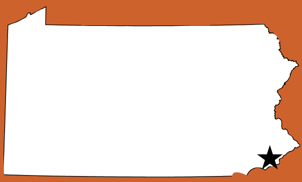
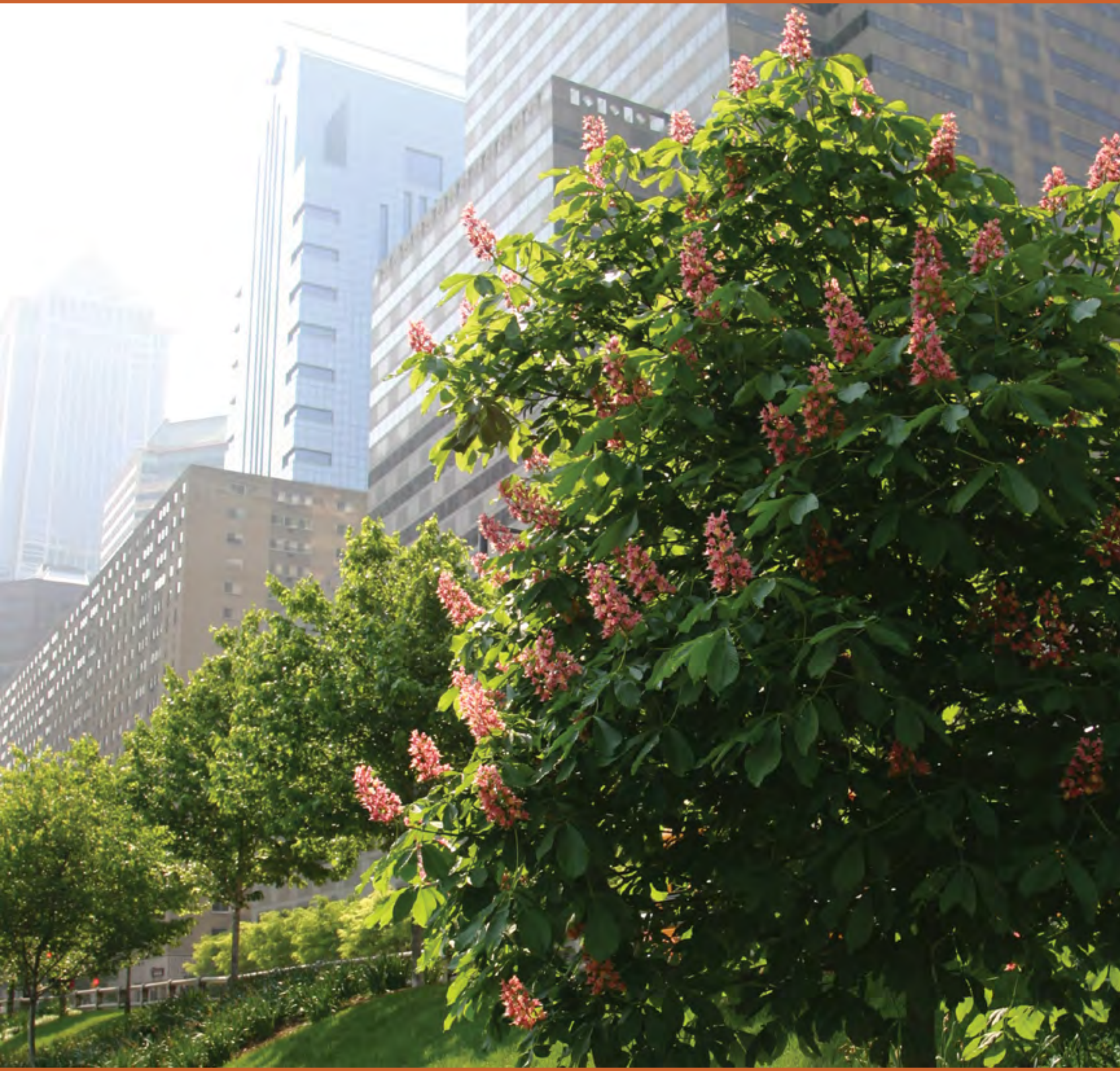
United States Department of Agriculture

The Urban Forest of Philadelphia





Forest Service

Northern Research Station

Resource Bulletin NRS-106

November 2016

Abstract

An analysis of the urban forest in Philadelphia, Pennsylvania, reveals that this city has an estimated 2.9 million trees (encompassing all woody plants greater than 1 inch diameter at breast height [d.b.h]) with tree canopy that covers 20 percent of the city. The most common tree species are spicebush, black cherry, ash, tree-of-heaven, and boxelder, but the most dominant species in terms of leaf area are sycamore spp. (including London planetree), northern red oak, black walnut, red maple, and Norway maple. Trees in Philadelphia currently store about 702,000 tons of carbon (2.6 million tons of carbon dioxide [CO_2]) valued at $93.4 million. In addition, these trees remove about 27,000 tons of carbon per year (99,000 tons CO_2/year) ($3.6 million per year) and about 513 tons of air pollution per year ($19.0 million per year). Philadelphia's urban forest is estimated to reduce annual residential energy costs by $6.9 million per year. The compensatory value of the trees is estimated at $1.7 billion. The city's parklands constitute 9.3 percent of the total land area, have an estimated 1.1 million trees, 64 percent canopy cover, and account for 38.8 percent of carbon storage and 34.8 percent of air pollution removal performed by the city's urban forest. 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 Philadelphia.

Quality Assurance

This publication conforms to the Northern Research Station's Quality Assurance Implementation Plan which requires technical and policy review for all scientific publications produced or funded by the Station. The process included a blind technical review by at least two reviewers, who were selected by the Assistant Director for Research and unknown to the author. This review policy promotes the Forest Service guiding principles of using the best scientific knowledge, striving for quality and excellence, maintaining high ethical and professional standards, and being responsible and accountable for what we do.

Cover Photo

Transportation corridor planting between railway and John F. Kennedy Boulevard in Philadelphia, PA. Photo used with permission from Philadelphia Horticultural Society.

