United States Department of Agriculture

The Urban Forest of New York City

Forest Service

Northern Research Station

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Abstract

An analysis of the urban forest in New York, New York, reveals that this city has an estimated 7.0 million trees (encompassing all woody plants greater than one-inch diameter at breast height [d.b.h.]) with tree canopy that covers 21 percent of the city. The most common tree species across public and private land are Norway maple, northern white-cedar, tree-of-heaven, sassafras, and white oak, but the most dominant species in terms of leaf area are Norway maple, London planetree, black locust, pin oak, and red maple. Trees in New York City currently store about 1.2 million tons of carbon (4.2 million tons carbon dioxide [CO_2]) valued at $153 million. In addition, these trees remove about 51,000 tons of carbon per year (186,000 tons CO_2/year) ($6.8 million per year) and about 1,100 tons of air pollution per year ($78 million per year). New York City's urban forest is estimated to reduce annual residential energy costs by $17.1 million per year and reduce runoff by 69 million cubic feet/year ($4.6 million/year). The compensatory value of the trees is estimated at $5.7 billion. The information presented in this report can be used by local organizations to advance urban forest policies, planning, and management to improve environmental quality and human health in New York City. The analyses also provide a basis for monitoring changes in the urban forest over time.

Cover Photos

Front, View from Freshkills Park. Photo by Richard Hallett, USDA Forest Service. Back, cherry tree on the High Line in Manhattan. Photo by D.S. Novem Auyeung, used wtih permission.

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Email: nrspubs@fs.fed.us

The Urban Forest of New York City

The Authors

DAVID J. NOWAK is a senior scientist and i-Tree team leader with the U.S. Forest Service's Northern Research Station at Syracuse, New York.

ALLISON R. BODINE is a former research forester with Davey Tree's Davey Institute at Syracuse, New York.

ROBERT E. HOEHN III is a forester with the U.S. Forest Service's Northern Research Station at Syracuse, New York.

ALEXIS ELLIS is a research urban forester with Davey Tree's Davey Institute at Syracuse, New York.

SATOSHI HIRABAYASHI is an environmental modeler with Davey Tree's Davey Institute at Syracuse, New York.

ROBERT COVILLE is an urban forest hydrology specialist with Davey Tree's Davey Institute at Syracuse, New York.

D.S. NOVEM AUYEUNG is a senior scientist with the NYC Department of Parks and Recreation at New York, New York.

NANCY FALXA SONTI is an ecologist with the U.S. Forest Service's Northern Research Station at Baltimore, Maryland.

RICHARD A. HALLETT is a research ecologist with the U.S. Forest Service's Northern Research Station at New York, New York.

MICHELLE L. JOHNSON is an interdisciplinary research scientist with the U.S. Forest Service's Northern Research Station at New York, New York.

EMILY STEPHAN is a former research assistant with the SUNY College of Environmental Science and Forestry at Syracuse, New York.

TOM TAGGART is a former research assistant with the SUNY College of Environmental Science and Forestry at Syracuse, New York.

TED ENDRENY is a professor with the SUNY College of Environmental Science and Forestry at Syracuse, New York.

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Street trees in Staten Island near a residential area. Photo by D.S. Novem Auyeung, used with permission.

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Trees in Forest Park, Queens. Photo by Alaine Ball, USDA Forest Service.

EXECUTIVE SUMMARY

The urban forest in New York City contributes to local environmental quality and human health. The urban forest resource, as defined in this report, is made up of all the trees within the city limits. Urban greening programs that are sponsored locally, such as MillionTreesNYC and Cool Neighborhoods NYC, are investing in tree planting campaigns in an effort to improve the city's environment and provide equal access to green space for all people in the city. However, there are mounting threats from insects, diseases, invasive plant species, climate change, development, and changing infrastructure that are negatively affecting urban forest resources. Addressing the challenge of developing a sustainable and healthy urban forest is complicated by a diversity of tree species, their dynamic characteristics, a fragmented ownership pattern, and a lack of comprehensive information about the urban forest resource. To address these critical information needs, the USDA Forest Service assessed New York City's trees to quantify its urban forest structure, and the associated services and values provided to society. This assessment consisted of field data collection and model analyses to inform and improve urban forest management. The methods and tools used for this assessment have also been used to assess the urban forest in Baltimore, Phildelphia, and many other cities in the United States and abroad. Thus, this assessment is part of a larger set of urban forest assessments happening globally.

The i-Tree Eco model (www.itreetools.org) was one of the tools used to advance the understanding of New York City's urban forest. i-Tree Eco is a software application that uses data to quantify forest structure, environmental effects, and value to communities. This computer model quantifies forest structure and associated ecosystem services and monetary values based on local data. Structure is a measure of physical attributes of the forest (e.g., species composition, number of trees, tree health, leaf area, species diversity). Ecosystem services are determined by forest structure and include such attributes as air pollution removal and reductions in air temperatures. Monetary values then are estimated for various ecosystem services.

To assess New York City's urban forest and establish a baseline for future monitoring, field data were collected during the summer of 2013 and processed and analyzed using the i-Tree Eco model. A total of 296 one-tenth-acre field plots were sampled throughout the city. This report summarizes the results of this study (Table 1), including analysis of the field data, model outputs, and management implications for New York City. i-Tree Eco results are also compared with a previous urban forest assessment from 1996 (Nowak et al. 2007) and the results from the Natural Areas Conservancy's Ecological Assessment of forested parkland (Forgione et al. 2016).

Table 1.—Summary of urban forest features, New York City, 2013

Feature	Estimate
Number of trees[a]	6,977,000
Tree cover	21%[b]
Most dominant species by:	
Number of trees	Norway maple, northern white-cedar, tree-of-heaven, sassafras, white oak
Leaf area	Norway maple, London planetree, black locust, pin oak, red maple
Trees 1-6 inches d.b.h.	69.7%
Air temperature reduction[c]	0.13 °F
Average UV radiation reduction[d]	25.1%
Pollution removal	1,100 tons/year ($77.9 million/year)
VOC emissions	804 tons/year
Avoided runoff	69 million cubic feet/year ($4.6 million/year)
Carbon storage	1.2 million tons ($153 million)
Carbon sequestration	51,000 tons/year ($6.8 million/year)
Value of reduced building energy use	$17.1 million/year
Value of reduced carbon emissions	$1.6 million/year
Compensatory value[e]	$5.7 billion

[a] all woody vegetation >1 inch diameter
[b] assessed using LiDAR in an earlier report (O'Neil-Dunne 2012)
[c] Average daytime (6 a.m.–5 p.m.) air temperature reduction on the average temperature summer day (7/23/2008)
[d] noon-time conditions
[e] Estimated value of compensation for the loss of the urban forest structure (a value of the forest's physical structure)
Note: ton = short ton (U.S.) (2,000 pounds)

Participants at an event at Joyce Kilmer Park in the Bronx celebrating the planting of 1 million trees in New York City in 2015. Photo by NYC Parks, used with permission.

BACKGROUND

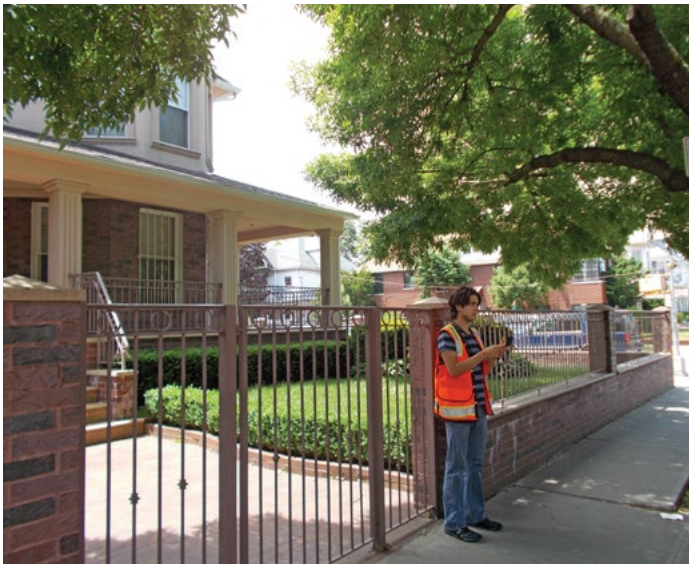
This report is a product of the New York City Urban Field Station1, a partnership between the USDA Forest Service Northern Research Station (Forest Service), New York City Department of Parks and Recreation (NYC Parks), and the nonprofit Natural Areas Conservancy2 (NAC). The NYC Urban Field Station, in addition to field stations in Baltimore, Chicago, and Philadelphia, grew from a commitment within the Forest Service to study the forests where most Americans live and work—in urban landscapes. The NYC Urban Field Station's goals are to foster collaborative science, science-delivery, and tools to assist partner organizations with natural resource management in the greater New York City region.

Urban trees are a vital component of New York City's infrastructure, providing numerous benefits to human health and environmental quality. Since the 1990s, the City of New York has supported citywide inventories aimed at quantifying the benefits of the urban forest, which is defined in this report as all trees in the city including street trees, trees in public parklands, as well as trees on private properties. A 1996 assessment used the Urban Forest Effects (UFORE) computer model, a precursor to the current i-Tree Eco computer model developed by the Forest Service. This report found that New York City trees store 1.35 million tons of carbon (valued at $24.9 million) and remove 42,300 tons of carbon per year (valued at $779,000 per year) and 2,202 tons of air pollution per year (valued at $10.6 million per year) (Nowak et al. 2007). Similarly, using data from the NYC Parks's 1995 street tree census, Forest Service scientists quantified the benefits provided by street trees using the Street Tree Resource Assessment Tool for Urban Forest Managers (STRATUM), a precursor to the current i-Tree Streets model. They found that New York City street trees produce annual benefits totaling $121.9 million based on their ability to store and sequester carbon, reduce air pollution, intercept stormwater, and improve aesthetics and property values (Peper et al. 2007). An updated analysis using data from NYC Parks's 2015–2016 street tree census found that street trees currently produce annual benefits totaling $151.2 million (New York City Department of Parks and Recreation 2016). These reports played an important role in the creation of programs like MillionTreesNYC, which was launched in 2007 and led to the successful planting of 1 million trees on public, private, and commercial land by 2015.

In addition to these models, the City of New York and its partners continually assess different aspects of the city's urban forest as it changes over time. Variables of interest include tree species and size class distribution, spatial distribution of trees, tree health, and ecosystem services. Since 1995, the NYC Parks's decadal street tree censuses have documented the location and species of all street trees. Data from the most recent 2015 street tree census are publicly available through an online report (New York Parks and Recreation 2016) and interactive map known as the NYC Street Tree Map (https://

[1] For more information about the New York City Urban Field Station, visit http://www.nrs.fs.fed.us/nyc.

[2] For more information about the Natural Areas Conservancy, visit http://www.naturalareasnyc.org.



Field data collection in New York City. Photo by Richard Hallett, USDA Forest Service.

tree-map.nycgovparks.org/), which provides detailed information on the structure, composition, ecosystem service value, and stewardship activity of trees along the public rights-of-way. Urban tree canopy cover analyses conducted by the Forest Service and the Spatial Analysis Laboratory of the University of Vermont in 2006, 2010, and 2017 monitor tree canopy using LiDAR data (Grove et al. 2006, O'Neil-Dunne 2012). New York City was also part of a multi-city study of tree cover change using paired aerial photographs from 2004 and 2009 (Nowak and Greenfield 2012). The Natural Areas Conservancy's ecological cover type map (O'Neil-Dunne et al. 2014) and upland forest ecological assessment in 2013-2014 (Forgione et al. 2016) provide landscape level information on land cover types citywide and plot level information on forested areas in New York City parks, respectively. A subset of the data from the upland forest assessment is included in this report and provides insight into the forest structure, composition, and value specifically in areas that are part of NYC Parks's "Forever Wild" program, which was created in 2001 to protect nearly 9,000 acres of forests, wetlands, and meadows citywide.

In response to continued interest from NYC Parks and as an update to the 1996 UFORE assessment, the Forest Service established and measured permanent plots in 2013 to analyze New York City's urban forest using the i-Tree Eco model. This report summarizes these findings and lays the foundation for future data collection to monitor changes in the urban forest over time. This report also provides information on the spatial distribution of urban tree benefits and examines how these benefits vary across the city's five boroughs and 71 community districts.3 The goal of this study is to provide information relevant to the sustainable and equitable management of New York City's urban forest (e.g., Design Trust for Public Space 2010, New York City Department of Parks and Recreation 2014).

[3] Large neighborhood areas defined by the New York City Department of City Planning

METHODS

Two analyses were conducted for New York City: 1) urban tree cover variation based on remote sensing, and 2) urban forest structure, ecosystem services, and values based on field plot data and remotely-sensed tree cover data where specified. In addition, the i-Tree Hydro model was used to predict effects of tree cover and impervious surface on stream flow in the Bronx River watershed. The methods and results of the Bronx River watershed analysis are discussed in appendix 1.

Tree Cover Assessment

New York City's tree cover estimates were derived from 2010 LiDAR and high resolution aerial imagery processed by the University of Vermont's Spatial Analytics Lab (O'Neil-Dunne 2012). Tree cover was defined as leaf area from vegetation at a height of 8 feet or greater. A tree cover map was created from the imagery and used to estimate tree cover at the community district and neighborhood level using a geographic information system (GIS).

Urban Forest Composition, Structure, and Values

To help assess the urban forest, data were collected in 2013 on field plots located within the boundaries of New York City and analyzed using the i-Tree Eco model (Nowak and Crane 2000, Nowak et al. 2008). The i-Tree Eco model uses standardized field data and local hourly air pollution and meteorological data to quantify forest structure and its numerous effects, including:

- Species composition
- Tree density
- Leaf area and biomass
- Air pollution removal
- Carbon storage
- Annual carbon sequestration
- Changes in building energy use
- Compensatory value
- Potential risk from insects or diseases

Field data collection in New York City. Photo by Richard Hallett, USDA Forest Service.

Field Measurements

Field crews sampled 296 one-tenth-acre plots that were randomly distributed throughout New York City proportional to each borough's land area (Fig. 1, Table 2). These plots fell randomly across the city's various land uses (Table 3). Values estimated from sample plots were expanded to provide estimates for citywide totals and by borough.

Field data were collected by trained interns hired through Yale University. Data collection took place during the leaf-on season, from May to September of 2013. For each one-tenth-acre circular plot, ground cover was assessed as a proportion of plot area by type. Trees were defined as woody plants with a diameter at breast height (d.b.h.; measured at 4.5 feet above ground level) greater than or equal to 1 inch. For each tree in the plot, the variables recorded included species, d.b.h., tree height, height to base of live crown, crown width,

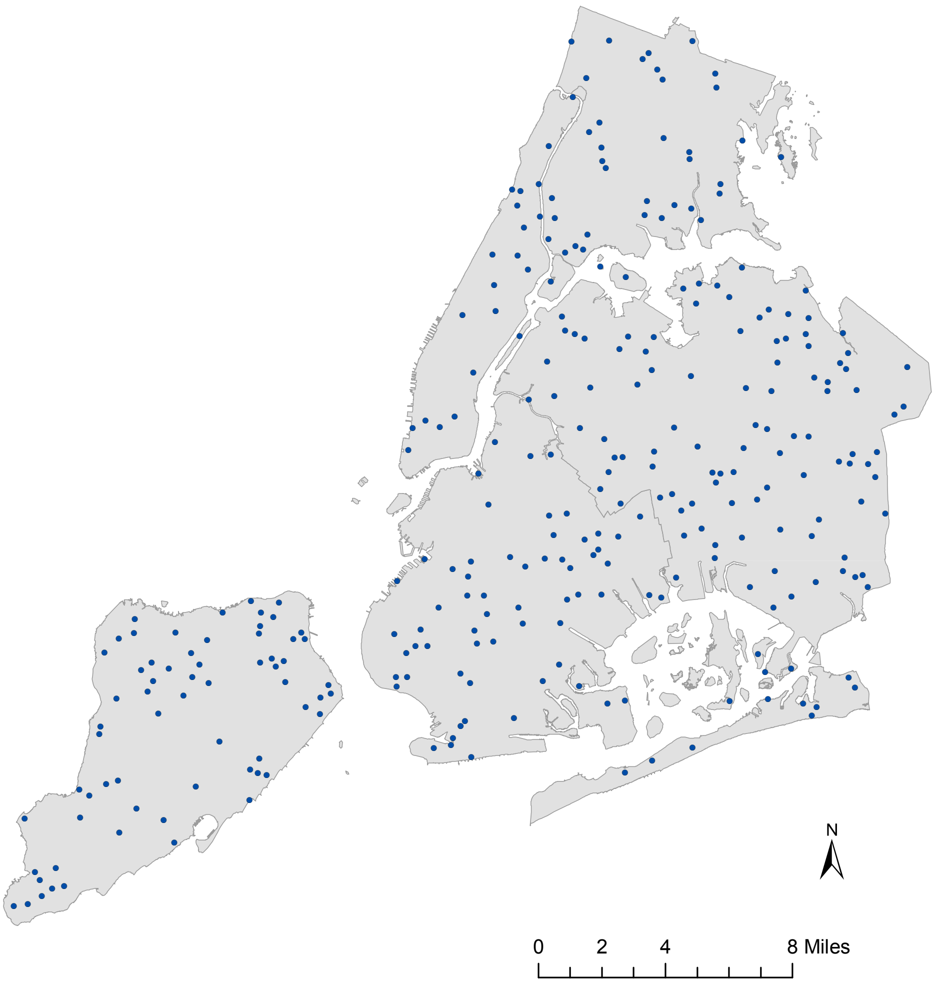


Figure 1.—Urban inventory plot locations by borough, New York City, 2013. Plot locations are approximate.

percentage crown canopy missing and dieback, crown light exposure, and distance and direction to residential buildings (i-Tree, 2009). Measurements of crown dimensions, percentage crown canopy missing, and crown dieback were used to assess tree leaf area.

For trees with more than six stems, tree stem diameter was measured below the fork and the height of the diameter measurement was recorded. For multi-stemmed trees with two to six stems at breast height, each stem d.b.h. was measured and a quadratic mean d.b.h. was calculated for the tree based on the basal area of each stem.

Trees were identified to the most specific taxonomic classification possible, e.g., the species or genus level. Trees designated as "hardwood" include broadleaved deciduous trees that could not be identified to a species or genera. Ninety-five percent of the trees designated as "hardwood" were standing dead. In this report, tree species, genera, or species groups (e.g., other hardwood) are hereafter referred to as tree species.

i-Tree Eco Model

The i-Tree Eco model was used to calculate totals, averages, and standard errors by species, borough, and city totals for forest structure and associated ecosystem services and values. The standard errors for derived estimates (i.e., leaf area, leaf biomass, carbon) report sampling error rather than error of estimation. The reported sampling errors underestimate the actual standard errors. Lack of information regarding errors in the allometric equations and adjustment factors make it impossible to fully account for estimation errors. The tabular results, including standard error estimates, of the i-Tree Eco analysis are available at https://doi.org/10.2737/NRS-RB-117.

The ecosystem services estimated through i-Tree Eco include:

Carbon storage and sequestration. Whole tree carbon storage was calculated for each tree using forest-derived biomass equations and field measured tree data (Nowak 1994, Nowak and Crane 2002, Nowak et al. 2002b). As deciduous trees drop their leaves annually, leaf biomass was not included in whole tree carbon storage for deciduous trees. Open-grown, maintained urban trees (e.g., street trees) tend to have less biomass than predicted by forest biomass equations. To adjust for this difference, biomass results for open-grown urban trees were multiplied by 0.8 (Nowak 1994). No adjustment was made for trees found in natural stand conditions. Tree dry-weight biomass was converted to stored carbon by multiplying by 0.5 (e.g., Chow and Rolfe 1989).

Carbon sequestration is the amount of carbon annually removed from the atmosphere and stored in the tree's biomass. To estimate annual carbon sequestration, average annual diameter growth from appropriate genera, diameter class, and tree condition was added to the existing tree diameter (year x) to estimate tree diameter and carbon storage in year $x+1$. Projected carbon estimates from year $x+1$ were subtracted from carbon estimates in year x to determine gross carbon sequestration.

Table 2.—Distribution of plots among boroughs, New York City, 2013

Borough	Plots with trees	Plots without trees	Proportion of NYC land area
	number	*number*	*percent*
Queens	67	47	35.9
Staten Island	44	20	19.1
Brooklyn	33	26	23.2
Bronx	21	16	13.9
Manhattan	9	13	7.8
Citywide total	174	122	100

Table 3.—Distribution of plots by borough and land use, New York City, 2013

Borough and land use[a]	Plots	Borough and land use[a]	Plots
	number		*number*
Queens		Brooklyn (continued)	
Commercial & Office Buildings	1	Open Space & Outdoor Recreation	9
Industrial & Manufacturing	5	Parking Facilities	2
Mixed Residential & Commercial Buildings	1	Public Facilities & Institutions	4
Multi-Family Elevator Buildings	3	Transportation & Utility	4
Multi-Family Walk-Up Buildings	7	Unclassified[b]	11
One- & Two-Family Buildings	36	Total	59
Open Space & Outdoor Recreation	14		
Public Facilities & Institutions	1	Bronx	
Transportation & Utility	7	Industrial & Manufacturing	2
Vacant Land	2	Multi-Family Elevator Buildings	2
Unclassified[b]	37	Multi-Family Walk-Up Buildings	2
Total	114	One &Two Family Buildings	4
		Open Space & Outdoor Recreation	4
Staten Island		Public Facilities & Institutions	2
Commercial & Office Buildings	5	Transportation & Utility	5
Industrial & Manufacturing	1	Vacant Land	1
One &Two Family Buildings	22	Unclassified[b]	15
Open Space & Outdoor Recreation	11	Total	37
Public Facilities & Institutions	4		
Transportation & Utility	4	Manhattan	
Vacant Land	5	Mixed Residential & Commercial Buildings	1
Total	64	Multi-Family Walk-Up Buildings	3
		Open Space & Outdoor Recreation	3
Brooklyn		Parking Facilities	2
Commercial & Office Buildings	2	Public Facilities & Institutions	1
Industrial & Manufacturing	3	Vacant Land	1
Multi-Family Elevator Buildings	2	Unclassified[b]	9
Multi-Family Walk-Up Buildings	5	Total	22
One &Two Family Buildings	17		

[a] Land use categories are derived from New York City's Department of City Planning primary land use tax lot output (PLUTO) dataset, http://www1.nyc.gov/site/planning/data-maps/open-data.page (June 2015)

[b] The land use category "Unclassified" is assigned to plots that fell outside the bounds of the PLUTO dataset. These areas are typically roadways, as PLUTO is based on tax lot data.

To estimate the monetary value of carbon storage and sequestration, tree carbon values were multiplied by $133.08 per ton of carbon based on the estimated social costs of carbon for 2015 using a 3-percent discount rate (Interagency Working Group 2013, U.S. EPA 2015a). The social cost of carbon is a monetary value that encompasses the economic impact of increased carbon emissions on factors such as agricultural productivity, human health, and property damages (Interagency Working Group 2013).

Air Pollution Removal. Poor air quality is a common problem in many urban areas that can affect human health, damage materials and ecosystem processes, and reduce visibility (e.g., Pope et al. 2002). The urban forest can help improve air quality by directly removing air pollutants and reducing energy consumption in buildings, which consequently reduces air pollutant emissions from power plants and other sources (Nowak et al. 2017). Trees also emit VOCs that can contribute to ozone formation. However, integrative studies have revealed that an increase in tree cover leads to reduced ozone formation (e.g., Cardelino and Chameides 1990, Nowak et al. 2000, Taha 1996).

The local effects of urban forest cover on air pollution were estimated using the New York City tree cover map (O'Neil-Dunne 2012) in conjunction with U.S. Census and local pollutant concentrations. Tree cover in each U.S. Census block group was combined with block group population data and hourly pollutant concentrations from the closest air quality monitor to estimate pollution removal and value at each block group. For $PM_{2.5}$, daily concentration estimates were for each Census tract based on EPA's fused air quality surfaces data (U.S. EPA 2015b). If a block group's tract was not included in the EPA's fused air quality surfaces, data for the nearest tract was used.

Air pollution removal estimates were calculated for ozone (O_3), sulfur dioxide (SO_2), nitrogen dioxide (NO_2), and particulate matter less than 2.5 microns ($PM_{2.5}$) using 2010 hourly pollution data from all city pollution monitors and 2010 hourly weather data from LaGuardia airport. Estimates are derived from calculated hourly tree-canopy resistances for O_3, SO_2, and NO_2 based on a hybrid of big-leaf and multi-layer canopy deposition models (Baldocchi 1988, Baldocchi et al. 1987). Removal and resuspension rates for $PM_{2.5}$ varied with wind speed and leaf area (Nowak et al. 2013).

Pollution removal value is estimated as the economic value associated with avoided human health impacts (i.e., cost of illness, willingness to pay, loss of wages, and the value of statistical life). The U.S. Environmental Protection Agency's (EPA) Environmental Benefits Mapping and Analysis Program (BenMAP) was used to estimate the monetary value that result from changes in NO_2, O_3, $PM_{2.5}$, and SO_2 concentrations due to pollution removal by trees. BenMAP is a MS® Windows-based computer program that uses local pollution and population data to estimate the health impacts of human exposure to changes in air quality and calculates the associated economic value of those changes (Nowak et al. 2013, 2014; U.S. EPA 2012).

