NYS Modeling Street Tree Populations on a Statewide Basis

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Executive Summary

Street tree inventory data provides detailed information about the structure and health of a street tree population and facilitates effective management. In the United States, some states have collated and analyzed data from multiple street tree inventories to better understand the street tree population on a statewide basis. New York State is fortunate to possess numerous street tree inventories widely distributed throughout the state. This study has been undertaken on the premise that street tree inventory data in New York State can be collated and analyzed to provide an understanding of the structure, functions, and trends of publicly managed trees statewide.

Accordingly, a sample of street tree inventory data was assembled from 138 municipalities in New York State. Street length of street types expected to contain street trees was summed for these municipalities. Sample validity was evaluated by comparing this street length measure to the same street length measure for all New York State Census Places (e.g. cities, villages, and Census Designated Places) and by 1990 USDA Plant Hardiness Zones in New York State (i.e. Zones 3, 4, 5, 6, and 7). Further analysis suggested that street length for Census Blocks with a population density of at least 500 persons per square mile needed to be included. On the basis of the summed street length percentage contained in the 138 municipalities and its relative distribution by plant hardiness zone, sample data was judged sufficient for the purposes of this study. It was decided to group for analysis data contained in Zone 3 and Zone 4 municipalities due to the small amount of summed street length contained in Zone 3 and to weight statewide statistical estimates by the relative percentage of summed street length in each plant hardiness zone class.

Summary statistics were calculated for street trees statewide and by 1990 USDA Plant Hardiness Zone class. *Acer* was found to be the most prevalent street tree genus and *Acer platanoides* the most prevalent street tree species in New York State. Significant differences in prevalence were found for many street tree species and genera by zone class, particularly between Zone 7 and the other zone classes. Species diversity increased with milder climate, but was found to be insufficient statewide, suggesting vulnerability to invasive pests such as the Asian Longhorned Beetle and Emerald Ash Borer. Analysis of trunk diameter profiles indicated an aging street tree population statewide requiring an increase in new plantings to maintain street tree numbers at current levels. Statistics for the youngest trees revealed a trend of increased plantings of small sized tree species relative to plantings of large and medium sized tree species regardless of overhead utility wires and planting location types. Benefits provided per street tree were found not to vary by zone class, but significant differences were found by zone class in the number of street trees planted per unit of street length with Zone 7 having the most trees and Zones 3 and 4 the least.

Statistical analyses were conducted for the 1990 USDA Plant Hardiness Zone classes and additional environmental and social variables to evaluate their ability to explain variability in the New York State street tree population. Variables such as annual precipitation, development intensity, median household income, educational attainment, presence of professional staff to manage community trees, and municipality type were found to have modest explanatory power, but were also found to be either multi-collinear with 1990 USDA Plant Hardiness Zone class or inconsistent in their effects. Therefore, 1990 USDA Plant Hardiness Zone class was judged the best predictor variable for explaining variability in the New York State street tree population and other variables were not used in calculating statewide statistical estimates.

Initial estimates for street tree numbers statewide of prevalent street tree species and genera and for annual benefits statewide provided by street trees were calculated based on stratifying data and weighting means from summary statistics by 1990 USDA Plant Hardiness Zone classes. A number of street tree inventories were then conducted to compare initial estimates with test inventory statistics and to evaluate whether statistically significant differences and trends found at the zone class level for sample data would be found for the test inventories also. While test inventory statistics did not agree completely with zone class level statistics, they did appear to reflect and confirm differences and trends found at the zone class level. Final estimates were generated for prevalent street tree species and genera and for annual street tree benefits statewide incorporating test inventory statistics with initial estimates calculated from sample data. Change from initial estimates for prevalent street tree species and genera was found to be slight, varied by species and genus, and revealed susceptibility to volatility in Zone 7 which has the fewest inventories relative to the other zone classes. Updated estimates for street tree numbers and annual street tree benefits showed small decreases in their means from initial estimates and a narrowing in the range of confidence intervals due to reductions in standard errors.

Final updated estimates are as follows:

Number of Street Trees Statewide	
Mean	4,145,602
90% Upper Confidence Interval	4,464,822
90% Lower Confidence Interval	3,826,382
Range	638,440

Statewide Population Percentages for Prevalent NYS Street Tree Species				
Species	Mean	Std Err	90% UCI	90% LCI
Acer platanoides	20.85	1.07	22.61	19.09
Acer saccharum	9.96	0.63	11.01	8.92
Acer saccharinum	5.67	0.67	6.77	4.58
Platanus x acerifolia	5.59	0.75	6.82	4.35
Acer rubrum	5.22	0.42	5.90	4.53
Gleditsia triacanthos	5.18	0.48	5.98	4.39
Pyrus calleryana	5.02	0.72	6.21	3.83
Quercus palustris	2.98	0.35	3.55	2.40
Tilia cordata	2.73	0.29	3.20	2.26
Malus species	2.47	0.21	2.82	2.12
Fraxinus pennsylvanica	2.08	0.22	2.44	1.72
Quercus rubra	1.66	0.13	1.88	1.44
Picea abies	1.25	0.14	1.48	1.02
Pinus strobus	1.04	0.17	1.31	0.76
Robinia pseudoacacia	1.04	0.15	1.28	0.79

Statewide Population Percentages for Prevalent NYS Street Tree Genera				
Genus	Mean	Std Err	90% UCI	90% LCI
Acer	44.27	2.34	48.13	40.42
Quercus	7.02	0.51	7.85	6.18
Platanus	5.65	0.73	6.85	4.44
Pyrus	5.55	0.82	6.91	4.20
Gleditsia	4.94	0.46	5.69	4.19
Tilia	4.07	0.38	4.70	3.44
Fraxinus	3.42	0.27	3.86	2.98
Picea	2.95	0.27	3.39	2.51
Prunus	2.89	0.22	3.25	2.53
Malus	2.50	0.23	2.88	2.12
Pinus	1.59	0.17	1.87	1.30
Ulmus	1.31	0.20	1.64	0.98
Robinia	1.03	0.16	1.29	0.77

Statewide Numbers of Trees for Prevalent NYS Street Tree Species			
Species	Mean	90% UCI	90% LCI
Acer platanoides	864,374	1,009,698	730,314
Acer saccharum	413,004	491,360	341,304
Acer saccharinum	235,259	302,473	175,066
Platanus x acerifolia	231,549	304,673	166,332
Acer rubrum	216,292	263,481	173,469
Gleditsia triacanthos	214,805	266,840	167,845
Pyrus calleryana	208,142	277,311	146,572
Quercus palustris	123,435	158,621	91,920
Tilia cordata	113,020	142,668	86,366
Malus species	102,501	125,993	81,241
Fraxinus pennsylvanica	86,278	108,956	65,894
Quercus rubra	68,895	84,014	55,179
Picea abies	51,742	66,065	38,897
Pinus strobus	42,938	58,365	29,245
Robinia pseudoacacia	42,936	57,296	30,156

Statewide Numbers of Trees for Prevalent NYS Street Tree Genera			
Genus	Mean	90% UCI	90% LCI
Acer	1,835,323	2,148,710	1,546,540
Quercus	290,832	350,515	236,481
Platanus	234,087	305,949	169,923
Pyrus	230,182	308,323	160,681
Gleditsia	204,743	254,135	160,161
Tilia	168,573	209,695	131,475
Fraxinus	141,848	172,538	113,984
Picea	122,386	151,375	96,194
Prunus	119,746	145,160	96,648
Malus	103,598	128,386	81,213
Pinus	65,712	83,619	49,642
Ulmus	54,301	73,282	37,436
Robinia	42,751	57,527	29,618

Statewide Annual Benefits ($) Per Street Tree	
Mean	134.15
90% Upper Confidence Interval	137.65
90% Lower Confidence Interval	130.66

Statewide Annual Benefits ($) All Street Trees	
Mean	556,148,138
90% Upper Confidence Interval	614,584,569
90% Lower Confidence Interval	499,944,101
Range	114,640,468

(1) Introduction

Summary. Street tree inventory data provides detailed information about the structure and health of a street tree population and facilitates effective management. In the United States, some states have collated and analyzed data from multiple street tree inventories to better understand the street tree population on a statewide basis. New York State is fortunate to possess numerous street tree inventories widely distributed throughout the state. This study has been undertaken on the premise that street tree inventory data in New York State can be assembled and analyzed to provide an understanding of the structure, functions, and trends of publicly managed trees statewide. Initial statistical estimates for prevalent street tree species and genera will be calculated and compared to results from a number of test inventories. Updated estimates will then be made for statewide numbers of street trees for prevalent species and genera and for benefits provided by street trees.

Management of any resource depends on the managers of that resource having sufficient information to make knowledgeable decisions. This need for information applies to urban trees and the street tree inventory has been the primary vehicle for urban forest managers to obtain the information they need to manage the urban forest. A street tree inventory is a survey of publicly managed trees in a community or municipality. In a typical inventory, data is collected about each tree including genus, species, trunk diameter, condition, management needs, and, if applicable, street address location. Inventories are usually conducted in one of three geographic scales. A complete inventory or census collects data for all publicly managed trees in the community. Sample and partial inventories collect data for a portion of the street tree population. In a sample inventory, the inventoried portion is randomly selected whereas in a partial inventory a particular neighborhood or area is targeted. Historically, the main reasons for conducting an inventory have been rooted in arboriculture: tree maintenance and limiting exposure to liability claims attributed to poor tree condition (Bond & Buchanan 2006; Tate 1985). Maintenance and liability concerns remain important considerations for conducting an inventory, but the inventory is also increasingly viewed as a proactive, ecological, systems based planning tool for improving urban forest health and sustainability by augmenting species diversity in a long-term planting plan (Peper et al 2004).

Advances in computers and information technology have transformed urban forest management and planning. Digitization of records once kept on paper has facilitated the rapid analysis of inventory data in computer spreadsheet programs. GIS (Geographic Information Systems) and GPS (Global Positioning System) have enabled the mapping of individual trees from longitude and latitude coordinates collected as part of the inventory process. Finally, remote sensing has made possible the analysis of urban forest canopy cover from aerial imagery. Canopy cover has proved a widely useful metric for assessing urban forests, initially with moderate resolution datasets such as the National Land Cover Database and more

recently with high resolution LIDAR data. Capturing most trees located in an urban area including trees located on private property that are not publicly managed and spanning civil jurisdictional boundaries to link urban trees between communities and to the rural and uncultivated forests beyond them, canopy cover has been used to measure changes to urban forests over time, assess ecosystem benefits provided by urban trees, and set goals and priorities for urban forest planning. However, it does not contain the more discrete kinds of data contained in a street tree inventory such as tree species composition, relative age distribution measured by trunk diameter at breast height (DBH), tree condition, planting location types, and overhead utility wires. These kinds of data are required for more detail dependent urban forest management such as evaluating species diversity, planning for invasive pests, assessing the number of new plantings necessary to sustain or increase the number of publicly managed trees, and making specific decisions as to which species to plant at which sites.

Ideally, an urban forestry manager would have access to both street tree inventory and canopy cover data. In reality, because street tree inventories are expensive and time consuming to conduct, most municipalities in a state and nationwide have not conducted them. The absence of a street tree inventory is especially evident for those municipalities lacking a dedicated urban forestry professional responsible for managing public trees, which is in turn often correlated with smaller sized municipalities with more modest financial resources (Maco & McPherson 2003). Therefore, while the larger cities in a state often, although not always, possess a street tree inventory, most municipalities in a state, and particularly municipalities other than the state's larger cities, do not possess a street tree inventory (Green et al 1998). This patchwork of tree inventory data existing at the statewide level has posed problems for state and federal officials involved in urban forest management and planning. For example, it is difficult for officials to gauge the statewide impact of the Emerald Ash Borer (EAB) on publicly managed street trees when most municipalities in the state do not have street tree inventories. They can only guess at the number of publicly managed ash trees at risk to the EAB and whose removal may need to be planned and budgeted for.

Attempts have been made to conduct statewide assessments of publicly managed trees by assembling street tree inventory data from those municipalities in a state possessing street tree inventories. In Indiana, a Sample Urban Statewide Inventory (SUSI) study comprised of street tree inventory data from twenty-three municipalities was commissioned in 2008 (Louks 2010); the study evaluated data from these municipalities and derived estimates of tree species composition (Davey Resource Group 2010A) and environmental services and economic benefits provided by street trees (Davey Resource Group 2010B) for 567 Indiana communities. In California, Lesser (1996) analyzed street tree inventory data from twenty-one Southern California cities and concluded that species diversity was declining and that more small statured trees were being planted than large statured trees, particularly in coastal communities. In New Jersey, data collected statewide from 432 plots (i.e. four one quarter mile long plots in 108 communities) in 1994

and 1999 found a lack of diversity in street tree plantings with a preponderance of maples (NJ Forest Service 2000). In Virginia, street tree inventory data from eight municipalities has been used to assess the potential impact of ash tree loss due to the EAB on the state's street tree population and the ecosystem services provided (Wiseman & Wright 2010). In South Dakota, thirty-four municipalities were surveyed for genus and species composition of their street trees and susceptibility to ash tree loss due to the EAB (Ball et al 2007). Additional efforts have included estimates of street tree species composition and street tree numbers statewide based on questionnaires in California (Bernhardt & Swiecki 1993, Thompson 2006) and Ohio (Sydnor et al 2007) and on sampled roadside plots in Maryland and Massachusetts (Cummings et al 2004). On a broader geographic scale, Raupp et al (2006) evaluated street tree vulnerability to the EAB and the Asian Longhorned Beetle (ALB) in the Eastern United States and Canada from street tree inventory data collated from twelve municipalities and one college campus, and McPherson and Rowntree (1989) used street tree inventory data from twenty-two municipalities distributed nationwide to study stocking levels, trees per capita, and the trend towards planting small sized trees as opposed to large sized ones.

The most reliably accurate analysis of publicly managed trees at the statewide level would be a census or complete count of all publicly managed trees in all municipalities in a state. For many reasons, including as mentioned the fact that most municipalities in a state, and especially municipalities other than a state's larger cities, lack a street tree inventory, such a census is not realistically achievable. Accordingly, any analysis of publicly managed trees at the statewide level must be based on a portion or sample of trees. Accuracy of such an analysis will in turn depend but not be limited to such factors as the number of trees in the sample, their geographic distribution, and the acceptable range of error. In the studies listed above, these factors vary widely. For example, in the Maryland and Massachusetts study (Cummings et al 2004), 286 randomly selected roadside plots containing 883 trees were sampled in Massachusetts and 296 randomly selected roadside plots containing 1,124 trees were sampled in Maryland. In the South Dakota study (Ball et al 2007), records for 22,390 trees were collected from a sample of municipalities stratified by population class and location east or west of the Missouri River. In the California study (Lesser 1996), results were generated from 370,000 tree records assembled from twenty-one Southern California municipalities stratified into coastal and inland groups.

Assessments of rural, uncultivated forests are routinely made on a statewide level. For example, the US Forest Service's Forest Inventory and Analysis (FIA) program estimates the number of trees and species and genus composition on both a statewide and regional basis. These estimates are derived from data collected from two sources: first, 4.5 million remote sensing plots interpreted from aerial imagery and, second, 125,000 permanent field plots containing 1.5 million trees (USDA Forest Service 2001). Variables for which data are collected include tree and sapling data (tree species, diameter at breast height, decay class, and damage type), regeneration data (tree species and seedling count), plot level data (size of forested

area, water proximity, trails or roads, recreation use, land use impact), and condition class data (slope, aspect, litter and humus depth, land cover type, and soil type, texture, and erosion class) (USDA Forest Service 1998). These analyses have been used to analyze historical trends in tree species composition, number of trees, and stand density. Data from the FIA program have also been combined with environmental variables such as mean January temperature, annual precipitation, soil bulk density, and soil pH to predict future trends in tree species composition due to climate change (USDA Forest Service 2007). Whether these analyses focus on the future or the past, rural uncultivated forests differ from urban forests in a fundamental way: while rural uncultivated forests are largely, although not exclusively, the product of naturally occurring and landscape scale ecological processes, urban forests, and especially publicly managed street trees, are largely the product of human intervention. In other words, many of the variables and factors that explain the characteristics of rural uncultivated forests will not necessarily explain the characteristics of urban cultivated forests, especially at a statewide or regional level. Nevertheless, the systematic and comprehensive coverage of FIA field data – there are 12,815 FIA field plots alone in New York State, for example (USDA Forest Service 2010a) – provides a breadth and depth of understanding for a state's rural uncultivated forests not yet achieved for a state's urban cultivated forests and, in particular, its publicly managed street trees despite attempts to do so.

It is the premise of this study that, if a sufficient number of street tree inventories can be obtained from municipalities in a state possessing an inventory, then data assembled from these inventories can provide the basis for a statistically valid assessment of street trees on a statewide basis and that this assessment will enable urban forest managers and planners to "see the forest" of publicly managed trees at the statewide level with greater accuracy and extent than has so far been attainable. The number of inventories deemed sufficient will be proportional to the number of municipalities in a state and therefore vary by state; states with a larger number of municipalities will require more inventories and states with a smaller number of municipalities will require fewer inventories. A broad geographic distribution of inventories will also be required to account, first, for variability in tree populations based on environmental factors such as plant hardiness and minimum temperatures, and, second, for similarity due to spatial autocorrelation (i.e. similarity based on proximity) rather than some other causal factor. Finally, data formatting must be standardized between inventory datasets. Since there has been no standardized methodology or format for collecting street tree inventory data, the presence or absence of data fields often differs from one inventory to the next and measures for the same data fields can differ widely also. For example, trunk diameter can be measured at breast height (DBH) at approximately 4½ feet above the ground or by caliper at approximately 6 inches above the ground, and collected as a specific measure or within a class range (e.g. 0 to 6 inches, 6 to 12 inches, etc.); tree condition can vary from good, fair, poor, and dead (four classifications) to excellent, good, fair, poor, very poor, and dead (six classifications), all subject to interpretation; and overhead wires cited for possible conflicts with street trees may

include only single and triple phase utility wires or telephone, cable, and secondary wires as well.

Notwithstanding these requirements and difficulties, the potential benefit of assembling street tree inventory data from multiple municipalities in order to create what would be in effect a statewide inventory of publicly managed trees was recognized by Washington State in March 2008 with passage of the Evergreen Communities Act (ECA). Finding that "about twelve percent of Washington's cities have urban forest management plans" and that the state needed to assist "cities, towns, and counties" in establishing "clear goals and standards for their urban forests," the ECA envisioned assembling a statewide inventory from existing municipal inventories supplemented with additional inventories to be conducted (State of Washington 2008). The statewide inventory would then be paired with remotely sensed canopy cover assessments to provide accurate information about "the condition, structure (species composition), and function of the urban forest" statewide (Washington State DNR 2009). Unfortunately, the economic downturn that occurred later in 2008 after passage of the ECA precipitated budget cuts which have precluded as of this writing implementation of the plan for a statewide inventory (Mead 2010).

Washington State is not alone in wanting a statewide inventory of its publicly managed trees. New York State has cited the creation of a "statewide database of community tree inventories" as a goal in a five year plan "to support municipalities, volunteer groups, and professional organizations in the planning and management of urban and community forests in the state" (New York State 2010). Whether or not this goal will be achieved has yet to be determined. However, due in part to an Urban and Community Forestry program that has funded street tree inventories statewide for many years, New York State possesses numerous inventories for inclusion in such a database. These inventories if assembled and analyzed may be sufficiently numerous and broadly distributed geographically to facilitate an accurate understanding of the structure, functions, and trends of publicly managed trees in New York State. Accordingly, this study has undertaken the following:

- Obtained data from street tree inventories (complete, sample, and partial) from municipalities (cities, villages, and Census Designated Places) throughout New York State

- Conducted additional inventories where needed to improve the geographic breadth of street tree data

- Created a sample of the state's population of publicly managed street trees from all assembled street tree inventory data and assessed sample validity

- Calculated summary statistics from sample data including prevalent street tree species and genera, street tree numbers per street length, and street tree benefits per tree

- Explored correlations between sample data statistics and environmental and social variables that might explain variability in New York State's street tree population

- Generated initial statistical estimates for street tree numbers statewide of prevalent street tree species and genera and statewide benefits provided by street trees

- Identified statewide trends in the planning and management of street tree populations

- Conducted a number of street tree inventories subsequent to generating initial statistical estimates and compared statistics from these inventories with the initial statistical estimates and statewide trends in the planning and management of street tree populations

- Updated initial estimates with test inventory statistics to generate final statewide estimates for street tree numbers statewide of prevalent street tree species and genera and statewide benefits provided by street trees

- Made recommendations on the basis of final statewide estimates and trends identified for the future planning and management of street tree populations in New York State

Finally, the adage "You can't manage what you don't know" is frequently stated as a reason for individual municipalities to inventory their street trees. This study has been undertaken in that vein although at a much more extensive scale. It is hoped that the statistics and estimates contained in this study will enable state and local officials to better plan and manage street trees on a statewide basis. Given the current challenge posed to tree health by invasive pest species and the future challenge likely to be posed by climate change, broad scale planning and management are needed to protect the investments made in publicly managed trees and to preserve the benefits they provide to community residents. Moreover, since these challenges, investments, and benefits are not unique to New York State, but are shared throughout the United States, this study has employed methods that can hopefully be replicated beyond New York State so that improved planning and management of street trees can be facilitated in other states as well.

(2) Street Tree Inventories and Street Length

Summary. A sample of street tree inventory data was assembled from 138 municipalities in New York State. Street length of street types expected to contain street trees was summed for these municipalities. Sample validity was evaluated by comparing this street length measure to the same street length measure for all Census Places in New York State and by USDA Plant Hardiness Zone. Further analysis suggested that street length for Census Blocks with a population density of at least 500 persons per square mile needed to be included in the study. On the basis of the summed street length percentage contained in the 138 municipalities and its relative distribution by USDA Plant Hardiness Zone, sample data was judged sufficient for the purposes of this study. It was decided to group for analysis data contained in municipalities in USDA Hardiness Zones 3 and 4 due to the relative lack of summed street length in Zone 3 and to weight statistical estimates by the relative percentage of summed street length in plant hardiness zones.

New York State is the thirtieth largest state in the United States with a land area of 47,214 square miles; it is also the third most populous state with an estimated population of 19,378,102 in 2010 and the seventh most densely populated state with a population of 410.4 per square mile of land area (US Census Bureau 2011). The state is divided into 62 counties which are subdivided further into 932 towns. At the time of initial writing between 2010 and 2011, it also contained 62 cities and 556 villages incorporated under state law with defined boundaries as well as 435 Census Designated Places (CDPs), unincorporated concentrations of population with defined boundaries identified by a name (NYS GIS Clearinghouse 2010). Results from the 2010 United States Census indicated that the number of cities remained at 62, the number of villages had decreased by one to 555, and the number of CDPs had increased to 572 (US Census Bureau 2011). Change in the number of cities, villages, and CDPs can impact the statistical estimates of this study. Since change in these entities is constant, research methods have been designed to accommodate it. However, in this chapter, the methods and analyses described are based on metrics collected in 2010 prior to the release of results from the 2010 United States Census.

To create a statewide inventory or database of publicly managed trees in New York State, street tree inventories were sought from municipalities throughout the state. Between 2008 and 2010, 586 New York State cities and villages, or 94.82% of all villages and cities in the state, were contacted by e-mail or telephone and asked about the presence or absence of an inventory of community trees. Cities and villages were prioritized rather than counties, towns, and CDPs based in part on surveys conducted in 2004 and 2009 by the New York State Urban & Community Forestry Council (NYSUCFC), a volunteer group organized in 1999 to advise and assist the New York State Department of Conservation (DEC) in executing its Urban and Community Forestry policies. These surveys indicate that in New York State cities are more likely to have a street tree inventory than villages, and towns are much less likely to have an inventory than villages or cities (Table 2.1).

Table 2.1 2004 and 2009 New York State Urban & Community Forestry Council (NYSUCFC) Surveys

Municipality Type	Respondents 2004 + 2009	Respondents per Muni Type	Respondents w/Inventories	Respondents w/Inventories per Muni Type
City (*n*=62)	40	64.52%	42.50%	27.42%
Village (*n*=556)	229	41.19%	29.26%	12.05%
Town (*n*=932)	127	13.63%	5.51%	0.75%

Initial results from seeking inventories from cities and villages in New York State indicated a lack of inventories for municipalities with populations between 20,000 and 80,000. In summer 2008, sample windshield surveys were conducted in six upstate New York State cities (Auburn, Binghamton, Corning, Elmira, Geneva, Utica) according to a stratified land use methodology described in Jaenson et al (1992); tree species and DBH (trunk diameter at breast height) data were collected. Subsequent results indicated a lack of inventories for municipalities in northeastern New York State. In summer 2010, complete windshield surveys were conducted in seven New York State villages (Champlain, Chateaugay, Heuvelton, Keeseville, Port Henry, Rouses Point, and Waddington); data for tree species alone was collected.

Inventories were obtained from most, but not all municipalities responding affirmatively to possessing one. Some municipalities that responded affirmatively were unable to locate their inventory and one municipality refused to provide its data. Other municipalities possessed paper-based inventories which were at least fifteen years old; a judgment was made that these inventories were too out-of-date for their data to be reliably accurate and these municipalities were not asked to provide them. In addition to the street tree inventories obtained from cities and villages, inventories were obtained from thirteen CDPs and two towns. The town inventories are partial inventories conducted for significant portions of those towns. Most of the CDP inventories are inventories conducted for two other towns where data has been apportioned to CDPs contained within town boundaries. Table 2.2 shows the breakdown of municipalities for which street tree inventory data have been obtained in New York State.

Table 2.2 Breakdown of municipalities for which street tree inventory data have been obtained in New York State

Municipality Type	Number of Inventories	Municipality Type Statewide	Percentage of Statewide Municipality Type
City	26	62	41.94%
Village	97	556	17.47%
Town	2	932	0.21%
CDP	13	435	2.99%

With respect to cities and villages, the distribution of inventories obtained is consistent with the distribution of inventories in the 2004 and 2009 NYSUCFC Surveys, namely that street tree inventories are more likely to be found and data obtained for cities than villages. This distribution parallels statistics from the Community Accomplishment Reporting System (CARS) of the USDA Forest Service's Urban and Community Forestry Program. CARS requires states to collect annually urban and community forestry data from municipalities about professional staff, tree protection ordinances or policies, advisory committees, and active urban forest management plans (USDA Forest Service 2010b). The assumption is made that an active urban forest management plan is based on and indicates the existence of a street tree inventory or assessment although inventory type (complete, partial, or sample) may vary and the assessment may include canopy cover analysis from aerial imagery (Parry 2009). The 2009 CARS statistics indicate that 35 of 62 New York State cities, or 56%, and 114 of 556 New York State villages, or 21% possess active management plans assumed to be based on a street tree inventory or assessment; no management plans or assessments were found for New York State CDPs and CARS does not collect data for towns (USDA Forest Service 2010c).

Therefore, street tree inventory data has been obtained from 136 of 1053 cities, villages, and CDPs (12.92%) and portions of two towns in New York State. Figure 2.1 shows the location of these inventories in New York State. This data comprises a sample of New York State's population of publicly managed street trees. Validity of this sample must be assessed. At face value, a sample comprising 12.92% of New York State cities, villages, and CDPs might be considered sufficient, although it is evident from Table 2.2 that cities are better represented percentagewise in this sample than other municipality types such as villages and geographic and demographic differences do exist between cities and villages statewide. For example, in the 2000 US Census, the median population for New York State cities was 20,650 while the median population for New York State villages was 1,757; the mean land area for New York State cities was 11.39 square miles while the mean land area for New York State villages was 1.77 square miles; and the mean population per square mile for New York State cities was 5123.47 while the mean

population per square mile for New York State villages was 2187.15 (US Census Bureau 2010a). These differences may not significantly impact street tree inventory data or bias the data sample obtained. In fact, preliminary analyses associated with this study have found that municipality type, population size, and population density have little explanatory power for street tree population characteristics such as species diversity and genus or species composition. These issues will be discussed in greater detail in subsequent chapters.

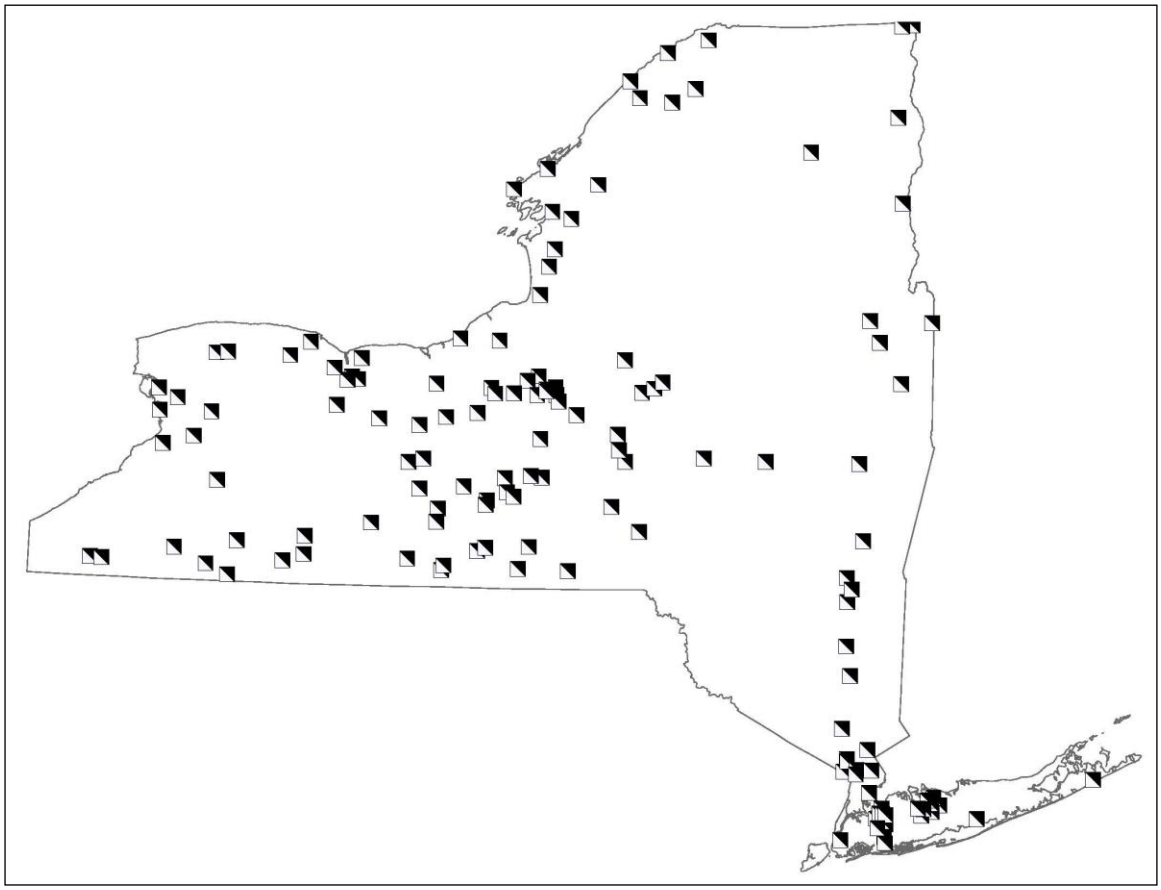


Figure 2.1 Municipalities in New York State where street tree inventory data has been obtained

While municipality type, population size, and population density may not be helpful in assessing the validity of the data sample obtained, land area should be considered, especially with regard to estimating street tree numbers. Municipalities with larger land area can be expected generally to contain more street segments and street length than municipalities with less land area. Since street trees are a function of streets – i.e. without streets there would be no street trees – it is fair to assume that street trees will increase in number as the number of street segments and amount of street length increase. Therefore, assessing the validity of the data sample should consider not simply the number of municipalities from which inventories have been obtained, but the area of those municipalities and, more specifically, the number of street segments and the amount of street length contained in these municipalities.

The number of all street segments contained within and intersecting municipal boundaries can be delineated easily using GIS (Geographic Information Systems) software. Length of these street segments can likewise be easily summed. However, these measures of street segments and street length may not be sufficiently valid for the purposes of this study since not all street segment types are equally likely to contain street trees. For example, primary and secondary roads with underpasses and interstate highways are street types where street trees are unlikely to be found. Consequently, a methodology to differentiate those street types where street trees would be expected to be found from those street types where street trees would not be expected to be found would increase accuracy of any estimates of street tree numbers based on measures of street segment numbers and street length. Such a methodology has been defined in a street segment sampling strategy devised by the USDA Forest Service (2008a) for i-Tree STRATUM software that has been updated for i-Tree Streets software (USDA Forest Service 2010d). In this sampling strategy, streets are differentiated by classes defined by the US Census Bureau in TIGER/Line (Topologically Integrated Geographic Encoding and Referencing system) street centerline GIS shapefiles. Street types classified as "primary road without limited access, US highways, unseparated," "secondary and connecting road, state highways, unseparated," and "local, neighborhood, and rural road, city street, unseparated" would be expected to contain street trees. Street types classified as "primary road with limited access or interstate highway, unseparated," "secondary and connecting road, state highways, unseparated, in tunnel," and "local, neighborhood, and rural road, city street, unseparated, underpassing" would not be expected to contain street trees. Figure 2.2 illustrates these different street types.

Street types expected to contain street trees

Street types not expected to contain street trees

Figure 2.2 Street types expected to contain street trees and not expected to contain street trees

Differentiating street types where street trees would be expected to be found from street types where street trees would not be expected to be found pursuant to i-Tree software's street segment sampling strategy provides a first step in constructing a measure to assess sample validity of street tree inventory data obtained. This measure will compare street length for street types expected to contain street trees for municipalities where street tree inventory data has been obtained with street length for street types expected to contain street trees for all municipalities statewide. Figure 2.3 illustrates a methodology for selecting street types expected to contain street trees. This methodology follows i-Tree software's street segment sampling strategy, but TIGER/Line codes have been adapted for use with New York State ALIS (Accident Location Information System) street centerline files obtained from the New York State GIS Clearinghouse. ALIS files have been selected instead of the TIGER/Line files because such "local" files are updated more regularly and have been found to be more accurate than TIGER/Line files (Zandbergen et al 2011). In addition, streets described in the ALIS files as driveways, parking lots, and "unnamed streets" (e.g. service roads, roads in shopping malls) have been deleted to increase estimate accuracy still further.

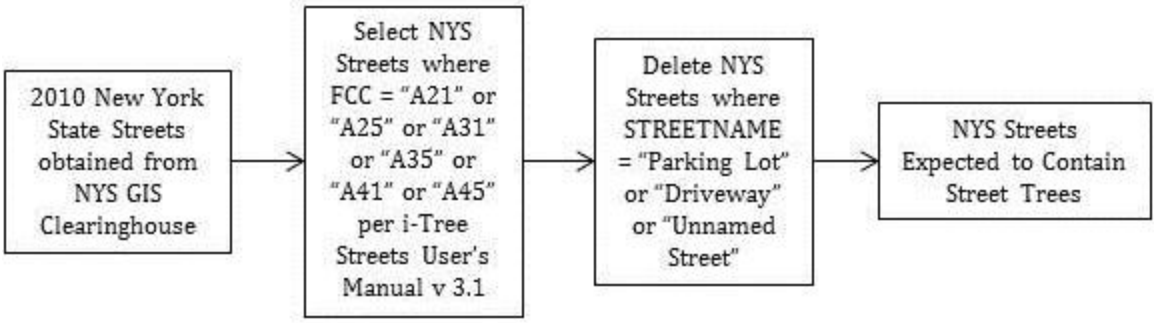


Figure 2.3 Methodology for selecting New York State streets expected to contain street trees

The methodology illustrated in Figure 2.3 does not select streets into municipalities. Accordingly, the first step must be followed by a second as illustrated in Figure 2.4 in which two subsets are derived: (1) "NYS Streets Expected to Contain Street Trees for Municipalities where Street Tree Data has been Obtained" and (2) "NYS Streets Expected to Contain Street Trees for all NYS Census Places." These subsets are produced from a methodology illustrated in Figure 2.4 whereby boundaries from New York State Census Places (i.e. all cities, villages, and CDPs), are used to select street segments contained within or touching municipal boundaries; boundaries for municipalities where street tree inventory data has been obtained are differentiated from boundaries for all municipalities and used to select street segments for these municipalities. Street length is then summed for all street segments contained in these subsets.