Manuscript received for publication 19 October 2015

Published by

U.S. FOREST SERVICE
11 CAMPUS BLVD SUITE 200
NEWTOWN SQUARE PA 19073

November 2016

For additional copies:

U.S. Forest Service
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The Urban Forest of Philadelphia

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Street trees in Philadelphia, PA. Photo by Sarah Tse, used with permission.

CONTENTS

Street trees in Philadelphia, PA. Photo used with permission from Philadelphia Horticultural Society.

EXECUTIVE SUMMARY

The urban forest in Philadelphia (i.e., all trees[1] within the city) affects environmental quality and human health. In Philadelphia, local organizations are investing in tree planting campaigns to encourage the growth of a healthy urban forest. At the same time, insects, diseases, invasive species, climate change and development continually alter the urban forest. Addressing the challenge of developing a sustainable and healthy urban forest is complicated by a diversity of tree species, their dynamic character, a fragmented ownership pattern, and a lack of comprehensive information about the urban forest. To address these critical information needs, the U.S. Forest Service assessed Philadelphia'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 i-Tree Eco model (www.itreetools.org) was one of the tools used to advance the understanding of Philadelphia's urban forest. 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 Philadelphia's urban forest and establish a baseline for future monitoring, field data were collected during the summer of 2012 and processed and analyzed using the i-Tree Eco model. A total of 133 one-tenth-acre field plots were sampled throughout the city, with supplemental plots added in parklands. The 72 additional parkland plots include forested natural areas as well as neighborhood parks. There are an estimated 2.9 million trees in Philadelphia that cover 20 percent of the city area and provide millions of dollars of benefits annually (Table 1). This report details these findings, provides analyses (tree effects on air temperatures and stream flow), and discusses various management issues to help guide urban forest management and policy in Philadelphia.

[1] Trees in this report include all woody plants with a stem diameter at breast height (d.b.h.; measured at 4.5 feet above the ground) greater than or equal to 1 inch. Thus, some species commonly thought of as shrubs are considered trees as these species are often defined in the literature as large shrub/small tree (i.e., there is no strict definition differentiating a tree vs. shrub).

Table 1.—Summary of city-wide urban forest features, Philadelphia, 2012

Feature	Estimate
Number of trees[a]	2,918,000
Tree cover	20%[b]
Most dominant species by:	
Number of trees	spicebush, black cherry, ash species, tree-of-heaven, boxelder
Leaf area	sycamore species, northern red oak, black walnut, red maple, Norway maple
Trees 1 to 6 inches d.b.h.	62.2%
Air temperature reduction[c]	0.3 °F
Pollution removal	513 tons/year ($19.0 million/year)
VOC emissions	228 tons/year
Carbon storage	702,000 tons ($50.0 million)
Carbon sequestration	27,000 tons/year ($1.9 million/year)
Value of reduced building energy use	$6.9 million/year
Value of reduced carbon emissions	$764,000/year
Compensatory value[d]	$1.7 billion
Rainfall interception	81.0 million cubic feet

[a] all woody vegetation >1 inch d.b.h.

[b] assessed using LiDAR in an earlier report (O'Neil-Dunne 2011)

[c] Average daytime (6 a.m.-5 p.m.) air temperature reduction on the average temperature summer day

[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)

BACKGROUND

Understanding the magnitude, composition, and value of trees and forests in a city is the first step toward developing management plans that can help sustain healthy and vibrant forests throughout a city. Good management requires good information on the resource being managed. As urban trees and forests provide numerous essential services to society (e.g., cooler air temperatures, reduced energy use, cleaner air and water), it is important to understand and quantify these services so that they can be optimized for future generations. However, many urban forest services cannot be quantified or valued at this time (e.g., aesthetics, sense of place, historical value). To help understand the urban forest of Philadelphia and its associated services and values, the Philadelphia Field Station of U.S. Forest Service, Northern Research Station (U.S. Forest Service 2011), assessed the city's urban forest. The Philadelphia Field Station, established in 2011, is part of a network of urban field stations that foster collaborative science, science-delivery, and tools to assist partner organizations with natural resource management. This report summarizes findings of this assessment and lays the foundation for future data collection to monitor changes in the urban forest. The goal of this assessment and subsequent analysis is to provide local organizations with information relevant to the sustainable management of Philadelphia's urban forest. For more information about the Philadelphia Field Station, visit http://www.nrs.fs.fed.us/philadelphia.

METHODS

Four types of analyses were conducted for Philadelphia: 1) urban tree cover variation based on remote sensing; 2) urban forest structure, ecosystem services, and values based on field plot data and the i-Tree Eco model; 3) change in urban tree and shrub cover from 2008 to 2012 based on photo interpretation of aerial imagery; and 4) modeled effects of tree cover and impervious surface on stream flow in the Cobbs Creek watershed using the i-Tree Hydro model.

Tree Cover Assessment

Philadelphia's tree cover estimates were derived from 2008 LiDAR and high resolution aerial imagery processed by the University of Vermont's Spatial Analytics Lab (O'Neil-Dunne 2011). Tree cover was defined as leaf area with a height of 8 feet or greater. A tree cover map was created from the imagery and used to estimate tree cover at the neighborhood and block group level using a geographic information system (GIS).

Urban Forest Composition, Structure, and Values

To help assess the urban forest, data were collected on field plots located within the boundaries of Philadelphia 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 temperature reduction
- Air pollution removal
- Carbon storage
- Annual carbon sequestration
- Changes in building energy use
- Compensatory value
- Potential risk from insects or diseases

Field Measurements

Field crews sampled 133 one-tenth-acre plots that were distributed throughout Philadelphia (Table 2). Plot locations were randomly placed within the boundaries of the entire city. The distribution of samples included 50 plots on residential land, 29 plots on commercial/industrial/utility land, 21 on institutional land, 14 in wooded areas, 8 in transportation (e.g., major highways, airports), 8 in other lands, and 3 in water. Land use locations and definitions are based on the Delaware Valley Regional Planning Commission's 2010 land use map (Delaware Valley Regional Planning Commission 2010) (appendix 1).

Table 2.—Distribution of plots among land use categories, Philadelphia, 2012. Total city land area is 90,990 acres.