Pollution removal and value estimates were calculated at the community district and neighborhood tabulation level to explore how these benefits vary across the city.

Neighborhood tabulation areas (NTAs) are aggregations of Census tracts used to represent New York City neighborhoods.[4] Pollution removal and value estimates were calculated for NTAs by summing block group level results within each NTA. To estimate pollution removal and value at the community district level, values for each NTA within a community district were summed. If only a proportion of an NTA existed within a community district, the NTA value was reduced proportional to the percentage of the NTA in the community district.

Mitigated surface water runoff. Annual avoided surface water runoff (commonly referred to as surface runoff) is calculated based on rainfall interception by vegetation, or more specifically the difference between annual runoff with and without vegetation, based on 2010 weather data. Interception by tree leaves, branches, and bark are accounted for in this analysis. To estimate the monetary value of avoided runoff, avoided runoff values were multiplied by $0.067 per cubic foot of runoff based on estimated national average water treatment and runoff control costs (e.g., McPherson et al. 2007). Avoided runoff by trees is estimated for the entire city. These results are apportioned by species based on leaf area proportion. Citywide results are apportioned by community district based on tree cover.

Measuring residential trees. Photo by Richard Hallett, USDA Forest Service.

Energy use. Tree effects on residential building energy use was calculated using distance and direction of trees from residential structures, tree height, and tree condition data (McPherson and Simpson 1999). Savings in residential energy costs were calculated based on state average 2012 costs for natural gas (Energy Information Administration 2014b), 2012/2013 heating season fuel oil costs (Energy Information Administration 2014c), 2012 residential electricity costs (Energy Information Administration 2012a), and 2012 costs of wood (Energy Information Administration 2012b).

Compensatory values. The estimated value of compensation for a loss of a tree was based on valuation procedures of the Council of Tree and Landscape Appraisers (2000), which uses tree species, diameter, condition, and location information (Nowak et al. 2002a).

Invasive species. Insects and tree diseases can infest urban forests, potentially killing trees and reducing the health, value, and sustainability of the urban forest. Various pests have different tree hosts, so the potential damage or risk of each pest will differ. Invasive species in the New York City urban forest are identified using an invasive species list (New York State Department of Environmental Conservation 2011).

To learn more about i-Tree Eco methods (Nowak and Crane 2000; Nowak et al. 2002b, 2008) visit www.itreetools.org.

[4] For more information on neighborhood tabulation areas, see NYC Department of City Planning website: https://www1.nyc.gov/site/planning/data-maps/open-data/dwn-nynta.page

Tree Effects on Ultraviolet Radiation Exposure

Ultraviolet (UV) radiation is emitted by the sun and is classified as a human carcinogen (e.g., skin cancer), according to the World Health Organization (IARC 2012) and the U.S. Department of Health and Human Services (National Toxicology Program 2011). While a small amount is beneficial in the production of vitamin D, prolonged exposure to UV radiation can also cause adverse health effects on eyes, skin, and the immune system.

A UV index was developed by the World Health Organization to more easily report daily levels of UV radiation and alert people when protection from overexposure is needed most. Ultraviolet index values are estimated from UV radiation amounts and adjustments made based on local cloud cover.

Tree leaves absorb about 90 to 95 percent of UV radiation (Grant et al. 2003), reducing the amount of UV radiation that reaches the ground and providing people with additional protection from the sun's harmful rays.

Using methods described by Na et al. (2014), i-Tree Eco model estimates this reduction in UV radiation for two scenarios:

- Shade: Reduction in UV exposure for a person who is always shaded by tree canopy in the local area.
- Overall: Reduction in UV exposure for a person who is in areas that are shaded and unshaded, based on the average tree cover in the local area.

For each of these two reduced-exposure classes, the effects of trees on UV radiation exposure are calculated for each land use and then combined to produce a weighted average effect for each New York City borough. The effects are as follows:

- Protection factor—a unitless value that captures the UV radiation-reducing capacity of trees. It is calculated as the unshaded UV index divided by the shaded or overall UV index, depending on exposure class. This factor is conceptually equivalent to the sun protection factor (SPF) used to indicate sun screen protection (Na et al. 2014). The protection factor of urban trees can be defined as how many times longer a person would have to spend in a particular environment to receive the same exposure as in an open location with no solar UV protection (Grant and Heisler 2006).
- Reduction in UV index —the change in UV index as the result of trees; it is calculated as unshaded UV index minus shaded or overall UV index.
- Percent reduction—the reduction in UV index expressed as a percent change and calculated as the reduction in UV index divided by unshaded (no reduced exposure) UV index.

Effects are estimated based on noon-time exposure conditions for every day of the year based on average UV data for New York City (2008–2013).

Tree Effects on Air Temperature

Air temperature reductions provided by trees are a critical ecosystem service as air temperatures affect many aspects of the environment and human health. Changes in air temperatures alter tree transpiration and volatile organic compound (VOC) emissions and thereby affect the hydrologic cycle as well as tree effects on air pollution. In addition, air temperatures affect building energy usage and consequent emissions from power plants and other pollutant sources. Changes in air temperature also affect human comfort and thermal stress related illnesses (Heisler and Wang 2002, Martens 1998).

To estimate the effects of trees on air temperatures, an urban forest regression-based air temperature model was used (Heisler et al. 2006, 2007, 2015). This model was developed in Baltimore, MD, and estimates changes in hourly air temperatures using tree and impervious cover at the site and within the upwind direction up to 3.1 miles (5 km). Changes in hourly air temperature were based on elevation difference from the weather station, cold air drainage from the site, Turner class (atmospheric stability), rain within the last hour, vapor pressure deficit, wind direction, and wind speed. The model uses GIS datasets to estimate hourly temperatures in each 30-meter cell using current tree cover conditions and a baseline scenario of zero percent tree cover based on the land cover maps (O'Neil-Dunne 2012). The differences between the two estimates represent the tree effects on air temperature.

Weather data from 2008 were examined to determine four representative days between June 1 and August 31 that could be modeled for tree effects on air temperatures. The air temperature model was run to estimate the average air temperature reduction due to trees for the following days:

- Windiest day (day with the highest average wind speed): June 22, 2008
- Least windy day (day with the lowest average wind speed): July 4, 2008
- Average temperature day (day with the average temperature closest to the summer average temperature): July 23, 2008
- Warmest day (day with the highest average summer daytime temperature): June 9, 2008

The days were selected to illustrate a range of temperature effects under different meteorological conditions. Days were divided into 12-hour blocks to compare daytime (6 a.m. to 5 p.m.) and nighttime (6 p.m. to 5 a.m.) conditions. Results were analyzed for each community district and NTA. Maps illustrating results by NTA are not displayed in this report, but are available at https://doi.org/10.2737/NRS-RB-117.

RESULTS

Tree Cover Assessment

Existing tree cover in New York City is estimated at 21 percent (O'Neil-Dunne 2012). Among the boroughs, Staten Island has the highest tree cover, estimated at 30 percent, followed by the Bronx (23 percent tree cover), Manhattan (20 percent), Queens (18 percent), and Brooklyn (16 percent).

Tree cover varies among community districts, from 2.3 percent to 77.2 percent (Fig. 2). Community districts with greater tree cover percentages correspond to some of the city's largest parks, including Forest Park in Queens, Prospect Park in Brooklyn, Van Cortlandt Park in the Bronx, and Central Park in Manhattan. Appendix 2 provides a community district key and tree cover estimates for each district.

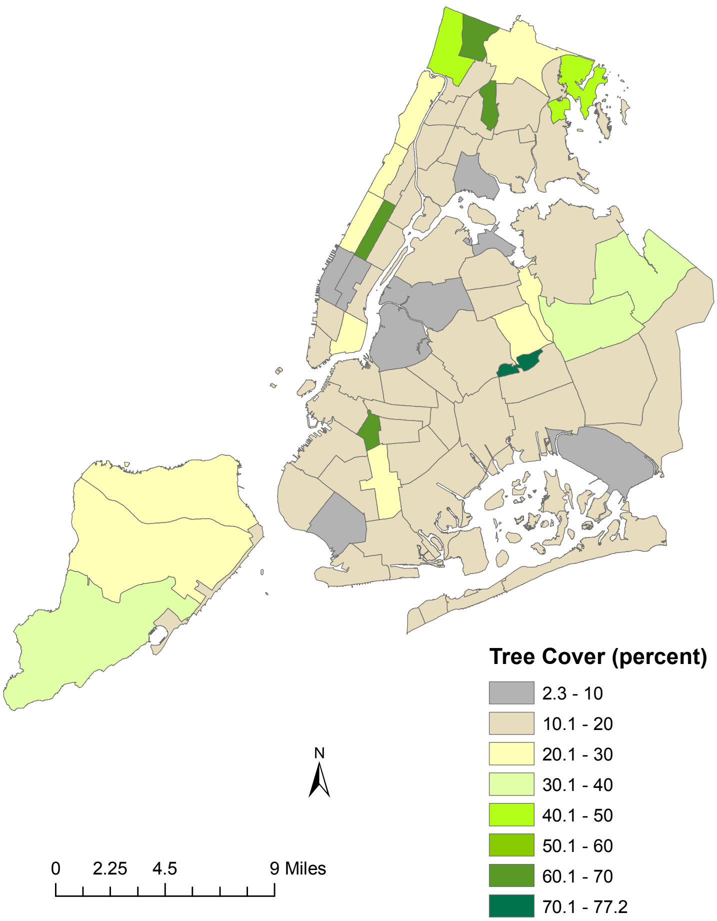


Figure 2.—Urban tree cover percentage by community district, New York City, imagery from 2010. Note: Many maps shown in this report are also available by NTA at https://doi.org/10.2737/NRS-RB-117.

Urban Forest Structure, Composition, and Values

Tree Characteristics of the Urban Forest

New York City's urban forest has an estimated 6,977,000 trees (standard error of 874,000). The five most common species in the urban forest, in terms of number of trees, are Norway maple, northern white-cedar, tree-of-heaven, sassafras, and white oak (Fig. 3) (scientific names of all tree species are listed in appendix 3). The 10 most common species account for 44.4 percent of all trees. In total, 138 woody species/genera were sampled in New York City; these species and their relative abundance are presented in appendix 3. See appendix 4 for more information on species distribution by borough.

The overall tree density in New York City is 35.9 trees per acre. The highest density of trees occurs in Staten Island (67.9 trees/acre), followed by the Bronx (48.4 trees/acre) and Brooklyn (27.0 trees/acre) (Fig. 4). Staten Island makes up 19.1 percent of the city land area (Table 2) and contains the most trees (36.2 percent of tree population), followed by Queens (35.9 percent of the land area, 24.6 percent of the trees).

Leaf area is a measure of leaf surface area (one side). Leaf area index (LAI) is a cumulative measure of the total leaf surface area (one side) of trees in an area divided by land area.

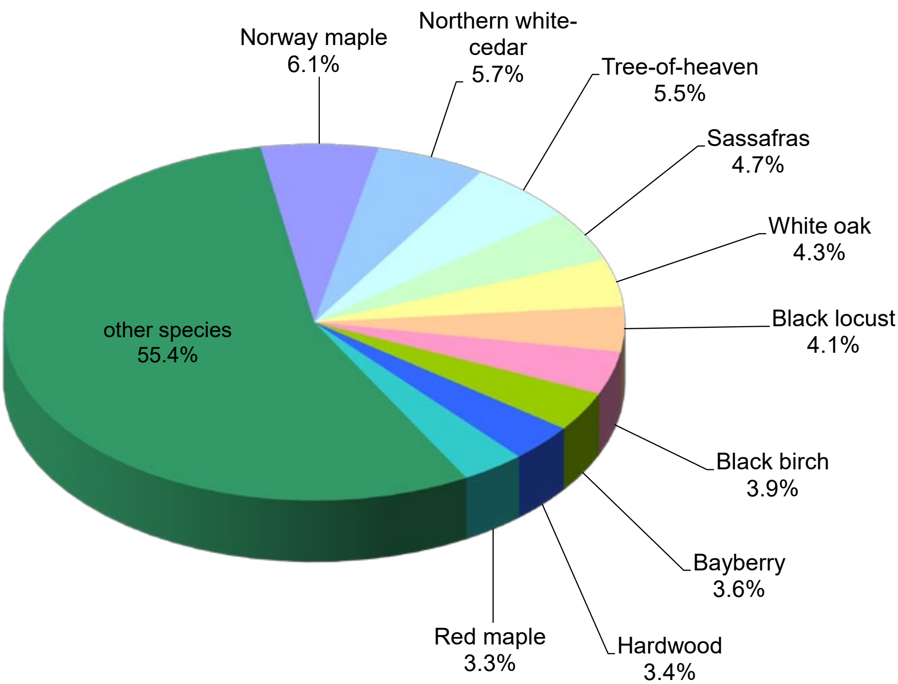


Figure 3.—Urban forest species composition as a percentage of all trees, New York City, 2013. Hardwood refers to broadleaved deciduous trees that could not be identified to a species or genera.

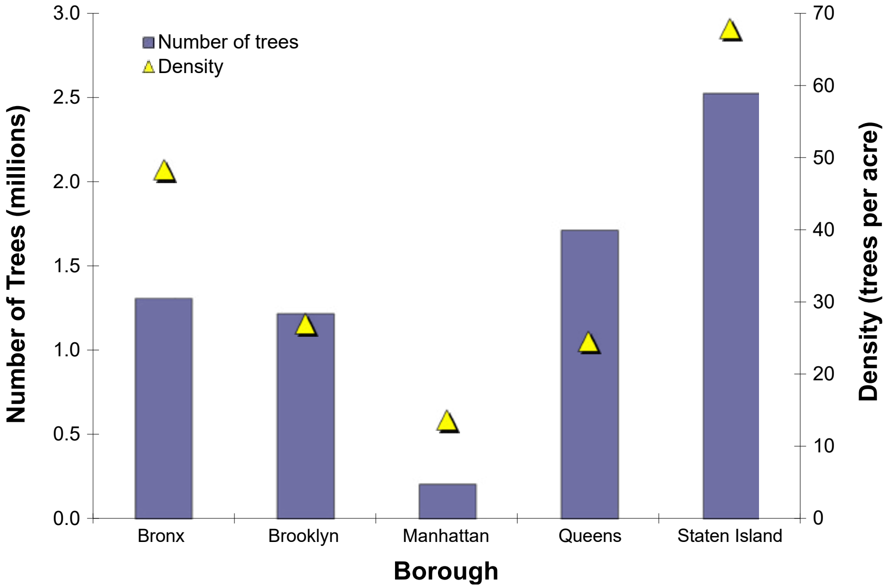


Figure 4.—Number of trees and tree density by borough, New York City, 2013.

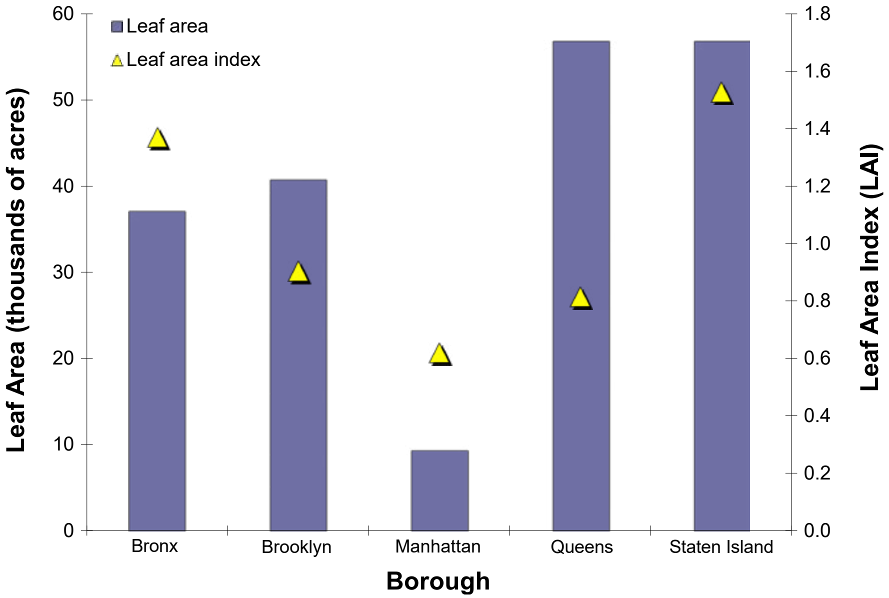


Figure 5.—Total leaf area and leaf area index by borough, New York City, 2013.

As each borough has a different land area, LAI standardizes the canopy depth on an equal area basis. Total leaf area is greatest in Staten Island (28.3 percent of total tree leaf area) and Queens (28.3 percent). A higher LAI indicates a greater leaf surface area per acre of land. Boroughs that have the highest LAI are Staten Island (1.5) and the Bronx (1.4) (Fig. 5).

Tree size is an important characteristic of the urban forest structure. Large healthy trees contribute significantly to the ecosystem services provided by the urban forest primarily because leaf area has a strong correlation with environmental benefits. Trees with diameters 1 to 6 inches account for 69.7 percent of the population (Fig. 6). Trees in this diameter class also contain 15.6 percent of the total leaf area. The 10 most abundant species in New York City have more than 50 percent of their population in the 1 to 6 inch d.b.h. class (Fig. 7). Trees that have diameters greater than 18 inches account for 7.3 percent of the tree population, but comprise 41.5 percent of the total leaf area. Though these large diameter trees are a small percentage of the tree population, they are an important part of the urban forest in New York City. For more information about the environmental benefits by tree diameter class, see appendix 5.

Tree species composition varies between the small diameter (less than 3 inches diameter) and large diameter trees (greater than 18 inches diameter). The 10 most common species of small diameter trees are northern white-cedar (9.6 percent of trees in small d.b.h. class), sassafras (9.2 percent), bayberry (6.5 percent), tree-of-heaven (5.1 percent), pignut hickory (5.0 percent), Norway maple (4.7 percent), black birch (4.1 percent), white oak (3.9 percent), red maple (3.6 percent), and hardwood (3.5 percent). The 10 most common species of large diameter trees are Norway maple (15.1 percent of trees in large diameter class), London planetree (14.9 percent), pin oak (11.7 percent), red maple (5.9 percent), northern red oak (5.7 percent), white oak (4.5 percent), black oak (3.8 percent), swamp white oak (3.4 percent), black locust (2.9 percent), and eastern hemlock (2.9 percent). Norway maple, white oak, and red maple are among the 10 most common small diameter trees and the 10 most common large diameter trees (Fig. 8). Some species

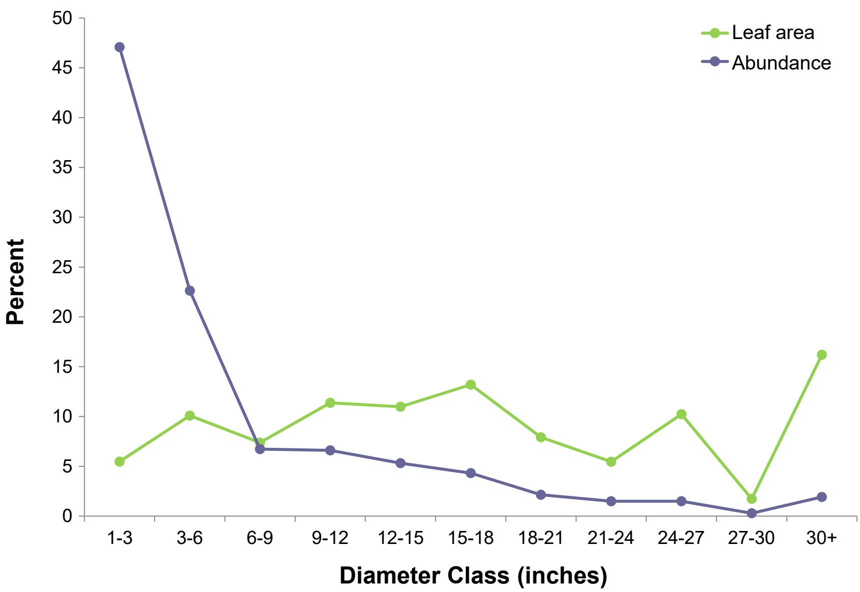


Figure 6.—Percentage of total tree population and leaf area by diameter class, New York City, 2013. Lower limit of the diameter class is greater than displayed (e.g., 3-6 is actually 3.01 to 6 inches).

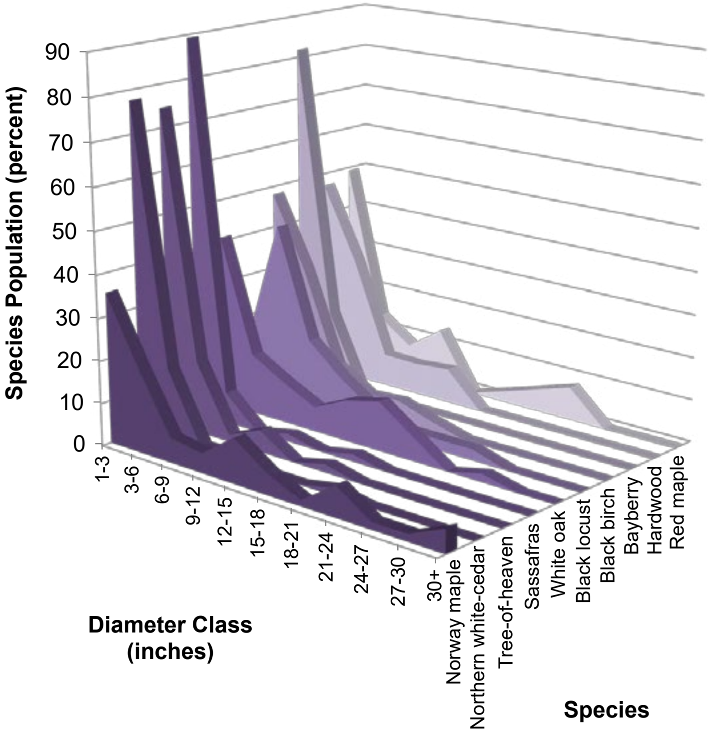


Figure 7.—Percentage of tree species population by diameter class for 10 most common species, New York City, 2013. Lower limit of the diameter class is greater than displayed (e.g., 3-6 is actually 3.01 to 6 inches). Hardwood refers to broadleaved deciduous trees that could not be identified to a species or genera.

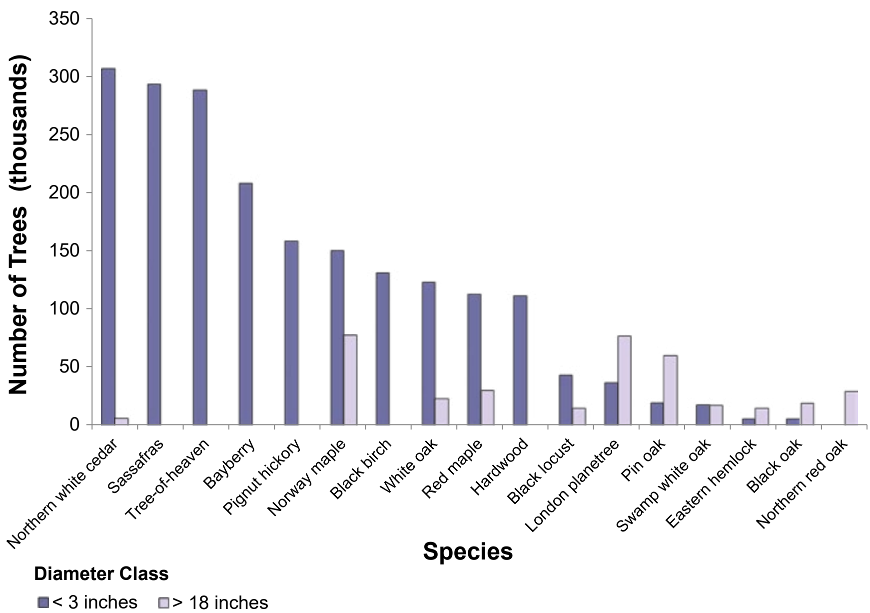


Figure 8.—Most common tree species in the small (<3 inches) and large (>18 inches) diameter classes, New York City, 2013. Hardwood refers to broadleaved deciduous trees that could not be identified to a species or genera.

Table 4.—Inventoried species listed on the New York State invasive species list, New York City, 2013

Common name	Population	Leaf area
	percent	*percent*
Norway maple	6.1	10.7
Tree-of-heaven	5.5	1.6
Black locust	4.1	7.0
Callery pear	2.3	1.3
Hall's honeysuckle	0.1	<0.1

(e.g., London planetree, pin oak, eastern hemlock, black oak, and northern red oak) have more large trees than small trees, which may lead to reduction of this species in the future as there is minimal planting or regeneration of these species to sustain the species population. Mean and median stem diameter by species are presented in appendix 3.