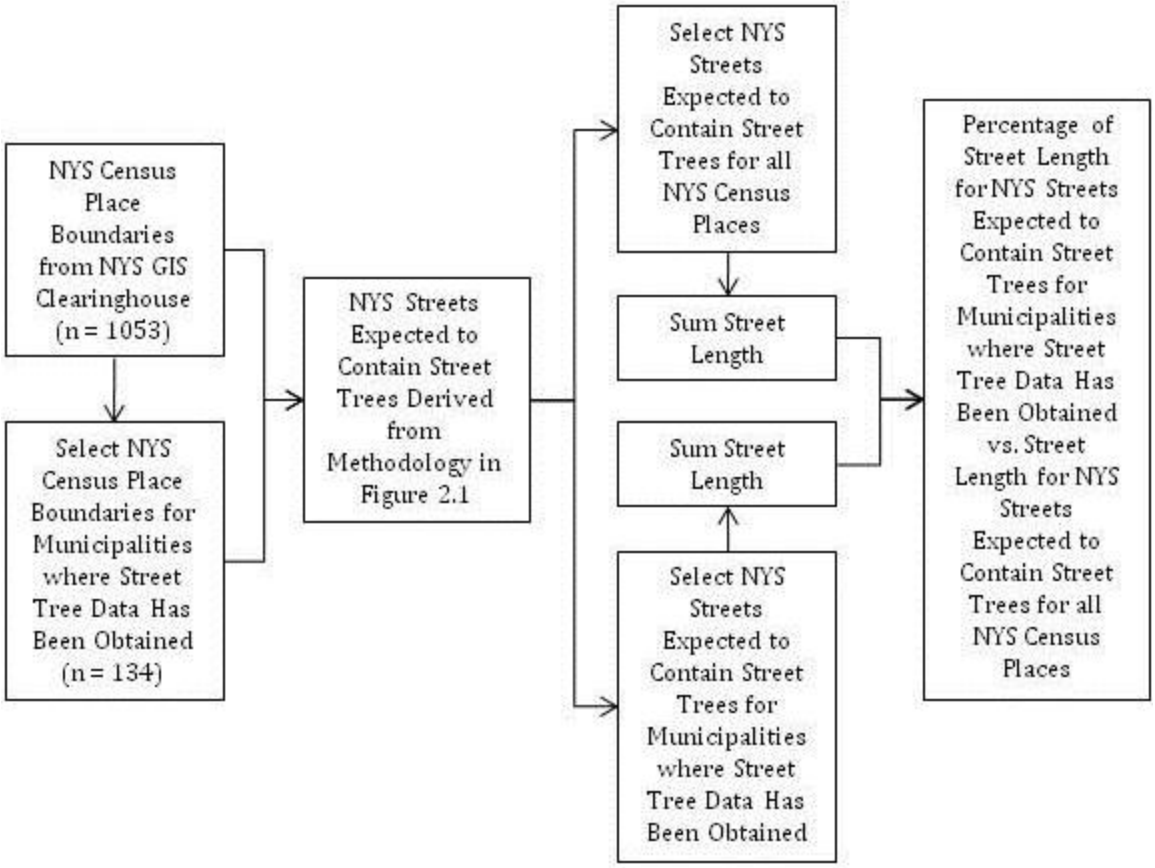


Figure 2.4 Methodology for comparing street length for NYS streets expected to contain street trees for municipalities where street tree inventory data has been obtained with street length for NYS streets expected to contain street trees for all Census Places (cities, villages, and CDPs) in New York State

Results comparing these subsets are as follows: street length for NYS streets expected to contain street trees for all Census Places (cities, villages, and CDPs) in New York State is 65,134,633 meters; street length for NYS streets expected to contain street trees for municipalities where street tree inventory data has been obtained is 21,217,451 meters. Therefore, the percentage of street length for NYS streets expected to contain street trees for municipalities where street tree data has been obtained is approximately 32.57% of street length for NYS streets expected to contain street trees for all Census Places statewide. At face value, this would appear to comprise an adequate sample, especially since for the USDA Forest Service i-Tree street segment sampling strategy where a 10% standard error is acceptable, a 3-6% sample of total street segments is deemed adequate (USDA Forest Service 2008b).

However, consideration should also be given to the geographic distribution of street length and, in particular, to the relationship between street length and minimum temperatures affecting plant hardiness. It was hypothesized early on in this research that geographic variability in New York State street trees would be explained at least in part by winter minimum temperature and plant hardiness. This hypothesis was based in part on horticultural reference books such as Dirr (1998) which judge plant hardiness to be a limiting factory in the landscape use of woody plants. Mean January temperature has also been employed as a predictor variable in the United States Forest Service's RandomForest (RF) Model assessing the current and future status following climate change of 134 tree species in the eastern United States (USDA Forest Service 2007). Finally, winter minimum temperature and plant hardiness have figured in previous analyses of street trees on a regional basis such as Lesser's research in Southern California (1996) where street trees in coastal cities where differentiated from street trees in inland cities, in part because the coastal cities experience very mild winters and the inland cities experience occasional winter frosts.

Since, as stated above, street trees are a function of streets and preliminary analyses associated with this study indicated that geographic variability in the species and genus composition of street trees in New York State could be explained at least in part by minimum winter temperatures affecting plant hardiness, assessment of sample validity and, in particular, the relationship between municipalities where street tree inventory data has been obtained and street length for streets expected to contain street trees should consider not simply summed street length for those municipalities, but the relationship of summed street length to minimum temperatures affecting plant hardiness. Consideration of this relationship is complicated by the fact that measurement of minimum winter temperatures is a complex endeavor made more so by recent evidence of climate change. Additionally, measurement of minimum winter temperatures should be broadly available and replicable by other states to facilitate conducting statewide street tree assessments in those states.

Horticultural reference books such as Dirr (1998) commonly attribute their plant hardiness ratings to the United States Department of Agriculture (USDA) Plant Hardiness Zone Map (US National Arboretum 1990) which plots zones of average annual minimum temperatures for the United States. Each zone is based on a 10° Fahrenheit increment (e.g. Zone 5: -20 to -10°F, Zone 6: -10 to 0°F) and each zone is divided into *a* and *b* zones with lower temperatures in the *a* zone (e.g. Zone5*a*: -20 to -15°F, Zone 5*b*: -15 to -10°F). There are five 1990 USDA Plant Hardiness Zones for New York State: Zones 3, 4, 5, 6, and 7 (Figure 2.4). The USDA decided subsequently to update the 1990 map and a new version depicting changes to 1990 zone boundaries (i.e. a northward movement of zone boundaries reflecting warmer minimum temperatures) was drafted in 2003 by the American Horticultural Society, but was rejected by the USDA on methodological grounds. A new version of the map is expected to be released in 2012.

The USDA Plant Hardiness Zone Map is one example in which minimum winter temperatures have been plotted. The Sunset Publishing Corporation, which publishes Sunset Magazine and Sunset Western Gardener, has created a national map of United States climate zones accounting not only for "winter lows," but also for distance from the equator, elevation, ocean influence, continental air mass influence, mountains and hills, and local terrain (2011). Because the Sunset climate zones are based on many factors besides minimum winter temperatures, they will not be considered further in this discussion. The PRISM (Parameter-elevation Regressions on Independent Slopes Model) Climate Group, Oregon State University (2007) has mapped areas of minimum temperature range from thirty year normals (i.e. the arithmetic mean of values over thirty years) used by the National Climatic Data Center (NCDC) to measure climate data. Finally, the Northeast Regional Climate Center (2011) has plotted areas of minimum monthly and annual temperatures from thirty year normals for states in the northeastern United States, including New York State. PRISM map looks to offer the most precision as 14 zones are mapped in New York State at increments of 2° Fahrenheit. The Northeast Regional Climate Center offers slightly less precision as 9 zones are mapped in New York State at increments of 2° or 3° Fahrenheit. The 1990 USDA Plant Hardiness Zone offers the least precision as 5 zones are mapped in New York State at increments of 10° Fahrenheit. However, while precision of a measure can be an important factor in evaluating accuracy and sample validity, there are additional factors that must be considered such as sample size.

The sample of New York State street tree inventory data is comprised of data assembled from 138 municipalities. This is not a large sample, especially if the municipalities and their data (street tree and street length) are associated with and aggregated by minimum winter temperature range. Since greater sample size tends to produce a sample mean more closely approximating the population mean, and a sample size of $n \geq 30$ is a common threshold to apply the Central Limit Theorem, it is likely to be statistically more advantageous to aggregate data to fewer groups such as those plotted by the 1990 USDA Plant Hardiness Zone Map than to more groups such as those plotted by PRISM and the Northeast Regional Climate Center. In addition, the 1990 USDA Plant Hardiness Zone Map is national in scope, more broadly available, and more widely used than the other data and therefore appears to facilitate more readily research replicability in other states. Based as well on the expectation that an updated version of the 1990 USDA Plant Hardiness Zone Map will be issued in 2012, a decision was made to use the 1990 USDA Plant Hardiness Zone Map to assess sample validity and especially the relationship between street tree inventory data, street length for streets expected to contain street trees, and minimum temperatures affecting plant hardiness

To account for the relationship between street length for NYS streets expected to contain street trees and minimum temperatures affecting plant hardiness in New York State, New York State zone boundaries from the Plant Hardiness Zone Map were digitized with GIS software (Figure 2.5). New York State streets expected to contain street trees identified by the methodology illustrated in Figure 2.3, and selected into municipalities according to the methodology illustrated in Figure 2.4, were then selected into their respective plant hardiness zones and their length summed. The methodology for selecting New York State streets expected to contain street trees into their respective plant hardiness zones and summing their length is described in Figure 2.6. Results are contained in Table 2.3.

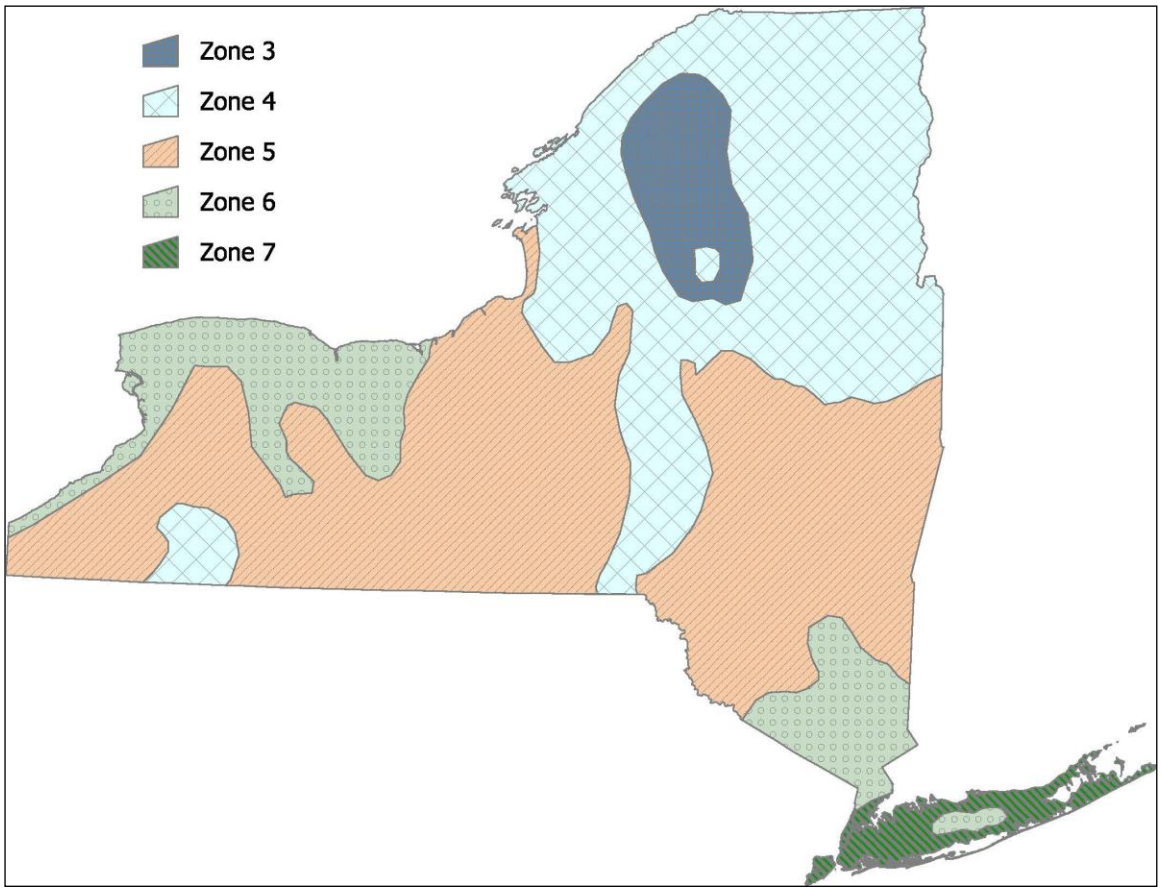


Figure 2.5 1990 USDA Plant Hardiness Zones for New York State

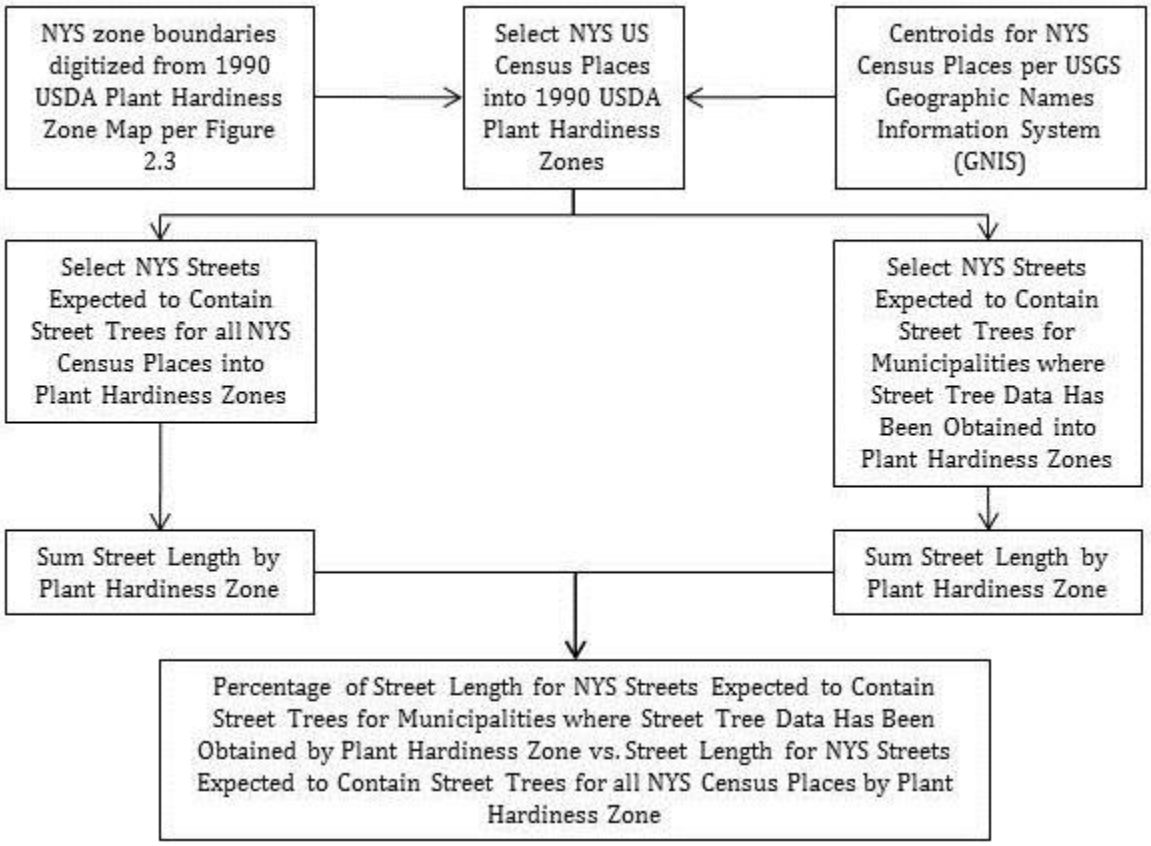


Figure 2.6 Methodology for selecting street length for NYS streets expected to contain street trees statewide and for municipalities where street tree inventory data has been obtained into their respective 1990 USDA Plant Hardiness Zones

Table 2.3 Percentage of street length (meters) by 1990 USDA Plant Hardiness Zone for municipalities where street tree inventory data has been obtained versus all NYS Census Places

	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7
Street Length -- NYS Municipalities With Street Tree Inventory Data	91160	1313156	4175985	3881400	11812080
Street Length -- All NYS Census Places	190874	4342440	13077273	19297512	28226563
Percent Street Length With Inventory Data	47.76%	30.24%	31.93%	20.11%	41.85%

Results shown in Table 2.3 indicate that percent street length with inventory data is less than the statewide average of 32.57% for Zones 4, 5, and 6 and greater than the statewide average of 32.57% for Zones 3 and 7. Having sufficient data for Zones 6 and 7 is a concern since 77.13% of all statewide Census Place street length for streets expected to contain street trees is contained in these densely populated zones which include Westchester, Nassau, and Suffolk Counties and New York City. A 20.11% sample for Zone 6 and a 41.85% sample for Zone 7 would appear at face to be adequate.

It should be noted, however, that percentage of street length expected to contain street trees contained within Census Place boundaries varies considerably by 1990 USDA Plant Hardiness Zone. For example, in Zone 6 the percentage of street length expected to contain street trees contained within Census Place boundaries is 44.90% of all such street length found in Zone 6; in Zone 7 the percentage of street length expected to contain street trees contained within Census Place boundaries is 98.63% of all such street length found in Zone 7. By contrast, in Zone 3 the percentage of street length expected to contain street trees contained within Census Place boundaries is 5.47% of all such street length found in Zone 3; in Zone 4 the percentage of street length expected to contain street trees contained within Census Place boundaries is 11.11% of all such street length found in Zone 4; and in Zone 5 the percentage of street length expected to contain street trees contained within Census Place boundaries is 15.36% of all such street length found in Zone 5. These percentages reflect differences in population density (population per area) and in street length density (street length per area). Table 2.4 illustrates the relationship between the percentage of street length expected to contain street trees contained within Census Place boundaries and street length density.

Table 2.4 Percentage of street length (meters) expected to contain street trees contained within Census Place boundaries and street length density, by 1990 USDA Plant Hardiness Zones for New York State

	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7
Percent Street Length Expected to Contain Street Trees Contained Within Census Place Boundaries	5.47%	11.11%	15.36%	44.90%	98.63%
Street Length Density	0.05%	0.09%	0.15%	0.27%	0.82%

Based on the figures in Table 2.4, it is evident that a sampling methodology relying exclusively on Census Place boundaries may not account sufficiently for all publicly managed street trees in New York State since, other than Zone 7, meaningful fractions of street length expected to contain street trees are not contained within Census Place boundaries. Although much of this street length is located in areas of low population density and would not be expected to contain street trees, some of this street length is located in areas of significant population density, but is not contained within Census Place boundaries (Figure 2.6). Accordingly, a methodology is needed to account for street length expected to contain street trees for areas of significant population density not contained within Census Place boundaries.

Population density of at least 500 persons per square mile (ppsm) within a two and one-half mile road distance "jump" of an urban area has been one criterion used by the Census Bureau to recognize urban territory beyond an urban core (US Census Bureau 2010b). Census Blocks are the most discrete geographical areas used by the Census Bureau for measuring population. Since the area of each Census Block is known, population density can be calculated for Census Blocks and streets can be selected into Census Blocks because they have defined boundaries. Changing the two and one half mile "jump" to a one and one half mile "jump" has been proposed for the 2010 Census due to a perceived overextension of urban area designation. Regardless of this proposed change, the above criterion does not capture population concentrations such as hamlets (populated sections of towns not incorporated as villages) located in suburban or rural areas that may not be contained within Census Places, yet are areas where street trees can be found. Accordingly, the following

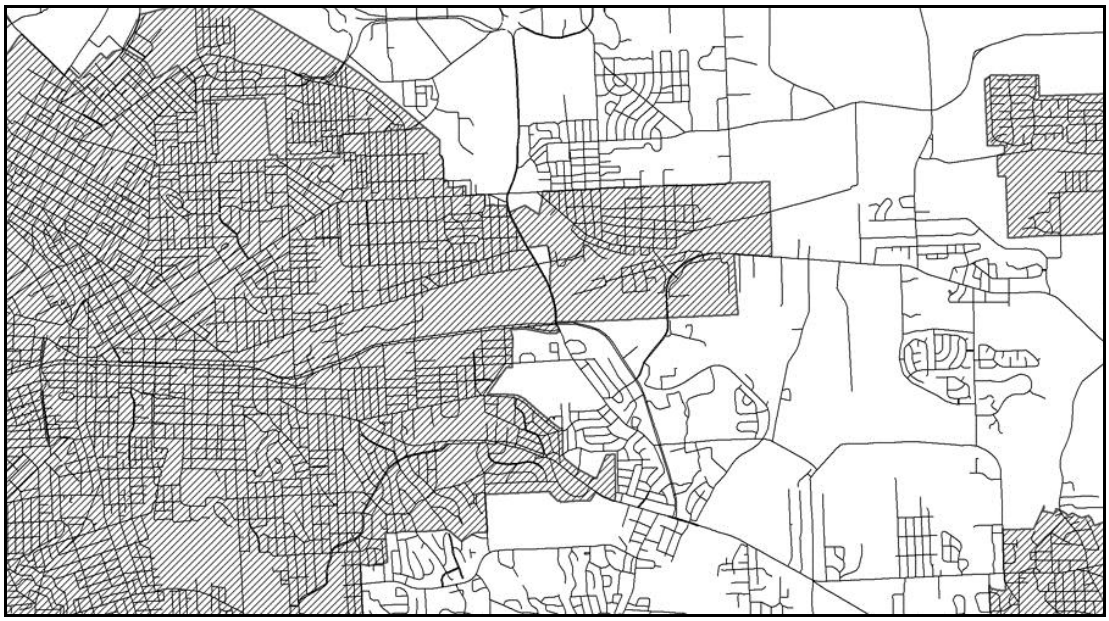


Figure 2.7 Hatched areas show streets of types expected to contain street trees contained within Census Places (City of Syracuse, Villages of East Syracuse, Manlius, and Minoa, Onondaga County, 1990 USDA Plant Hardiness Zone 5)

methodology was employed using Census Blocks to account for street length expected to contain street trees for areas of significant population density not contained within Census Place boundaries, but located both in proximity to urban areas and in more rural areas: (1) New York State Census Blocks from the 2000 Census were obtained from the NYS GIS Clearinghouse (2) Census Blocks contained within Census Places were deleted (3) Remaining Census Blocks with population density of at least 500 ppsm were selected as a subset (4) Subsetted Census Blocks with a population density of at least 500 ppsm were associated with their respective 1990 USDA Plant Hardiness Zones similar to the methodology illustrated in Figure 2.5 (5) New York State streets expected to contain street trees identified by the methodology illustrated in Figure 2.2, were selected into subsetted Census Blocks with a population density of at least 500 ppsm and their length summed. Figure 2.8 illustrates this methodology. Figures 2.9 and 2.10 depict additional streets captured using this methodology compared to Figure 2.7, but without including roads in areas of low population density, such as rural roads. Results from the methodology illustrated in Figure 2.8 are contained in Table 2.5.

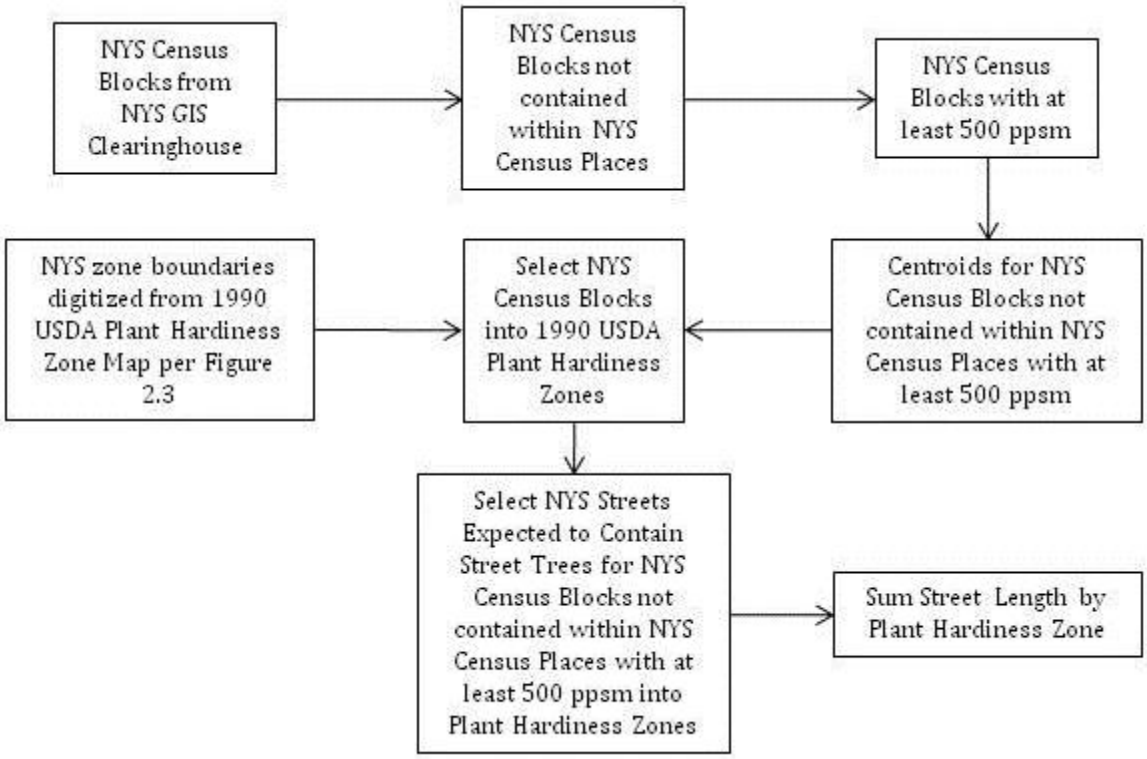


Figure 2.8 Methodology for selecting street length for NYS streets expected to contain street trees statewide for Census Blocks with at least 500 persons per square mile (ppsm) by 1990 USDA Plant Hardiness Zones

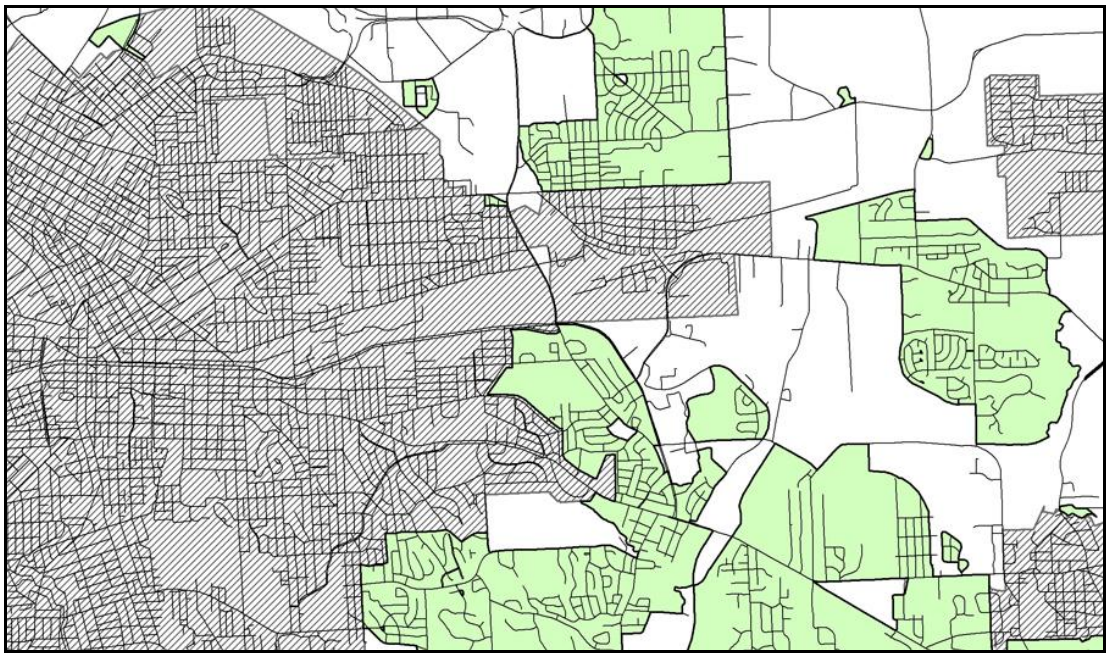


Figure 2.9 Shaded areas show streets of types expected to contain street trees not contained within Census Places (City of Syracuse, Villages of East Syracuse, Manlius, and Minoa, Onondaga County, 1990 USDA Plant Hardiness Zone 5), but which include Census Block population density of at least 500 ppsm

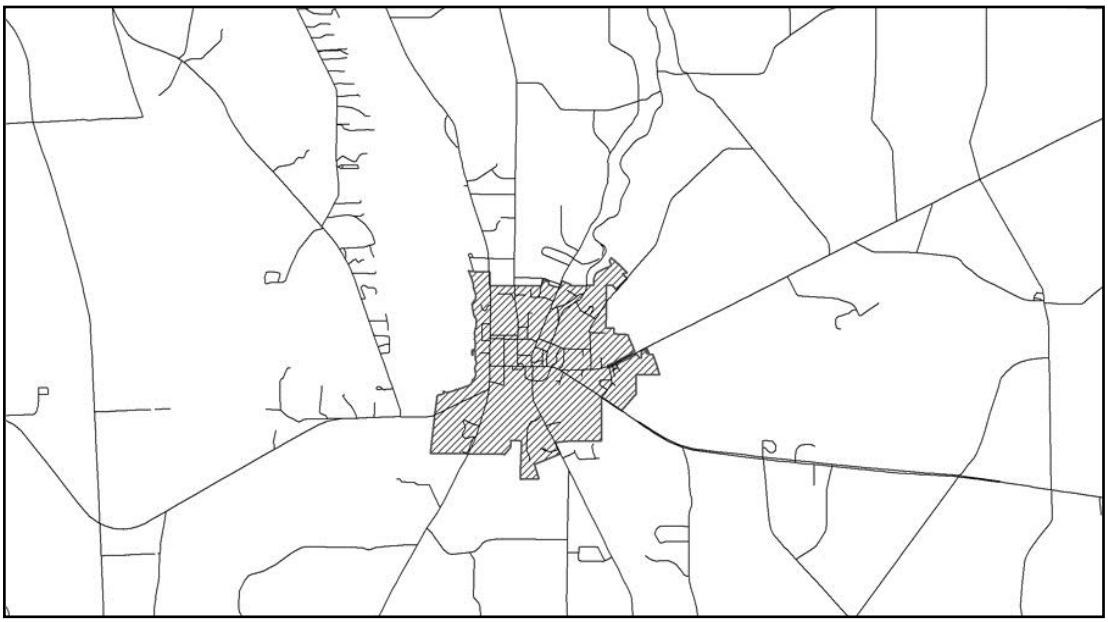


Figure 2.10 Hatched area shows streets of types expected to contain street trees contained within a Census Place: Village of Cazenovia, Onondaga County, 1990 USDA Plant Hardiness Zone 5. Rural roads in low population density areas in proximity to Cazenovia have not been selected using the methodology illustrated in Figure 2.8

Table 2.5 Street length (meters) expected to contain street trees contained within Census Blocks not within Census Places with population density at least 500 ppsm by 1990 USDA Plant Hardiness Zones for New York State

	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7
Street Length Expected to Contain Street Trees Within Census Blocks	132066	3006425	9203697	5847948	67749
Street Length Expected to Contain Street Trees Within Census Places	190874	4342440	13077273	19297512	28294312
Street Length Expected to Contain Street Trees Contained Within Census Blocks and Census Places	322940	7348865	22280970	25145460	28294312
Percent Increase from Street Length Expected to Contain Street Trees Within Census Places	69.19%	69.23%	70.38%	30.30%	0.24%

For 1990 USDA Plant Hardiness Zones 3, 4, 5, and 6, the methodology illustrated in Figure 2.8 and the results contained in Table 2.5 have produced significant additions of street length of streets expected to contain street trees to length contained within Census Places. Total length statewide of streets expected to contain street trees contained within Census Places and Census Blocks with a population density of at least 500 ppsm is 83,392,547 meters or 41.84% of the statewide total of 199,307,142 meters for all such street length. However, since it can be assumed that publicly managed street trees are more likely to be found in areas of greater population concentration than in areas of less population concentration, and in areas with defined boundaries rather than areas without defined boundaries, a population of streets expected to contain street trees contained within Census Places and Census Blocks with a population density of at least 500 ppsm can be expected to provide a more accurate measure of publicly managed street trees in New York State than would all such streets statewide.

Because Zone 3 contains 8 of 1053 Census Places located in New York State (0.76%) and only 322,940 meters of streets expected to contain street trees contained within Census Places and Census Blocks with a population density of at least 500 ppsm compared to 83,393,547 meters of such streets statewide (0.39%), and street tree species hardy in Zone 3 are not significantly different from street tree species hardy in Zone 4, street length and inventory data obtained for Zone 3 will be grouped with street length and inventory data obtained for Zone 4.

Thus, street tree inventory data obtained from 138 municipalities has been associated with street length in meters for streets expected to contain street trees contained within those municipalities and allocated to their respective 1990 USDA Plant Hardiness Zones. Summed street length in meters for streets expected to contain street trees for Census Places where street tree inventory data has been obtained allocated to 1990 USDA Plant Hardiness Zones has been delineated as a measure to assess sample validity. This measure must then be compared to the population of summed street length for all streets expected to contain street trees for all Census Places and Census Blocks not contained within Census Places with population density of at least 500 ppsm allocated similarly to 1990 USDA Plant Hardiness Zones. Table 2.6 shows the results of this comparison.

Table 2.6 Comparison of summed street length (meters) of streets expected to contain street trees for Census Places in New York State where street tree inventory has been obtained with summed street length (meters) of streets expected to contain street trees for all Census Places and Census Blocks not contained within Census Places with population density of at least 500 ppsm in New York State, by 1990 USDA Plant Hardiness Zones.

	Zones 3 + 4	Zone 5	Zone 6	Zone 7
Street Length Expected to Contain Street Trees for Census Places With Inventory Data	1404316	4175985	3881400	11812080
Street Length Expected to Contain Street Trees Contained Within Census Places and Census Blocks	7671805	22280970	25145460	28294312
Percent Street Length Expected to Contain Street Trees for Census Places With Inventory Data vs. All Street Length Expected to Contain Street Trees Contained Within Census Places and Census Blocks	18.30%	18.74%	15.44%	41.75%
Percentage of Statewide Total	9.20%	26.72%	30.15%	33.93%

Percentages range from a low of 15.44% for Zone 6 to a high of 41.75% for Zone 7. These percentages seem at face value to be adequate for sample validity. It should be noted, however, that data collection methodologies vary considerably between the municipalities from which street tree inventory data has been obtained. Some municipalities, for example, collect data for tree genus, but not for tree species; some municipalities collect tree diameter data by the inch while others group tree diameter data within a range of inches. As a result, depending on the variable of concern, street length sample size may be reduced because of limitations of data conformity (e.g. more data may be available for tree genus than is available for tree species). Reduced street length sample size may reduce in turn predictive capacity (e.g. predictive capacity may be greater for genus composition than for species composition). These issues will be addressed later in this study.

Summed street length (meters) of streets expected to contain street trees for all Census Places and Census Blocks with population density of at least 500 ppsm not contained within Census Places varies significantly between the four zone classes (Table 2.6). For example, Zone 7 contains more than 3½ times the summed street length contained in Zones 3 + 4, 27% more summed street length than Zone 5, and 13% more summed street length than Zone 6. These differences in summed street length need to be considered if statewide statistical analyses and estimates are to be accurate and reliable. Therefore, measures such as statewide summary statistics for genus and species composition will need to be weighted by the relative percentage of summed street length contained in each zone class (i.e. Zones 3 + 4, 5, 6, and 7).

(3) Summary Statistics

Summary. Summary statistics, weighted by the relative percentage of summed street length contained within 1990 USDA Plant Hardiness Zone class, were calculated for New York State street trees. *Acer* was found to be the most prevalent street tree genus and *Acer platanoides* the most prevalent species. Significant differences in prevalence were found for many species and genera by zone class, particularly between Zone 7 and the other zone classes. Species diversity increased with milder climate, but was found to be insufficient statewide, suggesting vulnerability to invasive pests such as the Asian Longhorned Beetle and Emerald Ash Borer. Analysis of trunk diameter profiles indicated an aging street tree population requiring an increase in new plantings to maintain statewide numbers at current levels. Statistics for the youngest trees revealed a trend for increased plantings of small sized species in place of large or medium sized species regardless of overhead utility wires and planting location types. Benefits provided per tree were found not to vary by zone class, but significant differences were found by zone class in number of street trees planted per unit street length with Zone 7 having the most trees and Zones 3 and 4 the least.

Street tree inventory data has been obtained from 136 of 1053 cities, villages, and CDPs (12.82%) and portions of two towns in New York State. This data has been allocated to 1990 USDA Plant Hardiness Zones (i.e. Zones 3, 4, 5, 6, and 7) associated with inner centroids of municipal boundaries. Data from Zone 3 has been aggregated with data from Zone 4 and summary statistics generated for four zone classes (i.e. Zones 3 + 4, Zone 5, Zone 6, and Zone 7). Within Zone 7, data from New York City has been disaggregated into its five boroughs (i.e. Bronx, Brooklyn, Manhattan, Queens, and Staten Island), each of which comprises an entire county.

Summed street length (meters) of streets expected to contain street trees for all Census Places and Census Blocks with population density of at least 500 ppsm not contained within Census Places varies significantly between the four zone classes (Table 3.1). For example, Zone 7 contains more than 3½ times the summed street length contained in Zones 3 + 4, 27% more summed street length than Zone 5, and 13% more summed street length than Zone 6. These differences in summed street length need to be considered if statewide statistical analyses and estimates are going to be accurate and reliable. Therefore, measures such as statewide summary statistics for genus and species composition will need to be weighted by the relative percentage of summed street length contained in each zone class (i.e. Zones 3 + 4, 5, 6, and 7). For example, to determine the relative prevalence of street tree species and genera, the mean percentages of street tree species and genera in each zone class have been weighted by the relative percentage of summed street length contained within each zone class according to the formula:

$$((w1 * m1) + (w2 * m2) + (w3 * m3) + (w4 * m4)) / (w1 + w2 + w3 + w4)$$

Where $m1$, $m2$, $m3$, and $m4$ denote the group means for each species and genus (i.e. the mean percentages for 1990 USDA Plant Hardiness Zone classes 3+4, 5, 6, and 7) and $w1$, $w2$, $w3$, and $w4$ denote the different weights for each group (i.e. percentages of summed street length (meters) of streets expected to contain street trees for all Census Places and Census Blocks with population density of at least 500 ppsm not contained within Census Places for 1990 USDA Plant Hardiness Zone classes in New York State) as stated in Table 3.1.

Table 3.1 Summed street length (meters) of streets expected to contain street trees for all Census Places and Census Blocks with population density of at least 500 ppsm not contained within Census Places for 1990 USDA Plant Hardiness Zone classes in New York State.

