival (75-100% - no time frame for survival rates were noted). Beatty and Heckman found the 5 most common problems associated with urban tree growth to be: 1) insufficient water; 2) nutrient deficiency; 3) vandalism; 4) soil compaction; and 5) mechanical injury.

Gilbertson and Bradshaw (5) found similar results in a study of city trees in northern England. Newly planted tree mortality was generally higher in larger metropolitan areas than smaller towns. This difference was attributed to the likely differences in average site quality, vandalism, and planting and maintenance practices. They also determined the most frequent cause of newly planted tree mortality was water and nutrient stress (56%), followed by vandalism (18%), tree guard girdling (12%), soil compaction (9%), and improper staking and tying techniques (5%).

Trees planted by different contractors have been shown to have differing survival rates (4). Mortality rates in Oakland, California were also shown to be much higher in areas planted without ceremony or community participation in contrast with areas planted by block parties (11).

The purpose of this study was to analyze the first 2 years of post-planting mortality and growth of street trees planted along a major boulevard extending from southern Berkeley through inner-city Oakland, California. This study specifically analyzes: 1) how growth, vandalism, and mortality differ by species and year; 2) how socio-economic variables and adjacent land use relate to mortality; 3) if tree size and mortality are related; 4) if adjacent root competition influences growth; 5) if planting strip size influences growth and mortality; and 6) if crown volume and growth are related.

Methods

Four hundred eighty street trees were planted in the fall of 1985 along 5.4 miles of Martin Luther King Blvd. extending from southern Berkeley

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through western Oakland, California to San Francisco Bay. Volunteers planted 254 black locusts *(Robinia pseudoacacia* 'Purple Robe'); 199 southern magnolias *(Magnolia grandiflora* 'Samuel Sommer') and 27 London plane trees *(Platanus* x *acerifolia).* The majority of these trees were double staked after planting, although some center nursery stakes were left attached.

In January of 1986, 1987 and 1988, all trees were measured with regard to: 1) diameter at 4.5 feet above the curb (to the nearest 1/32 inch); 2) tree height; 3) height to lowest branch; 4) branch length parallel and perpendicular to the street; 5) vandalism and 6) mortality. Vandalized trees were defined as trees in which the main stem had broken or the main stems were cut off above the tree base. This classification includes both intentionally and accidentally damaged trees, though most trees were thought to be intentionally damaged. Relatively minor vandalism acts (e.g., broken branches) were not included in this classification.

Additional information was also collected on: 1) planting strip size; 2) height of and distance to trees within two competitor's tree heights; and 3) adjacent land use. Planting strip size was calculated by multiplying the planting width not covered by impervious surfaces by planting length. For continuous planting strips, a length of twice the average tree height (2 × 2.97 m) was substituted.

The boulevard was stratified by census tracts (3) and socio-economic data were collected for each of 9 different census tract areas. The socio-economic data included percent of population of black persons; percent of population of white persons; median house value; median monthly rent; population density; percent of population less than 25 years old; percent unemployment; per capita income; percent of population with high school degrees; and ratio of owner occupied housing units to rented housing units. Areas where Martin Luther King Blvd. was a border between two census tracts, weighted averages of the two tracts were used to obtain socio-economic data.

A root competition index was devised to assess the relative impact of competing trees. Any two trees were considered competing if the distance between them was less than two times the tallest tree's height. An index value was calculated for every tree competing with a street tree as: [2 / (distance to tree / competitor's height)] - 1. For each street tree, these values were summed for all competing trees to yield a relative root competition index.

Crown volume was estimated for each tree using standard geometric formulas and measurements of crown height (tree height -height to lowest branch) and average branch length (crown radius). Black locust's crown was characterized by a cylinder ($V = (pi)(r^2)(h)$);

Table 1. Measurements of recently planted street tree mortality rates found in the literature.