New York City's urban forest is a mix of native tree species and exotic species that were introduced by residents or other means. Urban forests often have greater tree species diversity than the surrounding native landscapes because of the large impact of species imported from outside the region and the country (Nowak 2010). Increased tree species diversity can minimize the overall impact or destruction by a species-specific insect or disease (Laćan and McBride 2008, Santamour 1990), but the increase in the number of exotic species can also pose a risk to native plants if exotic species are invasive and out-compete and displace native species. In New York City, about 46.9 percent of the trees are native to New York State, and 65.4 percent native to North America. Trees with a native origin outside of North America are mostly from Asia (28.7 percent of the trees).

Invasive plant species are often characterized by their vigor, ability to adapt, reproductive capacity, and lack of natural enemies. These factors enable them to displace native plants and threaten natural areas (National Agriculture Library 2011). Five of the 138 tree species sampled in New York City are identified on the state invasive species list (New York State Department of Environmental Conservation 2011). These invasive species comprise 17.5 percent of the population with the most common species being Norway maple, tree-of-heaven, and black locust (Table 4).

Many tree benefits are linked to the leaf area, i.e., the greater the leaf area, the greater the benefit. In New York City's urban forest, tree species with the greatest leaf area are London planetree, Norway maple, and black locust (Fig. 9). Common tree species (>1% of the total population) with relatively large individual trees (percentage of total leaf area greater than percent of total tree population) are London planetree, pin oak, and Norway maple. Tree species dominated by smaller individuals with relatively low amounts of leaf area per stem are bayberry, cedar spp., and northern white-cedar.

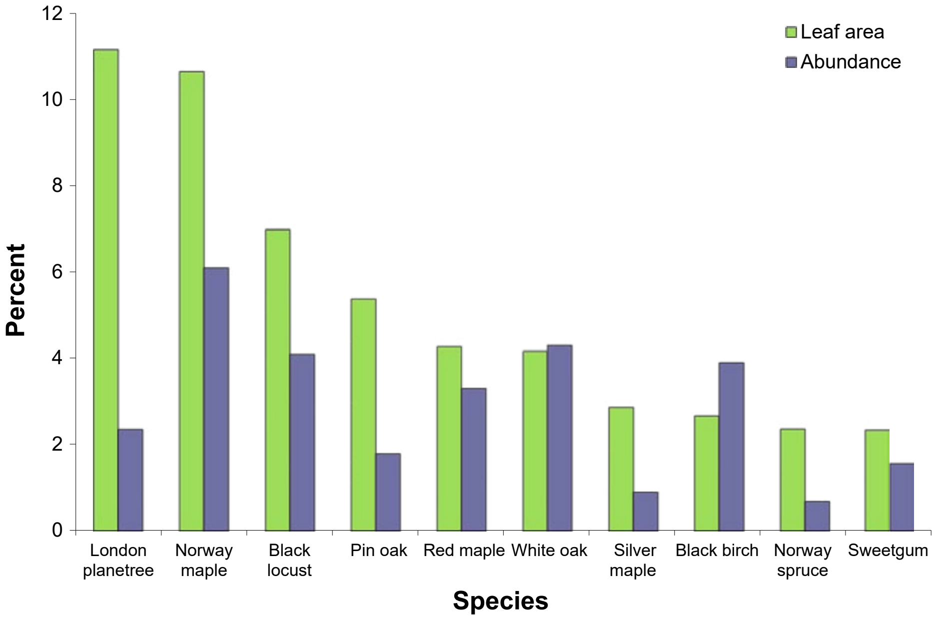


Figure 9.—Percentage of tree population and total leaf area for 10 species contributing the greatest amount of leaf area, New York City, 2013.

Table 5.—Percentage of total population and leaf area, and importance value of species with the greatest importance values, New York City, 2013

Common Name	Population[a]	Leaf area[b]	IV[c]
	percent	*percent*	
Norway maple	6.1	10.7	16.8
London planetree	2.4	11.2	13.6
Black locust	4.1	7.0	11.1
White oak	4.3	4.2	8.5
Red maple	3.3	4.3	7.6
Pin oak	1.8	5.4	7.2
Tree-of-heaven	5.5	1.6	7.1
Black birch	3.9	2.7	6.6
Northern white-cedar	5.7	0.7	6.4
Sassafras	4.7	0.8	5.5

[a] The percent of total tree population
[b] The percent of total leaf area
[c] IV = Population (%) + Leaf area (%)

Importance values (IV) are calculated using a formula that combines the relative leaf area and relative abundance. High importance values do not mean that these trees should necessarily be encouraged in the future; rather these species currently dominate the urban forest structure. The three species in the urban forest with the greatest IVs are Norway maple, London planetree, and black locust (Table 5).

1996 Urban Forest Assessment

An earlier assessment of New York City's urban forest was based on field data collected in 1996 and used the Urban Forest Effects (UFORE) model (Nowak et al. 2007). These UFORE results were based on 206 field plots randomly located in different land use strata of New York City. These older plots were not permanently referenced, hence new permanent plots were established for the current study. The 1996 assessment and this report are independent and cannot be directly compared due to differing samples and methods. However, results from 1996 are mentioned here to help explain potential differences.

The five most common species recorded in the 1996 UFORE study were tree-of-heaven, black cherry, sweetgum, northern red oak, and Norway maple; the current i-Tree Eco assessment finds the five most common species to be Norway maple, northern white-cedar, tree-of-heaven, sassafras, and white oak. In 1996, the 10 most common species accounted for 61.6 percent of all trees, compared to 44.4 percent in the current assessment. In total, 138 tree species/genera were recorded in New York City during the i-Tree Eco assessment, while 66 species were recorded in 1996 (Table 6).

In 1996, 42.7 percent of trees were less than 6 inch diameter compared to 69.7 percent of trees under 6 inch in 2013. The overall urban tree density in New York City is 35.9 trees per acre with an average diameter of 6.3 inches. In 1996 the overall urban tree density was 26.4 trees per acre with an average diameter of 9.2 inches.

This apparent increase in species and number of trees is, in part, due to a difference in definition of trees between the studies. In 1996, field data were collected for tree species with a minimum diameter of 1 inch and a minimum of 4 inches for shrub species. Using this procedure, species was used to determine trees, not size. Conversely, the 2013 field study included all woody plants with a minimum d.b.h. of 1 inch. Thus, the most recent assessment will classify more small shrub-like species (such as northern white-cedar, one of the most common species observed in 2013) as trees, making these estimates incomparable.

Forest Parkland Assessment

Forested parkland is a critical subset of New York City's urban forest. From 2013-2014, the Natural Areas Conservancy (NAC) conducted an assessment of upland forests designated as part of NYC Parks' Forever Wild program. Within these 7,200 acres of upland forests, which represent roughly 4 percent of New York City, the NAC established 1,124 randomized 10-m radius plots and collected data on vegetation, soils, and other characteristics described in Forgione et al. (2016). The woody species data from these plots were analyzed separately using the i-Tree Eco model to determine the structure, ecosystem services, and values provided by trees in Forever Wild upland forests (Table 7). Out of the 296 citywide i-Tree plots, only 40 were on NYC Parks properties and only 11 of those were in forested parkland. Thus, the NAC's upland assessment provides a more in-depth look at forested parkland in NYC.

Table 6.—Summary of 1996 and 2013 urban forest assessments, New York City

	1996	2013
Methods		
Number of plots	206	296
Stratification method	By land use	By borough
Model used	Urban Forest Effects (UFORE)	i-Tree Eco (f.k.a. UFORE)
Urban forest characteristics[a]		
Most common species recorded	Tree-of-heaven, black cherry, sweetgum, northern red oak, and Norway maple	Norway maple, northern white-cedar, tree-of-heaven, sassafras, and white oak
Number of species recorded	66	138
Percentage of trees <6 inches diameter	42.7%	69.7%
Tree density	26.4 trees per acre	35.9 trees per acre
Average diameter (d.b.h.)	9.2 inches	6.3 inches

[a] Results were generated using different methods and are directly not comparable.

Table 7.—Summary of forested parkland features, New York City, 2013-2014

Feature	Estimate
Number of trees[a]	3,310,000
Tree cover[b]	88.0%
Most dominant species by:	
Number of trees	Sweetgum, black cherry, sassafras, red maple, spicebush
Leaf area	Sweetgum, northern red oak, red maple, black cherry, sassafras
Trees 1-6 inches d.b.h.	79.4%
Air temperature reduction	Not analyzed[c]
Pollution removal	314 ton/year ($55.4 million/year)
VOC emissions	Not analyzed[c]
Avoided runoff	13.8 million feet^3/year ($920,000/yr)
Carbon storage	362,000 tons ($48.2 million)
Carbon sequestration	13,700 tons/year ($1.82 million/year)
Value of reduced building energy use	Not analyzed[c]
Value of reduced carbon emissions	Not analyzed[c]
Compensatory value[d]	$491 million

[a] All woody vegetation >1 inch diameter
[b] Assessed using LiDAR in an earlier report (O'Neil-Dunne 2012)
[c] Not analyzed due to missing required data
[d] Estimated value of compensation for the loss of the urban forest structure (a value of the forest's physical structure)
Note: ton = short ton (U.S.) (2,000 lbs)

Dominant species, tree cover, and tree density in forested parkland differ greatly compared to the citywide assessment across public and private land. Within forested parkland, all five of the most abundant species are native—sweetgum, black cherry, sassafras, red maple, and spicebush – compared to only two out of five citywide—sassafras and white oak. Both tree cover and tree density in forested parkland are much higher than tree cover and density citywide, so forested parkland has a disproportionately higher number of trees and ecosystem service benefits relative to its geographic size.

Air Temperature Reductions

Average air temperature reductions by trees in New York City varied across the community districts among the four representative days and the time of day (Table 8). Average air temperature reduction in the community districts was greatest (0.4 °F) during the daytime (6 a.m. – 5 p.m.) hours on the warmest summer day of 2008. The greatest maximum temperature reduction in the community districts (1.4 °F) was also recorded on this day.

For the average-temperature summer day of 2008, daytime air temperature reductions varied by community district (Fig. 10). The greatest temperature reduction was estimated at 0.5 °F and the smallest reduction was estimated at less than 0.1 °F. Community districts that showed the greatest temperature reductions are areas that also have greater percentage of tree cover (Fig. 10) and overlap with some of the city's larger parks. More information on the distribution of temperature reduction across the neighborhoods appendix 2. Maps illustrating results by NTA are available at https://doi.org/10.2737/NRS-RB-117.

An important factor in the estimation of temperature reductions by trees is the local air temperature. Estimated air temperatures varied across New York City and are reported in appendix 6. Local air temperature can also be used to identify priority areas for tree planting. One method of doing this is to estimate potential heat exposure to the city population by mapping air temperature combined with city population data. This method determines areas with the greatest number of people exposed to the warmest temperatures (appendix 6) where tree planting would likely be most beneficial in reducing temperature around people.

Clove Lakes Park in Staten Island in 2014.
Photo by David Chang, USDA Forest Service.

Table 8.—Average, minimum, and maximum air temperature reductions in community districts, New York City[a], 2010

Representative days	Time	Average	Minimum	Maximum
		°F	°F	°F
Windiest (6/22/08)	AM[b]	0.2	<0.1	0.6
	PM[c]	0.1	<0.1	0.5
Least windy (7/4/08)	AM	0.2	<0.1	0.6
	PM	0.2	<0.1	0.8
Average temperature (7/23/08)	AM	0.1	<0.1	0.5
	PM	0.1	<0.1	0.4
Warmest (6/9/08)	AM	0.4	<0.1	1.4
	PM	0.2	<0.1	0.7

[a] Derived using 2008 air pollution and weather data and tree canopy data from O'Neil-Dunne 2012.
[b] The average air temperature reduction for the daytime hours (6 a.m.–5 p.m.) of the representative day.
[c] The average air temperature reduction for the nighttime hours (6 p.m.–5 a.m.) of the representative day.

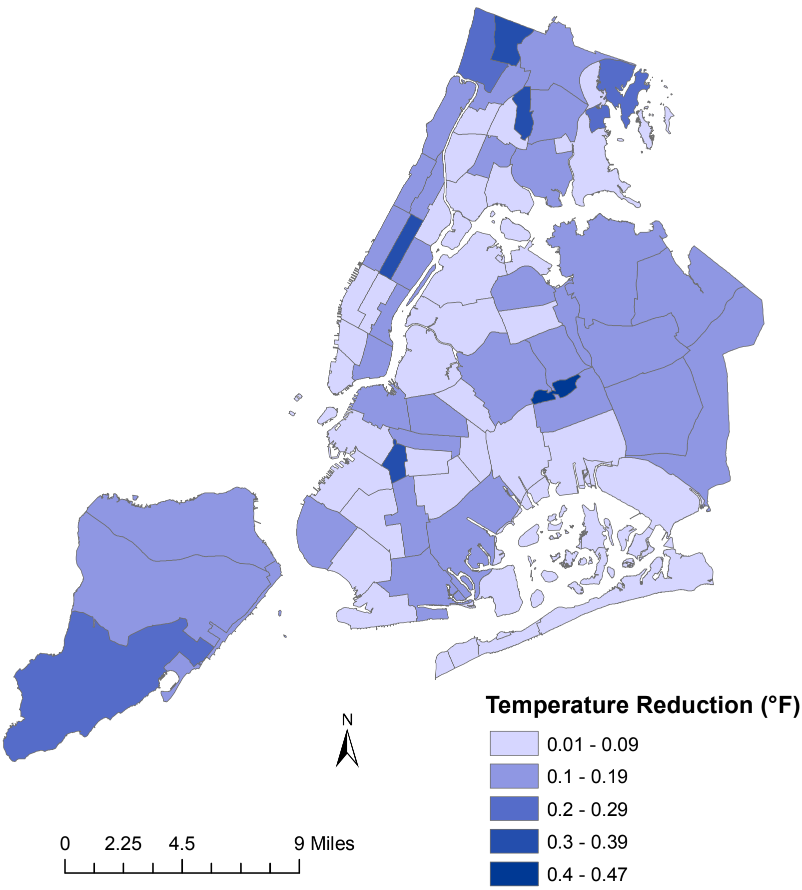


Figure 10.—Daytime (6 a.m.–5 p.m.) air temperature reductions by trees, by community district, for the average temperature summer day, New York City, 2008.

Air Pollution Removal

Pollution removal by trees in New York City was estimated using the i-Tree Eco model in conjunction with field data, the high resolution land cover map, and hourly pollution and weather data for the year 2010. Pollution removal was greatest for O_3 (735 tons removed per year), followed by NO_2 (242 tons/year), SO_2 (88 tons/year), and $PM_{2.5}$ (41 tons/year) (Fig. 11). By contrast, the value associated with pollution removal was greatest for $PM_{2.5}$ ($59.9 million), followed by O_3 ($16.9 million), NO_2 ($985,000) and SO_2 ($135,000). It is estimated that trees remove 1,100 tons of air pollution (NO_2, O_3, $PM_{2.5}$, and SO_2) per year with an associated value of $77.9 million.

Reduction in pollution concentration due to pollution removal by trees also have a positive effect on human health in New York City. The economic value of pollution removal is based on the number of cases per year of avoided health effects. For example, in 2010, reductions in NO_2 concentration resulted in about 320 fewer cases of acute respiratory symptoms with an associated value of $10,100 (Tables 9-10).

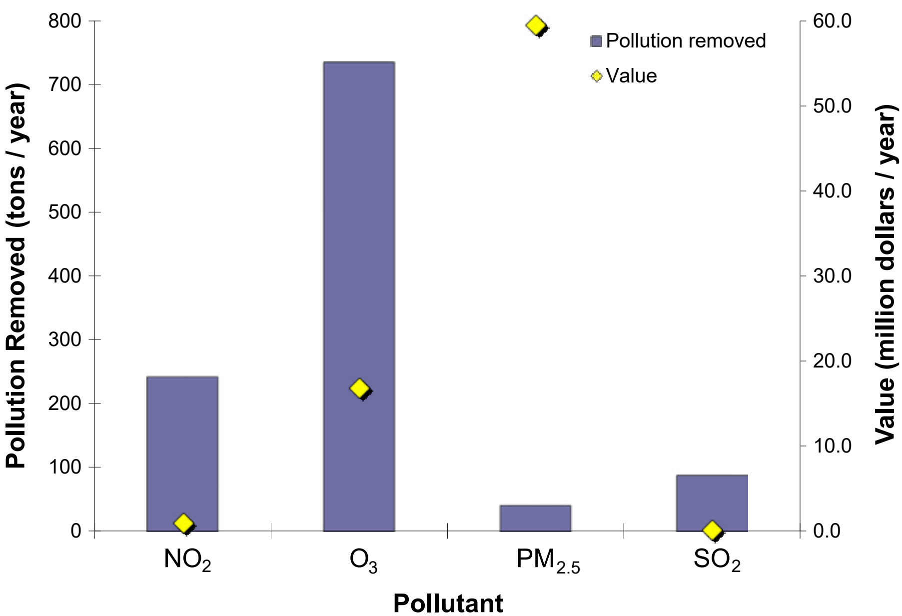


Figure 11.—Annual air pollution removal and value by urban trees, New York City, 2010.

Table 9.—Associated value ($/year) of avoided health effects from changes in pollution concentrations due to pollution removal by trees, New York City, 2010

Health Effect	NO_2	SO_2	O_3	$PM_{2.5}$
		$/year		
Acute bronchitis	n/a[a]	n/a	n/a	400
Acute myocardial infarction	n/a	n/a	n/a	140,100
Acute respiratory symptoms	10,100	1,500	392,600	259,700
Asthma exacerbation	392,100	31,400	n/a	138,100
Chronic bronchitis	n/a	n/a	n/a	613,400
Emergency room visits	8,700	4,100	4,600	5,500
Hospital admissions	574,400	98,100	258,500	n/a
Hospital admissions, cardiovascular	n/a	n/a	n/a	50,600
Hospital admissions, respiratory	n/a	n/a	n/a	26,600
Lower respiratory symptoms	n/a	n/a	n/a	2,600
Mortality	n/a	n/a	16,033,700	58,580,500
School loss days	n/a	n/a	162,300	n/a
Upper respiratory symptoms	n/a	n/a	n/a	1,800
Work loss days	n/a	n/a	n/a	69,400
Total value	985,300	135,100	16,851,600	59,888,800

[a] n/a indicates that the value is not estimated for that pollutant and health effect. The same health effects were not analyzed for each pollutant.

Table 10.—Incidences (number of cases/year) of avoided health effects from changes in pollution concentrations due to pollution removal by trees, New York City, 2010

Health Effect	NO_2	SO_2	O_3	$PM_{2.5}$
		number of cases/year		
Acute bronchitis	n/a[a]	n/a	n/a	4.1
Acute myocardial infarction	n/a	n/a	n/a	1.6
Acute respiratory symptoms	319.9	46.1	4,592.6	2,649.9
Asthma exacerbation	4,686.2	399.1	n/a	1,699.4
Chronic bronchitis	n/a	n/a	n/a	2.2
Emergency room visits	20.8	9.8	10.9	13.2
Hospital admissions	19.4	3.2	8.6	n/a
Hospital admissions, cardiovascular	n/a	n/a	n/a	1.3
Hospital admissions, respiratory	n/a	n/a	n/a	0.8
Lower respiratory symptoms	n/a	n/a	n/a	50.9
Mortality	n/a	n/a	2.1	7.5
School loss days	n/a	n/a	1,652.6	n/a
Upper respiratory symptoms	n/a	n/a	n/a	40.4
Work loss days	n/a	n/a	n/a	454.8

[a] n/a indicates that the number of cases is not estimated for that pollutant and health effect. The same health effects were not analyzed for each pollutant.

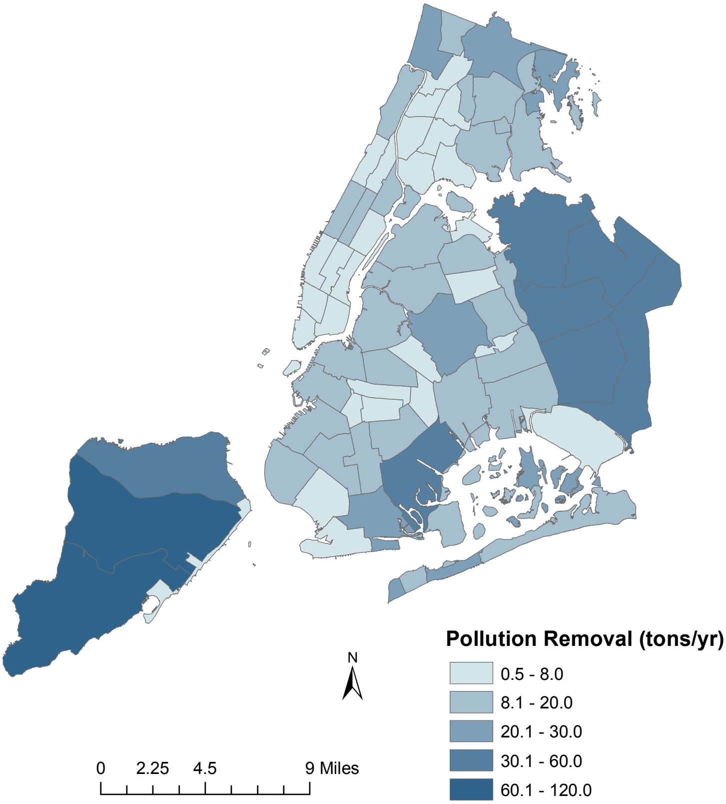


Figure 12.—Pollution removal by trees by community district, New York City, 2010.

Pollution removal by trees in New York City varies across the city's community districts and, as with other ecosystem services, is correlated with leaf area. Pollution removal ranged from 0.6 tons per year to 117 tons per year. Removal was highest in the community districts on Staten Island and Queens (Fig. 12), which are the boroughs with the greatest leaf area and LAI. Pollution removal value also varied across the city's community districts. The maximum pollution removal value was estimated at $2.8 million per year and is located in community district 318 in Brooklyn (Fig. 13 and appendix 2). Several community districts, mostly located in Queens, Staten Island, and Brooklyn, had an estimated annual pollution removal value over $1.85 million per year (Fig. 13). The value of pollution removal is dependent on both the size of the community district population and the change in pollution concentration. The more people receiving the benefits of pollution removal in a given community district, the larger the value of those benefits (Nowak et al. 2014). For example, trees in the community district in which Central Park in Manhattan is located removed 10.5 tons per year of pollution removal, but has an associated value of $6,600 per year because it has a low human population estimated from U.S. Census data. Conversely, the community district that encompasses the Upper East Side and Yorkville, located east of Central Park, removed 7.2 tons per year of pollution with an associated value of $1.7 million per year. Estimates of pollution removal by community district are provided in appendix 2.

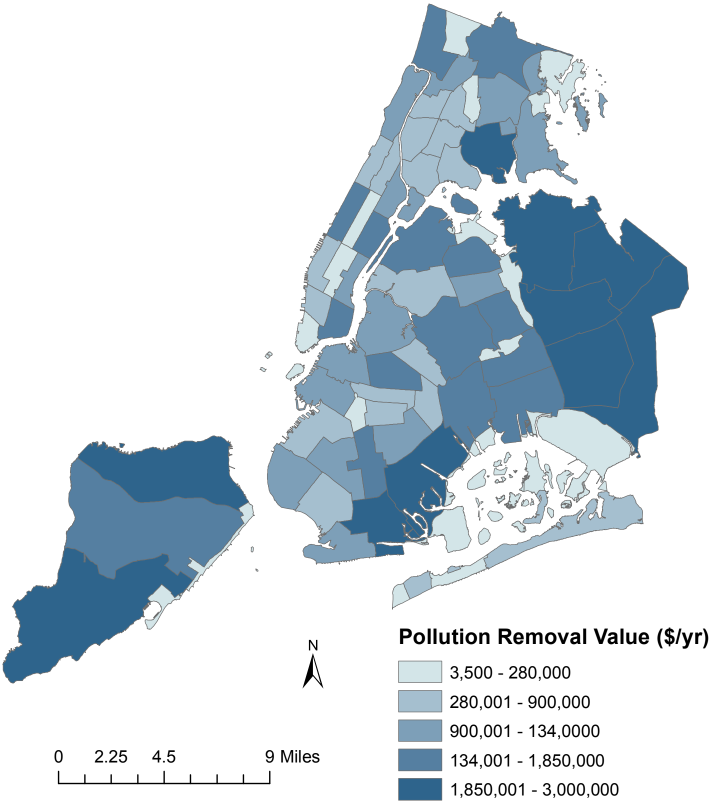


Figure 13.—Pollution removal value by community district, New York City, 2010.

Estimates of total VOC emissions from anthropogenic sources in New York City are around 340 tons per day (U.S. EPA 2011), however, trees also emit VOCs. In 2013, trees in New York City emitted an estimated 717 tons of VOCs (566 tons of isoprene and 151 tons of monoterpenes) over the entire year. Emissions vary among genera and amount of leaf biomass. Sixty-six percent of the urban forest's VOC emissions were from oak and sycamore genera (Fig. 14). These VOCs are precursor chemicals to ozone formation.[5] General recommendations for improving air quality with trees are given in appendix 7.