	Zones 3 + 4	Zone 5	Zone 6	Zone 7
Street Length Expected to Contain Street Trees Contained Within Census Places and Census Blocks	7671805	22280970	25145460	28294312
Percentage of Statewide Total	9.20%	26.72%	30.15%	33.93%

Genus Composition

For each municipality from which data was obtained, trees were aggregated by genus. Trees whose genus was categorized in the data as "unknown" were grouped as "Other." The sum of all trees for each genus was divided by the sum of all trees in each inventory to calculate a percentage for each genus for each inventory accurate to three decimal points. These percentages were allocated to four zone classes (e.g. Zones 3 +4, Zone 5, Zone 6, and Zone 7) based on the 1990 USDA Plant Hardiness Zones associated with their respective municipalities. Mean and median percentage, standard deviation, standard error, and upper and lower confidence levels (α = .10) were calculated for all genera in all zone classes.

To determine the relative prevalence of street tree genera statewide, the mean percentage of each genus in each zone class was weighted by the relative percentage of summed street length expected to contain street trees for all Census Places and Census Blocks with population density of at least 500 ppsm not contained within Census Places within that zone class. Weighted mean percentages were ranked to determine relative prevalence statewide. Genera whose weighted mean percentage was found to be at least 1.000% were judged to be prevalent. Together these genera account for 87.075% of all trees for whom data was obtained. Table 3.2 shows statistics for the relative prevalence of street tree genera statewide.

Table 3.2 Relative prevalence of street tree genera statewide (n=142)

Genus	**Zones 3 + 4 (mean %, *n*=31)**	**Zone 5 (mean %, *n*=60)**	**Zone 6 (mean %, *n*=28)**	**Zone 7 (mean %, *n*=23)**	**Weighted Mean %, All Zones**
Acer	54.774	55.880	51.080	25.830	44.135
Quercus	3.960	2.895	4.852	13.042	7.026
Platanus	0.101	0.654	3.812	13.142	5.792
Pyrus	2.245	2.423	3.302	10.359	5.364
Gleditsia	4.304	4.915	6.164	4.108	4.962
Tilia	3.551	3.234	4.472	4.559	4.086
Fraxinus	5.396	3.693	3.713	2.215	3.355
Picea	4.162	5.706	2.032	1.389	2.992
Prunus	1.342	2.198	2.509	4.048	2.841
Malus	4.490	4.277	2.304	0.659	2.474
Pinus	2.041	1.713	1.351	1.694	1.627
Ulmus	1.353	0.904	1.616	1.501	1.363
Robinia	1.271	0.822	1.123	1.130	1.058

Percentages for some street tree genera vary meaningfully between zone classes in Table 3.2. For example, *Platanus* is scarce in Zones 3 + 4 and 5, but is more common in Zones 6 and 7, presumably due to plant hardiness and minimum temperatures, and prevalence of *Acer* in Zone 7 is substantially reduced from prevalence in the other zone classes. This variation is illustrated in Figure 3.1.

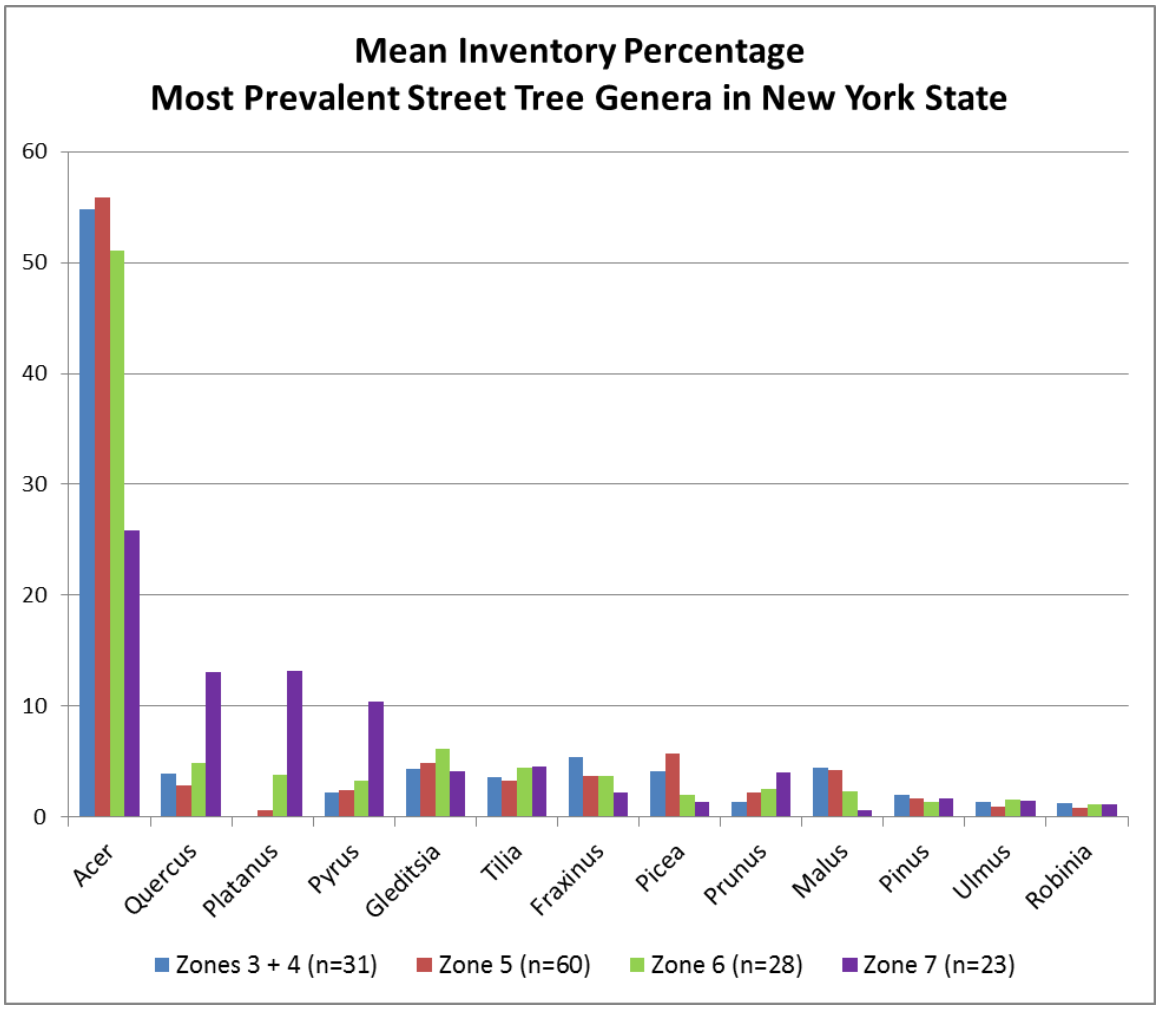


Figure 3.1 Mean inventory percentage for most prevalent street tree genera in New York State by 1990 USDA Plant Hardiness Zone classes

Finally, summary statistics have been generated for prevalent street tree genera in each zone class (i.e. Zones 3 + 4, Zone 5, Zone 6, and Zone 7). These statistics can be found in Table 3.3.

Table 3.3 Summary statistics for prevalent street tree genera in New York State by 1990 USDA Plant Hardiness Zone classes

Zones 3 + 4 (*n*=31)	**Mean**	**Median**	**StdDev**	**StdErr**	**UCL 90%**	**LCL 90%**
Acer	54.774	56.977	15.445	2.774	59.337	50.211
Fraxinus	5.396	4.140	4.092	0.735	6.605	4.188
Malus	4.490	3.185	4.393	0.789	5.788	3.193
Gleditsia	4.304	2.986	4.179	0.751	5.538	3.069
Picea	4.162	3.822	3.286	0.590	5.132	3.191
Quercus	3.960	2.098	4.093	0.735	5.170	2.751
Tilia	3.551	2.064	3.651	0.656	4.630	2.473
Pyrus	2.245	1.745	2.711	0.487	3.046	1.444
Pinus	2.041	0.955	3.262	0.586	3.004	1.077
Ulmus	1.353	0.873	1.967	0.353	1.934	0.771
Prunus	1.342	0.867	1.417	0.255	1.760	0.923
Robinia	1.271	0.262	2.573	0.462	2.031	0.511
Platanus	0.101	0.000	0.300	0.054	0.189	0.012

Zone 5 (*n*=60)	**Mean**	**Median**	**StdDev**	**StdErr**	**UCL 90%**	**LCL 90%**
Acer	55.880	55.869	12.163	7.214	67.747	44.013
Picea	5.706	4.305	5.188	0.737	6.918	4.495
Gleditsia	4.915	4.054	3.967	0.634	5.959	3.871
Malus	4.277	3.492	3.443	0.552	5.185	3.369
Fraxinus	3.693	3.391	2.657	0.477	4.477	2.909
Tilia	3.234	2.129	3.434	0.417	3.920	2.547
Quercus	2.895	2.256	2.498	0.374	3.510	2.281
Pyrus	2.423	1.853	2.475	0.313	2.937	1.908
Prunus	2.198	1.565	2.004	0.284	2.664	1.731
Pinus	1.713	0.967	2.243	0.221	2.077	1.349
Ulmus	0.904	0.604	0.889	0.117	1.096	0.712
Robinia	0.822	0.360	1.050	0.106	0.997	0.648
Platanus	0.654	0.378	0.868	0.084	0.792	0.515

Zone 6 (*n*=28)	**Mean**	**Medan**	**StdDev**	**StdErr**	**UCL 90%**	**LCL 90%**
Acer	51.080	46.995	17.943	3.391	56.659	45.502
Gleditsia	6.164	5.523	4.089	0.773	7.436	4.893
Quercus	4.852	3.134	5.466	1.033	6.551	3.153
Tilia	4.472	2.640	4.527	0.856	5.879	3.065
Platanus	3.812	1.653	6.221	1.176	5.746	1.878
Fraxinus	3.713	2.119	3.138	0.593	4.689	2.738
Pyrus	3.302	2.022	4.391	0.830	4.667	1.936
Prunus	2.509	1.844	2.380	0.450	3.249	1.769
Malus	2.304	1.282	2.573	0.486	3.104	1.504
Picea	2.032	1.177	2.188	0.414	2.713	1.352
Ulmus	1.616	0.673	2.411	0.456	2.366	0.867
Pinus	1.351	0.738	1.556	0.294	1.835	0.867
Robinia	1.123	0.473	1.889	0.357	1.710	0.536

Zone 7 (*n*=23)	Mean	Median	StdDev	StdErr	UCL 90%	LCL 90%
Acer	25.830	24.324	10.960	2.285	29.590	22.071
Quercus	13.142	12.868	9.275	1.934	16.323	9.961
Platanus	13.042	12.423	5.401	1.126	14.895	11.190
Pyrus	10.359	7.183	10.751	2.242	14.046	6.671
Tilia	4.559	3.426	3.693	0.770	5.826	3.293
Gleditsia	4.108	2.340	5.049	1.053	5.840	2.377
Prunus	4.048	3.829	1.989	0.415	4.730	3.366
Fraxinus	2.215	2.022	1.182	0.246	2.621	1.810
Pinus	1.694	0.588	1.862	0.388	2.332	1.055
Ulmus	1.501	0.898	2.052	0.428	2.205	0.797
Picea	1.389	0.310	1.747	0.364	1.988	0.790
Robinia	1.130	0.572	1.504	0.314	1.646	0.614
Malus	0.659	0.344	0.996	0.208	1.001	0.318

Species Composition

For each municipality from which data was obtained, trees were aggregated by species. The number of municipalities from which species data was obtained is less than the number of municipalities from which genus data was obtained primarily because some municipalities collect street tree data for genus (e.g. *Acer species*) but not for species (e.g. *Acer saccharum*). Trees categorized in the data as "unknown" were grouped as "Other."

Similar to the methodology employed to generate statistics for street tree genera, the sum of all trees for each species was divided by the sum of all trees in each inventory to calculate a percentage for each species for each inventory accurate to three decimal points. These percentages were allocated to four zone classes (e.g. Zones 3 +4, Zone 5, Zone 6, and Zone 7) based on the 1990 USDA Plant Hardiness Zones associated with their respective municipalities. Mean and median percentage, standard deviation, standard error, and upper and lower confidence levels ($\alpha = .10$) were calculated for all species in all zone classes.

Again, following the methodology employed for street tree genera, to determine the relative prevalence of street tree species statewide, the mean percentage of each species in each zone class was weighted by the relative percentage of summed street length expected to contain street trees for all Census Places and Census Blocks with population density of at least 500 ppsm not contained within Census Places within that zone class. Weighted mean percentages were ranked to determine relative prevalence statewide. Species whose weighted mean percentage was found to be at least 1.000% were judged to be prevalent. Together these species account for 72.255% of all trees for whom data was obtained. Table 3.4 shows statistics for the relative prevalence of street tree species statewide.

Table 3.4 Relative prevalence of street tree species statewide (*n*=132)

Species	**Zones 3+4 (Mean %, *n*=28)**	**Zone 5 (Mean %, *n*=57)**	**Zone 6 (Mean %, *n*=29)**	**Zone 7 (Mean %, *n*=18)**	**Weighted Mean %, All Zones**
Acer platanoides	15.524	21.248	28.359	14.729	20.653
Acer saccharum	20.612	20.190	5.626	2.665	9.892
Acer saccharinum	6.844	6.232	8.877	2.424	5.794
Platanus x acerifolia	0.057	0.485	3.283	13.551	5.722
Acer rubrum	6.243	5.288	5.498	4.859	5.294
Gleditsia triacanthos	4.222	4.853	6.205	4.875	5.210
Pyrus calleryana	2.281	2.440	3.184	8.534	4.718
Quercus palustris	0.661	0.760	2.397	5.265	2.773
Tilia cordata	2.295	2.277	3.238	2.646	2.694
Malus species	4.540	4.245	2.220	0.664	2.447
Fraxinus pennsylvanica	2.252	2.145	1.761	1.979	1.983
Quercus rubra	1.867	1.472	1.229	2.220	1.689
Picea abies	0.867	2.728	0.673	0.762	1.270
Pinus strobus	1.565	0.862	0.785	1.395	1.084
Robinia pseudoacacia	1.110	0.833	1.082	1.125	1.033

As with the genera statistics, percentages for some street tree species vary meaningfully between zone classes in Table 3.4. For example, *Acer saccharum* (Sugar Maple) is the most prevalent street tree species in Zones 3 + 4 and second most prevalent in Zone 5, but is much less prevalent in Zones 6 and 7. Similarly, *Malus species* (Crabapple Species) is more common in Zones 3 + 4 and Zone 5 and less common in Zones 6 and 7, while conversely *Pyrus calleryana* (Callery Pear) is more common in Zones 6 and 7 and less common in Zones 3 + 4 and Zone 5. This variation is illustrated in Figure 3.2.

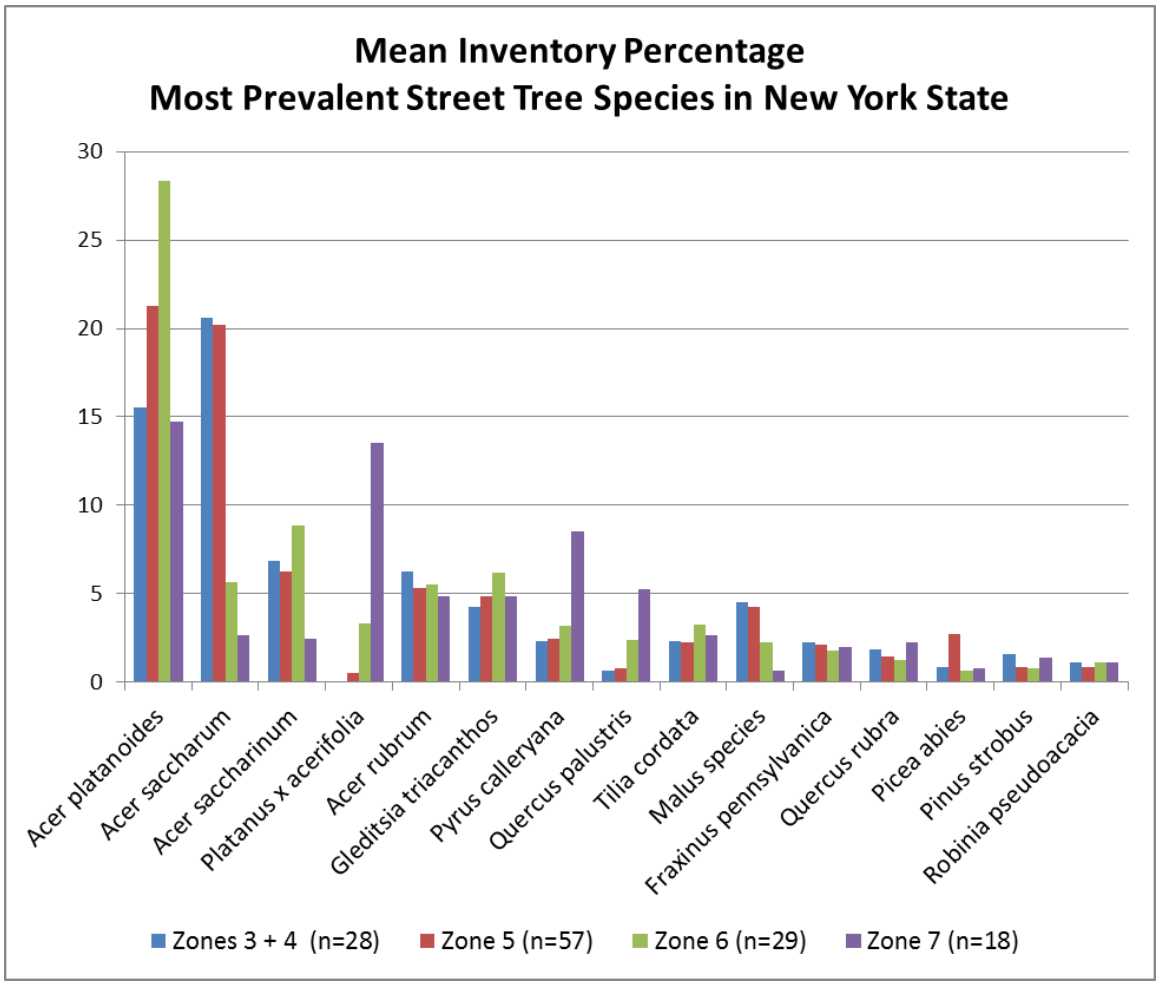


Figure 3.2 Mean inventory percentage for most prevalent street tree species in New York State by 1990 USDA Plant Hardiness Zone classes

Finally, summary statistics have been generated for prevalent street tree species in each zone class (i.e. Zones 3 + 4, Zone 5, Zone 6, and Zone 7). These statistics can be found in Table 3.5.

Table 3.5 Summary statistics for prevalent street tree species in New York State by 1990 USDA Plant Hardiness Zone classes

Zones 3 + 4 (*n*=28)	**Mean**	**Median**	**StdDev**	**StdErr**	**UCL 90%**	**LCL 90%**
Acer saccharum	20.612	20.135	11.278	2.131	24.118	17.106
Acer platanoides	15.524	14.330	12.613	2.384	19.445	11.603
Acer saccharinum	6.844	3.708	10.151	1.918	10.000	3.688
Acer rubrum	6.243	5.727	3.648	0.689	7.377	5.109
Malus species	4.540	3.339	4.518	0.854	5.944	3.136
Gleditsia triacanthos	4.222	3.120	3.775	0.713	5.396	3.049
Tilia cordata	2.295	0.839	2.930	0.554	3.206	1.384
Pyrus calleryana	2.281	1.919	2.679	0.506	3.114	1.448
Fraxinus pennsylvanica	2.252	1.418	2.522	0.477	3.036	1.468
Quercus rubra	1.867	0.639	2.682	0.507	2.700	1.033
Pinus strobus	1.565	0.368	2.569	0.486	2.363	0.766
Robinia pseudoacacia	1.110	0.289	2.284	0.432	1.820	0.400
Picea abies	0.867	0.390	1.074	0.203	1.201	0.533
Quercus palustris	0.661	0.343	1.100	0.208	1.003	0.319
Platanus x acerifolia	0.057	0.000	0.178	0.034	0.113	0.002

Zone 5 (*n*=57)	**Mean**	**Median**	**StdDev**	**StdErr**	**UCL 90%**	**LCL 90%**
Acer platanoides	21.248	20.234	10.270	1.360	23.485	19.010
Acer saccharum	20.190	17.702	14.253	1.888	23.296	17.085
Acer saccharinum	6.232	4.000	6.925	0.917	7.741	4.723
Acer rubrum	5.288	4.383	3.413	0.452	6.032	4.545
Gleditsia triacanthos	4.853	3.720	3.988	0.528	5.722	3.984
Malus species	4.245	3.415	3.508	0.465	5.010	3.481
Picea abies	2.728	2.000	2.625	0.348	3.300	2.156
Pyrus calleryana	2.440	1.910	2.506	0.332	2.986	1.894
Tilia cordata	2.277	1.189	2.743	0.363	2.875	1.680
Fraxinus pennsylvanica	2.145	1.439	2.457	0.325	2.680	1.609
Quercus rubra	1.472	1.095	1.333	0.177	1.762	1.181
Pinus strobus	0.862	0.219	1.641	0.217	1.219	0.504
Robinia pseudoacacia	0.833	0.355	1.070	0.142	1.066	0.600
Quercus palustris	0.760	0.261	1.403	0.186	1.066	0.455
Platanus x acerifolia	0.485	0.178	0.765	0.101	0.651	0.318

Zone 6 (*n*=29)	Mean	Median	StdDev	StdErr	UCL 90%	LCL 90%
Acer platanoides	28.359	28.110	12.117	2.250	32.060	24.657
Acer saccharinum	8.877	4.252	11.001	2.043	12.238	5.517
Gleditsia triacanthos	6.205	5.686	3.931	0.730	7.405	5.004
Acer saccharum	5.626	3.518	5.877	1.091	7.421	3.831
Acer rubrum	5.498	3.963	5.953	1.105	7.316	3.680
Platanus x acerifolia	3.283	0.833	6.101	1.133	5.147	1.419
Tilia cordata	3.238	2.065	3.939	0.731	4.442	2.035
Pyrus calleryana	3.184	1.830	4.246	0.788	4.481	1.888
Quercus palustris	2.397	0.441	3.674	0.682	3.519	1.274
Malus species	2.220	1.235	2.496	0.463	2.982	1.458
Fraxinus pennsylvanica	1.761	0.833	2.190	0.407	2.430	1.092
Quercus rubra	1.229	0.714	1.269	0.236	1.616	0.841
Robinia pseudoacacia	1.082	0.417	1.835	0.341	1.643	0.522
Pinus strobus	0.785	0.093	1.315	0.244	1.187	0.383
Picea abies	0.673	0.311	1.218	0.226	1.045	0.301

Zone 7 (*n*=18)	Mean	Median	StdDev	StdErr	UCL 90%	LCL 90%
Acer platanoides	14.729	12.493	9.141	2.155	18.274	11.185
Platanus x acerifolia	13.551	12.921	8.824	2.080	16.972	10.130
Pyrus calleryana	8.534	6.890	7.955	1.875	11.619	5.450
Quercus palustris	5.265	5.773	2.161	0.509	6.103	4.427
Gleditsia triacanthos	4.875	3.121	5.305	1.251	6.933	2.818
Acer rubrum	4.859	4.903	2.829	0.667	5.956	3.763
Acer saccharum	2.665	1.557	2.763	0.651	3.736	1.594
Tilia cordata	2.646	1.970	1.903	0.449	3.384	1.908
Acer saccharinum	2.424	2.380	1.506	0.355	3.008	1.840
Quercus rubra	2.220	1.961	1.204	0.284	2.687	1.753
Fraxinus pennsylvanica	1.979	1.859	1.197	0.282	2.444	1.515
Pinus strobus	1.395	0.307	1.728	0.407	2.066	0.725
Robinia pseudoacacia	1.125	0.724	1.261	0.297	1.614	0.636
Picea abies	0.762	0.104	1.080	0.255	1.181	0.343
Malus species	0.664	0.352	1.039	0.245	1.067	0.261

Species and Genus Diversity

As a general rule, no tree species should comprise more than 10% and no tree genera should comprise more than 20% of a municipality's street tree population (Santamour 1990). Bassuk et al (2009) have taken this rule further and proposed limiting any tree species to between 5% and 10% of a municipality's street tree population; Ball et al (2007) have recommended a 10% limit on genera based on full stocking; and Cummings et al (2004) suggest that diversity should be evaluated at taxonomic classification levels higher than genus such as family. Whatever the percentage or the level, the underlying principle is the same: diversity is a key

component in the long term health of street tree populations. As was learned from the devastation wrought by Dutch elm disease to streets lined with American Elms, excessive planting of any tree species (i.e. low species diversity) renders a large proportion of a municipality's street tree population vulnerable to depredation from an insect or disease. Conversely, distributing plantings more equally among a range of tree species (i.e. high species diversity) reduces such vulnerability since, if any one species or genus becomes susceptible to an insect or disease, a majority of the municipality's street tree population will likely not be affected.

On a statewide basis, the percentage of *Acer* (44.135) exceeds the 20% rule for genera and the percentage of *Acer platanoides* (20.653) exceeds the 10% rule for species. Within the 1990 USDA Plant Hardiness Zone classes, the percentage of *Acer* exceeds the 20% rule for genera in all four zone classes (50.211, 55.880, 45.502, 22.071), the percentage of *Acer platanoides* exceeds the 10% rule for species in all four zone classes (15.524, 21.248, 28.359, 14.729) , the percentage of *Acer saccharum* exceeds the 10% rule for species in Zones 3 + 4 (20.612) and Zone 5 (20.190), and the percentage of *Platanus x acerifolia* (13.551) exceeds the 10% rule for species in Zone 7. Additional genera and species exceed the 20% and 10% rules within specific municipalities. For example, the percentages of *Tilia* (21.107) in Buffalo (Erie County, Zone 6) and *Pyrus* (36.375) in Garden City Park (Nassau County, Zone 7) exceed the 20% rule for genera, and the percentages of *Acer saccharinum* (49.448) in Cape Vincent (Jefferson County, Zones 3 + 4) and *Gleditsia triacanthos* (20.528) in Hilton (Monroe County, Zone 6) exceed the 10% rule for species.

Another measure of species diversity is Simpson's Diversity Index (SDI) which accounts for the number of species present in a population and the abundance of each species. Sun (1992) used the inverse of the SDI (i.e. 1/SDI) to study street tree populations in twenty-one cities and towns in the United States, United Kingdom, China, Greece, and Hong Kong. A larger inverse SDI value indicates greater species diversity and a smaller inverse SDI value indicates less species diversity. Because the inverse SDI value represents the number of species if all species were evenly distributed in a population, an inverse SDI value of 10 approximates conformity with a 10% rule for species diversity and an inverse SDI value of 20 approximates conformity with a 5% rule for species diversity.

Inverse SDI values were calculated for the 132 municipalities from which street tree species data has been obtained. The mean inverse SDI and median inverse SDI were found to be 8.65 and 7.86 respectively. Only 36 of 131 municipalities (27.48%) were found to have an inverse SDI of at least 10.00. There was some variation in the inverse SDI values between municipalities by 1990 USDA Plant Hardiness Zone class: the mean inverse SDI value for Zone 7 (11.79) was significantly higher than the mean inverse SDI values for Zones 3 + 4 (8.08), Zone 5 (8.16), and Zone 6 (8.20). Finally, inverse SDI values for all municipalities were found to be weakly correlated with municipal population size (.12) and population density (.11).

The Shannon-Weiner Diversity Index is sometimes preferred to the SDI because the SDI weights the most abundant species more heavily than the less abundant species; on the other hand, SDI values are less sensitive to variation in sample size (Barbour et al 1987). McPherson and Rowntree (1989) used the Shannon-Weiner Diversity Index to measure street tree species diversity for twenty-two municipalities in the United States including two in New York State, the City of Syracuse and the Village of Great Neck Estates. Shannon-Weiner values ranged from 2.1 to 3.9 and the mean for all municipalities was 2.7. McPherson and Rowntree found that species diversity was greatest in municipalities with milder climates and attributed the higher values in these cities more to the larger number of species than to the evenness of species distribution.

Shannon-Weiner values were calculated for the 132 municipalities from which street tree species data has been obtained. Mean and median values were found to be 2.66 and 2.67 respectively with a range from 1.73 to 3.92. Similar to results for inverse SDI values, there was some variation in Shannon-Weiner values between municipalities by 1990 USDA Plant Hardiness Zone class: the mean Shannon-Weiner value for Zone 7 (2.95) was significantly higher than the mean Shannon-Weiner values for Zones 3 + 4 (2.55), Zone 5 (2.64), and Zone 6 (2.60). Consistent with the findings made by McPherson and Rowntree, higher Shannon-Weiner values were correlated more with a larger number of species (0.62) than with the evenness of species distribution (0.23). Finally, and once again similar to results for inverse SDI values, Shannon-Weiner values for all municipalities were found to be weakly correlated with municipal population size (.14) and population density (.13).

Thus, results for inverse SDI and Shannon-Weiner values coupled with summary statistics for genus and species composition reveal insufficient species and genus diversity in New York State street trees. Consistent with the findings made by McPherson and Rowntree, species diversity increased with milder temperatures and higher species diversity should be attributed more to a larger number of species than to the evenness of species distribution. Although species diversity was found to be appreciably greater in Zone 7 than in Zones 3+4, 5, and 6, even for Zone 7, where Acer (22.071) exceeds the 20% rule for genera and *Acer platanoides* (14.729) and *Platanus x acerifolia* (13.551) exceed the 10% rule for species, diversity should be increased to reduce street tree population vulnerability to depredation from an insect or disease. Of particular worry in this respect is the Asian Longhorned Beetle (ALB), an invasive pest which has been found in New York City, on Long Island, and elsewhere in the United States and Canada. Because *Acer* is among the tree genera attacked and killed by the ALB, and *Acer* species have been excessively planted as street trees in New York State, a large proportion of the New York State street tree population is vulnerable to the ALB. Therefore, new street tree plantings statewide should de-emphasize trees in the *Acer* genus.

Relative Age Distribution

Another component in the long term health of street tree populations is the relative age distribution of street trees. There needs to be a sufficient number of younger, smaller trees to account for the loss of trees over time in order to maintain a sustainable street tree population. Because of mortality among both newly planted trees failing to achieve maturity and older trees reaching the end of their life cycle, the number of younger trees should exceed the number of older trees, creating a j-shaped profile in the relative age distribution. Figure 3.3 contains two graphs depicting contrasting age distribution profiles in street tree populations with tree diameter measured at breast height (DBH). The j-shaped profile on the left depicts a sustainable street tree population with sufficient younger, smaller trees to account for the loss of trees over time. The inverted v-shaped profile on the right depicts a street tree population not sustainable over time because it contains insufficient younger trees and a disproportionate share of older trees.

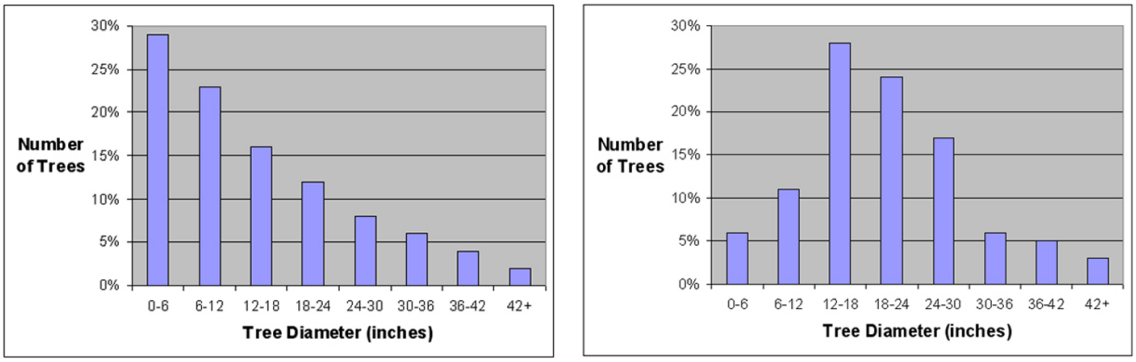


Figure 3.3 Street tree population age profiles: the population on the left contains a sufficient number of younger, smaller trees to account for the loss of trees over time and is therefore sustainable whereas the population on the right contains too many older trees and is therefore not sustainable.

In the sustainable j-shaped relative age distribution profile, approximately 30% of a street tree population is contained within the 0 to 6 inch DBH class. Another profile of DBH distribution has been postulated by Richards (1983) such that a sustainable distribution of street trees would find 40% of trees with a DBH less than 8 inches, 30% of trees with a DBH 8 to 16 inches, 20% of trees with a DBH 16 to 24 inches, and 10% of trees with a DBH greater than 24 inches. While Richards's profile accounts for approximately 12.5% more trees within a DBH 0 to 24 inch class than does the sustainable j-shaped relative age distribution profile and also accounts for slightly more trees within the 0 to 6 inch DBH class than does sustainable j-shaped relative age distribution profile, the sustainable j-shaped relative age distribution profile and DBH classes in 6 inch intervals are much more widely used in urban forestry. Therefore, DBH classes in 6 inch intervals, including the 0 to 6 inch DBH class and the 30% benchmark for that class, will be used in the subsequent analysis of the relative age distribution of street trees in New York State.

For each municipality from which data was obtained, trees were aggregated into the following eight DBH classes: 0 to 5.9 inches, 6 to 11.9 inches, 12 to 17.9 inches, 18 to 23.9 inches, 24 to 29.9 inches, 30 to 35.9 inches, 36 to 41.9 inches, and 42 inches and greater. The number of municipalities for which DBH data was aggregated is less than the number of municipalities from which genus data was obtained because DBH data was not collected for some municipalities or DBH data was collected in classes other than those specified above. For each municipality, aggregated DBH data was converted to a percentage of all trees in the inventory for each DBH class. Percentages were allocated to the 1990 USDA Plant Hardiness Zone class associated with the municipality. Means for each zone class were calculated and weighted in a manner similar to genus and species composition (i.e. by the relative percentage of summed street length expected to contain street trees for all Census Places and Census Blocks with population density of at least 500 ppsm not contained within Census Places within that zone class – see Table 3.1). Figure 3.4 depicts a statewide distribution of New York State street trees by DBH class. Its profile corresponds more closely to the street tree population age profile in Figure 3.3 judged to be not sustainable because it contains insufficient younger trees and a disproportionate share of older trees. It indicates that increased numbers of street trees need to be planted statewide to maintain street tree populations at current levels.

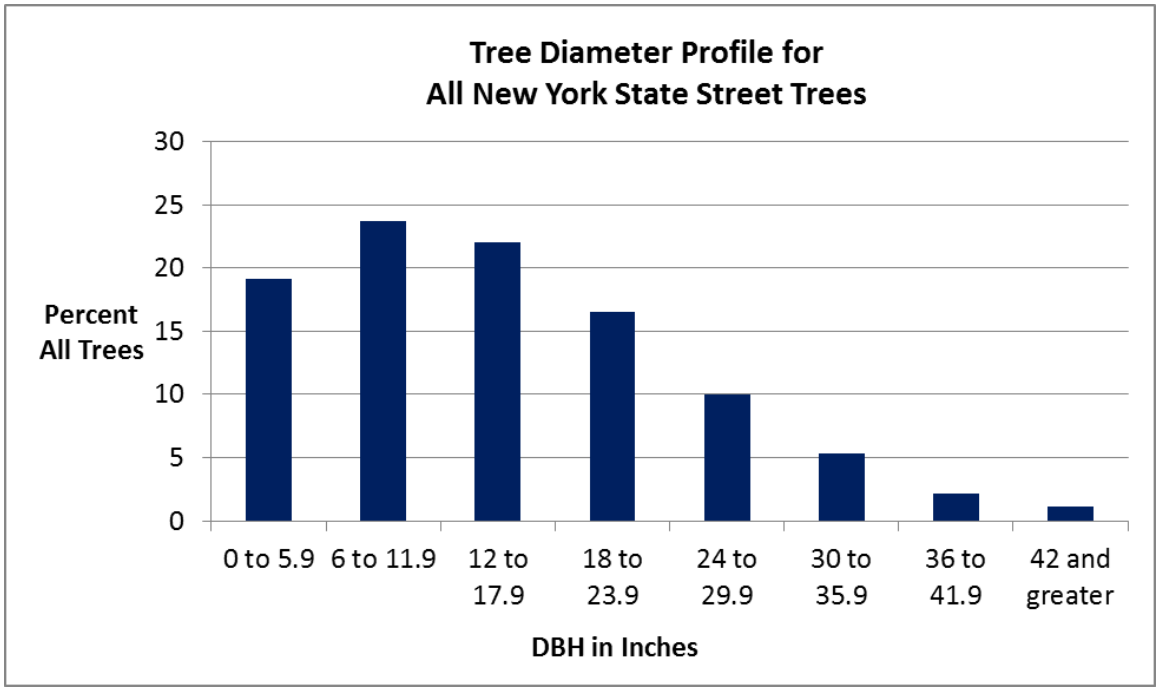


Figure 3.4 Tree diameter profile (DBH) for all New York State street trees

Data for the 0 to 5.9 inch DBH class was selected for the most prevalent street tree species identified in Table 3.4. Although some trees contained in this class may be "volunteers," especially in more rural and/or less densely populated places, this DBH class represents street trees most recently planted and indicates trends in the population. Table 3.6 compares the relative abundance of the most prevalent street tree species for all DBH classes to the relative abundance of the most prevalent street tree species for only the 0 to 5.9 inch DBH class.

