New York City, New York
Municipal Forest Resource Analysis

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Center for Urban Forest Research
USDA Forest Service, Pacific Southwest Research Station

Technical Report to:
Fiona Watt, Chief
Forestry and Horticulture
Department of Parks & Recreation
New York City, New York

—March 2007—

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Table of Contents

Executive Summary

New York City, the largest city in the United States and one of the world's major global cities, maintains trees as an integral component of the urban infrastructure (*Figure 1*). Since 1995, over 120,000 trees have been planted along the streets of the city's five boroughs. Over 592,000 street trees are managed by the New York City Department of Parks & Recreation (referred to as Parks hereafter). Parks manages about half of the city's 5.2 million trees and these street trees compose over one-fifth of all managed trees. For the purpose of this report the terms municipal trees and municipal forest are used in reference to street trees only.

Trees are a critical component of the city. Research indicates that healthy trees can lessen impacts associated with the built environment by reducing stormwater runoff, energy consumption, and air pollutants. Trees improve urban life, making New York City a more enjoyable place to live, work, and play, while mitigating the city's environmental impact. Over the years, the people of New York City have invested millions of dollars in their public right of way trees. Some may question the need for the level of service presently provided and the need for additional services. Hence, the primary question that this study asks is what are the accrued benefits from New York City street trees?

This analysis combines results of a citywide street tree census with benefit–cost modeling data to produce four types of information on the city-managed street tree resource:

- Structure: species composition, diversity, age distribution, condition, etc.
- Function: magnitude of annual environmental and aesthetic benefits
- Value: dollar value of benefits minus management costs
- Management needs: sustainability, planting, maintenance

Resource Structure

New York City's tree inventory includes 592,130 publicly managed street trees. This represents 584,036 live trees and 8,036 standing dead trees tallied over the course of two summer inventory periods. The inventory contains 168 tree species with London planetree (*Platanus acerifolia*), Norway maple (*Acer platanoides*), callery pear (*Pyrus calleryana*), honeylocust (*Gleditsia triacanthos*) and pin oak (*Quercus palustris*) as the predominant species. The managers of the city's urban forest can be commended for the overall diversity of their urban forest, in terms of the number of species and efforts over the past ten years to improve distribution of trees among the species.

Although the age structure of New York City's street tree population appears fairly close to the desired distribution, there is a need to increase tree planting to maintain the flow of benefits provided by the urban forest currently. Citywide, there are

Figure 1—Trees shade historic homes in New York City, New York. Street trees in New York City provide great benefits, improving air quality, sequestering carbon dioxide, reducing stormwater runoff and beautifying the city. The trees of New York City return $5.80 in benefits for every $1 spent on tree care

about 10% fewer trees in the 0- to 6-inch diameter at breast height (DBH) size class than are desired for an ideal distribution.

The largest size classes are represented almost entirely by London planetrees and silver maples (*Acer saccharinum*) which were heavily planted in the first half of the 20th century and are nearing the end of their natural lifespan. The current challenge to the health of the city's second most predominant species, Norway maple, in the form of the Asian longhorned beetle (ALB) infestation illustrates the necessity for further species diversification. Over 23% of the city's street trees are of the maple genus. Loss of these trees would represent a tremendous impact on the flow of benefits the city currently receives from its street tree population. The planetrees and maples account for over 50% of all the canopy cover attributable to street trees.

Resource Function and Value

The street trees of New York provide great benefits to the citizens. Their ability to moderate climate—thereby reducing energy use—is substantial. Electricity saved annually in New York City from both shading and climate effects of trees totals 45,609 MWh ($6.9 million), and annual natural gas saved totals 16,306,516 therms ($20.8 million) for a total energy cost savings of $27.8 million or $47.63 per tree.

Citywide, annual carbon dioxide (CO_2) sequestration and emission reductions due to energy savings by public trees are 56,060 tons and 68,687 tons, respectively. CO_2 released during decomposition and tree-care activities is 11,730 tons. Net CO_2 reduction is 113,016 tons, valued at $754,947 or $1.29 per tree.

Net annual air pollutants removed, released, and avoided average 1.73 lb per tree and are valued at $5.27 million or $9.02 per tree. Ozone ($O_3$) and particulate matter (PM_{10}) are the most significant pollutants intercepted by trees, with 129.1 and 63 tons per year removed, respectively, with implied values of $1.2 and $1.0 million. In the absence of the cooling effects of trees, higher temperatures contribute to O_3 formation. Interception of O_3 by street trees is important to the health of New York residents because short-term increases in O_3 concentrations have been statistically associated with increased tree mortality for 95 large U.S. cities (Bell et al. 2004). Nitrogen dioxide (NO_2), an O_3 precursor is the most economically significant air pollutant whose production is avoided at the power plant, due to reduced energy needs (193 tons) per year ($1.8 million).

New York City's street trees intercept rain, reducing stormwater runoff by 890.6 million gallons annually, with an estimated value of $35.6 million. Citywide, the average tree intercepts 1432 gallons of stormwater each year, valued at $61 per tree.

The estimated total annual benefits associated with aesthetics, property value increases, and other less tangible improvements are approximately $52.5 million or $90 per tree on average.

Annual benefits total $121.9 million and average $209 per tree. The city's 89,425 London planetrees produce the highest total level of benefits at $27.4 million, annually ($307 per tree, 23% of total benefits). Norway maple is the second most important species to the city, accounting for 14% of all benefits ($16.6 million/year; $224/tree). Species providing the least benefits on an individual tree basis include cherry (*Prunus* spp., $47) and ginkgo (*Ginkgo biloba,* $82). Benefit levels for cherry will probably not improve, but gingko benefits will increase as the population matures.

New York City spends approximately $21.8 million in a typical year planting new trees and maintaining existing public trees ($37/tree). Current expenses include additional funding for the ALB quarantine program, but these costs are not included since this analysis focuses on typical costs over time. The highest single cost is for contracted tree planting ($8.2 million), followed by personnel costs ($6.3 million) for the management and maintenance of the tree resource.

New York City's street trees are a valuable asset, providing approximately $100.2 million or $172 per tree ($15 per capita) in net annual benefits to the community. Over the years, the city has invested millions in its urban forest. Citizens are now receiving a return on that investment—trees are providing $5.60 in benefits for every $1 spent on tree planting and care. New York City's benefit-cost ratio of 5.60 exceeds all other cities studied to date, including Fort Collins, Colorado (2.18), Glendale, Arizona (2.41), and Charlotte, North Carolina (3.25).

Another way of describing the worth of trees is their replacement value, which assumes that the value of a tree is equal to the cost of replacing it in its current condition. Replacement value is a function of the number, stature, placement and condition of the city's trees and reflects their value over a lifetime. As a major component of New York's green infrastructure, the 584,036 live street trees are estimated to have a replacement value of $2.3 billion or $3,938 per tree.

Resource Management

New York City's street trees are a dynamic resource. Managers of the urban forest and the community alike can take pride in knowing that municipal trees do improve the quality of life in the city; the resource, however, is fragile and needs constant care to maximize and sustain the benefits through the future. Achieving resource sustainability requires that New York City:

1. Plant more large-stature species where conditions are suitable to maximize benefits.

2. Develop a strong young-tree care program that emphasizes reducing mortality. Inspection and pruning on a 2- to 3-year cycle will provide a good foundation for new trees being planted.

3. Use findings from the mortality study currently underway to assist in determining how best to prepare sites for new plantings. Track the success of the newly planted trees to determine those most adaptable to difficult conditions.

4. Sustain benefits by investing in intensive maintenance of mature trees to prolong the life spans of these heritage trees. Develop a replacement plan for the London planetrees and Norway maples to replace them with trees of similar stature gradually before they must be removed.

5. Use the existing canopy cover study of the city to identify and prioritize available planting space for small, medium, and large tree future planting. Public right-of-way lands (e.g., streets, parking lots, schools, parks) may provide good opportunities for maximizing air quality, energy savings, and aesthetic benefits.

6. Study the economic and environmental tradeoffs between planting new trees and the ability to maintain all trees at levels necessary to reduce mortality levels and sustain health and benefits.

7. Continue diversifying to reduce dependence on species like London planetree and Norway maple to guard against catastrophic losses from storms, pests or disease while concentrating species choice on those that have proven most successful. Include large species like linden (silver, littleleaf, basswood, Crimean), zelkova, and oaks (pin, willow, red, and others).

The challenge ahead is to better integrate New York City's green infrastructure with its gray infrastructure. This can be achieved by including green space and trees in the planning phase of development and street retrofit projects, providing adequate space for trees, planting available spaces, and maintaining plantings to maximize net benefits over the long term. By acting now to implement these recommendations, New York City will benefit from a more functional and sustainable urban forest in the future.

Stately trees shade a residential street in New York City

Chapter One—Introduction

New York City is an international center for business, finance, fashion, medicine, entertainment, media, and culture. Often called the "City that Never Sleeps," the "Capital of the World," or the "Big Apple," New York attracts people from around the world. Trees are maintained as an integral component of the city's urban infrastructure and have long been beloved and cared for by the city's residents and visitors. The New York City Department of Parks & Recreation (hereafter "Parks") actively manages over 592,000 street trees, and has planted over 120,000 new trees over the past 10 years. The city believes that the public's investment in stewardship of the urban forest produces benefits that far outweigh the costs to the community. Investing in New York City's green infrastructure makes sense economically, environmentally, and socially.

Research indicates that healthy city trees can mitigate impacts associated with urban environs: polluted stormwater runoff, poor air quality, high requirements for energy for heating and cooling buildings, and heat islands. Healthy public trees increase real estate values, provide neighborhood residents with a sense of place, and foster psychological, social, and physical health. Street and park trees are associated with other intangibles, too, such as increasing community attractiveness for tourism and business and providing wildlife habitat and corridors. The urban forest makes New York City a more enjoyable place to visit, live, work and play, while mitigating the city's environmental impact.

In an era of decreasing public funds and rising costs, however, there is a need to scrutinize public expenditures that may be viewed as "nonessential," such as planting and maintaining street and park trees. Some may question the need for the level of service presently provided and the need for additional services. Hence, the primary question that this study asks is *what are the accrued benefits from New York City street trees?*

In answering this question, information is provided to do the following:

- Assist decision-makers to assess and justify the degree of funding and type of management program appropriate for New York City's urban forest.
- Provide critical baseline information for evaluating program cost-efficiency and alternative management structures.
- Highlight the relevance and relationship of New York's municipal tree resource to local quality of life issues such as environmental health, economic development, and psychological well-being.
- Provide quantifiable data to assist in developing alternative funding sources through utility purveyors, air quality districts, federal or state agencies, legislative initiatives, or local assessment fees.

This report includes six chapters and three appendices:

Chapter One—Introduction: Describes the purpose of the study.

Chapter Two—New York City's Municipal Tree Resource: Describes the current structure of the street tree resource.

Chapter Three—Costs of Managing New York's Municipal Trees: Details management expenditures for publicly managed trees.

Chapter Four—Benefits of New York City's Municipal Trees: Quantifies the estimated value of tangible benefits and calculates net benefits and a benefit–cost ratio.

Chapter Five—Management Implications: Evaluates relevancy of this analysis to current programs and describes management challenges for street tree maintenance.

Chapter Six—Conclusions: Final word on the use of this analysis.

Appendix A—Tree Distribution: Lists species and tree numbers in the street tree population.

Appendix B—Street Tree Condition: Describes species condition for trees with 500 or more representatives

Appendix C—Replacement Values: Lists replacement values for the entire municipal tree population.

Appendix D—Describes procedures and methodology for calculating structure, function, and value of the urban tree resource.

References—Lists publications cited in the study.

Chapter Two—New York's Municipal Tree Resource

All trees growing in the public right-of-way—along streets and in parks—are under the jurisdiction of the Parks, which manages about half of the City's 5.2 million trees (Nowak et al., in press). Parks provides a number of basic services for over 592,000 street trees. These include removing dead trees within 30 days of notification, pruning all trees on a 10-year cycle, responding to storms and other emergencies, and assisting with the control of invasive pests such as the Asian longhorned beetle (ALB). Over the past 10 years, Parks has pruned more than 320,000 trees as part of a block pruning program, as well as inspecting, pruning, and/or removing trees in parks as needed. The city also works closely with state and federal officials as part of the monitoring and removal program for trees infested with ALB.

Parks is also responsible for planting trees on city streets and in park properties. It is at the forefront of efforts to apply new and better methods for planting and maintaining street trees in a variety of environments ranging from Manhattan's urban canyons to the tree-lined streets of quiet Staten Island neighborhoods. One example is the piloting of structural soils and the redesign and repair of sidewalks specifically to provide more growth space for trees. Since 1995, Parks has planted over 120,000 trees, and currently plants an average of about 8,000 trees annually.

The citizens of New York City are passionate about their trees, believing that they add character, beauty, and serenity to the city. Since 1995, citizen volunteers have participated in two street tree inventories. The second census (Trees Count 2005–2006 Street Tree Census) has just been completed and involved over 1,000 citizen volunteers. The summary results of this census are contained within this report.

Parks, together with Partnerships for Parks—a group that works to increase community support for and involvement in parks throughout New York City—provides stewardship materials for citizens who commit to caring for young street trees. The New York Tree Trust attracts private donations to Parks' forestry programs through its nonprofit fiscal sponsor, The City Parks Foundation. Additionally, Parks, along with Columbia University Press, published a New York City tree field guide that includes color photos and drawings to help residents and visitors identify 130 species, detailed guides to 28 parks, botanical gardens, wildlife refuges and forest reserves within the city, and information on the city's "Great Trees," including the "Hangman's Elm" in Washington Square, which may be over 300 years old. A second book focuses upon the city's "great trees" – many old and famous trees, some dating back to the signing of the Declaration of Independence.

Tree Numbers

The 2005–2006 New York City street tree census included 592,130 trees (*Figure 2*). These trees are distributed amongst the five boroughs: Brooklyn (24.2%), Bronx (10.1%), Manhattan (8.4%), Queens (40.5%), and Staten Island (16.8%). This census included 8,094 dead trees inventoried over two summer seasons.

The municipal tree population is dominated by deciduous trees (99.1% of the total). Because broadleaf trees are usually larger than coniferous street trees or palms and most of the benefits provided by trees are related to leaf surface area, broadleaf trees usually provide the highest level of benefit. Not surprisingly, given the climate in the Northeast, there are only 1,051 broadleaf evergreen street trees (0.2% of total). Conifers account for only 0.7% percent of the population.

Species Richness, Composition and Diversity

The tree population in New York City includes a mix of more than 168 species—over three times more than the mean of 53 species reported by McPherson and Rowntree (1989) in their nationwide survey of street tree populations in 22 U.S.

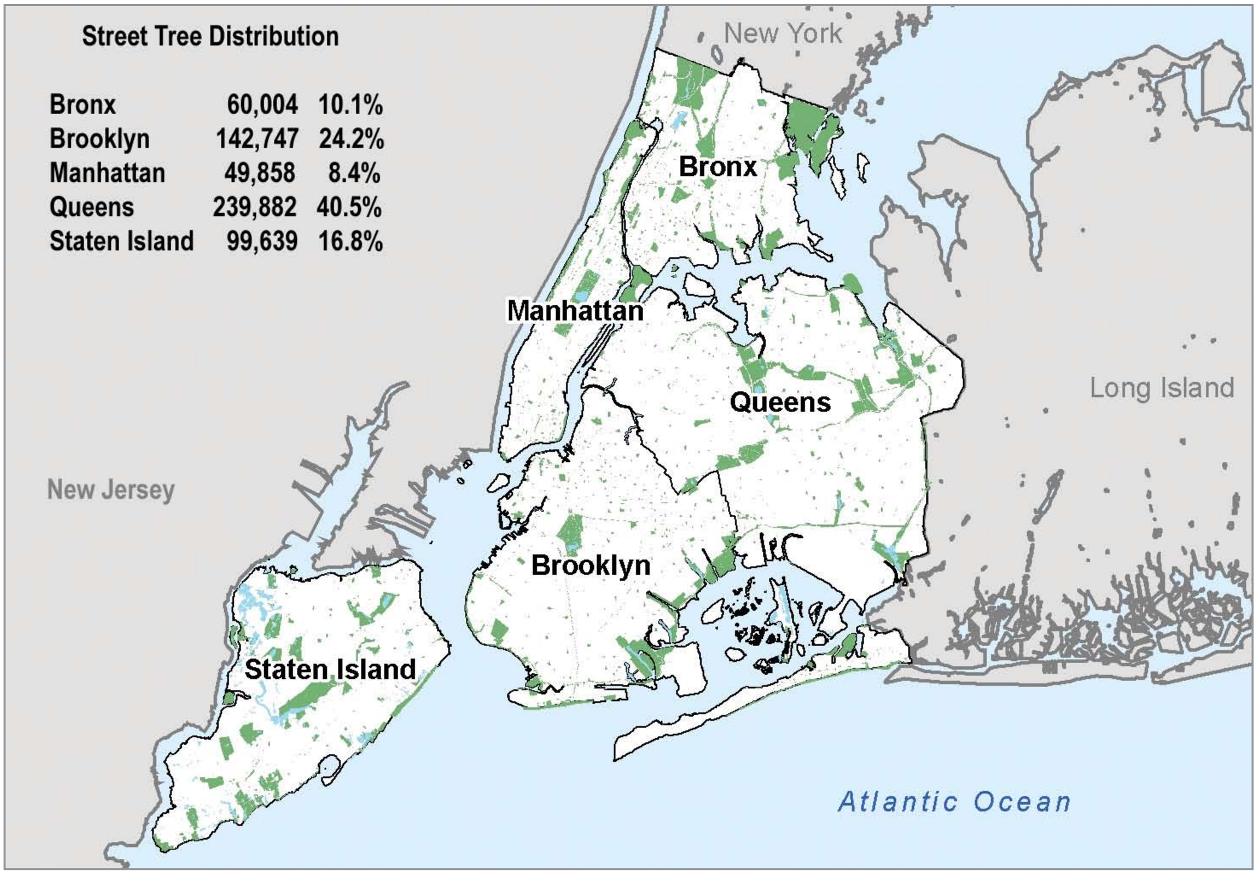

Figure 2—New York City's five boroughs

cities. This is especially impressive considering the challenging growing conditions in this densely urbanized city.

The predominant municipal tree species are London planetree (*Platanus acerifolia,* 15.3%), Norway maple (*Acer platanoides,* 12.7%), Callery pear (*Pyrus calleryana,* 10.9%), honeylocust (*Gleditsia triacanthos,* 8.9%) and pin oak (*Quercus palustris,* 7.5%; *Table 1*; see also *Appendix A*). In New York City, the percentages of London planetree, Norway maple, and callery pear exceed the general rule that no single species should represent more than 10% of the population and no genus more than 20% (Clark et al. 1997). Together these three species constitute nearly 39% of the street tree population. Maple, as a genus, constitutes over 23% of the population.

Dominance of this kind is of concern because of the catastrophic impact that storms, drought, disease, pests, or other stressors can have on the forest and its flow of benefits to the city over time. Urban forest managers and others have become well aware of the problem with the current ALB infestation.

Examining species distribution among the five boroughs increases the cause for concern *(Table 2*; see *Figure 2* for borough map). In three of the five boroughs (Brooklyn, Manhattan, Staten Island), about one-quarter of the populations consist of just one species, far exceeding the recommended cap of 10% for any one species. Bronx is the only borough without a significantly dominant species (honeylocust 12.9%; Norway maple 12.3%; planetree 11.1%). For every borough except Bronx, two species account for one-third or more of the populations. The most predominant trees in all boroughs, with the exception of Staten Island, are large-growing planetree, honeylocust, and Norway maple. Staten Island's most predominant street tree species is callery pear. This is a small- to medium-stature deciduous species that tends to be relatively short-lived, particularly in comparison with the London planetrees. Planetrees were once the pre-

***Table 1**—Most abundant street tree species in order of predominance by DBH class and tree type*

Species	DBH class									Total	% of total
	0–3	3–6	6–12	12–18	18–24	24–30	30–36	36–42	>42		
Broadleaf deciduous large (BDL)											
Planetree, London	355	1,911	7,862	19,650	26,415	19,208	9,747	3,079	1,198	89,425	15.3
Maple, Norway	985	4,761	22,102	24,935	14,600	4,746	1,210	370	341	74,050	12.7
Honeylocust	3,227	11,487	25,835	9,240	1,515	343	180	96	103	52,026	8.9
Oak, pin	1,861	3,626	8,150	10,144	9,710	6,317	2,741	811	444	43,804	7.5
Ash, green	528	2,847	10,130	5,221	987	422	208	122	98	20,563	3.5
Maple, silver	297	841	2,932	3,332	3,949	3,351	2,285	1,069	520	18,576	3.2
Ginkgo	1,757	3,520	7,207	2,630	663	215	87	52	53	16,184	2.8
Zelkova, Japanese	1,794	4,230	6,188	1,758	379	117	45	12	23	14,546	2.5
Oak, northern red	832	1,861	2,228	1,973	1,706	1,206	710	377	182	11,075	1.9
Sweetgum	297	1,606	3,042	1,808	901	426	178	62	46	8,366	1.4
Maple, Norway-cr kng	504	2,317	3,605	1,288	277	66	27	14	11	8,109	1.4
Linden, American	337	1,760	2,658	1,229	563	396	152	63	36	7,194	1.2
Linden, silver	481	2,125	2,368	599	191	127	41	29	13	5,974	1.0
Unknown large	-	2,330	4,939	2,463	1,294	654	360	145	112	12,297	2.1
BDL other	3,319	7,452	11,544	7,615	4,127	2,306	1,131	528	369	38,391	6.6
Total	16,574	52,674	120,790	93,885	67,277	39,900	19,102	6,829	3,549	420,580	72.0
Broadleaf deciduous medium (BDM)											
Pear, callery	5,948	24,371	24,877	6,794	811	267	151	65	90	63,374	10.9
Linden, little leaf	1,638	6,261	11,837	4,710	1,745	806	278	92	82	27,449	4.7
Maple, red	1,121	4,437	6,818	3,802	2,242	1,073	414	129	122	20,158	3.5
Pagoda tree, Japanese	649	1,408	2,890	1,588	345	96	30	13	10	7,029	1.2
BDM other	2,862	3,969	1,683	844	468	231	110	66	40	10,273	1.8
Total	12,218	40,446	48,105	17,738	5,611	2,473	983	365	344	128,283	22.0
Broadleaf deciduous small (BDS)											
Cherry, other	2,179	4,177	2,227	632	195	90	40	15	20	9,575	1.6
BDS other	5,696	7,522	4,508	1,445	583	253	125	37	50	20,219	3.5
Total	7,875	11,699	6,735	2,077	778	343	165	52	70	29,794	5.1
Broadleaf evergreen medium (BEM)											
BEM other	79	122	271	177	119	48	21	8	8	853	0.1
Total	79	122	271	177	119	48	21	8	8	853	0.1
Broadleaf evergreen small (BES)											
BES other	32	64	78	19	3	-	2	-	-	198	0.0
Total	32	64	78	19	3	-	2	-	-	198	0.0
Conifer evergreen large (CEL)											
CEL other	394	777	1,262	717	242	90	39	7	9	3,537	0.6
Total	394	777	1,262	717	242	90	39	7	9	3,537	0.6
Conifer evergreen medium (CEM)											
CEM other	109	219	297	102	37	15	8	-	1	788	0.1
Total	109	219	297	102	37	15	8	-	1	788	0.1
Conifer evergreen small (CES)											
CES other	-	2	-	1	-	-	-	-	-	3	-
Total	-	2	-	1	-	-	-	-	-	3	-
Citywide Total	37,281	106,003	177,538	114,716	74,067	42,869	20,320	7,261	3,981	584,036	100.0

Table 2*—Most abundant tree species listed by borough with percentage of totals in parenthesis*

Zone	1st (%)	2nd (%)	3rd (%)	4th (%)	5th (%)
Brooklyn	Planetree, London (26.3)	Maple, Norway (11)	Honeylocust (8.8)	Oak, pin (6.9)	Pear, callery (6.7)
Bronx	Honeylocust (12.9)	Maple, Norway (12.3)	Planetree, London (11.1)	Oak, pin (8.7)	Pear, callery (7.6)
Manhattan	Honeylocust (23.3)	Pear, callery (15.7)	Ginkgo (9.9)	Planetree, London (8.2)	Linden, little leaf (6.3)
Queens	Maple, Norway (18.3)	Planetree, London (13.7)	Oak, pin (8.2)	Pear, callery (7.4)	Honeylocust (7.2)
Staten Island	Pear, callery (24.8)	Planetree, London (9.6)	Maple, red (8.8)	Maple, Norway (7.5)	Oak, pin (6.9)
Citywide total	Planetree, London (15.3)	Maple, Norway (12.7)	Pear, callery (10.9)	Honeylocust (8.9)	Oak, pin (7.5)

dominant species, but now represent slightly less than 10% of Staten Island's street tree population.