[5] Some economic studies have estimated VOC emission costs. These costs are not included here as there is a tendency to add positive dollar estimates of ozone removal effects with negative dollar values of VOC emission effects to determine whether tree effects are positive or negative in relation to ozone. This combining of dollar values to determine tree effects should not be done, rather estimates of VOC effects on ozone formation (e.g., via photochemical models) should be conducted and directly contrasted with ozone removal by trees (i.e., ozone effects should be directly compared, not dollar estimates). In addition, air temperature reductions by trees have been shown to significantly reduce ozone concentrations (Cardelino and Chameides 1990, Nowak et al. 2000), but are not considered in this analysis. Photochemical modeling that integrates tree effects on air temperature, pollution removal, VOC emissions, and emissions from power plants can be used to determine the overall effect of trees on ozone concentrations. A study of increasing urban tree cover in the New York City region showed a general reduction in ozone concentrations in cities, but a tendency to increase average ozone concentrations in the overall modeling domain (Nowak et al. 2000).

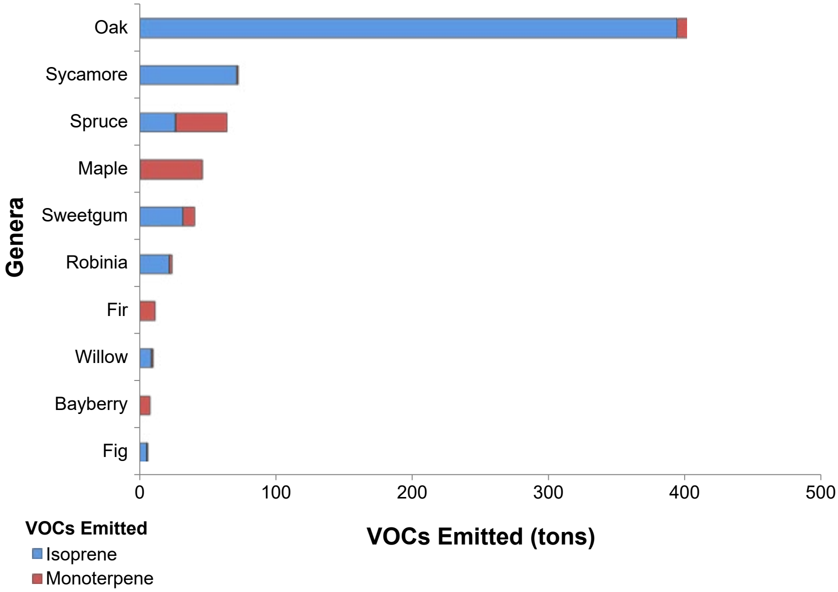


Figure 14.—Annual volatile organic compounds (VOCs) emitted by tree genera with highest total emissions, New York City, 2013.

Reduction in UV Radiation

Tree leaves absorb about 90 to 95 percent of UV radiation (e.g., Grant et al. 2003), reducing the amount of UV radiation that reaches the ground and providing people with additional protection from the sun's harmful rays. Overall, trees are estimated to reduce UV exposure by about 25 percent and within tree shade by about 48 percent. This reduction equates to an overall protection factor of 1.35 and 2.26 with tree shade (Table 11). The greatest reductions are in Staten Island due to its relatively high percentage tree cover.

Inwood Hill Park. Photo by Lakshman Kalasapudi, USDA Forest Service.

Table 11.—Estimated effects of trees shade on UV radiation in New York City.

Borough	UV Effects in Tree Shade			UV Effects Overall		
	Protection factor[a]	Reduction in UV Index	Percent reduction	Protection factor	Reduction in UV Index	Percent reduction
Bronx	2.25	2.11	48.1	1.34	0.91	24.9
Brooklyn	2.16	2.05	45.6	1.28	0.78	21.2
Manhattan	1.86	1.82	37.2	1.08	0.32	7.8
Queens	2.23	2.09	47.5	1.33	0.88	24.1
Staten Island	2.70	2.33	57.3	1.65	1.36	38.7
Study Area	2.26	2.11	48.2	1.35	0.91	25.1

[a] Protection factor is a unitless value meant to capture the UV radiation-blocking capacity of trees. It is comparable to the SPF rating in sunscreen and is calculated as the unshaded UV index divided by the shaded or overall UV index (depending on exposure class). The protection factor of urban trees can be defined as how many times longer a person would have to spend in a particular environment to receive the same exposure as in an open location with no solar UV protection (Grant and Heisler 2006).

Avoided Runoff

Surface water runoff can be a cause for concern in many urban areas as it can contribute pollution to streams, wetlands, rivers, lakes, and oceans. During precipitation events, some portion of the precipitation is intercepted by vegetation while the other portion reaches the ground. The portion of the precipitation that reaches the ground and does not infiltrate into the soil or end up in depression storage becomes surface runoff (Hirabayashi 2012). In urban areas, the large extent of impervious surfaces increases the amount of surface runoff.

Urban trees, however, are beneficial in reducing surface runoff. Trees intercept precipitation and transpire water, while their root systems promote infiltration and water storage in the soil. Although trees have other impacts on local hydrology, avoided runoff is estimated by i-Tree Eco as a function of the annual precipitation interception, evaporation, and transpiration by trees. The trees of New York City help to reduce runoff by an estimated 69 million cubic feet a year (valued at $4.6 million per year). Tree species with the greatest overall impact on runoff are London planetree, Norway maple, and black locust (Fig. 15). Avoided runoff and value are also apportioned by community district based on tree cover (Figs. 16 and 17).

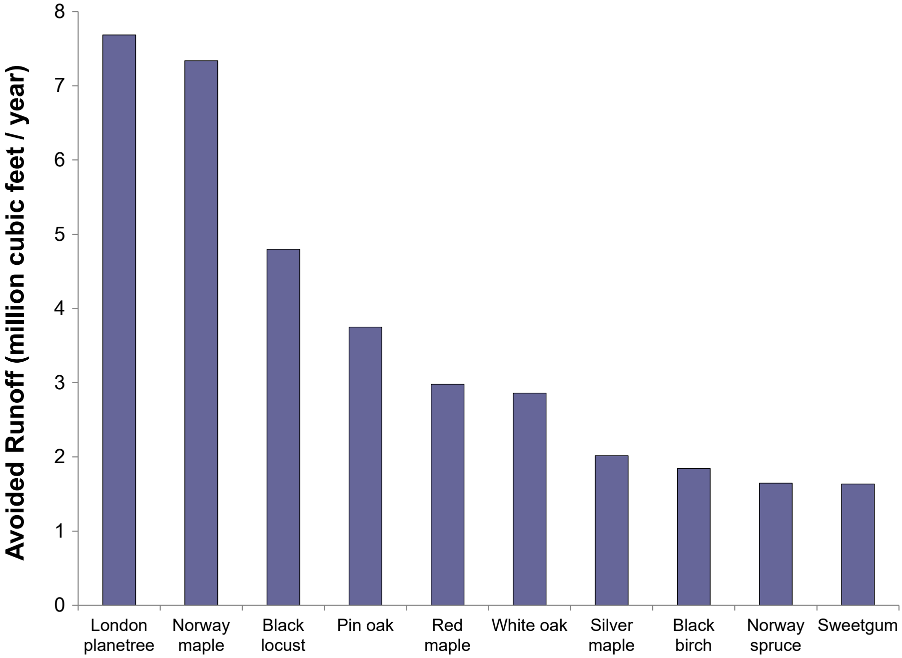


Figure 15.—Tree species with greatest overall impact on surface water runoff, New York City, 2010. Avoided runoff by species is proportional to leaf area as runoff reduction is estimated on a citywide basis.

Street trees in Queens, near a residential area (left), and street trees in the Bronx, near a ballfield in a residential area (right). Photos by D.S. Novem Auyeung, used with permission.

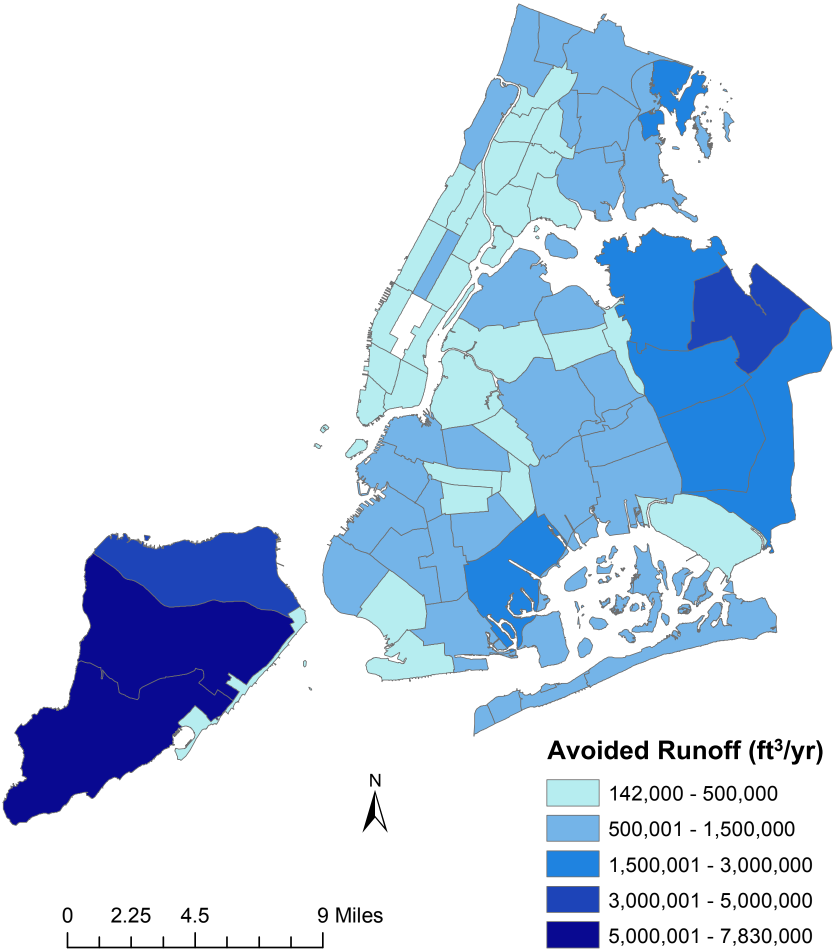


Figure 16.—Avoided surface water runoff by trees by community district, New York City, 2010. Avoided runoff by community district is proportional to tree cover as runoff reduction is estimated on a citywide basis..

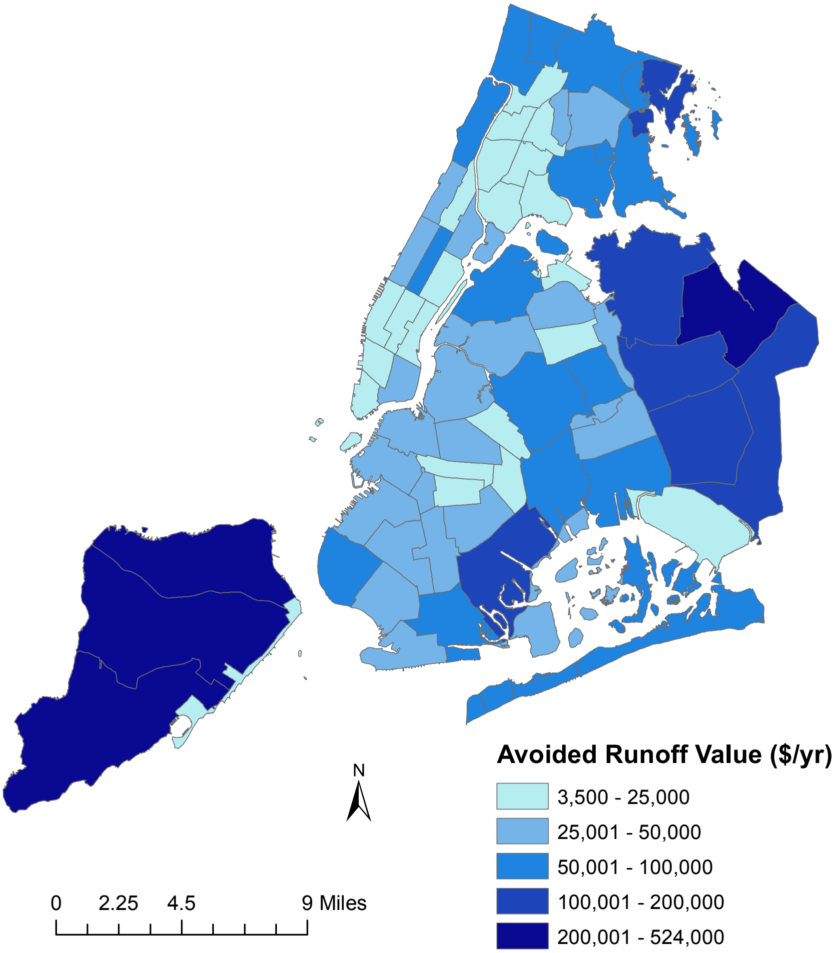


Figure 17.—Avoided surface water runoff value by community district, New York City, 2010.

Carbon Storage and Sequestration

Climate change is an issue of global concern that threatens to impact species extinctions, vulnerable ecosystems such as coral reefs and polar or coastal areas, food production, water resources, and human health (Intergovernmental Panel on Climate Change 2014). The city's trees can help mitigate climate change by sequestering atmospheric carbon (from carbon dioxide [CO_2]) in its tissue and by reducing the amout of energy used to heat or cool buildings, thus reducing CO_2 emissions from fossil-fuel based power sources (Abdollahi et al. 2000).

As a tree grows, it stores carbon in its accumulated tissue. As a tree dies and decays, it releases much of the stored carbon back into the atmosphere. Thus, carbon storage is an indication of the amount of carbon that can be released if trees are allowed to die and decompose. Maintaining healthy trees will keep the carbon stored in trees, but tree maintenance can contribute to carbon emissions (Nowak et al. 2002c). Using the wood contained in dead trees for wood products is one way to help forestall carbon emissions due to wood decomposition. Wood from dead trees can also be used to produce energy (e.g., heat buildings). This energy use will release stored carbon, but can reduce energy productions and emissions from fossil-fuel based power sources. Trees in New York City store an estimated 1.2 million tons of carbon (4.2 million tons of CO_2 valued at $153 million).

In addition to carbon storage, trees reduce the amount of carbon in the atmosphere by sequestering carbon in new tissue growth. The amount of carbon annually sequestered is increased with healthier and larger diameter trees. Gross sequestration by urban trees in New York City is about 51,000 tons of carbon per year (186,000 tons per year of CO_2) with an associated value of $6.8 million per year. Net carbon sequestration in New York City is estimated at about 36,000 tons per year (132,000 tons per year of CO_2) by subtracting estimated carbon loss due to tree mortality and decomposition from gross sequestration.

Highbridge Park in Queens. Photo by D.S. Novem Auyeung, used with permission.

Of all the species sampled, pin oak stores the most carbon (approximately 14.0 percent of total estimated carbon stored) and Norway maple annually sequesters the most carbon (10.6 percent of all sequestered carbon) (Figs. 18 and 19). Trees greater than 30 inches in diameter store the most carbon in the city (Figs. 20 and 21).

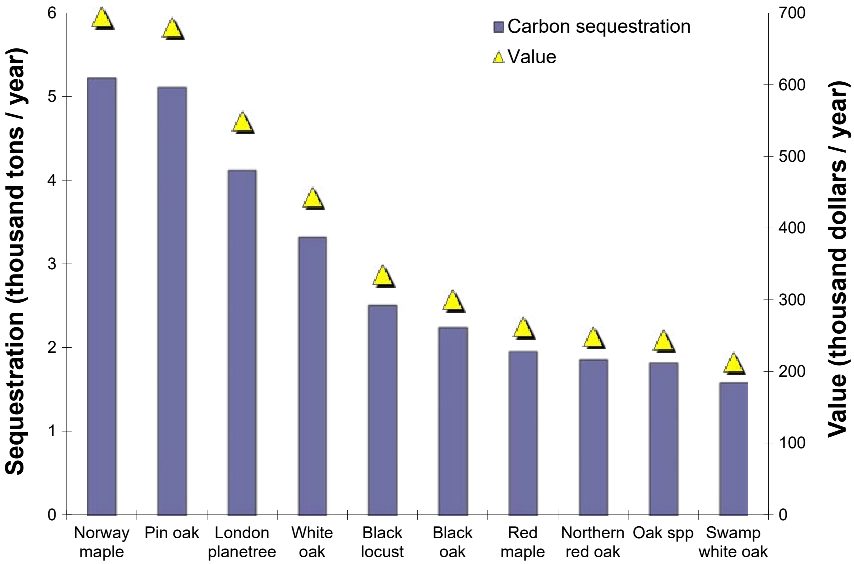


Figure 18.—Estimated annual carbon sequestration and value for urban tree species with the greatest sequestration, New York City, 2013.

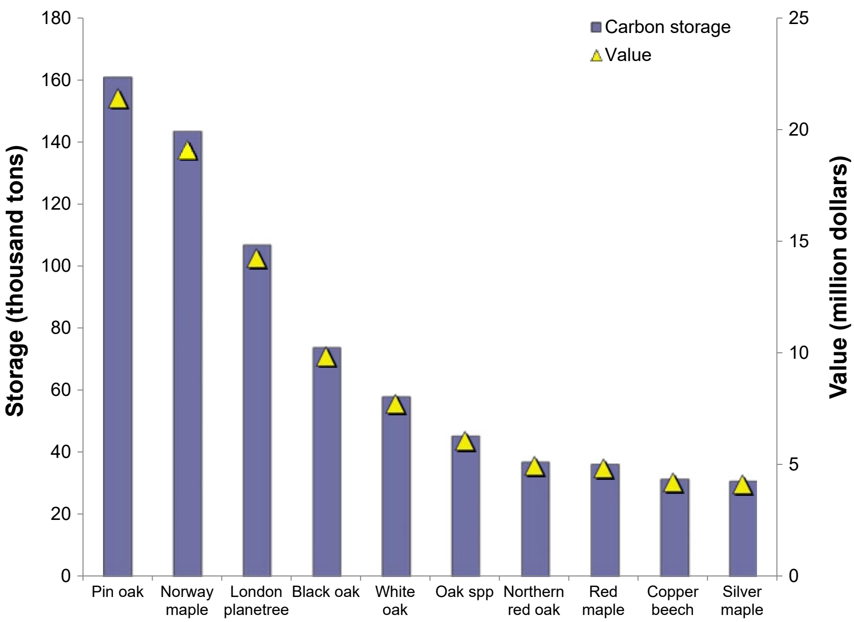


Figure 19.—Estimated annual carbon storage and value for urban tree species with the greatest storage, New York City, 2013.

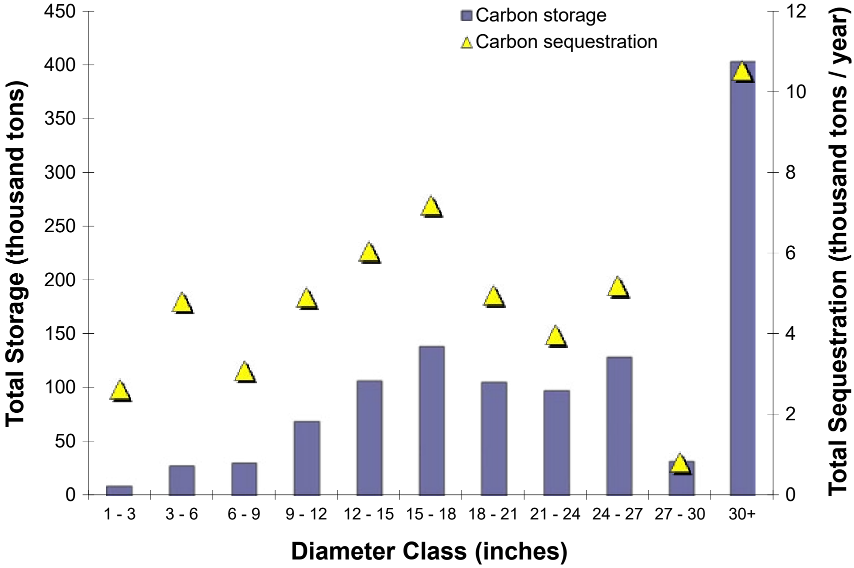


Figure 20.—Estimated total carbon storage and sequestration by diameter class, New York City, 2013. The lower limit of each diameter class is greater than displayed (e.g., 3-6 is actually 3.01 to 6 inches).

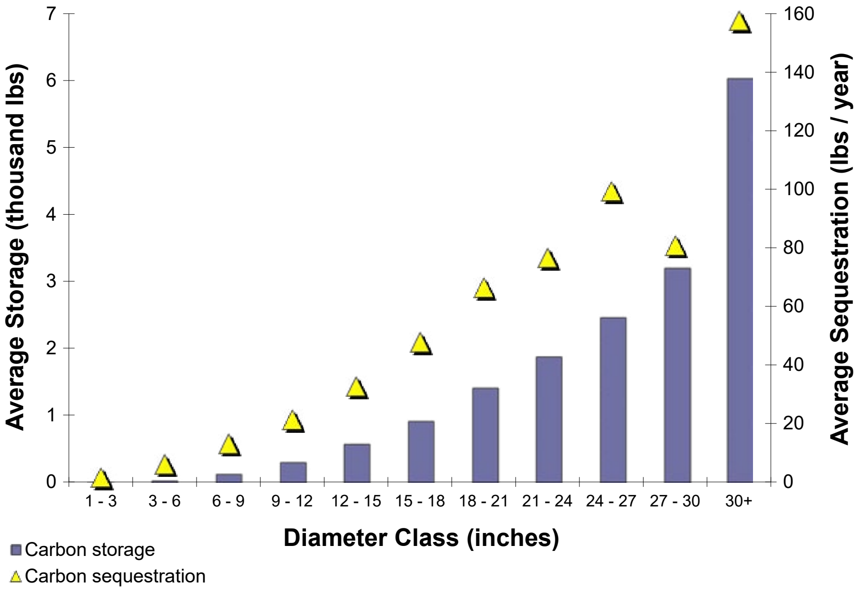


Figure 21.—Estimated average carbon storage and sequestration per tree by diameter class, New York City, 2013. The lower limit of each diameter class is greater than displayed (e.g., 3-6 is actually 3.01 to 6 inches).

Table 12.—Annual monetary savings[a] ($) in residential energy expenditures during heating and cooling seasons, New York City, 2012

	Heating	Cooling	Total
MBTU[b]	4,833,000	n/a	4,833,000
MWH[c]	838,000	11,455,000	12,293,000
Carbon avoided	844,000	729,000	1,574,000

[a] Based on 2012 statewide energy costs (Energy Information Administration 2012a, 2012b, 2014b, 2014c)
[b] MBTU – Million British Thermal Units (not used for cooling)
[c] MWH – Megawatt-hour

Table 13.—Annual energy savings (MBTU, MWH, or tons) due to trees near residential buildings, New York City, 2012

	Heating	Cooling	Total
MBTU[a]	305,100	n/a	305,100
MWH[b]	4,700	64,900	69,700
Carbon avoided (t)[c]	6,300	5,500	11,800

[a] MBTU – Million British Thermal Units (not used for cooling)
[b] MWH – Megawatt-hour
[c] To convert carbon estimates to CO_2, multiply carbon value by 3.667

Energy Consumption

Trees affect building energy use 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 (McPherson and Simpson 1999).

Based on average energy costs in 2012 (Energy Information Administration 2012a, 2012b, 2014b, 2014c), trees in New York City reduce energy costs from residential buildings by an estimated $17.1 million annually (Table 12). Trees also provide an additional $1.6 million in value per year by reducing the amount of carbon released by fossil-fuel-based power sources (a reduction of 11,800 tons of carbon emissions or 43,000 tons of CO_2) (Table 13).

Structural and Functional Values

The city's forest has a structural value based on the tree itself that includes compensatory value and carbon storage value. The compensatory value is an estimate of the value of the tree as a structural asset (e.g., how much should one be compensated for the loss of the physical structure of the tree). For small trees, a replacement cost can be used. For larger trees, several estimation procedures are used (Nowak et al. 2002a). The compensatory value of the trees in New York City is about $5.7 billion (Fig. 22). The structural value of the forest resource tends to increase with an increase in the number and size of healthy trees. Note that some invasive tree species are listed with a high compensatory value because the methods used to estimate compensatory value do not necessarily discount invasives species in the species rating.

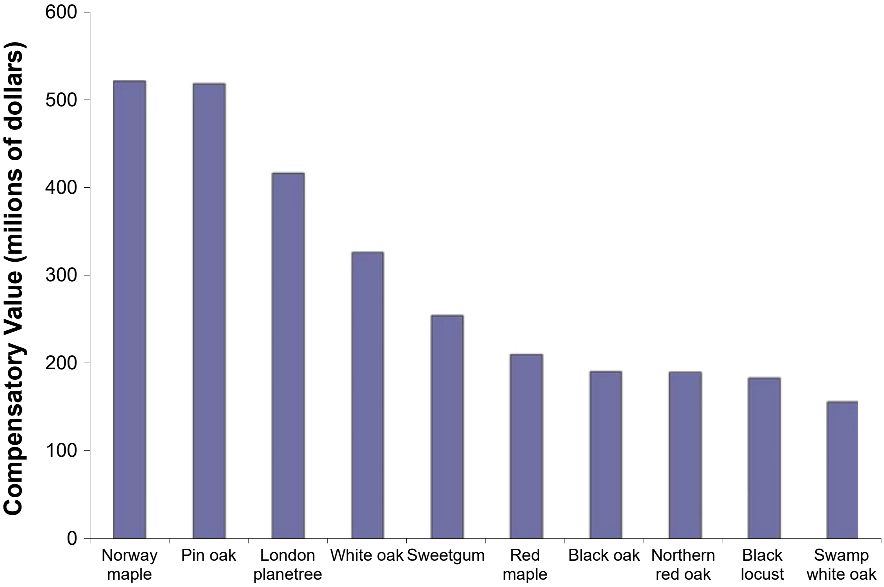


Figure 22.—Figure 22—Tree species with the greatest compensatory value, New York City, 2013.