Table 3.6 Relative abundance for most prevalent street tree species

	All Trees, Weighted Mean %, All Zones	Trees DBH 0 to 5.9, Weighted Mean %, All Zones	% Change
Acer platanoides	20.653	12.924	–37.42%
Acer saccharum	9.892	4.158	–57.97%
Acer saccharinum	5.794	1.315	–77.30%
Platanus x acerifolia	5.722	1.085	–81.04%
Acer rubrum	5.294	6.313	+19.24%
Gleditsia triacanthos	5.210	4.810	–7.68%
Pyrus calleryana	4.718	8.787	+86.24%
Quercus palustris	2.773	1.186	–57.25%
Tilia cordata	2.694	3.065	+13.78%
Malus species	2.447	5.697	+132.80%
Fraxinus pennsylvanica	1.983	1.829	–7.77%
Quercus rubra	1.689	1.873	+10.88%
Picea abies	1.270	0.770	–39.37%
Pinus strobus	1.084	1.345	+24.06%
Robinia pseudoacacia	1.033	0.473	–54.20%

Table 3.6 results suggest that tree species such as *Platanus x acerifolia* (London Plane), *Acer saccharinum* (Silver Maple), and *Acer saccharum* (Sugar Maple) are being planted less frequently and their percentage of the statewide street tree population is likely to decline while tree species such as *Malus species* (Crabapple), *Pyrus calleryana* (Callery Pear), and *Quercus rubra* (Northern Red Oak) are being planted more frequently and their percentage of the statewide street tree population is likely to increase. This trend reflects to some extent wise horticultural practice since *Acer saccharinum* is a large, rapidly growing tree species susceptible to branch failure whose use as a street tree has been discouraged (Gilman & Watson 1993). However, it is also suggests that more small and medium sized street trees (i.e. mature height less than 60 feet) are being planted relative to large sized street trees (i.e. mature height greater than 60 feet). Table 3.7 allocates the results from Table 3.6 into two tree size classes, small and medium sized trees and large sized trees, based on estimates for mature growing heights derived from i-Tree's tree species database for the Northeast Climate Zone (USDA Forest Service 2008a).

Table 3.7 Percentage change for most prevalent street tree species, small and medium sized trees and large sized trees

Small and Medium Sized Trees	
Acer rubrum	
Pyrus calleryana	
Tilia cordata	
Malus species	
Mean Percentage Change	+57.47%
Large Sized Trees	
Acer platanoides	
Acer saccharum	
Acer saccharinum	
Gleditsia triacanthos	
Platanus x acerifolia	
Quercus palustris	
Fraxinus pennsylvanica	
Quercus rubra	
Picea abies	
Pinus strobus	
Robinia pseudoacacia	
Mean Percentage Change	–44.37%

Table 3.7 results restate the trend suggested by Table 3.6 that small and medium sized trees have been increasingly planted in New York State relative to large sized trees for the most prevalent street tree species. A similar trend was identified by McPherson and Rowntree (1989) for twenty-two municipalities in the United States, and by Bernhardt and Swiecki (1993) and Thompson (2006) statewide in California. Attempting to explain this trend, both Bernhardt and Swiecki and Thompson found that street tree species selection was driven primarily by two criteria: planting site space limitations and reduction in tree maintenance costs (the assumption being made that small and medium sized street trees are less costly to maintain than large sized street trees). These criteria may be operational in New York State as well. In addition to these criteria, however, electric utility companies in New York State such as National Grid have promoted planting small sized street trees (i.e. mature height less than 30 feet) and not medium and large sized street trees under utility wires (National Grid 2011).

To further explore these trends, 103 inventories for which tree species and DBH data was available were analyzed such that the mean percentage of trees for small sized tree species and medium and large sized tree species was calculated for all trees and for trees with a DBH ≤ 6 inches. Results are shown in Figure 3.5.

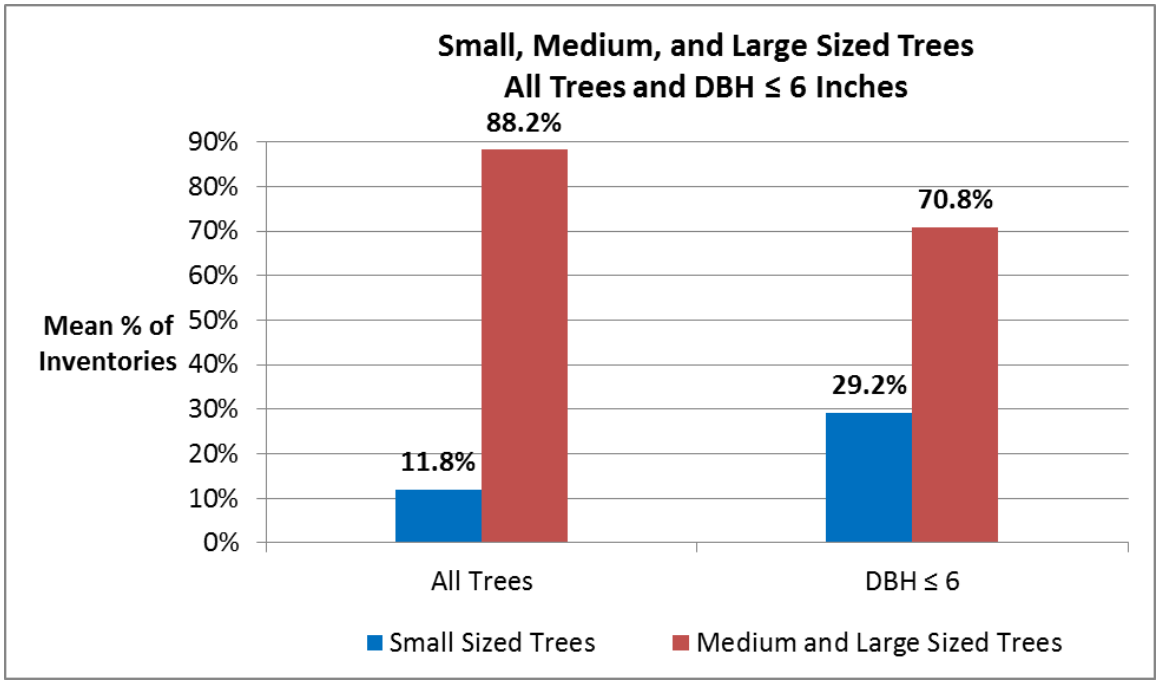


Figure 3.5 Mean percentage of inventory data (n = 103) for small, medium, and large sized street trees comparing all trees to trees with a DBH ≤ 6 inches

In addition, 31 inventories for which tree species, DBH, and utility wire data was available was analyzed such that the mean percentage of trees for small sized tree species and medium and large sized tree species was calculated for all trees and for trees with a DBH ≤ 6 inches. Results are shown in Figure 3.6.

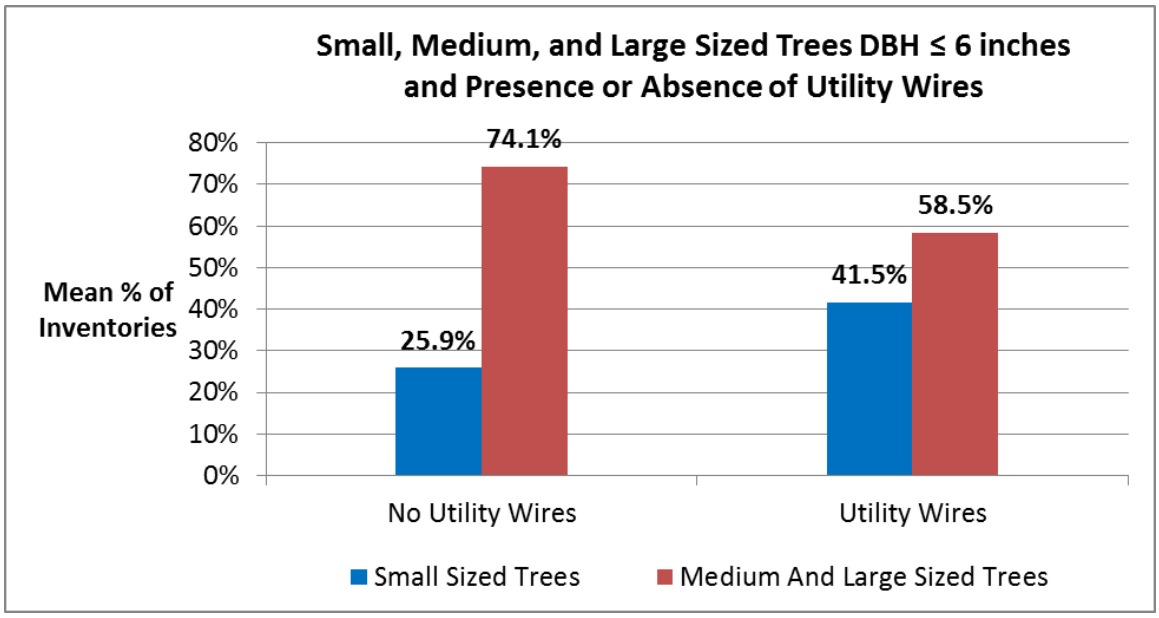


Figure 3.6 Mean percentage of inventory data (n = 31) for small, medium, and large sized street trees with the presence or absence of single or triple phase utility wires

Results shown in Figures 3.5 and 3.6 suggest that, similar to the trend identified for the most prevalent statewide street tree species (Table 3.7) and findings made by McPherson and Rowntree (1989), Bernhardt and Swiecki (1993), and Thompson (2006), there is a trend towards increased plantings of smaller sized street tree species relative to plantings of larger sized street tree species. In addition, while some of this increase may be attributed to planting smaller sized street tree species below utility wires in order to avoid conflicts with them, the presence or absence of overhead utility wires does not fully explain this increase. In other words, smaller sized street tree species are being planted increasingly whether overhead utility wires exist or not.

Planting site space limitations have also been attributed by Bernhardt and Swiecki (1993) and Thompson (2006) as a factor in the trend towards increased plantings of small and medium sized street trees relative to large sized street trees. Accordingly, 30 inventories for which tree species, DBH, and location site type data was available were analyzed as follows: a count was made for the most prevalent street tree species specified in Table 3.6 for each of four location site types: front yard or lawn, treelawn (strip between sidewalk and street curb), sidewalk pit, and other (median,

unmanaged areas, etc.), for both all trees contained in the 30 inventories (n = 54449) and all trees contained in the 30 inventories with a DBH < 6 inches (n = 9303). The percentage of street tree species per location site type was calculated for all street trees contained in the 30 inventories and all street trees contained in the 30 inventories with a DBH < 6 inches. Table 3.8 and Table 3.9 contain results of this analysis. Table 3.8 shows the distribution by location site type for each street tree species and Table 3.9 shows the distribution by street tree species for each location site type.

Planting site space limitations are usually most restrictive for sidewalk pits and least restrictive for front yards and lawns. Treelawn restrictiveness varies greatly depending on the width and length of the area between sidewalk and curb, but can be assumed to fall somewhere between sidewalk pits and front yards. Additionally, soil compaction, an important factor in street tree species selection and tree growth and survivability, can be assumed to be greater for sidewalk pits and treelawns than for front yards and lawns.

Results contained in Table 3.8 and Table 3.9 suggest that smaller sized street tree species such as Malus species and Pyrus calleryana are being planted increasingly in front yards and lawns, both as a percentage of each species and as a percentage of location site type, thereby occupying planting sites where space limitations are typically least restrictive. Conversely, larger sized street tree species, such as Acer platanoides, Platanus x acerifolia, Quercus palustris, and Quercus rubra are being planted less frequently in front yards and lawns, both as a percentage of each species and as a percentage of location site type. Results are similar for treelawns: Malus species and Pyrus calleryana are being planted increasingly in treelawns as a percentage of location site type, but less frequently as a percentage of each species, perhaps reflecting the increase in front yard plantings; Acer platanoides, Platanus x acerifolia, Quercus palustris, and Quercus rubra are being planted less frequently in treelawns as a percentage of location site type, but more frequently as a percentage of each species. Finally, results for sidewalk pits are mixed: Acer saccharum, Pyrus calleryana, and Tilia cordata are being planted increasingly in sidewalk pits as a percentage of location site type while Acer platanoides, Platanus x acerifolia, and Malus species are being planted less frequently.

Table 3.8 Distribution by location site type for each street tree species

All Trees	% Front Yard	% Treelawn	% Sidewalk Pit	% Other
Acer platanoides	37.73%	58.47%	1.27%	2.53%
Acer saccharum	53.66%	41.89%	1.59%	2.86%
Acer saccharinum	42.58%	53.65%	0.80%	2.98%
Acer rubrum	50.73%	44.32%	0.89%	4.06%
Gleditsia triacanthos	35.38%	48.19%	12.25%	4.18%
Platanus x acerifolia	74.67%	24.21%	0.92%	0.20%
Pyrus calleryana	31.68%	48.96%	16.00%	3.36%
Tilia cordata	25.52%	63.02%	10.61%	0.85%
Malus species	24.47%	64.26%	4.15%	7.13%
Quercus palustris	47.60%	42.21%	6.86%	3.33%
Fraxinus pennsylvanica	38.63%	52.46%	3.35%	5.56%
Quercus rubra	66.70%	29.69%	1.13%	2.47%
Picea abies	86.21%	4.91%	0.00%	8.89%
Pinus strobus	89.76%	2.44%	0.16%	7.64%
Robinia pseudoacacia	75.09%	13.23%	0.00%	11.68%

Trees DBH < 6 inches	% Front Yard	% Treelawn	% Sidewalk Pit	% Other
Acer platanoides	31.44%	64.35%	1.64%	2.57%
Acer saccharum	42.10%	53.34%	3.50%	1.06%
Acer saccharinum	46.67%	50.00%	3.33%	0.00%
Acer rubrum	37.97%	53.22%	3.73%	5.08%
Gleditsia triacanthos	25.06%	53.76%	15.49%	5.69%
Platanus x acerifolia	55.88%	33.82%	7.35%	2.94%
Pyrus calleryana	41.34%	46.81%	10.33%	1.52%
Tilia cordata	26.56%	51.88%	21.25%	0.31%
Malus species	30.82%	56.62%	3.35%	9.21%
Quercus palustris	30.91%	61.82%	7.27%	0.00%
Fraxinus pennsylvanica	31.49%	62.98%	3.83%	1.70%
Quercus rubra	48.62%	44.04%	2.75%	4.59%
Picea abies	84.11%	10.28%	0.00%	5.61%
Pinus strobus	95.20%	4.80%	0.00%	0.00%
Robinia pseudoacacia	74.19%	12.90%	0.00%	12.90%

Percent Change	% Front Yard	% Treelawn	% Sidewalk Pit	% Other
Acer platanoides	-20.02%	10.06%	29.08%	1.73%
Acer saccharum	-27.46%	27.33%	119.93%	-168.91%
Acer saccharinum	9.61%	-7.30%	317.42%	NA
Acer rubrum	-33.62%	20.07%	318.77%	25.35%
Gleditsia triacanthos	-41.18%	11.56%	26.42%	36.14%
Platanus x acerifolia	-33.62%	39.70%	698.80%	1406.30%
Pyrus calleryana	30.48%	-4.60%	-54.82%	-121.09%
Tilia cordata	4.07%	-21.48%	100.34%	-172.26%
Malus species	25.96%	-13.50%	-23.75%	29.24%
Quercus palustris	-54.00%	46.44%	6.08%	NA
Fraxinus pennsylvanica	-22.68%	20.05%	14.32%	-226.62%
Quercus rubra	-37.18%	48.32%	142.70%	85.40%
Picea abies	-2.49%	109.50%	NA	-58.47%
Pinus strobus	6.07%	96.80%	NA	NA
Robinia pseudoacacia	-1.20%	-2.53%	NA	10.44%

Table 3.9 Distribution by street tree species for each location site type

All Trees	% Front Yard	% Treelawn	% Sidewalk Pit	% Other
Acer platanoides	17.454%	32.733%	9.656%	15.823%
Acer saccharum	6.080%	5.745%	2.962%	4.382%
Acer saccharinum	4.225%	6.442%	1.303%	3.992%
Acer rubrum	7.387%	7.811%	2.133%	7.984%
Gleditsia triacanthos	3.868%	6.377%	22.038%	6.183%
Platanus x acerifolia	9.642%	3.783%	1.955%	0.341%
Pyrus calleryana	1.426%	2.667%	11.848%	2.045%
Tilia cordata	1.621%	4.842%	11.078%	0.730%
Malus species	1.743%	5.540%	4.858%	6.865%
Quercus palustris	1.750%	1.879%	4.147%	1.655%
Fraxinus pennsylvanica	1.952%	3.208%	2.784%	3.797%
Quercus rubra	2.330%	1.255%	0.652%	1.168%
Picea abies	2.341%	0.161%	0.000%	3.262%
Pinus strobus	1.988%	0.065%	0.059%	2.288%
Robinia pseudoacacia	1.574%	0.336%	0.000%	3.311%

Trees DBH < 6 inches	% Front Yard	% Treelawn	% Sidewalk Pit	% Other
Acer platanoides	9.861%	18.733%	4.015%	11.419%
Acer saccharum	6.778%	7.970%	4.398%	2.422%
Acer saccharinum	1.028%	1.022%	0.574%	0.000%
Acer rubrum	2.740%	3.565%	2.103%	5.190%
Gleditsia triacanthos	2.691%	5.359%	13.002%	8.651%
Platanus x acerifolia	0.930%	0.522%	0.956%	0.692%
Pyrus calleryana	6.655%	6.994%	13.002%	3.460%
Tilia cordata	2.080%	3.769%	13.002%	0.346%
Malus species	4.502%	7.675%	3.824%	19.031%
Quercus palustris	0.832%	1.544%	1.530%	0.000%
Fraxinus pennsylvanica	1.811%	3.361%	1.721%	1.384%
Quercus rubra	1.297%	1.090%	0.574%	1.730%
Picea abies	2.202%	0.250%	0.000%	2.076%
Pinus strobus	2.912%	0.136%	0.000%	0.000%
Robinia pseudoacacia	0.563%	0.091%	0.000%	1.384%

Percent Change	% Front Yard	% Treelawn	% Sidewalk Pit	% Other
Acer platanoides	-77.01%	-74.74%	-140.49%	-38.57%
Acer saccharum	11.48%	38.74%	48.47%	-80.90%
Acer saccharinum	-311.12%	-530.46%	-127.21%	NA
Acer rubrum	-169.57%	-119.10%	-1.40%	-53.83%
Gleditsia triacanthos	-43.73%	-19.00%	-69.50%	39.91%
Platanus x acerifolia	-937.02%	-624.42%	-104.49%	103.06%
Pyrus calleryana	366.61%	162.18%	9.74%	69.22%
Tilia cordata	28.32%	-28.47%	17.36%	-111.05%
Malus species	158.26%	38.54%	-27.03%	177.23%
Quercus palustris	-110.42%	-21.66%	-171.10%	NA
Fraxinus pennsylvanica	-7.82%	4.76%	-61.80%	-174.37%
Quercus rubra	-79.70%	-15.17%	-13.61%	48.07%
Picea abies	-6.31%	54.88%	NA	-57.12%
Pinus strobus	46.45%	108.38%	NA	NA
Robinia pseudoacacia	-179.69%	-269.51%	NA	-139.19%

These results generally confirm the findings made by McPherson and Rowntree (1989), Bernhardt and Swiecki (1993), and Thompson (2006) of a trend towards increased plantings of smaller sized street tree species relative to plantings of larger sized street tree species. Causal factors for this trend are not entirely clear. Planting smaller sized street tree species below overhead utility wires in order to minimize conflicts between trees and wires appears to be part of the explanation. However, less convincing as a causal factor is planting site space limitations given findings of increased plantings of smaller sized street tree species and fewer plantings of larger sized street tree species in front yards and lawns where planting site space limitations are least restrictive and, to a lesser extent, in treelawns where planting site space limitations are more restrictive than front yards and lawns, but less restrictive than sidewalk pits. It is possible that pursuit of reductions in street tree maintenance costs may be a causal factor although it is not possible to ascertain this from the current data. It is also possible that aesthetic preference could be part of the explanation and that more smaller sized street tree species are being planted relative to larger sized street tree species because smaller, flowering tree species are preferred to larger growing shade tree species.

Whatever the reasons underlying a trend towards increased plantings of smaller sized street tree species relative to plantings of larger sized street tree species, the implications are not merely aesthetic. As Bernhardt and Swiecki (1993) and Thompson (2006) have pointed out, the trend towards planting small and medium sized street trees rather than large sized street trees reduces environmental and social benefits provided by street trees. Since most benefits provided by trees are a function of leaf surface area and large sized trees have more leaf surface area than small and medium sized trees, larger sized trees are able to absorb and sequester more carbon than smaller trees and remove larger quantities of pollutants (Nowak et al 2002). Therefore, the trend towards increased plantings of smaller sized street tree species relative to plantings of larger sized street tree species comes at the expense of energy conservation, air quality improvement, and stormwater reduction and lowers the structural ceiling of benefits potentially provided by street trees. If the environmental and social benefits provided by street trees are to be prioritized, more large sized street tree species need to be planted relative to small and medium sized street tree species than is happening currently.

Street Tree Benefits

Research has shown that urban and community trees provide ecological and social benefits including energy conservation (McPherson & Rowntree 1993), stormwater reduction (Xiao et al 1998), air and water pollution abatement (Brack 2002), carbon storage and sequestration (Nowak & Crane 2002), and increased real estate values (Anderson & Cordell 1988). To encourage public awareness of these benefits and to support urban and community tree management, the USDA Forest Service developed the i-Tree suite of computer software programs, including UFORE (Urban Forest Effects Model) and STRATUM (Street Tree Resource Analysis Tool for Urban Forest Managers), to facilitate the collection of urban and community tree data and quantify the benefits provided by trees derived from this data. STRATUM, created specifically for street trees and since renamed Streets, quantifies in dollar values the annual benefits provided by street trees in five categories: energy conservation, air quality improvement, CO_2 reduction, stormwater control, and property value increase (USDA Forest Service 2011). It requires collection at a minimum of species and DBH data for each tree surveyed. Benefits can be calculated from a complete street tree inventory where all street trees in a municipality have been surveyed or from a sample street tree inventory where data has been collected consistent with a sampling methodology (i.e. stratified by land use, 2000 to 2200 tree minimum) devised by Jaensen et al (1992).

Benefits calculated by i-Tree Streets are estimates based on statistical models. For example, leaf surface area by species is estimated from computer processing of tree-crown imagery, a technique whose accuracy has been found to be ± 20% of actual leaf surface area (Peper & McPherson 2003). Tree growth rates are estimated from randomly sampled street trees stratified by size (small, medium, large) and type (deciduous, evergreen) in a climate zone reference city; most of New York State is contained in a Northeast climate zone for which the reference city is the Borough of Queens, New York City (McPherson et al 2007). As McPherson (2010) admits, benefit calculations in i-Tree Streets are simulations that approximate reality.

Notwithstanding this limitation, benefit calculations provide an improved metric for evaluating street trees within and between municipalities. Metrics for evaluating street trees have most often consisted of a count of street trees per unit measure such as street length. For example, in considering street trees as a pedestrian amenity affecting pedestrian mobility, safety, and comfort, the GIS protocols of the Twin Cities Walking Study (2007) calculated a density measure based on the number of street trees per length of road within an area. Similarly, to explore possible relationships between street trees and childhood asthma in New York City, Lovasi et al (2008) correlated the total number of trees on street segments both contained within and divided by hospital catchment areas with prevalence of and hospitalizations for childhood asthma. Related metrics are street trees per capita, or the number of street trees in an area divided by the area's population (McPherson and Rowntree 1989), and stocking level, or the number of street trees planted as a percentage of all available planting sites, whether those sites contain trees or not.

Metrics evaluating street trees based on a street tree count contain a fundamental flaw, namely that they give all trees equal weight regardless of species type and size, thereby failing to account for significant differences in ecosystem services provided by a large tree compared to that of a small tree (Nowak et al 2002). To paraphrase Gertrude Stein, a tree is not a tree is not a tree. Therefore, evaluating street trees more comprehensively requires moving beyond metrics based on street tree counts to metrics that account for ecological and social benefits. i-Tree Streets provides an opportunity to create these latter, more comprehensive type of metrics.

For 123 municipalities where tree species and DBH data was available, including sample and partial street tree inventories, i-Tree Streets was used to calculate total annual benefits (energy conservation, air quality improvement, CO_2 reduction, stormwater control, and property value increase) provided by inventoried street trees in that municipality. Total annual benefits (in dollars) per community were divided by the number of street trees surveyed in that community to calculate benefits per street tree per community in dollars. Mean benefits per street tree were found to be 133.75 with a median of 135.57, a standard deviation of 24.05, a standard error of 2.17, and upper and lower confidence levels ($\alpha = .10$) of 137.32 and 130.18. Benefits per street tree per community were then allocated to four zone classes (e.g. Zones 3 +4, Zone 5, Zone 6, and Zone 7) based on the 1990 USDA Plant Hardiness Zones associated with their respective municipalities. Mean and median figures, standard deviation, standard error, and upper and lower confidence levels ($\alpha = .10$) were calculated for all zone classes. Table 3.10 contains the results. No significant difference ($\alpha = .10$) was found in a comparison of means of benefits per street tree for each 1990 USDA Plant Hardiness Zone class. Benefits per street tree and population density were found to be weakly correlated (-0.14) for all 123 municipalities.

Table 3.10 Benefits per Street Tree by 1990 USDA Plant Hardiness Zone classes

Benefits per Street Tree ($)	Zones 3 + 4 (*n*=21)	Zone 5 (*n*=58)	Zone 6 (*n*=24)	Zone 7 (*n*=20)
Mean	140.73	131.98	133.82	131.45
Median	138.55	133.29	130.72	135.14
StdDev	23.82	26.04	22.42	20.11
StdErr	5.20	3.42	4.58	4.50
UCL (α =.10)	149.28	137.61	141.35	138.85
LCL (α =.10)	132.18	126.36	126.29	124.05

Means for each zone class were weighted in a manner similar to genus and species composition (i.e. by the relative percentage of summed street length expected to contain street trees for all Census Places and Census Blocks with population density of at least 500 ppsm not contained within Census Places within that zone class – see Table 3.1). The weighted mean of benefits per street tree statewide was found to be 133.16, nearly equivalent to the unweighted mean of 133.75.

Next, for each municipality where tree species and DBH data was available and the inventoried summed street length of streets expected to contain street trees could be determined, i-Tree Streets was used to calculate total annual benefits (energy conservation, air quality improvement, CO_2 reduction, stormwater control, and property value increase) provided by street trees in that municipality. Total annual benefits (in dollars) were then divided by summed street length (meters) of streets expected to contain street trees for each municipality to create a metric of street tree benefits per meter per municipality. Figure 3.7 illustrates the methodology for creating this metric. Results are shown in Table 3.11. A metric for benefits per mile has also been calculated.

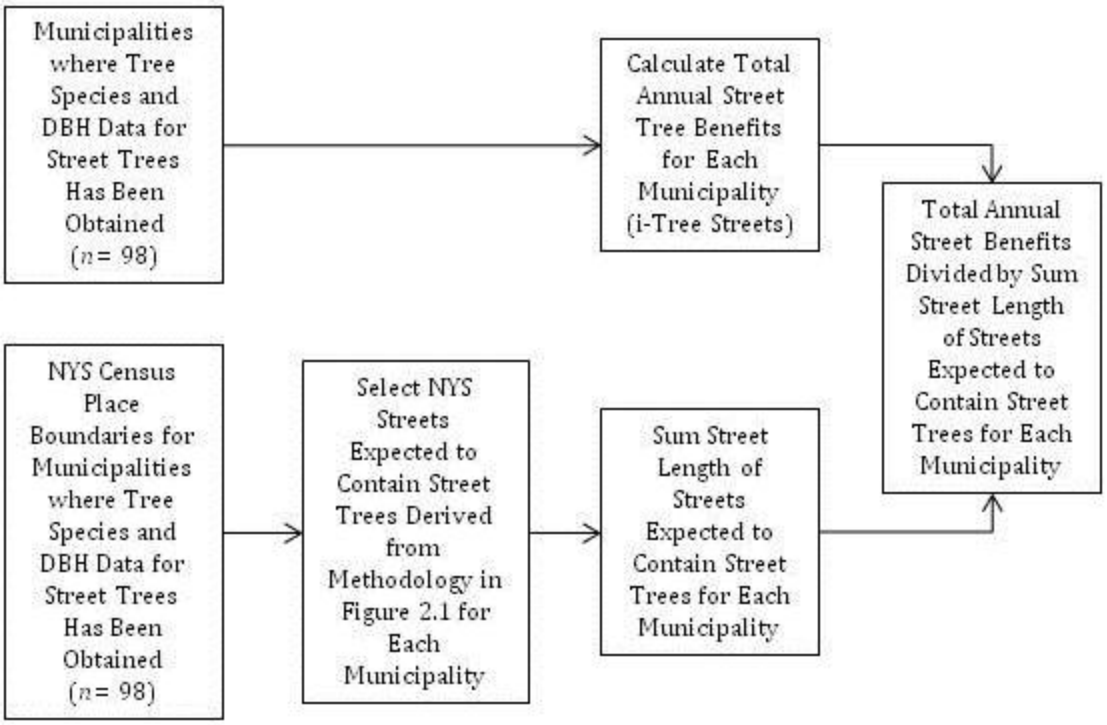


Figure 3.7 Methodology for creating street tree benefits per meter metric for municipalities in New York State where tree species and DBH data was available and i-Tree Streets was used to calculate total annual benefits

Table 3.11 Benefits ($) by street length for streets expected to contain street trees

n = 98	Benefits per Meter	Benefits per Mile
Mean	5.20	8365.77
Median	4.74	7630.39
StdDev	3.13	5034.46
StdErr	0.32	508.56
UCL (α =.10)	5.72	9202.35
LCL (α =.10)	4.68	7529.19

Results for benefits by street length were analyzed further to explore variability by 1990 USDA Plant Hardiness Zone class. Results of the one way analysis of variance (ANOVA) for benefits per mile by 1990 USDA Plant Hardiness Zone class are contained in Table 3.12 ($\alpha = .10$, $r^2 = 0.23$, $F < .0001$).

Table 3.12 One way analysis of variance (ANOVA) for benefits per mile by 1990 USDA Plant Hardiness Zone class

USDA Zone Class	Mean	Std Error	Lower 90%	Upper 90%
3 + 4 (n = 19)	7382.86	1029.88	5672.00	9093.72
5 (n = 45)	6702.38	669.20	5590.68	7814.07
6 (n = 21)	9388.16	979.61	7760.81	11015.50
7 (n = 13)	13908.67	1245.06	11840.30	15977.00

Results contained in Table 3.12, confirmed by a statistical comparison of means, indicate significant differences in benefits between Zone 7 and all other zones, and between Zone 6 and Zone 5. Benefits per mile increased with higher minimum temperatures and benefits per mile for inventories in Zone 7 were found to be significantly higher than benefits per mile in all other zones. The reasons for these results are not immediately clear, but, as with benefits per street tree, population density is weakly correlated with benefits per mile (0.19) and does not appear to be an explanatory factor.

Street Tree Numbers

Although an argument has been made that metrics based on street tree benefits are preferable to metrics based on street tree counts for evaluating street trees within and between municipalities, estimation of street tree numbers by municipality and statewide is still a useful endeavor. For example, if both street tree numbers and the percentages of street tree genera can be estimated by municipality and statewide, then the number of street trees in a particular genus can be estimated. Given the threat posed by the Emerald Ash Borer (EAB) to all *Fraxinus* (ash) trees and the threat posed by the Asian Longhorned Beetle (ALB) to many hardwood tree genera including all Acer (maple) trees, estimating the number of street trees in a particular genus could be helpful in understanding the scope of the threat posed by an invasive pest species, budgeting for potential tree removals, etc.

To estimate street tree numbers by municipality and statewide, a similar methodology to the one shown in Figure 3.7 was used to create a metric for street trees per meter (i.e. the number of street trees in each municipality divided by the summed length of streets expected to contain street trees for each municipality) for municipalities where street tree numbers and summed street length of streets expected to contain street trees that had been inventoried could be determined. Preliminary results (i.e. unweighted means) are shown in Table 3.13. A metric for street trees per mile has also been calculated.

Table 3.13 Street trees by street length for streets expected to contain street trees in New York State (unweighted)

n = 127	Street Trees per Meter	Street Trees per Mile
Mean	0.042	67.00
Median	0.035	56.93
StdDev	0.025	40.87
StdErr	0.002	3.63
UCL (α =.10)	0.045	72.97
LCL (α =.10)	0.038	61.03

Results for trees by street length were analyzed further to explore variability by 1990 USDA Plant Hardiness Zone class. Statistics for street tree numbers per meter of street length and street tree numbers per mile of street length by 1990 USDA Plant Hardiness Zone Class were calculated and are contained in Table 3.14.

Table 3.14 Street trees by street length for streets expected to contain street trees in New York State by 1990 USDA Plant Hardiness Zone Class

	Trees per Meter Zones 3+4	Trees per Meter Zone 5	Trees per Meter Zone 6	Trees per Meter Zone 7
Mean	0.029	0.032	0.049	0.071
Std Dev	0.019	0.017	0.018	0.029
Count	30	49	25	23
Std Err	0.003	0.002	0.004	0.006
90% UCL	0.034	0.036	0.055	0.081
90% LCL	0.023	0.028	0.043	0.061

	Trees per Mile Zones 3+4	Trees per Mile Zone 5	Trees per Mile Zone 6	Trees per Mile Zone 7
Mean	45.90	52.01	78.25	114.24
Std Dev	30.50	27.42	29.41	46.62
Count	30	49	25	23
Std Err	5.57	3.92	5.88	9.72
90% UCL	55.06	58.45	87.92	130.23
90% LCL	36.74	45.56	68.57	98.25

Statistics in Table 3.14 suggest meaningful differences in street tree numbers by street length for 1990 USDA Plant Hardiness Zone classes. These differences were assessed for statistical significance in a one way analysis of variance (ANOVA) for street trees per street length (miles) by 1990 USDA Plant Hardiness Zone class. Results were found to be statistically significant ($\alpha = .10$, $r^2 = 0.37$, $F < .0001$) and are contained in Table 3.15.

Table 3.15 One way analysis of variance (ANOVA) for number of street trees per mile by 1990 USDA Plant Hardiness Zone class

USDA Zone Class	Mean	Std Error	Lower 90%	Upper 90%
3 + 4 (n = 30)	45.90	5.97	36.00	65.60
5 (n = 49)	52.01	4.67	44.26	59.75
6 (n = 25)	78.25	6.54	67.40	89.09
7 (n = 23)	114.24	6.82	102.94	125.55

Statistically significant differences were found in street tree numbers between most, although not all, 1990 USDA Plant Hardiness Zone classes. For example, significant differences were not found between Zones 3+4 and Zone 5, but significant differences were found between Zones 3+4 and Zone 6, Zones 3 + 4 and Zone 7, Zone 5 and Zone 6, Zone 5 and Zone 7, and Zone 6 and Zone 7. These results are consistent with results for benefits per mile by 1990 USDA Plant Hardiness Zone class contained in Table 3.12. They also suggest that statewide summary statistics for street tree numbers per meter and per mile should be weighted, similar to statistics for prevalent street tree species and genera, by the relative percentage of summed street length contained within each zone class. For example, to determine statewide summary statistics for street tree numbers per meter and per mile the means for street trees per meter and street trees per mile in each zone class would be weighted by the relative percentage of summed street length contained within each zone class according to the formula:

$$((w1 * m1) + (w2 * m2) + (w3 * m3) + (w4 * m4)) / (w1 + w2 + w3 + w4)$$

Where $m1$, $m2$, $m3$, and $m4$ denote the group means for street trees per meter or street trees per mile (i.e. the mean for 1990 USDA Plant Hardiness Zone classes 3+4, 5, 6, and 7) and $w1$, $w2$, $w3$, and $w4$ denote the different weights for each group (i.e. percentages of summed street length (meters) of streets expected to contain street trees for all Census Places and Census Blocks with population density of at least 500 ppsm not contained within Census Places for 1990 USDA Plant Hardiness Zone classes in New York State) as stated in Table 3.1.

Weighted statewide statistics for street tree numbers per meter of street length and street tree numbers per mile of street length were calculated and compared to unweighted statistics. Results are contained in Table 3.16. Weighted means per meter and per mile represent meaningful increases relative to unweighted means. However, based on statistically significant differences found for street numbers and street length by 1990 USDA Plant Hardiness Zone classes, these weighted means should be judged the more reliable and accurate statistics and will be used in subsequent calculations.

Table 3.16 Street trees by street length for streets expected to contain street trees in New York State (weighted and unweighted means)

New York State	Weighted Mean	Unweighted Mean
Street Trees per Meter	0.050	0.042
Street Trees per Mile	80.47	67.00

(4) Statistical Model

Summary. Summary statistics revealed significant differences in statewide street tree population characteristics based on 1990 USDA Plant Hardiness Zone classes which it is assumed primarily reflect tree response to minimum temperatures. Statistical analyses were conducted for zone classes as well as other environmental and social variables to evaluate their ability to explain variability in the New York State street tree population. Variables such as annual precipitation, development intensity, median household income, educational attainment, presence of professional staff to manage community trees, and municipality type were found to have some explanatory power, but were found either multi-collinear with 1990 USDA Plant Hardiness Zone class or inconsistent in their effects. 1990 USDA Plant Hardiness Zone class was found to be the best predictor variable for explaining variability in the New York State street tree population and will be used to calculate mean percentages and 90% confidence interval levels for prevalent street tree species and genera based on summary statistics from sample street tree inventory data.