Species Importance

Importance values (IV) are particularly meaningful to managers because they indicate a community's reliance on the functional capacity of particular species. For this study, IV takes into account not only total tree numbers, but canopy cover and leaf area, providing a useful comparison with the total population distribution.

IV, a mean of three relative values, can in theory range between 0 and 100, where an IV of 100 implies total reliance on one species and an IV of 0 suggests no reliance. Urban tree populations with one dominant species (IV>25%) may have low maintenance costs due to the efficiency of repetitive work, but may still incur large costs if decline, disease, or senescence of the dominant species results in large numbers of removals and replacements. When IVs are more evenly dispersed among five to 10 leading species, the risks of a catastrophic loss of a single dominant species are reduced. Of course, suitability of the dominant species is an important consideration. Planting short-lived or poorly adapted trees can result in short rotations and increased long-term management costs.

The 18 most abundant municipal tree species listed in *Table 3* constitute 85% of the total population and 89% of the total leaf area and canopy cover, for an overall IV of 88. As *Table 3* illustrates, New York City is relying on the functional capacity of London planetree to a great extent. Though the species accounts for 15% of all public trees, because of the trees' large size, the amount of leaf area and canopy cover they provide is great, increasing their importance value to 24.5 when all components are considered. This makes them twice as significant as the next closest species, Norway maple, and 2.5 times more significant than pin oak. Although callery pears are the third most common street tree, accounting for nearly 11% of the population, their importance value is less than 7%. Many of these trees are young. In fact, nearly half have less than 6 inches diameter at breast height (DBH). Importance will increase some as these grow, but never at the same rate as larger-growing, longer-lived trees.

Some large trees on the list, like Northern red oak (*Quercus rubra*), appear to have significantly lower importance values; however, more 40% of these trees are less than 12-inch DBH, with 22% under 6 inches. They will continue to grow in importance as they age. Red oak's current importance is only one-third that of callery pear, but note that there is less than one-fifth the number of trees. If there were as many red oaks as callery pears, they would be contributing three times the leaf area and canopy cover and have double the pear's importance value. Similarly, many of the city's other young, large-growing, long-lived species have the potential for increasing in importance as they mature.

Age Structure

The distribution of ages within a tree population influences present and future costs as well as the

Table 3*—Importance values (IV) indicate which species dominate the population due to their numbers and size*

Species	No. of trees	% of total trees	Leaf area (ft^2)	% of total leaf area	Canopy cover (ft^2)	% of total canopy cover	Importance value
Planetree, London	89,425	15.31	393,326,112	29.10	140,679,776	29.07	24.49
Maple, Norway	74,050	12.68	159,902,720	11.83	63,579,560	13.14	12.55
Pear, callery	63,374	10.85	65,562,228	4.85	23,769,374	4.91	6.87
Honeylocust	52,026	8.91	102,771,048	7.60	39,769,236	8.22	8.24
Oak, pin	43,804	7.50	151,974,288	11.24	52,854,592	10.92	9.89
Linden, little leaf	27,449	4.70	34,929,912	2.58	12,308,027	2.54	3.28
Ash, green	20,563	3.52	42,394,740	3.14	14,836,756	3.07	3.24
Maple, red	20,158	3.45	40,087,076	2.97	13,671,332	2.82	3.08
Maple, silver	18,576	3.18	88,904,168	6.58	25,638,000	5.30	5.02
Ginkgo	16,184	2.77	12,467,663	0.92	4,589,810	0.95	1.55
Zelkova, Japanese	14,546	2.49	18,919,952	1.40	6,689,108	1.38	1.76
Oak, northern red	11,075	1.90	32,213,202	2.38	12,520,374	2.59	2.29
Cherry, other	9,575	1.64	3,375,013	0.25	1,808,485	0.37	0.75
Sweetgum	8,366	1.43	15,705,935	1.16	5,646,068	1.17	1.25
Maple, Norway-cr kng	8,109	1.39	7,753,856	0.57	3,500,852	0.72	0.90
Linden, American	7,194	1.23	11,560,793	0.86	4,060,315	0.84	0.98
Pagoda tree, Japanese	7,029	1.20	10,234,731	0.76	3,707,942	0.77	0.91
Linden, silver	5,974	1.02	6,550,512	0.48	2,161,834	0.45	0.65
Unknown large	12,297	2.11	32,798,032	2.43	10,728,730	2.22	2.25
Other trees	74,262	12.72	120,063,352	8.88	41,426,320	8.56	10.05
Total	584,036	100.00	1,351,495,040	100.00	483,946,560	100.00	100.00

flow of benefits. An uneven-aged population allows managers to allocate annual maintenance costs uniformly over many years and assures continuity in overall tree-canopy cover. A desirable distribution has a high proportion of new transplants to offset establishment-related mortality, while the percentage of older trees declines with age (Richards 1982/83).

The overall age structure, represented here in terms of DBH, for street trees in New York City either meets or exceeds the ideal at every relative age class with the exception of youngest trees (0- to 6-inch DBH) where the proportion is 15% lower than the ideal (*Figure 3*). Closer examination shows that the results differ greatly by species. The species most heavily represented in the smaller size classes include honeylocust and callery pear with 28.3% (14,714 trees) and 47.8% (30,319 trees) in the 0- to 6-inch DBH class, respectively. Although 28.8% of littleleaf lindens (*Tilia cordata*) are in the 0- to 6-inch class, there are only 7,899 trees. It is important to understand that these numbers reflect the ability of certain species to survive through establishment periods. In every city, some species thrive better than others. Pears and honeylocust predominate in the 0- to 6-inch size classes. This may indicate that these species have adapted better than others to challenging growing conditions, as City planting records do not reflect this pattern. It may also reflect difficulties in species identification of small trees, as pears and lindens are often confused and thousands of small trees were simply not identified in the inventory. The predominance of all of the species shown in *Figure 3* indicates that they are among those trees that do tend to survive the city conditions.

Red maple (*Acer rubrum*) comes closest to ideal distributions across DBH classes, but the majority of species shown actually exceed ideal proportions in one or both of the 6- to 12-inch and 12- to 18-inch DBH classes. Across species, the middle- to largest size classes (18 to >42 inch DBH) are less well-represented, which may partly be a reflection of fewer trees having been planted over that

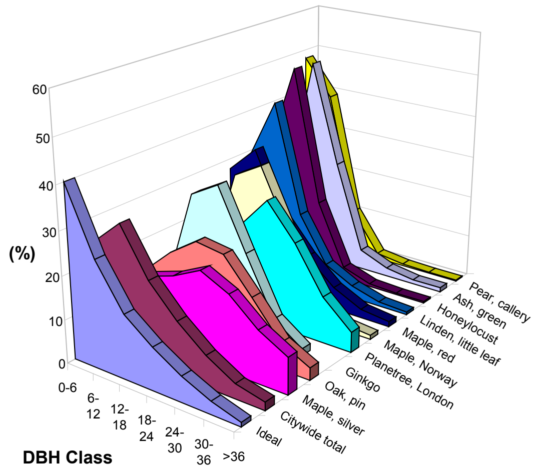

Figure 3—Relative age distribution for New York City's 10 most abundant street tree species citywide shown with an ideal distribution

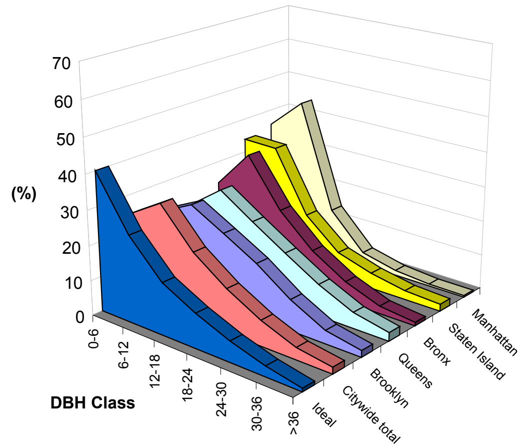

Figure 4—Relative age distribution of all street trees by borough

time period, but is also due to the high mortality of trees in the area coupled with dependence upon long-established trees like silver maple (*Acer saccharinum*), pin oak, and London planetree. These species exceed the ideal proportions for every size class except 0–12 inches. Records maintained by Parks indicate the tree mortality of new plantings in New York City at around 2.7% per year for the first 5 years and 1.3% per year subsequently (Watt 2006). The challenge New York City urban foresters face is how to help street trees live long enough to grow large and maximize benefit production. Parks, in partnership with the U.S. Forest Service, is currently conducting an extensive mortality study, extending through 2008, visiting 14,000 trees planted within the last 10 years to examine factors leading to survival and mortality.

Figure 4 shows relative age distribution by borough. Notably, the presence of very old trees heavily planted in the last century—London planetree, pin oak, silver and Norway maple—are primarily responsible for meeting ideal distribution percentages in the oldest age classes. Again with the exception of the first DBH class, all boroughs except Manhattan nearly meet or exceed ideal population distribution levels. Manhattan has the fewest large-stature street trees of all the boroughs, not surprising, considering that the majority grow where planting space is limited to sidewalk cutouts (87%) near multistory buildings. Callery pear and honeylocust are present in the highest numbers, each representing about 21% of 0- to 6-inch DBH trees for this borough. Although the majority of Staten Island's street trees grow in front lawns or planting strips (81%), callery pear again is the most common "young" tree, accounting for nearly 40% (13,195) of all Staten Island trees in the 0- to 6-inch DBH class. This number represents about 44% of all of the 0- to 6-inch pears citywide. However, the borough still has a significant population of large, old planetrees, primarily responsible for raising the 18-inch and larger relative age distribution to nearly ideal levels. Although pears are clearly well-adapted to a range of growing conditions, foresters should strive for increased diversification when planting new trees in Manhattan and Staten Island. Tree planting in general needs to be increased in every borough, but most significantly in Brooklyn, Bronx, and Queens where relatively young trees represent only about 50% of the ideal 0- to 6-inch relative age distribution.

Tree Condition

Tree condition indicates both how well trees are managed and how well they perform given site-specific conditions. The condition of trees in New York City is very good, with 90% in good or better shape (*Figure 5*). Standing dead trees were not

Table 4—Condition for New York City's 18 predominant species. See Appendix B for complete listing

Species	Poor	Good	Excellent	# of trees total	% of total population
Planetree, London	7.7	73.8	18.5	89,425	15.3
Maple, Norway	17.8	65.6	16.7	74,050	12.7
Pear, callery	4.3	67.0	28.7	63,374	10.9
Honeylocust	6.2	71.4	22.4	52,026	8.9
Oak, pin	5.8	67.8	26.4	43,804	7.5
Linden, little leaf	7.6	65.8	26.6	27,449	4.7
Ash, green	6.0	68.1	25.9	20,563	3.5
Maple, red	10.6	68.8	20.6	20,158	3.5
Maple, silver	8.2	70.9	20.9	18,576	3.2
Ginkgo	7.1	58.9	33.9	16,184	2.8
Zelkova, Japanese	4.3	63.8	31.9	14,546	2.5
Oak, northern red	6.7	63.4	29.9	11,075	1.9
Cherry, other	6.5	63.4	30.1	9,575	1.6
Sweetgum	3.9	73.1	23.0	8,366	1.4
Maple, Norway-cr kng	8.1	68.4	23.5	8,109	1.4
Linden, American	7.8	64.9	27.2	7,194	1.2
Pagoda tree, Japanese	6.7	67.7	25.6	7,029	1.2
Linden, silver	6.2	59.1	34.6	5,974	1.0

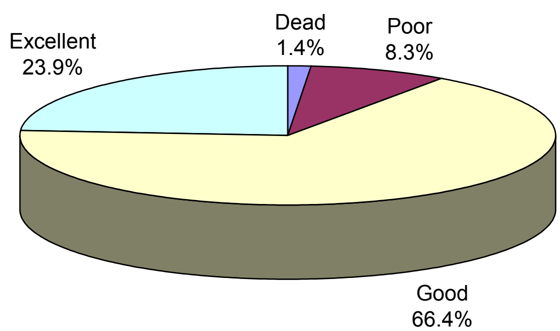

Figure 5—Condition of the street trees citywide

identified by species in the new census, but only as dead, so the values reported in *Table 4* and *Appendix B* are based on live trees reported to be in poor, good, or excellent health.

Among the city's predominant species, those with the highest percentage in poor condition are the four most prevalent maples: Norway maple (17.8%), red maple (10.6%), silver maple (8.2%), and Norway maple 'Crimson King' (8.1%). Looking at species represented by 500 or more trees, Norway maple, horsechestnut (*Aesculus hippocastanum*, 16.5%), Eastern redbud (*Cercis canadensis*, 14.5%) and Katsura tree (*Cercidiphyllum japonicum*, 14.2%) have the highest percentages of trees in poor condition. Predominant species with the largest percentage of trees in excellent condition include sweetgum (*Liquidambar styraciflua*, 96.1%), callery pear (95.7%), Japanese zelkova (*Zelkova serrata*, 95.7%), and pin oak (94.2%). Sweetgum, callery pear, and Japanese zelkova are also species in top condition, along with willow oak (*Quercus phellos*, 95.7%), for species with 500 or more trees.

Care should be taken when analyzing the condition of the street tree resource to ensure that relevant factors such as tree age are taken into consideration. For example, over 40% of callery pear, zelkova, silver linden (*Tilia tomentosa*), and hackberry (*Celtis occidentalis*) are relatively young trees (most under 15 years old) under 6 inches DBH. Over 80% of the large-growing species among these are less than 12 inches DBH. It is important to compare relative age (*Figure 5*) with tree condition (*Table 4*) to determine whether various species have actually stood the test of time. Conclusions about their suitability to the region should be postponed until those trees predominantly represented in only 0- to 6-inch size classes have matured more.

Tree Canopy

Canopy cover, or more precisely, the amount and distribution of leaf surface area, is the driving force behind the urban forest's ability to produce benefits for the community. As canopy cover increases, so do the benefits afforded by leaf area. It is important to remember that street and park trees throughout the United States—and those of New York City—likely represent less than 20% of the entire urban forest (Moll and Kollin 1993). A recent study of New York City canopy cover by Grove and others (2006) confirms this in that total cover for the city (private and public) was 24%. Given a city land area of 188,304 acres (294 square miles), we estimate street tree canopy in New York City at 11,110 acres, covering 5.9% of the city. Grove found similar coverage in the GIS analysis of cover (5.7%). The largest portion of the street tree canopy cover is in Queens (45.2%), followed by Brooklyn (26.6%), Staten Island (13.5%), the Bronx (9.4%), and Manhattan (5.3%).

Replacement Value

Replacement value should be distinguished from the value of annual benefits produced by the urban forest. The latter will be described in Chapter 4 as a "snapshot" of benefits during one year, while the former accounts for the historical investment in trees over their lifetimes. Hence, the replacement value of New York City's municipal tree population is many times greater than the value of annual benefits it produces.

Replacement value is a way of describing the value of trees at a given time, reflecting their current number, stature, placement, and condition. There are several methods that arborists employ to develop a fair and reasonable perception of a tree's value (CTLA 1992, Watson 2002). The cost approach is widely used today and assumes that value equals the cost of production, or in other words, the cost of replacing a tree in its current state (Cullen 2002).

Replacing New York City's 584,036 municipal street trees with trees of similar size, species, and condition if, for example, all were destroyed by a catastrophic storm, would cost approximately $2.3 billion (*Table 5*; see also *Appendix C*). New York's street trees are a valuable legacy, and as a central component of the city's green infrastructure can be considered a public asset with a value of $2.3 billion. The average replacement value per tree is $3,938. London planetrees account for nearly 38% of the total, followed by Norway maple (12%), pin oak (7%), honeylocust and silver maple (4%). Most of the overall value is in the older and larger trees.

Ginkgos shade a Manhattan street

***Table 5**—Replacement values, summed by DBH class, for the 20 most valuable species of street trees in New York City. See Appendix C for complete listing*

Species	0–3	3–6	6–12	12–18	18–24	24–30	30–36	36–42	>42	Total	% of total
Planetree, London	37,834	809,995	11,806,541	81,096,224	214,718,704	258,999,200	194,958,720	81,403,560	34,214,860	878,045,696	38.18
Maple, Norway	139,687	1,805,799	25,957,780	75,079,056	84,805,864	45,828,656	17,622,648	7,131,975	7,545,434	265,916,896	11.56
Oak, pin	330,820	1,252,068	7,481,848	23,185,554	42,132,436	44,618,952	28,876,420	11,085,614	6,887,744	165,851,456	7.21
Honeylocust	407,580	4,816,573	36,585,524	34,769,132	11,051,327	4,148,102	3,242,040	2,332,038	2,785,718	100,138,040	4.35
Maple, silver	52,370	287,073	2,636,003	7,327,220	16,519,472	22,778,194	22,886,976	14,296,792	7,906,964	94,691,072	4.12
Oak, northern red	68,407	949,214	4,354,713	10,654,546	17,938,492	21,338,614	18,695,578	12,927,106	7,184,013	94,110,680	4.09
Maple, red	106,258	2,073,272	11,776,321	17,357,374	19,860,516	15,947,726	9,044,236	3,942,837	3,967,763	84,076,296	3.66
Linden, little leaf	186,301	2,840,734	18,866,782	20,272,906	14,661,552	11,132,524	5,670,872	2,389,954	2,450,983	78,472,608	3.41
Pear, callery	1,068,575	8,662,551	23,318,640	15,501,284	3,494,964	1,960,410	1,680,624	937,953	1,444,896	58,069,896	2.52
Ash, green	77,685	1,140,058	12,727,028	17,413,314	6,259,048	4,352,868	3,198,292	2,382,876	2,223,278	49,774,448	2.16
Ginkgo	174,758	1,723,812	12,976,075	13,464,274	6,645,540	3,487,278	2,124,889	1,656,287	2,025,083	44,277,996	1.93
Sweetgum	29,303	778,489	5,298,852	8,580,200	8,565,852	6,811,265	4,213,992	2,073,699	1,668,170	38,019,820	1.65
Zelkova, Japanese	182,225	2,094,080	11,223,436	8,823,416	3,630,585	1,965,175	1,103,547	412,344	728,762	30,163,570	1.31
Linden, American	38,927	797,336	4,247,163	5,345,529	4,678,137	5,353,126	3,165,656	1,686,086	1,016,317	26,328,276	1.14
Pagoda tree, Japanese	75,133	650,339	4,566,675	6,735,323	2,904,833	1,338,388	669,776	371,816	366,571	17,678,852	0.77
Elm, American	50,813	245,168	1,603,164	2,667,374	2,690,557	2,901,082	2,493,674	1,686,247	1,640,059	15,978,138	0.69
Maple, sycamore	18,039	200,931	1,508,338	3,303,906	3,893,817	3,459,035	1,622,089	573,284	278,082	14,857,522	0.65
Oak, white	13,472	187,934	520,679	1,092,918	2,411,106	3,188,898	2,990,137	2,773,344	1,516,517	14,695,004	0.64
Linden, silver	55,245	990,614	3,923,459	2,694,205	1,694,454	1,868,428	922,342	908,019	437,594	13,494,359	0.59
Maple, Norway-cr kng	73,458	912,345	4,457,269	4,190,295	1,755,186	697,519	415,494	275,694	236,732	13,013,992	0.57
Other trees	2,135,256	10,197,399	31,256,929	40,582,014	37,811,321	31,482,614	23,859,119	13,282,617	11,721,788	202,329,055	9.0
Citywide total	5,322,145	43,415,782	237,093,218	400,136,063	508,123,761	493,658,053	349,457,119	164,530,141	98,247,324	2,299,983,672	100.00

Trees add value to residential property

Chapter Three—Costs of Managing New York's Municipal Trees

The benefits that New York City's trees provide come, of course, at a cost. This chapter presents a breakdown of annual expenditures for fiscal years 2004–2005. Total annual tree-related expenditures for New York City's street trees are currently approximately $21.8 million (Watt 2006), excluding funds spend for Asian longhorned beetle (ALB) monitoring and control (*Table 6*). For this report we examine typical costs, so ALB costs were not included.

The city spends about $37 per tree on average during the year, approximately double the 1997 mean value of $19 per tree reported for 256 California cities after adjusting for inflation (Thompson and Ahern 2000). However, non-program expenditures (e.g., sidewalk repair, litter clean-up) were not included in the California survey. New York's annual expenditure is approximately equal to that of Charleston, South Carolina ($35), and far less than Santa Monica ($53), and Berkeley, California ($65) (McPherson et al. 2006, 2005a, Maco et al. 2005, respectively).

Street tree expenditures fall into three general categories: tree planting and establishment, pruning and general tree care, and administration.