Land use	Plots	City land area
	number	*percent*
Citywide plots		
Residential	50	40.0
Commercial/Industrial/Utility	29	19.8
Institutional	21	13.0
Wooded	14	8.4
Transportation	8	6.2
Other	8	6.9
Water	3	5.7
Subtotal	133[a]	100.0
Parkland	73	9.3
Grand total	192	n/a

[a] The 133 citywide plots includes 14 plots also used in the parkland assessment

To help assess the structure and function of parkland in the city, Philadelphia Parks and Recreation provided a map of parkland areas (Fig. 1). As only 14 of the original 133 plots fell within parkland, an additional 59 randomly located plots were sampled within the parkland area. These parklands included forested natural areas as well as neighborhood parks managed by the Fairmount Park Commission prior to its merger with the Philadelphia Department of Recreation (now the Philadelphia Department of Parks and Recreation).

Thus, two analyses were conducted: one for the entire city (133 plots) and one as a separate analysis of parklands (14+59=73 plots). Although there is some overlap between 14 plots used for the parkland and citywide analyses, they were treated as separate samples for estimation purposes.

Field data were collected by trained interns from the Philadelphia Horticultural Society and University of Pennsylvania. Data collection took place during the leaf-on season, from May to August of 2012. Within each one-tenth acre circular plot, ground cover was assessed and characteristics of all trees were recorded. Trees were defined as woody plants with a diameter at breast height (4.5 feet; d.b.h.) greater than or equal to 1 inch,

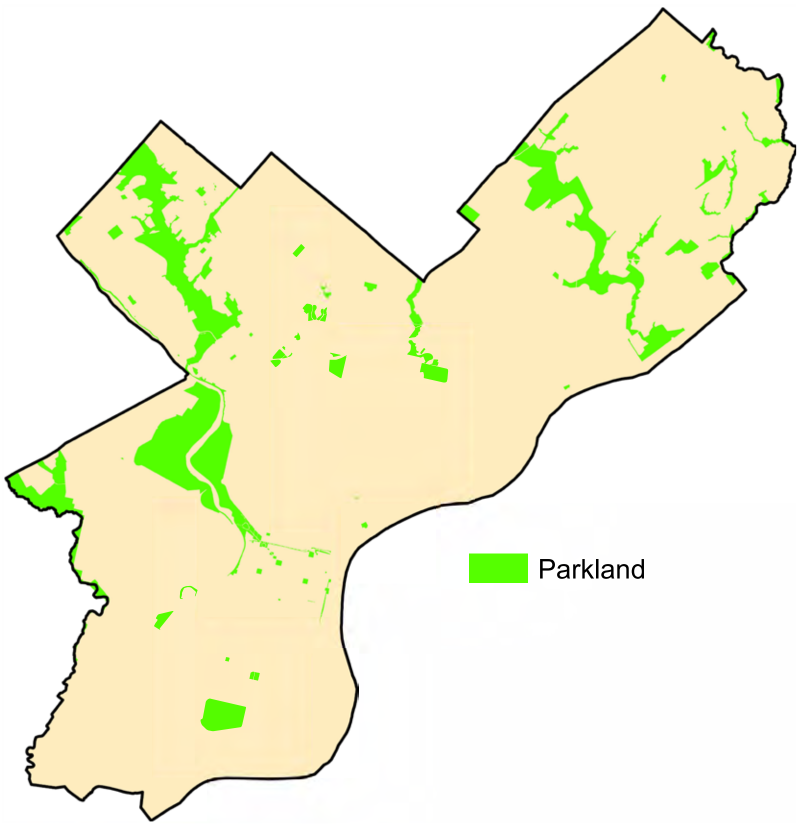

Figure 1.—Philadelphia city boundaries and designated parkland areas, 2012.

and therefore include some species commonly considered to be shrubs. For each tree, data collected included species, d.b.h., tree height, height to base of live crown, crown width, percentage crown canopy missing and dieback, crown light exposure, and distance and direction to residential buildings (i-Tree 2009). Measurements of crown dimensions and percentage crown canopy missing were used to assess tree leaf area.

For trees with more than six stems at breast height, 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 species or genus level. Certain species (e.g., green ash [*Fraxinus pennsylvanicus*]) were only classified to the genus level (e.g., ash [*Fraxinus*]) to ensure consistent identification across field data collection teams. Some species, such as apple (*Malus* spp.), were identified at the genus level due to many hybrids and varieties. Trees designated as “other hardwood” include broadleaved deciduous trees that could not be identified to a specific species or genera. Eighty-four percent of the trees designated as “other hardwood” were standing dead. In this report, tree species, genera, or species groups (e.g., other hardwood) are hereafter referred to as tree species.

On parkland plots, field data were also collected on the presence of native and nonnative invasive plant species. Data were collected on 72 one-tenth-acre plots (one plot had missing data) and included 42 invasive tree, woody shrub, herbaceous plants, vines, and grass genera or species (based on a list developed from Huebner et al. [2007] and through a 2012 consultation[2]). The invasive plant list is found in appendix 2. Although some native species can exhibit similar invasive characteristics, they were not included in this analysis. The relative abundance of each of these invasive species found on a plot was recorded based on the percentage of plot area occupied by the species and categorized as follows: a) <5 percent; b) 5 to 25 percent; c) 26 to 50 percent; d) 51 to 75 percent; or e) 76 to 100 percent.

i-Tree Eco Model

The i-Tree Eco model was used to calculate totals, averages, and standard errors by species, land use, 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 http://nrs.fs.fed.us/data/urban.

[2] Personal communication, May 25, 2012, Tom Witmer, Director of Natural Resources, Philadelphia Department of Conservation and Natural Resources; and Jason Lubar, Associate Director of Urban Forestry, Morris Arboretum, Univesrity of Pennsylvania.

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.

To estimate the monetary value of carbon storage and sequestration, tree carbon values were multiplied by $133.10 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 estimates were calculated for ozone (O_3), sulfur dioxide (SO_2), nitrogen dioxide (NO_2), and particulate matter less than 2.5 microns ($PM_{2.5}$). 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. 2013a).

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 values 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 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. 2013a, 2014; U.S. EPA 2012).

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 (i.e., estimated value of compensation for a loss of a tree) were 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).

