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Forest Service

**Northern
Research Station**

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Assessing Urban Forest Effects and Values

New York City's Urban Forest

Northern
RESEARCH STATION
USDA Forest Service

UFORE
Urban Forest Effects Model

Abstract

An analysis of trees in New York City reveals that this city has about 5.2 million trees with canopies that cover 20.9 percent of the area. The most common tree species are tree of heaven, black cherry, and sweetgum. The urban forest currently stores about 1.35 million tons of carbon valued at $24.9 million. In addition, these trees remove about 42,300 tons of carbon per year ($779,000 per year) and about 2,202 tons of air pollution per year ($10.6 million per year). The structural, or compensatory, value is estimated at $5.2 billion. Information on the structure and functions of the urban forest can be used to improve and augment support for urban forest management programs and to integrate urban forests within plans to improve environmental quality in the New York City area.

The Authors

DAVID J. NOWAK is a research forester and project leader, ROBERT E. HOEHN III, is a biological sciences technician, DANIEL E. CRANE is an information technology specialist, JACK C. STEVENS is a forester, and JEFFREY T. WALTON is a research forester with the Forest Service's Northern Research Station at Syracuse, NY.

Photographs

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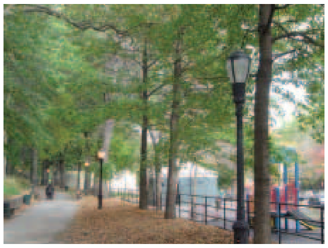


Urban forests provide numerous benefits to society, yet relatively little is known about this important resource.

In 1996, the UFORE model was used to survey and analyze New York City's urban forest.

The calculated environmental benefits of the urban forest are significant, yet many environmental and social benefits still remain to be quantified.

Executive Summary

Trees in cities can contribute significantly to human health and environmental quality. Unfortunately, little is known about the urban forest resource and what it contributes to the local and regional society and economy. To better understand the urban forest resource and its numerous values, the U.S. Forest Service, Northern Research Station, developed the Urban Forest Effects (UFORE) model. Results from this model are used to advance the understanding of the urban forest resource, improve urban forest policies, planning and management, provide data for potential inclusion of trees within environmental regulations, and determine how trees affect the environment and consequently enhance human health and environmental quality in urban areas.

Forest structure is a measure of various physical attributes of the vegetation, such as tree species composition, number of trees, tree density, tree health, leaf area, biomass, and species diversity. Forest functions, which are determined by forest structure, include a wide range of environmental and ecosystem services such as air pollution removal and cooler air temperatures. Forest values are an estimate of the economic worth of the various forest functions.

To help determine the vegetation structure, functions, and values of the urban forest in New York City, a vegetation assessment was conducted during the summer of 1996. For this assessment, one-tenth acre field plots were sampled and analyzed using the UFORE model. This report summarizes results and values of:

- Forest structure
- Potential risk to forest from insects or diseases
- Air pollution removal
- Carbon storage
- Annual carbon removal (sequestration)
- Changes in building energy use

New York City Urban Forest Summary

Feature	Measure
Number of trees	5.2 million
Tree cover	20.9%
Most common species	tree of heaven, black cherry, sweetgum
Percentage of trees < 6-inches diameter	42.7%
Pollution removal	2,202 tons/year ($10.6 million/year)
Carbon storage	1.35 million tons ($24.9 million)
Carbon sequestration	42,300 tons/year ($779,000/year)
Building energy reduction	$11.2 million/year
Avoided carbon emissions	$167,000/year
Structural value	$5.2 billion
Ton – short ton (U.S.) (2,000 lbs)	

Benefits ascribed to urban trees include:

- Air pollution removal
- Air temperature reduction
- Reduced building energy use
- Absorption of ultraviolet radiation
- Improved water quality
- Reduced noise
- Improved human comfort
- Increased property value
- Improved physiological & psychological well-being
- Aesthetics
- Community cohesion

Urban Forest Effects Model and Field Measurements

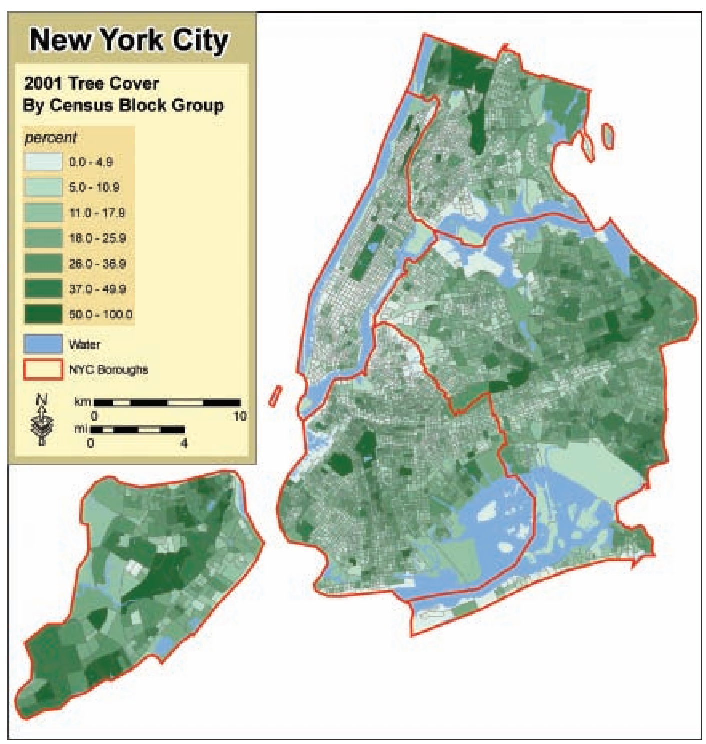
Though urban forests have many functions and values, currently only a few of these attributes can be assessed. To help assess the city's urban forest, data from 206 field plots located throughout the city were analyzed using the Forest Service's Urban Forest Effects (UFORE) model.[1]

UFORE is designed to use standardized field data from randomly located plots and local hourly air pollution and meteorological data to quantify urban forest structure and its numerous effects, including:

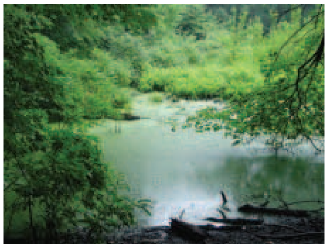
- Urban forest structure (e.g., species composition, tree density, tree health, leaf area, leaf and tree biomass, species diversity, etc.).
- Amount of pollution removed hourly by the urban forest, and its associated percent air quality improvement throughout a year. Pollution removal is calculated for ozone, sulfur dioxide, nitrogen dioxide, carbon monoxide and particulate matter (<10 microns).
- Total carbon stored and net carbon annually sequestered by the urban forest.
- Effects of trees on building energy use and consequent effects on carbon dioxide emissions from power plants.
- Compensatory value of the forest, as well as the value of air pollution removal and carbon storage and sequestration.
- Potential impact of infestations by Asian longhorned beetles, emerald ash borers, gypsy moth, and Dutch elm disease.

For more information go to http://www.ufore.org

In the field, one-tenth acre plots were randomly located in the different land use strata of New York City. Land uses were used to divide the analysis into smaller zones. The plots were divided among the following land uses: Commercial/Industrial (15 plots), Multi-Family Residential (10 plots), Open Space (45 plots), Public Facility (10 plots), 1-2 Family Residential (66 plots), Vacant Land (60 plots). This distribution allows for comparison among land uses.