Forests also have functional values (either positive or negative) based on the functions the trees perform, including sequestering carbon, removing air pollutants, and reducing the amount of energy used to heat or cool buildings. 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 forest, though they are not quantified here (e.g., aesthetics, wildlife habitat). Thus the functional estimates provided in this report only represent a portion of the total forest functional values. 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 or if improper forest designs are used (e.g., increasing energy use). There are also various monetary costs associated with urban forest management, such as tree pruning, inspection, removal, and disposal, which are not accounted for in this assessment (McPherson et al. 2005).

Urban trees in New York City have the following structural values:

- Compensatory value: $5.7 billion
- Carbon storage: $153 million

Urban trees in New York City have the following annual functional values:

- Carbon sequestration: $6.8 million
- Pollution removal: $77.9 million
- Avoided surface water runoff: $4.6 million
- Reduced energy costs: $17.1 million

MANAGEMENT IMPLICATIONS

The urban forest of New York City and its associated benefits vary across the city and inevitably will change through time. An important aspect of managing the urban forest for current and future residents is to understand how to sustain the benefits for all city residents. This report provides a means to communicate urban forest benefits and provides a baseline by which to start making decisions about planting and management. Future measurements will ascertain how the forest is changing due to human and natural forces.

While current tree cover for the entire city is 21 percent, it ranges from 2.3 to 77.2 percent among the community districts. There are numerous options in determining areas to target tree cover enhancements, and these priorities should be determined locally based on issues that are important to the City of New York. One option for determining priority planting areas could be based on enhancing desired ecosystem services. For example, tree planting could be targeted in the warmest areas of the city to help cool air temperatures (appendix 6). Other options for enhancing ecosystem services from trees could be to target planting in a) riparian zones to enhance water quality; b) the most polluted areas to help enhance pollution removal; or c) near buildings to reduce energy use, or any combination of these or other options.

Current Tree Size Distribution and Potential Species Changes

Change in species composition and tree sizes may have a significant influence on the benefits provided by the urban forest for the next several decades. These changes are likely to require a different approach in forest management strategies that affect species composition, including pest management, regeneration, and restoration efforts.

The future forest will be determined, in part, by the structure and composition of today's urban forest. Younger trees will grow to larger sizes and older trees will eventually decline and die. Overall, New York City has more small trees than large trees, which leads to an inverse J-shaped distribution of diameter structure (Fig. 6). This pattern indicates a potential for long-term sustainability of tree cover. The shape of the diameter curve is dependent on many factors such as mortality rates, growth rates, and influx rates (i.e., the number of trees being planted or naturally regenerating each year).

By comparing the species composition of small trees with that of the large trees, potential changes in the species composition and size structure of the forest over time are revealed. Other factors that will influence future forest structure include insects, diseases, land use changes, climate change, development, and natural resource management. Several of the most common large diameter tree species, particularly northern red oak, black oak, pin oak, and London planetree, are underrepresented among the small diameter trees (Fig. 8), which is an indication that there may not be enough regeneration and planting of these species to sustain the current species population totals into the future. Species that dominate the small diameter classes and appear to be regenerating well (including tree planting by humans) are northern white-cedar and white oak. There are several factors that may contribute to dominance in the small diameter classes. Species, such as tree-of-heaven, that tend to be prolific seeders can easily become established in open areas and corridors throughout New York City. Tree-of-heaven is classified as an invasive species in New York State and can contribute to future changes in species composition. Additionally, if individual small-stature trees (e.g., bayberry) are replacing large trees in the urban landscape, this will likely lead to lower tree cover and altered size structure.

Changes in urban forest structure and diversity can be assessed over time. Urban forest monitoring is important as long-term urban forest plot data can be used to assess changes in species composition, size class distribution, and environmental benefits, in addition to assessing tree growth and mortality (Nowak et al. 2004, 2016). The USDA Forest Service Forest Inventory and Analysis program, in cooperation with New York City, started a long-term urban forest monitoring program in New York City in 2018. This program will measure urban forest data annually to assess urban forest structure, ecosystem services and values, and changes in structure, services and values through time (Forest Service 2016).

Insect and Disease Impacts

Thirty-one exotic insects and tree diseases were assessed for their potential impact on New York City's urban forest using range maps of the pests in the coterminous United States (USDA Forest Service 2013, 2014; Worrall 2007). For a complete list of the 31 exotic insects and diseases, see appendix 8.

Although there are numerous pests that could impact New York City's urban forest, Asian longhorned beetle (ALB), gypsy moth (GM), oak wilt (OW), large aspen tortrix (LAT), and laurel wilt disease (LWD) pose the most serious threats based on the number of trees at risk to infestation.

Of these five insects and diseases, ALB, GM, and LAT were confirmed present in New York City at the time of this study (summer 2013). As of 2018, OW has also been confirmed, and the USDA Animal and Plant Health Inspection Service (USDA-APHIS) has declared that the boroughs of Manhattan and Staten Island are free from ALB although parts of Queens and Brooklyn are still under quarantine. Potential loss from ALB is 1.5 million trees with an associated compensatory value of $1.6 billion, GM is 1.4 million trees ($2.3 billion), and LAT is 372,000 ($118 million). Potential loss of trees from OW is 733,000 ($1.5 billion in compensatory value). LWD has been found within


Asian longhorned beetle. Photo by Kenneth R. Law USDA APHIS PPQ, from bugwood.org, 0949056.


Oak wilt symptom. Photo by Joseph O'Brien, USDA Forest Service, from bugwood.org, 5039074.


Large aspen tortrix. Photo by Steven Katovich, USDA Forest Service, from bugwood.org, 1398256.

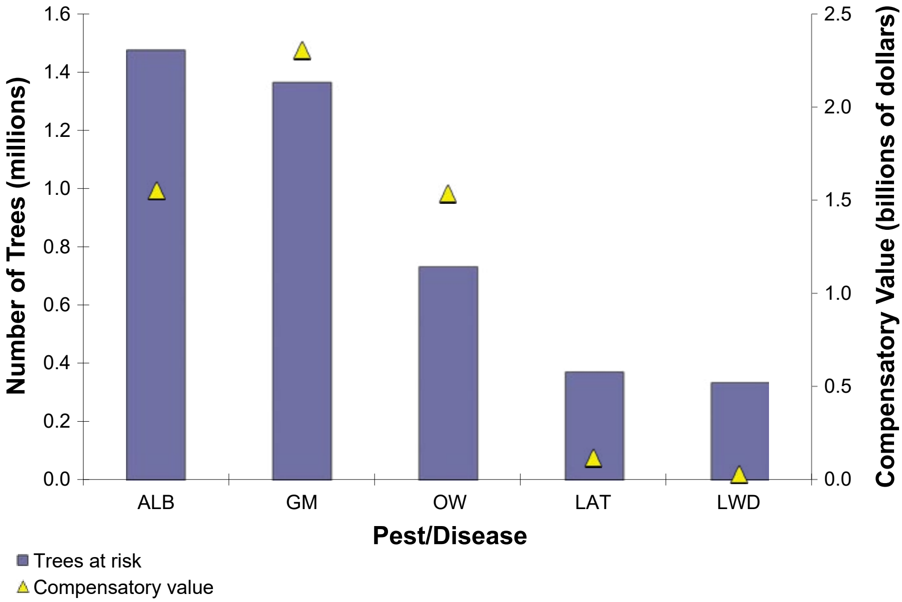


Figure 23.—Number of trees at risk and associated compensatory value for five most threatening insects/ or diseases, New York City, 2013.

750 miles of New York City. Potential loss of trees from LWD is 335,000 ($30 million in compensatory value) (Fig. 23). These five insects and diseases threaten common trees such as willow, pine, spruce, and birch (appendix 8).

Two other pests that are of concern in New York City are the southern pine beetle (SPB) and emerald ash borer (EAB). Though SPB is not currently found in the city, it has been detected in New York State as close as Rockland and Orange Counties. Potential loss of trees due to an infestation of SPB is 163,000 trees ($246 million in compensatory value). EAB was confirmed in Brooklyn and Queens in 2017 and Staten Island in 2018. This pest poses a risk to 40,000 trees with an associated value of $99 million.

Adult southern pine beetle. Photo by USDA Forest Service, Region 8, from bugwood.org, 1510071.

Emerald ash borer feeding on ash leaf. Photo by Leah Bauer, USDA Forest Service, from bugwood.org, 5473689.

CONCLUSION

New York City's urban forest contributes significantly to the environment, the economy, and residents' well-being. Throughout the city, nearly 7.0 million trees, representing at least 138 species/genera, provide a canopy cover of 21 percent. That canopy provides a wide range of important environmental benefits including air pollution removal, reduced carbon emissions, carbon storage and sequestration, reduced energy use for buildings, storm water runoff reduction, and many other benefits (and costs). Forested parkland, in particular, provides a disproportionate amount of ecosystem service benefits relative to its geographic size because of its greater tree density.

There are a number of change forces that will impact New York City's forest structure, health, management costs, and environmental benefits provided to the city's 8.2 million residents. The forces discussed in this report include insects and disease infestation, invasive trees, and aging and loss of larger trees. Additional change forces that could be considered in urban forest management plans and policies include climate change, the expansion of nonnative, opportunistic species, future changes due to urban development, and changes in the use of the forest. Managers can use data in this report to inform long-term management plans and policies to sustain a healthy urban tree population and ecosystem services for future generations.

More information on trees in New York City can be found at: https://doi.org/10.2737/NRS-RB-117

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APPENDIX 1

Bronx River Watershed Analysis

Introduction

To better understand the impact of tree and impervious cover on stream flow and water quality in New York City, the i-Tree Hydro model (Wang et al. 2008) was applied to the approximately 25,000-acre Bronx River watershed (Fig. 24). The model was calibrated using existing stream flow data and used to compare how simulated flow and runoff change when tree or impervious surface cover is changed in the watershed. Due to limitations in calibration and determining the exact hourly flow rates, the i-Tree Hydro model is used to evaluate relative changes in stream flow under different scenarios, as opposed to determining exact increases or decreases in the volume of flow due to changes in tree or impervious cover.

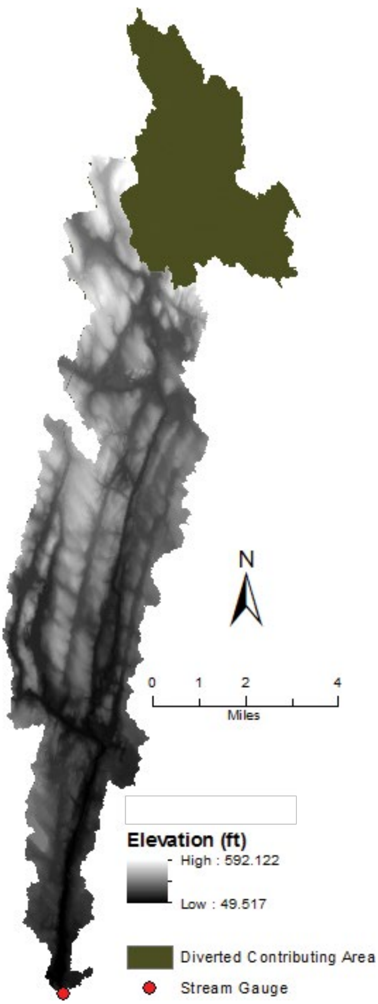

Figure 24.—Figure 24—Digital elevation model of Bronx River watershed and U.S. Geologic Survey (USGS) gauge for Bronx River at New York Botanical Garden, Bronx, NY, 2012.

Table 14.—Cover estimates for Bronx River Watershed, 2016

	Cover (%)[a]				
Area (ac)	Impervious	Tree/ shrub[b]	Grass/ herbaceous	Bare soil	Water
24,576	40.75	45.8	20.0	0.5	1.25

[a] Total is greater than 100% because 8.3% of ground cover beneath tree canopies was modeled as impervious.
[b] Tree/shrub is hereafter referred to as tree cover.

Methods

Data and Model Calibration

Hourly weather data were obtained from LaGuardia Airport weather station (i.e., station number: 725030-14732). Tree and impervious land cover parameters for the watershed were estimated by interpretation of Google Earth imagery (survey completed in April 2016) using a sample of 400 random locations (Table 14). Leaf area index (LAI) was set to 5 based on various field studies (Asner et al. 2003, and unpublished data[6]). The impervious land area directly connected to the stream is a key model input. Under the current condition case of 40.75 percent of the land area impervious, 34 percent of the impervious cover was assumed directly connected to the stream. The percentage of impervious cover connected to the stream varied with percentage impervious so that as percent impervious land cover increased, the percent connected also increased, based on effective impervious area (EIA) equations from Sutherland (2000).

Model calibration is necessary to adjust several model parameters, mostly related to soils, to find the best fit between the observed and modeled flows on an hourly basis. There can be mismatches between the precipitation data, which were collected outside of the watershed, and the actual precipitation that occurred in the watershed. Since the model assumes the same amount of rain fell everywhere in the watershed, local variations in precipitation intensity can lead to differences between the actual precipitation reaching the watershed and precipitation observed at the weather station. These differences in precipitation can lead to a lack of agreement between the observed and modeled estimates of flow as precipitation is a main driver of the stream flow. For the Bronx River watershed, i-Tree Hydro model parameters were estimated by calibrating the model for the best match between predicted stream flow and observed hourly stream flow data. Observed hourly stream flow data was collected at the U.S. Geological Survey (USGS) gauging station "Bronx River at NY Botanical Garden at Bronx NY" for the 2012 calendar year. The natural contributing area of this stream gauge includes an area that is now diverted for municipal water supplies. To perform model calibration, it was necessary to reduce the difference between model inputs affecting predicted streamflow and actual conditions affecting observed streamflow. For this purpose, the contributing area of this stream gauge

[6] Auyeung, N.; Larson, M. 2016. Shapefiles for watersheds and sub-catchments of New York City. New York City Parks. Unpublished information and personal communication on April 11, 2016.

was reduced from its natural area (51.1 square miles) to only the undiverted area (38.4 square miles; Fig. 24) based on maps of watersheds provided by the NYC Parks.[6]

Water Quality Effects and Pollution Load

Event mean concentration (EMC) data are used for estimating pollutant loading into watersheds. EMC is a statistical parameter representing the flow-proportional average concentration of a given parameter during a storm event and is defined as the total constituent mass divided by the total runoff volume. EMC estimates are usually obtained from a flow-weighted composite of concentration samples taken during a storm and are calculated as (Charbeneau and Barretti 1998, Sansalone and Buchberger 1997):

$$EMC = \bar{C} = \frac{M}{V} = \frac{\int C(t)\,Q(t)dt}{\int Q(t)dt} \approx \frac{\sum C(t)\,Q(t)\Delta t}{\sum Q(t)\Delta t} \qquad (1)$$

Where $C(t)$ and $Q(t)$ are the time-variable concentration and flow measured during the runoff event, and M and V are pollutant mass and runoff volume. It is clear that the EMC results from a flow-weighted average, not simply a time average of the concentration. EMC data is used for estimating pollutant loading into watersheds. EMCs are reported as a mass of pollutant per unit volume of water (usually millagrams per liter).

The pollution load (L) calculation from the EMC method is

$$L = EMC * Q = EMC * d_r * A \qquad (2)$$

Where EMC is event mean concentration (mg/l, mg/m^3, …), Q is runoff of a time period associated with EMC (l/h, m^3 /day…), d_r is runoff depth of unit area (mm/h, m/h, m/day…), A is the land area (m^2, …) which is catchment area in i-Tree Hydro.

Thus, when the EMC is multiplied by the runoff volume, an estimate of the pollution loading to the receiving water is provided. The instantaneous concentration during a storm can be higher or lower than the EMC, but the use of the EMC as an event characterization replaces the actual time variation of C versus *t* in a storm with a pulse of constant concentration having equal mass and duration as the actual event. This process ensures that mass loadings from storms will be adequately represented. EMCs represent the concentration of a specific pollutant contained in stormwater runoff coming from a particular land use type or from the whole watershed. Under most circumstances, the EMC provides the most useful means for quantifying the level of pollution resulting from a runoff event (U.S. EPA 2002).

Figure 25 illustrates the inter-storm variation of pollutographs and EMC.

Since collecting the data necessary for calculating site-specific EMCs can be cost-prohibitive, researchers or regulators will often use values that are already available in the literature. If site-specific numbers are not available, regional or national averages can be used although the accuracy of using these numbers is questionable. Due to the specific

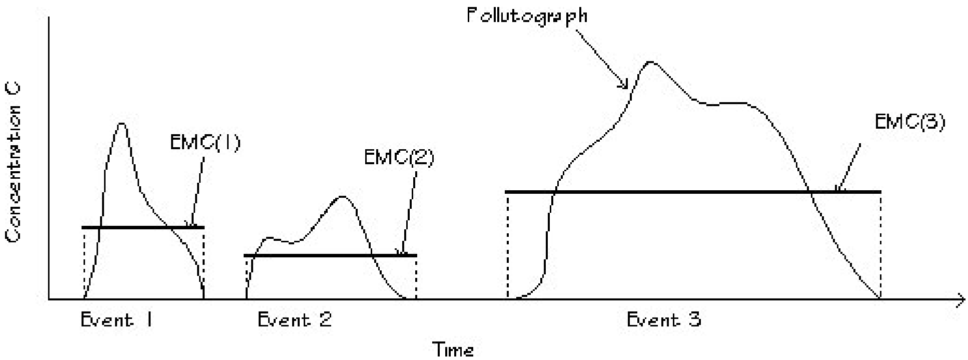

Figure 25.—Interstorm variation of pollutographs and EMCs.

climatological and physiographic characteristics of individual watersheds, agricultural and urban land uses can exhibit a wide range of variability in nutrient export (Beaulac and Reckhow 1982).

To understand and control urban runoff pollution, the U.S. Congress included the establishment of the Nationwide Urban Runoff Program (NURP) in the 1977 amendments of the Clean Water Act. The U.S. Environmental Protection Agency developed the NURP to expand the state knowledge of urban runoff pollution by applying research projects and instituting data collection in selected urban areas throughout the country.

In 1983, the U.S. Environmental Protection Agency published the results of the NURP, which nationally characterizes urban runoff for 10 standard water quality pollutants, based on data from 2,300 station-storms at 81 urban sites in 28 metropolitan areas (U.S. EPA 1983).

Subsequently, the USGS created another urban stormwater runoff base (Driver et al. 1985), based on data measured through mid-1980s for over 1,100 stations at 97 urban sites located in 21 metropolitan areas. Additionally, many major cities in the United States collected urban runoff quality data as part of the application requirements for stormwater discharge permits under the National Pollutant Discharge Elimination System (NPDES). The NPDES data are from over 30 cities and more than 800 station-storms for over 150 paramaters (Smullen et al. 1999).

The data from the three sources (NURP, USGS, and NPDES) were used to compute new estimates of EMC population means and medians for the 10 pollutants with many more degrees of freedom than were available to the NURP investigators (Smullen et al. 1999). A “pooled” mean was calculated representing the mean of the total population of sample data. The NURP and pooled mean EMCs for the 10 constitutes are listed in Table 15 (Smullen et al. 1999). NURP or pooled mean EMCs were selected because they are based on field data collected from thousands of storm events. These estimates are based on nationwide data, however, so they do not account for regional variation in soil types, climate, and other factors.

Table 15.—National pooled EMCs and NURP EMCs

Constitute		Data Source	EMCs (mg/l)		Events
			mean	*median*	*number*
Total suspended solids	TSS	Pooled[a]	78.4	54.5	3,047
		NURP	17.4	113	2,000
Biochemical oxygen demand	BOD_5	Pooled[b]	14.1	11.5	1,035
		NURP	10.4	8.39	474
Chemical oxygen demand	COD	Pooled[a]	52.8	44.7	2,639
		NURP	66.1	55	1,538
Total phosphorus	TP	Pooled[a]	0.315	0.259	3,094
		NURP	0.337	0.266	1,902
Soluble phosphorus	Soluble P	Pooled[c]	0.129	0.103	1,091
		NURP	0.1	0.078	767
Total Kjeldhal nitrogen:	TKN	Pooled[a]	1.73	1.47	2,693
		NURP	1.67	1.41	1,601
Nitrite and nitrate:	NO_2 and NO_3	Pooled[a]	0.658	0.533	2,016
		NURP	0.837	0.666	1,234
Copper:	Cu	Pooled[a]	0.0135	0.0111	1,657
		NURP	0.0666	0.0548	849
Lead:	Pb	Pooled[a]	0.0675	0.0507	2,713
		NURP	0.175	0.131	1,579
Zinc:	Zn	Pooled[a]	0.162	0.129	2,234
		NURP	0.176	0.140	1,281

[a] Pooled data sources include: NURP, USGS, NPDES.
[b] Pooled data sources include: NURP, NPDES. No BOD5 data available in the USGS dataset.
[c] Pooled data sources include: NURP, USGS. No Soluble P data available in the NPDES dataset.

For i-Tree-Hydro, the pooled median and mean EMC value for each pollutant (Table 15) were applied to the runoff regenerated from pervious and impervious surface flow, not the base flow values, to estimate effects on pollutant load across the entire modeling time frame. All rain events are treated equally using the EMC values, which means some events may be over-estimated and others underestimated. In addition, local management actions (e.g., street sweeping) can affect these values. However, across the entire season, if the EMC value is representative of the watershed, the estimate of cumulative effects on water quality should be relatively accurate. Accuracy of pollution estimates will be increased by using locally derived coefficients. It is not known how well the national EMC values represent local conditions.

Results

The i-Tree Hydro model was calibrated to find the best fit between the observed stream flow and the modeled stream flow for the Bronx River watershed. Following calibration, a number of scenarios were modeled by increasing or decreasing existing tree canopy and impervious cover parameters to evaluate the effects of land cover change within the watershed (see https://doi.org/10.2737/NRS-RB-117 for calibration evaluation).

Existing Cover Effects

The LaGuardia Airport weather station used for the i-Tree Hydro simulation of Bronx River watershed recorded 32.6 inches of rainfall during the 2012 simulation year. It was assumed that this amount fell over the entire 24,576-acre watershed and contributed 1.12 billion cubic feet of rainfall in the watershed during 2012.

The total modeled stream flow in the watershed throughout the simulation period for the existing cover (i.e., no cover change from measured conditions) was 453.0 million cubic feet. The total stream flow is made up of surface runoff (from pervious and impervious areas) and baseflow (i.e., water that travels underground to the stream). Runoff from pervious and impervious areas are the biggest contributors to stream flow with 37.2 and 33.3 percent of total flow generated from pervious runoff and impervious runoff, respectively. Base flow was estimated to generate 29.5 percent of the total flow.

Tree canopies were estimated to intercept about 13.5 percent of the total rainfall, but only 45.8 percent of the watershed was covered by trees, so precipitation interception by trees was only 6.2 percent (69.5 million cubic feet). Areas of herbaceous cover were estimated to intercept about 5.4 percent of the total rainfall, but only 20 percent of the watershed was herbaceous cover, so precipitation interception by this vegetation was only 1.1 percent (12.2 million cubic feet).

Estimated reduction in chemical constituents is based on the simulated changes in runoff rates and national pooled event mean concentration (EMC) values. EMC represents the average concentration of a given constituent during a storm event and is defined as the total constituent mass divided by the total runoff volume. The current tree cover is estimated to reduce total suspended solids in 2012 by around 26.2 tons based on median EMC values. Other chemical constituents were also reduced (Table 16).

Table 16.—Estimated reduction in chemical constituents due to existing tree cover, Bronx River Watershed, 2012

	Reduction	
Constituent	Median	Mean
	tons	tons
Total suspended solids	26.2	37.6
Biochemical oxygen demand	5.5	6.8
Chemical oxygen demand	21.5	25.4
Total phosphorus	0.12	0.15
Soluble phosphorus	0.05	0.06
Total Kjeldhal nitrogen	0.71	0.83
Nitrite and nitrate	0.26	0.32
Copper	0.005	0.006

Tree Cover Effects

Reducing the existing 45.8 percent tree cover in the Bronx River Watershed to 0 percent would increase total runoff by 15.4 million cubic feet (4.8 percent of total runoff under existing conditions) for 2012 (Fig. 26). Increasing canopy cover from 45.8 percent to 50.0 percent would reduce total runoff by 2.2 million cubic feet (0.7 percent of total runoff under existing conditions) for the same period (Fig. 26). Increasing tree cover reduces runoff generated from impervious areas and generally reduces runoff from pervious land (Fig. 27).