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

Local Scale Estimates of Air Pollution Removal by Trees

The local effects of urban forest cover on air pollution removal were estimated using the Philadelphia tree cover map (O'Neil-Dunne 2011) in conjunction with U.S. Census and local pollutant concentrations. Tree cover in each U.S. Census block group was combined with block 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.

To estimate pollution removal and value at the neighborhood level (appendix 3), values for each block group within a neighborhood were summed. If only a proportion of block group existed within a neighborhood, the block group value was reduced proportional to the percent of the block group in the neighborhood.

Tree Effects on Local Air Temperature

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, upwind tree and impervious cover at varying distances, and wind speed. The model uses GIS data sets to estimate hourly temperatures in each 30 meter pixel cell using current tree cover conditions and a baseline scenario of zero percent tree cover based on the land cover maps (O'Neil-Dunne 2011). The differences between the two estimates represent the tree effects on air temperature.

Weather data from 2008 were explored 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:

a. Windiest day (day with the highest average wind speed): June 1, 2008
b. Least windy day (day with the lowest average wind speed): August 21, 2008
c. Average temperature day (day with the average temperature closest to the summer average temperature): August 4, 2008
d. Warmest day (day with the highest average summer daytime temperature): June 10, 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 night-time (6 p.m. to 5 a.m.) conditions. Results were analyzed for each block group and neighborhood. Maps illustrating results by block group are not displayed in this report but are available at http://nrs.fs.fed.us/data/urban.

Tree Cover Change Analysis

In addition to the tree cover assessment based on remote sensing and i-Tree Eco analysis, a tree and shrub cover change analysis was conducted based on photo interpretation of a sampling of 1,000 randomly paired points on aerial photographs of Philadelphia in 2008 and 2012. This analysis is based on methods detailed in Nowak and Greenfield (2012) and uses the McNemar test (Sokal and Rohlf 1994) to determine if tree cover change between 2008 and 2012 is statistically significant at alpha level = 0.05.

Cobbs Creek Watershed Analysis

To better understand the impact of tree and impervious cover on stream flow and water quality in Philadelphia, the i-Tree Hydro model (Wang et al. 2008) was applied to the 13,000-acre Cobbs Creek watershed (Fig. 2). The model was calibrated using existing flow data and used to compare how simulated flow and runoff changed 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 cubic-foot volume of flow due to changes in tree or impervious cover.

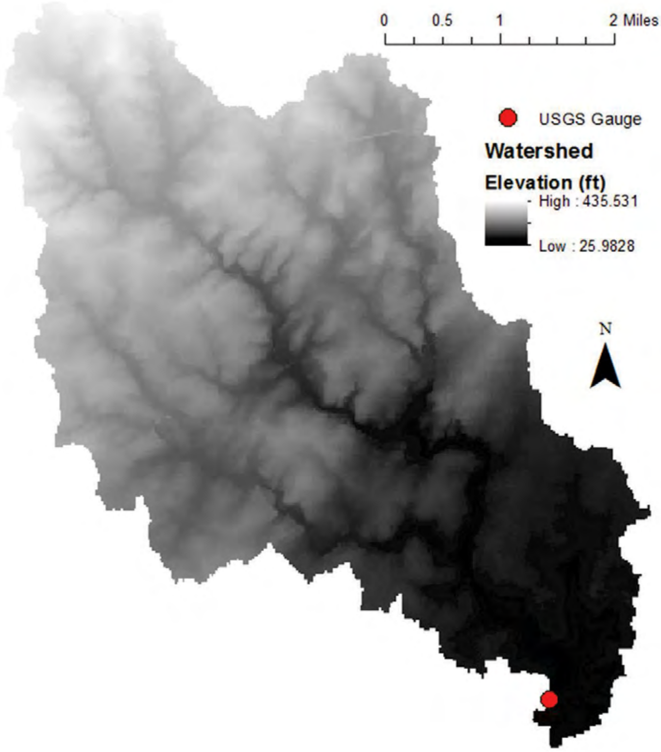

Figure 2.—Digital elevation model of Cobbs Creek watershed and U.S. Geological Survey (USGS) gauge at Mt. Moriah Cemetery, 2011.

Data and Model Calibration

Hourly weather data were obtained from the Philadelphia International Airport weather station (National Weather Service station number 724080). Tree and impervious land cover parameters for the watershed were estimated by interpretation of Google Earth imagery (image date circa 2013) using a sample of 300 random locations (Table 3). A default tree canopy leaf area index (LAI = 5) was used. The amount of impervious area directly connected to the stream is a key model input. Under the current condition case of 54 percent impervious, 48 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 percentage impervious cover increased, the percent connected also increased.

Table 3.—Cover estimates for Cobbs Creek watershed, 2011

	Cover			
Area	Impervious	Tree/shrub	Grass/herbaceous	Bare Soil
acres	------------*percent*------------			
12,676	54.0[a]	46.8	10.5	0.0

[a] Total is greater than 100 percent because 24 percent of ground cover beneath tree canopies was modeled as impervious.

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 rainfall 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 Cobbs Creek 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 "Cobbs Creek at Mt. Moriah Cemetery" for the 2011 calendar year.

A full report of the Cobbs Creek analysis is available at http://nrs.fs.fed.us/data/urban.

Species Score

The tree species sampled in Philadelphia were ranked to guide species selections for the urban forest. Tree species received a service score based on their ability, at maturity, to provide ecosystem services, as well as a pest score based on their risk to potentially harmful insects and diseases.

First, the i-Tree Species model was used to rank the trees based on their ability to provide nine potential ecosystem services including:

- Air pollution removal
- Low emissions of volatile organic compounds (VOCs)
- Air temperature reduction
- Streamflow reduction
- Carbon storage
- Ultraviolet (UV) radiation reduction
- Low allergenicity
- Wind reduction
- Building energy use reduction

The nine ecosystem services were considered equally important and were thus weighted equally. i-Tree Species evaluated how well each tree species provided the nine ecosystem services relative to the other species analyzed. Based on this evaluation, tree species were ranked and divided into 10-percent classes (e.g., top 10%, 10-20%, 20-30%, and so on). The percentage classes determined by i-Tree Species were used to assign each tree species a service score. All tree species in the top 10 percent received a service score of 1, species in the 10 to 20 percent range received a service score of 2, and so on, with a maximum species service score of 10 (species in the 90-100%; bottom 10%).