Data obtained from municipalities (e.g. cities, villages, CDPs) in New York State possessing a street tree inventory comprise a sample of the statewide population of street trees. Summary statistics of this sample data are helpful in suggesting inferences for the statewide population as a whole, including municipalities in New York State that do not possess a street tree inventory. They provide the basis for a statistical model to make reliable and valid estimates for street trees on a statewide basis. Objectives of the model include calculation of street tree numbers statewide for prevalent species and genera statewide and calculation of annual benefits statewide provided by street trees. It has been affirmed previously that statewide calculations should account for statistically significant differences found by 1990 USDA Plant Hardiness Zone classes for (1) mean percentages of prevalent street tree species and genera and (2) means for street trees per meter and street trees per mile of streets expected to contain street trees. Stratifying data and weighting means by 1990 USDA Plant Hardiness Zone class was predicated on the hypothesis that street tree populations vary significantly due to minimum temperatures affecting plant hardiness. The validity of this hypothesis will be assessed below and whether additional variables should be included in the statistical model to facilitate its objectives. However, it should be noted that stratifying data and weighting means by 1990 USDA Plant Hardiness Zone class may not only reflect significant differences based on plant hardiness, but might also capture significant effects for other criteria as well such as development intensity. In that light, not only will the validity of stratifying data and weighting means by 1990 USDA Plant Hardiness Zone class be assessed, but additional environmental and social factors will be explored and tested for statistical significance in calculating street tree numbers statewide for prevalent species and genera statewide and the annual benefits statewide provided by street trees

Minimum Temperature

It was affirmed in deriving summary statistics from the sample street inventory data that consideration should be given to minimum temperature and plant hardiness in explaining variability in street tree populations and in particular tree species and genus composition. Minimum temperature is employed frequently as a variable in assessing plant geography. For example, Sunset Western Garden (2011) evaluates "winter lows" in mapping gardening climate zones and mean January temperature is one of thirty-eight environmental variables used by the USDA Forest Service (2007) in predicting habitat for common tree species in forests in the Eastern United States. To investigate an effect on New York State street trees due to minimum temperature, municipalities in New York State (e.g. cities, villages, CDPs) were referenced to the 1990 USDA Plant Hardiness Zone Map (US National Arboretum 1990). Each municipality was selected into one of five plant hardiness zones (Zone 3, Zone 4, Zone 5, Zone 6, or Zone 7) according to a methodology illustrated in Figure 2.2. Municipalities located in Zones 3 and 4 were grouped into one zone class and four zone classes were used to explore differences in sample street inventory data due to minimum temperature. Summary statistics suggested effects based on zone class for prevalence of street tree species and genera, species diversity, benefits provided by street trees, and street tree numbers.

To test the statistical significance of zone class effects for prevalence of street tree species and genera, Oneway Analysis of Variance (ANOVA) and rank sum Kruskal-Wallis analyses were conducted to compare differences between the means of prevalent street tree genera and species inventory percentages by 1990 USDA Plant Hardiness Zone class. Both ANOVA and Kruskal-Wallis analyses were conducted because ANOVA assumes that data is normally distributed and some sample data was found not to be normally distributed. For example, *Acer platanoides* data was found to be normally distributed for Zone 5 (n = 57) and for Zone 6 (n = 29), but was found not to be normally distributed for Zones 3and 4 (n = 28) or Zone 7 (n = 18). Data transformations such as taking the log of a distribution were successful in some but not all cases in normalizing non-normal data. Therefore, a Kruskal-Wallis analysis, which is non-parametric and does not assume data is normally distributed, was run in addition to ANOVA.

With respect to genera, results indicate statistically significant effects (α = .10) for *Acer*, *Quercus*, *Platanus*, *Pyrus*, *Fraxinus*, *Picea*, *Prunus*, and *Malus* meaning these street tree genera vary significantly between 1990 USDA Plant Hardiness Zone classes. Results did not indicate statistically significant effects for *Gleditsia*, *Tilia*, *Pinus*, *Ulmus*, and *Robinia* meaning these street tree genera do not vary significantly between 1990 USDA Plant Hardiness Zone classes. With respect to species, results indicate statistically significant effects (α = .10) for *Acer platanoides*, *Acer saccharum*, *Platanus x acerifolia, Pyrus calleryana*, *Quercus palustris*, *Malus species*, and *Picea abies* meaning these street tree species vary significantly between 1990 USDA Plant Hardiness Zone classes. Results did not indicate statistically significant effects for

Acer saccharinum, *Acer rubrum*, *Gleditsia triacanthos*, *Tilia cordata*, *Fraxinus pennsylvanica*, *Quercus rubra*, *Pinus strobus*, and *Robinia pseudoacacia* meaning these street tree genera do not vary significantly between 1990 USDA Plant Hardiness Zone classes. Eight of the ten most prevalent genera were found to have statistically significant effects for zone class and six of the ten most prevalent species were found to have statistically significant effects for zone class.

Results for species diversity, street tree benefits per mile, and street tree numbers per mile were mixed. For species diversity, effects were found in both ANOVA and Kruskal-Wallis analyses for the Shannon-Weiner Diversity Index whereby the mean value for Zone 7 was significantly greater than the values for the other zone classes. Similarly, after the log of the inverse of Simpson's Diversity Index was taken to normalize the data, effects were found in both ANOVA and Kruskal-Wallis analyses for the inverse of Simpson's Diversity Index whereby the mean value for Zone 7 differed significantly from values for the other zone classes. In other words, species diversity for Zone 7 was found to be significantly greater than species diversity for Zones 3 + 4, Zone 5, and Zone 6. This effect would appear to be due in part to fewer maples being planted as street trees in Zone 7 relative to the other zone classes. For street tree benefits per mile, although summary statistics indicated that benefits per mile increased with higher minimum temperatures, a statistically significant effect for zone class was not found in either ANOVA or Kruskal-Wallis analyses. For street tree numbers per mile, a Kruskal-Wallis analysis found a statistically significant effect for zone class with street tree numbers per mile increasing from Zones 3 + 4 to Zone 7; an ANOVA analysis indicated a similar effect but, because data could not be normalized, statistical significance of an effect for zone class is predicated on the Kruskal-Wallis analysis.

Although results above do not uniformly show statistically significant effects for zone class, it does appear that the 1990 USDA Plant Hardiness Zone class is a useful predictor for modeling species and genus prevalence, species diversity, and street tree numbers per mile statewide. An assumption has been made that effects indicated by 1990 USDA Plant Hardiness Zone classes reflect minimum temperature. It is also possible, however, that these zones could vary by additional characteristics. For example, Zone 7, encompassing New York City, southern Westchester County, and much of Long Island, is more densely populated and intensely developed than other zone classes in New York State. It has already been reported that species diversity, street tree benefits per tree, and street tree benefits per street mile are weakly correlated with population density and that population density does not appear to have much explanatory power with regard to these measures. Potential effects attributable to development intensity and additional factors, both singularly and in conjunction with 1990 USDA Plant Hardiness Zone classes, will be assessed in detail below.

Additional Climatic Variables

As cited previously, the United States Forest Service (2007) uses mean January temperature as one of thirty-eight environmental variables to predict habitat for common tree species in eastern United States forests. A list of the thirty-eight variables, which include variables for elevation, soils, and land use, is contained in Table 4.1. Sunset Western Garden (2011) cites in addition to "winter lows" these environmental variables in their mapping of gardening climate zones: distance from the equator, elevation, ocean influence, continental air mass influence, mountains and hills, and local terrain. Minimum temperature as referenced by 1990 USDA Plant Hardiness Zones has been hypothesized as an explanatory variable for street tree populations in New York State and the statistically significant effects reported above suggest strongly that it would be a useful predictor for modeling street trees statewide. It is possible, however, that additional climatic and environmental variables, including some of those used by the US Forest Service to predict habitat for common tree species in eastern United States forests and by Sunset Western Garden to map gardening climate zones, could be helpful in explaining variability in New York State street tree populations and in generating reliable and valid estimates for street trees on a statewide basis. At the same, models that apply to forest habitat and gardening climate zones are unlikely to be directly analogous to street trees since street trees are not randomly distributed, but have been planted intentionally. In addition, urban environmental conditions differ in many respects from environmental conditions found in forests. For example, Craul and Klein (1980) found that streetside soils in Syracuse, NY had higher bulk density, pH, specific conductance, and weight loss on ignition and lower air-filled pore space and available water than native soils. The urban heat island effect, whereby buildings and streets release at night solar heat absorbed during the day, has also increased minimum temperatures in cities relative to rural environments (Kalnay & Cai 2003). Finally, most variables used in forest habitat modeling, which is based on Forest Inventory Analysis (FIA) field data, are typically not collected in street tree inventories, making extension of forest habitat modeling to street tree population modeling limited in most respects.

Table 4.1 Environmental variables used to predict tree species habitat for forests in the Eastern United States

Climate	
TAVG:	Mean annual temperature (°C)
TJAN:	Mean January temperature (°C)
TJUL:	Mean July temperature (°C)
TMAYSEP:	Mean May-September temperature (°C)
PPT:	Annual precipitation (mm)
PPTMAYSEP:	Mean May-September precipitation (mm)
JULJANDIFF:	Mean difference between July and January Temperature (°C)
Elevation	
ELV_CV:	Elevation coefficient of variation
ELV_MAX:	Maximum elevation (m)
ELV_MEAN:	Average elevation (m)
ELV_MIN:	Minimum elevation (m)
ELV_RANGE:	Range of elevation (m)
Soil Class	
ALFISOL:	Alfisol (%)
ARIDISOL:	Aridisol (%)
ENTISOL:	Entisol (%)
HISTOSOL:	Histosol (%)
INCEPTSOL:	Inceptisol (%)
MOLLISOL:	Mollisol (%)
SPODOSOL:	Spodosol (%)
ULTISOL:	Ultisol (%)
VERTISOL:	Vertisol (%)
Soil Property	
BD:	Soil bulk density (g/cm3)
CLAY:	Percent clay (< 0.002 mm size)
KFFACT:	Soil erodibility factor, rock fragment free (susceptibility of soil erosion to water movement)
NO10:	Percent soil passing sieve No. 10 (coarse)
NO200:	Percent soil passing sieve No. 200 (fine)
OM:	Organic matter content (% by weight)
ORD:	Potential soil productivity (m3 of timber/ha)
PERM:	Soil permeability rate (cm/hr)
PH:	Soil pH
ROCKDEP:	Depth to bedrock (cm)
SLOPE:	Soil slope (%) of a soil component
TAWC:	Total available water capacity (cm, to 152 cm)
Land Use and Fragmentation	
FRAG:	Fragmentation Index (Riitters et al. 2002)
AGRICULT:	Cropland (%)
FOREST:	Forest land (%)
NONFOREST:	Nonforest land (%)
WATER:	Water (%)

To assess whether climatic and environmental variables in addition to minimum temperature could be helpful in explaining variability in New York State street tree populations and in generating reliable and valid estimates for street trees on a statewide basis, the following data was gathered for municipalities in New York for which street tree inventory data has been obtained: annual precipitation, elevation, and distance from the equator. Data for annual precipitation was obtained from the PRISM Climate Group, Oregon State University (2007); this data consists of geographic areas computed from thirty year normals (i.e. the arithmetic mean of values over a thirty year period) used by the National Climatic Data Center (NCDC) to measure climate data. Data for elevation and distance from the equator was obtained from the Geographic Names Information System (GNIS) of the United States Geological Survey (USGS 2011); elevation data is based on the elevation of the GNIS determined centroid (i.e. geographic center point) for each New York State municipality and distance from the equator was computed from the latitude and longitude coordinates of all centroids.

Data for soils and bedrock geology were also considered for assessment. STATSGO (State Soil Geographic) soils data (e.g. pH, available water capacity, and bulk density) was obtained from the National Resources Conservation Service (NRCS); bedrock geology data (e.g. dominant and secondary lithology) was obtained from the New York State Geological Survey via the New York State Museum. These data were then mapped in relation to municipal boundaries from which street tree inventory data had been obtained. This mapping indicated a complete or partial lack of soils data for many municipalities; many cities statewide and most municipalities in Zone 7 were impacted. For municipalities where soils data was available, multiple soil classes were found within municipal boundaries, thereby requiring individual trees to be geo-referenced (i.e. mapped with latitude and longitude coordinates) in order to be associated with accurate data, a situation which applied as well to bedrock geology; since many street tree inventory datasets are not geo-referenced, these datasets would not be included in any assessment. Given the seriously reduced sample size due to the factors mentioned above and the finding made by Craul and Klein (1980) that streetside soils differ significantly from native soils, a decision was made to omit data for soils and bedrock geology in assessing variability in New York State street tree populations.

Linear regressions were run in which mean inventory percentages for prevalent species and genera by 1990 USDA Plant Hardiness Zone class were regressed with annual precipitation, elevation, and distance from the equator. Prevalent species and genera rather than street trees per mile were selected as dependent variables since there is no evidence in peer reviewed scientific literature to suggest that the number of street trees in a municipality is influenced by climatic and environmental factors. However, there is extensive evidence in peer reviewed scientific literature to indicate that climatic and environmental factors influence species composition in both urban and natural forests (Iverson et al 2004, Yang 2009, Goldblum 2010).

Regression results found statistically significant effects (α =.10) for many, but not all prevalent street tree species and genera for annual precipitation, elevation, and distance from the equator. Distance from the equator explained more variability than annual precipitation and elevation, and annual precipitation explained more variability than elevation. However, when included in ANCOVA (Analysis of Co-variance) models with 1990 USDA Plant Hardiness Zone classes, zone class was found to be a much better predictor of street tree species and genera than either annual precipitation, elevation, and distance from the equator. In addition, values for variance inflation factor (VIF), a measure of multi-collinearity between variables in a model, were consistently and significantly larger for distance from the equator and elevation with zone class than values for annual precipitation with zone class. Therefore, annual precipitation would appear to be a better candidate for inclusion in a model with 1990 USDA Plant Hardiness Zone class than either distance from the equator or elevation.

Land Use

Studies correlating urban trees with urban land use have typically targeted tree canopy cover rather than characteristics of individual street trees such as species and genus composition. Moreover, most correlations between tree canopy cover and land use have focused on canopy cover for the entire urban forest rather than on canopy cover for street trees. For example, Sanders and Stevens (1984) found for Dayton, OH that single family residential land use had the highest percentage of tree canopy cover compared to all other land uses; Rowntree (1984) found in a comparison of four cities (Birmingham, AL, Cincinnati, OH, Dayton, OH, and Syracuse, NY) that 50 to 60% of available growing space in residential areas was occupied by tree canopy; Nowak et al (1996) found for fifty-eight cities in the United States that park and residential land use had the greatest percentage of tree canopy cover compared to other land uses; and Heynen and Lindsey (2003) found for sixty urban areas in Central Indiana that increased urban tree canopy cover was associated with counties that already had more canopy cover. Fewer studies have correlated street tree canopy cover with land use. Maco and McPherson (2002) found for Davis, CA increased street tree canopy cover in older city-center neighborhoods, and Porcasky and Banis (2005) found in Portland, OR that residential areas had more canopy cover than commercial/industrial areas, but that street trees contributed a greater percentage of canopy cover in commercial/industrial areas than in residential areas.

Land use correlations with urban forest tree canopy cover should not be assumed to translate directly into land use correlations with either street tree canopy cover or street tree population characteristics. Nevertheless, the preponderance of findings from the studies above suggests there may be an effect for land use type on street tree populations and, more specifically, an effect predicated on residential land use versus commercial or industrial land use. Such an effect would be consistent with the sample street tree inventory methodology delineated by Jaenson et al (1992) in which street tree populations were assumed to vary sufficiently by land use type

that a sample stratified by at least three land use types – rectilinear residential (older neighborhoods with gridded streets, sidewalks, and treelawns), curvilinear residential (newer, cul-de-sac neighborhoods), and downtown (central business district) – is required. Although results from sample street tree inventories in four New York State cities were deemed sufficiently accurate (within ± 10%) in estimating street tree numbers and species composition when checked against existing complete or partial inventories, the assumption that street tree populations vary by land use type was not specifically tested.

Correlating land use with street tree populations is complicated further by infrequent collection of land use data associated with individual street trees in street tree inventories. In addition, when land use data is collected in street tree inventories, data classes are often not standardized making the union of data from multiple inventories difficult. Finally, associating street tree data post-inventory with land use classifications from adjacent tax parcels can be problematic since land use at parcel scale is commonly subject to change and may not be accurate. For example, Lu et al (2010) found in a study of street tree mortality in New York City that 48% of tax parcel land use classifications associated with planting locations by the New York City Department of City Planning proved inaccurate and locations had to be field-verified for their correct land use class. In addition, associating street tree data post-inventory with land use classifications from adjacent tax parcels requires accurately referencing each street tree location with latitude and longitude coordinates, whether collected with GPS (global positioning system) equipment in an inventory or geocoded (i.e. converted to latitude and longitude coordinates) from a street address. However, latitude and longitude coordinates for tree locations are often not collected in a street tree inventory while street address locations are not always sufficiently precise to satisfy the requirements of geocoding software.

Notwithstanding these issues, the following methodology was employed to assess land use correlations with street tree populations in New York State. Land use land cover (LULC) data was obtained from the 2006 National Land Cover Dataset (NLCD) generated by the Multi-Resolution Land Characteristics (MRLC) Consortium, a group of nine United States government agencies (USGS, EPA, USFS, NOAA, NASA, BLM, NPS, NRCS and USFWS). NLCD data is collected in 30 meter by 30 meter gridded cells for the entire United States and differentiated into 25 LULC classes (MRLC 2011). Descriptions of the NLCD LULC classes are shown in Table 4.2.

Table 4.2 National Land Cover Dataset land use land cover (LULC) data classes

11 - Open water
12 - Perennial Ice/Snow
21 - Developed, Open Space
22 - Developed, Low Intensity
23 - Developed, Medium Intensity
24 - Developed, High Intensity
31 - Barren Land
32 - Unconsolidated Shore
41 - Deciduous Forest
42 - Evergreen Forest
43 - Mixed Forest
51 - Dwarf Scrub (Alaska only)
52 - Scrub/Shrub
81 - Pasture/Hay
82 - Cultivated Crops
90 - Woody Wetlands
91 - Palustrine Forested Wetland (coastal only)
92 - Palustrine Scrub/Shrub (coastal only)
93 - Estuarine Forested Wetlands (coastal only)
94 - Estuarine Scrub/Shrub (coastal only)
95 - Emergent Herbaceous Wetland
96 - Palustrine Emergent Wetland (Persistent) (coastal only)
97 - Palustrine Emergent Wetland (coastal only)
98 - Palustrine Aquatic Bed (coastal only)
99 - Estuarine Aquatic Bed (coastal only)

Of particular interest are LULC classes 21, 22, 23, and 24 which encompass residential and non-residential development. These classes approximate more closely than other classes Census Places and Census Blocks with population density of at least 500 ppsm, or those geographies where it has been argued previously that street trees are most likely to be found. Detailed descriptions for these classes are as follows:

> 21. Developed, Open Space - Includes areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces account for less than 20 percent of total cover. These areas most commonly include large-lot single-family housing units, parks, golf courses, and vegetation planted in developed settings for recreation, erosion control, or aesthetic purposes.

22. Developed, Low Intensity - Includes areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 20-49 percent of total cover. These areas most commonly include single-family housing units.

23. Developed, Medium Intensity - Includes areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 50-79 percent of the total cover. These areas most commonly include single-family housing units.

24. Developed, High Intensity - Includes highly developed areas where people reside or work in high numbers. Examples include apartment complexes, row houses and commercial/industrial. Impervious surfaces account for 80 to100 percent of the total cover.

The profile of LULC grid cell distribution within all Census Places in New York State (i.e. cities, villages, and CDPs) was analyzed, both statewide and by 1990 USDA Plant Hardiness Zone classes, according to a methodology illustrated in Figure 4.1. LULC grid cells characterized by development (i.e. LULC classes 21, 22, 23, and 24) were found to comprise 58.88% of all grid cells for all NYS Census Places statewide. Distribution varied geographically with grid cells characterized by development totaling 44.02% in Zones 3 + 4, 45.32% in Zone 5, 67.58% in Zone 6, and 69.35% in Zone 7, reflecting increased intensity of development in southern New York State. Distribution also varied by municipality type with grid cells characterized by development totaling 70.72% for cities, 51.59% for Villages, and 58.03% for CDPs reflecting increased intensity of development in cities relative to villages and CDPs.

To assess whether LULC grid cells can be correlated with street tree populations in New York State, and more specifically whether LULC classes 21, 22, 23, and 24 might be helpful in explaining those correlations, street trees in forty-one municipalities where tree locations have been geo-referenced (i.e. assigned latitude and longitude coordinates) were associated with the LULC grid cell classification of those locations according to a methodology illustrated in Figure 4.2. Results indicate that for these forty-one municipalities, most street trees (94.13% mean, 95.34% median) were associated with LULC grid cell classes 21, 22, 23, and 24. In other words, LULC grid cells characterized by development (i.e. LULC classes 21, 22, 23, and 24) account for the overwhelming majority of streets trees in the forty-one municipalities sampled. While the cumulative percentage of LULC grid cells in classes 21, 22, 23, and 24 associated with street trees was consistent between municipalities, distribution of these four grid cell classes varied significantly (i.e. mean percentage relative to the others): LULC 21 – 24.57%, LULC 22 – 38.65%, LULC 23 – 22.20%, and LULC 24 – 8.72%. Further examination revealed differences in distribution profiles between cities, villages, and CDPs with cities having smaller percentages of LULC 21 grid cells than villages and CDPs, but greater percentages of LULC 23 and 24 grid cells than villages and CDPs (Figure 4.3). These differences were found to be consistent for all municipalities and also for municipalities with street tree inventories across 1990 USDA Plant Hardiness Zone classes.

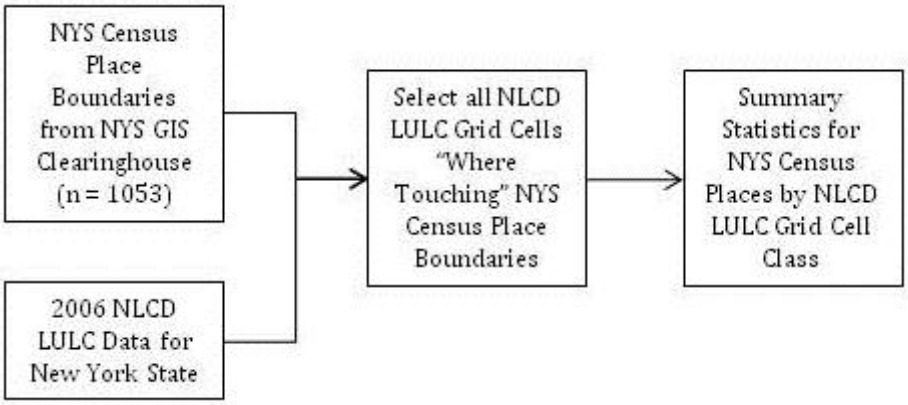


Figure 4.1 Methodology for generating profile of LULC grid cell class distribution within all Census Places in New York State

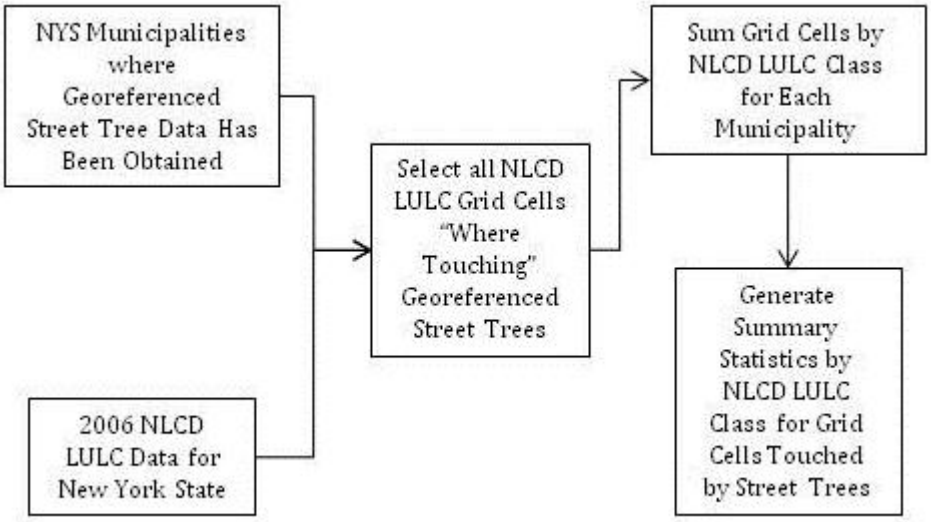


Figure 4.2 Methodology for determining grid cells by class touched by street trees for forty-one municipalities in New York State

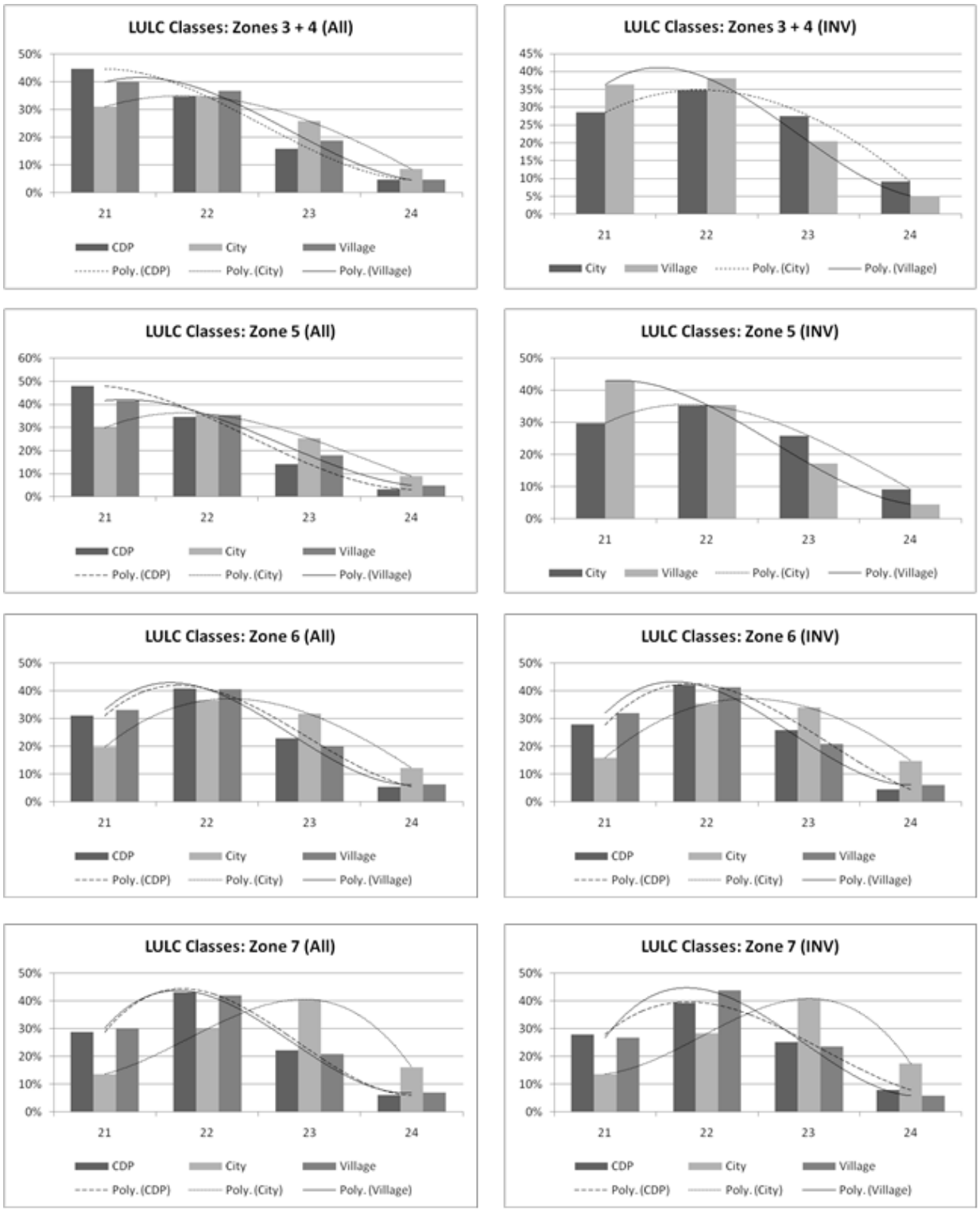


Figure 4.3 LULC grid cell distribution profiles for cities, villages, and CDPS by 1990 USDA Plant Hardiness Zones and municipalities with street tree inventories

The sample of inventoried municipalities was then assessed in relation to all municipalities for LULC grid cell classes 21, 22, 23, and 24 by comparing the relative percentages of these grid cell classes. Statewide results from paired t-tests and Mann–Whitney U tests indicated statistically significant differences for grid cells classes 21, 23, and 24 with the sample mean for grid cell class 21 less than the population mean and the sample mean for grid cell classes 23 and 24 greater than the population mean. This suggests that the sample of inventoried municipalities may be biased towards increased intensity of development.

Although results generated by methodologies illustrated in Figures 4.1, 4.2. and 4.3 assess trends in the distribution of LULC grid cell classes and development intensity relative to 1990 USDA Plant Hardiness Zones and municipality types, they do not indicate whether these trends translate into differences in street tree species and genus composition relative to development intensity. To assess whether street tree species and genus composition might vary due to development intensity, prevalent street trees species and genera were associated with LULC grid cell classes 21, 22, 23, and 24 according to a methodology shown in Figure 4.4. Relative percentages for grid cell classes by prevalent street tree species and genera were calculated for each municipality. These percentages were then averaged and plotted for prevalent species and genera as shown in Figure 4.5 and Figure 4.6. Results suggest effects for several species and genera due to development intensity. For example, percentages of *Acer saccharum* (Sugar Maple) and *Platanus x acerifolia* (London Planetree) decline with development intensity (i.e. percentages decline from LULC grid cell class 21 to LULC grid cell class 24) while percentages of *Gleditsia triacanthos* (Honeylocust) and *Pyrus calleryana* (Callery Pear) increase with development intensity (i.e. percentages increase from LULC grid cell class 21 to LULC grid cell class 24). These effects are seen as well when cities are analyzed separately from villages and CDPs and percentages for some species and genera vary meaningfully by municipality type (Figures 4.7, 4.8, 4.9, 4.10). For example, the percentages of *Pyrus calleryana* (Callery Pear) appear greater for cities than villages and CDPs, but the percentages of *Gleditsia triacanthos* (Honeylocust) appear greater for villages and CDPs than for cities.

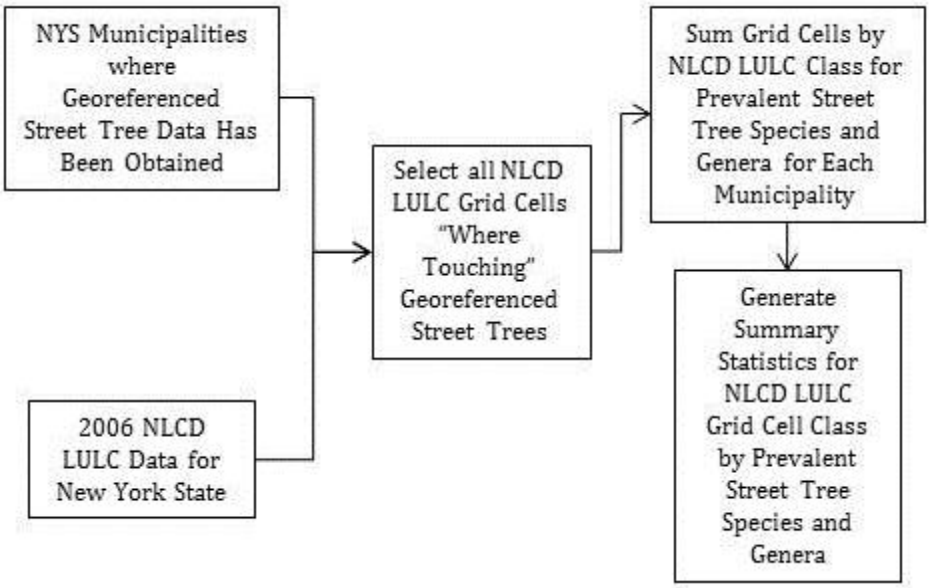
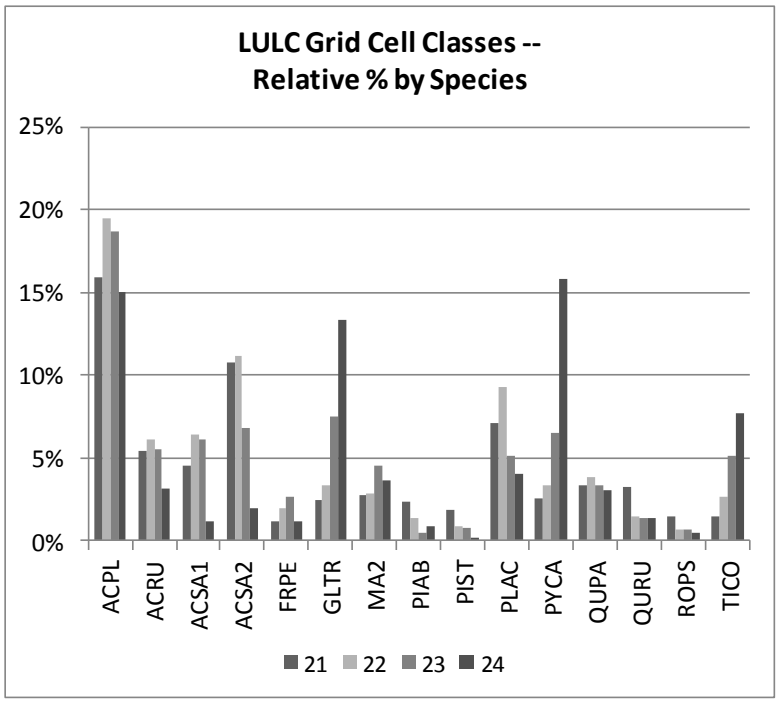


Figure 4.4 Methodology for associating LULC grid cell classes 21, 22, 23, and 24 with prevalent street tree species and genera in New York State



ACPL	*Acer platanoides*
ACRU	*Acer rubrum*
ACSA1	*Acer saccharinum*
ACSA2	*Acer saccharum*
FRPE	*Fraxinus pennsylvanica*
GLTR	*Gleditsia triacanthos*
MA2	*Malus species*
PIAB	*Picea abies*
PIST	*Pinus strobus*
PLAC	*Platanus x acerifolia*
PYCA	*Pyrus calleryana*
QUPA	*Quercus palustris*
QURU	*Quercus rubrum*
ROPS	*Robinia pseudoacacia*
TICO	*Tilia cordata*

Figure 4.5 Relative percentages of LULC grid cell classes characterized by development (21, 22, 23, and 24) by prevalent New York State street tree species

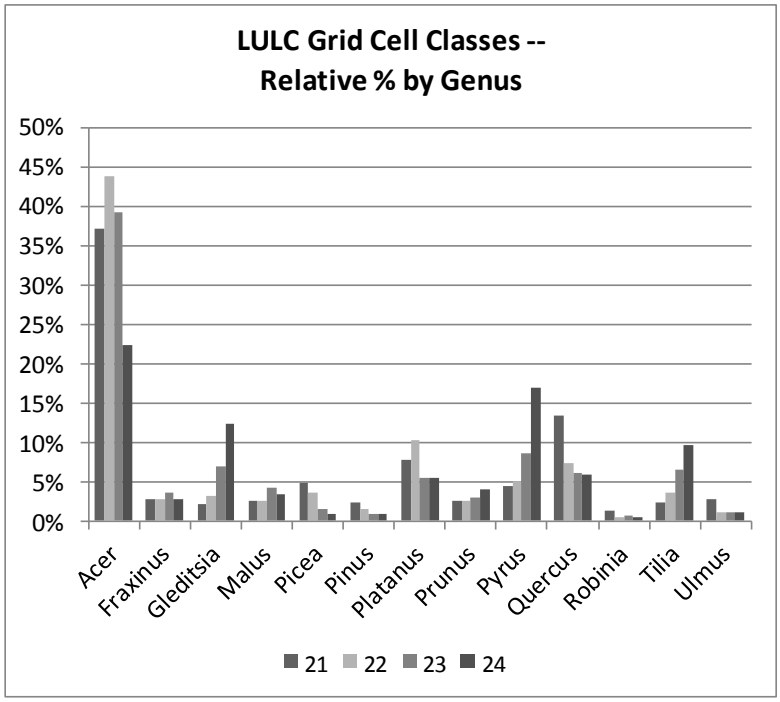
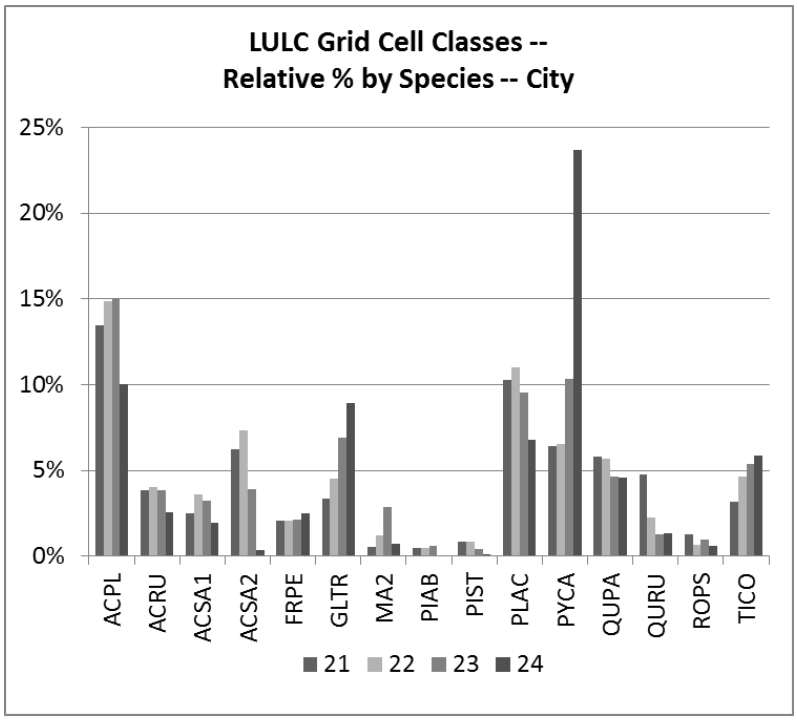
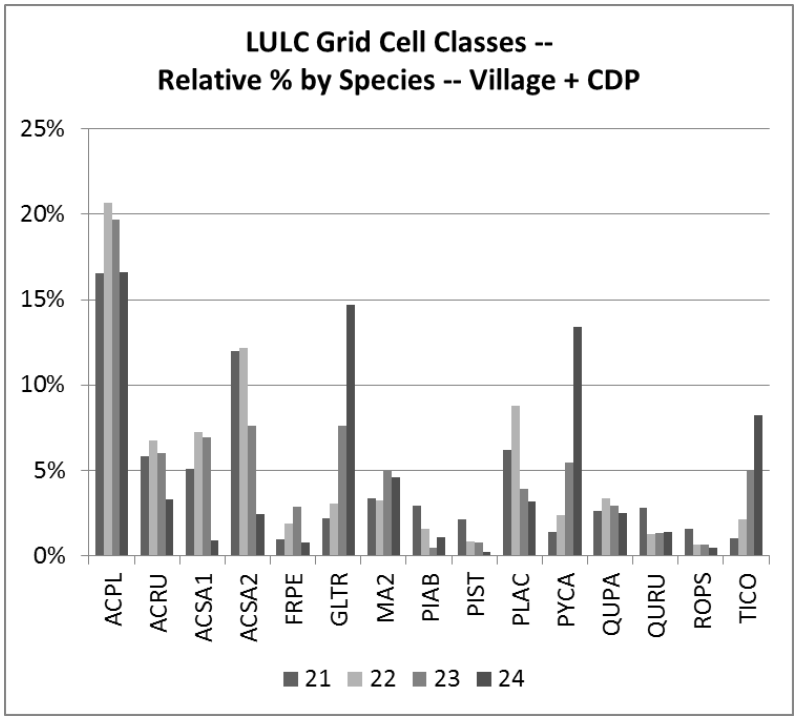