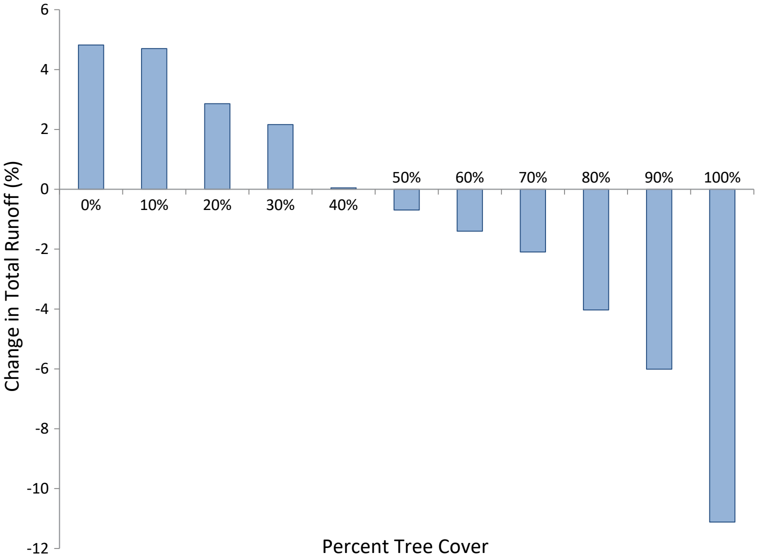

Figure 26.—Percentage change in total annual runoff by percentage tree cover, Bronx River watershed, 2012.

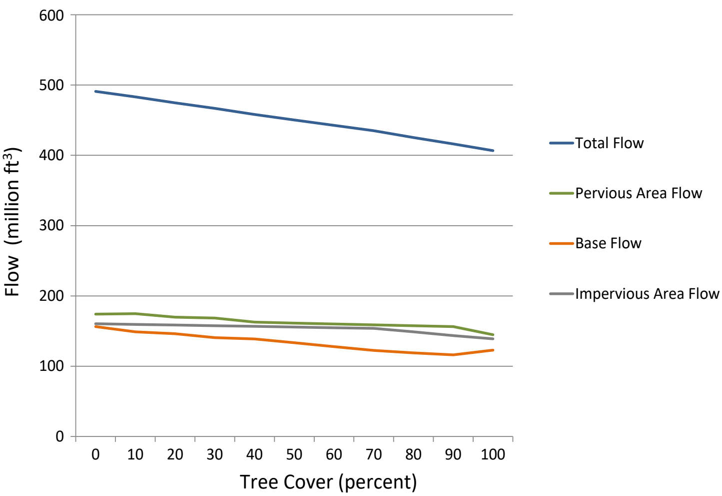

Figure 27.—Changes in total flow and its components (pervious area runoff, impervious area runoff, and base flow) with changes in percentage tree cover in Bronx River watershed, 2012.

Impervious Cover Effects

Removing all impervious cover in the Bronx River watershed (currently 41.9 percent) would reduce total annual runoff by 210.6 million cubic feet (66.0 percent of total runoff under existing conditions) for 2012. Increasing impervious cover from 41.9 percent to 50 percent of the watershed would increase total annual runoff by 56.2 million cubic feet (17.6 percent of total runoff under existing conditions) for the same period (Fig. 28). Increasing impervious cover reduces base flow and pervious runoff while significantly increasing runoff from impervious surfaces (Fig. 29).

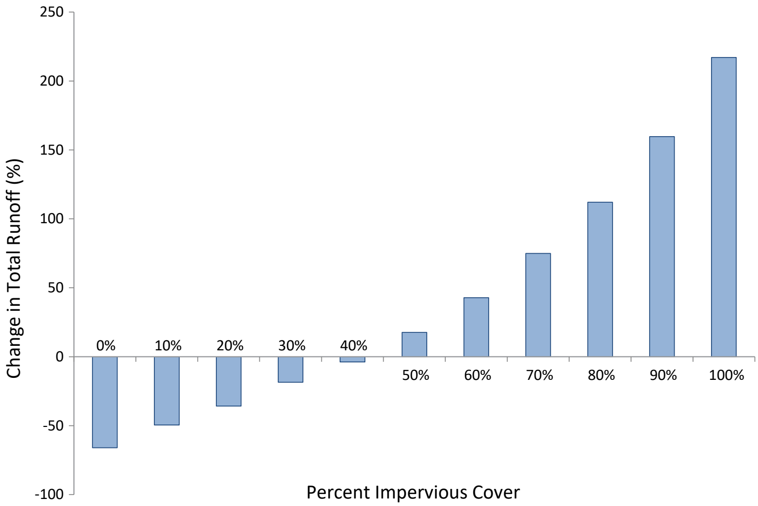

Figure 28.—Percent change in total annual runoff by percentage impervious cover, Bronx River Watershed, 2012.

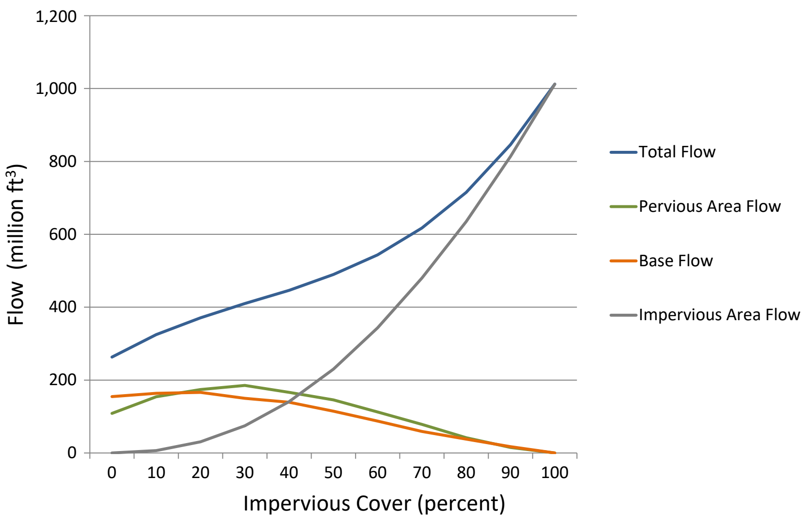

Figure 29.—Changes in total flow and its components (pervious area runoff, impervious area runoff, and base flow) with changes in percentage impervious cover in the Bronx River watershed, 2012.

The i-Tree Hydro model projects that increasing tree cover will reduce annual stream flow, but the dominant cover type influencing stream flow is impervious surfaces. Relative to current cover conditions, increasing impervious cover had an almost eight times greater impact on total flow than tree cover. Increasing impervious cover by 1 percent resulted in an average 1.45 percent increase in annual stream flow, while increasing tree cover by 1 percent resulted in an average of only 0.19 percent decrease in annual stream flow. The interactions between changing both tree and impervious cover are illustrated for changes in percent flow in Figure 30.

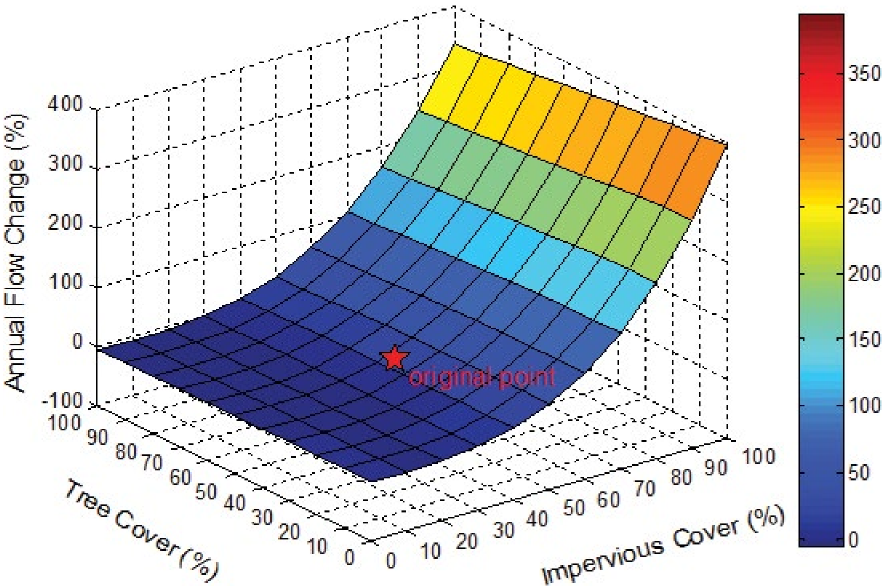

Figure 30.—Percentage change in total flow during simulation period based on percent impervious and percent tree cover, Bronx River watershed, 2012. Red star indicates existing conditions. Note: some simulation scenarios (e.g., 100 percent tree cover and 100 percent impervious cover) are not realistic, but are included to illustrate the range of possibilities.

APPENDIX 2

Ecosystem Services by Community District

Ecosystem services are presented by community district for New York City and estimated using the LiDAR urban tree canopy assessment (O'Neil-Dunne 2012) (Table 17). Each community district is assigned a code (New York City Department of City Planning 2015) (Fig. 31). Detailed information on ecosystem services by neighborhood tabulation area (NTA) can be found at: https://doi.org/10.2737/NRS-RB-117.

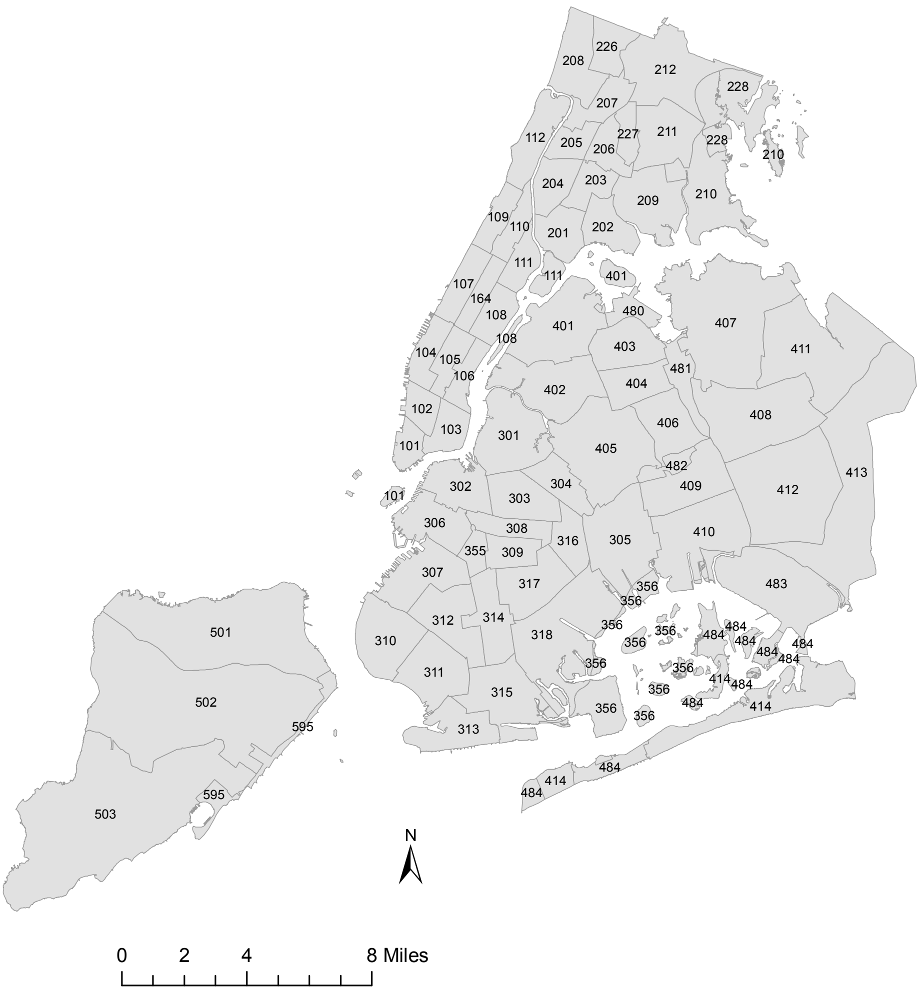

Figure 31.—Community districts, New York City, 2010.

Table 17.—Current tree cover, temperature planting index values, and available space for planting by community district (CD code), New York City, 2010

CD Code	Borough	Tree Cover	Pollution Removal		TPI[a]	Plantable Space[b]	Temperature Reduction[c]
		%	*lbs/yr*	*$/yr*		*acres*	*°F*
101	Manhattan	12.1	9,100	245,000	34.4	204.77	0.1
102	Manhattan	11.9	6,900	580,300	60.0	116.87	0.1
103	Manhattan	21.1	15,200	1,405,600	87.2	293.76	0.1
104	Manhattan	8.5	6,300	589,500	53.6	118.51	0.1
105	Manhattan	3.4	3,300	235,500	31.4	40.30	<0.1
106	Manhattan	16.6	9,100	1,049,600	90.6	172.95	0.1
107	Manhattan	21.7	18,200	1,716,200	98.0	340.14	0.1
108	Manhattan	16.9	14,400	1,716,500	100.0	279.02	0.1
109	Manhattan	23.5	12,900	771,400	65.0	308.17	0.1
110	Manhattan	17.1	7,500	785,800	75.6	213.89	0.1
111	Manhattan	15.7	23,500	963,400	45.7	533.43	0.1
112	Manhattan	29.2	22,900	960,700	61.3	686.69	0.2
164	Manhattan	62.9	21,000	6,600	0.1	639.63	0.4
201	Bronx	11.5	9,200	844,300	38.4	268.38	0.1
202	Bronx	6.3	4,300	284,900	21.5	182.52	<0.1
203	Bronx	16.6	9,800	560,600	44.8	302.07	0.1
204	Bronx	13.7	8,300	726,200	66.5	264.72	0.1
205	Bronx	13.7	6,500	748,900	84.0	185.81	0.1
206	Bronx	13.0	7,200	568,000	48.8	214.20	0.1
207	Bronx	17.2	11,400	1,110,100	66.6	315.82	0.1
208	Bronx	40.1	42,400	1,632,500	27.2	1,099.33	0.2
209	Bronx	17.3	25,500	1,850,600	38.3	853.91	0.1
210	Bronx	15.5	36,100	1,234,200	16.7	1,717.61	0.1
211	Bronx	17.9	22,000	1,211,000	28.7	725.89	0.1
212	Bronx	22.5	43,600	1,589,000	24.9	1,429.45	0.1
226	Bronx	64.0	29,500	14,400	0.2	1,013.53	0.4
227	Bronx	60.5	18,200	9,300	1.2	558.20	0.4
228	Bronx	45.6	53,600	31,700	0.2	1,796.19	0.3
301	Brooklyn	8.7	19,000	1,153,900	33.1	420.57	0.1
302	Brooklyn	18.1	24,500	1,212,800	32.0	430.18	0.1
303	Brooklyn	18.2	23,700	1,518,500	48.6	477.35	0.1
304	Brooklyn	14.2	11,900	716,300	50.4	323.80	0.1
305	Brooklyn	13.8	25,200	1,758,800	29.6	1,079.58	0.1
306	Brooklyn	15.5	20,400	1,173,300	30.9	403.80	0.1
307	Brooklyn	15.7	18,900	820,000	30.3	697.83	0.1
308	Brooklyn	17.8	13,500	842,900	52.7	255.91	0.1

continued

Table 17.—continued

CD Code	Borough	Tree Cover	Pollution Removal		TPI[a]	Plantable Space[b]	Temperature Reduction[c]
309	Brooklyn	15.1	10,900	693,700	55.1	210.94	0.1
310	Brooklyn	17.8	22,000	1,057,000	28.1	790.02	0.1
311	Brooklyn	9.8	12,400	894,100	44.5	322.60	0.1
312	Brooklyn	15.5	23,500	1,265,200	48.9	503.76	0.1
313	Brooklyn	13.0	15,000	1,143,800	29.9	691.53	0.1
314	Brooklyn	21.5	29,200	1,554,000	49.1	529.66	0.1
315	Brooklyn	17.1	40,400	2,097,300	30.1	769.41	0.1
316	Brooklyn	14.3	12,000	842,500	42.4	280.23	0.1
317	Brooklyn	14.3	23,000	1,274,000	41.7	495.68	0.1
318	Brooklyn	18.3	69,400	2,808,600	20.1	2,205.67	0.1
355	Brooklyn	60.2	8,300	12,600	1.2	452.69	0.4
356	Brooklyn	13.1	38,700	277,200	0.3	2,214.15	0.1
401	Queens	11.8	29,400	1,483,600	27.9	931.34	0.1
402	Queens	8.5	22,100	862,200	20.7	817.32	0.1
403	Queens	16.5	17,200	1,435,400	52.0	463.86	0.1
404	Queens	12.8	11,000	1,168,600	65.8	284.60	0.1
405	Queens	17.6	50,100	1,444,300	20.3	1,891.00	0.1
406	Queens	25.1	25,400	1,466,200	34.7	685.36	0.2
407	Queens	19.6	79,500	2,572,800	19.0	2,938.37	0.1
408	Queens	31.2	75,000	2,770,000	18.4	2,381.87	0.2
409	Queens	17.7	25,600	1,799,100	33.6	675.41	0.1
410	Queens	14.2	31,600	1,341,800	17.7	1,344.35	0.1
411	Queens	31.0	94,700	2,171,600	11.2	3,063.81	0.2
412	Queens	17.3	60,800	2,709,100	21.4	1,985.89	0.1
413	Queens	19.6	90,100	2,620,700	13.5	3,340.77	0.1
414	Queens	10.5	26,500	841,400	14.1	1,988.92	0.1
480	Queens	4.5	1,100	10,700	0.8	143.99	<0.1
481	Queens	20.3	17,900	3,600	0.1	490.98	0.1
482	Queens	77.2	9,200	38,900	1.5	502.41	0.5
483	Queens	2.3	5,800	9,500	0.0	1,411.24	<0.1
484	Queens	15.8	39,400	48,000	0.2	2,003.97	0.1
501	Staten Island	26.4	111,000	2,309,000	11.5	3,905.66	0.2
502	Staten Island	29.8	185,600	1,560,500	5.4	8,644.42	0.2
503	Staten Island	33.3	233,400	2,500,100	6.6	8,210.10	0.2
595	Staten Island	17.3	11,700	135,600	2.3	1,008.10	0.1

[a] TPI = temperature planting index; see appendix 6 for explanation

[b] Plantable space is the area of grass/shrub and bare soil as estimated using the LiDAR urban tree canopy assessment (O'Neil-Dunne 2012)

[c] Temperature reduction was based on daytime hours (6 a.m. – 5 p.m.) for average temperature summer day (7/23/08)

APPENDIX 3

Woody Trees and Shrubs Sampled in the New York City Urban Forest

Table 18.—Species sampled in the urban forest, New York City, 2013

Genus	Species[a]	Common Name	Trees		Leaf Area	IV[b]	Median d.b.h.	Average d.b.h.	Basal Area[c]	Compensatory Value	Pest Score[d]
			number	%	%		*inches*	*inches*	ft^2	*$ millions*	
Abies	*fraseri*	Fraser fir	6,000	0.1	0.0	0.1	2.5	2.5	300	0.6	0
Abies	*grandis*	Grand fir	6,000	0.1	0.9	1.0	23.5	23.5	19,240	39.3	2
Acer	*buergerianum*	Trident maple	19,000	0.3	0.1	0.4	3.5	3.5	1,740	4.6	4
Acer	*campestre*	Hedge maple	6,000	0.1	0.0	0.1	4.5	4.5	800	3.0	4
Acer	*negundo*	Boxelder	6,000	0.1	0.0	0.1	4.5	4.5	840	2.9	4
Acer	*palmatum*	Japanese maple	38,000	0.5	0.6	1.1	4.7	7.5	22,060	40.8	4
Acer	*platanoides*	Norway maple	425,000	6.1	10.7	16.8	5.1	9.7	451,580	525.2	4
Acer	*pseudoplatanus*	Sycamore maple	6,000	0.1	0.1	0.2	10.5	10.5	4,040	5.9	4
Acer	*rubrum*	Red maple	230,000	3.3	4.3	7.6	3.2	6.7	119,280	212.9	4
Acer	*saccharinum*	Silver maple	64,000	0.9	2.9	3.8	8.5	12.7	130,000	99.7	4
Acer	*saccharum*	Sugar maple	6,000	0.1	0.0	0.1	1.5	1.5	130	0.5	4
Acer	*species*	Maple spp	22,000	0.3	0.0	0.3	1.7	1.8	690	1.6	4
Aesculus	*hippocastanum*	Horse chestnut	6,000	0.1	0.0	0.1	2.5	2.5	300	0.8	4
Ailanthus	*altissima*	Tree-of-heaven	387,000	5.5	1.6	7.1	1.6	2.6	37,960	43.9	0
Albizia	*species*	Albizia spp	14,000	0.2	0.1	0.3	5.1	5.1	2,360	7.2	0
Amelanchier	*species*	Serviceberry spp	33,000	0.5	0.2	0.7	2.4	6.6	17,040	21.7	0
Aucuba	*japonica*	Japanese aucuba	18,000	0.3	0.0	0.3	2.7	2.8	1,140	2.4	0
Betula	*lenta*	Black birch	274,000	3.9	2.7	6.6	3.1	4.3	53,700	83.7	8
Betula	*nigra*	River birch	22,000	0.3	0.1	0.4	2.7	2.8	1,360	4.0	12
Betula	*occidentalis*	Water birch	14,000	0.2	0.2	0.4	3.0	5.0	2,740	6.2	8
Betula	*papyrifera*	Paper birch	12,000	0.2	0.1	0.3	4.5	4.5	1,600	4.9	12

continued

Table 18.—continued

Genus	Species[a]	Common Name	Trees		Leaf Area	IV[b]	Median d.b.h.	Average d.b.h.	Basal Area[c]	Compensatory Value	Pest Score[d]
			number	%	%		*inches*	*inches*	*ft²*	*$ millions*	
Betula	*populifolia*	Gray birch	12,000	0.2	0.0	0.2	4.5	4.5	1,670	6.4	12
Betula	*species*	Birch spp	6,000	0.1	0.0	0.1	3.5	3.5	530	0.0	8
Buddleja	*species*	Butterflybush spp	6,000	0.1	0.0	0.1	3.5	3.5	510	1.2	0
Carpinus	*caroliniana*	American hornbeam	8,000	0.1	0.0	0.1	3.5	3.5	670	2.1	0
Carya	*alba*	Mockernut hickory	18,000	0.3	0.1	0.4	4.5	5.2	3,690	12.3	0
Carya	*glabra*	Pignut hickory	159,000	2.3	0.3	2.6	1.5	1.6	3,750	9.3	0
Carya	*species*	Hickory spp	6,000	0.1	0.0	0.1	2.5	2.5	290	0.6	0
Carya	*x ludoviciana*	Hickory	15,000	0.2	0.1	0.3	3.0	3.0	1,010	2.4	0
Castanea	*dentata*	American chestnut	6,000	0.1	0.0	0.1	2.5	2.5	300	0.7	4
Cedrus	*atlantica glauca*	Blue atlas cedar	12,000	0.2	0.0	0.2	4.0	3.0	960	3.3	0
Cedrus	*species*	Cedar spp	165,000	2.4	0.2	2.6	2.8	3.9	24,300	63.2	0
Celtis	*occidentalis*	Northern hackberry	121,000	1.7	1.6	3.3	3.2	4.7	31,110	50.4	0
Celtis	*species*	Hackberry spp	31,000	0.5	1.0	1.5	10.7	10.3	24,700	36.6	0
Cephalotaxus	*fortunei*	Chinese plum yew	8,000	0.1	0.0	0.1	10.5	10.5	5,090	5.2	0
Cercis	*reniformis*	Southwestern redbud	12,000	0.2	0.0	0.2	2.5	2.5	600	1.3	0
Chamaecyparis	*thyoides*	Atlantic white cedar	14,000	0.2	0.1	0.3	13.1	9.0	8,440	16.0	0
Cornus	*florida*	Flowering dogwood	73,000	1.0	0.5	1.5	2.4	3.7	9,480	20.2	4
Cornus	*mas*	Cornelian cherry	6,000	0.1	0.0	0.1	2.5	2.5	290	0.5	4
Cornus	*species*	Dogwood spp	45,000	0.7	0.3	1.0	4.3	4.7	8,850	17.7	4
Crataegus	*mollis*	Downy hawthorn	7,000	0.1	0.0	0.1	1.5	1.5	150	0.3	4
Crataegus	*phaenopyrum*	Washington hawthorn	34,000	0.5	1.1	1.6	13.3	17.7	73,990	94.1	4
Crataegus	*species*	Hawthorn spp	46,000	0.7	0.1	0.8	3.3	3.3	4,080	9.4	4
Cryptomeria	*species*	Japanese cedar spp	6,000	0.1	0.0	0.1	2.5	2.5	300	0.7	0
Diospyros	*virginiana*	Common persimmon	12,000	0.2	0.0	0.2	2.0	3.0	930	3.3	0