Field data were collected for the Forest Service by ACRT Inc. (Appraisal, Consulting, Research, and Training, Akron, OH); data collection took place during the leaf-on season



Field Survey Data

Plot Information

- Land use type
- Percent tree cover
- Percent shrub cover
- Percent plantable
- Percent ground cover types
- Shrub species/ dimensions

Tree parameters

- Species
- Stem diameter
- Total height
- Height to crown base
- Crown width
- Percent foliage missing
- Percent dieback
- Distance and direction to buildings from trees

to properly assess tree canopies. Within each plot, data included land-use, ground and tree cover, shrub characteristics, and individual tree attributes of species, stem-diameter at breast height (d.b.h.; measured at 4.5 ft.), tree height, height to base of live crown, crown width, percentage crown canopy missing and dieback, and distance and direction to residential buildings.[2]

To calculate current carbon storage, biomass for each tree was calculated using equations from the literature and measured tree data. Open-grown, maintained trees tend to have less biomass than predicted by forest-derived biomass equations.[3] To adjust for this difference, biomass results for open-grown urban trees are multiplied by 0.8.[3] No adjustment is made for trees found in natural stand conditions. Tree dry-weight biomass was converted to stored carbon by multiplying by 0.5.

To estimate the gross amount of carbon sequestered annually, average diameter growth from the appropriate genera and diameter class and tree condition was added to the existing tree diameter (year x) to estimate tree diameter and carbon storage in year x+1.

Air pollution removal estimates are derived from calculated hourly tree-canopy resistances for ozone, and sulfur and nitrogen dioxides based on a hybrid of big-leaf and multi-layer canopy deposition models.[4, 5] As the removal of carbon monoxide and particulate matter by vegetation is not directly related to transpiration, removal rates (deposition velocities) for these pollutants were based on average measured values from the literature[6, 7] that were adjusted depending on leaf phenology and leaf area. Particulate removal incorporated a 50 percent resuspension rate of particles back to the atmosphere.[8]

Seasonal effects of trees on residential building energy use were calculated based on procedures described the literature[9] using distance and direction of trees from residential structures, tree height and tree condition data.

Compensatory values were based on valuation procedures of the Council of Tree and Landscape Appraisers, which uses tree species, diameter, condition and location information.[10]

To learn more about UFORE methods[11] visit:
http://www.nrs.fs.fed.us/UFORE/data/ or www.ufore.org

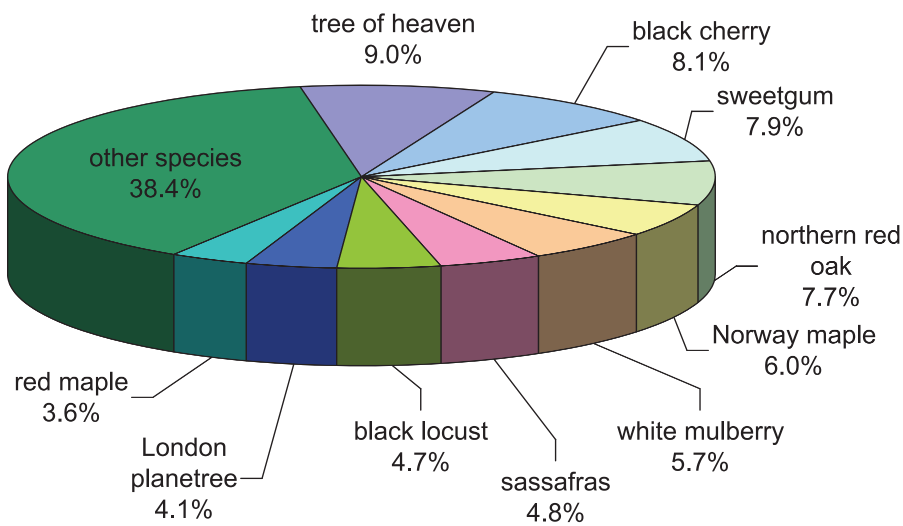
Tree Characteristics of the Urban Forest

The urban forest of New York City has an estimated 5.2 million trees with a tree cover of 20.9 percent. Trees that have diameters less than 6 inches account for 42.7 percent of the population. The three most common species in the urban forest are tree of heaven (9.0 percent), black cherry (8.1 percent), and sweetgum (7.9 percent). The 10 most common species account for 61.6 percent of all trees; their relative abundance is illustrated below.

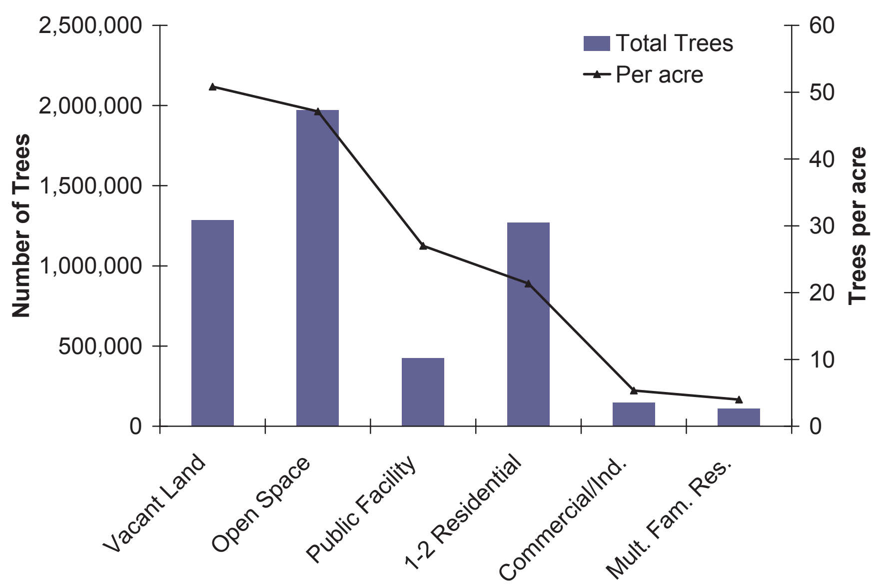
There are an estimated 5.2 million trees in New York City with canopies that cover 20.9 percent of the city.

The 10 most common species account for 61.6 percent of the total number of trees.

Tree density is highest in the vacant land, and lowest in the multifamily residential areas.

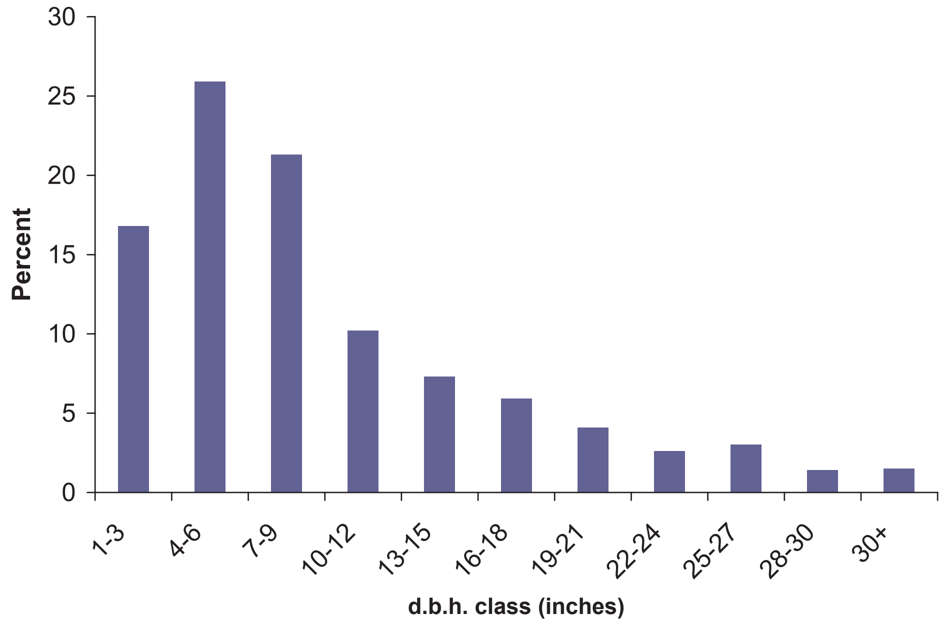


The highest density of trees occurs in Vacant Land (50.8 trees/acre), followed by Open Space (47.1 trees/acre) and Public Facility (27.0 trees/acre). The overall tree density in New York City is 26.4 trees/acre, which is comparable to other city tree densities (Appendix I), of 9.1 to 119.2 trees/acre..