Each tree species was also scored based on risk to potential insects and diseases (appendix 4) and as to whether it was an invasive species (appendix 2). Pest scores were designated using a numerical point system where each pest that could attack a tree species was assigned 4 points if the pest was within Philadelphia County, 3 points if it was within 250 miles of the county, 2 points if it was within 750 miles, and 1 point if it was outside of these ranges. The sum of all points for each tree species was used as the pest score.

To compile a final recommendation list, all tree species classified as invasive were removed from the list as well as species not analyzed by i-Tree Species (including Japanese angelica tree, barberry spp., butterflybush spp. boxwood spp., rose-of-sharon, honeysuckle spp., spicebush, Japanese maple, red-osier dogwood, witch hazel, and bigtooth aspen). In addition, all tree species with a potential insect or disease pest within Philadelphia County were removed from the list. For the remaining tree species, the pest risk score was added to the ecosystem services score to produce a combined score. Tree species with the lowest combined score were considered the most highly recommended as they have the fewest number of pests or pests at greater distances away from Philadelphia, and the greatest ability to provide ecosystem services.

RESULTS

Tree Cover Assessment

Existing tree cover (O'Neil-Dunne 2011) in Philadelphia is estimated at 20 percent. Tree cover varied by neighborhood with the highest percent tree cover exhibited in the northern and western neighborhoods. Percentage tree cover varies tremendously throughout the city with Pennypack Park and Wissahickon Park (shown in Fig. 3 in dark green) having the greatest percentage tree cover (81 and 84 percent, respectively) and the southeastern part of the city (i.e., Newbold [2.4 percent], Callowhill [2.5 percent] and Chinatown [2.6 percent]) have the lowest percentage tree cover. Estimates of tree cover by neighborhood are given in appendix 3. Note: Many maps shown in this report are also available by U.S. Census block group at http://nrs.fs.fed.us/data/urban.

Urban Forest Structure, Composition, and Values

Tree Characteristics of the Urban Forest

Philadelphia's urban forest has an estimated 2,918,000 trees (standard error of 456,000). The five most common species (or species group) in the urban forest are spicebush, black cherry, ash species, tree-of-heaven, and boxelder (Fig. 4). The 10 most common species account for 55.4 percent of all trees. In total, 69 tree species were sampled in Philadelphia; these species and their relative abundance are presented in appendix 5. See appendix 6 for more information on species distribution by land use.

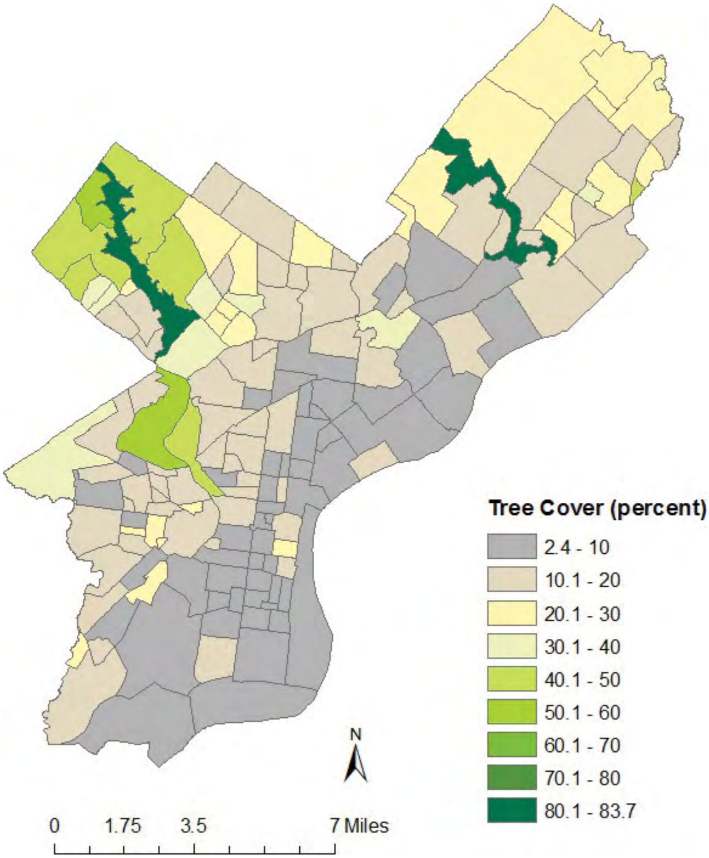

Figure 3.—Urban tree cover percentage by neighborhood, Philadelphia, 2008.

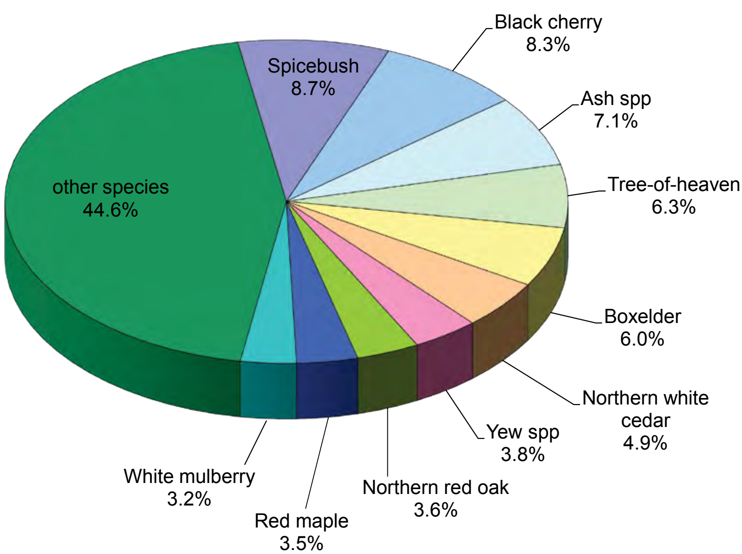

Figure 4.—Urban forest species composition as a percentage of all trees, Philadelphia, 2012.