continued

Table 18.—continued

Genus	Species[a]	Common Name	Trees		Leaf Area	IV[b]	Median d.b.h.	Average d.b.h.	Basal Area[c]	Compensatory Value	Pest Score[d]
			number	%	%		*inches*	*inches*	*ft²*	*$ millions*	
Fagus	*species*	Beech spp	12,000	0.2	0.9	1.1	11.0	12.5	11,090	23.0	4
Fagus	*sylvatica 'purpurea'*	Copper beech	6,000	0.1	1.9	2.0	43.5	43.5	64,660	93.5	4
Ficus	*carica*	Common fig	74,000	1.1	0.3	1.4	3.1	3.2	6,540	19.5	0
Ficus	*species*	Fig spp	76,000	1.1	0.4	1.5	3.6	4.2	11,170	25.9	0
Fraxinus	*americana*	White ash	6,000	0.1	0.4	0.5	32.5	32.5	36,370	51.2	3
Fraxinus	*nigra*	Black ash	8,000	0.1	0.3	0.4	8.5	8.5	3,410	5.4	3
Fraxinus	*pennsylvanica*	Green ash	26,000	0.4	1.6	2.0	14.1	12.9	26,240	42.0	7
Ginkgo	*biloba*	Ginkgo	37,000	0.5	0.8	1.3	9.5	8.4	21,130	31.0	0
Gleditsia	*triacanthos*	Honeylocust	64,000	0.9	1.4	2.3	13.4	11.4	56,600	106.0	0
Gymnocladus	*dioicus*	Kentucky coffeetree	6,000	0.1	0.3	0.4	13.5	13.5	6,280	11.1	0
Hibiscus	*syriacus*	Rose-of-sharon	58,000	0.8	0.1	0.9	2.9	3.2	5,210	13.5	0
Hydrangea	*species*	Hydrangea spp	8,000	0.1	0.0	0.1	2.5	2.5	380	1.1	0
Ilex	*aquifolium*	English holly	35,000	0.5	0.2	0.7	2.6	4.1	6,860	11.0	0
Ilex	*species*	Holly spp	12,000	0.2	0.0	0.2	2.0	2.0	430	1.2	0
Juglans	*species*	Walnut spp	6,000	0.1	0.4	0.5	19.5	19.5	13,360	20.5	0
Juniperus	*species*	Juniper spp	28,000	0.4	0.0	0.4	3.0	2.8	1,720	3.8	0
Juniperus	*virginiana*	Eastern red cedar	44,000	0.6	0.3	0.9	3.2	4.4	10,840	19.4	0
Juniperus	*virginiana silicicol*	Southern redcedar	12,000	0.2	0.1	0.3	8.0	8.0	4,650	9.7	0
Koelreuteria	*paniculata*	Goldenrain tree	20,000	0.3	0.3	0.6	6.6	7.0	6,390	14.1	0
Lagerstroemia	*indica*	Common crapemyrtle	18,000	0.3	0.1	0.4	5.5	6.2	5,060	10.3	0
Ligustrum	*species*	Privet spp	28,000	0.4	0.0	0.4	1.7	1.8	820	1.7	0
Lindera	*benzoin*	Spicebush	6,000	0.1	0.0	0.1	1.5	1.5	130	0.4	2
Liquidambar	*styraciflua*	Sweetgum	110,000	1.6	2.4	4.0	5.0	10.5	129,610	254.3	4
Liriodendron	*tulipifera*	Tulip tree	92,000	1.3	0.4	1.7	1.5	1.9	3,520	11.9	0

continued

Table 18.—continued

Genus	Species[a]	Common Name	Trees		Leaf Area	IV[b]	Median d.b.h.	Average d.b.h.	Basal Area[c]	Compensatory Value	Pest Score[d]
			number	%	%		*inches*	*inches*	*ft²*	*$ millions*	
Lonicera	*japonica*	Hall's honeysuckle	6,000	0.1	0.0	0.1	3.5	3.5	530	1.4	0
Maclura	*pomifera*	Osage orange	7,000	0.1	0.3	0.4	26.5	26.5	29,410	30.8	0
Magnolia	*species*	Magnolia spp	19,000	0.3	0.2	0.5	1.8	4.7	4,470	8.9	0
Malus	*species*	Apple spp	43,000	0.6	0.1	0.7	3.0	4.3	7,570	13.1	4
Malus	*spectabilis*	Asiatic apple	7,000	0.1	0.3	0.4	17.5	17.5	13,070	17.1	0
Malus	*tschonoskii*	Crabapple	12,000	0.2	0.2	0.4	3.0	6.0	3,640	6.6	4
Morella	*pensylvanica*	Bayberry	255,000	3.6	0.3	3.9	2.2	2.2	11,200	21.2	0
Morus	*species*	Mulberry spp	57,000	0.8	0.4	1.2	3.8	7.1	25,580	37.3	0
Nyssa	*sylvatica*	Black tupelo	12,000	0.2	0.2	0.4	5.0	5.5	2,370	7.1	0
Phellodendron	*amurense*	Amur corktree	6,000	0.1	0.5	0.6	29.5	29.5	30,060	35.1	0
Photinia	*species*	Chokeberry spp	6,000	0.1	0.1	0.2	5.5	5.5	1,150	3.0	0
Picea	*abies*	Norway spruce	51,000	0.7	2.4	3.1	2.6	9.6	61,040	123.6	13
Picea	*pungens*	Blue spruce	19,000	0.3	0.1	0.4	4.6	5.0	3,710	10.0	8
Picea	*species*	Spruce spp	6,000	0.1	0.0	0.1	2.5	2.5	300	0.8	7
Pinus	*species*	Pine spp	18,000	0.3	0.2	0.5	2.5	6.4	8,640	11.0	10
Pinus	*strobus*	Eastern white pine	12,000	0.2	0.0	0.2	2.0	3.0	930	3.3	14
Platanus	*hybrida*	London planetree	166,000	2.4	11.2	13.6	17.1	14.8	307,870	415.3	4
Prunus	*cerasus*	Sour cherry	6,000	0.1	0.1	0.2	5.5	5.5	1,200	3.5	0
Prunus	*mume*	Japanese apricot	8,000	0.1	0.0	0.1	4.5	4.5	1,050	3.0	0
Prunus	*persica*	Peach	32,000	0.5	0.1	0.6	3.3	3.5	3,260	8.0	0
Prunus	*pissardii*	Purpleleaf plum	29,000	0.4	0.2	0.6	4.5	4.8	5,450	13.0	0
Prunus	*serotina*	Black cherry	25,000	0.4	0.4	0.8	8.1	6.9	8,490	14.3	0
Prunus	*serrulata*	Kwanzan cherry	30,000	0.4	0.1	0.5	4.0	4.3	4,080	10.4	0
Prunus	*species*	Plum spp	86,000	1.2	0.4	1.6	3.5	3.4	8,090	17.7	0

continued

Table 18.—continued

Genus	Species[a]	Common Name	Trees		Leaf Area	IV[b]	Median d.b.h.	Average d.b.h.	Basal Area[c]	Compensatory Value	Pest Score[d]
			number	%	%		*inches*	*inches*	*ft*^{2}	*$ millions*	
Prunus	*subhirtella*	Higan cherry	6,000	0.1	0.1	0.2	5.5	5.5	1,200	3.4	0
Prunus	*x orthosepala*	Prunus	6,000	0.1	0.0	0.1	6.5	6.5	1,570	3.6	0
Prunus	*yedoensis*	Yoshino flowering cherry	6,000	0.1	0.0	0.1	2.5	2.5	290	0.5	0
Pyrus	*calleryana*	Callery pear	160,000	2.3	1.3	3.6	3.3	5.7	54,820	95.8	4
Pyrus	*species*	Pear spp	14,000	0.2	0.1	0.3	9.1	6.0	4,340	8.7	4
Quercus	*alba*	White oak	302,000	4.3	4.2	8.5	4.2	7.5	178,960	322.4	7
Quercus	*bicolor*	Swamp white oak	89,000	1.3	1.0	2.3	10.7	11.3	86,810	156.6	7
Quercus	*palustris*	Pin oak	123,000	1.8	5.4	7.2	17.9	19.2	352,640	506.9	8
Quercus	*fastigiata*	Fastigiate pin oak	7,000	0.1	0.0	0.1	2.5	2.5	360	1.2	7
Quercus	*phellos*	Willow oak	12,000	0.2	0.7	0.9	16.0	16.5	19,370	31.5	7
Quercus	*prinus*	Chestnut oak	6,000	0.1	0.0	0.1	7.5	7.5	2,050	4.9	7
Quercus	*rubra*	Northern red oak	98,000	1.4	2.1	3.5	9.7	12.3	112,590	188.7	8
Quercus	*species*	Oak spp	36,000	0.5	0.8	1.3	13.0	19.1	97,820	135.8	7
Quercus	*velutina*	Black oak	61,000	0.9	2.3	3.2	16.2	17.0	134,720	190.5	7
Rhododendron	*arborescens*	Smooth azalea	14,000	0.2	0.0	0.2	2.9	3.0	900	1.9	1
Rhododendron	*azalea*	Azalea	31,000	0.4	0.1	0.5	4.3	4.9	5,850	13.4	1
Rhus	*hirta*	Staghorn sumac	15,000	0.2	0.0	0.2	0.0	1.1	200	0.8	4
Rhus	*species*	Sumac spp	52,000	0.7	0.1	0.8	1.9	2.2	2,360	5.6	0
Robinia	*pseudoacacia*	Black locust	285,000	4.1	7.0	11.1	5.3	6.8	117,550	186.3	0
Salix	*fragilis*	Crack willow	8,000	0.1	0.1	0.2	14.5	14.5	9,470	6.4	14
Salix	*species*	Willow spp	18,000	0.3	0.2	0.5	7.5	7.5	6,680	5.9	14
Salix	*x sepulcralis simonk*	Weeping willow	6,000	0.1	0.3	0.4	3.5	3.5	510	0.5	14
Sassafras	*albidum*	Sassafras	329,000	4.7	0.8	5.5	1.8	2.3	23,560	29.9	2
Schizomeria	*ovata*	Cherry birch	6,000	0.1	0.0	0.1	1.5	1.5	130	0.3	0

continued

Table 18.—continued

Genus	Species[a]	Common Name	Trees		Leaf Area	IV[b]	Median d.b.h.	Average d.b.h.	Basal Area[c]	Compensatory Value	Pest Score[d]
			number	%	%		*inches*	*inches*	ft^2	*$ millions*	
Sophora	*japonica*	Japanese pagoda tree	32,000	0.5	1.2	1.7	17.3	16.7	52,350	70.0	0
Syringa	*reticulata*	Japanese tree lilac	7,000	0.1	0.0	0.1	2.5	2.5	340	0.6	0
Syringa	*species*	Lilac spp	6,000	0.1	0.0	0.1	0.0	0.8	30	0.3	0
Tabebuia	*heterophylla*	White cedar	6,000	0.1	0.0	0.1	3.5	3.5	530	1.7	0
Taxus	*canadensis*	Canada yew	14,000	0.2	0.0	0.2	6.1	5.2	2,600	6.4	0
Taxus	*species*	Yew spp	110,000	1.6	0.4	2.0	3.1	3.9	15,760	36.8	0
Thuja	*occidentalis*	Northern white-cedar	395,000	5.7	0.7	6.4	1.9	2.6	38,810	78.7	0
Thuja	*species*	Red cedar spp	46,000	0.7	0.1	0.8	2.4	2.3	2,060	6.6	0
Tilia	*americana*	American basswood	20,000	0.3	0.3	0.6	3.4	7.5	11,760	22.2	4
Tilia	*cordata*	Littleleaf linden	27,000	0.4	1.4	1.8	8.0	13.2	54,900	92.6	4
Tilia	*tomentosa*	Silver linden	14,000	0.2	1.5	1.7	9.9	21.7	49,760	101.8	4
Tilia	*x vulgaris*	Common linden	6,000	0.1	0.2	0.3	9.5	9.5	3,340	7.1	4
Tsuga	*canadensis*	Eastern hemlock	51,000	0.7	2.1	2.8	10.3	11.4	58,220	96.3	7
Tsuga	*species*	Hemlock spp	6,000	0.1	0.0	0.1	3.5	3.5	510	1.5	3
Ulmus	*americana*	American elm	21,000	0.3	1.7	2.0	21.4	17.0	47,200	45.7	8
Ulmus	*parvifolia*	Chinese elm	48,000	0.7	2.1	2.8	9.5	9.9	31,710	33.9	8
Ulmus	*species*	Elm spp	14,000	0.2	0.1	0.3	3.0	3.0	960	1.6	8
Unknown	*species*	Hardwood	237,000	3.4	0.1	3.5	3.2	4.7	52,720	3.7	0
Viburnum	*species*	Viburnum spp	6,000	0.1	0.0	0.1	2.5	2.5	290	0.5	0
Vitis	*species*	Grape spp	22,000	0.3	0.1	0.4	1.8	1.9	680	1.6	0
Zelkova	*serrata*	Japanese zelkova	50,000	0.7	0.9	1.6	9.7	8.2	26,300	63.3	0

[a] Species refers to tree species, genera, or species groups that were classified during field data collection
[b] IV = importance value (% population + % leaf area)
[c] Basal area is the cross sectional area of the tree stems measured at d.b.h.
[d] Numerical scoring system based on sum of points assigned to pest risks for species. Each pest that could attack the tree species is assigned points based on pest range (i.e., 4 points if the pest is located in the city, 3 points if within 250 miles, 2 points if within 750 miles, and 1 point if greater than 750 miles away). See Table 21 in appendix 8.
* Invasive species

APPENDIX 4
Tree Species Distribution

The tree species distributions for New York City and for each borough for the 20 most common species, or all species if there are less than 20 species in the borough, are presented in Figs. 32 through 39.

During field data collection, trees are identified to the most specific classification possible. Some trees have been identified to the species or genus level. The designation "hardwood" includes the sampled hardwood trees that could not be identified to a species or genera classification.

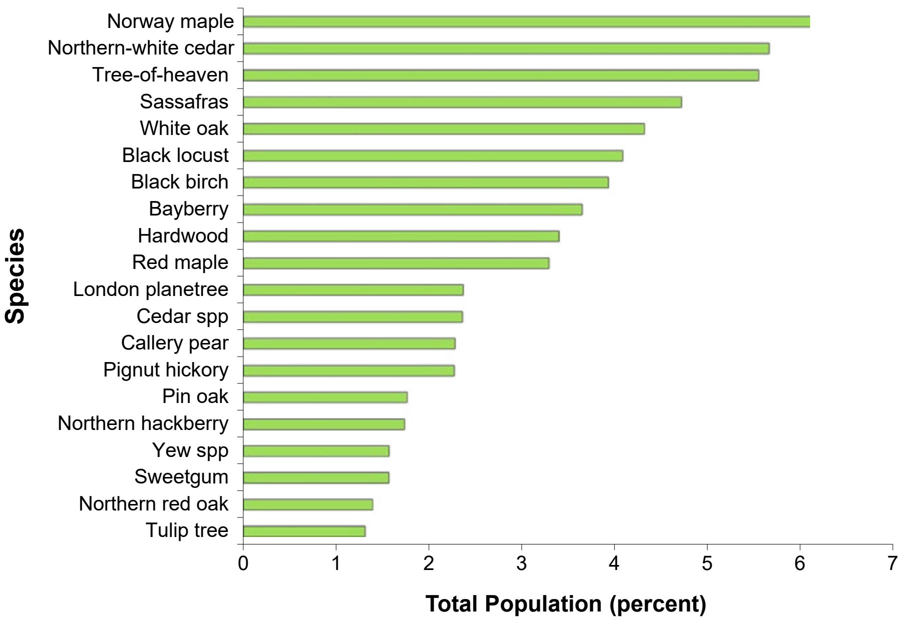

Figure 32.—The 20 most common tree species as a percentage of the total urban tree population, New York City, 2013.

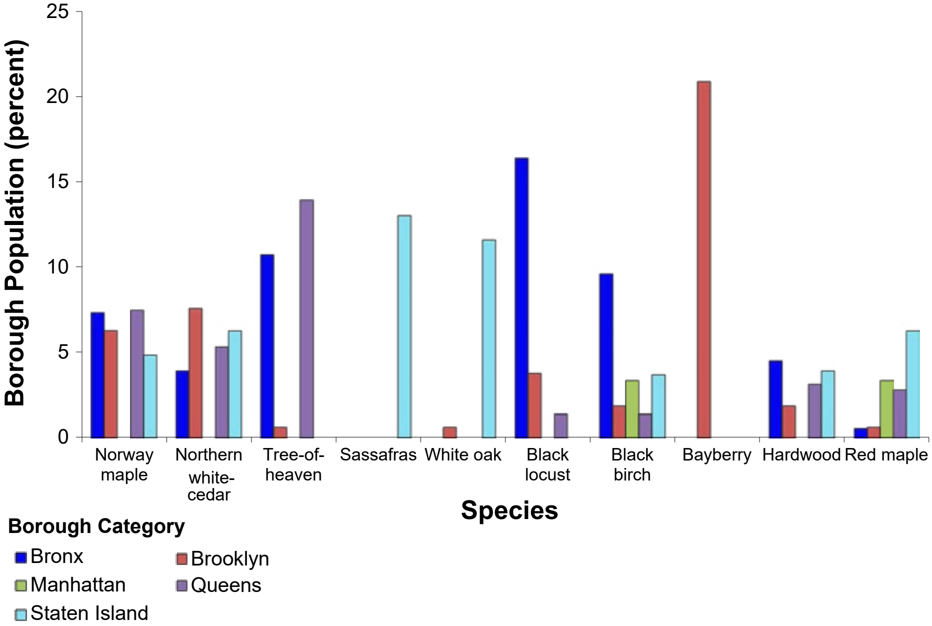

Figure 33.—The percentage of borough tree population occupied by the 10 most common tree species, New York City, 2013. For example, bayberry comprises 21 percent of Brooklyn's tree population.

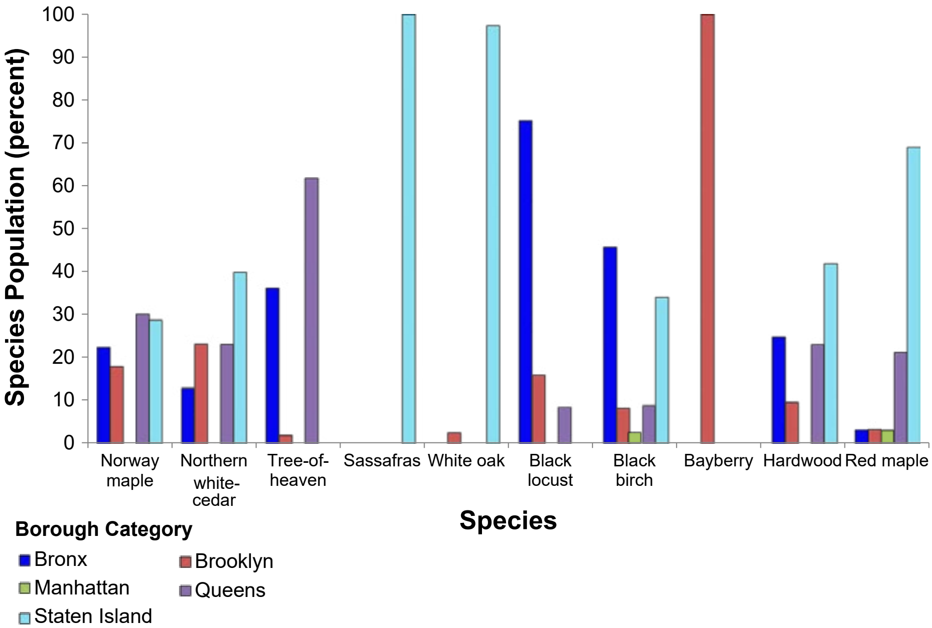

Figure 34.—The percentage of species population in each borough, New York City, 2013. For example, 100 percent of bayberry was found in Brooklyn.

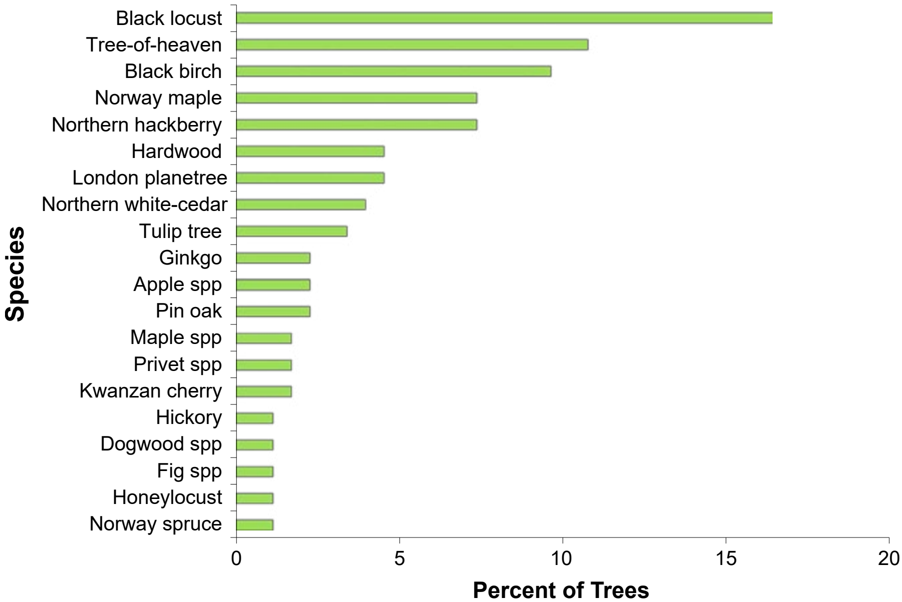

Figure 35.—Percentage of trees by species in the Bronx, New York City, 2013

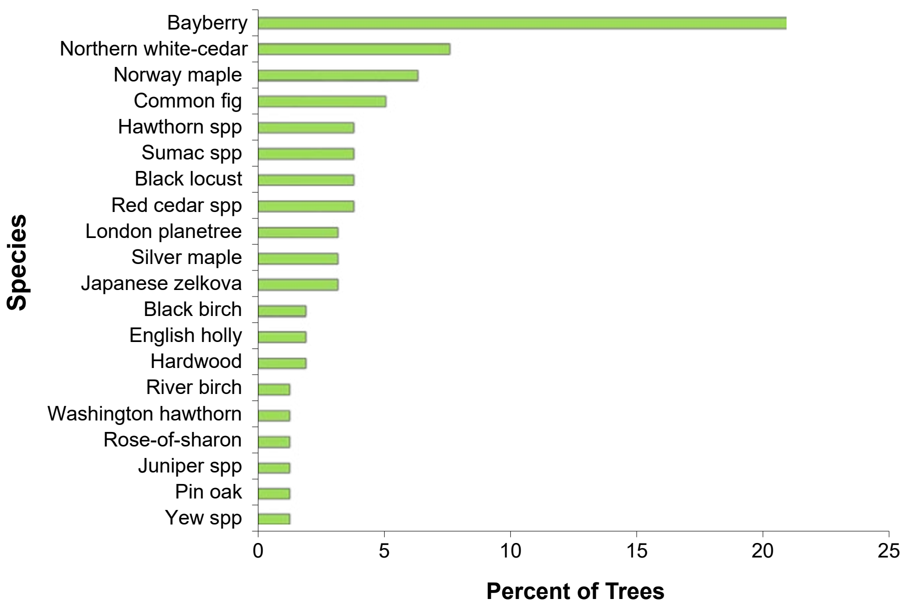

Figure 36.—Percentage of trees by species in Brooklyn, New York City, 2013

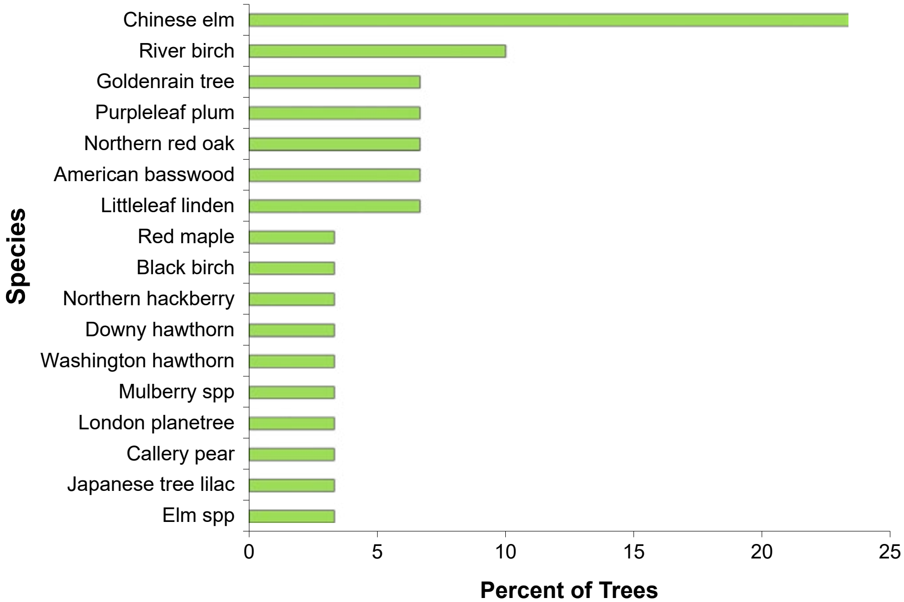

Figure 37.—Percentage of trees by species in Manhattan, New York City, 2013.