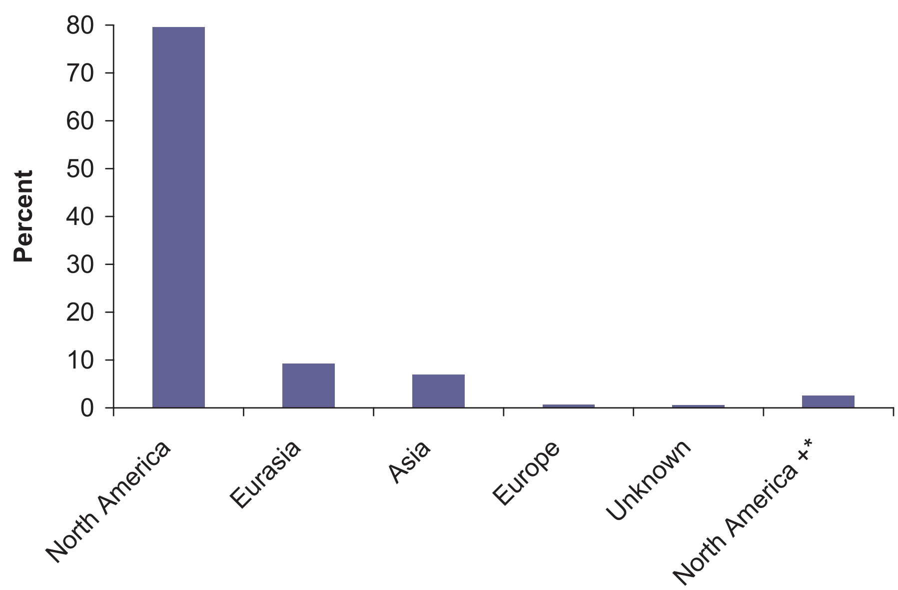


55 percent of the tree species in New York City are native to New York.

Urban forests are a mix of native tree species that existed prior to the development of the city and exotic species that were introduced by residents or other means



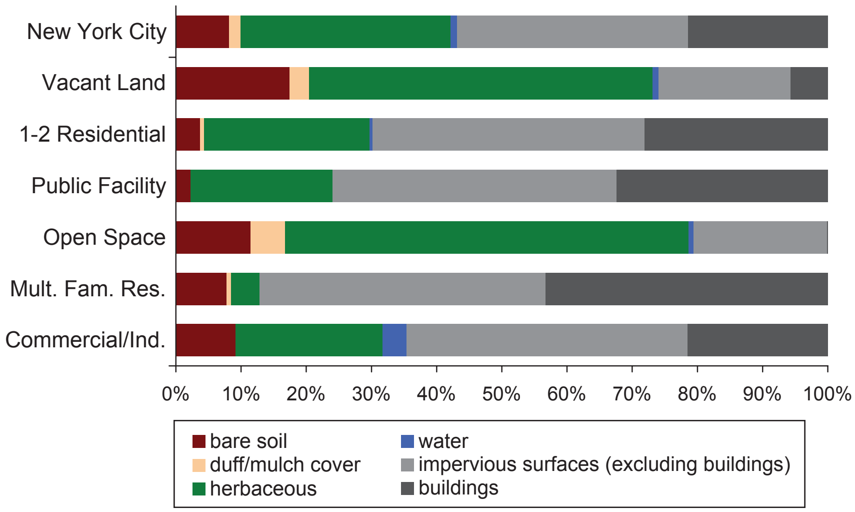
Urban forests are a mix of native tree species that existed prior to the development of the city and exotic species that were introduced by residents or other means. Thus, urban forests often have a tree diversity that is higher than surrounding native landscapes. An increased tree diversity can minimize the overall impact or destruction by a species-specific insect or disease, but the increase in the number of exotic plants can also pose a risk to native plants if some of the exotic species are invasive plants that can potentially out-compete and displace native species. In New York City, about 55 percent of the trees are from species native to the state of New York. Trees with a native origin outside of North America are mostly from Asia (15.5 percent of the species).



*North America + refers to tree species that are native to North America and one other continent.

Urban Forest Cover and Leaf Area

Trees cover about 20.9 percent of New York City, shrubs cover 6.1 percent of the city. Dominant ground cover types include impervious surfaces (excluding buildings) (e.g., driveways, sidewalks, parking lots) (33.3 percent), herbaceous (e.g., grass, gardens) (30.3 percent), and buildings (20.1 percent).



Healthy leaf area equates directly to tree benefits provided to the community.

London planetree has the greatest importance to the New York City urban forest based on relative leaf area and relative population.

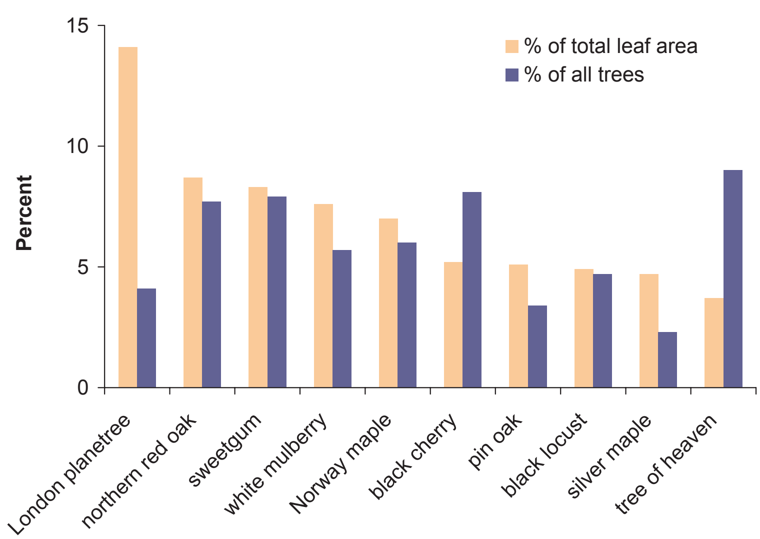
Many tree benefits are linked directly to the amount of healthy leaf surface area of the plant. In New York City, trees that dominate in terms of leaf area are London planetree, northern red oak, and sweetgum.

Tree species contributing a relatively large amount of leaf area per tree (typically larger trees) are London planetree, silver maple, and pin oak. Species contributing a relatively small amount of leaf area per tree (typically smaller trees) are black tupelo, honeylocust, and flowering dogwood.