The overall tree density in Philadelphia is 32.1 trees per acre. The highest density of trees occurs in wooded areas (191.2 trees/ac), followed by other (34.6 trees/ac) and residential land (22.4 trees/ac) (Fig. 5). Although the wooded land use only covers 8.4 percent of the city, it contains the most trees (49.8 percent of tree population), followed by residential areas (40 percent of the land area, 27.9 percent of the trees) (Fig. 5).

Leaf area is a measure of leaf surface area (one side). Leaf area index (LAI) is a measure of the total leaf surface area (one side) divided by land area. As each land use has a different land area, LAI standardizes the canopy depth on an equal area basis. Total leaf area is greatest in wooded (44.4 percent of total tree leaf area) and residential (39.5 percent) land uses (Fig. 6). Higher LAIs indicate a greater leaf surface area per acre of land. Land uses that have the highest LAI are wooded (5.4) and residential (1.0) (Fig. 6).

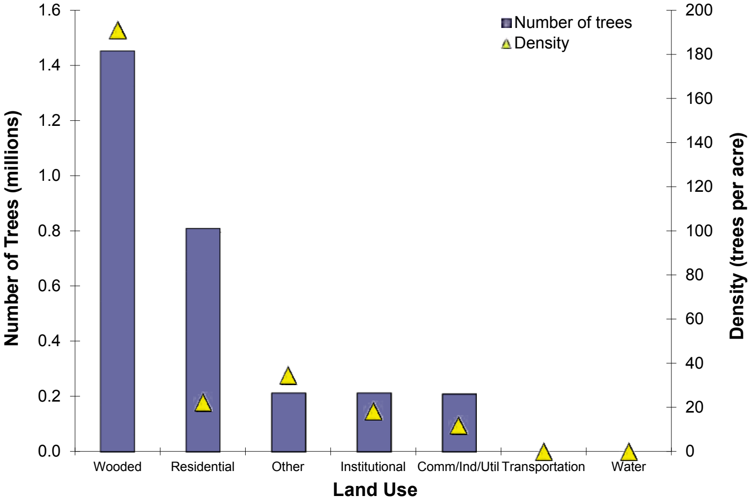

Figure 5.—Number of trees and tree density by land use, Philadelphia, 2012.

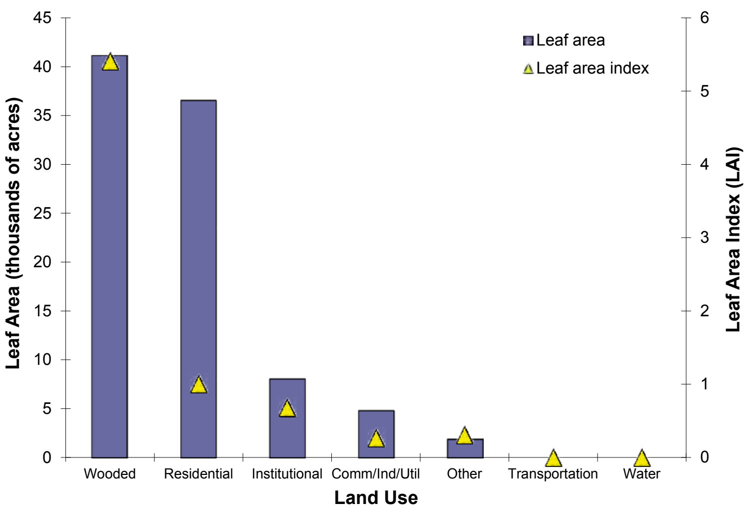

Figure 6.—Total leaf area and leaf area index by land use, Philadelphia, 2012.

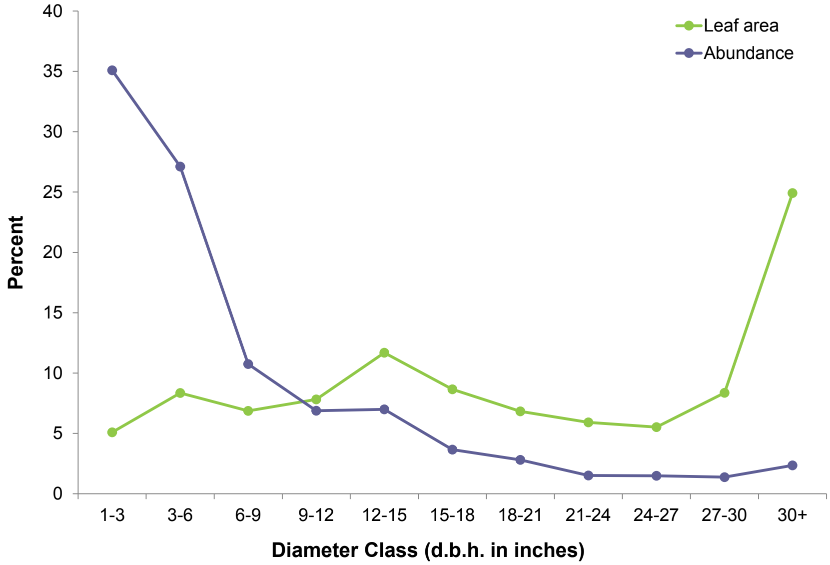

Figure 7.—Percentage of total population and leaf area by diameter class, Philadelphia, 2012. Lower limit of each diameter (d.b.h.) class is greater than displayed (e.g., 3-6 is actually 3.01 to 6 inches).

Tree size is an important characteristic of the urban forest structure. Large diameter 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 62.2 percent of the population (Fig. 7). Trees in this d.b.h. class also contain 13.4 percent of the total leaf area. Nearly all of the 10 most abundant trees in Philadelphia, with the exception of boxelder, northern red oak, and red maple, have more than 50 percent of their population in the 1 to 6 inch d.b.h. class (Fig. 8). Trees that have diameters greater than 18 inches account for 9.5 percent of the tree population, but comprise 51.5 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 Philadelphia. For more information about environmental benefits by d.b.h. class, see appendix 7.