Percent mortality	*No. years since planting*	*Location*	*Notes*	*Reference*
3-38	1	Boston, MA	Differences due to contractors	(4)
6.5-19.7	1	Brussels, Belgium	1 yr. mortality range studied over 4 years	(7)
9.7	1	Northern England	Conservative estimate	(5)
10-12	10	Syracuse, NY	Modeling estimates	(10)
15-30	5	Wisconsin	Survey of five communities	(9)
16.6-60.3	1	Surrey, England	See * (below)	(8)
23	2	Boston, MA	Mt. Vernon St. dead and dying	(4)
26	2-4	Boston, MA	Average from Boylston St.	(4)
30-40	3	Oakland, CA	Estimate from block party plantings**	(11)
33	1	Boston, MA	Phillips St. dead and dying	(4)
99.5	6-10	Oakland, CA	Plantings w/o ceremony or community participation	(11)

* - Range of mortality for a comparison of white birch *(Betula pubescens)* grown in Japanese Paperpot with open nursery bare rooted seedlings when planted at monthly intervals on a roadside site at Esher, Surrey.

** - Conservative estimate - replaced trees were considered to have survived.

magnolia as an ellipsoid (V = (4/3) (pi) (0.5h) (road parallel radius) (road perpendicular radius)); and London plane tree as a paraboloidal segment (V = (1/2) (pi) (r^2) (h)).

City maintenance practices were generally limited to pruning, restaking and replanting (B. Jones and J. Ryugo, personal communication, 1988). Watering and fertilization (if any) were left up to adjacent homeowners. In Oakland, trees in the predominantly commercial/industrial areas (i.e., few homeowners) were watered by city personnel during summer months (J. Ryugo, personal communication, 1988).

Tests of significance employed were paired t-tests to test for species growth differences between years, 1-way analysis of variance with Scheffe test to separate the growth and diameter means among species, t-tests for signficance of Pearson's r and chi-square tests for signficant differences in mortality and vandalism. The level for statistical significance was set at alpha = 0.05.

Results

Diameter and Growth. Black locust and London plane had greater diameters at the time of planting than magnolia (Table 2). These two species also exhibited faster growth rates (Table 2) and their increased growth rates were still significant when compared among trees of equal diameter. Species growth rates did not significantly differ between the first and second year.

Diameter growth rates were not significantly correlated with the root competition index or planting space area, but were correlated with crown volume. Diameter growth in 1986 was significantly correlated with crown volume for only 1 species (plane tree, r=0.54). For 1987, growth and crown volume were significantly correlated for all species (black locust, r=0.41; magnolia, r=0.31; plane tree, r=0.54).

Mortality and Vandalism. For the first two years, the combined mortality rate for Martin Luther King Blvd. was 34%, with an average annual mortality rate of 19%. Mortality rates differed by species and year but these differences were not significant (Table 3). There was also no significant difference in the diameter of dead or removed trees compared with trees remaining alive.

When categorizing the trees by vandalism classes, again no statistical differences were observed among species or between years (Table 4). Only 62% of the trees remained alive and non-vandalized after 2 years. A minimum of 11% of the population has been vandalized with 71% of the vandalized trees dead. The vandalism rate is likely higher but 27% of the population was removed or cut off at the base and the cause of mortality could not be determined. Much of the mortality is likely due to automobile damage (J. Ryugo, personal communication, 1988), but at least 23% of the mortality is due to vandalism.

Mortality among the census tracts was significantly different and ranged from 15% to 56%. In analyzing census tract mortality by socio-economic data, only owner/renter occupied housing ratio and percent unemployment were significantly correlated with percent mortality (Table 5). Of these two variables, mortality was most strongly correlated with percent unemployed. Percent with high school education, per capita income and median rent were modestly, but not significantly correlated with percent mortality ($R > 0.6$; alpha = 0.1). Planting strip area was correlated with various socio-economic variables, but not significantly correlated with mortality (Table 5).

Adjacent land use also influenced mortality, with apartments and public greenspaces exhibiting high mortality and single family residences and

Table 2. Comparison of species diameter and growth (inches).

Species	*1986 Diameter*	*1986 Diameter growth*	*1987 Diameter growth*
Black locust	0.98 A	0.32 A	0.38 A
Southern magnolia	0.85 AB	0.17 A	0.18 AB
London plane tree	0.94 B	0.25 B	0.33 B

Species with the same letter indicate significant difference in measurement with type I experimentwise error rate = 0.05.

Table 3. Percent mortality by species and growing season.

Species	*N*	*1986*	*1987**	*1986-1987*
Black locust	254	16.1	22.1	34.6
Southern magnolia	199	20.6	19.6	36.2
London plane tree	27	11.1	8.3	18.5
Total sample	480	17.7	20.3	34.4

* - Percent based on trees surviving the first year.