Tree Planting and Establishment

Quality nursery stock, careful planting, and follow-up care are critical to perpetuation of a healthy urban forest. All trees planted by Parks are planted by contractors. New York City has detailed tree planting guidelines which all contractors must follow. New trees are relatively large, with an acceptable caliper of 2.5–3.5 inches measured 6 inches from the ground. Stock is must be grown within a 200-mile radius of New York City and may be planted only while dormant during the season specified in the street tree planting list. Contractors planting for Parks must provide a 2-year guarantee with unlimited replacement of dead, dying or vandalized plant material within that guarantee period. The guidelines include detailed installation procedures, pruning, watering and mulching specifications, pest control requirements, and other required maintenance activities. Any private entities seeking planting permits from Parks are required to follow these same guidelines. Any tree work in violation of the specifications is subject to restitution and penalty at the direction of Parks and at the expense of the property owner (City of New York Parks & Recreation 2003).Clearly, the city is focused on providing the best start possible for new trees. Since 1995, Parks has contracted for the planting of about 8,000 trees per year, with nearly 8,500 planted in 2005. The contract planting budget for FY2006 was $8.16 million and accounted for 47.6% of the street tree expenditures reported here.

Pruning, Removals, and General Tree Care

Pruning for trees over 5 inches DBH accounts for about 11% of the annual expenditures at $1.87 million. On average, 33,100 trees are pruned each year at an average cost of $56.58/tree ($3.07/tree across entire street tree population). New trees receive pruning at planting (included in planting

Table 6—*New York City's annual municipal forestry-related expenditures*

Expenditures	Total ($)	$/tree	$/capita	% of total
Purchasing trees and planting	8,160,000	13.97	1.00	37.5
Contract pruning	1,871,000	3.20	0.23	8.6
Pest management	135,000	0.23	0.02	0.6
Removal	1,784,976	3.06	0.22	8.2
Administration	6,255,000	10.71	0.77	28.7
Infrastructure repairs	3,000,000	5.14	0.37	13.8
Other costs	568,600	0.97	0.07	2.6
Total expenditures	21,774,576	37.28	2.67	100.0

cost) to remove crossing, broken or badly bruised branches. Subsequently, pruning is conducted on a 10-year cycle with small trees (defined as greater than 5-inch DBH) pruned at the same frequency as medium and large trees.

As might be expected in a city where 60% of the trees are planted in cutouts or planting strips, establishment irrigation is necessary for the health and survival of newly planted trees. This expenditure is included in the contract planting cost and, in many cases, the contractors use water gators. Trees are watered for the first two summers after planting. Beyond this expenditure, there is no other programmed irrigation expenditure for street trees (Watt 2006).

Tree and stump removal account for 10.4% of tree-related expenses ($1.78 million). About 9,300 dead trees are removed annually. The new census tallied 8,094 standing dead trees over the course of two summer inventory periods. This represents about 1.4% of the total tree population (live trees plus standing dead). Of these, the DBH was measured for 7,030 trees (*Table 7*). Dead trees in each DBH class are proportional to the ideal tree distribution, showing greater mortality in newly planted trees with fewer dying as they mature.

Currently the city spends $84/ton in landfill fees to dump about 16,773 tons of wood waste each year for a total of $1.4 million annually. Approximately 25% of removed wood is chipped and reused thereby avoiding an additional $353,658 in landfill fees.

Pest and disease control expenditures average about $135,000 annually for Dutch elm disease (DED) control. Although the city spent an additional $2.9 million on the ALB private-tree wood-chipping program to protect municipal and private trees citywide, these expenditures were not included due to the difficulty of isolating the proportion of that expenditure that relates to municipal street trees only.

Administration

About $6.25 million or 36% of the program budget is spent on employee salaries. This figure includes supervisory, clerical and field-going personnel salaries for tree management and care.

Other Tree-Related Expenditures

In a typical year, New York spends about $558,600 for vehicle maintenance costs and an additional $10,000 for equipment associated with tree care. Annually, nearly $3 million ($4.92/tree) is spent by the city on infrastructure repair related to tree roots. The City's Department of Transportation also fixes some sidewalks damaged by tree roots as part of its regular sidewalk repair program, but these costs are not tracked separately and are therefore not included in this analysis. Considering that in New York City 60% of trees grow in cutouts or planting strips, the likelihood for root conflict with infrastructure is very high. The inventory showed that 10% of trees were associated with cracked sidewalks and an additional 17% were associated with raised sidewalks. Other cities that have trees growing predominantly in cutouts and planting strips include Berkeley and San Francisco, California. At $29 and $14/tree, respectively, their infrastructure repair expenditures far exceed New York's (Maco et al. 2005).

Table 7*—Measured dead trees as a percentage of total population*

Borough	0–3	3–6	6–12	12–18	18–24	24–30	30–36	36–42	Measured dead trees as % total trees
Brooklyn	4.03	1.47	0.84	0.46	0.21	0.13	0.24	0.33	1.04
Bronx	7.23	2.64	1.20	0.74	0.44	0.48	0.39	-	1.96
Manhattan	5.90	1.23	0.53	0.20	0.27	0.14	0.37	-	1.33
Queens	5.64	1.63	1.35	1.13	0.65	0.39	0.29	0.20	1.46
Staten Island	6.78	0.96	0.52	0.48	0.31	0.41	0.31	0.33	1.28
Citywide	5.70	1.49	0.97	0.77	0.45	0.32	0.29	0.23	1.37

Chapter Four—Benefits of New York's Municipal Trees

City trees work ceaselessly, providing ecosystem services that directly improve human health and quality of life. In this section, the benefits of New York City's municipal trees are described. It should be noted that this is not a full accounting because some benefits are intangible or difficult to quantify (e.g., impacts on psychological and physical health, crime, and violence). Also, our limited knowledge about the physical processes at work and their interactions makes these estimates imprecise (e.g., fate of air pollutants trapped by trees and then washed to the ground by rainfall). Tree growth and mortality rates are highly variable. A true and full accounting of benefits and costs must consider variability among sites throughout the city (e.g., tree species, growing conditions, maintenance practices), as well as variability in tree growth.

For these reasons, the estimates given here provide first-order approximations of tree value. Our approach is a general accounting of the benefits produced by municipal trees in New York City—an accounting with an accepted degree of uncertainty that can nonetheless provide a platform from which decisions can be made (Maco and McPherson 2003). Methods used to quantify and price these benefits are described in more detail in *Appendix D*.

Energy Savings

Trees modify climate and conserve energy in three principal ways:

- Shading reduces the amount of radiant energy absorbed and stored by built surfaces.
- Transpiration converts moisture to water vapor and thus cools the air by using solar energy that would otherwise result in heating of the air.
- Wind-speed reduction reduces the movement of outside air into interior spaces and heat loss where thermal conductivity is relatively high (e.g., glass windows) (Simpson 1998).

Trees and other vegetation in built-up areas (*Figure 6*) may lower air temperatures 5°F (3°C) compared to outside the greenspace (Chandler 1965). At the larger scale of city-wide climate (6 miles or 10 km square), temperature differences of more than 9°F (5°C) have been observed between city centers and more vegetated suburban areas (Akbari et al. 1992). The relative importance of these effects depends on the size and configuration of trees and other landscape elements (McPherson 1993). Tree spacing, crown spread, and vertical distribution of leaf area influence the transport of warm air and pollutants along streets and out of urban canyons. The New York State Energy and Regulatory Authority recently completed a study with scientists at Columbia University and the National Oceanic and Atmospheric Administration on the heat island in NYC and mitigation scenarios, in which trees are one of the most effective measures to reduce urban heat islands (Rosenzweig et al. 2006).

Trees reduce air movement into buildings and conductive heat loss from buildings. Trees can reduce wind speed and resulting air infiltration by up to 50%, translating into potential annual heating savings of 25% (Heisler 1986). Decreasing wind speed

Figure 6—Trees add value to commercial areas and mitigate heat island effects

Table 8—Net annual energy savings produced by New York City street trees

Species	Electricity (MWh)	Electricity ($)	Natural gas (therms)	Natural gas ($)	Total ($)	% of total trees	% of total $
Planetree, London	12,322	1,883,959	4,260,491	5,446,185	7,330,144	15.3	26.4
Maple, Norway	6,167	942,997	2,224,821	2,843,989	3,786,986	12.7	13.6
Pear, callery	2,314	353,880	821,053	1,049,552	1,403,431	10.9	5.1
Honeylocust	3,763	575,291	1,431,871	1,830,361	2,405,652	8.9	8.6
Oak, pin	4,626	707,369	1,475,714	1,886,405	2,593,775	7.5	9.3
Linden, little leaf	1,260	192,610	477,685	610,625	803,235	4.7	2.9
Ash, green	1,468	224,405	555,118	709,607	934,012	3.5	3.4
Maple, red	1,319	201,749	503,903	644,139	845,888	3.5	3.0
Maple, silver	2,276	348,010	809,923	1,035,324	1,383,334	3.2	5.0
Ginkgo	494	75,548	186,564	238,485	314,033	2.8	1.1
Zelkova, Japanese	1,013	154,918	394,959	504,876	659,795	2.5	2.4
Oak, northern red	1,091	166,775	378,743	484,147	650,922	1.9	2.3
Cherry, other	181	27,674	84,008	107,387	135,061	1.6	0.5
Sweetgum	557	85,228	204,406	261,292	346,520	1.4	1.3
Maple, Norway-cr kng	350	53,565	138,794	177,420	230,985	1.4	0.8
Linden, American	399	60,983	145,842	186,430	247,413	1.2	0.9
Pagoda tree, Japanese	378	57,787	147,273	188,259	246,046	1.2	0.9
Linden, silver	219	33,440	83,803	107,126	140,566	1.0	0.5
Unknown large	1,263	193,072	457,007	584,192	777,264	2.1	2.8
Other street trees	4,149	634,340	1,524,531	1,948,808	2,583,149	12.7	9.3
Citywide total	45,609	6,973,598	16,306,516	20,844,622	27,818,220	100.0	100.0

reduces heat transfer through conductive materials as well. *Appendix D* provides additional information on specific contributions that trees make toward energy savings.

Electricity and Natural Gas Results

Electricity and natural gas saved annually in New York City from both shading and climate effects equal 45,609 MWh ($6.9 million) and 16,306,516 therms ($20.8 million), respectively, for a total retail savings of $27.8 million or a citywide average of $47.63 per tree (*Table 8*). London planetrees provide 26.4% of the energy savings although they account for only 15.3% of total tree numbers, as expected for a tree species with such a high importance value (IV). Norway maple (13.6%) and pin oak (9.3%) make the next greatest contributions to overall energy savings. On a per tree basis, London planetrees again are the greatest contributors, reducing energy needs by approximately $82 per tree annually. Silver maple and pin oak provide the next greatest savings on a per tree basis ($74 and $55).

It should be noted again that this analysis describes the urban forest as it exists at the time of the inventory. This explains why the energy benefits of the London planetree on a per tree basis ($81.97) are so much greater than other large-growing trees, for instance, the green ash (*Fraxinus pennsylvanica*, $45.42) or Japanese zelkova ($45.36). Over one-third of New York City's planetrees are old and large (37% greater than 24 inches DBH), while the green ash and zelkova still have 66 and 84% of their populations under 12 inches DBH, respectively. As these younger species age and increase in size, the benefits that they provide will increase accordingly.

Atmospheric Carbon Dioxide Reduction

Urban forests can reduce atmospheric carbon dioxide (CO_2) in two ways:

- Trees directly sequester CO_2 as woody and foliar biomass as they grow.
- Trees near buildings can reduce the demand for

heating and air conditioning, thereby reducing emissions associated with electric power production and consumption of natural gas.

At the same time, however, CO_2 is released by vehicles, chain saws, chippers, and other equipment during the process of planting and maintaining trees. Also, eventually all trees die and most of the CO_2 that has accumulated in their woody biomass is released into the atmosphere as they decompose unless the wood is recycled. These factors must be taken into consideration when calculating the CO_2 benefits of trees.

Avoided and Sequestered Carbon Dioxide

Citywide, New York City's municipal forest reduces atmospheric CO_2 by a net of 113,016 tons annually (*Table 9*). This benefit was valued at $754,947 or $1.29 per tree. Avoided CO_2 emissions from power plants due to cooling energy savings totaled 68,687 tons, while CO_2 sequestered by trees was 56,060 tons. CO_2 released through decomposition and tree care activities totaled 11,730 tons, or 9.4% of the net total benefit.

On a per tree basis, pin oak ($2.12), London planetree ($2.20), Norway and silver maple ($1.71 each) provide the greatest CO_2 benefits (Table 8). Because of their age and size, London planetrees provide the greatest total CO_2 benefits, accounting for nearly 24% of citywide CO_2 reduction.

Air Quality Improvement

Urban trees improve air quality in five main ways:

- Absorbing gaseous pollutants (ozone [O_3], nitrogen dioxide [NO_2]) through leaf surfaces
- Intercepting particulate matter (e.g., dust, ash, dirt, pollen, smoke)
- Reducing emissions from power generation by reducing energy consumption
- Releasing oxygen through photosynthesis
- Transpiring water and shading surfaces, resulting in lower local air temperatures, thereby reducing O_3 levels

***Table 9**—CO_2 reductions, releases, and net benefits produced by street trees*

Species	Sequestered (lb)	Decomp. release (lb)	Maint. release (lb)	Avoided (lb)	Net total (lb)	Total ($)	% of total trees	% of total $	Avg. $/tree
Planetree, London	23,537,256	-6,191,313	-252,672	37,112,192	54,205,464	181,046	15.31	24.0	2.02
Maple, Norway	23,076,136	-3,698,341	-143,039	18,576,132	37,810,888	126,288	12.68	16.7	1.71
Pear, callery	8,207,886	-592,460	-12,358	6,971,090	14,574,158	48,678	10.85	6.4	0.77
Honeylocust	5,738,997	-756,164	-62,716	11,332,693	16,252,811	54,284	8.91	7.2	1.04
Oak, pin	17,617,692	-3,637,793	-98,950	13,934,500	27,815,448	92,904	7.50	12.3	2.12
Linden, little leaf	2,863,473	-481,956	-36,748	3,794,227	6,138,996	20,504	4.70	2.7	0.75
Ash, green	2,068,648	-353,785	-30,062	4,420,556	6,105,357	20,392	3.52	2.7	0.99
Maple, red	2,089,045	-481,749	-31,236	3,974,257	5,550,316	18,538	3.45	2.5	0.92
Maple, silver	4,886,695	-2,155,731	-51,285	6,855,466	9,535,144	31,847	3.18	4.2	1.71
Ginkgo	1,121,907	-177,050	-19,474	1,488,218	2,413,601	8,061	2.77	1.1	0.50
Zelkova, Japanese	1,266,640	-121,636	-15,281	3,051,745	4,181,468	13,966	2.49	1.9	0.96
Oak, northern red	2,988,450	-871,197	-22,618	3,285,301	5,379,937	17,969	1.90	2.4	1.62
Cherry, other	637,320	-96,556	-7,689	545,157	1,078,232	3,601	1.64	0.5	0.38
Sweetgum	552,229	-143,923	-13,384	1,678,904	2,073,826	6,927	1.43	0.9	0.83
Maple, Norway-cr kng	1,127,611	-144,540	-9,422	1,055,188	2,028,836	6,776	1.39	0.9	0.84
Linden, American	997,232	-187,294	-10,711	1,201,300	2,000,527	6,682	1.23	0.9	0.93
Pagoda tree, Japanese	626,913	-101,401	-8,960	1,138,346	1,654,898	5,527	1.20	0.7	0.79
Linden, silver	620,247	-79,946	-6,642	658,735	1,192,394	3,983	1.02	0.5	0.67
Unknown large	1,758,247	-321,390	-20,420	3,803,325	5,219,762	17,434	2.11	2.3	1.42
Other street trees	10,336,987	-1,917,328	-95,681	12,495,888	20,819,866	69,538	12.72	9.2	0.94
Citywide total	112,119,608	-22,511,552	-949,349	137,373,216	226,031,920	754,947	100.00	100.0	1.29

In the absence of the cooling effects of trees, higher temperatures contribute to O_3 formation. Additionally, short-term increases in O_3 concentrations have been statistically associated with increased tree mortality for 95 large U.S. cities (Bell et al. 2004). On the other hand, most trees emit various biogenic volatile organic compounds (BVOCs) such as isoprenes and monoterpenes that can also contribute to O_3 formation. The ozone-forming potential of different tree species varies considerably (Benjamin and Winer 1998). The contribution of BVOC emissions from city trees to O_3 formation depends on complex geographic and atmospheric interactions that have not been studied in most cities.

Deposition and Interception

Each year 272 tons ($2.8 million) of NO_2, small particulate matter (PM_{10}), O_3, and SO_2 are intercepted or absorbed by trees (pollution deposition and particulate interception) in New York City (*Table 10*). The city's trees are most effective at removing O_3 and PM_{10}, with an implied annual value of $2.3 million. Again, due to their substantial leaf area, London planetrees contribute the most to pollutant uptake, removing more than 77 tons each year, accounting for 28.6% of the overall pollutant uptake. Norway maples are the next most important, accounting for an additional 13.6% of the pollutant uptake.

Avoided Pollutants

Energy savings result in reduced air pollutant emissions of NO_2, PM_{10}, volatile organic compounds (VOCs), and SO_2 (*Table 9*). Together, 313 tons of pollutants are avoided annually with an implied value of $2.7 million. In terms of amount, avoided emissions of NO_2 are greatest (193 tons, $1.8 million). London planetrees have the greatest impact on reducing energy needs: by moderating the climate they account for 84 tons of pollutants whose production is avoided in power plants each year or 27% of the overall benefit value ($724,866).

BVOC Emissions

BVOC emissions from trees must be considered. At a total of 81 tons, these emissions offset about 14% of air quality improvements and are calculated as a cost to the city of $372,962. London planetrees are fairly heavy emitters of BVOCs, accounting for more than half of the urban forest's emissions. However, it is important to note that human-caused (ambient) VOC emissions are so high in New York City that additional BVOCs from new tree plantings will have little impact on overall air quality.

Net Air Quality Improvement

Net air pollutants removed, released, and avoided are valued at $5.3 million annually. The average benefit per tree is $9.02 (1.73 lb). Trees vary dramatically in their ability to produce net air-quality benefits. Typically, large-canopied trees with large leaf surface areas that are not high emitters produce the greatest benefits. Although London planetrees are higher emitters, the large amount of leaf area associated with New York's numerous large, old planetrees population counteracts the overall effect, reducing nearly four times the pollutants (161 tons) than they produce (42 tons) for a net benefit that is 15.3% of the total overall air quality benefit or $15.28/tree. Again, Norway maple is the second highest remover of pollutants, accounting for 12.7% of the overall benefit or $10.15/tree.

Stormwater Runoff Reductions

According to federal Clean Water Act regulations, municipalities must obtain a permit for managing their stormwater discharges into water bodies. Each city's program must identify the Best Management Practices (BMPs) it will implement to reduce its pollutant discharge. Many older cities have combined sewer outflow systems, and during large rain events excess runoff can mix with raw sewage. Rainfall interception by trees can reduce the magnitude of this problem during large storms. Trees are mini-reservoirs, controlling runoff at the source. Healthy urban trees can reduce the amount of runoff and pollutant loading in receiving waters in three primary ways:

- Leaves and branch surfaces intercept and store rainfall, thereby reducing runoff volumes and delaying the onset of peak flows.

Table 10—*Pollutant deposition, avoided and BVOC emissions, and net air-quality benefits produced by predominant street tree species*

	Deposition					Avoided					BVOCemissions		Nettotal			
Species	O_3 (lb)	NO_2 (lb)	PM_{10} (lb)	SO_2 (lb)	Total ($)	NO_2 (lb)	PM_{10} (lb)	VOC (lb)	SO_2 (lb)	Total ($)	(lb)	($)	(lb)	($)	% of trees	Avg. $/tree
Planetree,London	75,607	31,781	36,435	11,612	836,819	102,909	6,642	3,914	54,063	724,866	-84,409	-194,984	238,554	1,366,701	15.3	15.28
Maple, Norway	35,394	15,301	17,378	5,808	397,660	52,451	3,394	2,009	27,066	367,849	-5,860	-13,537	152,940	751,973	12.7	10.15
Pear, callery	14,284	6,236	6,967	2,434	160,690	19,542	1,263	746	10,156	137,289	-	-	61,629	297,979	10.9	4.70
Honeylocust	20,282	8,219	9,632	3,112	221,880	32,759	2,126	1,266	16,516	228,474	-9,366	-21,634	84,546	428,720	8.9	8.24
Oak, pin	28,276	12,211	14,106	4,720	319,761	37,375	2,402	1,403	20,292	265,414	-25,177	-58,158	95,607	527,017	7.5	12.03
Linden, little leaf	6,615	2,781	3,188	1,016	73,213	10,950	710	423	5,530	76,401	-3,771	-8,711	27,441	140,903	4.7	5.13
Ash, green	7,974	3,352	3,843	1,225	88,255	12,744	827	492	6,442	88,935	-	-	36,897	177,190	3.5	8.62
Maple, red	7,314	3,159	3,649	1,221	82,709	11,506	747	445	5,792	80,219	-1,685	-3,892	32,147	159,036	3.5	7.89
Maple, silver	14,272	6,170	7,008	2,342	160,354	19,243	1,244	735	9,988	135,147	-4,717	-10,896	56,286	284,604	3.2	15.32
Ginkgo	2,467	1,037	1,189	379	27,302	4,287	278	165	2,169	29,923	-997	-2,304	10,973	54,922	2.8	3.39
Zelkova, Japanese	3,595	1,511	1,732	552	39,789	8,917	579	346	4,448	62,036	-	-	21,681	101,825	2.5	7.00
Oak, northern red	6,698	2,893	3,341	1,118	75,746	9,126	589	347	4,786	64,254	-5,857	-13,530	23,042	126,470	1.9	11.42
Cherry, other	1,007	435	494	165	11,311	1,730	114	69	795	11,815	-7	-16	4,803	23,109	1.6	2.41
Sweetgum	2,879	1,167	1,367	442	31,500	4,774	309	183	2,446	33,427	-8,262	-19,086	5,306	45,842	1.4	5.48
Maple, Norway-cr kng	1,949	843	957	320	21,896	3,106	202	121	1,538	21,571	-284	-656	8,751	42,811	1.4	5.28
Linden, American	2,182	917	1,052	335	24,152	3,412	221	131	1,750	23,895	-651	-1,504	9,350	46,544	1.2	6.47
Pagoda tree, Japanese	1,984	857	990	331	22,432	3,326	216	129	1,659	23,137	-430	-993	9,061	44,577	1.2	6.34
Linden, silver	1,162	488	560	178	12,859	1,910	124	74	960	13,312	-369	-854	5,087	25,318	1.0	4.24
Unknown large	5,766	2,424	2,779	886	63,819	10,754	696	412	5,542	75,396	-	-	29,258	139,214	2.1	11.32
Other street trees	22,841	9,787	11,391	3,854	258,054	35,568	2,304	1,366	18,209	248,968	-9,613	-22,205	95,705	484,817	12.7	6.53
Citywide total	262,547	111,567	128,054	42,048	2,930,204	386,391	24,987	14,778	200,149	2,712,329	-161,455	-372,962	1,009,065	5,269,572	100.0	9.02

- Root growth and decomposition increase the capacity and rate of soil infiltration by rainfall and reduce overland flow.
- Tree canopies reduce soil erosion and surface transport by diminishing the impact of raindrops on barren surfaces.