Figure 4.6 Relative percentages of LULC grid cell classes characterized by development (21, 22, 23, and 24) by prevalent New York State street tree genera



ACPL	*Acer platanoides*
ACRU	*Acer rubrum*
ACSA1	*Acer saccharinum*
ACSA2	*Acer saccharum*
FRPE	*Fraxinus pennsylvanica*
GLTR	*Gleditsia triacanthos*
MA2	*Malus species*
PIAB	*Picea abies*
PIST	*Pinus strobus*
PLAC	*Platanus x acerifolia*
PYCA	*Pyrus calleryana*
QUPA	*Quercus palustris*
QURU	*Quercus rubrum*
ROPS	*Robinia pseudoacacia*
TICO	*Tilia cordata*

Figure 4.7 Relative percentages of LULC grid cell classes characterized by development (21, 22, 23, and 24) by prevalent New York State street tree species in New York State cities



ACPL	*Acer platanoides*
ACRU	*Acer rubrum*
ACSA1	*Acer saccharinum*
ACSA2	*Acer saccharum*
FRPE	*Fraxinus pennsylvanica*
GLTR	*Gleditsia triacanthos*
MA2	*Malus species*
PIAB	*Picea abies*
PIST	*Pinus strobus*
PLAC	*Platanus x acerifolia*
PYCA	*Pyrus calleryana*
QUPA	*Quercus palustris*
QURU	*Quercus rubrum*
ROPS	*Robinia pseudoacacia*
TICO	*Tilia cordata*

Figure 4.8 Relative percentages of LULC grid cell classes characterized by development (21, 22, 23, and 24) by prevalent New York State street tree species in New York State villages and CDPs

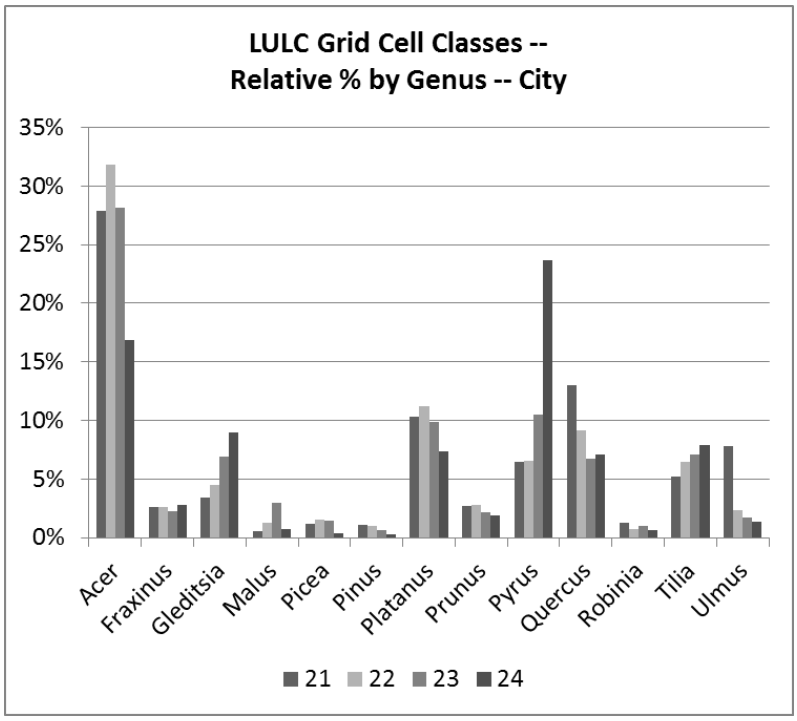


Figure 4.9 Relative percentages of LULC grid cell classes characterized by development (21, 22, 23, and 24) by prevalent New York State street tree genera in New York State cities

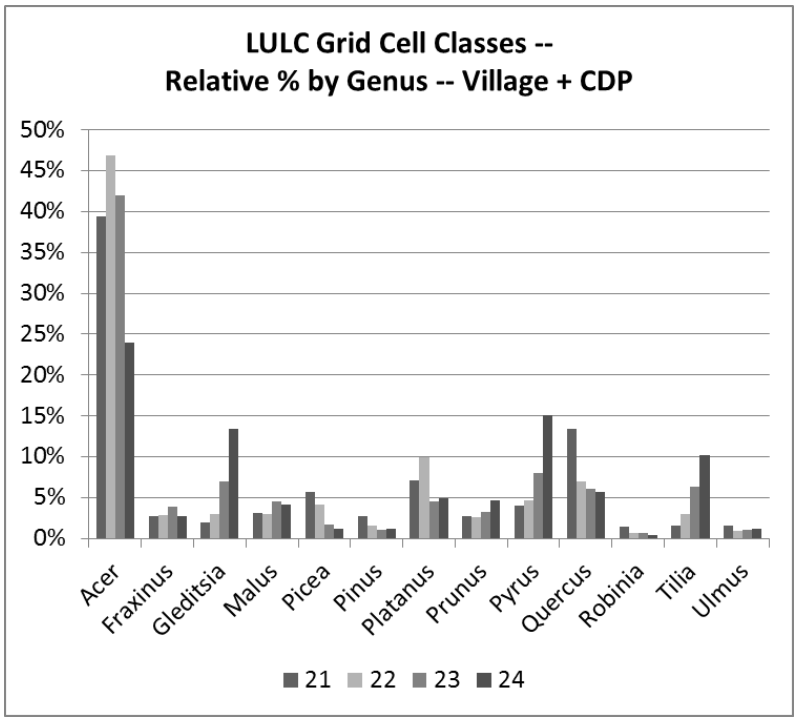


Figure 4.10 Relative percentages of LULC grid cell classes characterized by development (21, 22, 23, and 24) by prevalent New York State street tree species in New York State villages and CDPs

It must be noted, however, that many street tree inventories in New York State are not geo-referenced. In fact, the number of geo-referenced street tree inventories obtained in New York State is meaningfully fewer than the number of street tree inventories obtained in New York State overall. Also, many geo-referenced street tree inventories (42.5% of all geo-referenced street tree inventories) are located in 1990 USDA Plant Hardiness Zone 7 municipalities. This substantial representation of Zone 7 data can potentially bias results since street tree species and genera vary by 1990 USDA Plant Hardiness Zone class. For example, *Pyrus* is more prevalent in Zone 7 than in Zone 5 while the reverse is true for *Malus*. It is possible that a larger effect would be seen for *Malus* due to development intensity (i.e. *Malus* percentages would increase more significantly from LULC grid cell class 21 to LULC grid cell class 24) if additional geo-referenced data was obtained from municipalities in Zone 5. It must be noted additionally that the number of grid cells in LULC grid cell class 24 is far fewer than the number of grid cells in LULC grid cell classes 21, 22, and 23. Results for LULC grid cell class 24, consequently, contain more variability than results for the other grid cell classes. Finally, the number of geo-referenced street tree inventories obtained from New York State cities is meaningfully fewer than the number of geo-referenced street tree inventories obtained from New York State villages and CDPs. This is somewhat to be expected since the number of New York State villages and CDPs far exceeds the number of New York State cities.

Nevertheless, the relatively small number of cities from which geo-referenced street tree inventory data has been obtained cautions the reliability and validity of results when percentages of street tree species and genera are differentiated on the basis of municipality type.

Despite the caveats and data limitations, land use, and more specifically NLCD LULC grid cell classes 21, 22, 23, and 24 reflecting differences in development intensity, look to have explanatory power regarding New York State street tree populations. Small and medium sized trees such as *Pyrus calleryana*, *Malus species*, and *Tilia cordata* appear to be more prevalent as development intensity increases and large sized trees such as *Acer saccharum* and *Platanus x acerifolia* appear to be less prevalent as development intensity increases. Municipality type (i.e. city versus village and CDP) may also impact street tree species and genera prevalence although effects for municipality type and development intensity can be expected to be somewhat multi-collinear. Since development intensity generally increases from north to south in New York State and 1990 USDA Plant Hardiness Zones mirror to a great extent a north-south geographic axis, multi-collinearity is also likely to be an issue between land use effects associated with development intensity and effects associated with 1990 USDA Plant Hardiness Zone classes. Attention must be given, therefore, not to overfit any model seeking to explain street tree populations in New York State which includes land use variables such as municipality type, LULC grid cell classes, and 1990 USDA Plant Hardiness Zone classes. In addition, possible bias in sample data towards increased intensity of development must be considered.

Sociodemographics

Similar to land use, studies correlating urban trees with sociodemographics have focused more on urban forest canopy cover than on street tree canopy cover or street tree characteristics. For example, Iverson and Cook (2000) found for Chicago, IL that increased tree canopy cover was associated with higher median household income; Heynen and Lindsey (2003) found for sixty urban areas in Central Indiana that increased urban tree canopy cover was associated with higher levels of educational attainment and older housing stock, but not with population density or median household income; Hope et al (2003) found for Phoenix, AZ that increased plant diversity was associated with higher median family income and older housing; and Heynen et al (2006) found for Milwaukee, WI that census tracts with higher median household income, more non-Hispanic White residents, and lower housing vacancy rates were more likely to have greater tree canopy cover. Fewer studies have correlated street tree canopy cover with sociodemographics. Grove et al (2006) found for Baltimore, MD that tree canopy cover in public rights-of-way was associated with housing age and lifestyle behavior while Landry and Chakraborty (2009) found for Tampa, FL a significantly lower proportion of street tree canopy cover in neighborhoods with higher proportions of African-American residents, lower median household incomes, and lower proportions of owner-occupied housing. Two studies correlated street tree counts rather than street tree canopy

cover with sociodemographics. Lovasi et al (2008) found for New York, NY that street tree density (i.e. density of street trees per km2) was higher in the most densely populated areas and in areas with less poverty and Neckerman et al (2009) found for New York, NY as well that poorer census tracts with at least 20% of residents living in poverty had fewer street trees.

Just as correlations with urban forest tree canopy cover should not be assumed to translate directly into land use correlations with either street tree canopy cover or street tree population characteristics, correlations with urban forest canopy cover do not necessarily apply to sociodemographic correlations with street tree canopy cover or street tree population characteristics. Nevertheless, the preponderance of findings from the studies above coupled with the two studies focusing on street tree counts in New York City suggest there may be a sociodemographic effect on street tree populations and, more specifically, an effect for median household income and higher levels of educational attainment. Therefore, the following methodology was employed to assess sociodemographic correlations with street tree populations in New York State. Sociodemographic data was obtained from the US Census Bureau (Census 2000 Summary File 1 [SF 1] 100-Percent Data and Census 2000 Summary File 3 [SF 3] - Sample Data) for all Census Places in New York State (e.g. cities, villages, and Census Designated Places). Data from the 2000 Census was used since data from the 2010 Census for a comprehensive range of variables at the scale of the Census Place was not sufficiently available at time of writing.

Data for the following Census variables was analyzed: housing unit density (i.e. housing units per square mile), median age, median household income, median year structure built, percent population below the poverty line, percent population with a college degree, percent owner occupied housing, percent rural population, and population density. Comparisons were made between data for New York State Census Places where street tree inventory data has been obtained and data for all New York State Census Places to assess possible biases contained in the street tree inventory data sample. Paired *t*-tests and Mann–Whitney *U* tests for Census variables revealed the following: no statistically significant differences were found statewide for median age and percent population with a college degree between New York State Census Places where street tree inventory data has been obtained and all New York State Census Places. Statistically significant differences were found statewide for housing unit density, median household income, median year structure built, percent population below the poverty line, percent owner occupied housing, percent rural population, and population density such that Census Places where street tree inventory data has been obtained are characterized by less housing unit density, lower median household income, older median structures built, a higher percentage of population below the poverty line, a lower percentage of owner occupied housing, a lower percentage of rural population, and higher population density than all New York State Census Places.

While these statewide differences in Census variables between New York State Census Places where street tree inventory data has been obtained and all New York

State Census Places are noteworthy, they do not necessarily mean that the street tree inventory data sample is irreparably biased. Further examination suggests that these statewide differences reflect disproportionate representation between Census Places downstate and Census Places upstate contained in the sample compared to all Census Places statewide. More specifically, Census Places upstate are more heavily represented in the sample than they are statewide. For example, the number of Census Places where street tree inventory data has been obtained represents 7% of all Census Places located downstate in 1990 USDA Plant Hardiness Zone 7 compared to 15% elsewhere in New York State. Because significant differences exist between upstate and downstate Census variables and the number of upstate Census Places where street tree inventory data has been obtained has been overrepresented relative to the number of all Census Places upstate, these differences have been reflected in differences found between New York State Census Places where street tree inventory data has been obtained and all New York State Census Places. If additional street tree inventory datasets were obtained from Census Places located in 1990 USDA Plant Hardiness Zone 7, differences found between New York State Census Places where street tree inventory data has been obtained and all New York State Census Places would likely be mitigated. In the absence of that event, the upstate overrepresentation in sample Census variables will be accounted for by grouping Census variables by 1990 USDA Plant Hardiness Zone classes and analyzing them on that basis, consistent with what has been done in assessing other potential model variables.

The efficacy of this strategy was tested for median household income. Whereas statistically significant differences were found for median household between New York State Census Places where street tree inventory data has been obtained and all New York State Census Places, and statistically significant differences can also be found for median household income between all New York State Census Places in all 1990 USDA Plant Hardiness Zone classes (i.e. mean household income for all Census Places is 33830 for Zones 3+4, 38366 for Zone 5, 58562 for Zone 6, and 81856 for Zone 7), there are no statistically significant differences for median household income between Census Places where street tree inventory data has been obtained and all Census Places in Zone 3+4, Zone 6, or Zone7; there is a slight statistically significant difference in Zone 5 (e.g. 38366 for all Census Places vs. 34896 for Census Places where street tree inventory data has been obtained) which can be attributed to efforts by Cooperative Extension in some Zone 5 counties to conduct street tree inventories in smaller, less affluent, rural communities. Therefore, correlations between sociodemographic variables and street tree populations in New York State will be assessed by 1990 USDA Plant Hardiness Zone class to mitigate statewide differences in Census variables between New York State Census Places where street tree inventory data has been obtained and all New York State Census Places.

Linear regressions were run in which street trees per mile by 1990 USDA Plant Hardiness Zone class were regressed with sociodemographic variables. Street trees per mile rather than prevalent street tree species and genera was selected as the

dependent variable since there is no evidence in peer reviewed scientific literature to suggest that street tree species and genus composition within a municipality is influenced by sociodemographic factors. However, as cited above, there is evidence in peer reviewed scientific literature to indicate that sociodemographic factors do influence street tree numbers and canopy cover within a municipality although only one study (Heynen & Lindsey 2003) analyzed relationships between canopy cover and sociodemographic variables across multiple municipalities. Regression results found statistically significant effects (α =.10) for at least two zone classes for median household income, median year structure built, and percent population with a college degree; statistically significant effects (α =.10) for at least two zone classes were not found for housing unit density, median age, percent population below the poverty line, percent owner occupied housing, percent rural population, and population density. For these variables, percent population with a college degree explained more variability in street trees per mile than median year structure built and median household income, and median year structure built explained more variability than median household income. Models were then run for each 1990 USDA Plant Hardiness Zone class with street trees per mile as a dependent variable and median household income, median year structure built, and percent population with a college degree as independent variables. The model for 1990 USDA Plant Hardiness Zones 3 + 4 was not found to be statistically significant for any of these variables; median age and percent rural population were found to be statistically significant individually, but not when combined in a model. The model for 1990 USDA Plant Hardiness Zone 5 was found to be statistically significant with median household income, median year structure built, and percent population with a college degree included as independent variables, but none of these variables was found to be significant when combined with the others in the model. Percent population with a college degree was found to have the most explanatory power of these variables for street trees per mile in 1990 USDA Plant Hardiness Zone 5; an increase in street trees per mile was correlated with an increase in percent population with a college degree. The model for 1990 USDA Plant Hardiness Zone 6 was found to be statistically significant with median household income, median year structures built, and percent population with a college degree included as independent variables, but only median household income was found to be significant when combined with the others in the model. Median household income was found to have the most explanatory power of these variables for street trees per mile in 1990 USDA Plant Hardiness Zone 6; an increase in street trees per mile was correlated with an increase in median household income. The model for 1990 USDA Plant Hardiness Zone 7 was found to be statistically significant with median household income, median year structure built, and percent population with a college degree included as independent variables, but only one variable at a time was found to be significant when combined with the others in the model. Median household income was found to have the most explanatory power of these variables for street trees per mile in 1990 USDA Plant Hardiness Zone 7; an increase in street trees per mile was correlated with an increase in median household income.

Results overall suggest that median household income has more explanatory power than either median year structure built or percent population with a college degree in explaining variability in street trees per mile. On a statewide basis, results from a linear regression with street trees per mile as the dependent variable and median household income as the independent variable found a statistically significant effect (r^2 = 39.0, prob > F <.0001, n = 110). However, when 1990 USDA Plant Hardiness Zone class was added to the regression model, median household income was no longer found to be statistically significant (α =.10) and 1990 USDA Plant Hardiness Zone class was indicated as the superior predictor. Therefore, median household income as well as median year structure built and percent population with a college degree would not appear to be warranted for inclusion in a model predicting street trees per mile on a statewide basis, especially in comparison to 1990 USDA Plant Hardiness Zone class. Although the explanatory power for these sociodemographic variables appears limited across multiple municipalities, it is possible they might have greater explanatory power within a municipality, but that analysis is beyond the scope of the present study.

Additional Factors

Clark et al (1997) hypothesized a model of urban forest sustainability with three principal components: species and age diversity in urban trees, community support for urban forestry, and comprehensive management of urban trees as a municipal resource. Included in those components were employment and training of staff dedicated to tree care, planting, and pruning, municipal ordinances protecting existing trees and replacing trees lost to development, and citizen groups such as shade tree boards or commissions advocating for funding and policies promoting urban forestry. Thus, staff, ordinances, and advocacy were hypothesized as factors associated with the health and sustainability of urban and community trees.

The Community Accomplishment Reporting System (CARS) of the United States Forest Service's Urban and Community Forestry Program requires states to collect data from municipalities regarding the number of communities that (1) employ or retain professional forestry staff to manage urban and community trees, (2) have adopted ordinances or polices focused on planting, protecting, and maintaining urban and community trees, and (3) have local advisory or advocacy organizations such as tree boards or commissions that advocate for the planting, protection, and maintenance of urban and community trees (USDA Forest Service 2011). Data is collected for cities, villages, and Census Designated Places, but not for towns. Rines et al (2011) studied CARS data for Massachusetts municipalities and found positive correlations (Spearman's p) between professional staff, ordinances, and advocacy groups with population size, median household income, and percentage of residents with a college degree. These findings are consistent with findings made by Zhang et al (2007) in a statewide telephone survey of Alabama residents that individuals holding a full-time job and with an annual income greater $75,000 were more likely to donate money and volunteer time in support of urban forestry programs and

activities; those made by Dickerson et al (2001) that communities in Illinois with higher mean annual per capita income and higher levels of educational attainment were more likely than poorer, less educated communities to employ professional personnel to make tree care decisions; and those made by Lorenzo et al (2000) that residents of a New Orleans, LA suburb with annual incomes greater than $40,000 and a college education were more likely to appreciate the value of urban trees and financially support urban forestry programs than residents with annual incomes less than $25,000 and a high school education. While these studies make important contributions in identifying potential demographic bias in components assumed to foster urban forest sustainability, they do not directly correlate these components to tree population characteristics such as species and genus composition, relative age distribution, or species diversity that are closely associated with the long term health of urban and community trees.

To assess whether Urban and Community Forestry CARS statistics and the presence or absence of professional staff, ordinances, and advocacy groups could be helpful in explaining variability in New York State street tree populations, CARS statistics for the years 2007 through 2010 were obtained from the USDA Forest Service for communities in New York State. Duplicate responses were removed to create a list of communities credited with professional staff, ordinances, or advocacy groups for any one of the years between 2007 and 2010. Spearman's *p* correlations were run for all New York State Census Places where the presence or absence of professional staff, ordinances, or advocacy groups were correlated with population size, median household income, and percentage of population with a college degree. Population size was found significantly correlated (α =.10) with professional staff (r = 0.28), ordinances (r = 0.31), and advocacy groups (r = 0.25); median household income was found significantly correlated with advocacy groups (r = –0.11), but significant correlations were not found for professional staff or ordinances; and percentage of population with a college degree was found significantly correlated for professional staff (r = 0.14), ordinances (r = 0.18), and advocacy groups (r = 0.08). These figures are similar to those found by Rines et al (2011) for population size, differ somewhat for percentage of population with a college degree, and differ greatly for median household income. Reasons for these differences are not clear.

Spearman's *p* correlations were then run where the presence or absence of professional staff, ordinances, or advocacy groups were correlated with species diversity and street trees per mile for those New York State municipalities for which street tree inventory data has been obtained. Three species diversity indices were used for these correlations: the Inverse of Simpson's Diversity Index (SDI), the Shannon-Weiner Diversity Index, and Fisher's alpha. Kempton and Taylor (1976) have contended that Fisher's alpha better represents species abundance (i.e. is less sensitive to and does not over-represent rarer species) and, therefore, depending on the population being sampled, may be a superior measure. Professional staff was found significantly correlated (α =.10) with Shannon-Weiner (r = 0.19) and Fisher's alpha (r = 0.36), but a significant correlation was not found for the Inverse SDI. Ordinances and advocacy groups were found significantly correlated with Fisher's

alpha (r = 0.18 and r = 0.19 respectively), but significant correlations were not found for the Inverse SDI or Shannon-Weiner. Spearman's p correlations were then run for the presence or absence of professional staff, ordinances, and advocacy groups with street trees per mile for New York State municipalities where street tree inventory data has been obtained and values for street trees per mile can be calculated. Professional staff, ordinances, or advocacy groups were found significantly correlated with street trees per mile (r = 0.24, r = 0.41, and r = 0.28 respectively). Finally, Spearman's p correlations were run for the presence or absence of professional staff, ordinances, and advocacy groups with annual benefits per tree for New York State municipalities where street tree inventory data has been obtained and values for annual benefits per tree can be calculated. Professional staff, ordinances, or advocacy groups were found significantly correlated with annual benefits per tree (r = –0.33, r = –0.28, and r = –0.27 respectively).

The results above suggest that CARS statistics, and specifically the presence or absence of professional staff, ordinances, and advocacy groups, might be helpful in explaining variability in New York State street tree populations. Professional staff appears to have greater explanatory power with respect to species diversity than ordinances or advocacy groups, but professional staff, ordinances, and advocacy groups all appear to have explanatory power for street trees per mile and annual benefits per tree. The negative correlations for annual benefits per tree are not immediately explainable. One possible explanation could be that communities with professional staff, ordinances, and advocacy groups are associated with increased numbers of younger, newly planted street trees relative to communities without professional staff, ordinances, and advocacy groups; since younger, newly planted street trees provide fewer annual benefits than older, more mature street trees, communities with increased numbers of recent street tree plantings could be expected to provide fewer annual benefits per tree than communities where recent street tree plantings have not been as abundant.

Species and Genus Composition

Four zone classes (i.e. Zones 3+4, Zone 5, Zone 6, and Zone 7) based on 1990 USDA Plant Hardiness Zones have been hypothesized as a significant predictor variable in estimating species and genus composition in New York State. This hypothesis has been predicated on the assumption that plant hardiness zones reflect differences in minimum temperature and that minimum temperature affecting plant hardiness is an important factor in explaining the distribution and prevalence of street tree species and street tree genera. Annual precipitation, elevation, and distance from the equator have also been hypothesized as predictor variables in estimating species and genus composition in New York State. Linear regressions found statistically significant effects (α =.10) for many, but not all prevalent street tree species and genera for annual precipitation, elevation, and distance from the equator. Distance from the equator explained more variability than annual

precipitation and elevation, and annual precipitation explained more variability than elevation. However, when included in ANCOVA (Analysis of Co-variance) models with 1990 USDA Plant Hardiness Zone classes, zone class was found to be a much better predictor of street tree species and genera than annual precipitation, elevation, and distance from the equator and values for variance inflation factor (VIF), a measure of multi-collinearity between variables in a model, were consistently and significantly larger for distance from the equator and elevation with zone class than values for annual precipitation with zone class. Therefore, it was suggested that annual precipitation would be a better candidate for inclusion with 1990 USDA Plant Hardiness Zone class in a model estimating species and genus composition in New York State than would distance from the equator or elevation. Development intensity and municipality type have been hypothesized as additional predictor variables in estimating species and genus composition in New York State. Relative percentages of NLCD LULC grid cell classes 21, 22, 23, and 24 for New York State municipalities have been identified as measures of development intensity and cities have been differentiated from villages and Census Designated Places (CDPs) for capturing effects based on municipality type.

Linear regressions were run for prevalent New York State street tree species and genera with species and genera percentages of municipality street tree populations as dependent variables and 1990 USDA Plant Hardiness Zone class, annual precipitation, municipality type, and relative percentages of NLCD LULC grid cell classes 21, 22, 23, and 24 as independent variables. Findings (α =.10) are as follows:

- 1990 USDA Plant Hardiness Zone class is the best predictor variable for most prevalent street tree genera and many prevalent street tree species

- Municipality type generally explains less variability than 1990 USDA Plant Hardiness Zone class, but is the best predictor variable for several street tree species and genera, including *Tilia* and *Gleditsia*, for which statistically significant effects were not found for 1990 USDA Plant Hardiness Zone class and whose percentages increase with development intensity (i.e. greater for city than village or CDP)

- Statistically significant effects were found for annual precipitation and LULC grid cell classes 21, 22, 23, and 24, but these effects were not consistent and often found to be multi-collinear with effects for 1990 USDA Plant Hardiness Zone class and municipality type

- In a multivariate model containing both 1990 USDA Plant Hardiness Zone and municipality type, the two variables were frequently found to be multi-collinear and 1990 USDA Plant Hardiness Zone class explained much more variability than did municipality type

Based on these findings, 1990 USDA Plant Hardiness Zone class will be used to calculate mean species and genus percentages and 90% confidence interval levels by zone class based on summary statistics from assembled street tree inventory data. Annual precipitation, municipality type, and LULC grid cell classes 21, 22, 23, and 24 will not be used to calculate mean species and genus percentages and 90% confidence interval levels. Because municipality type was found to be the best predictor variable of mean percentages for some species and genera including *Tilia* and *Gleditsia* where summary statistics indicate greater prevalence in cities than in villages and CDPs, additional analysis may be warranted to explore adjustments to mean species and genus percentages and 90% confidence levels to account for effects due to municipality type. However, a conservative approach is advisable in this regard pending the collection of additional data since r^2 values for municipality type are comparatively slight (i.e. r^2 for Gleditsia = 0.13 and r^2 for Tilia = 0.08), municipality type effects seem concentrated in 1990 USDA Plant Hardiness Zone class 7, and municipality type effects may already be captured substantially at the zone class level.

(5) Initial Statewide Estimates

Summary. Estimates for tree numbers statewide for prevalent street tree species and genera and annual benefits statewide provided by street trees were calculated based on stratifying data and weighting means from summary statistics by 1990 USDA Plant Hardiness Zone classes. These calculations comprise initial estimates to be compared to and updated by statistics from a number of street tree inventories to be conducted subsequently.

A statistical model for making reliable and valid estimates for street trees on a statewide basis has been delineated predicated on stratifying data and weighting means from summary statistics by 1990 USDA Plant Hardiness Zone class. Objectives of the model include calculation of street tree numbers statewide for prevalent species and genera and calculation of annual benefits statewide provided by street trees. These calculations will be based on the following measures:

(i) Summed street length of streets expected to contain street trees for all Census Places and Census Blocks with population density of at least 500 ppsm not contained within Census Places

(ii) Means for street trees per meter and street trees per mile of streets expected to contain street trees

(iii) Mean percentages of prevalent street tree species and genera

(iv) Mean annual benefits per street tree

The methodology for calculating street tree numbers statewide for prevalent species and genera is illustrated in Figure 5.1 and the methodology for calculating annual benefits statewide provided by street trees is illustrated in Figure 5.2. Calculations comprise initial estimates to be compared to and updated by statistics from a number of street tree inventories to be conducted subsequently,

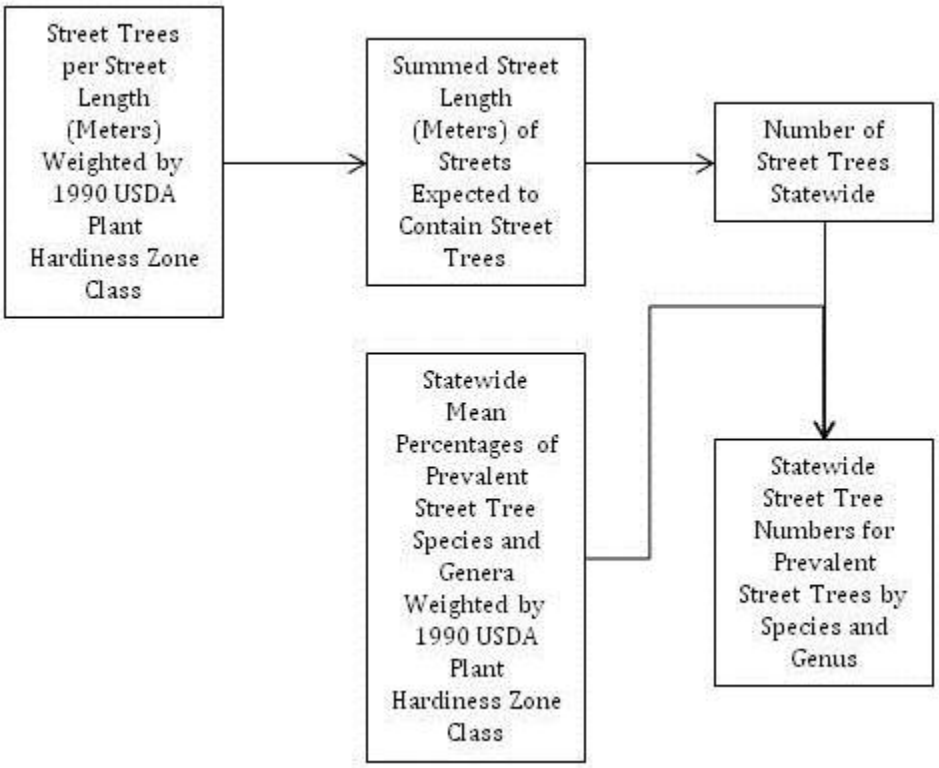


Figure 5.1 Methodology for estimating statewide street tree numbers for prevalent species and genera

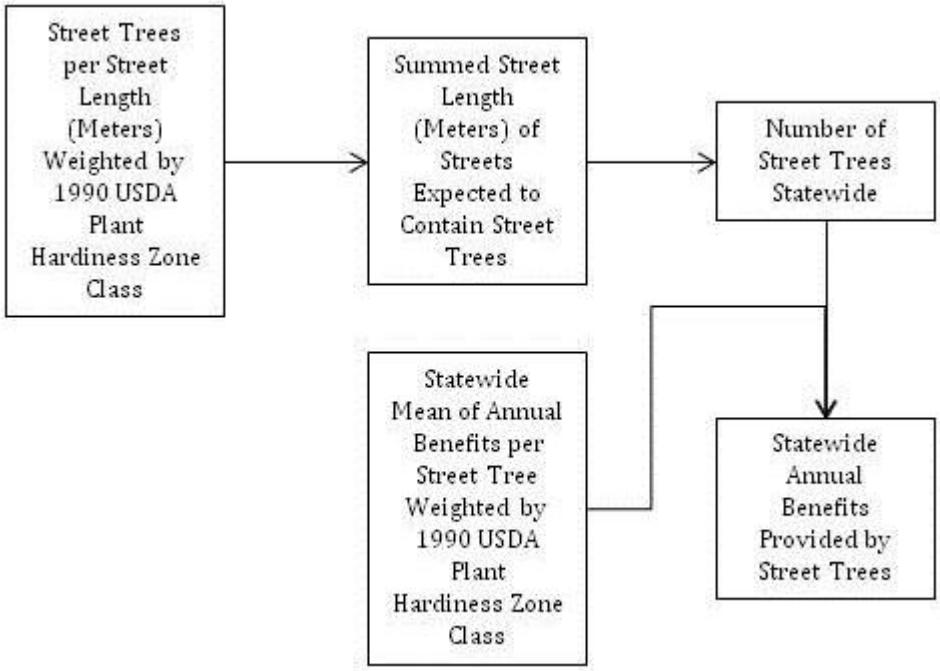


Figure 5.2 Methodology for estimating statewide annual benefits provided by street trees

Street Tree Numbers Statewide

Estimates of street tree numbers statewide are based on two measures: first, summed street length of streets expected to contain street trees for all Census Places and Census Blocks with population density of at least 500 ppsm not contained within Census Places and, second, means for street trees per meter and street trees per mile of streets expected to contain street trees.

Summed street length of streets expected to contain street trees for all Census Places and Census Blocks with population density of at least 500 ppsm not contained within Census Places was calculated according to a methodology explained in Chapter 2. Results, contained in Table 2.6, indicate that summed street length in meters of streets expected to contain street trees is 83,392,547 meters.

Means and standard errors for street trees per meter and street trees per mile of streets expected to contain street trees by 1990 USDA Plant Hardiness Zone Class were calculated (Table 3.14). Means were weighted by percentages of summed street length of streets expected to contain street trees by 1990 USDA Plant Hardiness Zone Class (Table 3.1) according to the formula:

$$((w1 * m1) + (w2 * m2) + (w3 * m3) + (w4 * m4)) / (w1 + w2 + w3 + w4)$$

Where $m1$, $m2$, $m3$, and $m4$ denote the group means for street trees per meter or street trees per mile of street expected to contain street trees (i.e. the means for each 1990 USDA Plant Hardiness Zone class) and $w1$, $w2$, $w3$, and $w4$ denote the different weights for each group (i.e. percentages of summed street length (meters) of streets expected to contain street trees for all Census Places and Census Blocks with population density of at least 500 ppsm not contained within Census Places for each 1990 USDA Plant Hardiness Zone class). The weighted statewide mean of street trees per meter of street was estimated to be 0.0500003 trees per meter and the weighted statewide mean of street trees per mile of street was estimated to be 80.47 trees per mile.

To calculate a 90% confidence interval for the weighted statewide means, standard error for the weighted statewide means was calculated according to the formula:

$$\sqrt{((se1^2 * w1^2) + (se2^2 * w2^2) + (se3^2 * w3^2) + (se4^2 + w4^2))/ (w1 + w2 + w3 + w4)}$$

Where $se1$, $se2$, $se3$, and $se4$ denote the group standard error for street trees per meter or street trees per mile of street expected to contain street trees (i.e. the standard error for each 1990 USDA Plant Hardiness Zone class). The standard error of the statewide weighted mean of street trees per meter of street was found to be 0.002440023 and the standard error of the statewide weighted mean of street trees per mile of street was found to be 3.926838067. The upper 90% confidence interval of the weighted mean was calculated as 0.0500003 + (1.645 * 0.002440023) or

0.05401716 and the lower 90% confidence interval of the weighted mean was calculated as 0.0500003 – (1.645 * 0.002440023) or 0.045989484.

Based on these measures, street tree numbers statewide can be estimated in meters as follows:

Number of Trees = 83,392,547 meters * 0.0500003 trees per meter = 4,169,904
90% UCI = 83,392,547 meters * 0.05401716 trees per meter = 4,504,629
90% UCI = 83,392,547 meters * 0.045989484 trees per meter = 3,835,180

Street Tree Numbers Statewide for Prevalent Species and Genera

Estimates of street tree numbers statewide for prevalent species and genera are based on two measures: first, street tree numbers statewide as calculated above and, second, mean percentages of street tree populations for prevalent species and genera. Conceptually, if the estimated number of street trees statewide is 4,169,904 and the statewide weighted mean percentage of street tree species x is y %, then the estimated number of street trees statewide for species x can be calculated as 4,169,904 * y %.

Statewide weighted mean percentages were calculated for prevalent species and genera according to the formula:

$$((w1 * m1) + (w2 * m2) + (w3 * m3) + (w4 * m4)) / (w1 + w2 + w3 + w4)$$

Where $m1$, $m2$, $m3$, and $m4$ denote the group means for each species and genus (i.e. the mean percentages for each1990 USDA Plant Hardiness Zone class for each species and genus) and $w1$, $w2$, $w3$, and $w4$ denote the different weights for each group (i.e. percentages of summed street length (meters) of streets expected to contain street trees for all Census Places and Census Blocks with population density of at least 500 ppsm not contained within Census Places for 1990 USDA Plant Hardiness Zone classes in New York State) as stated in Table 3.1.