Bay Area Rapid Transit (BART) stations exhibiting low mortality rates (Table 6). Percent of census tract trees adjacent to these land uses was not correlated with the socio-economic variables. This lack of association indicates that the differences in mortality due to adjacent land use are not due to socio-economic factors that may be associated with various land uses.

Table 4. Percent of population within 4 vandalism classes.

Species	NONVAND**	VAND-ALIV	VAND-DEAD	REMOVED
1986				
Black locust	78.7	5.1	4.7	11.4
Magnolia	75.4	4.0	4.5	16.1
Plane tree	85.2	3.7	7.4	3.7
Total sample	77.7	4.6	4.8	12.9
1987*				
Black locust	78.0	1.0	0.0	21.0
Magnolia	81.3	1.3	2.7	14.7
Plane tree	91.3	4.3	0.0	4.3
Total sample	80.2	1.3	1.1	17.4
1986-1987				
Black locust	61.4	3.9	6.7	28.0
Magnolia	61.3	2.5	9.0	27.1
Plane tree	77.8	3.7	11.1	7.4
Total sample	62.3	3.3	7.9	26.5

*Percentages based on 1986 non-vandalized trees.
NONVAND - Non-vandalized.
VAND-ALIV - Severely vandalized but alive.
VAND-DEAD - Death due to vandalism.
REMOVED - Tree missing or cut off at base. Unknown cause of mortality.

The 2-year mortality rate in Oakland (37%) was significantly higher than Berkeley's 2-year mortality rate (23%). However, Berkeley's sample contained all of the London plane trees which averaged the lowest mortality rates. When London plane trees were removed from the analysis, a large, but non-significant mortality difference between cities remained, with Oakland still exhibiting greater mortality (37% vs. 25%). Because a large difference between mortality in cities still existed after London plane trees were removed from the analysis, the relatively low mortality rate of London plane tree may be due to its sample being confined to Berkeley, not that this species is a better species in terms of early street tree survival.

Discussion

Growth and diameter differed significantly among the species with black locust and London plane tree exhibiting larger growth and diameters than magnolias. Although there was no difference in diameters of the dead trees in comparison with the live trees, this lack of difference is likely because all the trees are relatively small. As diameters increase beyond a certain caliper, mortality may decrease because these larger trees are better able to withstand vandalism and automobile damage. Planting relatively large street trees has been noted to help reduce vandalism (2). Thus, black locust and London plane tree mortality rates may drop sooner than magnolia's

Table 5. Correlation coefficients among percent mortality, 5 socioeconomic variables and 1 site variable (n = 9).

	AREA	UNEMPL	RENT	PERCAP$	OWNRENT	HSCHOOL
%MORTALITY**	-0.57	0.78*	-0.61	-0.66	-0.67*	-0.63
HSCHOOL	0.81*	-0.70*	0.81*	0.99*	0.39	1.00
OWNRENT	0.69*	-0.64	0.77*	0.42	1.00	
PERCAP$	0.79*	-0.67*	0.79*	1.00		
RENT	0.95*	-0.81*	1.00			
UNEMPL	-0.80*	1.00				

*Significant at alpha = 0.05.
%MORTALITY - Percent tree mortality.
HSCHOOL - Percent of population with high school degrees.
OWNRENT - Ratio of owner occupied housing units to rented housing units.
PERCAP$ - Per capita income.
RENT - Median monthly rent.
UNEMPL - Percent unemployment.
AREA - Average surface growing space area.

mortality rate.

To attain large trees more quickly, thereby potentially reducing young tree mortality, growth rates should be enhanced. Along with irrigation, fertilization and reducing competition, one way to enhance growth is to preserve crown volume (photosynthetic area) by minimizing pruning. Although pruning is an important part of early tree maintenance, excessive pruning should be avoided to maximize early total growth rates.

Staking techniques have also been noted to be a cause of newly planted tree mortality (5). The double staking technique (with a high crossbar) employed on Martin Luther King Blvd. may lead to increased mortality. With double staking, a high crossbar or a rigid pair of ties between the two stakes can act as a fulcrum at which trees are readily snapped by vandals. Single staking with a steel-reinforcing-bar at least 5 feet tall, tied close to the tree, is reported to reduce this problem (2), but may increase damage to the trunk due to the bark rubbing against the stake. Smooth steel stakes may reduce this type of damage.