The importance values (IV) are calculated using a formula that takes into account the relative leaf area and relative abundance. The most important species in the urban forest, according to calculated IVs, are London planetree, northern red oak, and sweetgum.

Common Name	% Pop[a]	% LA[b]	IV[c]
London planetree	4.1	14.1	18.2
northern red oak	7.7	8.7	16.4
sweetgum	7.9	8.3	16.2
white mulberry	5.7	7.6	13.3
black cherry	8.1	5.2	13.3
Norway maple	6.0	7.0	13.0
tree of heaven	9.0	3.7	12.7
black locust	4.7	4.9	9.6
pin oak	3.4	5.1	8.5
silver maple	2.3	4.7	7.0

[a] percent of population
[b] percent of leaf area
[c] Percent Pop + Percent LA



The urban forest of New York City removes approximately 2,202 tons of pollutants each year, with a societal value of $10.6 million/year.

General urban forest management recommendations to improve air quality are given in Appendix II.

Air Pollution Removal by Urban Trees

Poor air quality is a common problem in many urban areas. It can lead to human health problems, damage to landscape materials and ecosystem processes, and reduced visibility. The urban forest can help improve air quality by reducing air temperature, directly removing pollutants from the air, and reducing energy consumption in buildings, which consequently reduce air pollutant emissions from the power plants. Trees also emit volatile organic compounds that can contribute to ozone formation. However, integrative studies have revealed that an increase in tree cover leads to reduced ozone formation.[12]

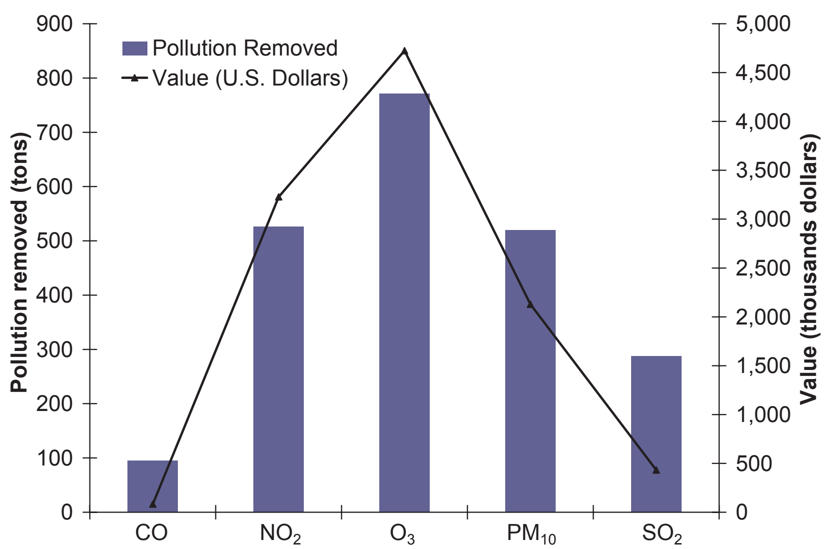
Pollution removal by trees and shrubs in New York City was estimated using the UFORE model in conjunction with field data and hourly pollution and weather data for the year 2000. Pollution removal was greatest for ozone (O_3), followed by nitrogen dioxide (NO_2), particulate matter less than ten microns (PM_{10}), sulfur dioxide (SO_2), and carbon monoxide (CO). It is estimated that trees and shrubs remove 2,202 tons of air pollution (CO, NO_2, O_3, PM_{10}, SO_2) per year with an associated value of $10.6 million (based on estimated national median externality costs associated with pollutants[13]). Trees remove about three times more air pollution than shrubs in New York City.

The average percentage of air pollution removal during the daytime, in-leaf season was estimated to be:

- O_3 0.50%
- SO_2 0.48%
- CO 0.002%
- PM_{10} 0.47%
- NO_2 0.31%

Peak 1-hour air quality improvements during the in-leaf season for heavily-treed areas were estimated to be:

- O_3 11.4%
- SO_2 11.3%
- CO 0.05%
- PM_{10} 10.9%
- NO_2 6.3%



Carbon storage:

Carbon currently held in tree tissue (roots, stems, and branches).

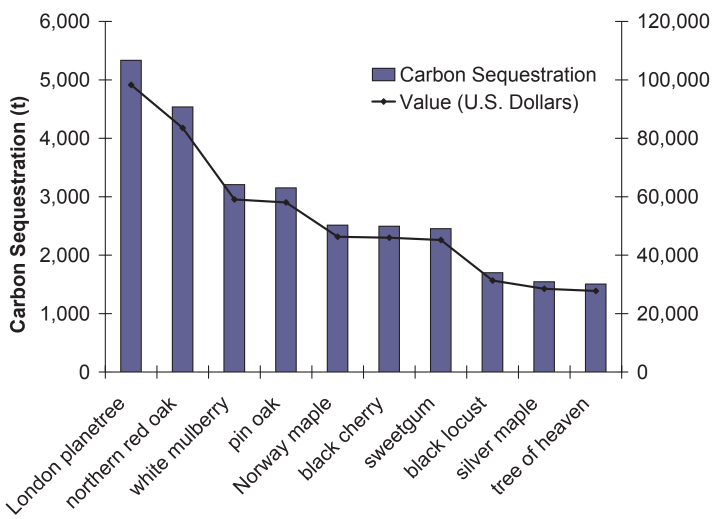
Carbon sequestration:

Estimated amount of carbon removed annually by trees. Net carbon sequestration can be negative if emission of carbon from decomposition is greater than amount sequestered by healthy trees.

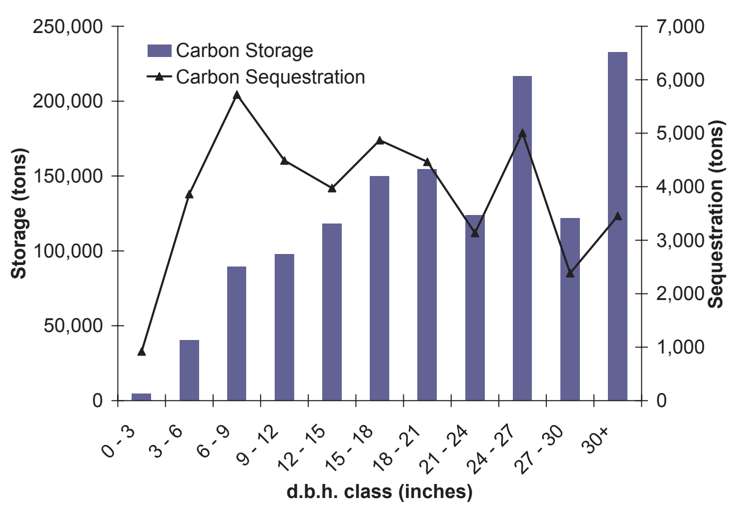
Carbon Storage and Sequestration

Climate change is an issue of global concern. Urban trees can help mitigate climate change by sequestering atmospheric carbon (from carbon dioxide) in tissue and by reducing energy use in buildings, and consequently reducing carbon dioxide emissions from fossil-fuel based power plants.[14]

Trees reduce the amount of carbon in the atmosphere by sequestering carbon in new tissue growth every year. The amount of carbon annually sequestered is increased with healthier trees and larger diameter trees. Gross sequestration by trees in New York City is about 42,300 tons of carbon per year with an associated value of $779,000. Net carbon sequestration in the New York City urban forest is about 22,900 tons.