Standard errors for the statewide weighted mean percentages have been calculated according to the formula:

$$\sqrt{((se1^2 * w1^2) + (se2^2 * w2^2) + (se3^2 * w3^2) + (se4^2 + w4^2))} / (w1 + w2 + w3 + w4)$$

Where $se1$, $se2$, $se3$, and $se4$ denote the group standard errors for each species and genus (i.e. the standard error of mean percentages for each 1990 USDA Plant Hardiness Zone class for each species and genus). Results from these calculations for prevalent street tree species are contained in Table 5.1 and results from these calculations for prevalent street tree genera are contained in Table 5.2. For example, the mean statewide percentage of *Acer platanoides* (Norway Maple) is calculated to be 20.65% and there is a 90% probability that the statewide percentage of *Acer*

platanoides is between 22.44% and 18.87% of the statewide street tree population. Similarly, the mean statewide percentage of the *Acer* (Maple) genus is calculated to be 44.14% and there is a 90% probability that the statewide percentage of *Acer* is between 47.97% and 40.30% of the statewide street tree population.

Table 5.1 Statewide mean percentages, standard errors, and 90% confidence intervals for prevalent New York State street tree species

Species	**Mean**	**Std Err**	**90% UCI**	**90% LCI**
Acer platanoides	20.65	1.08	22.44	18.87
Acer saccharum	9.89	0.67	11.00	8.79
Acer saccharinum	5.79	0.70	6.94	4.65
Platanus x acerifolia	5.72	0.78	7.01	4.43
Acer rubrum	5.29	0.43	5.99	4.59
Gleditsia triacanthos	5.21	0.50	6.04	4.38
Pyrus calleryana	4.72	0.69	5.85	3.59
Quercus palustris	2.77	0.27	3.22	2.32
Tilia cordata	2.69	0.29	3.17	2.22
Malus species	2.45	0.22	2.81	2.09
Fraxinus pennsylvanica	1.98	0.18	2.28	1.68
Quercus rubra	1.69	0.14	1.91	1.46
Picea abies	1.27	0.15	1.51	1.03
Pinus strobus	1.08	0.17	1.37	0.80
Robinia pseudoacacia	1.03	0.15	1.29	0.78

Table 5.2 Statewide mean percentages, standard errors, and 90% confidence intervals for prevalent New York State street tree genera

Genus	**Mean**	**Std Err**	**90% UCI**	**90% LCI**
Acer	44.14	2.33	47.97	40.30
Quercus	7.03	0.51	7.86	6.19
Platanus	5.79	0.75	7.02	4.56
Pyrus	5.36	0.81	6.69	4.04
Gleditsia	4.96	0.46	5.73	4.20
Tilia	4.09	0.39	4.72	3.45
Fraxinus	3.35	0.24	3.76	2.95
Picea	2.99	0.27	3.43	2.55
Prunus	2.84	0.21	3.19	2.49
Malus	2.47	0.23	2.85	2.09
Pinus	1.63	0.18	1.92	1.33
Ulmus	1.36	0.20	1.70	1.03
Robinia	1.06	0.16	1.32	0.80

Based on these measures, street tree numbers statewide can be estimated as follows:

Number of Trees = 4,169,904 trees * (Species or Genus) Mean%
90% UCI = 4,504,629 trees * (Species or Genus) 90% UCI
90% LCI = 3,835,180 trees * (Species or Genus) 90% LCI

For example, the estimated number of *Fraxinus* (Ash) street trees statewide could be estimated as follows:

Number of Trees = 4,169,904 trees * 3.3545% = 139,881
90% UCI = 4,504,629 trees * 3.7566% = 169,222
90% LCI = 3,835,180 trees * 2.9524% = 113,231

Based on this methodology, estimates have been made for mean number of trees and upper and lower 90% confidence intervals for prevalent street tree species and genera. Estimates for prevalent street tree species are contained in Table 5.3 and estimates for prevalent street tree genera are contained in Table 5.4.

Table 5.3 Estimates of numbers of trees for prevalent street tree species

Species	**Mean**	**90% UCI**	**90% LCI**
Acer platanoides	861226	1010677	723711
Acer saccharum	412474	495291	337044
Acer saccharinum	241595	312596	178263
Platanus x acerifolia	238622	315909	169975
Acer rubrum	220749	269983	176198
Gleditsia triacanthos	217254	271943	168101
Pyrus calleryana	196721	263385	137619
Quercus palustris	115638	145217	89077
Tilia cordata	112332	142802	85050
Malus species	102025	126453	80011
Fraxinus pennsylvanica	82678	102916	64462
Quercus rubra	70414	86204	56131
Picea abies	52960	67973	39547
Pinus strobus	45214	61657	30676
Robinia pseudoacacia	43065	57939	29887

Table 5.4 Estimates of numbers of trees for prevalent street tree genera

Genus	**Mean**	**90% UCI**	**90% LCI**
Acer	1840400	2160762	1545694
Quercus	292986	354112	237449
Platanus	241533	316214	175069
Pyrus	223673	301377	154849
Gleditsia	206900	257897	161013
Tilia	170381	212840	132199
Fraxinus	139881	169222	113231
Picea	124747	154715	97745
Prunus	118446	143582	95633
Malus	103172	128594	80298
Pinus	67864	86487	51198
Ulmus	56819	76562	39332
Robinia	44136	59517	30515

Statewide Annual Benefits Provided by Street Trees

Estimates of statewide annual benefits provided by street trees are based on two measures: first, street tree numbers statewide as calculated above and, second, statewide means for benefits per street tree. Conceptually, if the estimated number of street trees statewide is 4,169,904 and mean statewide benefits per street tree is *z*, then estimated statewide annual benefits provided by street trees can be calculated as 4,169,904 * *z*.

Mean benefits per street tree have been found to be 133.75 (dollars) with a median of 135.57, a standard deviation of 24.05, a standard error of 2.17, and upper and lower 90% confidence intervals of 137.32 and 130.18. An analysis of benefits per street tree by 1990 USDA Plant Hardiness Zone classes (e.g. Zones 3 +4, Zone 5, Zone 6, and Zone 7) found no statistically significant difference between the means of benefits per street tree for each 1990 USDA Plant Hardiness Zone class. Therefore, the unweighted statewide mean and standard error will be used to estimate statewide annual benefits provided by street trees and upper and lower 90% confidence intervals.

Estimates are as follows:

Statewide Annual Benefits = 4,169,904 trees * $133.75/tree = $557,724,660
90% UCI = 4,504,629 trees * $137.32/tree = $ 618,575,654
90% LCI = 3,835,180 trees * $130.18/tree = $ 499,263,732

Discussion

In the example above estimating the number of *Fraxinus* (Ash) street trees statewide, the range between the 90% UCI and the 90% LCI was found to be 55,991 trees or a 20.98% difference relative to the mean. Similarly for statewide annual benefits, the range between the 90% UCI and the 90% LCI was found to be $119,311,922 or a 9.84% difference relative to the mean. For numbers of street trees statewide the range between the 90% UCI and the 90% LCI was found to be 669,499 trees or an 8.03% difference relative to the mean. These are not small numbers and ideally they would be reduced to improve estimate precision. At the same time, accuracy and reliability must not be compromised and a conservative approach to accuracy and reliability has been followed throughout the estimation process. For example, a preliminary iteration for calculating street trees per length of street involved estimates by linear regression in which street tree numbers per municipality were regressed on street length per municipality to yield the following model:

Number of Trees = -694.2735 + 0.0591657 * Street Length Meters

Although this model appeared highly accurate and statistically significant ($r^2 = .987$, $p < .0001$, RMSE = 3412.98), further analysis revealed extreme heteroskedasticity (i.e. unequal variance) for the error terms. Therefore, while the range between the 90% UCI and the 90% LCI predicted by the regression model was only 83,319 trees or a 1.81% difference relative to the mean, these estimates could not be accepted as reliable and the model could not be used.

Estimate precision can typically be improved (i.e. standard error can be reduced) by increasing sample size. In other words, if additional street tree inventory datasets evenly distributed by 1990 USDA Plant Hardiness Zone class were included in these analyses, it is likely although not certain that precision would be improved for measures of street trees per meter and street trees per mile of streets expected to contain street trees, percentages of prevalent street tree species and genera, and annual benefits per street tree. Precision could also be improved with greater standardization of street tree inventory data. As has been mentioned previously, considerable variation exists between municipalities in data collection (e.g. types of data fields and data field measures) which in turn limits the ability to group datasets and creates uncertainty about the accuracy of data collection. Finally, it should be recognized that plant biogeography which includes the geographic distribution of street trees is intrinsically variable and, depending on the geographies and the tree species and genera in question, may not yield standard errors that can easily be reduced.

(6) Testing Initial Estimates

Summary. Five street tree inventories were conducted to compare statistics with initial estimates made for prevalent species and genera and annual benefits statewide. Evaluation focused on whether statistically significant differences and trends found at the zone class level for sample data would be found for these test inventories as well. While test inventory statistics did not agree completely with zone class level statistics, they did appear to reflect and confirm zone class level differences and trends.

Street tree numbers statewide for prevalent species and genera and annual benefits statewide provided by street trees have been calculated on the basis of a sample of 142 street tree inventory datasets widely distributed throughout New York State. These estimates have been made in the belief that sample data statistics accurately predict statistics for the statewide population of street trees and by inference for the many municipalities in New York State (e.g. cities, villages, CDPs) that do not have a street tree inventory. Assessing the accuracy of statewide estimates is inherently problematic since statistics for the statewide population are unknown. It might be tempting to assess the accuracy of statewide estimates by conducting street tree inventories in municipalities lacking inventories and comparing these results to the statewide estimates. To do so, however, would be to commit "ecologic fallacy" since Robinson (1950) has demonstrated that correlations made at the ecologic (i.e. group) level are not implicitly valid at the individual level. In other words, estimates made for New York State will not necessarily predict statistics accurately for its individual municipalities. However, as Subramanian et al (2009) have pointed out in a critique of Robinson, correlations can operate at multiple levels and correlations not valid at one level might be valid at another. A multilevel approach seems appropriate in the context of this study since statewide estimates for New York State have been predicated on stratifying and weighting sample data by 1990 USDA Plant Hardiness Zone class. Accordingly, while conducting test inventories in municipalities lacking inventories and comparing these results to the statewide estimates would be of questionable validity, comparing results from individual municipalities to summary statistics at the zone class level might have more legitimacy, especially with regard to statistically significant differences and trends found at the zone class level.

To evaluate whether results from test inventories would reflect differences and trends found at the zone class level, street tree inventories were conducted in municipalities lacking an inventory from each of the four 1990 USDA Plant Hardiness Zone classes in New York State: Unadilla (Zones 3 + 4), Greene (Zone 5), Lima and Shortsville (Zone 6), and Great Neck Plaza (Zone 7). Another reason for selecting these municipalities was their relatively small area enabling one person to inventory all street trees in each municipality by walking survey in two days. Finally, these municipalities are all villages. Since municipality type has been found to have a slight effect on street tree populations, restricting test inventories to villages avoids biasing results by municipality type. Demographic statistics for each municipality are contained in Table 6.1 and their locations are shown in Figure 6.1.

In each municipality, all street trees located in the right-of-way were inventoried. Data taken for each tree included genus and species, trunk diameter at breast height (DBH), planting location type (front yard or lawn, treelawn, sidewalk tree pit, and median), wood and leaf condition, presence or absence of single or triple phase utility wires, street addresses, and GPS coordinates. Park trees were excluded from the surveys although municipalities typically manage these trees. Data was given to the respective municipality to be used in managing its street tree population.

Table 6.1 Demographics for test inventory municipalities

Municipality	**Unadilla**	**Greene**	**Lima**	**Shortsville**	**Great Neck Plaza**
Zone Class	3+4	5	6	6	7
County	Otsego	Chenango	Livingston	Ontario	Nassau
Population (2010 Census)	1,128	1,580	2,139	1,439	6,707
Area (Sq Miles)	1.037	1.068	1.346	0.700	0.312
Population Density (Sq Mile)	1,088	1,480	1,589	2,156	21,485
Housing Units	559	804	847	603	4,052
Housing Unit Density (Sq Mile)	539	753	629	861	12,980

Figure 6.1 Locations of test inventory municipalities

Genus Composition

449 streets trees were inventoried in Unadilla, 410 in Greene, 577 in Lima, 368 in Shortsville, and 715 in Great Neck Plaza. The genus composition of inventoried trees was analyzed and compared to statistics for the most prevalent genera in each village's 1990 USDA Plant Hardiness Zone class. Table 6.2 compares summary statistics for the most prevalent street tree genera in New York State to inventory percentages for prevalent street tree genera in Unadilla, Greene, Lima, Shortsville, and Great Neck Plaza.

Some test inventory results are similar to the zone class means and fall within the 90% confidence intervals while others do not. For example, the percentage of *Acer* found in Lima (49.220%) is similar to the mean (51.080%) and falls within the upper and lower 90% confidence intervals (56.659% and 45.502%) for Zone 6 class level statistics. Likewise, the percentage of *Gleditsia* found in Great Neck Plaza (4.755%) is similar to the mean (4.108%) and falls within the upper and lower 90% confidence intervals (5.840% and 2.377%) for Zone 7 class level statistics. However, the percentage of *Acer* found in Greene (71.220%), the percentage of *Fraxinus* found in Lima (15.078%), and the percentage of *Pyrus* found in Great Neck Plaza (26.434%) are larger than the mean percentages for those genera in their respective zone classes and do not fall within the upper and lower 90% confidence intervals. Likewise, the percentage of *Fraxinus* found in Unadilla (2.895%) and the percentage of *Tilia* found in Shortsville (1.087%) are smaller than the mean percentages for those genera in their respective zone classes and do not fall within the upper and lower 90% confidence intervals.

Similarities and differences between test inventory genera percentages and zone class summary statistics are to some extent less significant than they seem. For example, the percentage of *Acer* found in Greene (71.220%) is large and differs meaningfully from the zone class mean, but it should not be seen as that atypical since 11 of 60 municipalities in Zone 5 (11.67%) have even larger percentages of *Acer*. Likewise, the percentage of *Fraxinus* found in Lima (15.078%) is large and exceeds the percentages of *Fraxinus* for all other municipalities in Zone 6 for which data has been obtained, but several municipalities in Zones 3 + 4 and Zone 5 have percentages of *Fraxinus* that are larger. Moreover, given that comparisons are being made between zone class statistics and statistics from one or two test inventories in each zone class, it is not surprising that substantial differences exist between them.

Table 6.2 Comparison of summary statistics for the most prevalent street tree genera in New York State to inventory percentages for prevalent street tree genera in Unadilla, Greene, Lima, Shortsville, and Great Neck Plaza

Zones 3 + 4 (n=31)	**Mean**	**UCL 90%**	**LCL 90%**	**Unadilla**
Acer	54.774	59.337	50.211	65.033
Fraxinus	5.396	6.605	4.188	2.895
Malus	4.490	5.788	3.193	3.118
Gleditsia	4.304	5.538	3.069	5.568
Picea	4.162	5.132	3.191	6.013
Quercus	3.960	5.170	2.751	3.563
Tilia	3.551	4.630	2.473	1.336
Pyrus	2.245	3.046	1.444	0.891
Pinus	2.041	3.004	1.077	2.227
Ulmus	1.353	1.934	0.771	2.004
Prunus	1.342	1.760	0.923	3.786
Robinia	1.271	2.031	0.511	0.668
Platanus	0.101	0.189	0.012	0.000

Zone 5 (n=60)	**Mean**	**UCL 90%**	**LCL 90%**	**Greene**
Acer	55.880	67.747	44.013	71.220
Picea	5.706	6.918	4.495	3.902
Gleditsia	4.915	5.959	3.871	1.707
Malus	4.277	5.185	3.369	7.073
Fraxinus	3.693	4.477	2.909	4.878
Tilia	3.234	3.920	2.547	0.000
Quercus	2.895	3.510	2.281	1.463
Pyrus	2.423	2.937	1.908	7.561
Prunus	2.198	2.664	1.731	0.488
Pinus	1.713	2.077	1.349	0.244
Ulmus	0.904	1.096	0.712	0.244
Robinia	0.822	0.997	0.648	0.000
Platanus	0.654	0.792	0.515	0.000

Zone 6 (n=28)	Mean	UCL 90%	LCL 90%	Lima	Shortsville
Acer	51.080	56.659	45.502	49.220	78.261
Gleditsia	6.164	7.436	4.893	9.359	0.815
Quercus	4.852	6.551	3.153	0.173	0.000
Tilia	4.472	5.879	3.065	2.946	1.087
Platanus	3.812	5.746	1.878	0.520	0.000
Fraxinus	3.713	4.689	2.738	15.078	1.359
Pyrus	3.302	4.667	1.936	0.347	0.543
Prunus	2.509	3.249	1.769	3.466	9.511
Malus	2.304	3.104	1.504	3.640	3.533
Picea	2.032	2.713	1.352	2.080	0.272
Ulmus	1.616	2.366	0.867	0.000	0.000
Pinus	1.351	1.835	0.867	0.867	0.000
Robinia	1.123	1.710	0.536	1.386	0.272

Zone 7 (n=23)	Mean	UCL 90%	LCL 90%	Great Neck Plaza
Acer	25.830	29.590	22.071	10.629
Platanus	13.142	16.323	9.961	8.112
Quercus	13.042	14.895	11.190	19.580
Pyrus	10.359	14.046	6.671	26.434
Tilia	4.559	5.826	3.293	8.112
Gleditsia	4.108	5.840	2.377	4.755
Prunus	4.048	4.730	3.366	1.818
Fraxinus	2.215	2.621	1.810	0.699
Pinus	1.694	2.332	1.055	0.420
Ulmus	1.501	2.205	0.797	0.140
Picea	1.389	1.988	0.790	0.000
Robinia	1.130	1.646	0.614	0.000
Malus	0.659	1.001	0.318	0.000

Similarities and differences are to some extent the product of chance depending on municipalities chosen to be inventoried. It is also likely that conducting additional test inventories per zone class would smooth out deviations between zone class and test inventory statistics although, in the case of Zone 6, two inventories were not sufficient as can be seen from the averaging of Lima and Shortsville percentages in Table 6.3. For example, averaging percentages from these two inventories has produced a test statistic for *Gleditsia* that falls within the 90% zone class confidence intervals whereas the individual test statistics for Lima and Shortsville do not. However, averaging percentages from these two inventories has produced a test statistic for *Acer* that does not fall within the 90% zone class confidence intervals whereas the individual test statistic for Lima approximates the zone class mean.

Table 6.3 Comparison of summary statistics for the most prevalent street tree genera in Zone 6 to the average of inventory percentages for prevalent street tree genera in Shortsville and Lima

Zone 6 (n=28)	**Mean**	**Median**	**UCL 90%**	**LCL 90%**	**L + S**
Acer	51.080	46.995	56.659	45.502	63.740
Gleditsia	6.164	5.523	7.436	4.893	5.087
Quercus	4.852	3.134	6.551	3.153	0.087
Tilia	4.472	2.640	5.879	3.065	2.017
Platanus	3.812	1.653	5.746	1.878	0.260
Fraxinus	3.713	2.119	4.689	2.738	8.218
Pyrus	3.302	2.022	4.667	1.936	0.445
Prunus	2.509	1.844	3.249	1.769	6.489
Malus	2.304	1.282	3.104	1.504	3.586
Picea	2.032	1.177	2.713	1.352	1.176
Ulmus	1.616	0.673	2.366	0.867	0.000
Pinus	1.351	0.738	1.835	0.867	0.433
Robinia	1.123	0.473	1.710	0.536	0.829

Finally, as suggested above, the real value of the test inventory statistics may be in corroborating differences and trends for genera percentages found at the zone class level. In other words, test inventory statistics comment on the validity of 1990 USDA Plant Hardiness Zone class as a predictor variable of statewide street tree population characteristics and the reliability of statewide estimates made on that basis. Although only five test inventories have been conducted with regard to this study and more test inventories would be desirable, test inventory statistics appear consistent with zone class level differences and trends. For example, percentages of *Acer*, *Picea*, and *Malus* decline between Zone 7 and the other zone classes and percentages of *Quercus*, *Platanus*, and *Pyrus* increase. More specifically, *Acer* prevalence in Great Neck Plaza is reduced from *Acer* prevalence in Unadilla, Greene, Lima, and Shortsville, similar to what has been found at the zone class level (Figure 6.2). Likewise, *Quercus* prevalence is greater in Great Neck Plaza than in Unadilla, Greene, Lima, and Shortsville similar to what has been found at the zone class level (Figure 6.3). Therefore, while test inventory statistics for prevalent street tree genera do not conflate in many cases with zone class level statistics and perhaps should not be expected to, they do appear to reflect and confirm zone class level differences and trends.

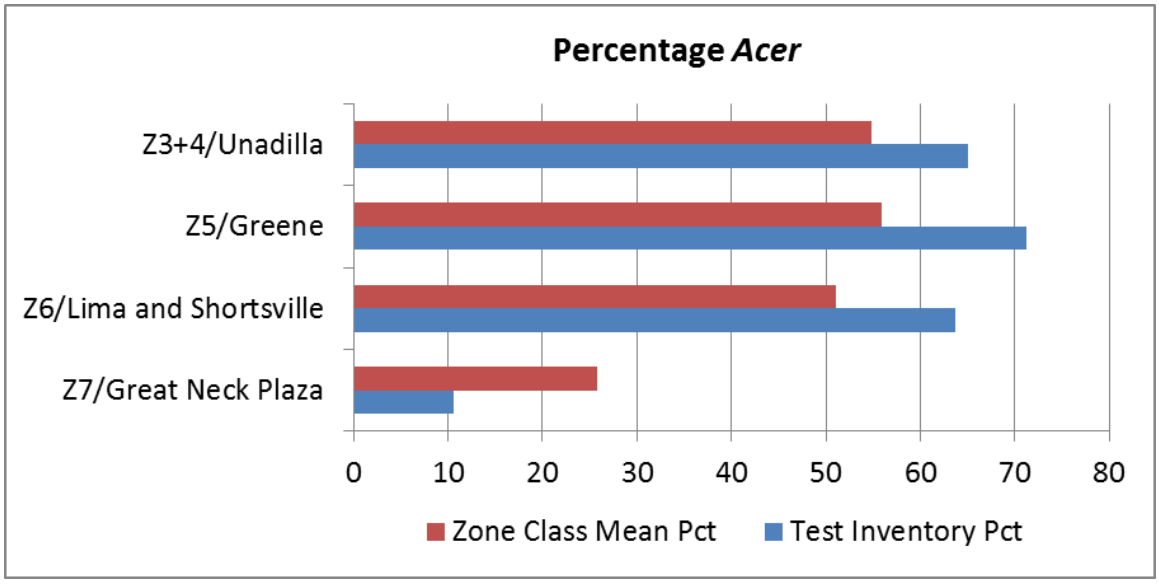


Figure 6.2 *Acer* prevalence for zone class and test inventories

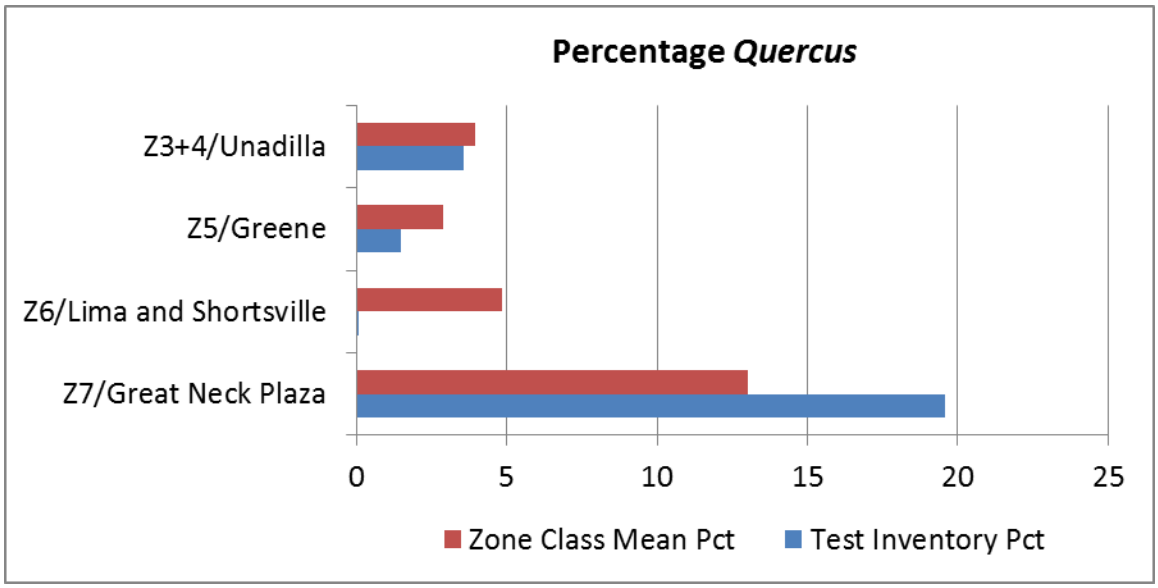


Figure 6.3 *Quercus* prevalence for zone class and test inventories

Species Composition

An analysis similar to the one performed for genus composition was performed for species composition with inventory results from Unadilla, Greene, Lima, Shortsville, and Great Neck Plaza. The species composition of inventoried trees was analyzed and compared to statistics for the most prevalent species in each village's respective 1990 USDA Plant Hardiness Zone class. Table 6.3 compares summary statistics for the most prevalent street tree species in New York State to inventory percentages for prevalent street tree species in Unadilla, Greene, Lima, Shortsville, and Great Neck Plaza.

Mirroring results for genus composition, some test inventory results are similar to the zone class means and fall within the 90% confidence intervals while others do not. For example, the percentage of *Gleditsia triacanthos* found in Great Neck Plaza (4.755%) is similar to the mean (4.875%) and falls within the upper and lower 90% confidence intervals (6.933% and 2.818%) for Zone 7 class level statistics. Likewise, the percentage of *Acer platanoides* found in Lima (26.170%) is similar to the mean (28.359%) and falls within the upper and lower 90% confidence intervals (32.060% and 24.657%) for Zone 6 class level statistics. However, the percentage of *Acer rubrum* found in Greene (12.683%), the percentage of *Fraxinus pennsylvanica* found in Lima (14.385%), and the percentage of *Quercus palustris* found in Great Neck Plaza (18.462%) are larger than the mean percentages for those genera in their respective zone classes and do not fall within the upper and lower 90% confidence intervals. Likewise, the percentage of *Acer platanoides* found in Great Neck Plaza (6.993%) and the percentage of *Gleditsia triacanthos* found in Greene (1.707%) are smaller than the mean percentages for those genera in their respective zone classes and do not fall within the upper and lower 90% confidence intervals.

As with genus composition, the real value of the test inventory statistics may be in corroborating differences and trends for species percentages found at the zone class level. Results from the five test inventories indicate general agreement between differences at the zone class level for prevalent street tree species and differences at the zone class level for the test inventory municipalities. For example, percentages of *Acer saccharum* and *Acer saccharinum* decline between Zone 7 and the other zone classes while the percentages of *Platanus x acerifolia*, *Pyrus calleryana*, and *Quercus palustris* increase. More specifically, *Acer platanoides* prevalence in Great Neck Plaza is reduced from *Acer platanoides* prevalence in Unadilla, Greene, Lima, and Shortsville, similar to what has been found at the zone class level (Figure 6.4). Likewise, *Platanus x acerifolia* prevalence is greater in Great Neck Plaza than in Unadilla, Greene, Lima, and Shortsville similar to what has been found at the zone class level (Figure 6.5). Therefore, while test inventory statistics for prevalent street tree species do not conflate in many cases with zone class level statistics, they do appear to reflect and confirm zone class level differences and trends.

Table 6.4 Comparison of summary statistics for the most prevalent street tree species in New York State to inventory percentages for prevalent street tree species in Unadilla, Greene, Lima, Shortsville, and Great Neck Plaza

Zones 3 + 4 (*n*=28)	**Mean**	**Median**	**UCL 90%**	**LCL 90%**	**Unadilla**
Acer saccharum	20.612	20.135	24.118	17.106	46.102
Acer platanoides	15.524	14.330	19.445	11.603	13.808
Acer saccharinum	6.844	3.708	10.000	3.688	2.673
Acer rubrum	6.243	5.727	7.377	5.109	0.668
Malus species	4.540	3.339	5.944	3.136	3.118
Gleditsia triacanthos	4.222	3.120	5.396	3.049	5.568
Tilia cordata	2.295	0.839	3.206	1.384	1.336
Pyrus calleryana	2.281	1.919	3.114	1.448	0.891
Fraxinus pennsylvanica	2.252	1.418	3.036	1.468	1.559
Quercus rubra	1.867	0.639	2.700	1.033	2.895
Pinus strobus	1.565	0.368	2.363	0.766	2.227
Robinia pseudoacacia	1.110	0.289	1.820	0.400	0.668
Picea abies	0.867	0.390	1.201	0.533	3.786
Quercus palustris	0.661	0.343	1.003	0.319	0.223
Platanus x acerifolia	0.057	0.000	0.113	0.002	0.000

Zone 5 (*n*=58)	**Mean**	**Median**	**UCL 90%**	**LCL 90%**	**Greene**
Acer platanoides	21.248	20.234	23.485	19.010	29.756
Acer saccharum	20.190	17.702	23.296	17.085	24.146
Acer saccharinum	6.232	4.000	7.741	4.723	0.732
Acer rubrum	5.288	4.383	6.032	4.545	12.683
Gleditsia triacanthos	4.853	3.720	5.722	3.984	1.707
Malus species	4.245	3.415	5.010	3.481	6.829
Picea abies	2.728	2.000	3.300	2.156	2.683
Pyrus calleryana	2.440	1.910	2.986	1.894	7.561
Tilia cordata	2.277	1.189	2.875	1.680	0.000
Fraxinus pennsylvanica	2.145	1.439	2.680	1.609	4.390
Quercus rubra	1.472	1.095	1.762	1.181	0.732
Pinus strobus	0.862	0.219	1.219	0.504	0.244
Robinia pseudoacacia	0.833	0.355	1.066	0.600	0.000
Quercus palustris	0.760	0.261	1.066	0.455	0.488
Platanus x acerifolia	0.485	0.178	0.651	0.318	0.000

Zone 6 (*n*=28)	**Mean**	**Median**	**UCL 90%**	**LCL 90%**	**L + S**
Acer platanoides	28.359	28.110	32.060	24.657	26.170
Acer saccharinum	8.877	4.252	12.238	5.517	3.813
Gleditsia triacanthos	6.205	5.686	7.405	5.004	9.359
Acer saccharum	5.626	3.518	7.421	3.831	15.425
Acer rubrum	5.498	3.963	7.316	3.680	2.946
Platanus x acerifolia	3.283	0.833	5.147	1.419	0.347
Tilia cordata	3.238	2.065	4.442	2.035	2.426
Pyrus calleryana	3.184	1.830	4.481	1.888	0.347
Quercus palustris	2.397	0.441	3.519	1.274	0.000
Malus species	2.220	1.235	2.982	1.458	3.640
Fraxinus pennsylvanica	1.761	0.833	2.430	1.092	14.385
Quercus rubra	1.229	0.714	1.616	0.841	0.173
Robinia pseudoacacia	1.082	0.417	1.643	0.522	1.386
Pinus strobus	0.785	0.093	1.187	0.383	0.173
Picea abies	0.673	0.311	1.045	0.301	1.040

Zone 7 (*n*=18)	**Mean**	**Median**	**UCL 90%**	**LCL 90%**	**GNP**
Acer platanoides	14.729	12.493	18.274	11.185	6.993
Platanus x acerifolia	13.551	12.921	16.972	10.130	8.112
Pyrus calleryana	8.534	6.890	11.619	5.450	26.434
Quercus palustris	5.265	5.773	6.103	4.427	18.462
Gleditsia triacanthos	4.875	3.121	6.933	2.818	4.755
Acer rubrum	4.859	4.903	5.956	3.763	1.119
Acer saccharum	2.665	1.557	3.736	1.594	0.559
Tilia cordata	2.646	1.970	3.384	1.908	6.014
Acer saccharinum	2.424	2.380	3.008	1.840	0.559
Quercus rubra	2.220	1.961	2.687	1.753	0.979
Fraxinus pennsylvanica	1.979	1.859	2.444	1.515	0.280
Pinus strobus	1.395	0.307	2.066	0.725	0.420
Robinia pseudoacacia	1.125	0.724	1.614	0.636	0.000
Picea abies	0.762	0.104	1.181	0.343	0.000
Malus species	0.664	0.352	1.067	0.261	0.000

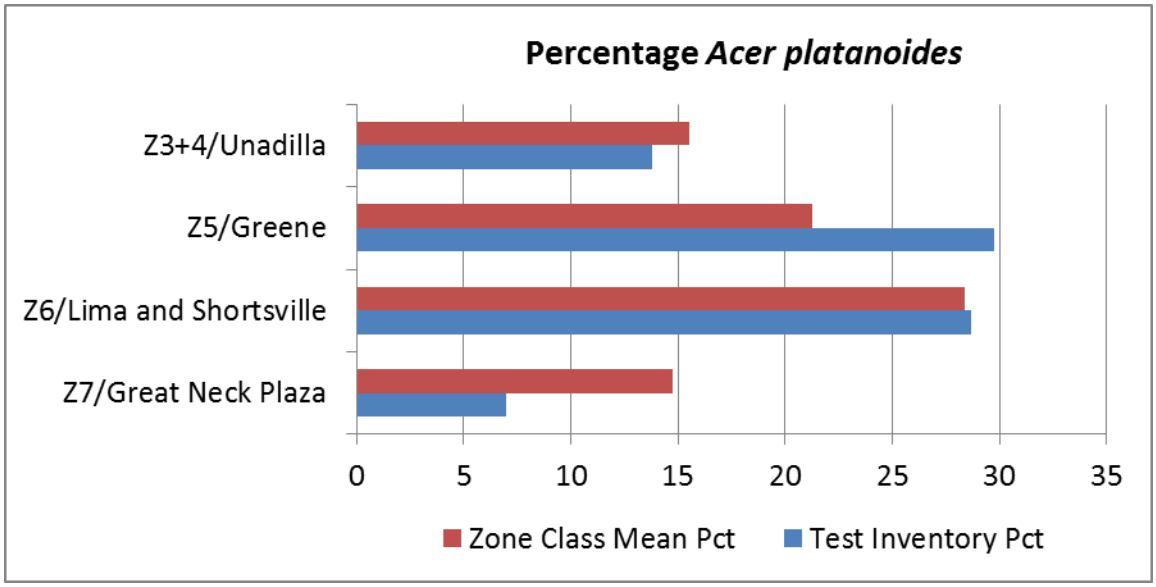


Figure 6.4 *Acer platanoides* prevalence for zone class and test inventories

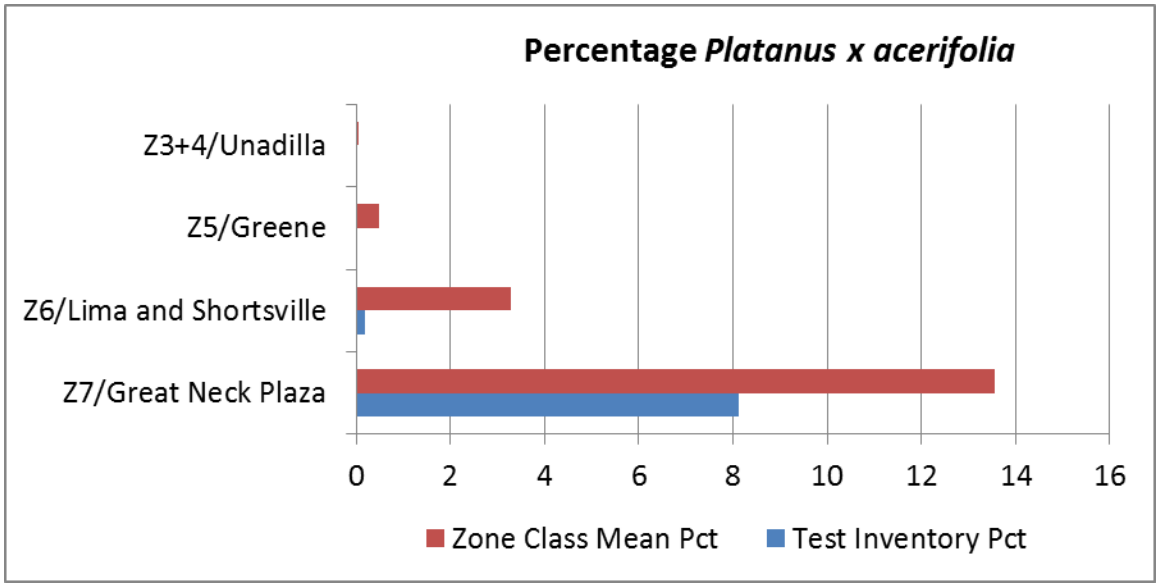


Figure 6.5 *Platanus x acerifolia* prevalence for zone class and test inventories

Species and Genus Diversity

As a general rule, no tree species should comprise more than 10% and no tree genera should comprise more than 20% of a municipality's street tree population (Santamour 1990). Statistics from all five test inventory municipalities violate this rule. For example, with respect to genera, 71.22% of street trees in Greene and 78.261% of street trees in Shortsville are *Acer* and 26.43% of street trees in Great Neck Plaza are *Pyrus*. With respect to species, 46.10% of street trees in Unadilla are *Acer saccharum* and 20.653% of street trees in Lima are *Acer platanoides*.