Other staking techniques that may reduce vandalism are: 1) double staking without a high crossbar and one flexible tie to hold the tree upright, provide flexibility, and minimize tree injury; 2) triple staking; or 3) using sturdy stakes encircled with heavy wire or metal grillwork (6).

Our finding on first year mortality rates (18%) did not differ much from the average first year mortality found in the literature (approx. 16%) (4, 7). Our 2-year mortality findings (34%) were higher than what was found in Boston (23%) and were within the 3-year mortality range found in Oakland (30-40%) (4, 11).

Black (2) reported no link between Seattle's vandalism and economic status or racial make-up of neighborhoods, but did note that most vandalized trees were broken by males age 17 to 25. Although males age 17 to 25 may cause the most vandalism, we found no association between the percent of the population less than 25 years old and mortality. Mortality also was not associated with race.

Mortality was negatively associated with socio-economic status. Our sample transect though, did not include the more affluent areas of Berkeley or Oakland. The best socio-economic indicator of mortality appears to be percent unemployed. The areas of higher unemployment also generally had lower rents, lower per capita income, fewer owner-occupied homes, and fewer high school graduates.

Various reasons could be hypothesized as to why lower socio-economic areas had greater tree mortality. Increased unemployment signifies more time spent in the neighborhood and increased activity in the street tree environment, both social (pedestrian) and possibly automobile activity. Lower income indicates less funds available for tree care. Fewer owner-occupied residences connotes a lack of sense of ownership toward the street trees and therefore a possible lack of care. Fewer high school graduates implies that an increase in education may decrease mortality.

Berkeley's lower mortality rates are likely due to differences in soci-economic status between the cities (the Berkeley sample area has a relatively higher socio-economic standing than most of the Oakland sample area). This difference may lead to greater homeowner care for Berkeley street trees.

Sklar and Ames (11) concluded the success of an Oakland inner-city tree planting program (which included neighborhood meetings, corporate sponsorship and ceremonial plantings) was not due to the program educating the residents. Rather, the tree planting program tended to define the parkway trees as part of the resident's property, thus decreasing the significance of the parkway-property barrier. Future studies are needed to

Table 6. Percent 2-year mortality by adjacent land use. Overall significant difference in mortality at alpha = 0.05.

Adjacent land use	*Percent mortality*	*N*	*Sign.* *
Apartments	50.0	52	S
Public greenspace	50.0	16	S
Construction site	50.0	12	
Multi-family residence	38.7	62	
Parking lot	35.1	37	
Vacant lot	34.0	53	
Institutional (church, hospital, school)	32.7	52	
Commercial/industrial	31.5	127	
Single family residence	24.5	53	S
Subway station (BART)	0.0	16	S

*Significant contribution to the overall chi-square value.

determine what factors or combination of factors are responsible for increased mortality.

Areas of lower socio-economic status also had significantly smaller planting spaces. Although differences in planting space size did not affect mortality, smaller planting spaces indicate a harsher physical tree environment.

Different adjacent land uses affected mortality in different ways. Apartments and public greenspaces were associated with increased mortality while single family residences and subway stations (BART) were associated with decreased mortality. The major differences between these land uses are likely the sense of ownership and care toward the trees and the amount of people concentrated about these trees.

In areas with apartments and public greenspaces, one would expect a lower sense of tree ownership and relatively high concentrations of people. The opposite would be expected for single family homes and BART stations. The street trees adjacent to BART were not near the station entrance and likely had low pedestrian flow. These trees were also likely maintained by BART personnel.

Conclusion

The social environment around the tree is just as important as the physical tree environment for insuring early tree survival. Management and maintenance activities of the urban forester can greatly impact early tree health and survival. Areas of lower socio-economic status, as well as public greenspaces and apartment complexes, should be identified for their increased potential for high mortality. In these areas, a more intensive effort of public education and involvement should be sustained. These efforts will likely promote a sense of ownership and pride toward the trees and decrease mortality. Planting larger trees and proper staking techniques may also aid in reducing mortality rates in problem areas.

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