Carbon storage by trees is another way trees can influence global climate change. As trees grow, they store more carbon by holding it in their accumulated tissue. As trees die and decay, they release much of the stored carbon back to the atmosphere. Thus, carbon storage is an indication of the amount of carbon that can be lost if trees are allowed to die and decompose. Trees in New York City are estimated to store 1.35 million tons of carbon ($24.9 million). Of all the species sampled, London planetree stores and sequesters the most carbon (approximately 13.7% of the total carbon stored and 12.6% of all sequestered carbon).



Trees Affect Energy Use in Buildings

Trees affect energy consumption by shading buildings, providing evaporative cooling, and blocking winter winds. Trees tend to reduce building energy consumption in the summer months and can either increase or decrease building energy use in the winter months, depending on the location of trees around the building. Estimates of tree effects on energy use are based on field measurements of tree distance and direction to space-conditioned residential buildings.[9]

Based on average energy costs in 2002 dollars, trees in New York City are estimated to reduce energy costs from residential buildings by $11.2 million annually. Trees also provide an additional $167,000 in value per year by reducing the amount of carbon released by fossil-fuel based power plants (a reduction of 9,100 tons of carbon emissions).

Trees affect energy consumption by shading buildings, providing evaporative cooling, and blocking winter winds.

Interactions between buildings and trees save an estimated $11.2 million in heating and cooling costs.

Lower energy use in residential buildings reduced carbon emissions from power plants by 9,100 tons ($167,000).

Annual energy savings due to trees near residential buildings

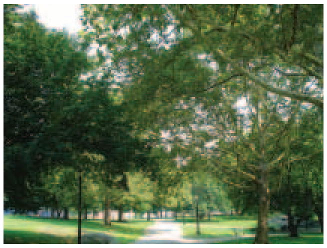
	Heating	Cooling	Total
MBTU[a]	-137,400	n/a	-137,400
MWH[b]	-1,900	82,900	81,000
Carbon avoided (t)	-2,600	11,700	9,100

[a]Million British Thermal Units
[b]Megawatt-hour

Annual savings[c] (U.S. $) in residential energy expenditures during heating and cooling seasons

	Heating	Cooling	Total
MBTU[a]	-1,263,000	n/a	-1,263,000
MWH[b]	-294,000	12,788,000	12,494,000
Carbon avoided	-49,000	216,300	167,000

[a]Million British Thermal Units
[b]Megawatt-hour
[c]Based on state-wide energy costs



Urban forests have a structural value based on the tree itself.

Urban forests also have functional values based on the functions the tree performs.

Large, healthy, long-lived trees provide the greatest structural and functional values.

A map of priority planting locations for New York City is found in Appendix IV.

A list of tree species found in New York City is in Appendix V.

Structural and Functional Values

Urban forests have a structural value based on the tree itself (e.g., the cost of having to replace the tree with a similar tree). The structural value[10] of the urban forest in New York City is about $5.2 billion. The structural value of an urban forest tends to increase with a rise in the number and size of healthy trees.

Urban forests also have functional values (either positive or negative) based on the functions the tree performs. Annual functional values also tend to increase with increased number and size of healthy trees, and are usually on the order of several million dollars per year. There are many other functional values of the urban forest, though they are not quantified here (e.g., reduction in air temperatures and ultra-violet radiation, improvements in water quality). Through proper management, urban forest values can be increased. However, the values and benefits also can decrease as the amount of healthy tree cover declines.

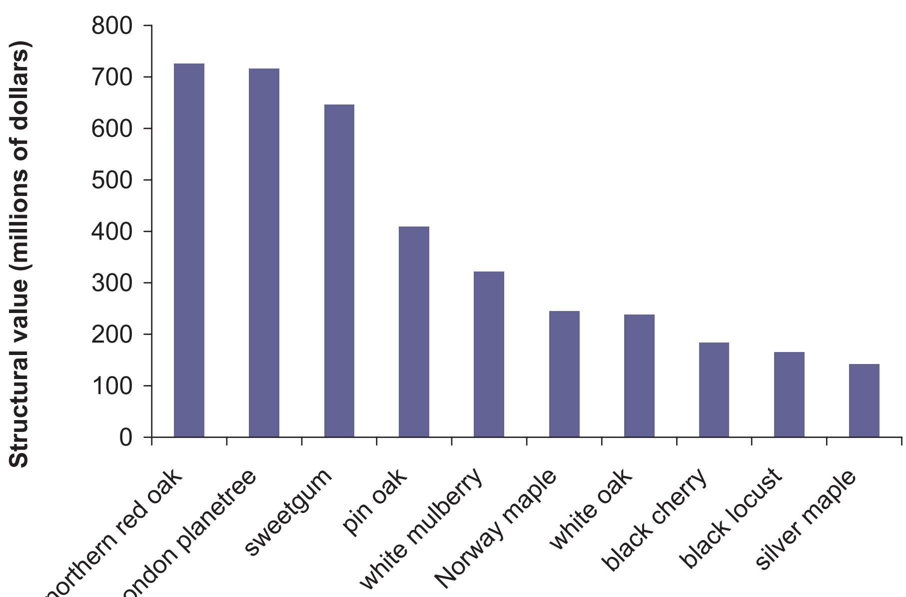
Structural values:

- Structural value: $5.2 billion
- Carbon storage: $24.9 million

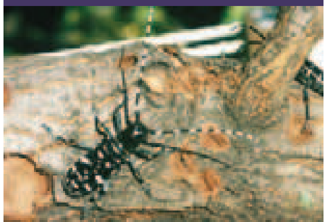
Annual functional values:

- Carbon sequestration: $779,000
- Pollution removal: $10.6 million
- Lower energy costs and reduces carbon emissions: $11.2 million

More detailed information on the urban forest in New York City can be found at http://www.nrs.fs.fed.us/UFORE/data. Additionally, information on other urban forest values can be found in Appendix I and information comparing tree benefits to estimates of average carbon emissions in the city, average automobile emissions, and average household emissions can be found in Appendix III.

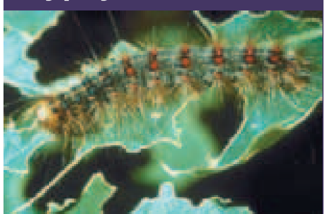


Asian longhorned beetle



Kenneth R. Law
USDA APHIS PPQ
(www.invasive.org)

Gypsy moth



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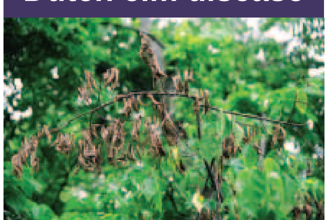
Emerald ash borer

David Cappaert
Michigan State University
(www.invasive.org)