New York's street trees intercept 890.6 million gallons of stormwater annually, or 1,525 gallons per tree on average (*Table 11*). The total value of this benefit to the city is $35.6 million, or $61 per tree.

Certain species are much better at reducing stormwater runoff than others. Leaf type and area, branching pattern and bark, as well as tree size and shape all affect the amount of precipitation trees can intercept and hold to reduce runoff. Trees that perform well include silver maple ($117.94 per tree), London planetree ($115.00 per tree), and pin oak ($90.77 per tree). Interception by London planetree alone accounts for 29% of the total dollar benefit from street trees. Norway maples account for an additional 13% of the benefit. Comparatively poor performers are species with relatively small leaf and stem surface areas, such as cherry and ginkgo. While it is doubtful that performance will improve for cherry and ginkgo due to mature size or growth habits in the Northeast, it is expected that the stormwater benefit value of the linden will increase as its relatively young population ages and grows.

Aesthetic, Property Value, Social, Economic and Other Benefits

Many benefits attributed to urban trees are difficult to translate into economic terms. Wildlife habitat, beautification, improved human health, privacy, shade that increases human comfort, sense of place, and well-being are difficult to price. However, the value of some of these benefits may be captured in the property values of the land on which trees stand. To estimate the value of these "other" intangible benefits, research that compares differences in sales prices of houses was used to estimate the contribution associated with trees. The difference in sales price reflects the willingness of

Table 11*—Annual stormwater reduction benefits of New York City's public trees by species*

Species	Rainfall interception (gal)	Total ($)	% of trees	% of total $	Avg. $/tree
Planetree, London	257,070,928	10,283,550	15.3	28.9	115.00
Maple, Norway	114,411,880	4,576,794	12.7	12.9	61.81
Pear, callery	47,177,660	1,887,238	10.9	5.3	29.78
Honeylocust	63,644,920	2,545,974	8.9	7.2	48.94
Oak, pin	99,399,768	3,976,267	7.5	11.2	90.77
Linden, little leaf	22,555,098	902,267	4.7	2.5	32.87
Ash, green	27,031,498	1,081,335	3.5	3.0	52.59
Maple, red	26,490,984	1,059,713	3.5	3.0	52.57
Maple, silver	54,768,640	2,190,898	3.2	6.2	117.94
Ginkgo	8,146,074	325,866	2.8	0.9	20.14
Zelkova, Japanese	12,086,616	483,498	2.5	1.4	33.24
Oak, northern red	22,605,374	904,278	1.9	2.5	81.65
Cherry, other	2,744,724	109,797	1.6	0.3	11.47
Sweetgum	9,561,547	382,488	1.4	1.1	45.72
Maple, Norway-cr kng	5,889,959	235,615	1.4	0.7	29.06
Linden, American	7,459,384	298,396	1.2	0.8	41.48
Pagoda tree, Japanese	6,944,941	277,817	1.2	0.8	39.52
Linden, silver	4,093,626	163,756	1.0	0.5	27.41
Unknown large	20,223,930	809,013	2.1	2.3	65.79
Other street trees	78,335,952	3,133,656	12.7	8.8	42.20
Citywide total	890,643,392	35,628,220	100.0	100.0	61.00

buyers to pay for the benefits and costs associated with trees. This approach has the virtue of capturing what buyers perceive as both the benefits and costs of trees in the sales price. One limitation of using this approach is the difficulty associated with extrapolating results from front-yard trees on residential properties to trees in other locations (e.g., commercial vs. residential) (see *Appendix D* for more details).

The calculation of annual aesthetic and other benefits is tied to a tree's annual increase in leaf area. When a tree is actively growing, leaf area increases rapidly. At maturity, there may be no net increase in leaf area from year to year, thus there is little or no incremental annual aesthetic benefit for that year, although the cumulative benefit over the course of the entire life of the tree may be large. Since this report represents a 1-year snapshot of the street tree population, benefits reflect the increase in leaf area for each tree over the course of one year. As a result, a very young population of 100 callery pears will have a greater *annual* aesthetic benefit than an equal number of mature planetrees. However, the cumulative aesthetic value of the planetrees would be much greater than that of the pear.

The estimated total annual benefit associated with property value increases and other less tangible benefits is $52.5 million, or $90 per tree on average (*Table 12*). Tree species that produced the highest average annual benefits for the 2005–2006 period include honeylocust ($116 per tree), callery pear ($120 per tree), pin oak ($110), and zelkova ($105). These species have a large number of relatively young trees that are still actively growing and putting on leaf area. Conversely, trees like ginkgo ($38) and cherry ($18), that are either slower growing or generally much smaller at maturity, have less annual increase in leaf area and produced fewer annual benefits in New York City.

Total Annual Net Benefits and Benefit-Cost Ratio (BCR)

Total annual benefits produced by New York City's street trees are estimated at $121.9 million ($209

Table 12*—Total annual increases in property value produced by street trees*

Species	Total ($)	% of trees	% of total $	Avg. $/tree
Pear, callery	7,618,479	10.9	14.5	120.21
Honeylocust	6,044,766	8.9	11.5	116.19
Oak, pin	4,806,207	7.5	9.2	109.72
Zelkova, Japanese	1,526,614	2.5	2.9	104.95
Maple, Norway	7,344,264	12.7	14.0	99.18
Planetree, London	8,280,614	15.3	15.8	92.60
Ash, green	1,570,527	3.5	3.0	76.38
Maple, red	1,495,424	3.5	2.8	74.19
Pagoda tree, Japanese	517,803	1.2	1.0	73.67
Linden, American	529,945	1.2	1.0	73.66
Linden, silver	435,720	1.0	0.8	72.94
Maple, silver	1,345,366	3.2	2.6	72.42
Oak, northern red	787,855	1.9	1.5	71.14
Sweetgum	512,122	1.4	1.0	61.21
Linden, little leaf	1,656,059	4.7	3.2	60.33
Maple, Norway-cr kng	444,361	1.4	0.9	54.80
Ginkgo	630,918	2.8	1.2	38.98
Cherry, other	175,702	1.6	0.3	18.35
Unknown large	1,498,764	2.1	2.9	121.88
Other street trees	5,270,880	12.7	10.0	70.98
Citywide total	52,492,380	100.0	100.0	89.88

per tree, $14.93 per capita) (*Table 13*). Over the same period, tree-related expenditures are estimated to be $21.8 million ($37 per tree, $2.67 per capita). Net annual benefits (benefits minus costs) are $100.2 million or $171.55 per tree and $12.27 per capita. New York City street trees currently return $5.60 to the community for every $1 spent on management. The city's benefit-cost ratio of 5.6 exceeds that of every other city studied to date including Fort Collins, Colorado (2.18), Glendale, Arizona (2.41), and Charlotte, North Carolina (3.25) (McPherson et al. 2003, 2005a–d).

The city's municipal trees have beneficial effects on the environment. Over half (57%) of the annual benefits provided to residents of the city are environmental services. Stormwater runoff reduction accounts for 51% of environmental benefits, with energy savings accounting for another 40%. Air quality improvement (8%) and CO_2 reduction (1%) provide the remaining environmental benefits. Annual increases in property value are very valuable, accounting for 43% of total annual benefits.

Table 14 shows the distribution of total annual benefits in dollars for the predominant municipal tree species. London planetrees are most valuable to the city overall (22.5% of total benefits, $307 per tree). On a per tree basis, silver maple ($282 per tree) and pin oak ($274 per tree) produce significant benefits. The small-stature cherry produces the least benefit at $47/tree. It should be noted once again that this analysis provides benefits for a snapshot in time. Benefits are large, overall, for all predominant species, but a significant portion of green ash, zelkova, honeylocust and other large-stature tree populations are still immature. As they grow they will provide more benefits than they currently provide.

This is not to argue that large trees are always the best option. Numerous considerations drive species choice, including planting site, potential conflicts with infrastructure, maintenance concerns, water use, and design considerations. In some cases, small or medium-sized trees are the best or only option. Nonetheless, the results of this analysis emphasize that large trees should be planted and replaced wherever possible to increase the benefits to the citizens of New York City.

Figure 7 illustrates the average annual benefits per tree by borough and reflects differences in tree types and relative ages. The trees of Queens and Brooklyn provide the highest benefits on average

***Table 13**—Benefit–cost summary for all public trees*

Benefits	Total ($)	$/tree	$/capita
Energy	27,818,220	47.63	3.41
CO_2	754,947	1.29	0.09
Air quality	5,269,572	9.02	0.65
Stormwater	35,628,224	61.00	4.36
Aesthetic/other	52,492,384	89.88	6.43
Total benefits	121,963,347	208.83	14.93
Costs			
Planting	8,160,000	13.97	1.00
Contract pruning	1,871,000	3.20	0.23
Pest management	135,000	0.23	0.02
Removal	1,784,976	3.06	0.22
Administration	6,255,000	10.71	0.77
Infrastructure repairs	3,000,000	5.14	0.37
Other costs	568,600	0.97	0.07
Total costs	21,774,576	37.28	2.67
Net benefits	100,188,771	171.55	12.27
Benefit-cost ratio		5.60	

Table 14—Average annual benefits ($ per tree) of street trees by species

Species	Energy	CO_2	Air quality	Stormwater	Aesthetic/other	$/tree	Total $	% of total $
Planetree, London	81.97	2.02	15.28	115.00	92.60	306.87	27,442,058	22.50
Maple, Norway	51.14	1.71	10.15	61.81	99.18	223.99	16,586,303	13.60
Pear, callery	22.15	0.77	4.70	29.78	120.21	177.61	11,255,804	9.23
Honeylocust	46.24	1.04	8.24	48.94	116.19	220.65	11,479,396	9.41
Oak, pin	59.21	2.12	12.03	90.77	109.72	273.86	11,996,168	9.84
Linden, little leaf	29.26	0.75	5.13	32.87	60.33	128.35	3,522,967	2.89
Ash, green	45.42	0.99	8.62	52.59	76.38	183.99	3,783,456	3.10
Maple, red	41.96	0.92	7.89	52.57	74.19	177.53	3,578,600	2.93
Maple, silver	74.47	1.71	15.32	117.94	72.42	281.87	5,236,050	4.29
Ginkgo	19.40	0.50	3.39	20.14	38.98	82.41	1,333,799	1.09
Zelkova, Japanese	45.36	0.96	7.00	33.24	104.95	191.51	2,785,698	2.28
Oak, northern red	58.77	1.62	11.42	81.65	71.14	224.60	2,487,494	2.04
Cherry, other	14.11	0.38	2.41	11.47	18.35	46.71	447,270	0.37
Sweetgum	41.42	0.83	5.48	45.72	61.21	154.66	1,293,898	1.06
Maple, Norway-cr kng	28.49	0.84	5.28	29.06	54.80	118.45	960,549	0.79
Linden, American	34.39	0.93	6.47	41.48	73.66	156.93	1,128,980	0.93
Pagoda tree, Japanese	35.00	0.79	6.34	39.52	73.67	155.32	1,091,771	0.90
Linden, silver	23.53	0.67	4.24	27.41	72.94	128.78	769,343	0.63
Unknown large	63.21	1.42	11.32	65.79	121.88	263.62	3,241,689	2.66
Other street trees	34.78	0.94	6.53	42.20	70.98	155.42	11,542,040	9.46

each year ($223 and $220, respectively), which can attributed to the predominant species (see *Table 2*); large-stature, mature London planetree and Norway maple compose about one-third or more of their overall population (*Figure 6*). In contrast, Staten Island and Manhattan street trees provide from 22 to 34% ($183 and $167, respectively) fewer benefits than trees in Queens. In Manhattan, 69% of the tree population is large at maturity and 27% are medium. Currently, however, one-third of all Manhattan street trees are under 6-inch DBH and nearly three-quarters are under 12 inches. This suggests that Manhattan's flow of benefits will increase as long as large and medium-sized trees survive some of the most challenging growing conditions within the city (e.g., tree crowns are not significantly reduced from natural forms in order to grow adjacent to buildings and other infrastructure elements). In all boroughs with the exception of Staten Island, species that will be large at maturity exceed the number of small- to medium-stature trees in the 0- to 6-inch size class, indicating a distinct effort to plant species that will produce more benefits.

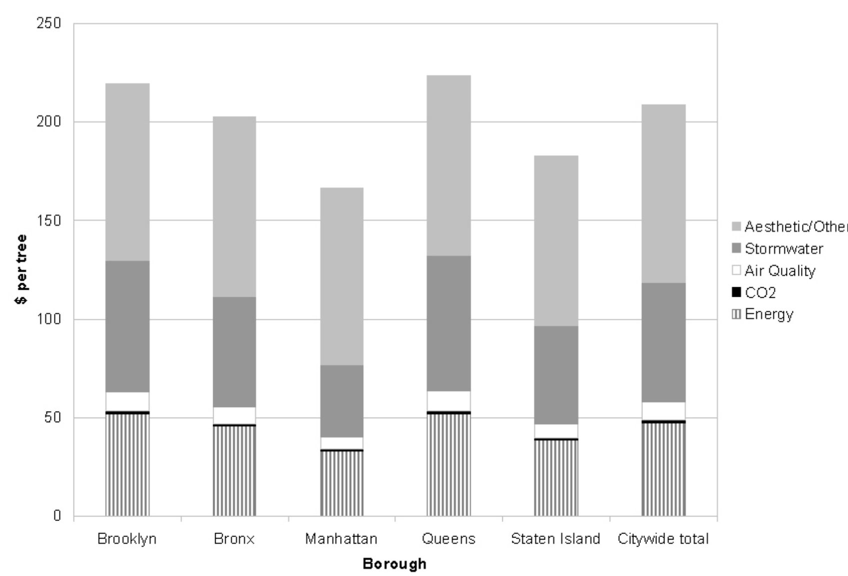

Figure 7—Average annual street tree benefits per tree by borough

Residents and visitors alike enjoy the environmental and aesthetic benefits of New York City's municipal trees.

Chapter Five—Management Implications

New York City's urban forest reflects the values, lifestyles, preferences, and aspirations of current and past residents. It is a dynamic legacy whose character will continue to change greatly over the next decades. Although this study provides a "snapshot" in time of the resource, it also serves as an opportunity to speculate about the future. Given the status of the city's street tree population, what future trends are likely and what management challenges will need to be met to sustain or increase this level of benefits?

Focusing on three components—resource complexity, resource extent, and maintenance—will help refine broader municipal tree management goals. Achieving resource sustainability will produce long-term net benefits to the community while reducing the associated costs incurred in managing the resource.

Resource Complexity

The New York City Department of Parks & Recreation is to be commended for its commitment to increasing the planting and diversity of the urban forest. The number of species (168) is remarkable, considering many site conditions throughout the city are not conducive to successful plant establishment. It is evident that there has been an intensive effort to both diversify and improve the age structure of the public right of way trees. Because of the potential for catastrophic losses due to disease or pests, the continued dominance of two species—Norway maple and London planetree—will remain a management concern as long as each species represents significantly more than 10% of the street tree population. Indeed, the concern over predominance is deepened by the ALB infestation, which puts maple, as a preferred host, especially at risk but which also jeopardizes London planetrees, ash, elm, birch, willow, and horsechestnut trees. In all, 44% of the municipal tree population is at risk to the ALB.

Park's aggressive approach to monitoring and removing infested trees demonstrates a clear understanding of the threat to the urban forest and the tremendous benefits it provides. Norway maples alone (including the Crimson King cultivar) provide the community with annual benefits of $17.5 million. These maples constitute 14.4% of the entire street tree population, provide 13.9% of the public right of way canopy cover, and are second only to London planetree in overall importance value to New York City. Additionally, there are four other maples among the city's predominant species and, together, the maple genus constitutes 22% of the total street tree canopy cover and benefit value.

Figure 8 displays large- and medium-growing species in the smallest DBH size classes. These represent the predominant species present in the city in this size class. As previously discussed, callery pears dominate, with honeylocust coming in second as the most prevalent species. Maples represent nearly 10% of the 0- to 6-inch DBH class, for a total of 14,125 trees. The presence of ALB precludes the planting of maples and other host material in infested areas of Brooklyn, Queens, and Manhattan. Recent plantings of these species have been significantly reduced compared to the past. Currently no Norway maples are being planted. Among other ALB host species is green ash, which is also susceptible to the emerald ash borer currently infesting ash in other parts of the country. It is vital that federal, state and city efforts continue the extensive education, monitoring and eradication programs currently in place to protect the flow of benefits that these street trees currently provide and are poised to provide well into the future.

Particular attention should be paid to further diversification in all boroughs. Large-growing species that were predominant in the first half of the 20th century (planetrees and Norway maples) should not be supplanted by smaller-growing species like callery pear and honeylocust. In Manhattan, Staten Island, and the Bronx, one or both of these species now represent over 10% of the boroughs' populations. On Staten Island, callery pear is currently present at more than double the ideal species ratio.

This may result in a decrease in the flow of benefits for this borough because pears are neither large-stature nor long-lived in comparison to old, established Staten Island plantings.

Callery pear and honeylocust together represent 42% of all trees in the 0- to 6-inch size class. Parks should continue ongoing efforts to find, plant, and nurture additional species in this borough. Similarly, the current efforts to diversify in the other boroughs in order to reduce overall representation of maples and planetrees should continue.

Large-stature species recommended for future planting include lindens (basswood, silver, littleleaf and others), oaks (Northern red, pin, shingle, willow), and hardy rubber tree (*Eucommia ulmoides*). Continued experimentation and testing of new species and cultivars is also recommended, including disease resistant cultivars of American elm in those boroughs not under ALB quarantine.

Resource Extent

Canopy cover, or more precisely the amount and distribution of leaf surface area, is the driving force behind the urban forest's ability to produce benefits for the community. As the number of trees, and therefore canopy cover increases, so do the benefits afforded by leaf area. Maximizing the return on investment is contingent upon maximizing and maintaining the quality and extent of New York City's canopy cover.

The importance of tree size in achieving high levels of benefits cannot be forgotten. Remarkably, for a city as densely built and populated as New York, only about 5% of the street tree population is small stature at maturity. Large and medium stature trees account for 73% and 22%, respectively, of the population citywide. Nearly one-third of the large-stature trees are still relatively young, measuring less than 12-inch DBH. If overall tree numbers do not decrease due to catastrophic losses, the future flow of benefits may well surpass those presented in this report. This increase would be due to the predominance of large-stature species. Accordingly, a significant reduction in large-stature species through replacement with medium- or small-stature trees would likely decrease the amount of overall benefit.

The greater concern at this time, however, is that at current planting levels, the city is on a course to suffer a net loss in tree numbers and canopy cover

Figure 8—Municipal trees being planted in the highest numbers.

each year, resulting in benefits forgone in the future. Parks currently plants an average of 8,000 new trees annually. Annual tree removals average about 9,300. Nearly 1,300 fewer trees are being planted than removed. Added to this is the tree loss due to mortality. Given current mortality rates, only 41% of the 8,000 newly-planted trees will live to 40 years (2.7% die annually for the first five years and 1.3% every year thereafter), leaving only 3,280 of the original 8,000. To maintain the flow of benefits the city currently enjoys, many more trees must be planted and young tree mortality rates reduced. It is recommended that new trees continue being planted to meet, at the very least, the recommended ideal levels.

Any tree "lost" reduces the flow of benefits the city currently enjoys. Conversely, any tree added to a city adds benefits in terms of air quality improvement, climate moderation, reductions in energy use, stormwater management and aesthetic improvement—benefits that have been described in detail above. Planting trees along streets and in parking lots, however, offers additional benefits beyond those that come from planting trees in parks. Most importantly, trees located along streets and in parking lots are more likely to shade structures. By moderating the immediate climate around a building, energy use is reduced, lowering costs for building owners and simultaneously reducing air pollutants and CO_2.

Trees along streets have also been shown to reduce the wear on asphalt by lowering surface temperatures and thereby reducing maintenance costs (McPherson and Muchnick 2005). A study comparing several blocks in Modesto, California, demonstrated that streets shaded by large trees required fewer than half the number of slurry seals (2.5 vs. 6 on an unshaded street) over a 30-year period, with associated savings of $0.66/ft^2. In areas with on-street parking, trees can have an additional benefit of reducing pollutant emissions from parked cars by lowering local air temperature (Scott et al. 1999). Evaporative emissions from non-operating vehicles account for 16% of total vehicular emissions; lowering the air temperature by increasing shade cover in Sacramento parking lots to 50% from 8% was estimated to reduce overall emissions by 2% (0.85 tons per day). Although seemingly modest, many existing programs to improve air quality have similar goals.

Considering the air and water quality issues facing New York City, along with the urban heat island effect generated by the vast areas of hardscape and buildings, it is vital that the city increase its tree canopy, planting additional large-stature trees like linden, ginkgo, oak (e.g., shingle, pin, red), scholar tree (*Styphnolobium japonicum*) and zelkova. Many additional areas exist where public rights of way can be planted to increase tree cover, thereby increasing benefits to New York City neighborhoods and the region at large (Grove et al. 2006). The 2005–2006 census tallied potential planting spaces, for example, those occupied by dead trees, stumps, or empty pits (*Table 15*). If these spaces were planted, the citywide street tree population would increase over 5%, increasing total tree numbers in Bronx and Queens by the greatest percentages (8.0 and 5.9%, respectively).

Maintenance

New York City's maintenance challenges in the coming years will be to balance establishing and

Table 15—*Potential planting sites*

Zone	No. of sites w/ stumps	No. of empty pits	Total unplanted sites	Total planted sites	% increase if all planted
Brooklyn	1,720	5,942	7,662	141,257	5.15
Bronx	1,348	3,782	5,130	58,830	8.02
Manhattan	584	1,190	1,774	49,195	3.48
Queens	4,059	10,763	14,822	236,391	5.90
Staten Island	807	1,331	2,138	98,363	2.13
Citywide total	8,518	23,008	31,526	584,036	5.12

caring properly for the planting of many new trees while maintaining and eventually removing the old or diseased London planetrees and Norway maples as they continue to decline. The future of the planetrees and Norway maples, which provide an enormous share of the benefits of the urban forest, should continue to receive special care and attention. A replacement plan, particularly for those boroughs where these species predominate, should be established so that species that will provide similar benefits over long lifetimes replace these trees. Wherever possible, new replacements should be planted in anticipation of removals.

The overall cost of the ALB quarantine program is not addressed in this report, but with Norway maples providing $16.6 million in benefits annually, it is clearly a cost that should be borne over the next years to protect the remaining maples and other host species.

Currently, the average expenditure per tree is relatively low compared to the benefits they provide the city, but the level of maintenance is also lower than in many U.S. cities, particularly for young trees during the first 5 years of establishment when it is estimated that 13.5% of all newly planted trees in New York City are lost (Maco et al. 2005; McPherson et al. 2005d, 2006).