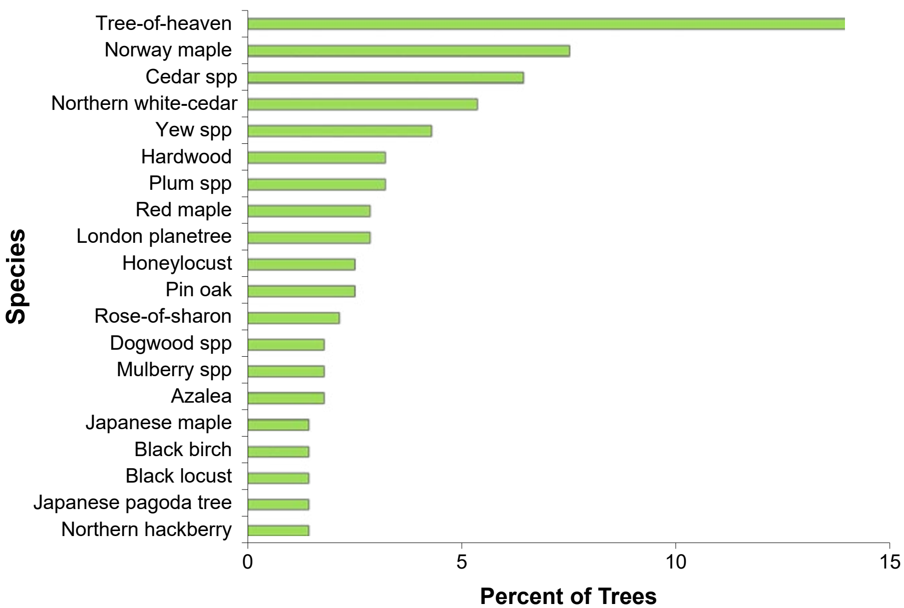

Figure 38.—Percentage of trees by species in Queens, New York City, 2013.

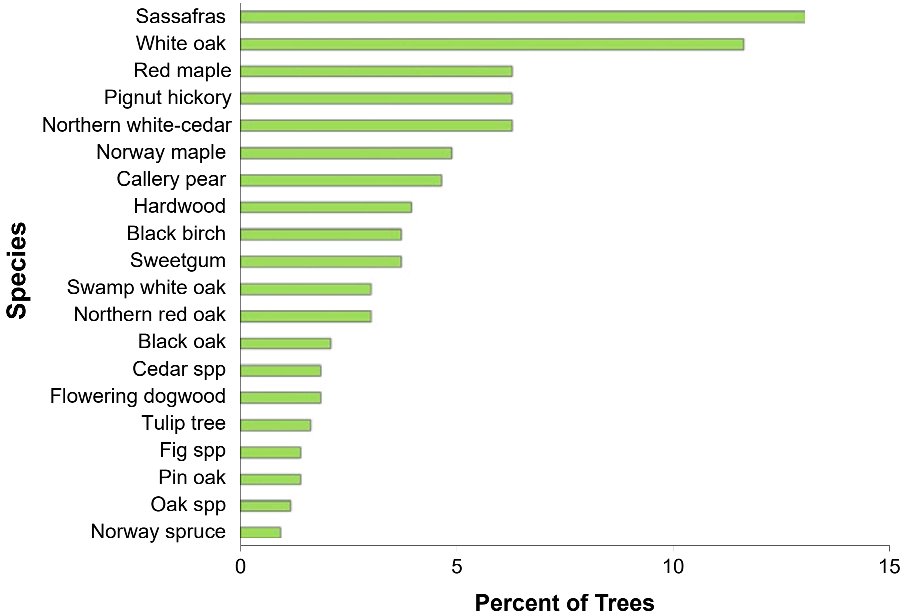

Figure 39—Percentage of trees by species in Staten Island, New York City, 2013.

APPENDIX 5

Relative Tree Effects

The urban forest in New York City provides benefits that include carbon storage and sequestration, and air pollutant removal. These benefits vary across d.b.h classes (Table 19). Total annual pollution removal per pollutant was contrasted with annual emissions per city, vehicle, and household to determine offset equivalents of urban forests versus city, vehicle, and household emissions.

Municipal carbon emissions are based on 2010 U.S. per capita carbon emissions (World Bank 2010). Per capita emissions were multiplied by city population to estimate total city carbon emissions.

Light duty vehicle emission rates (grams/mile) for carbon monoxide (CO), nitrogen oxides (NO_x), VOCs, particulate matter less than 10 microns (PM_{10}), SO_2 for 2010 (Bureau of Transportation Statistics 2010; Heirigs et al. 2004), and CO_2 for 2011 (U.S. EPA 2010) were multiplied by average miles driven per vehicle in 2011 (Federal Highway Administration 2013) to determine average emissions per vehicle.

Household emissions are based on average electricity kWh usage, natural gas Btu usage, fuel oil Btu usage, kerosene Btu usage, LPG Btu usage, and wood Btu usage per household in 2009 (Energy Information Administration 2013, 2014a).

- CO_2, SO_2, and NO_x power plant emission per KWh are from Leonardo Academy (2011). CO emission per kWh assumes one-third of 1 percent of C emissions is CO based on Energy Information Administration (1994).
- CO_2, NO_x, SO_2, and CO emission per Btu for natural gas, propane and butane (average used to represent LPG), Fuel #4 and #6 (average used to represent fuel oil and kerosene) from Leonardo Academy (2011).
- CO_2 emissions per Btu of wood from Energy Information Administration (2014a).
- CO, NO_x and sulfur oxides (SO_x) emission per Btu based on total emissions and wood burning (tons) from British Columbia Ministry (2005); Georgia Forestry Commission (2009).

General tree information:

Average tree diameter = 6.3 inches

Median tree diameter = 3.3 inches

Number of trees sampled = 1,015

Number of species/genera sampled = 138

Table 19.—Average tree effects by tree diameter class (d.b.h.), New York City, 2013

d.b.h.[a]	Carbon storage			Carbon sequestration			Pollution removal	
inch	*lbs*	*$*	*miles*[b]	*lbs/yr*	*$/yr*	*miles*[b]	*lbs/yr*	*$/yr*
1-3	6	0.38	10	1.6	0.11	2	0.04	1.30
3-6	35	2.34	40	6.1	0.40	7	0.14	4.97
6-9	130	8.65	140	13.2	0.88	14	0.35	12.25
9-12	302	20.08	330	21.3	1.42	23	0.55	19.20
12-15	579	38.53	630	32.7	2.17	36	0.66	23.05
15-18	924	61.48	1,010	47.8	3.18	52	0.97	34.10
18-21	1,419	94.40	1,550	66.4	4.42	73	1.17	41.26
21-24	1,884	125.38	2,060	76.6	5.10	84	1.16	40.92
24-27	2,465	164.05	2,690	99.4	6.61	109	2.17	76.23
27-30	3,206	213.36	3,500	80.9	5.38	88	1.92	67.36
30+	6,027	401.08	6,580	157.6	10.49	172	2.68	94.28

[a] lower limit of the diameter class is greater than displayed (e.g., 3-6 is actually 3.01 to 6 inches)
[b] miles = number of automobile miles driven that produces emissions equivalent to tree effect

The trees in New York City provide:

Carbon storage (C) equivalent to:

Amount of C emitted in region in 10 days or

Annual C emissions from 814,000 automobiles or

Annual C emissions from 333,800 single family houses

Nitrogen dioxide (NO_2) removal equivalent to:

Annual NO_2 emissions from 34,700 automobiles or

Annual NO_2 emissions from 15,600 single family houses

Sulfur dioxide (SO_2) removal equivalent to:

Annual SO_2 emissions from 951,600 automobiles or

Annual SO_2 emissions from 2,500 single family houses

Annual C sequestration equivalent to:

Amount of C emitted in region in 0.5 days or

Annual C emissions from 38,300 automobiles or

Annual C emissions from 15,700 single family home

APPENDIX 6

Temperature Index Map

Air temperature is an important climatic variable in urban areas. The air temperature model (Heisler et al. 2006, 2007, 2015) was used to determine the average temperature for four different days between June 1, 2008, and August 31, 2008. The representative days were as follows:

- Windiest day (day with the highest average wind speed): June 22, 2008
- Least Windy day (day with the lowest average wind speed): July 4, 2008
- Average day (day with the average temperature closest to the summer average temperature): July 23, 2008 (Fig. 40)
- Warmest temperature day (day with the highest average summer daytime temperature): June 9, 2008

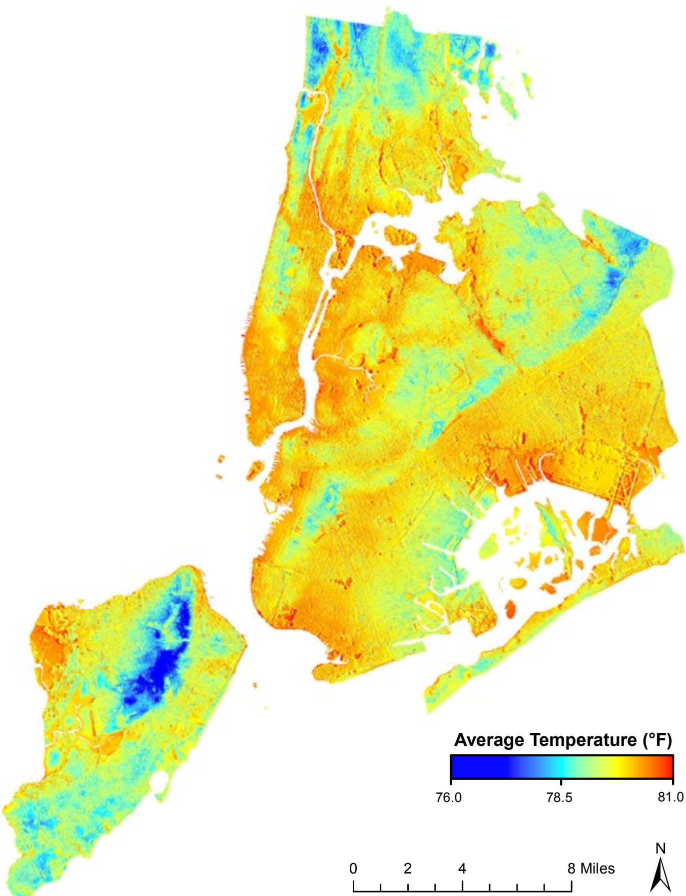

Figure 40.—Average temperature distribution (6 a.m. to 5 p.m.) for the average summer day, New York City, 2010.

Tree cover can reduce air temperatures in urban areas. Based on modeled temperature estimates, tree planting could be targeted in the warmest areas of the city to help cool air temperatures. To determine the areas of the city with the greatest potential to reduce heat stress, average air temperatures were calculated for U.S. Census block groups and multiplied by population density in each block group and a standardized air temperature planting index (TPI) was calculated for each of the representative days.

TPI = (n – m) / r

Where TPI is the air temperature planting index (0-1),

n is the daily average temperature x population / km^2 for the Census block,

m is the minimum value for all Census blocks, and

r is the range of values among all Census blocks (maximum value – minimum value).

All four days produced similar TPI index maps as the relative temperature difference among block groups were similar, though the actual temperatures would differ. The results of the block groups were averaged within each community district (weighted average proportional to block group area within neighborhood) and standardized a second time on a scale of 0 to 100 to produce community district temperature index maps. This "heat stress" index illustrates one method that can be used to prioritize tree planting to reduce air temperatures in the warmest parts of the city with the most people (Fig. 41).

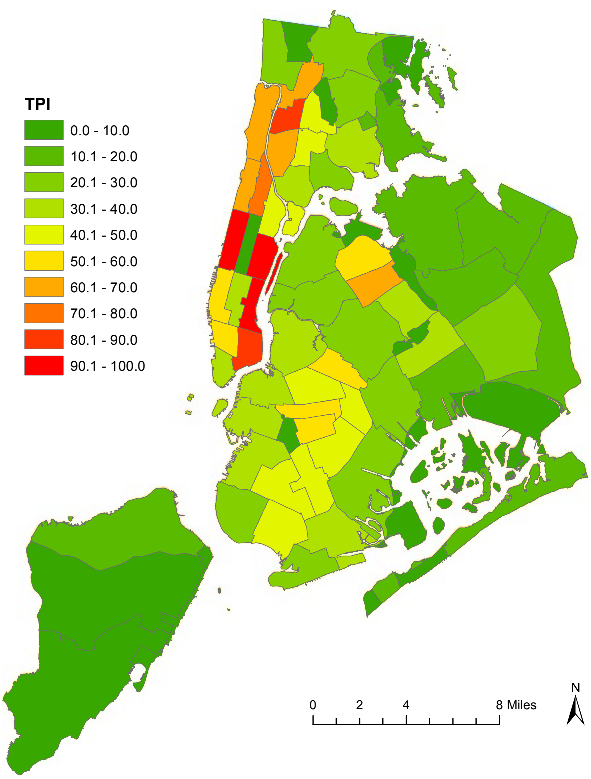

Figure 41.—Temperature planting index (TPI) by community district for average summer day, New York City, 2010. Higher index scores indicate higher priority areas for planting trees to reduce air temperature.

APPENDIX 7

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 on 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	Increases pollution removal
Sustain existing tree cover	Maintains 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	Reduces long-term pollutant emissions from planting and removal
Use low maintenance trees	Reduces pollutant emissions from maintenance activities
Reduce fossil fuel use in maintaining vegetation	Reduces pollutant emissions
Plant trees in energy conserving locations	Reduces pollutant emissions from power plants
Plant trees to shade parked cars	Reduces vehicular VOC emissions
Supply ample water to vegetation	Enhances pollution removal and temperature reduction
Plant trees in polluted or heavily populated areas	Maximizes tree air quality benefits
Avoid pollutant-sensitive species	Improves tree health
Utilize evergreen trees for particulate matter	Provides year-round removal of particles

APPENDIX 8
Potential Insect and Disease Impacts

Thirty-one insects and tree diseases were analyzed to quantify their potential impact on the urban forest. As each insect/disease is likely to attack different host tree species, the implications for New York City will vary by pest. The number of trees at risk reflects only the known host species that are likely to experience mortality (Table 20). The species host lists used for these insects and diseases can be found at https://www.itreetools.org/eco/resources/iTreeEco_pest_host_list_06292016.xlsx.

Table 20.—Potential risk to trees by insect or disease, New York City, 2013

Code	Scientific name	Common name	Trees at risk	Compensatory value
			number	*$ millions*
AL	*Phyllocnistis populiella*	Aspen Leafminer	32,000	13
ALB	*Anoplophora glabripennis*	Asian Longhorned Beetle	1,476,000	1,555
BBD	*Cryptococcus fagisuga*	Beech Bark Disease	18,000	116
BC	*Sirococcus clavigignenti-juglandacearum*	Butternut Canker	0	0
CB	*Cryphonectria parasitica*	Chestnut Blight	6,000	0.7
DA	*Discula destructive*	Dogwood Anthracnose	79,000	21
DED	*Ophiostoma novo-ulmi*	Dutch Elm Disease	36,000	47
DFB	*Dendroctonus pseudotsugae*	Douglas-Fir Beetle	0	0
EAB	*Agrilus planipennis*	Emerald Ash Borer	40,000	99
FE	*Scotylus ventralis*	Fir Engraver	6,000	39
FR	*Cronartium fusiforme*	Fusiform Rust	0	0
GSOB	*Agrilus auroguttatus*	Goldspotted Oak Borer	0	0
GM	*Lymantria dispar*	Gypsy Moth	1,367,000	2,307
HWA	*Adelges tsugae*	Hemlock Woolly Adelgid	51,000	96
JPB	*Dendroctonus jeffreyi*	Jeffrey Pine Beetle	0	0
LAT	*Choristoneura conflictana*	Large Aspen Tortrix	372,000	118
LWD	*Raffaelea lauricola*	Laurel Wilt	335,000	30
MPB	*Dendroctonus ponderosae*	Mountain Pine Beetle	51,000	124
NSE	*Ips perturbatus*	Northern Spruce Engraver	0	0
OW	*Ceratocystis fagacearum*	Oak Wilt	733,000	1,538
POCRD	*Phytophthora lateralis*	Port-Orford-Cedar Root Disease	0	0
PSB	*Tomicus piniperda*	Pine Shoot Beetle	80,000	138
SB	*Dendroctonus rufipennis*	Spruce Beetle	76,000	134
SBW	*Choristoneura fumiferana*	Spruce Budworm	0	0
SOD	*Phytophthora ramorum*	Sudden Oak Death	265,000	711
SPB	*Dendroctonus frontalis*	Southern Pine Beetle	163,000	246
SW	*Sirex noctilio*	Sirex Woodwasp	30,000	14
TCD	*Pityophthorus juglandis & Geosmithia spp.*	Thousand Canker Disease	0	0
WPB	*Dendroctonus brevicomis*	Western Pine Beetle	0	0
WPBR	*Cronartium ribicola*	White Pine Blister Rust	12,000	3
WSB	*Choristoneura occidentalis*	Western Spruce Budworm	76,000	173

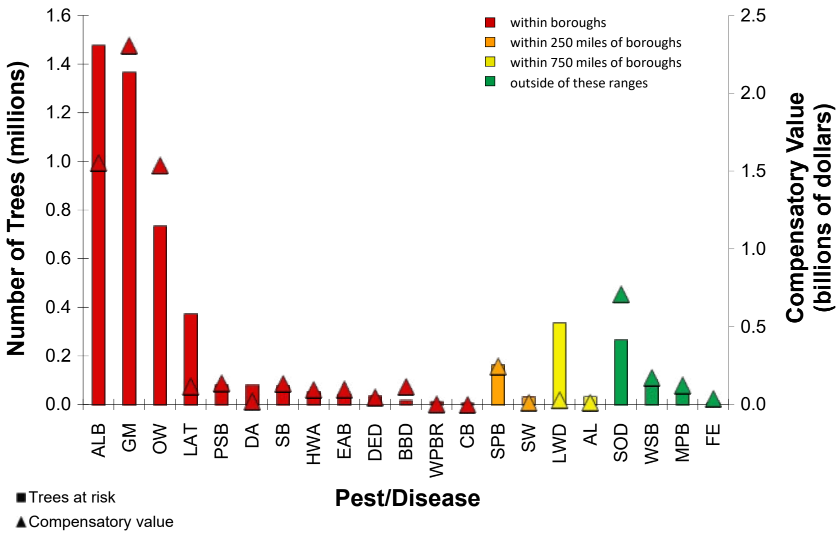

Figure 42.—Number of trees at risk and associated compensatory value of insect/disease effects, New York City, 2013 tree population, 2018 pest information. This figure does not include the pests and diseases that were not a threat to any of the species sampled in the city. For a complete list of the pests and diseases assessed, see Table 20.

The range of these pests was based on known occurrence and the tree-host range, respectively (U.S. Forest Service 2013, 2014; Worrall 2007). We used pest range maps from the Forest Health Technology Enterprise Team (FHTET) (U.S. Forest Service 2013, 2014; Worrall 2007) to determine the proximity of each pest to the five counties (i.e., Bronx, Kings, New York, Queens, and Richmond) that make up New York City. Pest proximity was classified into the following categories: within New York City, within 250 miles, within 750 miles, greater than 750 miles; these are illustrated in Figure 42. FHTET did not have pest range maps for Dutch elm disease and chestnut blight.

Based on the host tree species for each pest and the current range of the pest, it is possible to determine the potential risk from insects and disease for each tree species sampled in New York City. In Table 21, tree species risk is designated as one of the following:

- Red - tree species is at risk to at least one pest within city
- Orange - tree species has no pest risk within city, but has a risk to at least one pest within 250 miles from the city
- Yellow - tree species has no risk to pests within 250 miles of city, but has a risk to at least one pest that is 250 to 750 miles from the city
- Green - tree species has no risk to pests within 750 miles of city, but has a risk to at least one pest that is greater than 750 miles from the city

Species that were sampled in New York City, but that are not listed in this matrix, are not known to be hosts to any of the 31 insects and diseases analyzed. Tree species at the greatest risk to existing pest infestations in New York City are willow species and eastern white pine.

Table 21.—Potential insect and disease risk for tree species, New York City, 2013 tree population, 2018 pest information

Spp. risk[a]	Pest score[b]	Common name	ALB	GM	OW	LAT	DA	PSB	SB	HWA	EAB	DED	BBD	WPBR	CB	SPB	SW	LWD	AL	SOD	WSB	MPB	FE
red	14	Crack willow	red	red		red													yellow				
red	14	Eastern white pine						red						red		orange	orange						
red	14	Weeping willow	red	red		red													yellow				
red	14	Willow spp	red	red		red													yellow				
red	13	Norway spruce						red	red							orange					green	green	
red	12	Gray birch	red	red		red																	
red	12	Paper birch	red	red		red																	
red	12	River birch	red	red		red																	
red	10	Pine spp						red								orange	orange						
red	9	Northern red oak		red	red															green			
red	9	Pin oak		red	red															green			
red	8	American elm	red									red											
red	8	Birch spp	red			red																	
red	8	Black birch	red			red																	
red	8	Black oak		red	red																		
red	8	Blue spruce							red							orange					green		
red	8	Chestnut oak		red	red																		
red	8	Chinese elm	red	red																			
red	8	Elm spp	red									red											
red	8	Fastigiate pin oak		red	red																		
red	8	Green ash	red								red												
red	8	Oak spp		red	red																		
red	8	Swamp white oak		red	red																		
red	8	Water birch	red			red																	
red	8	White oak		red	red																		
red	8	Willow oak		red	red																		
red	7	Eastern hemlock								red						orange							
red	7	Spruce spp							red							orange							
red	4	Albizia spp	red																				
red	4	American basswood		red																			
red	4	American chestnut													red								
red	4	Apple spp		red																			
red	4	Beech spp											red										
red	4	Black ash									red												
red	4	Boxelder	red																				
red	4	Callery pear		red																			
red	4	Common linden		red																			

Spp. risk[a]	Pest score[b]	Common name	ALB	GM	OW	LAT	DA	PSB	SB	HWA	EAB	DED	BBD	WPBR	CB	SPB	SW	LWD	AL	SOD	WSB	MPB	FE
	4	Copper beech																					
	4	Cornelian cherry																					
	4	Crabapple																					
	4	Dogwood spp																					
	4	Downy hawthorn																					
	4	Flowering dogwood																					
	4	Hawthorn spp																					
	4	Hedge maple																					
	4	Horse chestnut																					
	4	Japanese maple																					
	4	Littleleaf linden																					
	4	London planetree																					
	4	Maple spp																					
	4	Norway maple																					
	4	Pear spp																					
	4	Red maple																					
	4	Silver linden																					
	4	Silver maple																					
	4	Staghorn sumac																					
	4	Sugar maple																					
	4	Sweetgum																					
	4	Sycamore maple																					
	4	Trident maple																					
	4	Washington hawthorn																					
	4	White ash																					
	3	Hemlock spp																					
	2	Sassafras																					
	2	Spicebush																					
	2	Grand fir																					
	1	Azalea																					
	1	Smooth azalea																					

[a] Species risk

Red indicates that the tree species is at risk to at least one pest within New York City.

Orange indicates that the tree species has no risk to pests within New York City, but has a risk to at least one pest within 250 miles of the city.

Yellow indicates that the tree species has no risk to pests within 250 miles of New York City, but has a risk to at least one pest that is 250 to 750 miles from the city.

Green indicates that the tree species has no risk to pests within 750 miles of New York City, but has a risk to at least one pest that is greater than 750 miles from the city.

[b] Risk weight

Numerical scoring system based on sum of points assigned to pest risks for species. Each pest that could attack tree species is scored as 4 points if red, 3 points if orange, 2 points if yellow and 1 point if green.

[c] Pest color codes

Red indicates pest is within New York City.

Orange indicates pest is within 250 miles of New York City.

Yellow indicates pest is within 750 miles of New York City.

Green indicates pest is outside of these ranges.

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An analysis of the urban forest in New York, New York, reveals that this city has an estimated 7.0 million trees (encompassing all woody plants greater than one-inch diameter at breast height [d.b.h.]) with tree canopy that covers 21 percent of the city. The most common tree species across public and private land are Norway maple, northern white-cedar, tree-of-heaven, sassafras, and white oak, but the most dominant species in terms of leaf area are Norway maple, London planetree, black locust, pin oak, and red maple. Trees in New York City currently store about 1.2 million tons of carbon (4.2 million tons carbon dioxide [CO_2]) valued at $153 million. In addition, these trees remove about 51,000 tons of carbon per year (186,000 tons CO_2/year) ($6.8 million per year) and about 1,100 tons of air pollution per year ($78 million per year). New York City's urban forest is estimated to reduce annual residential energy costs by $17.1 million per year and reduce runoff by 69 million cubic feet/year ($4.6 million/year). The compensatory value of the trees is estimated at $5.7 billion. The information presented in this report can be used by local organizations to advance urban forest policies, planning, and management to improve environmental quality and human health in New York City. The analyses also provide a basis for monitoring changes in the urban forest over time.

KEY WORDS: urban forestry, i-Tree, ecosystem services, insects and diseases, invasive species, air temperature, water quality, air quality, carbon, energy savings

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