Dutch elm disease



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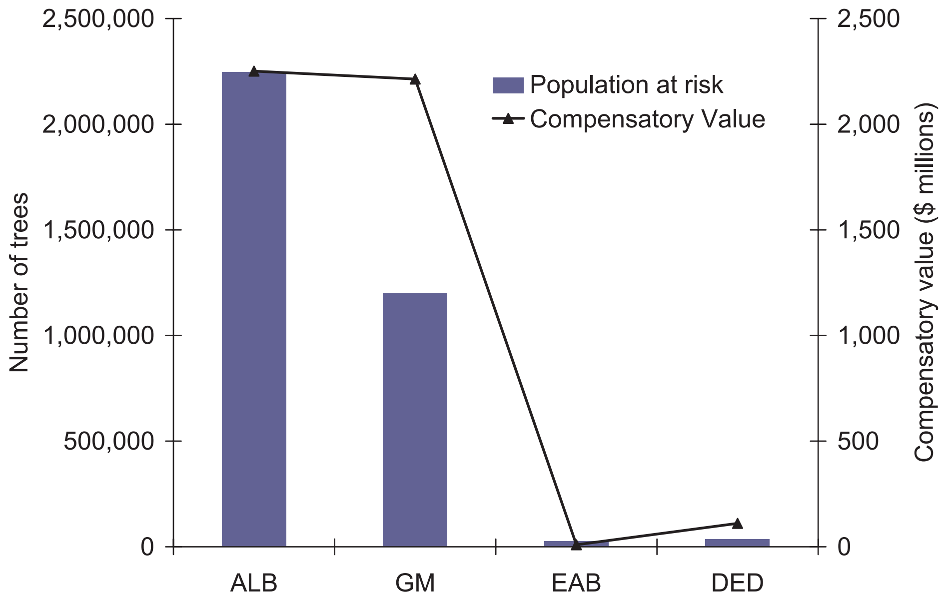
Potential Insect and Disease Impacts

Various insects and diseases can infest urban forests, potentially killing trees and reducing the health, value and sustainability of the urban forest. As various pests have differing tree hosts, the potential damage or risk of each pest will differ. Four exotic pests were analyzed for their potential impact: Asian longhorned beetle, gypsy moth, emerald ash borer, and Dutch elm disease.

The Asian longhorned beetle (ALB)[15] is an insect that bores into and kills a wide range of hardwood species. ALB represents a potential loss to the New York City urban forest of $2.25 billion in structural value (43.1 percent of the tree population).



The gypsy moth (GM)[16] is a defoliator that feeds on many species causing widespread defoliation and tree death if outbreak conditions last several years. This pest could potentially result in damage to or a loss of $2.21 billion in structural value (23.0 percent of the population).

Emerald ash borer (EAB)[17] has killed thousands of ash trees in Michigan, Ohio, and Indiana. EAB has the potential to affect 0.5 percent of the population ($9.8 million in structural value).

American elm, one of the most important street trees in the 20th century, has been devastated by Dutch elm disease (DED). Since first reported in the 1930s, it has killed more than 50 percent of the native elm population in the United States.[18] Although some elm species have shown varying degrees of resistance, New York City possibly could lose 0.7 percent of its trees to this disease ($111 million in structural value).

Appendix I. Comparison of Urban Forests

A commonly asked question is, "How does this city compare to other cities?" Although comparison among cities should be made with caution as there are many attributes of a city that affect urban forest structure and functions, summary data are provided from other cities analyzed using the UFORE model.

I. City totals, trees only

City	% Tree cover	Number of trees	Carbon storage (tons)	Carbon sequestration (tons/yr)	Pollution removal (tons/yr)	Pollution value U.S. $
Calgary, Canada[a]	7.2	11,889,000	445,000	21,400	326	1,611,000
Atlanta, GA[b]	36.7	9,415,000	1,344,000	46,400	1,663	8,321,000
Toronto, Canada[c]	20.5	7,542,000	992,000	40,300	1,212	6,105,000
New York, NY[b]	20.9	5,212,000	1,350,000	42,300	1,677	8,071,000
Baltimore, MD[d]	21.0	2,627,000	597,000	16,200	430	2,129,000
Philadelphia, PA[b]	15.7	2,113,000	530,000	16,100	576	2,826,000
Washington, DC[e]	28.6	1,928,000	526,000	16,200	418	1,956,000
Boston, MA[b]	22.3	1,183,000	319,000	10,500	284	1,426,000
Woodbridge, NJ[f]	29.5	986,000	160,000	5,560	210	1,037,000
Minneapolis, MN[g]	26.4	979,000	250,000	8,900	306	1,527,000
Syracuse, NY[d]	23.1	876,000	173,000	5,420	109	568,000
San Francisco, CA[a]	11.9	668,000	194,000	5,100	141	693,000
Morgantown, WV[h]	35.5	658,000	93,000	2,890	72	333,000
Moorestown, NJ[f]	28.0	583,000	117,000	3,760	118	576,000
Jersey City, NJ[f]	11.5	136,000	21,000	890	41	196,000
Freehold, NJ[f]	34.4	48,000	20,000	545	22	110,000

II. Per acre values of tree effects

City	No. of trees	Carbon Storage (tons)	Carbon sequestration (tons/yr)	Pollution removal (lbs/yr)	Pollution value U.S. $
Calgary, Canada[a]	66.7	2.5	0.12	3.7	9.0
Atlanta, GA[b]	111.6	15.9	0.55	39.4	98.6
Toronto, Canada[c]	48.3	6.4	0.26	15.5	39.1
New York, NY[b]	26.4	6.8	0.21	17.0	40.9
Baltimore, MD[d]	50.8	11.6	0.31	16.6	41.2
Philadelphia, PA[b]	25.1	6.3	0.19	13.6	33.5
Washington, DC[e]	49.0	13.4	0.41	21.3	49.7
Boston, MA[b]	33.5	9.1	0.30	16.1	40.4
Woodbridge, NJ[f]	66.5	10.8	0.38	28.4	70.0
Minneapolis, MN[g]	26.2	6.7	0.24	16.4	40.9
Syracuse, NY[d]	54.5	10.8	0.34	13.5	35.4
San Francisco, CA[a]	22.5	6.6	0.17	9.5	23.4
Morgantown, WV[h]	119.2	16.8	0.52	26.0	60.3
Moorestown, NJ[f]	62.1	12.4	0.40	25.1	61.3
Jersey City, NJ[f]	14.4	2.2	0.09	8.6	20.7
Freehold, NJ[f]	38.3	16.0	0.44	34.9	88.2

Data collection group

[a] City personnel
[b] ACRT, Inc.
[c] University of Toronto
[d] U.S. Forest Service
[e] Casey Trees Endowment Fund
[f] New Jersey Department of Environmental Protection
[g] Davey Resource Group
[h] West Virginia University

Appendix II. General Recommendations for Air Quality Improvement

Urban vegetation can directly and indirectly affect local and regional air quality by altering the urban atmospheric environment. Four main ways that urban trees affect air quality are:

Temperature reduction and other microclimatic effects
Removal of air pollutants
Emission of volatile organic compounds (VOC) and tree maintenance emissions
Energy conservation in buildings and consequent power plant emissions

The cumulative and interactive effects of trees on climate, pollution removal, and VOC and power plant emissions determine the overall impact of trees on air pollution. Cumulative studies involving urban tree impacts on ozone have revealed that increased urban canopy cover, particularly with low VOC emitting species, leads to reduced ozone concentrations in cities. Local urban forest management decisions also can help improve air quality.