Funding should be allocated to reduce the inspection and pruning cycle from the current 10-year cycle for young trees on a species basis. This may well assist in decreasing the overall mortality rate for street trees. A stronger young-tree care program is imperative to insure, first, that the trees survive after the planting contract period is over, and second, that they transition into well-structured, healthy mature trees requiring minimal pruning. Investing in extending the young-tree care program will reduce costs for routine maintenance as trees mature and reduce removal and replacement costs for dead trees. Funding for continued irrigation as required, inspection and pruning of young trees after the first 2 years (contract period) should be a priority.

Of key importance is the recognition that reducing young tree mortality and increasing canopy cover throughout New York City entails improving growing conditions for trees and improving tree selection.

Tree establishment and longevity in New York poses a unique set of problems because the majority of street trees grow in sidewalk cutouts and planting strips in soils that have been impacted and compacted by construction for many years. Resolving establishment and mortality issues requires a toolbox full of options that foresters are allowed to apply when assessing sites for new and replacement planting. For existing trees, this may include recommending one or more of the following infrastructure changes to increase planting space:

- Curving walks around trees
- Creating tree islands
- Ramping or bridging over tree roots
- Lowering sites and installing grates
- Using alternatives to concrete (e.g., rubber paving, asphalt, pavers)

Alternatively, recommendations may be soil-based, increasing soil volume by creating root paths or channeling, or installing structural soils. These are only a few of the "tools" that should be available to the city's foresters. Many of the same strategies should be applied as needed for new planting or for replacement planting after trees have been removed.

Chapter Six—Conclusion

This analysis describes structural characteristics of the municipal street tree population and uses tree growth and geographic data for New York City to model the ecosystem services trees provide the city and its residents. In addition, the benefit–cost ratio has been calculated and management needs identified. The approach is based on established tree sampling, numerical modeling, and statistical methods and provides a general accounting of the benefits produced by municipal trees in New York that can be used to make informed decisions.

The city's 592,130 street trees are a valuable asset, providing approximately $121.9 million ($209 per tree) in annual gross benefits. Benefits to the community are most pronounced for stormwater retention, energy savings, and aesthetic and other benefits. Thus, municipal trees play a particularly important role in maintaining the environmental and aesthetic qualities of the city. New York City currently spends approximately $21.8 million per year maintaining its inventoried street trees or $37 per tree.

After costs are taken into account, the city's street tree resource provides approximately $100.2 million, or $171 per tree ($12.79 per capita), in net benefits annually to the community. Over the years, New York has invested millions of dollars in its municipal forest. **Citizens are seeing a return on that investment—receiving $5.60 in benefits for every $1 spent on tree care**. The fact that New York's benefit-cost ratio exceeds 1.0 indicates that the program is not only operationally efficient, but is capitalizing on the services its trees can produce.

The benefit-cost ratio in this city is greater than in any other city studied to date. This is due to a combination of factors, particularly the presence of many large, old trees as well as the higher value placed on the services trees provide. The cost of living is 72% higher than the average cost of living across the United States. Utility costs are about 63% higher and median home prices are over double the average (Sperling 2006). It follows that environmental and aesthetic benefits trees provide (e.g., energy savings associated with tree shade and property value increase due to trees) are worth more compared to other cities. Additionally, expenditures for street trees are relatively low, considering the challenges faced by foresters to nurture and maintain these trees.

The value of New York City's municipal urban forest should increase as existing young trees mature and an adequate number of new trees are planted. As the resource grows, continued investment in management is critical to insuring that residents will continue receiving a high return on investment in the future. New York City's municipal trees are a dynamic resource. It is not enough to simply plant more trees to increase canopy cover and benefits; planning and funding for care and management must also be achieved to insure the success of new plantings. Existing trees must also be protected because the greatest benefits will accrue from the continued growth of existing canopy.

Managers of the urban forest and the community alike can take pride in knowing that street trees do improve the quality of life in the city. However, the city's trees are a fragile resource needing constant care to maximize and sustain production of benefits into the future. The challenge will be to increase the city's canopy cover to further mitigate heat island effects, air quality, energy consumption and stormwater runoff, while sustaining the flow of benefits the current forest provides.

Management recommendations derived from this analysis are as follows:

1. Plant more large-stature species where conditions are suitable to maximize benefits.

2. Develop a strong young-tree care program that emphasizes reducing mortality. Inspection and pruning on a two- to three-year cycle will provide a good foundation for the new trees being planted.

3. Use findings from the mortality study currently underway to assist in determining how best to prepare sites for new plantings. Track the success of the newly planted trees to determine those most adaptable to difficult conditions.

4. Sustain benefits by investing in intensive maintenance of mature trees to prolong the life spans of these heritage trees. Develop a replacement plan for the London planetrees and Norway maples to replace them with trees of similar stature gradually before they must be removed.

5. Use the existing canopy cover study of the city to identify and prioritize available planting space for small, medium, and large tree future planting. Public right-of-way lands (e.g., streets, parking lots, schools, parks) may provide good opportunities for maximizing air quality, energy savings, and aesthetic benefits.

6. Study the economic and environmental tradeoffs between planting new trees and the ability to maintain all trees at levels necessary to reduce mortality levels and sustain health and benefits.

7. Continue diversification to reduce dependence on species like London planetree and Norway maple to guard against catastrophic losses due to storms, pests or disease while concentrating the species choice on those that have proven most successful. Include large-stature species like linden (silver, littleleaf, basswood, Crimean), zelkova, and oaks (pin, willow, red, and others).

These recommendations build on a history of dedicated management and commitment to natural resource preservation that put the city of New York on course to provide an urban forest resource that continues to be both functional and sustainable.

Appendix A—Tree Distribution

***Table A1**—Tree numbers by size class (DBH in inches) for all street and park trees*

Species	0–3	3–6	6–12	12–18	18–24	24–30	30–36	36–42	>42	Total
Broadleaf deciduous large (BDL)										
Platanus acerifolia	355	1,911	7,862	19,650	26,415	19,208	9,747	3,079	1,198	89,425
Acer platanoides	985	4,761	22,102	24,935	14,600	4,746	1,210	370	341	74,050
Gleditsia triacanthos	3,227	11,487	25,835	9,240	1,515	343	180	96	103	52,026
Quercus palustris	1,861	3,626	8,150	10,144	9,710	6,317	2,741	811	444	43,804
Fraxinus pennsylvanica	528	2,847	10,130	5,221	987	422	208	122	98	20,563
Acer saccharinum	297	841	2,932	3,332	3,949	3,351	2,285	1,069	520	18,576
Ginkgo biloba	1,757	3,520	7,207	2,630	663	215	87	52	53	16,184
Zelkova serrata	1,794	4,230	6,188	1,758	379	117	45	12	23	14,546
Unknown large	-	2,330	4,939	2,463	1,294	654	360	145	112	12,297
Quercus rubra	832	1,861	2,228	1,973	1,706	1,206	710	377	182	11,075
Liquidambar styraciflua	297	1,606	3,042	1,808	901	426	178	62	46	8,366
Acer platanoides crim	504	2,317	3,605	1,288	277	66	27	14	11	8,109
Tilia americana	337	1,760	2,658	1,229	563	396	152	63	36	7,194
Tilia tomentosa	481	2,125	2,368	599	191	127	41	29	13	5,974
Ulmus americana	275	704	1,782	1,180	632	408	237	122	101	5,441
Acer saccharum	117	522	1,595	1,143	661	242	93	45	37	4,455
Robinia pseudoacacia	300	766	1,636	1,016	332	145	74	40	33	4,342
Acer pseudoplatanus	126	522	1,282	1,082	625	311	96	28	13	4,085
Quercus phellos	127	309	626	507	272	181	71	25	19	2,137
Ulmus parvifolia	219	585	633	271	135	71	38	12	9	1,973
Quercus alba	175	376	267	204	224	181	112	77	40	1,656
Celtis occidentalis	431	591	401	132	51	21	16	8	1	1,652
Taxodium distichum	142	401	591	263	75	17	15	6	8	1,518
Ailanthus altissima	118	291	426	317	157	85	43	9	13	1,459
Aesculus hippocastanum	33	29	129	264	257	178	70	18	11	989
Metasequoia glyptostroboides	176	277	235	84	35	21	4	3	2	837
Quercus robur	100	358	169	81	50	31	16	10	3	818
Quercus bicolor	231	320	126	28	25	15	11	5	2	763
Fraxinus species	97	111	293	182	22	11	7	5	10	738
Gymnocladus dioicus	162	216	161	75	32	21	15	4	6	692
Liriodendron tulipifera	60	116	81	80	77	70	59	38	11	592
Quercus species	69	107	131	97	74	38	24	15	12	567
Cercidiphyllum japonicum	128	198	114	40	42	21	11	5	5	564
Ulmus species	26	88	92	94	61	43	28	11	5	448
Poplar species	30	89	119	73	39	32	20	8	8	418
Quercus acutissima	59	156	131	31	4	3	3	-	2	389
Catalpa species	12	26	76	93	68	42	12	3	2	334
Fraxinus americana	8	91	109	60	28	19	4	1	1	321
Tilia species	28	72	87	38	13	6	4	1	3	252
Prunus serotina	15	21	68	38	23	12	2	5	-	184
Carya species	2	20	41	37	36	14	6	3	-	159
Ulmus pumila	1	17	33	27	17	21	12	5	2	135
Populus deltoides	4	3	6	12	23	12	5	4	1	70
Quercus coccinea	2	4	13	19	9	7	3	2	2	61

Species	0–3	3–6	6–12	12–18	18–24	24–30	30–36	36–42	>42	Total
Fagus grandifolia	7	4	12	10	7	2	6	-	-	48
Juglans nigra	2	5	19	8	6	1	3	1	-	45
Fagus sylvatica	5	13	10	-	2	2	3	3	3	41
Quercus imbricaria	20	17	-	1	-	-	1	-	-	39
Ulmus procera	-	2	11	8	-	4	1	3	2	31
Quercus macrocarpa	8	8	-	2	1	1	1	-	-	21
Betula nigra	2	1	10	1	2	2	1	-	-	19
Maclura pomifera	-	1	2	-	1	9	1	2	2	18
Alnus glutinosa	-	2	7	3	2	1	-	-	-	15
Populus nigra	-	3	4	5	2	-	-	-	-	14
Betula papyrifera	-	2	3	2	-	-	-	-	-	7
Quercus laurifolia	-	-	1	1	1	2	1	-	-	6
Larix species	-	-	4	-	-	-	-	1	-	5
Acer nigrum	-	1	1	1	1	-	-	-	-	4
Betula alleghaniensis	-	1	1	-	-	1	1	-	-	4
Carya glabra	-	1	2	1	-	-	-	-	-	4
Quercus stellata	-	3	-	-	-	-	-	-	-	3
Taxodium ascendens	-	1	2	-	-	-	-	-	-	3
Castanea dentata	-	1	-	-	-	1	-	-	-	2
Carya illinoinensis	-	-	1	1	-	-	-	-	-	2
Magnolia acuminata	2	-	-	-	-	-	-	-	-	2
Oxydendrum arboreum	-	-	1	1	-	-	-	-	-	2
Populus grandidentata	-	-	-	1	1	-	-	-	-	2
Quercus falcata	-	-	-	-	1	1	-	-	-	2
Carya ovata	-	-	-	1	-	-	-	-	-	1
Larix laricina	-	-	-	-	1	-	-	-	-	1
Quercus velutina	-	-	-	-	-	-	1	-	-	1
Total	16,574	52,674	120,790	93,885	67,277	39,900	19,102	6,829	3,549	420,580
Broadleaf deciduous medium (BDM)										
Pyrus calleryana	5,948	24,371	24,877	6,794	811	267	151	65	90	63,374
Tilia cordata	1,638	6,261	11,837	4,710	1,745	806	278	92	82	27,449
Acer rubrum	1,121	4,437	6,818	3,802	2,242	1,073	414	129	122	20,158
Styphnolobium japonicum	649	1,408	2,890	1,588	345	96	30	13	10	7,029
Unknown medium	2,044	2,229	-	-	-	-	-	-	-	4,273
Acer campestre	223	611	294	54	25	8	11	3	2	1,231
Morus species	65	148	327	272	181	97	54	41	26	1,211
Carpinus betulus	205	308	251	116	37	21	15	6	2	961
Betula species	110	240	370	116	60	16	6	1	2	921
Acer species	77	239	259	146	57	30	9	3	2	822
Styrax japonica	26	42	36	16	16	4	1	-	1	142
Salix species	6	14	27	14	23	12	3	6	1	106
Ulmus rubra	1	4	30	30	16	10	1	-	1	93
Sassafras albidum	3	10	12	17	16	10	3	1	-	72
Acer negundo	14	6	11	11	13	6	1	-	1	63
Carpinus caroliniana	16	25	4	4	5	1	-	-	-	55
Maackia amurensis	24	20	3	1	1	-	-	-	-	49
Paulownia tomentosa	4	7	7	12	3	6	2	2	-	43
Phellodendron amurense	4	10	9	6	-	1	-	-	-	30

Species	0–3	3–6	6–12	12–18	18–24	24–30	30–36	36–42	>42	Total
Betula pendula	4	5	13	2	1	-	-	-	1	26
Juniperus recurva	2	5	4	9	2	2	-	-	-	24
Cladrastis lutea	2	8	6	3	2	-	-	-	-	21
Aesculus x carnea	-	2	3	2	4	4	1	1	-	17
Diospyros virginiana	2	7	6	1	-	-	-	-	-	16
Nyssa sylvatica	6	2	1	1	4	2	-	-	-	16
Eucommia ulmoides	8	4	1	-	-	-	-	-	-	13
Pyrus communis	2	9	2	-	-	-	-	-	-	13
Castanea mollissima	3	3	1	4	-	-	-	-	-	11
Ostrya virginiana	4	6	-	1	-	-	-	-	-	11
Populus tremuloides	2	1	-	3	1	1	-	-	-	8
Salix babylonica	-	-	2	2	-	-	1	1	1	7
Corylus colurna	4	1	-	-	1	-	-	-	-	6
Salix matsudana	1	1	1	1	-	-	1	1	-	6
Sorbus alnifolia	-	2	2	-	-	-	-	-	-	4
Ulmus ulata	-	-	1	-	-	-	-	-	-	1
Ulmus thomasii	-	-	-	-	-	-	1	-	-	1
Total	12,218	40,446	48,105	17,738	5,611	2,473	983	365	344	128,283
Broadleaf deciduous small (BDS)										
Prunus species	2,179	4,177	2,227	632	195	90	40	15	20	9,575
Prunus cerasifera	1,377	2,441	779	101	33	18	5	2	3	4,759
Acer palmatum	411	678	911	469	199	87	40	12	17	2,824
Prunus virginiana sh	647	963	375	74	25	7	-	1	4	2,096
Cornus florida	428	575	631	261	77	33	19	3	9	2,036
Malus species	454	707	563	147	38	18	11	4	3	1,945
Acer ginnala	127	760	382	140	80	37	30	2	5	1,563
Crataegus species	254	352	212	42	21	8	3	3	1	896
Syringa reticulata	425	312	90	36	14	5	3	-	1	886
Unknown small	870	-	-	-	-	-	-	-	-	870
Koelreuteria paniculata	255	229	144	34	11	4	1	2	3	683
Cercis canadensis	192	195	133	42	33	15	4	2	3	619
Prunus serrulata kw	55	132	116	55	20	7	2	2	-	389
Amelanchier species	114	55	43	8	6	2	1	-	-	229
Malus pumila	13	23	54	16	6	2	-	1	-	115
Cornus kousa	22	36	16	3	2	-	1	2	1	83
Cornus species	24	22	18	4	-	-	1	-	-	69
Aesculus glabra	-	-	2	8	16	8	2	1	-	37
Prunus persica	7	6	7	-	-	-	-	-	-	20
Albizia julibrissin	1	5	7	4	-	-	1	-	-	18
Acer buergerianum	2	7	8	-	-	-	-	-	-	17
Cornus mas	3	8	4	-	1	-	-	-	-	16
Halesia caroliniana	8	-	1	-	-	-	-	-	-	9
Quercus laevis	1	5	1	-	1	1	-	-	-	9
Laburnum watereri	2	2	2	1	-	-	1	-	-	8
Acer tataricum	-	5	1	-	-	-	-	-	-	6
Halesia diptera	1	1	3	-	-	-	-	-	-	5
Cornus amomum	2	1	-	-	-	-	-	-	-	3
Acer griseum	-	-	2	-	-	-	-	-	-	2

Species	0–3	3–6	6–12	12–18	18–24	24–30	30–36	36–42	>42	Total
Salix discolor	-	-	1	-	-	1	-	-	-	2
Cornus alternifolia	1	-	-	-	-	-	-	-	-	1
Cotinus coggygria	-	1	-	-	-	-	-	-	-	1
Elaeagnus angustifolia	-	-	1	-	-	-	-	-	-	1
Hamamelis virginiana	-	1	-	-	-	-	-	-	-	1
Sorbus americana	-	-	1	-	-	-	-	-	-	1
Total	7,875	11,699	6,735	2,077	778	343	165	52	70	29,794
Broadleaf evergreen medium (BEM)										
Magnolia species	78	119	263	171	115	46	21	8	8	829
Magnolia grandiflora	1	3	8	6	4	2	-	-	-	24
Total	79	122	271	177	119	48	21	8	8	853
Broadleaf evergreen small (BES)										
Ilex species	32	64	78	19	3	-	2	-	-	198
Total	32	64	78	19	3	-	2	-	-	198
Conifer evergreen large (CEL)										
Pinus strobus	97	281	476	290	126	56	28	4	7	1,365
Picea species	72	148	247	110	19	6	3	-	-	605
Pinus species	161	143	122	74	16	5	-	1	-	522
Picea pungens	24	83	178	85	11	3	1	1	-	386
Picea abies	13	49	119	91	45	14	4	1	-	336
Pinus thunbergii	9	24	27	17	8	2	1	-	2	90
Pinus nigra	3	10	20	16	10	1	-	-	-	60
Pinus resinosa	2	9	29	12	1	2	-	-	-	55
Pseudotsuga menziesii	5	15	22	11	2	-	-	-	-	55
Pinus sylvestris	2	2	4	5	2	-	2	-	-	17
Pinus echinata	4	9	3	-	-	-	-	-	-	16
Pinus rigida	1	1	9	2	1	-	-	-	-	14
Pinus virginiana	-	3	3	1	-	-	-	-	-	7
Abies balsama	1	-	2	1	-	1	-	-	-	5
Abies concolor	-	-	1	1	-	-	-	-	-	2
Cedrus deodara	-	-	-	-	1	-	-	-	-	1
Chamaecyparis pisifera	-	-	-	1	-	-	-	-	-	1
Total	394	777	1,262	717	242	90	39	7	9	3,537
Conifer evergreen medium (CEM)										
Juniperus virginiana	53	87	127	50	18	8	6	-	-	349
Tsuga canadensis	8	68	91	28	11	4	-	-	1	211
Cedrus atlantica	26	39	49	21	7	1	-	-	-	143
Chamaecyparis thyoides	18	6	10	1	-	-	-	-	-	35
Thuja occidentalis	4	10	15	-	-	2	2	-	-	33
Juniperus species	-	9	5	2	1	-	-	-	-	17
Total	109	219	297	102	37	15	8	-	1	788
Conifer evergreen small (CES)										
Taxodium species	-	1	-	1	-	-	-	-	-	2
Pinus mugo	-	1	-	-	-	-	-	-	-	1
Total	-	2	-	1	-	-	-	-	-	3
Citywide total	37,281	106,003	177,538	114,716	74,067	42,869	20,320	7,261	3,981	584,036

Appendix B—Condition

Table B1 *– Condition of live street tree species represented by 500 or more trees*

Species	Poor	Good	Excellent	# of trees	% of population
Planetree, London	7.7	73.8	18.5	89,425	15.31
Maple, Norway	17.8	65.6	16.7	74,050	12.68
Pear, callery	4.3	67.0	28.7	63,374	10.85
Honeylocust	6.2	71.4	22.4	52,026	8.91
Oak, pin	5.8	67.8	26.4	43,804	7.50
Linden, little leaf	7.6	65.8	26.6	27,449	4.70
Ash, green	6.0	68.1	25.9	20,563	3.52
Maple, red	10.6	68.8	20.6	20,158	3.45
Maple, silver	8.2	70.9	20.9	18,576	3.18
Ginkgo	7.1	58.9	33.9	16,184	2.77
Zelkova, Japanese	4.3	63.8	31.9	14,546	2.49
Unknown large	11.1	61.8	27.1	12,297	2.11
Oak, northern red	6.7	63.4	29.9	11,075	1.90
Cherry, other	6.5	63.4	30.1	9,575	1.64
Sweetgum	3.9	73.1	23.0	8,366	1.43
Maple, Norway-cr kng	8.1	68.4	23.5	8,109	1.39
Linden, American	7.8	64.9	27.2	7,194	1.23
Pagoda tree, Japanese	6.7	67.7	25.6	7,029	1.20
Linden, silver	6.2	59.1	34.6	5,974	1.02
Elm, American	7.5	66.7	25.8	5,441	0.93
Plum, purpleleaf	5.4	59.6	35.0	4,759	0.81
Maple, sugar	13.8	64.8	21.3	4,455	0.76
Locust, black	6.4	63.7	29.9	4,342	0.74
Unknown medium	10.6	55.0	34.4	4,273	0.73
Maple, sycamore	13.2	65.2	21.5	4,085	0.70
Maple, Japanese	5.2	51.4	43.3	2,824	0.48
Oak, willow	4.3	59.6	36.1	2,137	0.37
Chokecherry, shubert	7.7	55.4	36.9	2,096	0.36
Dogwood, flowering	9.0	61.1	29.9	2,036	0.35
Elm, Chinese	7.1	59.4	33.6	1,973	0.34
Crabapple	10.4	66.0	23.6	1,945	0.33
Oak, white	9.6	59.8	30.6	1,656	0.28
Hackberry	8.7	65.1	26.3	1,652	0.28
Maple, amur	10.4	68.8	20.8	1,563	0.27
Baldcypress	11.7	47.7	40.6	1,518	0.26
Tree of heaven	10.0	66.1	23.9	1,459	0.25
Pine, eastern white	8.0	62.9	29.1	1,365	0.23
Maple, hedge	7.7	67.7	24.5	1,231	0.21
Mulberry	9.9	69.1	20.9	1,211	0.21
Horsechestnut	16.5	66.5	17.0	989	0.17
Hornbeam, European	6.0	61.7	32.3	961	0.16
Birch, other	8.9	62.3	28.8	921	0.16
Hawthorn, other	9.7	60.4	29.9	896	0.15