Tree species composition varied 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 spicebush (22.2 percent of trees in ≤3 inch d.b.h. class), ash species (10.9 percent), staghorn sumac (8.6 percent), tree-of-heaven (6.6 percent), black cherry (6.1 percent), honeysuckle species (4.9 percent), boxelder (4.4 percent), northern white cedar (2.8 percent), apple species (2.7 percent), and red maple (2.4 percent). The 10 most common species of large diameter trees are northern red oak (14.4 percent of trees in d.b.h. classes > 18 inches), boxelder (9.5 percent), red maple (7.0 percent), black walnut (6.6 percent), white mulberry (5.2 percent), white oak (4.6 percent), American beech (4.0 percent), sycamore maple (4.0 percent), sycamore spp. (4.0 percent), and pin oak (4.0 percent). Boxelder and red maple are among the 10 most common small diameter trees and the 10 most common large diameter trees (Fig. 9).

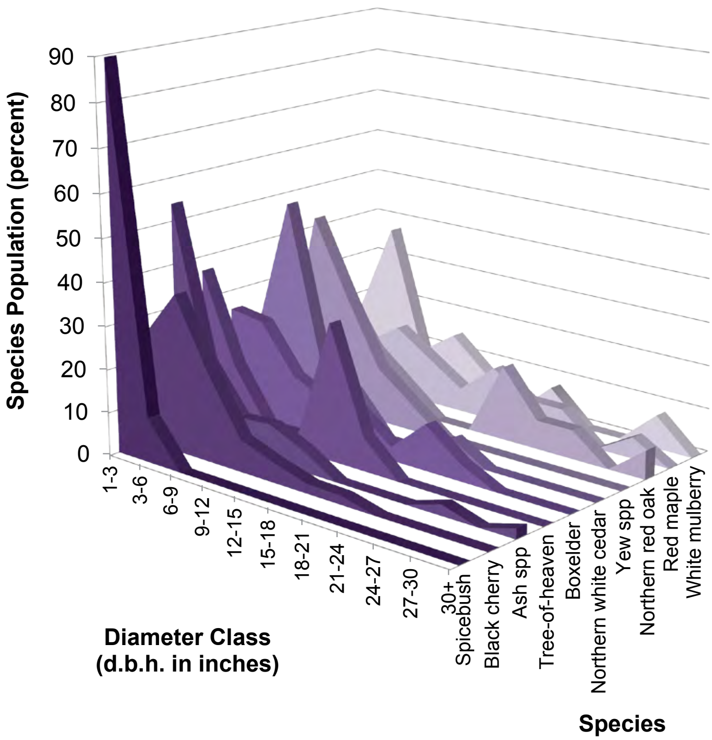

Figure 8.—Percentage of species population by diameter class for 10 most common species, Philadelphia, 2012. Lower limit of each diameter (d.b.h.) class is greater than displayed (e.g., 3-6 is actually 3.01 to 6 inches).

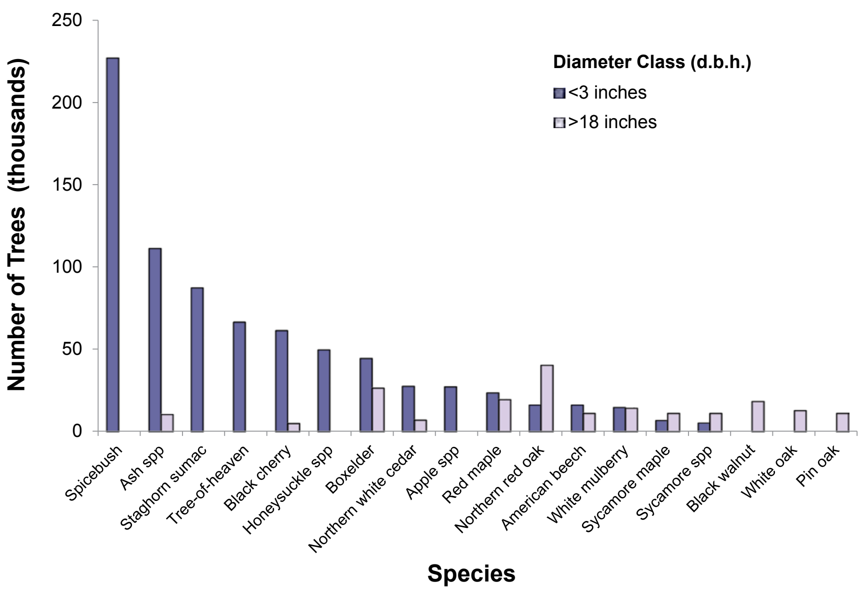

Figure 9.—Number of trees in diameter class (small trees, <3 inches and large trees, >18 inches) made up by the most common tree species in those classes, Philadelphia, 2012.

Tree-of-heaven, one of the 10 most common small diameter trees, is classified as invasive. Sycamore maple is one of the 10 most common large diameter trees and is also classified as invasive. Mean and median stem d.b.h. by species are presented in appendix 5.

Philadelphia'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 higher 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 (Lacan and McBride 2008, Santamour 1990), but the increase in the number of exotic plants can also pose a risk to native plants if exotic species are invasive and out-compete and displace native species. In Philadelphia, about 54 percent of the trees are native to Pennsylvania, and 78 percent native to North America. Trees with a native origin outside of North America are mostly from Asia (12 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). Eleven of the 69 species sampled in Philadelphia are identified on the state invasive species list (Pennsylvania Department of Conservation and Natural Resources, n.d.). These invasive species comprise 17.8 percent of the population with the most common being tree-of-heaven, white mulberry, and Norway maple (Table 4).

Table 4.—Inventoried species listed on the Pennsylvania invasive species list and Philadelphia Parks and Recreation invasive species list, Philadelphia, 2012

Common name	Population	Leaf area
	percent	*percent*
Tree-of-heaven[a,b]	6.3	4.2
White mulberry[a]	3.2	2.5
Norway maple[a,b]	2.5	5.4
Honeysuckle spp.[a]	2.1	0.3
Corktree spp.[a]	1.1	0.5
Sycamore maple[b]	1.0	1.9
Princesstree spp.[a]	0.8	1.3
Siberian elm[a,b]	0.2	0.9
Japanese angelica tree[a,b]	0.2	<0.1
Barberry spp.[a]	0.2	<0.1
Callery pear[a,b]	0.2	0.2

[a] Species found on parkland invasive species list (Huebner et al. 2007; Tom Witmer and Jason Lubar, personal communication, 2012)
[b] Species found on state invasive species list (Pennsylvania Department of Conservation and Natural Resources, n.d.)