Urban forest management strategies to help improve air quality include:

Strategy	Reason
Increase the number of healthy trees	Increase pollution removal
Sustain existing tree cover	Maintain pollution removal levels
Maximize use of low VOC-emitting trees	Reduces ozone and carbon monoxide formation
Sustain large, healthy trees	Large trees have greatest per-tree effects
Use long-lived trees	Reduce long-term pollutant emissions from planting and removal
Use low maintenance trees	Reduce pollutants emissions from maintenance activities
Reduce fossil fuel use in maintaining vegetation	Reduce pollutant emissions
Plant trees in energy conserving locations	Reduce pollutant emissions from power plants
Plant trees to shade parked cars	Reduce vehicular VOC emissions
Supply ample water to vegetation	Enhance pollution removal and temperature reduction
Plant trees in polluted or heavily populated areas	Maximizes tree air quality benefits
Avoid pollutant-sensitive species	Improve tree health
Utilize evergreen trees for particulate matter	Year-round removal of particles

Appendix III. Relative Tree Effects

The urban forest in New York City provides benefits that include carbon storage and sequestration, and air pollutant removal. To estimate a relative value of these benefits, tree benefits were compared to estimates of average carbon emissions in the city[19], average passenger automobile emissions[20], and average household emissions.[21]

General tree information:

Average tree diameter (d.b.h.) = 9.2 in.
Median tree diameter (d.b.h.) = 6.8 in.
Average number of trees per person = 0.6
Number of trees sampled = 643
Number of species sampled = 65

Average tree effects by tree diameter:

	Carbon storage			Carbon sequestration			Pollution removal	
D.b.h. Class (inch)	(lbs)	($)	(miles) [a]	(lbs/yr)	($/yr)	(miles)[a]	(lbs)	($)
1-3	11	0.10	40	201	0.02	8	0.1	0.26
3-6	60	0.55	220	5.7	0.05	21	0.2	0.53
6-9	160	1.47	590	10.3	0.09	38	0.5	1.20
9-12	367	3.38	1,340	16.8	0.15	62	0.2	0.44
12-15	630	5.80	2,310	21.2	0.19	78	0.8	1.91
15-18	968	8.91	3,540	31.4	0.29	115	1.8	4.33
18-21	1,478	13.61	5,410	42.7	0.39	156	1.8	4.26
21-24	1,798	16.56	6,590	45.6	0.42	167	2.1	5.05
24-27	2,775	25.56	10,160	64.1	0.59	235	2.1	5.11
27-30	3,346	30.82	12,260	65.3	0.60	239	3.1	7.51
30+	6,536	60.20	23,940	96.9	0.89	355	3.2	7.76

[a] miles = number of automobile miles driven that produces emissions equivalent to tree effect

New York City urban forest provides:

Carbon storage equivalent to:
Amount of carbon (C) emitted in city in 10 days or
Annual carbon emissions from 811,000 automobiles or
Annual C emissions from 407,000 single family houses

Carbon monoxide removal equivalent to:
Annual carbon monoxide emissions from 294 automobiles or
Annual carbon monoxide emissions from 1,200 single family houses

Nitrogen dioxide removal equivalent to:
Annual nitrogen dioxide emissions from 25,400 automobiles or
Annual nitrogen dioxide emissions from 16,900 single family houses

Sulfur dioxide removal equivalent to:
Annual sulfur dioxide emissions from 320,570 automobiles or
Annual sulfur dioxide emissions from 5,400 single family houses

Particulate matter less than 10 micron (PM_{10}) removal equivalent to:
Annual PM_{10} emissions from 1,039,500 automobiles or
Annual PM_{10} emissions from 100,300 single family houses

Annual C sequestration equivalent to:
Amount of C emitted in city in 0.3 days or
Annual C emissions from 25,400 automobiles or
Annual C emissions from 12,700 single family homes

Appendix IV. Tree Planting Index Map

To determine the best locations to plant trees, tree canopy and impervious cover maps from National Land Cover Data[22] were used in conjunction with 2000 U.S. Census data to produce an index of priority planting areas. Index values were produced for each census block with the higher the index value, the higher the priority of the area for tree planting. This index is a type of "environmental equity" index with areas with higher human population density and lower tree cover tending to get the higher index value. The criteria used to make the index were:

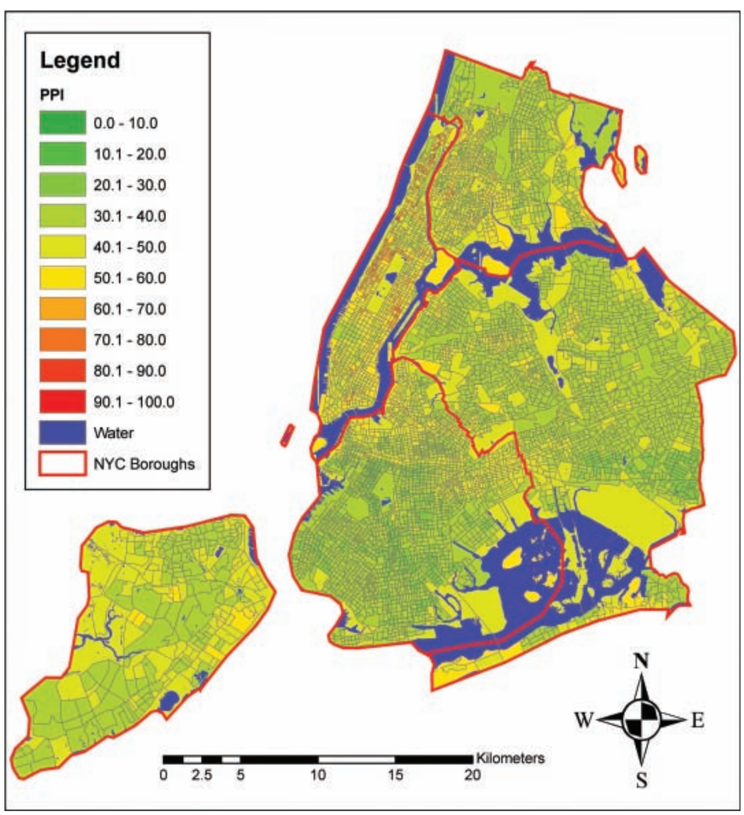
- Population density: the greater the population density, the greater the priority for tree planting
- Tree stocking levels: the lower the tree stocking level (the percent of available greenspace (tree, grass, and soil cover areas) that is occupied by tree canopies), the greater the priority for tree planting
- Tree cover per capita: the lower the amount of tree canopy cover per capita (m^2/capita), the greater the priority for tree planting

Each criteria was standardized[23] on a scale of 0 to 1 with 1 representing the census block with the highest value in relation to priority of tree planting (i.e., the census block with highest population density, lowest stocking density or lowest tree cover per capita were standardized to a rating of 1). Individual scores were combined and standardized based on the following formula to produce an overall priority index value between 0 and 100:

$$I = (PD * 40) + (TS * 30) + (TPC * 30)$$

Where I = index value, PD is standardized population density, TS is standardized tree stocking, and TPC is standardized tree cover per capita. The index can be used with other tree cover analyses[24] to help guide New York City's tree canopy cover.