Species	Poor	Good	Excellent	# of trees	% of population
Tree lilac, Japanese	11.4	64.7	23.8	886	0.15
Unknown small	7.8	44.9	47.2	870	0.15
Redwood, dawn	10.6	54.1	35.2	837	0.14
Magnolia, other	4.6	57.5	37.9	829	0.14
Maple, other	13.1	70.6	16.2	822	0.14
Oak, English	8.3	59.0	32.6	818	0.14
Oak, swamp white	11.1	59.0	29.9	763	0.13
Ash, other	7.3	84.7	8.0	738	0.13
Coffeetree, Kentucky	7.9	66.9	25.1	692	0.12
Goldenrain tree	6.7	66.6	26.6	683	0.12
Redbud, eastern	14.5	63.0	22.5	619	0.11
Spruce, other	5.5	56.4	38.2	605	0.10
Tulip tree	4.7	63.5	31.8	592	0.10
Oak, other	6.0	77.8	16.2	567	0.10
Katsura tree	14.2	54.4	31.4	564	0.10
Pine, other	6.7	46.2	47.1	522	0.09

Appendix C—Replacement Values

Table C1 *– Replacement value of New York City's street trees*

Species	0–3	3–6	6–12	12–18	18–24	24–30	30–36	36–42	>42	Total	% of total
Planetree, London	37,834	809,995	11,806,541	81,096,224	214,718,704	258,999,200	194,958,720	81,403,560	34,214,860	878,045,696	38.18
Maple, Norway	139,687	1,805,799	25,957,780	75,079,056	84,805,864	45,828,656	17,622,648	7,131,975	7,545,434	265,916,896	11.56
Pear, callery	1,068,575	8,662,551	23,318,640	15,501,284	3,494,964	1,960,410	1,680,624	937,953	1,444,896	58,069,896	2.52
Honeylocust	407,580	4,816,573	36,585,524	34,769,132	11,051,327	4,148,102	3,242,040	2,332,038	2,785,718	100,138,040	4.35
Oak, pin	330,820	1,252,068	7,481,848	23,185,554	42,132,436	44,618,952	28,876,420	11,085,614	6,887,744	165,851,456	7.21
Linden, little leaf	186,301	2,840,734	18,866,782	20,272,906	14,661,552	11,132,524	5,670,872	2,389,954	2,450,983	78,472,608	3.41
Ash, green	77,685	1,140,058	12,727,028	17,413,314	6,259,048	4,352,868	3,198,292	2,382,876	2,223,278	49,774,448	2.16
Maple, red	106,258	2,073,272	11,776,321	17,357,374	19,860,516	15,947,726	9,044,236	3,942,837	3,967,763	84,076,296	3.66
Maple, silver	52,370	287,073	2,636,003	7,327,220	16,519,472	22,778,194	22,886,976	14,296,792	7,906,964	94,691,072	4.12
Ginkgo	174,758	1,723,812	12,976,075	13,464,274	6,645,540	3,487,278	2,124,889	1,656,287	2,025,083	44,277,996	1.93
Zelkova, Japanese	182,225	2,094,080	11,223,436	8,823,416	3,630,585	1,965,175	1,103,547	412,344	728,762	30,163,570	1.31
Unknown large	-	1,094,433	8,714,094	11,742,425	11,753,123	9,943,806	8,267,881	4,375,453	3,656,687	59,547,900	2.59
Oak, northern red	68,407	949,214	4,354,713	10,654,546	17,938,492	21,338,614	18,695,578	12,927,106	7,184,013	94,110,680	4.09
Cherry, other	393,923	1,475,667	2,085,347	1,452,601	847,088	613,271	376,105	187,384	290,088	7,721,475	0.34
Sweetgum	29,303	778,489	5,298,852	8,580,200	8,565,852	6,811,265	4,213,992	2,073,699	1,668,170	38,019,820	1.65
Maple, Norway-cr kng	73,458	912,345	4,457,269	4,190,295	1,755,186	697,519	415,494	275,694	236,732	13,013,992	0.57
Linden, American	38,927	797,336	4,247,163	5,345,529	4,678,137	5,353,126	3,165,656	1,686,086	1,016,317	26,328,276	1.14
Pagoda tree, Japanese	75,133	650,339	4,566,675	6,735,323	2,904,833	1,338,388	669,776	371,816	366,571	17,678,852	0.77
Linden, silver	55,245	990,614	3,923,459	2,694,205	1,694,454	1,868,428	922,342	908,019	437,594	13,494,359	0.59
Elm, American	50,813	245,168	1,603,164	2,667,374	2,690,557	2,901,082	2,493,674	1,686,247	1,640,059	15,978,138	0.69
Plum, purpleleaf	295,010	748,949	473,643	135,996	79,028	72,996	28,232	12,632	26,987	1,873,472	0.08
Maple, sugar	20,614	173,937	1,408,774	2,484,503	2,660,821	1,659,399	930,100	547,880	544,377	10,430,404	0.45
Locust, black	43,377	310,946	2,071,684	3,481,863	2,114,490	1,534,573	1,143,046	833,868	829,422	12,363,268	0.54
Unknown medium	201,415	1,103,553	-	-	-	-	-	-	-	1,304,967	0.06
Maple, sycamore	18,039	200,931	1,508,338	3,303,906	3,893,817	3,459,035	1,622,089	573,284	278,082	14,857,522	0.65
Maple, Japanese	52,718	329,945	1,546,033	2,137,255	1,766,336	1,266,100	799,224	337,791	571,392	8,806,794	0.38
Oak, willow	14,204	144,829	1,060,492	2,303,744	2,421,921	2,625,113	1,388,183	737,893	614,922	11,311,300	0.49
Chokecherry, shubert	119,460	347,804	354,268	175,372	112,981	48,348	-	12,410	72,753	1,243,394	0.05
Dogwood, flowering	78,848	203,332	573,666	581,104	334,162	236,655	196,295	37,229	114,557	2,355,848	0.10
Elm, Chinese	32,751	248,848	831,453	892,779	819,940	652,610	559,631	230,362	211,921	4,480,296	0.19
Crabapple	57,752	303,872	768,734	527,523	254,661	220,441	168,008	69,677	63,020	2,433,689	0.11
Oak, white	13,472	187,934	520,679	1,092,918	2,411,106	3,188,898	2,990,137	2,773,344	1,516,517	14,695,004	0.64

Species	0–3	3–6	6–12	12–18	18–24	24–30	30–36	36–42	>42	Total	% of total
Hackberry	67,996	218,591	450,109	351,277	278,392	189,862	184,082	124,680	24,461	1,889,451	0.08
Maple, amur	13,871	333,413	593,058	576,600	634,678	515,795	591,699	39,764	161,291	3,460,169	0.15
Baldcypress	17,374	192,519	979,473	1,121,669	647,325	275,332	315,061	188,573	210,320	3,947,645	0.17
Tree of heaven	23,434	89,500	236,669	383,048	353,750	293,381	219,427	62,318	103,256	1,764,783	0.08
Pine, eastern white	13,305	121,387	674,787	1,085,315	944,718	720,258	535,793	95,896	218,763	4,410,223	0.19
Maple, hedge	24,588	278,724	467,902	215,146	188,416	98,014	228,105	74,609	77,896	1,653,401	0.07
Mulberry	6,164	71,967	549,276	1,256,786	1,680,921	1,486,295	1,140,482	1,160,092	831,252	8,183,235	0.36
Horsechestnut	6,031	10,132	109,756	548,721	991,600	1,191,389	702,617	219,028	187,079	3,966,352	0.17
Hornbeam, European	23,802	142,973	424,576	505,438	288,044	284,261	306,332	178,324	77,896	2,231,647	0.10
Birch, other	18,873	84,222	338,922	271,574	275,747	101,995	56,955	7,653	33,489	1,189,431	0.05
Hawthorn, other	36,489	141,101	274,787	143,319	123,318	93,024	42,641	63,219	20,675	938,573	0.04
Tree lilac, Japanese	59,213	121,738	119,419	111,217	91,854	56,135	47,814	-	20,675	628,065	0.03
Unknown small	166,436	-	-	-	-	-	-	-	-	166,436	0.01
Redwood, dawn	17,560	134,392	418,481	420,883	369,036	360,951	84,711	105,965	74,679	1,986,657	0.09
Magnolia, other	10,234	53,892	396,023	681,681	902,086	599,407	401,723	208,314	212,742	3,466,101	0.15
Maple, other	10,911	90,948	303,895	425,850	342,887	321,413	121,846	63,219	58,580	1,739,550	0.08
Oak, English	10,947	171,273	270,511	329,192	426,130	459,240	338,016	286,959	93,934	2,386,201	0.10
Oak, swamp white	26,178	144,166	205,362	124,932	210,742	197,091	206,202	143,479	66,441	1,324,593	0.06
Ash, other	16,078	35,236	246,876	390,346	91,075	74,306	70,183	77,973	133,265	1,135,339	0.05
Coffeetree, Kentucky	15,416	105,786	282,435	353,272	275,112	319,174	367,296	110,573	211,161	2,040,226	0.09
Goldenrain tree	28,719	104,974	231,417	145,644	95,111	61,657	26,329	49,193	105,389	848,433	0.04
Redbud, eastern	32,456	66,433	115,234	90,630	133,625	97,994	41,972	29,990	41,573	649,906	0.03
Spruce, other	8,392	72,551	411,192	494,087	166,477	92,486	79,608	-	-	1,324,792	0.06
Tulip tree	8,201	52,052	121,943	306,502	580,755	845,398	1,068,081	865,221	315,099	4,163,251	0.18
Oak, other	7,169	47,118	201,057	400,686	586,671	527,701	503,073	410,761	387,190	3,071,425	0.13
Katsura tree	10,065	99,851	223,489	222,194	443,151	373,949	257,124	141,685	201,287	1,972,796	0.09
Pine, other	33,243	54,115	114,640	166,540	73,816	37,856	-	12,410	-	492,620	0.02
Elm, other	3,397	32,343	111,531	302,715	356,568	404,012	393,571	197,057	111,991	1,913,184	0.08
Poplar, other	6,604	25,142	66,490	93,306	90,172	114,835	107,311	58,424	68,055	630,338	0.03
Cherry, kwanzan	8,324	56,295	145,523	173,900	119,898	67,362	28,318	44,716	-	644,336	0.03
Oak, sawtooth	6,749	72,879	211,661	130,376	37,425	43,585	41,777	-	66,441	610,892	0.03
Spruce, Colorado	3,792	34,721	229,535	289,783	72,213	29,190	19,825	26,213	-	705,271	0.03
Redcedar, Eastern	7,261	34,801	155,736	162,591	115,501	73,617	78,602	-	-	628,108	0.03

Species	0–3	3–6	6–12	12–18	18–24	24–30	30–36	36–42	>42	Total	% of total
Spruce, Norway	1,632	22,432	191,289	408,320	381,994	205,170	82,522	24,596	-	1,317,956	0.06
Catalpa	2,069	10,393	83,740	262,803	389,205	359,906	158,339	63,219	41,350	1,371,024	0.06
Ash, white	1,659	30,641	99,181	142,884	108,467	123,736	41,753	17,580	13,858	579,757	0.03
Linden, other	3,313	32,856	135,834	146,905	103,887	76,540	82,084	24,596	82,478	688,494	0.03
Serviceberry, other	12,707	23,793	72,997	38,502	52,911	30,829	26,329	-	-	258,068	0.01
Hemlock, eastern	1,086	24,550	103,566	90,475	58,141	42,502	-	-	12,750	333,070	0.01
Holly species	4,254	33,087	144,051	92,272	29,682	-	53,279	-	-	356,625	0.02
Cherry, black	3,006	7,577	57,716	74,474	76,338	62,949	18,808	62,048	-	362,916	0.02
Hickory	218	7,146	46,977	112,028	226,312	135,045	90,922	55,509	-	674,156	0.03
Cedar, atlas	2,891	19,543	87,087	104,794	64,400	14,323	-	-	-	293,039	0.01
Snowbell, Japanese	2,258	21,057	63,601	78,818	122,578	57,294	20,880	-	30,902	397,387	0.02
Elm, Siberian	193	5,192	19,510	31,063	35,151	64,046	56,448	31,791	14,080	257,475	0.01
Apple	2,353	8,732	47,778	37,149	25,557	12,979	-	17,580	-	152,128	0.01
Willow, other	1,120	4,911	27,917	33,014	95,058	76,037	29,190	89,969	19,632	376,847	0.02
Elm, slippery	135	1,053	34,961	85,454	87,065	92,543	13,994	-	20,675	335,881	0.01
Pine, Japanese black	1,987	6,319	15,401	20,812	18,574	8,111	3,036	-	14,080	88,321	0.00
Dogwood, kousa	2,116	16,537	26,861	15,214	17,366	-	20,880	55,286	43,777	198,039	0.01
Sassafras	404	3,567	12,616	50,664	94,003	92,543	36,821	18,503	-	309,121	0.01
Cottonwood, eastern	773	607	3,011	13,545	50,255	45,867	28,232	25,264	9,974	177,528	0.01
Dogwood	2,662	8,771	26,055	12,878	-	-	26,329	-	-	76,694	0.00
Boxelder	2,369	2,191	8,367	22,465	50,516	31,475	9,404	-	13,858	140,643	0.01
Oak, scarlet	298	1,863	19,289	71,494	70,204	84,407	55,755	59,441	66,441	429,193	0.02
Pine, Austrian	580	2,612	11,837	16,820	18,749	3,356	-	-	-	53,954	0.00
Hornbeam, American	1,776	12,210	6,520	17,591	38,716	12,757	-	-	-	89,570	0.00
Pine, red	548	2,463	15,767	13,545	1,297	8,111	-	-	-	41,730	0.00
Fir, douglas	841	5,865	26,105	34,841	11,726	-	-	-	-	79,378	0.00
Maackia, amur	2,933	8,868	4,508	3,513	6,803	-	-	-	-	26,625	0.00
Beech, American	890	1,741	16,977	35,129	56,125	27,042	124,888	-	-	262,792	0.01
Walnut, black	269	2,156	23,062	23,177	40,064	9,623	47,814	18,503	-	164,668	0.01
Royal paulownia	861	2,522	5,648	27,862	11,949	44,346	23,256	24,819	-	141,263	0.01
Beech, European	529	7,607	21,091	-	20,984	34,615	71,341	117,483	118,456	392,107	0.02
Oak, shingle	1,827	7,305	-	3,983	-	-	18,585	-	-	31,700	0.00
Ohio buckeye	-	-	1,699	15,210	51,512	49,429	15,203	7,653	-	140,705	0.01

Species	0–3	3–6	6–12	12–18	18–24	24–30	30–36	36–42	>42	Total	% of total
Atlantic whitecedar	1,895	2,512	14,762	3,983	-	-	-	-	-	23,152	0.00
Arborvitae, eastern	465	4,535	22,192	-	-	30,829	53,279	-	-	111,300	0.00
Elm, English	-	558	13,163	23,799	-	32,494	7,214	40,444	48,922	166,594	0.01
Corktree, amur	438	4,631	13,499	26,718	-	20,292	-	-	-	65,577	0.00
Birch, European white	773	1,698	6,780	2,325	2,103	-	-	-	4,341	18,021	0.00
Juniper, drooping	211	2,093	5,339	32,926	12,518	20,623	-	-	-	73,710	0.00
Magnolia, southern	105	1,605	13,655	28,876	37,425	25,513	-	-	-	107,180	0.00
Yellowood	269	3,419	6,977	10,396	11,726	-	-	-	-	32,788	0.00
Oak, bur	846	3,524	-	9,625	10,969	12,757	26,329	-	-	64,050	0.00
Peach tree	1,022	1,934	5,974	-	-	-	-	-	-	8,930	0.00
Birch, river	325	370	13,566	1,876	14,169	27,266	19,825	-	-	77,397	0.00
Mimosa	193	1,471	3,752	5,135	-	-	4,813	-	-	15,365	0.00
Osage-orange	-	370	2,810	-	8,306	90,618	13,994	44,716	41,350	202,164	0.01
Maple, trident	269	2,908	9,302	-	-	-	-	-	-	12,479	0.00
Horsechestnut, red	-	893	3,973	4,919	26,090	34,804	13,994	11,410	-	96,084	0.00
Juniper, other	-	4,097	6,298	6,086	5,863	-	-	-	-	22,344	0.00
Pine, Scotch	328	518	3,398	12,266	11,285	-	26,955	-	-	54,750	0.00
Cherry, cornelian	385	3,205	7,892	-	8,683	-	-	-	-	20,166	0.00
Persimmon, common	328	2,378	5,804	2,979	-	-	-	-	-	11,489	0.00
Blackgum	676	837	1,476	3,983	34,457	30,829	-	-	-	72,258	0.00
Pine, shortleaf	656	2,640	2,548	-	-	-	-	-	-	5,844	0.00
Alder, European	-	908	6,328	5,502	7,966	6,490	-	-	-	27,194	0.00
Pine, pitch	274	272	5,494	2,810	1,297	-	-	-	-	10,146	0.00
Poplar, lombardy	-	815	2,367	6,821	4,205	-	-	-	-	14,209	0.00
Hardy rubber tree	1,194	1,381	1,006	-	-	-	-	-	-	3,581	0.00
Common pear	328	3,420	2,407	-	-	-	-	-	-	6,154	0.00
Chestnut, Chinese	492	962	849	10,234	-	-	-	-	-	12,537	0.00
Hop hornbeam, eastern	384	2,365	-	3,983	-	-	-	-	-	6,733	0.00
Silverbell, Carolina	1,186	-	849	-	-	-	-	-	-	2,035	0.00
Oak, turkey	164	1,881	849	-	3,983	6,490	-	-	-	13,367	0.00
Golden-chain tree	312	439	1,519	1,647	-	-	6,974	-	-	10,891	0.00
Aspen, quaking	387	272	-	3,042	2,103	3,356	-	-	-	9,159	0.00
Birch, paper	-	775	2,902	4,206	-	-	-	-	-	7,882	0.00

Species	0–3	3–6	6–12	12–18	18–24	24–30	30–36	36–42	>42	Total	% of total
Pine, Virginia	-	815	1,608	717	-	-	-	-	-	3,140	0.00
Willow, weeping	-	-	1,699	3,399	-	-	9,404	12,410	13,858	40,769	0.00
Maple, tatarian	-	1,860	1,647	-	-	-	-	-	-	3,508	0.00
Hazelnut, Turkish	469	419	-	-	7,743	-	-	-	-	8,630	0.00
Oak, laurel	-	-	849	2,103	5,642	15,683	9,623	-	-	33,901	0.00
Willow, corkscrew	164	321	849	2,103	-	-	9,404	12,410	-	25,250	0.00
Fir, balsam	193	-	1,072	1,163	-	3,356	-	-	-	5,784	0.00
Silverbell	56	628	6,259	-	-	-	-	-	-	6,943	0.00
Larch	-	-	5,136	-	-	-	-	18,503	-	23,639	0.00
Maple, black	-	370	1,163	1,876	5,863	-	-	-	-	9,272	0.00
Birch, yellow	-	321	524	-	-	6,490	9,623	-	-	16,957	0.00
Hickory, pignut	-	370	2,326	4,311	-	-	-	-	-	7,006	0.00
Mountainash, Korean	-	775	1,699	-	-	-	-	-	-	2,474	0.00
Dogwood, knob-styled	254	419	-	-	-	-	-	-	-	673	0.00
Oak, post	-	1,430	-	-	-	-	-	-	-	1,430	0.00
Pondcypress	-	593	3,567	-	-	-	-	-	-	4,161	0.00
Fir, white	-	-	1,790	4,923	-	-	-	-	-	6,713	0.00
Maple, paperback	-	-	2,326	-	-	-	-	-	-	2,326	0.00
Chestnut, American	-	228	-	-	-	9,623	-	-	-	9,851	0.00
Pecan	-	-	1,163	3,043	-	-	-	-	-	4,206	0.00
Cucumber tree	211	-	-	-	-	-	-	-	-	211	0.00
Sourwood	-	-	1,476	3,983	-	-	-	-	-	5,459	0.00
Aspen, bigtooth	-	-	-	1,163	2,103	-	-	-	-	3,265	0.00
Oak, southern red	-	-	-	-	7,743	12,757	-	-	-	20,500	0.00
Willow, pussy	-	-	849	-	-	6,490	-	-	-	7,339	0.00
Yew, other	-	419	-	3,983	-	-	-	-	-	4,402	0.00
Hickory, shagbark	-	-	-	3,043	-	-	-	-	-	3,043	0.00
Cedar, deodar	-	-	-	-	5,863	-	-	-	-	5,863	0.00
Falsecypress, Japanese	-	-	-	3,983	-	-	-	-	-	3,983	0.00
Dogwood, alternateleaf	105	-	-	-	-	-	-	-	-	105	0.00
American smoketree	-	321	-	-	-	-	-	-	-	321	0.00
Olive, Russian	-	-	524	-	-	-	-	-	-	524	0.00
Witch hazel	-	593	-	-	-	-	-	-	-	593	0.00

Species	0–3	3–6	6–12	12–18	18–24	24–30	30–36	36–42	>42	Total	% of total
Tamarack	-	-	-	-	5,863	-	-	-	-	5,863	0.00
Pine, mugo	-	321	-	-	-	-	-	-	-	321	0.00
Oak, black	-	-	-	-	-	-	13,994	-	-	13,994	0.00
Mountainash, American	-	-	849	-	-	-	-	-	-	849	0.00
Elm, winged	-	-	849	-	-	-	-	-	-	849	0.00
Elm, rock	-	-	-	-	-	-	14,323	-	-	14,323	0.00
Citywide total	5,322,145	43,415,782	237,093,218	400,136,063	508,123,761	493,658,053	349,457,119	164,530,141	98,247,324	2,299,983,672	100.00

Appendix D—Methodology and Procedures

This analysis combines results of a citywide inventory with benefit–cost modeling data to produce four types of information:

1. Resource structure: species composition, diversity, age distribution, condition, etc.
2. Resource function: magnitude of environmental and aesthetic benefits
3. Resource value: dollar value of benefits realized
4. Resource management needs: sustainability, pruning, planting, and conflict mitigation

This Appendix describes tree sampling, tree growth modeling, and the model inputs and calculations used to derive the aforementioned outputs.