Two measures, the inverse of Simpson's Diversity Index and the Shannon-Weiner Diversity Index, have been used to assess species diversity in New York State street tree populations. Inverse SDI and Shannon-Weiner values were calculated for test inventory municipalities. Results are contained in Table 6.5 with results for Lima and Shortsville (Zone 6) averaged. Similar to species and genus composition, test inventory statistics for the Inverse SDI and Shannon-Weiner do not conflate with zone class means. For example, Inverse SDI and Shannon-Weiner values for test inventories are less than the Inverse SDI and Shannon-Weiner mean values for their respective zone class. Possible explanations include the small areas of the villages, the small number of trees to be inventoried as compared to larger municipalities, and the absence of professional staff making street tree management decisions. However, test inventory statistics do reflect differences and trends found at the zone class level in which species diversity increases with milder temperatures. For example, test inventory Inverse SDI values increase from Zones 3 + 4 to Zone 7 as they do for the zone class Inverse SDI mean (Figure 6.6). Likewise, notwithstanding the test inventory Shannon-Weiner value for Zone 5, test inventory Shannon-Weiner values increase from Zones 3 + 4 to Zone 7 as they do for the zone class Shannon-Weiner mean (Figure 6.7). Therefore, while test inventory statistics for species diversity do not conflate with zone class level means, they do appear to reflect and confirm differences and trends found at the zone class level.

Table 6.5 Species diversity measures for 1990 USDA Plant Hardiness Zone classes and test inventory municipalities

	Test Inventory Inverse SDI	Zone Class Inverse SDI	Test Inventory Shannon-Weiner	Zone Class Shannon-Weiner
Zones 3 + 4	4.13	8.08	2.21	2.55
Zone 5	5.62	8.16	2.13	2.64
Zone 6	5.73	8.20	2.24	2.60
Zone 7	7.32	11.79	2.41	2.95

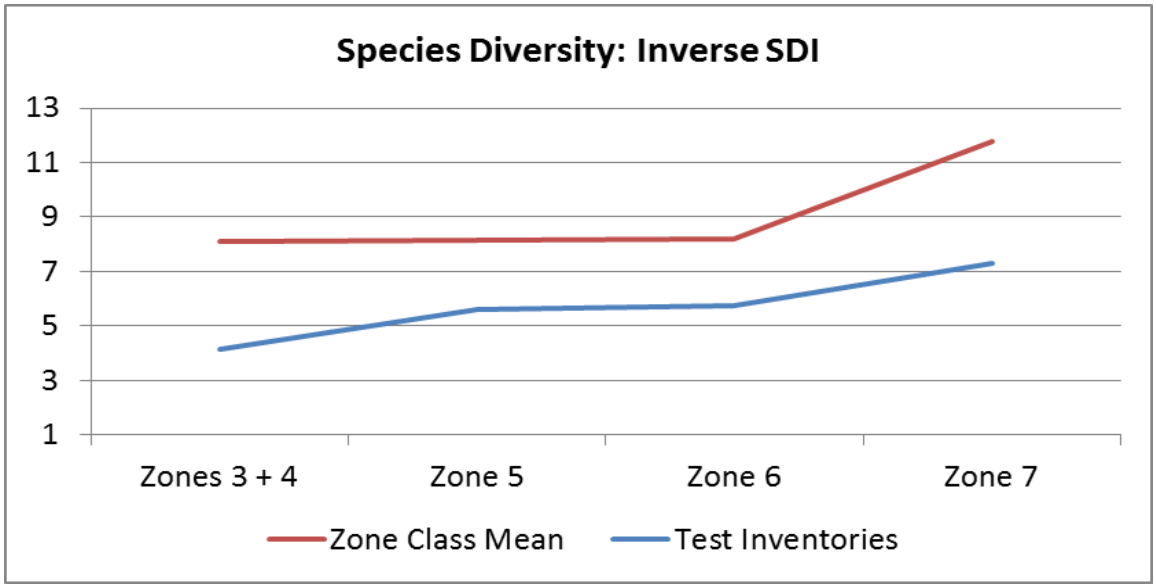


Figure 6.6 Inverse SDI values for zone class and test inventories

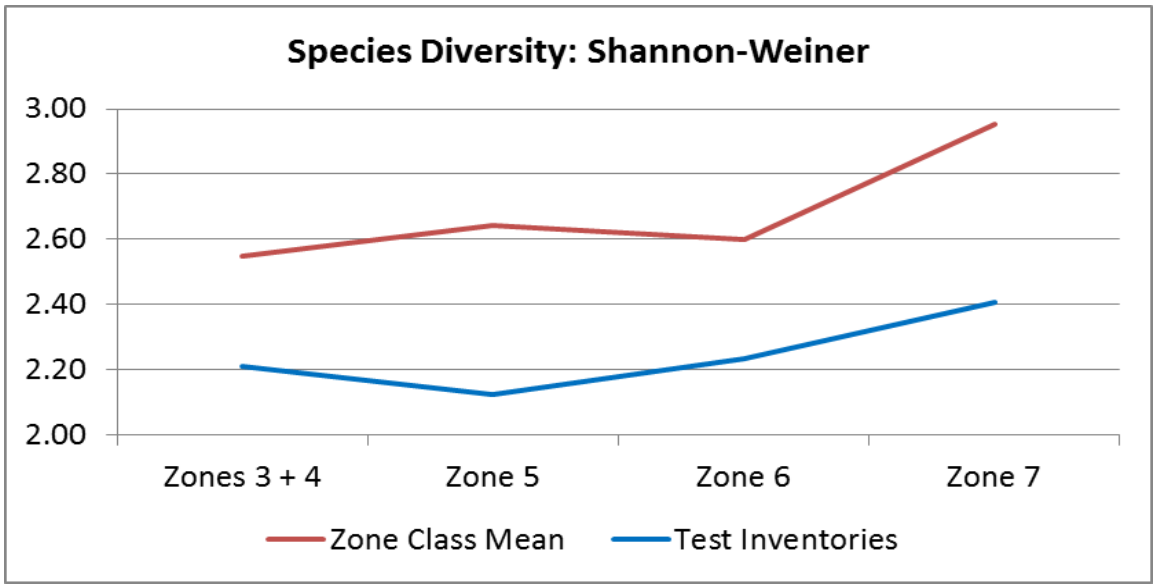


Figure 6.7 Shannon-Weiner values for zone class and test inventories

Relative Age Distribution

The relative age distribution of each test inventory's street trees was analyzed. Ideally, there needs to be a sufficient number of younger, smaller trees to account for the loss of trees over time to create a j-shaped profile in the age distribution by DBH class. Table 6.6 contains the relative percentages per tree diameter class for each test inventory and Figure 6.8 illustrates their tree diameter profiles. While none of the test inventory municipalities has the ideal j-shaped age distribution profile, between the municipalities Shortsville has the largest relative percentage in the 0-5.9 DBH inch class and Great Neck Plaza the smallest. Unadilla is notable in that its 30-35.9 DBH inch class has the largest values compared to its other classes, indicating a street tree population characterized by an unusually high proportion of large, old trees.

The relative age distribution of test inventory street trees was compared to the relative age distribution of street trees statewide. Analysis of street trees statewide had found an insufficient number of younger trees and a disproportionate share of older trees (Figure 3.4). DBH inch class percentages for the test inventories were averaged and compared to statewide DBH inch class percentages (Figure 6.9). Results indicate similarity between the test inventory and statewide profiles with a disproportionate share of older trees and too few younger trees being planted to maintain street tree populations at current levels

Table 6.6 Relative percentages per tree diameter class for test inventories

DBH in Inches	0-5.9	6-11.9	12-17.9	18-23.9	24-29.9	30-35.9	36-41.9	42 +
Unadilla	10.24	14.92	14.03	12.03	16.04	19.38	9.13	4.23
Greene	20.98	21.22	25.61	12.20	10.00	6.83	2.68	0.49
Lima	13.17	34.84	28.25	9.88	7.45	3.47	2.08	0.87
Shortsville	23.16	24.52	17.98	14.17	8.99	6.54	2.45	2.18
Great Neck Plaza	8.95	33.43	34.41	11.19	7.69	3.36	0.56	0.42

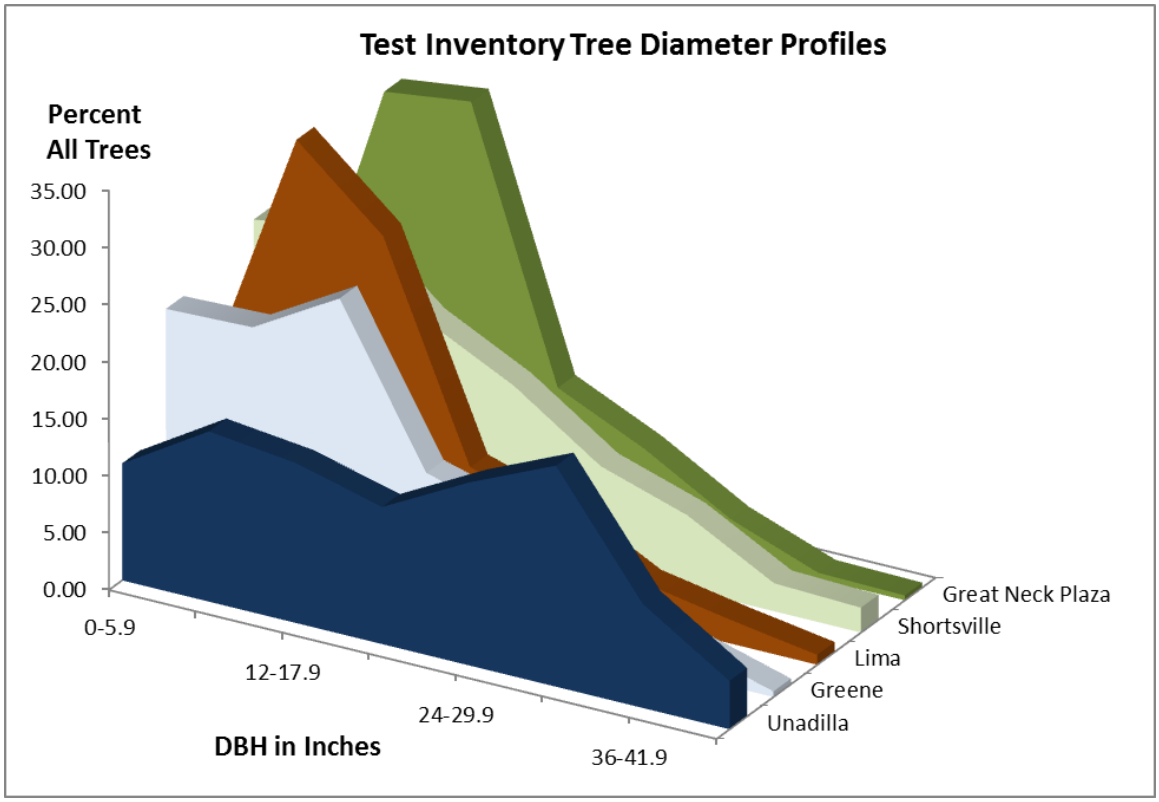


Figure 6.8 Tree diameter profiles for test inventories

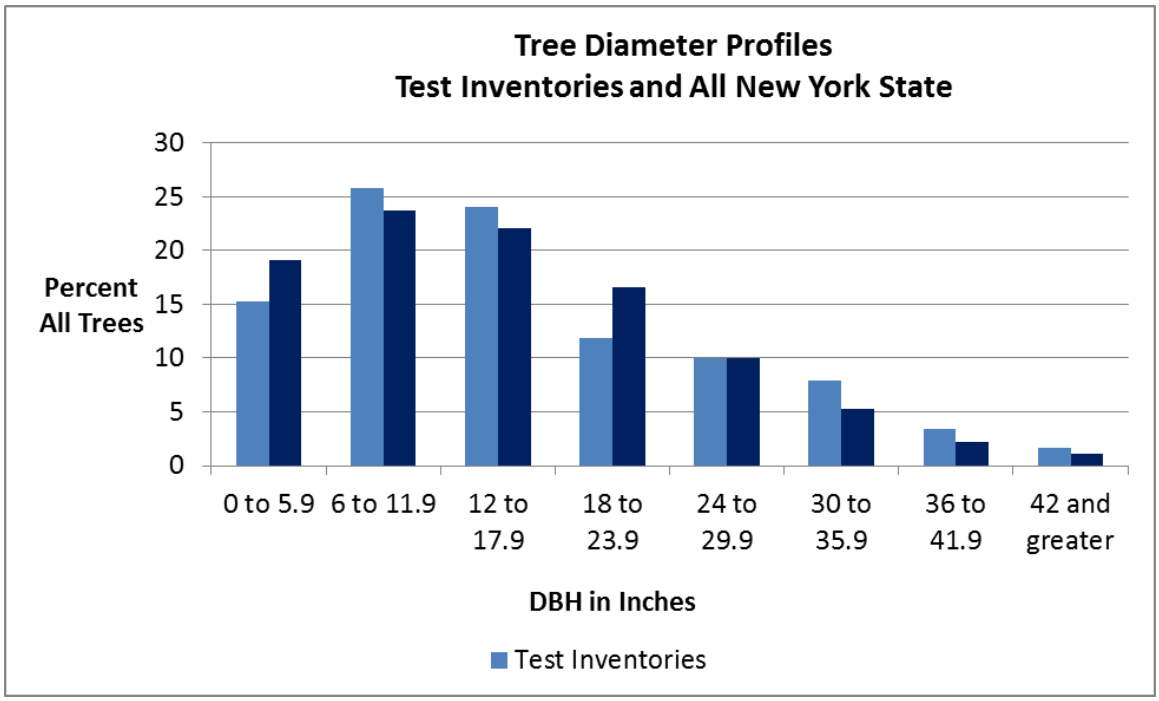


Figure 6.9 Comparison of test inventory and statewide tree diameter profiles

Street Tree Benefits

For test inventory municipalities, i-Tree Streets was used to calculate total annual benefits (energy conservation, air quality improvement, CO2 reduction, stormwater control, and property value increase) provided by street trees. Total annual benefits (in dollars) per municipality were divided by the number of street trees surveyed in that municipality to calculate benefits per street tree per municipality in dollars. Results are contained in Table 6.7.

Statewide estimates of benefits per street tree found no statistically significant difference by 1990 USDA Plant Hardiness Zone class. Mean benefits per street tree statewide were calculated to be $133.75 with 90% confidence intervals of $137.32 and $130.18. Mean benefits per street tree for test inventories are calculated to be $144.09, a value which does not fall within the statewide 90% confidence intervals. This deviation between the statewide and test inventory means can be attributed to Unadilla which, as documented in Figure 6.8, has an unusually high proportion of large, old trees and possesses the largest benefits per street tree measure found by this study in New York State. If Unadilla is considered an outlier and excluded from the test inventory mean calculation, then the mean of the test inventories is $134.28, a value which falls within the statewide 90% confidence intervals and approximates the statewide mean.

Benefits per mile of street length were also calculated for test inventories with values for Lima and Shortsville averaged. Results are contained in Table 6.8 and compared to zone class means and 90% confidence intervals. Test inventory values fall within the 90% confidence intervals for Zones 5, 6, and 7, but do not fall within the 90% confidence intervals for Zones 3 + 4. This deviation between the zone class mean and the Zones 3 + 4 test inventory statistic can again be attributed to Unadilla's high proportion of large, old trees.

Table 6.7 Street tree benefits per tree ($) for test inventories

	Unadilla	Greene	Lima	Shortsville	Great Neck Plaza
Street Trees Inventoried	449	410	577	368	715
Total Annual Benefits ($)	82,132	55,896	76,557	43,542	106,637
Benefits per Tree ($)	183.33	136.33	132.68	118.97	149.14

Table 6.8 Street tree benefits per street mile ($) for test inventories and zone class

	Zone Class Mean	90% UCI	90% LCI	Test Inventories
Zones 3 + 4	7382.86	5672.00	9093.72	9715.41
Zone 5	6702.38	5590.68	7814.07	5738.27
Zone 6	9388.16	7760.81	11015.50	7959.90
Zone 7	13908.67	11840.30	15977.00	15931.05

Street Tree Numbers

Street trees per meter (i.e. the number of street trees in each municipality divided by the summed length in meters of streets expected to contain street trees for each municipality) is a metric which has been used in this study to estimate street tree numbers statewide. Accordingly, the number of street trees surveyed in each test inventory municipality was divided by the summed length in meters of streets expected to contain street trees for each test inventory municipality to calculate a street trees per meter statistic. Results from these calculations are contained in Table 6.9 and compared to zone class means in Table 6.10 with values for Lima and Shortsville averaged. Test inventory values for Zones 3 + 4 and Zone 7 fall within zone class 90% confidence intervals. Test inventory values for Zone 5 and Zone 6 do not fall within zone class 90% confidence intervals. However, as illustrated in Figure 6.10, the trend for test inventory values approximates the trend for the zone class means with values increasing from Zones 3 + 4 to Zone 7. Therefore, as has been found previously, while test inventory statistics for street trees per meter do not agree completely with zone class level statistics, they do appear to reflect and confirm zone class level differences and trends.

Table 6.9 Street trees per meter for test inventories

	Unadilla	Greene	Lima	Shortsville	Great Neck Plaza
Street Trees Inventoried	449	410	577	368	715
Street Length (meters)	13605	15676	14297	9596	10772
Trees/Meter	0.0330	0.0262	0.0404	0.0383	0.0664

Table 6.10 Street trees per meter for test inventories and zone class

	Zone Class Mean	90% UCI	90% LCI	Test Inventories
Zones 3 + 4	0.0285	0.0342	0.0228	0.0330
Zone 5	0.0323	0.0363	0.0283	0.0262
Zone 6	0.0486	0.0546	0.0426	0.0394
Zone 7	0.0710	0.0809	0.0611	0.0664

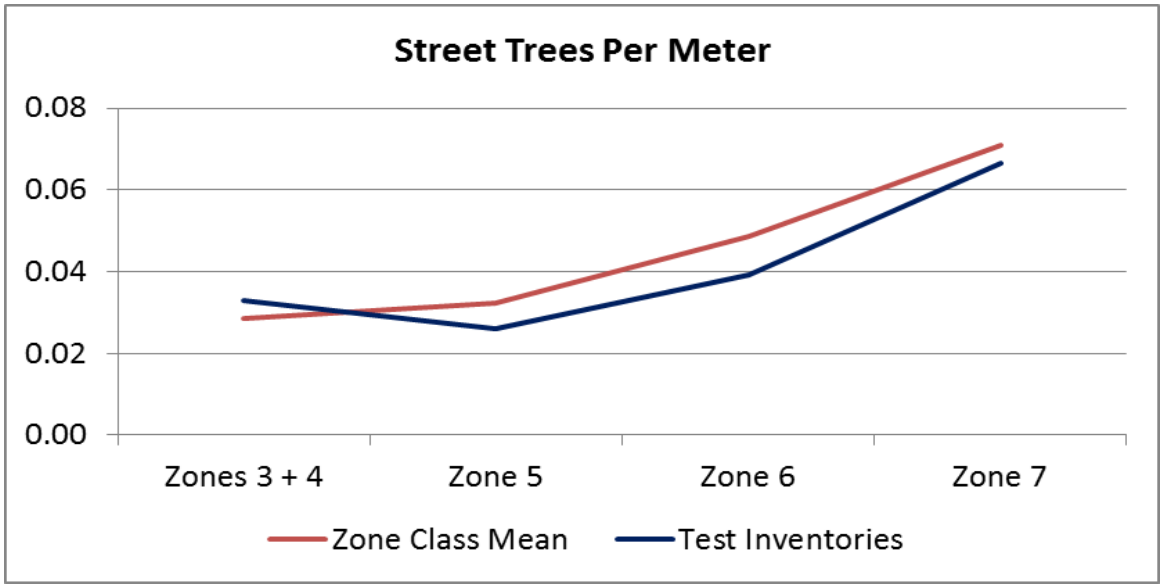


Figure 6.10 Street trees per meter for test inventories and zone class

(7) Final Statewide Estimates

Summary. Initial estimates made for prevalent street tree species and genera and annual street tree benefits statewide were updated with test inventory statistics. Change from initial estimates for prevalent street tree species and genera is slight, varies by species and genus, and reveals susceptibility to volatility in Zone 7 which has the fewest number of inventories relative to the other zone classes. Updated estimates for annual street tree benefits show a small reduction from initial estimates. The accuracy and reliability of these estimates would likely improve by incorporating data from additional street tree inventories and more data standardization. Consideration should be given to more plantings of large and medium sized trees to boost benefits provided by street trees and plantings of genera other than *Acer* to increase diversity.

Data collected in the five test inventories were added to the initial sample of street tree inventory data. Calculations made to generate statistics for the initial sample were updated with test inventory data included to yield final estimates.

Street Tree Numbers Statewide. Test inventory data was added to data contained in Table 3.14 to generate updated means and standard errors for street trees per meter and street trees per mile of streets expected to contain street trees by 1990 USDA Plant Hardiness Zone Class. As before, means were weighted by percentages of summed street length of streets expected to contain street trees by 1990 USDA Plant Hardiness Zone Class (Table 3.1) according to the formula:

$$((w1 * m1) + (w2 * m2) + (w3 * m3) + (w4 * m4)) / (w1 + w2 + w3 + w4)$$

Updated weighted means of 0.049711904 trees per meter and 80.00300962 trees per mile were calculated. An updated standard error for the updated weighted mean was calculated according to the formula:

$$\sqrt{((se1^2 * w1^2) + (se2^2 * w2^2) + (se3^2 * w3^2) + (se4^2 + w4^2))/ (w1 + w2 + w3 + w4)}$$

Where $se1$, $se2$, $se3$, and $se4$ denote the group standard error for street trees per meter or street trees per mile of street expected to contain street trees (i.e. the standard error for each 1990 USDA Plant Hardiness Zone class). The standard error of the updated statewide weighted mean of street trees per meter of street was found to be 0.002327004 and the standard error of the updated statewide weighted mean of street trees per mile of street was found to be 3.744966561. The upper 90% confidence interval of the updated weighted mean was calculated as 0.049711904 + (1.645 * 0.002327004) or 0.053539826 and the lower 90% confidence interval of the updated weighted mean was calculated as 0.049711904 – (1.645 * 0.002327004) or 0.045883983. Results are contained in Table 7.1 and show a slight lowering of updated means and confidence intervals from initial means and confidence intervals (e.g. the initial estimate of 80.472553 trees per mile

has been updated to 80.003010 trees per mile) and a reduction of 4.86% in standard error.

Based on the updated measures and 83,392,547 meters of street length expected to contain street trees (Table 2.6), final estimates of street tree numbers statewide can be calculated in meters as follows:

Number of Trees = 83,392,547 meters * 0.049711904 trees per meter = 4,145,602
90% UCI = 83,392,547 meters * 0.053539826 trees per meter = 4,464,822
90% UCI = 83,392,547 meters * 0.045883983 trees per meter = 3,826,382

Results are contained in Table 7.2 and show a slight lowering of estimates for street tree numbers statewide (e.g. the initial estimate of 4,169,904 street trees statewide has been updated to 4,145,602 street trees statewide). At the same time, the range in confidence intervals has been reduced by 4.86% reflecting the reduction in standard error.

Table 7.1 Initial and updated estimates for trees per meter and per mile

	Initial Estimates	**Updated Estimates**	**Change**
Trees per Meter	0.050003	0.049712	-0.59%
Standard Error	0.002440	0.002327	-4.86%
Trees per Mile	80.472553	80.003010	-0.59%
Standard Error	3.926838	3.744967	-4.86%
90% UCI (meters)	0.054017	0.053540	-0.89%
90% LCI (meters)	0.045989	0.045884	-0.23%
90% UCI (miles)	86.932201	86.163480	-0.89%
90% LCI (miles)	74.012904	73.842540	-0.23%

Table 7.2 Initial and updated estimates for street tree numbers statewide

	Initial Estimates	**Updated Estimates**	**Change**
Number of Trees	4,169,904	4,145,602	-0.59%
90% UCI	4,504,629	4,464,822	-0.89%
90% LCI	3,835,180	3,826,382	-0.23%
Range	669,449	638,440	-4.86%

Street Tree Numbers Statewide for Prevalent Species and Genera. Test inventory data was added to the initial sample used to calculate statewide mean percentages and 90% confidence intervals for prevalent street tree species and genera. Updated statewide weighted mean percentages were calculated for prevalent species and genera according to the formula:

$$((w1 * m1) + (w2 * m2) + (w3 * m3) + (w4 * m4)) / (w1 + w2 + w3 + w4)$$

Where $m1$, $m2$, $m3$, and $m4$ denote the group means for each species and genus (i.e. the mean percentages for each1990 USDA Plant Hardiness Zone class for each species and genus) and $w1$, $w2$, $w3$, and $w4$ denote the different weights for each group (i.e. percentages of summed street length (meters) of streets expected to contain street trees for all Census Places and Census Blocks with population density of at least 500 ppsm not contained within Census Places for 1990 USDA Plant Hardiness Zone classes in New York State) as stated in Table 3.1.

Updated standard errors for the statewide weighted mean percentages were also calculated according to the formula:

$$\sqrt{((se1^2 * w1^2) + (se2^2 * w2^2) + (se3^2 * w3^2) + (se4^2 + w4^2))} / (w1 + w2 + w3 + w4)$$

Where $se1$, $se2$, $se3$, and $se4$ denote the group standard errors for each species and genus (i.e. the standard error of mean percentages for each 1990 USDA Plant Hardiness Zone class for each species and genus). Updated results for prevalent street tree species are contained in Table 7.3 and updated results for prevalent street tree genera are contained in Table 7.4. Mean percentages have changed slightly from initial estimates, although the amount of change varies by species and genus. For example, with respect to genus, the mean percentage of *Acer* statewide has been updated to 44.27% from the initial estimate of 44.14%, an increase of 0.31%, the mean percentage of *Quercus* statewide has been updated to 7.015% from the initial estimate of 7.026%, a reduction of 0.15%, and the mean percentage of *Fraxinus* has been updated to 3.42% from the initial estimate of 3.35%, an increase of 2.09%. With respect to species, the mean percentage of *Acer platanoides* statewide has been updated to 20.85% from the initial estimate of 20.65%, an increase of 0.95%, the mean percentage of *Platanus x acerifolia* statewide has been updated to 5.59% from the initial estimate of 5.72%, a reduction of 2.45%, and the mean percentage of *Gleditsia triacanthos* has been updated to 5.18% from the initial estimate of 5.21%, a reduction of 0.55%.

Table 7.3 Updated statewide mean percentages, standard errors, and 90% confidence intervals for prevalent New York State street tree species

Species	**Mean**	**Std Err**	**90% UCL**	**90% LCL**
Acer platanoides	20.85	1.07	22.61	19.09
Acer saccharum	9.96	0.63	11.01	8.92
Acer saccharinum	5.67	0.67	6.77	4.58
Platanus x acerifolia	5.59	0.75	6.82	4.35
Acer rubrum	5.22	0.42	5.90	4.53
Gleditsia triacanthos	5.18	0.48	5.98	4.39
Pyrus calleryana	5.02	0.72	6.21	3.83
Quercus palustris	2.98	0.35	3.55	2.40
Tilia cordata	2.73	0.29	3.20	2.26
Malus species	2.47	0.21	2.82	2.12
Fraxinus pennsylvanica	2.08	0.22	2.44	1.72
Quercus rubra	1.66	0.13	1.88	1.44
Picea abies	1.25	0.14	1.48	1.02
Pinus strobus	1.04	0.17	1.31	0.76
Robinia pseudoacacia	1.04	0.15	1.28	0.79

Table 7.4 Updated statewide mean percentages, standard errors, and 90% confidence intervals for prevalent New York State street tree genera

Genus	**Mean**	**Std Err**	**90% UCL**	**90% LCL**
Acer	44.27	2.34	48.13	40.42
Quercus	7.02	0.51	7.85	6.18
Platanus	5.65	0.73	6.85	4.44
Pyrus	5.55	0.82	6.91	4.20
Gleditsia	4.94	0.46	5.69	4.19
Tilia	4.07	0.38	4.70	3.44
Fraxinus	3.42	0.27	3.86	2.98
Picea	2.95	0.27	3.39	2.51
Prunus	2.89	0.22	3.25	2.53
Malus	2.50	0.23	2.88	2.12
Pinus	1.59	0.17	1.87	1.30
Ulmus	1.31	0.20	1.64	0.98
Robinia	1.03	0.16	1.29	0.77

Based on the updated measures and the updated estimates of street tree numbers statewide, updated estimates of street tree numbers statewide for prevalent street tree species and genera can be calculated as follows:

Number of Trees = 4,145,602 trees * (Species or Genus) Mean%
90% UCI = 4,464,822 trees * (Species or Genus) 90% UCI
90% LCI = 3,826,382 trees * (Species or Genus) 90% LCI

For example, the updated estimated number of *Fraxinus* (Ash) street trees statewide could be estimated as follows:

Number of Trees = 4,145,602 trees * 3.4216% = 141,848
90% UCI = 4,464,822 trees * 3.8644% = 172,538
90% LCI = 3,826,382 trees * 2.9789% = 113,984

Based on this methodology, updated estimates have been calculated for mean number of trees and upper and lower 90% confidence intervals for prevalent street tree species and genera. Updated estimates for prevalent street tree species are contained in Table 7.5 and updated estimates for prevalent street tree genera are contained in Table 7.6. As with mean percentages for prevalent street tree species and genera, street tree numbers for prevalent street tree species and genera have changed slightly from initial estimates, although the amount of change varies by species and genus. For example, with respect to genus, street tree numbers of *Acer* statewide have been updated to 602,169 from the initial estimate of 615,068, a reduction of 0.28% and street tree numbers of *Fraxinus* have been updated to 141,848 from 139,881, an increase of 1.41%. With respect to species, street tree numbers of *Acer platanoides* statewide have been updated to 864,374 from the initial estimate of 861,226, an increase of 0.37%, and street numbers of *Pyrus calleryana* statewide have been updated to 208,142 from the initial estimate of 196,721, an increase of 5.81%.

Table 7.5 Updated estimates of numbers of trees for prevalent street tree species

Species	**Mean**	**90% UCL**	**90% LCL**
Acer platanoides	864,374	1,009,698	730,314
Acer saccharum	413,004	491,360	341,304
Acer saccharinum	235,259	302,473	175,066
Platanus x acerifolia	231,549	304,673	166,332
Acer rubrum	216,292	263,481	173,469
Gleditsia triacanthos	214,805	266,840	167,845
Pyrus calleryana	208,142	277,311	146,572
Quercus palustris	123,435	158,621	91,920
Tilia cordata	113020	142,668	86,366
Malus species	102,501	125,993	81,241
Fraxinus pennsylvanica	86,278	108,956	65,894
Quercus rubra	68,895	84,014	55,179
Picea abies	51,742	66,065	38,897
Pinus strobus	42,938	58,365	29,245
Robinia pseudoacacia	42,936	57,296	30,156

Table 7.6 Updated estimates of numbers of trees for prevalent street tree genera

Genus	**Mean**	**90% UCL**	**90% LCL**
Acer	1,835,323	2,148,710	1,546,540
Quercus	290,832	350,515	236,481
Platanus	234,087	305,949	169,923
Pyrus	230,182	308,323	160,681
Gleditsia	204,743	254,135	160,161
Tilia	168,573	209,695	131,475
Fraxinus	141,848	172,538	113,984
Picea	122,386	151,375	96,194
Prunus	119,746	145,160	96,648
Malus	103,598	128,386	81,213
Pinus	65,712	83,619	49,642
Ulmus	54,301	73,282	37,436
Robinia	42,751	57,527	29,618

For most prevalent street tree species and genera, updated mean percentages, tree numbers, and their respective 90% confidence intervals have changed only slightly from initial estimates. For some street tree species and genera, the change from initial estimates has been more substantial and predominantly reflects susceptibility to volatility in Zone 7 which has the fewest number of inventories relative to the other zone classes. It is likely, although not certain, that updating existing sample inventory data with additional inventory data in Zone 7 would improve estimates and decrease the susceptibility to volatility. Overall, however, the addition of test inventory data has confirmed and even improved the reliability of initial estimates with updated estimates generally reflecting reductions in standard error and in the range of confidence intervals for 12 of 15 prevalent street tree species and 10 of 13 prevalent street tree genera.

Statewide Annual Benefits Provided by Street Trees. Test inventory data was added to the initial sample used to calculate mean annual benefits per street tree and estimate statewide annual benefits provided by street trees. Updated mean annual benefits per street tree were calculated to be 134.15 dollars with a median of 135.61, a standard deviation of 24.05, a standard error of 2.13, and upper and lower 90% confidence intervals of 137.65 and 130.66. Results contained in Table 7.7 show a slight raise in the updated mean and confidence intervals from the initial mean and confidence intervals and a reduction of 2.01% in standard error.

The updated mean for annual benefits per street tree was used to estimate updated statewide annual benefits provided by street trees and updated upper and lower 90% confidence intervals.

Estimates are as follows:

Statewide Annual Benefits = 4,145,602 trees * $134.15/tree = $ 556,148,138
90% UCI = 4,464,822 trees * $137.65/tree = $ 614,584,569
90% LCI = 3,826,382 trees * $130.66/tree = $ 499,944,101

Results are contained in Table 7.8 and show a slight reduction in estimates for statewide annual benefits from the initial estimate of $ 557,724,660.00, a 0.28% decrease. At the same time, the range in confidence intervals has been reduced by 3.92% reflecting a reduction in standard error of 1.97%.

Table 7.7 Initial and updated estimates for statewide annual benefits ($) per street tree

	Initial Estimates	Updated Estimates	Change
Mean	133.75	134.15	0.30%
Median	135.57	135.61	0.03%
Standard Deviation	24.05	24.05	0.00%
Standard Error	2.17	2.13	-1.97%
90% UCI	137.32	137.65	0.24%
90% LCI	130.18	130.66	0.36%

Table 7.8 Initial and updated estimates for statewide annual benefits ($) provided by street trees

	Initial Estimates	Updated Estimates	Change
Annual Benefits	557,724,660.00	556,148,138	-0.28%
90% UCI	618,575,654.00	614,584,569	-0.65%
90% LCI	499,263,732.00	499,944,101	0.14%
Range	119,311,922	114,640,468	-3.92%

Recommendations

The following recommendations are offered based upon the analyses of data in this study.

Green infrastructure. Statistics in this study confirm trends found in other states that small sized tree species have been and are being planted in increasing numbers relative to large and medium sized tree species not only below utility wires, but also where utility wires are not overhead and where planting volumes are adequate to support large and medium sized trees. Research has shown that a mature large sized tree costs about twice as much annually to maintain as a mature small sized tree, but that a mature large sized tree provides up to eight times as many benefits and a mature medium sized tree provides up to four times as many benefits as a mature small sized tree (McPherson et al 2002). In other words, large and medium sized trees do more to reduce stormwater runoff, improve air quality, mitigate the heat island effect, lower energy consumption, and increase property values than do small sized trees on both a gross and net cost basis. If green infrastructure and the ecosystem and social benefits provided by street trees are identified as statewide priorities, greater emphasis should then be given to educating municipalities and

the general public regarding the greater benefits provided by large and medium sized trees as compared to small sized trees and to encourage the planting of large and medium sized trees where planting volume is adequate and single or triple phase utility wires are not overhead. Failure to reverse the current trend in planting small sized trees at the expense of large and medium sized trees will reduce the statewide structural potential of street trees to provide ecosystem and social benefits and their ability to function as green infrastructure.

Species diversity. Statistics in this study indicate that lessons learned from overplanting American Elms and the devastation wrought by Dutch elm disease were not learned well enough in New York State. The surfeit of American Elms has been replaced by excessive plantings of Maples, particularly upstate where some municipalities have percentages of Maples exceeding 70%. Since Maples are a favorite host of the Asian Longhorned Beetle and the jury is still out on the efforts being made to control the ALB in New York State and elsewhere, a large percentage of street trees statewide are potentially at risk. More emphasis should therefore be given to educating municipalities and the general public about the need for greater diversity in street tree plantings. This could possibly be done in tandem with work already being done to increase awareness about the threat posed to Ash trees by the Emerald Ash Borer. However, because reducing prevalence of Sugar Maple through increased plantings of Norway Maple will not lower overall risk to the ALB, diversity should be stressed at genus level and not at the level of species. Moreover, since this study has identified significant differences in species and genus prevalence on a geographic basis (i.e. by 1990 USDA Plant Hardiness Zone class), education on the need for increased diversity in street tree plantings should be tailored appropriately. For example, if reduced plantings of *Platanus* are called for, this should be limited to downstate since not only are there hardiness issues with *Platanus x acerifolia* in the coldest zones, but *Platanus* have not been found upstate to be planted abundantly.

Data standardization. In the best of all possible worlds, standardized data would be available for all variables at the most discrete geographic scales. This is not the case, however, for street tree data in New York State and the environmental and social variables with which it might be correlated. Data coverage varies widely between inventoried municipalities and is often not standardized and unable to be aggregated. As a result, dataset numbers and breadth of coverage at more discrete geographic scales are reduced from dataset numbers and breadth of coverage at broader geographic scales (e.g. zone class). Greater standardization of street tree inventory datasets would likely increase dataset numbers for some types of analysis, hopefully lowering standard error and improving estimate reliability and precision. For example, with greater data standardization, variation within groups (i.e. within each 1990 USDA Plant Hardiness Zone class) could be analyzed to the same extent as variation between groups (i.e. between 1990 USDA Plant Hardiness Zone classes). Although the United States Forest Service is working currently to identify standards for urban forestry data collection (USDA Forest Service 2010e), New York State could still take important steps to improve street tree data standardization. For example, as a condition for receiving urban and community forestry grants to

conduct street tree inventories, the state could stipulate to municipalities that street trees be identified by species rather than simply by genus and that DBH be measured by the centimeter or inch rather than simply by class.

Continued assessment. Just as any street tree inventory is only a snapshot in time, so too is this document. Using "final" to describe the estimates above is a misnomer since new street tree inventories will be conducted in New York State and existing inventories will be revised. Thought should therefore be given to formalizing the study of New York State street trees on a regular basis. In California, periodic assessments have been made of the statewide street tree population by querying urban foresters statewide. A recent proposal by New York State to the US Forest Service to create a statewide database of street tree inventory data would have facilitated regular assessments, but was not funded although such a database may still be created as part of the Urban Forest Health Information Center (UFORHIC). Irrespective of database creation, urging municipalities to regularly update their inventory data will ring hollow if the state fails to do the same with the present statewide assessment.

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