New York City



Appendix V. List of Species Sampled in New York City

Genus	Species	Common Name	% Population	% Leaf Area	IV[a]	Potential pest[b] ALB	GM	EAB	DED
Acer	negundo	boxelder	1.8	1.1	2.9	▲			
Acer	palmatum	Japanese maple	1.2	1.3	2.5	▲			
Acer	platanoides	Norway maple	6.0	7.0	13.0	▲			
Acer	pseudoplatanus	sycamore maple	1.6	1.5	3.1	▲			
Acer	rubrum	red maple	3.6	3.0	6.6	▲			
Acer	saccharinum	silver maple	2.3	4.7	7.0	▲			
Acer	saccharum	sugar maple	0.3	0.2	0.5	▲			
Ailanthus	altissima	tree of heaven	9.0	3.7	12.7				
Amelanchier	species	serviceberry	0.1	0.0	0.1				
Betula	populifolia	gray birch	0.2	0.1	0.3	▲	▲		
Carpinus	caroliniana	American hornbeam	0.2	0.1	0.3				
Carya	glabra	pignut hickory	0.2	0.1	0.3				
Carya	tomentosa	mockernut hickory	0.4	0.1	0.5				
Celtis	occidentalis	northern hackberry	0.6	0.1	0.7				
Cornus	florida	flowering dogwood	1.2	0.4	1.6				
Crataegus	species	hawthorn	0.5	0.1	0.6		▲		
Euonymus	species	euonymus	0.7	0.1	0.8				
Fagus	grandifolia	American beech	0.3	0.8	1.1				
Fagus	sylvatica	European beech	0.1	0.1	0.2				
Fraxinus	americana	white ash	0.2	0.3	0.5	▲		▲	
Fraxinus	pennsylvanica	green ash	0.4	0.0	0.4	▲		▲	
Gleditsia	triacanthos	honeylocust	2.3	0.8	3.1				
Hibiscus	syriacus	rose-of-sharon	0.2	0.0	0.2	▲			
Juglans	nigra	black walnut	0.5	0.7	1.2				
Koelreuteria	paniculata	goldenrain tree	0.4	0.0	0.4				
Liquidambar	styraciflua	sweetgum	7.9	8.3	16.2		▲		
Liriodendron	tulipifera	tulip tree	0.7	1.1	1.8				
Magnolia	species	magnolia	0.2	0.4	0.6				

Continued

Appendix V continued.

Genus	Species	Common Name	% Population	% Leaf Area	IV[a]	Potential pest[b] ALB	GM	EAB	DED
Malus	pumila	apple	1.2	1.1	2.3	▲	▲		
Malus	species	crabapple	0.2	0.2	0.4	▲	▲		
Morus	alba	white mulberry	5.7	7.6	13.3				
Nyssa	sylvatica	black tupelo	2.0	0.7	2.7				
Other	Species	other species - including dead	0.8	0.0	0.8				
Paulownia	tomentosa	royal paulownia	1.0	0.5	1.5				
Picea	abies	Norway spruce	0.5	0.8	1.3				
Picea	pungens	blue spruce	0.4	0.2	0.6				
Pinus	nigra	Austrian pine	0.3	0.4	0.7				
Pinus	strobus	eastern white pine	0.3	1.0	1.3				
Platanus	acerifolia	London planetree	4.1	14.1	18.2	▲			
Platanus	occidentalis	American sycamore	0.6	1.0	1.6	▲			
Populus	alba	white poplar	0.5	0.1	0.6	▲			
Populus	balsamifera	balsam poplar	0.3	0.2	0.5	▲	▲		
Populus	deltoides	eastern cottonwood	1.2	0.6	1.8	▲			
Prunus	cerasifera	cherry plum	0.2	0.1	0.3	▲			
Prunus	persica	nectarine	0.2	0.0	0.2	▲			
Prunus	serotina	black cherry	8.1	5.2	13.3	▲			
Prunus	serrulata	Kwanzan cherry	0.5	0.3	0.8	▲			
Prunus	species	cherry	2.6	1.5	4.1	▲			
Pyrus	communis	common pear	0.9	0.2	1.1	▲			
Quercus	alba	white oak	1.2	1.0	2.2		▲		
Quercus	bicolor	swamp white oak	0.1	0.1	0.2		▲		
Quercus	macrocarpa	bur oak	0.2	0.1	0.3		▲		
Quercus	palustris	pin oak	3.4	5.1	8.5		▲		
Quercus	rubra	northern red oak	7.7	8.7	16.4		▲		
Quercus	stellata	post oak	0.2	0.0	0.2		▲		
Quercus	velutina	black oak	0.7	0.3	1.0		▲		

Continued

Appendix V continued.

Genus	Species	Common Name	% Population	% Leaf Area	IV[a]	Potential pest [b] ALB	GM	EAB	DED
Robinia	pseudoacacia	black locust	4.7	4.9	9.6	▲			
Sassafras	albidum	sassafras	4.8	2.1	6.9				
Sorbus	aucuparia	European mountain ash	0.2	0.0	0.2		▲		
Taxus	species	yew	0.2	0.2	0.4				
Thuja	occidentalis	northern white cedar	0.2	0.1	0.3				
Tilia	americana	American basswood	0.2	0.1	0.3	▲	▲		
Tilia	cordata	littleleaf linden	0.3	0.4	0.7	▲	▲		
Tsuga	canadensis	eastern hemlock	0.5	0.0	0.5				
Ulmus	americana	American elm	0.7	3.6	4.3	▲			▲
Ulmus	pumila	Siberian elm	0.4	1.4	1.8	▲			

[a] IV = importance value (% population + % leaf area)

[b] ALB = Asian longhorned bettel; GM = gypsy moth; EAB = emerald ash borer; DED = Dutch elm disease

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Explanation of Calculations of Appendix III and IV

19 Total city carbon emissions were based on 2003 U.S. per capita carbon emissions, calculated as total U.S. carbon emissions (Energy Information Administration, 2003, Emissions of Greenhouse Gases in the United States 2003. http://www.eia.doe.gov/oiaf/1605/1605aold.html) divided by 2003 total U.S. population (www.census.gov). Per capita emissions were multiplied by Minneapolis population to estimate total city carbon emissions.

20 Average passenger automobile emissions per mile were based on dividing total 2002 pollutant emissions from light-duty gas vehicles (National Emission Trends http://www.epa.gov/ttn/chief/trends/index.html) by total miles driven in 2002 by passenger cars (National Transportation Statistics http://www.bts.gov/publications/national_transportation_statistics/2004/).

Average annual passenger automobile emissions per vehicle were based on dividing total 2002 pollutant emissions from light-duty gas vehicles by total number of passenger cars in 2002 (National Transportation Statistics http://www.bts.gov/publications/national_transportation_statistics/2004/).

Carbon dioxide emissions from automobiles assumed 6 pounds of carbon per gallon of gasoline with energy costs of refinement and transportation included (Graham, R.L.; Wright, L.L.; Turhollow, A.F. 1992. The potential for short-rotation woody crops to reduce U.S. CO_2 emissions. Climatic Change. 22:223-238.)

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23 Standardized value for population density was calculated as:

$$PD = (n - m)/r$$

where:
PD is the value (0-1)
n is the value for the census block (population/km^2)
m is the minimum value for all census blocks, and
r is the range of values among all census blocks (maximum value – minimum value).

Standardized value for tree stocking was calculated as :

$$TS = (1 - (T/(T+G))$$

where:
TS is the value (0-1)
T is percent tree cover, and
G is percent grass cover.

Standardized value for tree cover per capita was calculated as:

$$TPC = 1 - [(n - m)/r]$$

where:
TPC is the value (0-1)
n is the value for the census block (m^2/capita)
m is the minimum value for all census blocks, and
r is the range of values among all census blocks (maximum value – minimum value).

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An analysis of trees in New York City reveals that this city has about 5.2 million trees with canopies that cover 20.9 percent of the area. The most common tree species are tree of heaven, black cherry, and sweetgum. The urban forest currently stores about 1.35 million tons of carbon valued at $24.9 million. In addition, these trees remove about 42,300 tons of carbon per year ($779,000 per year) and about 2,202 tons of air pollution per year ($10.6 million per year). The structural, or compensatory, value is estimated at $5.2 billion. Information on the structure and functions of the urban forest can be used to improve and augment support for urban forest management programs and to integrate urban forests within plans to improve environmental quality in the New York City area.

KEY WORDS**:** urban forestry, ecosystem services, air pollution removal, carbon sequestration, tree value

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