Growth Modeling

Initially, a stratified random sample of 920 street trees was drawn from the 1995 street tree inventory for the borough of Queens, as part of the Northeast Reference City Project for the Northeast Community Tree Guidelines. In order to more accurately model tree growth, benefits and costs for the entire city, an additional 450 trees were randomly drawn, proportional to representation in each of the 4 remaining boroughs. Of the 1,370 trees originally drawn, we were able to locate and sample 1,222 to establish relations between tree age, size, leaf area and biomass; subsequently, estimates for determining the magnitude of annual benefits in relation to predicted tree size were derived. The sample was composed of the 21 most abundant species; from these data, growth of all trees was inferred. The species were as follows:

- Norway maple (*Acer platanoides*)
- Red maple (*Acer rubrum*)
- Sugar maple (*Acer saccharum*)
- Silver maple (*Acer saccharinum*)
- Horsechestnut (*Aesculus hippocastanum*)
- Green ash (*Fraxinus pennsylvanica*)
- Ginkgo (*Ginkgo biloba*)
- Honeylocust (*Gleditsia triacanthos*)
- Sweetgum (*Liquidambar styraciflua*)
- Crabapple (*Malus* species)
- Eastern white pine (*Pinus strobus*)
- London planetree (*Platanus acerifolia*)
- Kwanzan cherry (*Prunus serrulata*)
- Callery pear (*Pyrus calleryana*)
- Pin oak (*Quercus palustris*)
- Willow oak (*Quercus phellos*)
- Northern red oak (*Quercus rubra*)
- Littleleaf linden (*Tilia cordata*)
- Silver linden (*Tilia cordata*)
- American elm *(Ulmus americana)*
- Japanese zelkova (*Zelkova serrata*)

To obtain information spanning the life cycle of predominant tree species, the inventory was stratified into nine DBH classes:

- 0–3 inch (0–7.6 cm)
- 3–6 inch (7.6–15.2 cm)
- 6–12 inch (15.2–30.5 cm
- 12–18 inch (30.5–45.7 cm)
- 18–24 inch (45.7–61.0 cm)
- 24–30 inch (61.0–76.2 cm)
- 30–36 inch (76.2–91.4 cm)
- 36–42 inch (91.4–106.7 cm)
- >42 inch (>106.7 cm)

Thirty to seventy randomly selected trees of each species were selected to survey, along with an equal number of alternative trees. Tree measurements included DBH (to nearest 0.1 cm by sonar measuring device), tree crown and crown base (to nearest 0.5 m by altimeter), crown diameter in two directions (parallel and perpendicular to nearest street to nearest 0.5 m by sonar measuring device), tree condition and location. Replacement trees were sampled when trees from the original sample population could not be located. Tree age was determined by municipal tree managers. Fieldwork was conducted in August 2005.

Crown volume and leaf area were estimated from computer processing of tree crown images obtained using a digital camera. The method has shown greater accuracy than other techniques (±25% of actual leaf area) in estimating crown volume and leaf area of open-grown trees (Peper and McPherson 2003)

Linear and non-linear regression was used to fit predictive models—with DBH as a function of age—for each of the 20 sampled species. Predictions of leaf surface area (LSA), crown diameter, and height metrics were modeled as a function of DBH using best-fit models (Peper et al. 2001).

Challenges unique to this study included sampling one of the oldest street tree populations existing in the nation and having little historical tree age data available. As a result, the New York State Department of Environmental Conservation and the New York City Department of Parks & Recreation funded a project to core and age 150 of the sampled trees. This work was conducted by Dr. Brendan Buckley at the Lamont-Doherty Tree Ring Lab. In total, Dr. Buckley and his crew took 365 core samples from 164 trees, processing them at the lab to provide tree ring counts in 10-year increments (10 rings for 10 years) for each sample. It was possible to age only 105 trees from the counts because many of the cores were incomplete due to pockets of rot compartmentalized within some tree boles. The two oldest trees successfully cored were a sweetgum with earliest tree ring dating to 1869 (31.1 inch DBH), and a London plane dating back to 1881 (48.4 inch DBH). However, there were 12 additional species aged 75 years and older. These did not represent the oldest trees in the city or in the sample. Rather, these trees were simply the largest that the coring equipment could sample. Historical records indicate elms and linden nearly 300 years old and still thriving within the city. By combining viable tree ring counts with age data supplied by Parks, average age for the midpoint of each DBH size class for each species was calculated.

This data was then regressed to develop equations for each species to predict DBH based on age (ring count).

Replacement Value

The monetary worth, or value, of a tree is based on people's perception of it (Cullen 2000). There are several approaches that arborists use to develop a fair and reasonable perception of value (CTLA 1992, Watson 2002). The cost approach is widely used today and assumes that the cost of production equals value (Cullen 2002).

The trunk formula method (CTLA 1992), also called depreciated replacement cost, is a commonly used approach for estimating tree value in terms of cost. It assumes that the benefits inherent in a tree are reproduced by replacing the tree, and therefore, replacement cost is an indication of value. Replacement cost is depreciated to reflect differences in the benefits that would flow from an "idealized" replacement compared to the imperfect appraised tree.

We regard the terms "replacement value" and "replacement cost" as synonymous indicators of the urban forest's value. Replacement value is indicated by the cost of replacing existing trees with trees of similar size, species, and condition if all were destroyed, for example, by a catastrophic storm. Replacement cost should be distinguished from the value of annual benefits produced by the urban forest. The latter is a "snapshot" of benefits during one year, while the former accounts for the long-term investment in trees now reflected in their number, stature, placement, and condition. Hence, the replacement value of a street tree population is many times greater than the value of the annual benefits it produces.

The trunk formula method uses tree size, species, condition, and location factors to determine tree replacement value. Tree size is measured as trunk area (TA, cross-sectional area of the trunk based on DBH), while the other factors are assessed subjectively relative to a "high-quality" specimen and expressed as percentages. The equation is

Replacement value = Basic value × Condition% × Location%

where

Basic value = Replacement cost + (Basic price × [TAA−TAR] × Species%)

Replacement cost = Sum of the cost of the replacement tree (of size TA_R) and its installation

Basic price = Cost of the largest available transplantable tree divided by TA_R ($/inch^2)

TA_A = Trunk area of appraised tree (inch^2) or height of clear trunk (linear ft) for palms

TA_R = Trunk area of replacement tree (inch^2) or height of clear trunk (linear ft) for palms

Species% = Rating of the species' longevity, maintenance requirements, and adaptability to the local growing environment (CTLA 1992)

Condition% = Rating of structural integrity and health; a higher percentage indicates better condition (CTLA 1992)

Location% = Rating of the site itself (relative market value), contribution of the tree in terms of its aesthetic and functional attributes, and placement, which reflects the effectiveness of realizing benefits; location is the sum of site, contribution, and placement divided by three (CTLA 1992). A higher percentage indicates better location.

In this study, data from Region 1 of the "Tree Species Rating for New York State" were used to calculate replacement value (New York State Arborists ISA Chapter 1995). Species rating percentages were the midpoint for the ranges reported. Tree condition ratings were based on the inventory (or set at 70% when no data were available) and location ratings were arbitrarily set at 70%, indicative of a tree located in a typical park. TA_R is 121.56 inch^2 for a 4-inch caliper tree representing the largest tree that is normally available from wholesalers; TA_A is calculated using the midpoint for each DBH class. The basic price was $66/inch^2 TA, based on the wholesale cost of a 4-inch caliper tree. Replacement costs equaled the cost for a 4-inch tree plus installation.

Replacement values were calculated using the trunk formula equation for each species by DBH class, then summed across DBH classes and species to derive total replacement value for the population.

Identifying and Calculating Benefits

Annual benefits for New York City's municipal trees were estimated for the fiscal year 2005. Growth rate modeling information was used to perform computer-simulated growth of the existing tree population for one year and account for the associated annual benefits. This "snapshot" analysis assumed that no trees were added to, or removed from, the existing population during the year. Calculations of CO_2 released due to decomposition of wood from removed trees did consider average annual mortality. This approach directly connects benefits with tree-size variables such as DBH and LSA. Many benefits of trees are related to processes that involve interactions between leaves and the atmosphere (e.g., interception, transpiration, photosynthesis); therefore, benefits increase as tree canopy cover and leaf surface area increase.

For each of the modeled benefits, an annual resource unit was determined on a per-tree basis. Resource units are measured as MWh of electricity saved per tree; MBtu of natural gas conserved per tree; lbs of atmospheric CO_2 reduced per tree; lbs of NO_2, PM_{10}, and VOCs reduced per tree; cubic feet of stormwater runoff reduced per tree; and square feet of leaf area added per tree to increase property values.

Prices were assigned to each resource unit (e.g., heating/cooling energy savings, air-pollution absorption, stormwater runoff reduction) using economic indicators of society's willingness to pay for the environmental benefits trees provide. Estimates of benefits are initial approximations as some benefits are difficult to quantify (e.g., impacts on psychological health, crime, and violence). In addition, limited knowledge about the physical processes at work and their interactions makes estimates imprecise (e.g., fate of air pollutants trapped by trees and then washed to the ground by rainfall). Therefore, this method of quantification provides first-order approximations. It is meant to be a general accounting of the benefits produced by urban trees—an accounting with an accepted degree of uncertainty that can, nonetheless, provide a science-based platform for decision-making.

Energy Savings

Buildings and paving, along with little tree canopy cover and soil cover, increase the ambient temperatures within a city. Research shows that even in temperate climate zones temperatures in urban centers are steadily increasing by approximately 0.5°F per decade. Winter benefits of this warming do not compensate for the detrimental effects of increased summertime temperatures. Because the electricity demand of cities increases about 1–2% per 1°F increase in temperature, approximately 3–8% of the current electric demand for cooling is used to compensate for this urban heat island effect (Akbari et al. 1992).

Warmer temperatures in cities have other implications. Increases in CO_2 emissions from fossil-fuel power plants, increased water demand, unhealthy O_3 levels, and human discomfort and disease are all symptoms associated with urban heat islands. In New York, there are opportunities to ameliorate the problems associated with hardscape through strategic tree planting and stewardship of existing trees thereby creating street and park landscapes that reduce stormwater runoff, conserve energy and water, sequester CO_2, attract wildlife, and provide other aesthetic, social, and economic benefits.

For individual buildings, street trees can increase energy efficiency in summer and increase or decrease energy efficiency in winter, depending on their location. During the summer, the sun is low in the eastern and western sky for several hours each day. Tree shade to protect east—and especially west—walls helps keep buildings cool. In the winter, allowing the sun to strike the southern side of buildings can warm interior spaces.

Trees reduce air movement into buildings and conductive heat loss from buildings. The rate at which outside air moves into a building can increase substantially with wind speed. In cold, windy weather, the entire volume of air, even in newer or tightly sealed homes, may change every two to three hours. Trees can reduce wind speed and resulting air infiltration by up to 50%, translating into potential annual heating savings of 25% (Heisler 1986). Decreasing wind speed reduces heat transfer through conductive materials as well. Cool winter winds, blowing against single-pane windows, can contribute significantly to the heating load of homes and buildings

Calculating Electricity and Natural Gas Benefits

Calculations of annual building energy use per residential unit (unit energy consumption [UEC]) were based on computer simulations that incorporated building, climate, and shading effects, following methods outlined by McPherson and Simpson (1999). Changes in UECs due to the effects of trees (ΔUECs) were calculated on a per-tree basis by comparing results before and after adding trees. Building characteristics (e.g., cooling and heating equipment saturations, floor area, number of stories, insulation, window area, etc.) are differentiated by a building's vintage, or age of construction: pre-1950, 1950–1980, and post-1980. For example, all houses from 1950–1980 vintage are assumed to have the same floor area, and other construction characteristics. Shading effects for each of the 21 tree species were simulated at three tree-to-building distances, for eight orientations and for nine tree sizes.

The shading coefficients of the trees in leaf (gaps in the crown as a percentage of total crown silhouette) were estimated using a photographic method that has been shown to produce good estimates (Wilkinson 1991). Crown areas were obtained using the method of Peper and McPherson (2003) from digital photographs of trees from which background features were digitally removed. Values for tree species that were not sampled, and leaf-off values for use in calculating winter shade, were based on published values where available (McPherson 1984; Hammond et al. 1980). Where published values were not available, visual densities were assigned based on taxonomic considerations (trees of the same genus were assigned the same value) or observed similarity to known species. Foliation periods for deciduous trees were obtained from the literature (McPherson 1984; Hammond et al. 1980) and adjusted for New York's climate based on consultation with New York Central Forestry and Horticulture's forestry analyst (Watt 2006).

Average energy savings per tree were calculated as a function of distance and direction using tree location distribution data specific to New York City (i.e., frequency of trees located at different distances from buildings [setbacks] and tree orientation with respect to buildings). Setbacks were assigned to four distance classes: 0–20 ft, 20–40 ft, 40–60 ft and >60 ft. It was assumed that street trees within 60 ft of buildings provided direct shade on walls and windows. Savings per tree at each location were multiplied by tree distribution to determine location-weighted savings per tree for each species and DBH class, independent of location. Location-weighted savings per tree were multiplied by the number of trees of each species and DBH class and then summed to find total savings for the city. Tree locations were based on the stratified random sample conducted in summer 2005.

Land use (single-family residential, multifamily residential, commercial/industrial, other) for right-of-way trees was based on the same tree sample. A constant tree distribution was used for all land uses.

Three prototype buildings were used in the simulations to represent pre-1950, 1950–1980, and post-1980 construction practices for New York (Ritschard et al. 1992). Building footprints were modeled as square, which was found to reflect average impacts for a large number of buildings (Simpson 2002). Buildings were simulated with 1.5-ft overhangs. Blinds had a visual density of 37%, and were assumed to be closed when the air conditioner was operating. Thermostat settings were 78°F for cooling and 68°F for heating, with a 60°F night setback in winter. Unit energy consumptions were adjusted to account for equipment saturations (percentage of structures with different types of heating and cooling equipment such as central air conditioners, room air conditioners, and evaporative coolers) (*Table D1*).

Weather data for a typical meteorological year (TMY2) from New York were used (National Solar Radiation Data Base 2006). Dollar values for energy savings were based on electricity and natural gas prices of $0.1529/kWh and $1.2783/therm, respectively (ConEdison 2006).

Single-Family Residence Adjustments

Unit energy consumptions for simulated single-family residences were adjusted for type and saturation of heating and cooling equipment, and for various factors (F) that modify the effects of shade and climate on heating and cooling loads:

$$\Delta UEC_x = \Delta UEC^{sh}_{SFD} \times F^{sh} + \Delta UEC^{cl}_{SFD} \times F^{cl}$$

Equation 1

where

$$F^{sh} = F_{equipment} \times APSF \times F_{adjacent\ shade} \times F_{multiple\ tree}$$

$$F^{cl} = F_{equipment} \times PCF$$

$$F_{equipment} = Sat_{CAC} + Sat_{window} \times 0.25 + Sat_{evap} \times$$
(0.33 for cooling and 1.0 for heating).

Changes in energy use for higher density residential and commercial structures were calculated from single-family residential results adjusted by average potential shade factors (APSF) and potential climate factors (PCF); values were set to 1.0 for single-family residential buildings.

Table D1*—Saturation adjustments for cooling (%)*

	Single family detached			**Mobile homes**			**Single-family attached**			**Multi-family 2-4 units**			**Multi-family 5+ units**			**Commercial/ industrial**		**Institute/ Transpor-tation**
	pre-1950	**1950-1980**	**post-1980**	**pre-1950**	**1950-1980**	**post-1980**	**pre-1950**	**1950-1980**	**post-1980**	**pre-1950**	**1950-1980**	**post-1980**	**pre-1950**	**1950-1980**	**post-1980**	**Small**	**Large**	
									Cooling equipment factors									
Central air/ heat pump	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Evaporative cooler	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33
Wall/window unit	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25
None	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
									Cooling saturations									
Central air/ heat pump	13	35	69	13	35	69	13	35	69	13	35	69	13	35	69	86	86	86
Evaporative cooler	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wall/window unit	37	23	25	37	23	25	37	23	25	37	23	25	37	23	25	9	9	9
None	51	42	6	0	0	0	0	0	0	0	0	0	0	0	0	5	5	5
Adjusted cooling saturation	22	41	75	22	41	75	22	41	75	22	41	75	22	41	75	88	88	88

Total change in energy use for a particular land use was found by multiplying the change in UEC per tree by the number of trees (*N*):

$$\text{Total change} = N \times \Delta \text{UEC}_x \qquad \textit{Equation 2}$$

Subscript *x* refers to residential structures with 1, 2–4 or ≥5 units, SFD to simulated single-family detached structures, sh to shade, and cl to climate effects.

Estimated shade savings for all residential structures were adjusted to account for shading of neighboring buildings and for overlapping shade from trees adjacent to one another. Homes adjacent to those with shade trees may benefit from the trees on the neighboring properties. For example, 23% of the trees planted for the Sacramento Shade program shaded neighboring homes, resulting in an additional estimated energy savings equal to 15% of that found for program participants; this value was used here ($F_{\text{adjacent shade}}$ = 1.15). In addition, shade from multiple trees may overlap, resulting in less building shade from an added tree than would result if there were no existing trees. Simpson (2002) estimated that the fractional reductions in average cooling and heating energy use were approximately 6% and 5% percent per tree, respectively, for each tree added after the first. Simpson (1998) also found an average of 2.5–3.4 existing trees per residence in Sacramento. A multiple tree reduction factor of 85% was used here, equivalent to approximately three existing trees per residence.

In addition to localized shade effects, which were assumed to accrue only to street trees within 18–60 ft of buildings, lowered air temperatures and wind speeds due to neighborhood tree cover (referred to as climate effects) produce a net decrease in demand for summer cooling and winter heating. Reduced wind speeds by themselves may increase or decrease cooling demand, depending on the circumstances. To estimate climate effects on energy use, air-temperature and wind-speed reductions were estimated as a function of neighborhood canopy cover from published values following McPherson and Simpson (1999), then used as input for the building-energy-use simulations described earlier. Peak summer air temperatures were assumed to be reduced by 0.2°F for each percentage increase in canopy cover. Wind-speed reductions were based on the change in total tree plus building canopy cover resulting from the addition of the particular tree being simulated (Heisler 1990). A lot size of 10,000 ft^2 was assumed.

Cooling and heating effects were reduced based on the type and saturation of air conditioning (*Table D2*) or heating (*Table D3*) equipment by vintage. Equipment factors of 33 and 25% were assigned to homes with evaporative coolers and room air conditioners, respectively. These factors were combined with equipment saturations to account for reduced energy use and savings compared to those simulated for homes with central air conditioning ($F_{\text{equipment}}$). Building vintage distribution was combined with adjusted saturations to compute combined vintage/saturation factors for air conditioning (*Table D2*). Heating loads were converted to fuel use based on efficiencies in *Table D2*. The "other" and "fuel oil" heating equipment types were assumed to be natural gas for the purpose of this analysis. Building vintage distributions were combined with adjusted saturations to compute combined vintage/saturation factors for natural gas and electric heating (*Table D3*).

Multi-Family Residence Analysis

Unit energy consumptions (UECs) from single-family residential UECs were adjusted for multi-family residences (MFRs) to account for reduced shade resulting from common walls and multi-story construction. To do this, potential shade factors (PSFs) were calculated as ratios of exposed wall or roof (ceiling) surface area to total surface area, where total surface area includes common walls and ceilings between attached units in addition to exposed surfaces (Simpson 1998). A PSF of 1 indicates that all exterior walls and roofs are exposed and could be shaded by a tree, while a PSF of 0 indicates that no shading is possible (e.g., the common wall between duplex units). Potential shade factors were estimated separately for walls and roofs for both single- and multi-story structures. Average poten-

Table D2—*Saturation adjustments for heating (%, except AFUE [fraction] and HSPF [kBtu/kWh)*

	Single family detached			Mobile homes			Single-family attached			Multi-family 2-4 units			Multi-family 5+ units			Commercial/ industrial		Institutional/ Transportation
	pre-1950	1950-1980	post-1980	pre-1950	1950-1980	post-1980	pre-1950	1950-1980	post-1980	pre-1950	1950-1980	post-1980	pre-1950	1950-1980	post-1980	Small	Large	
Equipment efficiencies																		
AFUE	0.75	0.78	0.78	0.75	0.78	0.78	0.75	0.78	0.78	0.75	0.78	0.78	0.75	0.78	0.78	0.78	0.78	0.78
HSPF	6.8	6.8	8	6.8	6.8	8	6.8	6.8	8	6.8	6.8	8	6.8	6.8	8	8	8	8
HSPF	3.412	3.412	3.412	3.412	3.412	3.412	3.412	3.412	3.412	3.412	3.412	3.412	3.412	3.412	3.412	3.412	3.412	3.412
Electric heat saturations																		
Electric resistance	2.4	10.9	21.4	2.4	10.9	21.4	2.4	10.9	21.4	2.4	10.9	21.4	2.4	10.9	21.4	4.9	4.9	4.9
Heat pump	0.4	1.8	3.6	0.4	1.8	3.6	0.4	1.8	3.6	0.4	1.8	3.6	0.4	1.8	3.6	0.4	1.8	3.6
Adjusted electric heat saturations	0.4	1.7	2.9	0.4	1.7	2.9	0.4	1.7	2.9	0.4	1.7	2.9	0.4	1.7	209	1.7	1.7	1.7
Natural gas and other heating saturations																		
Natural gas	69.0	60.8	50.0	69.0	60.8	50.0	69.0	60.8	50.0	69.0	60.8	50.0	69.0	60.8	50.0	89.7	89.7	89.7
Oil	18.3	19.0	0.0	18.3	19.0	0.0	18.3	19.0	0.0	18.3	19.0	0.0	18.3	19.0	0.0	0.0	0.0	0.0
Other	9.9	7.6	25.0	9.9	7.6	25.0	9.9	7.6	25.0	9.9	7.6	25.0	9.9	7.6	25.0	0	0	0
NG heat saturations	97	87	75	97	87	75	97	87	75	97	87	75	97	87	75	90	90	90

Table D3—*Building vintage distribution and combined vintage/saturation factors for heating and air conditioning*

	Single family detached			Mobile homes			Single-family attached			Multi-family 2-4 units			Multi-family 5+ units			Commercial/ industrial		Institutional/ Transportation
	pre-1950	1950-1980	post-1980	pre-1950	1950-1980	post-1980	pre-1950	1950-1980	post-1980	pre-1950	1950-1980	post-1980	pre-1950	1950-1980	post-1980	Small	Large	
Vintage distribution by building type	53.0	36.5	10.5	44.5	36.2	19.2	53.0	36.5	10.5	54.7	36.3	10.5	49.7	41.8	8.5	100	100	100
Tree distribution by vintage and building type	30.1	20.7	6.0	0.2	0.1	0.1	22.7	15.6	4.5	14.6	9.7	2.4	36.5	30.7	6.2	63.0	37.0	100
Combined vintage, equipment saturation factors for cooling																		
Cooling factor: shade	6.42	8.33	4.37	0.04	0.06	0.05	4.26	5.53	2.90	2.30	2.88	1.29	3.19	5.05	1.87	19.4	5.7	0.0
Cooling factor: climate	6.57	8.52	4.47	0.04	0.05	0.05	4.01	5.21	2.73	1.43	1.79	0.80	3.67	5.81	2.15	17.4	34.1	0.0
Combined vintage, equipment saturation for heating																		
Heating factor, natural gas: shade	28.60	17.69	4.37	0.16	0.12	0.05	18.98	11.74	2.90	10.24	6.11	1.29	14.21	10.73	1.87	19.7	5.8	0.0
Heating factor, electric: shade	0.10	0.34	0.17	0.00	0.00	0.00	0.07	0.22	0.11	0.04	0.12	0.05	0.05	0.20	0.07	0.38	0.11	0.00
Heating factor, natural gas: climate	29.25	18.09	4.47	0.09	0.07	0.03	21.07	13.03	3.22	6.06	3.61	0.76	17.29	13.05	2.28	68.0	133.1	0
Heating factor, electric: climate	0.11	0.34	0.17	0.00	0.00	0.00	0.08	0.25	0.12	0.02	0.07	0.03	0.06	0.25	0.09	1.30	2.55	0.0

tial shade factors were 0.74 for multi-family residences of 2–4 units and 0.41 for ≥5 units.

Unit energy consumptions were also adjusted to account for the reduced sensitivity of multi-family buildings with common walls to outdoor temperature changes. Since estimates for these PSFs were unavailable for multi-family structures, a multi-family PCF value of 0.80 was selected (less than single-family detached PCF of 1.0 and greater than small commercial PCF of 0.40; see below).

Commercial and Other Buildings

Reductions in unit energy consumptions for commercial/industrial (C/I) and industrial/transportation (I/T) land uses due to the presence of trees were determined in a manner similar to that used for multi-family land uses. Potential shade factors of 0.40 were assumed for small C/I, and 0.0 for large C/I. No energy impacts were ascribed to large C/I structures since they are expected to have surface-to-volume ratios an order of magnitude larger than smaller buildings and less extensive window area. Average potential shade factors for I/T structures were estimated to lie between these extremes; a value of 0.15 was used here. However, data relating I/T land use to building-space conditioning were not readily available, so no energy impacts were ascribed to I/T structures. A multiple-tree reduction factor of 0.85 was used, and no benefit was assigned for shading of buildings on adjacent lots.

Potential climate-effect factors of 0.40, 0.25 and 0.20 were used for small C/I, large C/I, and I/T, respectively. These values are based on estimates by Akbari (1992) and others who observed that commercial buildings are less sensitive to outdoor temperatures than houses.

The beneficial effects of shade on UECs tend to increase with conditioned floor area (CFA) for typical residential structures. As building surface area increases so does the area shaded. This occurs up to a certain point because the projected crown area of a mature tree (approximately 700–3,500 ft^2) is often larger than the building surface areas being shaded. A point is reached, however, at which no additional area is shaded as surface area increases. At this point, ΔUECs will tend to level off as CFA increases. Since information on the precise relationships between change in UEC, CFA, and tree size is not available, it was conservatively assumed that ΔUECs in *Equation 1* did not change for C/I and I/T land uses.

Atmospheric Carbon Dioxide Reduction

Sequestration (the net rate of carbon dioxide [CO_2] storage in above- and below-ground biomass over the course of one growing season) is calculated for each species using the tree-growth equations for DBH and height, described above, to calculate either tree volume or biomass. Equations from Pillsbury et al. (1998) are used when calculating volume. Fresh weight (kg/m^3) and specific gravity ratios from Alden (1995, 1997) are then applied to convert volume to biomass. When volumetric equations for urban trees are unavailable, biomass equations derived from data collected in rural forests are applied (Tritton and Hornbeck 1982; Ter-Mikaelian and Korzukhin 1997).

CO_2 released through decomposition of dead woody biomass varies with characteristics of the wood itself, the fate of the wood (e.g., amount left standing, chipped, or burned), and local soil and climatic conditions. Recycling of urban waste is now prevalent, and we assume here that most material is chipped and applied as landscape mulch. Calculations were conservative because they assumed that dead trees are removed and mulched in the year that death occurs, and that 80% of their stored carbon is released to the atmosphere as CO_2 in the same year. Total annual decomposition is based on the number of trees in each species and age class that die in a given year and their biomass. Tree survival rate is the principal factor influencing decomposition. Tree mortality for New York was 2.65% per year for the first five years after planting for street trees and 1.3% every year thereafter (Watt 2006). Finally, CO_2 released during tree maintenance was estimated to be 0.15 lb CO_2 per inch DBH based on annual fuel consumption of gasoline (9,294 gal) and diesel fuel (34,840 gal) (Watt 2006).

Calculating Avoided CO_2 Emissions

Reducing building energy use reduces emissions of CO_2. Emissions were calculated as the product of energy use and CO_2 emission factors for electricity and heating. Heating fuel is largely natural gas and electricity in New York. The fuel mix for electrical generation included mainly natural gas (51.4%) and nuclear energy (34.8%) (U.S. EPA 2003).

Emissions factors for electricity (lb/MWh) and natural gas (lb/MBtu) fuel mixes are given in *Table D4*. The monetary value of avoided CO_2 was \$6.68/ton based on the average value in Pearce (2003).

Table D4—*Emissions factors and monetary implied values for CO_2 and criteria air pollutants.*

	Emission factor		Implied
	Electricity (lb/MWh)[a]	Natural gas (lb/MBtu)[b]	value[c] ($/lb)
CO_2	3,012	118	0.00334
NO_2	4.826	0.1020	4.59
SO_2	4.367	0.0006	3.48
PM_{10}	0.281	0.0075	8.31
VOCs	0.131	0.0054	2.31

[a]U.S. EPA 2003, except Ottinger et al. 1990 for VOCs
[b]U.S. EPA 1998
[c]CO_2 from Pearce (2003), values for all other pollutants are based on methods of Wang and Santini (1995) using emissions concentrations from U.S. EPA (2003) and population estimates from the U.S. Census Bureau (2003)

Improving Air Quality

Calculating Avoided Emissions

Reductions in building energy use also result in reduced emissions of criteria air pollutants (those for which a national standard has been set by the EPA) from power plants and space-heating equipment. This analysis considered volatile organic hydrocarbons (VOCs) and nitrogen dioxide (NO_2)—both precursors of ozone (O_3) formation—as well as sulfur dioxide (SO_2) and particulate matter of <10 micron diameter (PM_{10}). Changes in average annual emissions and their monetary values were calculated in the same way as for CO_2, again using utility specific emission factors for electricity and heating fuels (U.S. EPA 2003). The prices of emissions savings were derived from models that calculate the marginal cost of controlling different pollutants to meet air quality standards (Wang and Santini 1995). Emissions concentrations were obtained from U.S. EPA (2003, *Table D4*), and population estimates from the U.S. Census Bureau (2006).

Calculating Deposition and Interception

Trees also remove pollutants from the atmosphere. The hourly pollutant dry deposition per tree is expressed as the product of the deposition velocity $V_d = 1/(R_a+R_b+R_c)$, pollutant concentration (C), canopy projection (CP) area, and time step. Hourly deposition velocities for each pollutant were calculated using estimates for the resistances R_a, R_b, and R_c estimated for each hour over a year using formulations described by Scott et al. (1998). Hourly concentrations for 2003 for NO_2, SO_2, O_3 and PM_{10} for New York City and the surrounding area were obtained from the U.S. EPA. Hourly air temperature and wind speed data were obtained from the National Oceanic and Atmospheric Administration, and solar radiation data were calculated using the Northeast Regional Climate Center's solar radiation model based on weather data from JFK airport (for a description of the model, see DeGaetano et al. 1993). The year 2003 was chosen because data were available and it closely approximated long-term, regional climate records.

Deposition was determined for deciduous species only when trees were in-leaf. A 50% re-suspension rate was applied to PM_{10} deposition. Methods described in the section "Calculating Avoided Emissions" were used to value emissions reductions; NO_2 prices were used for O_3 since O_3 control measures typically aim at reducing NO_2.

Calculating BVOC Emissions

Emissions of biogenic volatile organic carbon (sometimes called biogenic hydrocarbons or BVOCs) associated with increased O_3 formation were estimated for the tree canopy using methods described by McPherson et al. (1998). In this approach, the hourly emissions of carbon in the form of isoprene and monoterpene are expressed as products of base emission factors and leaf biomass factors adjusted for sunlight and temperature (isoprene) or simply temperature (monoterpene). Annual dry foliar biomass was derived from field data collected in New York, NY, during September 2005. The amount of foliar biomass present for each year of the simulated tree's life was unique for each species. Hourly air temperature and solar radiation data for 2003 described in the pollutant uptake section were used as model inputs. Hourly emissions were summed to get annual totals (*Table D4*).

The ozone-reduction benefit from lowering summertime air temperatures, thereby reducing hydrocarbon emissions from biogenic sources, was estimated as a function of canopy cover following McPherson and Simpson (1999). Peak summer air temperatures were reduced by 0.2°F for each percentage increase in canopy cover. Hourly changes in air temperature were calculated by reducing this peak air temperature at every hour based on the hourly maximum and minimum temperature for that day, the maximum and minimum values of total global solar radiation for the year. Simulation results from Los Angeles indicate that O_3 reduction benefits of tree planting with "low-emitting" species exceeded costs associated with their BVOC emissions (Taha 1996). This is a conservative approach, since the benefit associated with lowered summertime air temperatures and the resulting reduced hydrocarbon emissions from anthropogenic sources were not accounted for.

Reducing Stormwater Runoff

The social benefits that result from reduced peak runoff include reduced property damage from flooding and reduced loss of soil and habitat due to erosion and sediment flow. Reduced runoff also results in improved water quality in streams, lakes, and rivers. This can translate into improved aquatic habitats, less human disease and illness due to contact with contaminated water and reduced stormwater treatment costs.

Calculating Stormwater Runoff Reductions

A numerical simulation model was used to estimate annual rainfall interception (Xiao et al. 1998). The interception model accounts for rainwater intercepted by the tree, as well as throughfall and stem flow. Intercepted water is stored on canopy leaf and bark surfaces. Once the storage capacity of the tree canopy is exceeded, rainwater temporarily stored on the tree surface will drip from the leaf surface and flow down the stem surface to the ground. Some of the stored water will evaporate. Tree canopy parameters related to stormwater runoff reductions include species, leaf and stem surface area, shade coefficient (visual density of the crown), tree height, crown diameter, and foliation period. Wind speeds were estimated for different heights above the ground; from this, rates of evaporation were estimated.

The volume of water stored in the tree crown was calculated from crown-projection area (area under tree dripline), leaf area indices (LAI, the ratio of leaf surface area to crown projection area), the depth of water captured by the canopy surface, and the water storage capacity of the tree crown. Tree surface saturation was 0.04 inch (1 mm). Species-specific shading coefficient, foliation period, and tree surface saturation storage capacity influence the amount of projected throughfall.

Hourly meteorological and rainfall data for 2000 at the JFK International Airport climate monitoring station (National Oceanic and Atmospheric Administration/National Weather Service, COOP ID: 305803, latitude: 40° 38' N, longitude: 73° 46' W, elevation: 11 feet) in Queens County, New York, were used in this simulation. The year 2000 was chosen because it most closely approximated the 30-year average rainfall of 41.97 inches (1,065.9 mm). Annual precipitation in New York during 1998 was 41.0 in (1,041.9 mm). Storm events less than 0.1 in (2.5 mm) were assumed not to produce runoff and were dropped from the analysis. More complete descriptions of the interception model can be found in Xiao et al. (1998, 2000).

Treatment of runoff is one way of complying with federal Clean Water Act regulations by preventing contaminated stormwater from entering local waterways. Lacking data for New York City, we relied on stormwater management control costs for Washington, D.C., as the basis for calculating the implied value of each gallon of stormwater intercepted by trees. In Washington, D.C., the monetized benefit value is $0.04/gal based on projected costs and water savings from the Water and Sewer Authority's 2002 Long-Term Control Plan (Greeley and Hansen 2002).

Property Value and Other Benefits

Trees provide a host of aesthetic, social, economic, and health benefits that should be included in any benefit–cost analysis. One of the most frequently cited reasons for planting trees is beautification. Trees add color, texture, line, and form to the landscape softening the hard geometry that dominates built environments. Research on the aesthetic quality of residential streets has shown that street trees are the single strongest positive influence on scenic quality (Schroeder and Cannon 1983). Consumer surveys have shown that preference ratings increase with the presence of trees in the commercial streetscape. In contrast to areas without trees, shoppers indicated that they shopped more often and longer in well-landscaped business districts, and were willing to pay more for goods and services (Wolf 1999). Research in public-housing complexes found that outdoor spaces with trees were used significantly more often than spaces without trees. By facilitating interactions among residents, trees can contribute to reduced levels of violence, as well as foster safer and more sociable neighborhood environments (Sullivan and Kuo 1996).

Well-maintained trees increase the "curb appeal" of properties. Research comparing sales prices of residential properties with different numbers and sizes of trees suggests that people are willing to pay 3–7% more for properties with ample trees versus few or no trees. One of the most comprehensive studies on the influence of trees on residential property values was based on actual sales prices and found that each large front-yard tree was associated with about a 1% increase in sales price (Anderson and Cordell 1988). Depending on average home sale prices, the value of this benefit can contribute significantly to property tax revenues.

Scientific studies confirm our intuition that trees in cities provide social and psychological benefits. Humans derive substantial pleasure from trees, whether it is inspiration from their beauty, a spiritual connection, or a sense of meaning (Dwyer et al. 1992; Lewis 1996). Following natural disasters, people often report a sense of loss if the urban forest in their community has been damaged (Hull 1992). Views of trees and nature from homes and offices provide restorative experiences that ease mental fatigue and help people to concentrate (Kaplan and Kaplan 1989). Desk-workers with a view of nature report lower rates of sickness and greater satisfaction with their jobs compared to those having no visual connection to nature (Kaplan 1992). Trees provide important settings for recreation and relaxation in and near cities. The act of planting trees can have social value, for community bonds between people and local groups often result.

The presence of trees in cities provides public health benefits and improves the well being of those who live, work and play in cities. Physical and emotional stress has both short-term and long-term effects. Prolonged stress can compromise the human immune system. A series of studies on human stress caused by general urban conditions and city driving showed that views of nature reduce the stress response of both body and mind (Parsons et al. 1998). City nature also appears to have an "immunization effect," in that people show less stress response if they have had a recent view of trees and vegetation. Hospitalized patients with views of nature and time spent outdoors need less medication, sleep better, have a better outlook, and recover quicker than patients without connections to nature (Ulrich 1985). Trees reduce exposure to ultraviolet light, thereby lowering the risk of harmful effects from skin cancer and cataracts (Tretheway and Manthe 1999).

Certain environmental benefits from trees are more difficult to quantify than those previously described, but can be just as important. Noise can reach unhealthy levels in cities. Trucks, trains, and planes can produce noise that exceeds 100 decibels, twice the level at which noise becomes a health risk. Thick strips of vegetation in conjunction with landforms or solid barriers can reduce highway noise by 6–15 decibels. Plants absorb more high frequency noise than low frequency, which is advantageous to humans since higher frequencies are most distressing to people (Miller 1997).

Urban forests can be oases, sometimes containing more vegetative diversity than surrounding rural areas. Numerous types of wildlife inhabit cities and are generally highly valued by residents. For example, older parks, cemeteries, and botanical gardens often contain a rich assemblage of wildlife. Street-tree corridors can connect a city to surrounding wetlands, parks, and other greenspace resources that provide habitats that conserve biodiversity (Platt et al.1994).

Urban and community forestry can provide jobs for both skilled and unskilled labor. Public service programs and grassroots-led urban and community forestry programs provide horticultural training to volunteers across the United States. Also, urban and community forestry provides educational opportunities for residents who want to learn about nature through first-hand experience (McPherson and Mathis 1999). Local nonprofit tree groups, along with municipal volunteer programs, often provide educational materials, work with area schools, and offer hands-on training in the care of trees.

Calculating Changes in Property Values and Other Benefits

In an Athens, GA, study (Anderson and Cordell 1988), a large front-yard tree was found to be associated with a 0.88% increase in average home resale values. In our study, the annual increase in leaf surface area of a typical mature large tree (30-year-old zelkova, average leaf surface area 4,256 ft^2) was the basis for valuing the capacity of trees to increase property value.

Assuming the 0.88% increase in property value held true for the city of New York, each large tree would be worth $4,728 based on the 4th quarter, 2005, median single-family-home resale price in New York ($537,300) (National Association of Realtors 2005). However, not all trees are as effective as front-yard trees in increasing property values. For example, trees adjacent to multifamily housing units will not increase the property value at the same rate as trees in front of single-family homes. Therefore, a citywide reduction factor (0.88) was applied to prorate trees' value based on the assumption that trees adjacent to different land uses make different contributions to property sales prices. For this analysis, the reduction factor reflects the distribution of municipal trees in New York by land use. The overall reduction factor for street trees reflects tree distribution by land use. Reduction factors were single-home residential (100%), multi-home residential (75%), small commercial (66%), industrial/institutional/large commercial (50%), vacant/other (50%) (McPherson et al. 2001). Trees in parks were assigned a reduction factor of 0.50.

Estimating Magnitude of Benefits

Resource units describe the absolute value of the benefits of New York City's street trees on a per-tree basis. They include kWh of electricity saved per tree, kBtu of natural gas conserved per tree, lbs of atmospheric CO_2 reduced per tree, lbs of NO_2, PM_{10}, and VOCs reduced per tree, cubic feet of stormwater runoff reduced per tree, and square feet of leaf area added per tree to increase property values. A dollar value was assigned to each resource unit based on local costs.

Estimating the magnitude of the resource units produced by all street trees in New York City required four steps: (1) categorizing street trees by species and DBH based on the city's street-tree inventory, (2) matching other significant species with those that were modeled, (3) grouping remaining "other" trees by type, and (4) applying resource units to each tree.

Categorizing Trees by DBH Class

The first step in accomplishing this task involved categorizing the total number of street trees by relative age (as a function of DBH class). The inventory was used to group trees into the DBH classes described at the beginning of this chapter.

Next, the median value for each DBH class was determined and subsequently used as a single value to represent all trees in each class. For each DBH value and species, resource units were estimated using linear interpolation.

Applying Resource Units to Each Tree

The interpolated resource-unit values were used to calculate the total magnitude of benefits for each DBH class and species. For example, assume that there are 300 London planetrees citywide in the 30- to 36-inch DBH class. The interpolated electricity and natural gas resource unit values for the class midpoint (33 inch) were 199.3 kWh and 6,487.9 kBtu per tree, respectively. Therefore, multiplying the resource units for the class by 300 trees equals the magnitude of annual heating and cooling benefits produced by this segment of the population: 59,790 kWh of electricity saved and 1,946,370 kBtu of natural gas saved.

Matching Significant Species with Modeled Species

To extrapolate from the 21 municipal species modeled for growth to the entire inventoried tree population, each species representing over 1% of the population was matched with the modeled species that it most closely resembled. Less abundant species that were not matched were then grouped into the "Other" categories described below.

Grouping Remaining "Other" Trees by Type

The species that were less than 1% of the population were labeled "other" and were categorized according into classes based on tree type (one of four life forms and three mature sizes):

- Broadleaf deciduous: large (BDL), medium (BDM), and small (BDS).
- Broadleaf evergreen: large (BEL), medium (BEM), and small (BES).
- Coniferous evergreen: large (CEL), medium (CEM), and small (CES).
- Palm: large (PEL), medium (PEM), and small (PES).

Large, medium, and small trees were >50 ft, 35–50 ft, and < 35 ft in mature height, respectively. A typical tree was chosen to represent each of the above 12 categories to obtain growth curves for "other" trees falling into each of the categories:

BDL Other = Japanese zelkova (*Zelkova serrata*)

BDM Other = Red maple (*Acer rubrum*)

BDS Other = Kwanzan cherry (*Prunus serrulata*)

BEL Other = none in inventory

BEM Other = Southern magnolia (*Magnolia grandiflora*)

BES Other = American holly (*Ilex opaca*)

CEL Other = Eastern white pine (*Pinus strobus*)

CEM Other = Eastern red cedar (*Juniperus virginiana*)

CES Other = Bolander beach pine (*Pinus contorta* var. *bolanderi*)

PEL Other = Canary Island date palm (*Phoenix canariensis*)

PEM Other = Cabbage palm (*Sabal palmetto*)

PES Other = Jelly palm (*Butia capitata*)

When local data were not measured for certain categories (e.g., CES, PES), growth data from similar-sized species in a different region were used.

Calculating Net Benefits and Benefit-Cost Ratio

It is impossible to quantify all the benefits and costs produced by trees. For example, owners of property with large street trees can receive benefits from increased property values, but they may also benefit directly from improved health (e.g., reduced exposure to cancer-causing UV radiation) and greater psychological well-being through visual and direct contact with trees. On the cost side, increased health-care costs may be incurred because of nearby trees, due to allergies and respiratory ailments related to pollen. The values of many of these benefits and costs are difficult to determine. We assume that some of these intangible benefits and costs are reflected in what we term “property value and other benefits.” Other types of benefits we can only describe, such as the social, educational, and employment/training benefits associated with the city’s street tree resource. To some extent connecting people with their city trees reduces costs for health care, welfare, crime prevention, and other social service programs.

New York City residents can obtain additional economic benefits from street trees depending on tree location and condition. For example, street trees can provide energy savings by lowering wind velocities and subsequent building infiltration, thereby reducing heating costs. This benefit can extend to the neighborhood, as the aggregate effect of many street trees reduces wind speed and reduces citywide winter energy use. Neighborhood property values can be influenced by the extent of tree canopy cover on streets. The community benefits from cleaner air and water. Reductions in atmospheric CO_2 concentrations due to trees can have global benefits.

Net Benefits and Costs Methodology

To assess the total value of annual benefits (*B*) for each park and street tree (*i*) in each management area (*j*) benefits were summed (*Equation 3*):

where

$$B = \sum_{1}^{n} j \left[\sum_{1}^{n} i \left(e_{ij} + a_{ij} + c_{ij} + h_{ij} + p_{ij} \right) \right]$$

e = price of net annual energy savings = annual natural gas savings + annual electricity savings

a = price of annual net air quality improvement = PM_{10} interception + NO_2 and O_3 absorption + avoided power plant emissions – BVOC emissions

c = price of annual CO_2 reductions = CO_2 sequestered – releases + CO_2 avoided from reduced energy use

h = price of annual stormwater runoff reductions = effective rainfall interception

p = price of aesthetics = annual increase in property value

Total net expenditures were calculated based on all identifiable internal and external costs associated with the annual management of municipal trees citywide (Koch 2004). Annual costs for the municipality (*C*) were summed:

$$C = p + t + r + d + e + s + cl + l + a + q$$

p = annual planting expenditure

t = annual pruning expenditure

r = annual tree and stump removal and disposal expenditure

d = annual pest and disease control expenditure

e = annual establishment/irrigation expenditure

s = annual price of repair/mitigation of infrastructure damage

cl = annual price of litter/storm clean-up

l = average annual litigation and settlements expenditures due to tree-related claims

a = annual expenditure for program administration

q = annual expenditures for inspection/answer service requests

Total citywide annual net benefits as well as the benefit–cost ratio (BCR) were calculated using the sums of benefits and costs:

Citywide Net Benefits = *B* – *C* *Equation 4*

BCR = *B* / *C* *Equation 5*

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