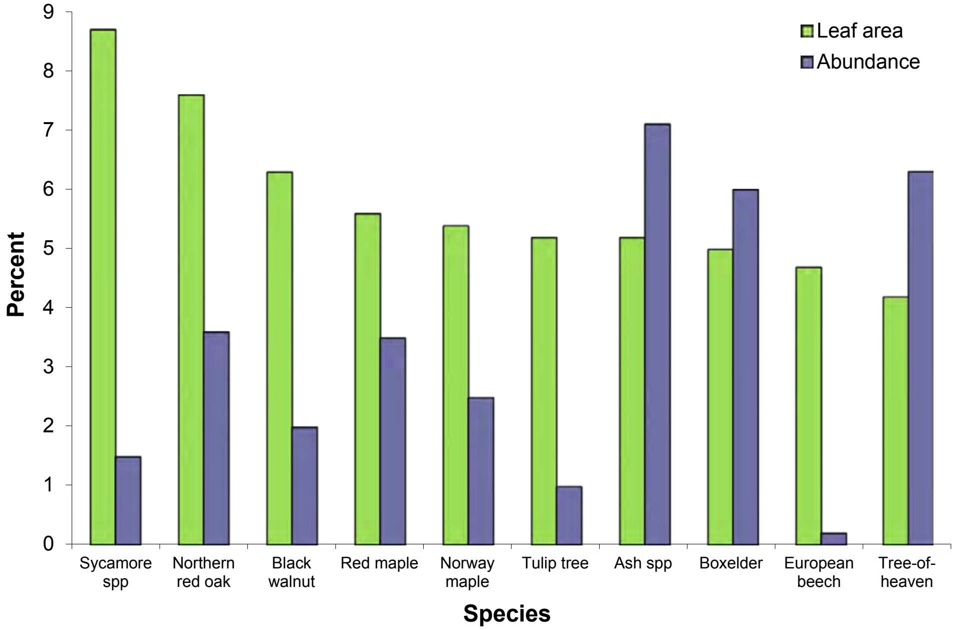

Figure 10.—Percentage of total tree population and total leaf area for 10 species contributing the greatest amount of leaf area, Philadelphia, 2012.

Many tree benefits are linked to the leaf area of the plant, i.e., the greater the leaf area, the greater the benefit. In Philadelphia's urban forest, tree species with the greatest leaf area are sycamore spp., northern red oak, and black walnut (Fig. 10). Tree species that represent a much greater percentage of Philadelphia's leaf area than percentage of total population are sycamore species (including London planetree), tulip tree, and black walnut. Tree species dominated by smaller individuals with relatively low amounts of leaf area per stem are staghorn sumac and honeysuckle species.

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 ash species, black cherry, and northern red oak (Table 5).

Air Temperature Reductions

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).

Table 5.—Percentage of total population and leaf area, and importance value of species with the greatest importance values, Philadelphia, 2012

Common name	Population[a]	Leaf area[b]	IV[c]
	percent	*percent*	
Ash spp.	7.1	5.2	12.3
Black cherry	8.3	3.6	11.9
Northern red oak	3.6	7.6	11.2
Boxelder	6.0	5.0	11.0
Tree-of-heaven	6.3	4.2	10.5
Spicebush	8.7	1.5	10.2
Sycamore spp.	1.5	8.7	10.2
Red maple	3.5	5.6	9.1
Black walnut	2.0	6.3	8.3
Norway maple	2.5	5.4	7.9

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

Average air temperature reductions by trees citywide in Philadelphia varied among the four representative days and the time of day (Table 6). The greatest average air temperature reduction for the city was estimated as 0.9 °F during the nighttime hours (6 p.m. to 5 a.m.) on the warmest summer day of 2008. The lowest average air temperature reduction for the city was estimated as 0.3 °F during the daytime hours (6 a.m. to 5 p.m.) on the average temperature summer day of 2008.

Air temperature reductions by trees in Philadelphia also varied among the city's neighborhoods. On all four of the representative days, the area with the greatest reduction in daytime or nighttime air temperature was Wissahickon Park. The neighborhood with the smallest daytime or nighttime temperature reduction was Riverfront. The maximum temperature reduction occurred during the nighttime hours with the maximum reduction during this period being 3.6 °F in Wissahickon Park on the warmest day. Figure 11 shows the variability of daytime air temperature reductions by neighborhood for the average temperature summer day of 2008. On this average temperature day, the greatest temperature reduction was estimated at 1.5 °F and the smallest reduction was estimated at less than 0.1 °F. For a neighborhood key and more information on the distribution of temperature reduction across the neighborhoods, see appendix 8.

An important factor in the estimation of temperature reductions by trees is the local air temperature. Estimated air temperatures varied across Philadelphia and are reported in appendix 8. 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 people exposed to the warmest temperatures (appendix 8) where tree planting would be most beneficial.

Table 6.—Average, minimum, and maximum air temperature reductions, Philadelphia, 2008

Representative days	Time	Average Philadelphia °F	Minimum neighborhood	Minimum °F	Maximum neighborhood	Maximum °F
Windiest (6/1/08)	AM[a]	0.5	Riverfront	<0.1	Wissahickon Park	1.3
	PM[b]	0.5	Riverfront	0.1	Wissahickon Park	2.0
Least windy (8/21/08)	AM	0.4	Riverfront	<0.1	Wissahickon Park	1.3
	PM	0.7	Riverfront	0.1	Wissahickon Park	3.1
Average temperature (8/4/08)	AM	0.3	Riverfront	<0.1	Wissahickon Park	1.5
	PM	0.6	Riverfront	0.1	Wissahickon Park	2.7
Warmest (6/10/08)	AM	0.5	Riverfront	<0.1	Wissahickon Park	2.0
	PM	0.9	Riverfront	0.1	Wissahickon Park	3.6

[a] The average air temperature reduction for the daytime hours (6 a.m. to 5 p.m.) of the representative day
[b] The average air temperature reduction for the nighttime hours (6 p.m. to 5 a.m.) of the representative day

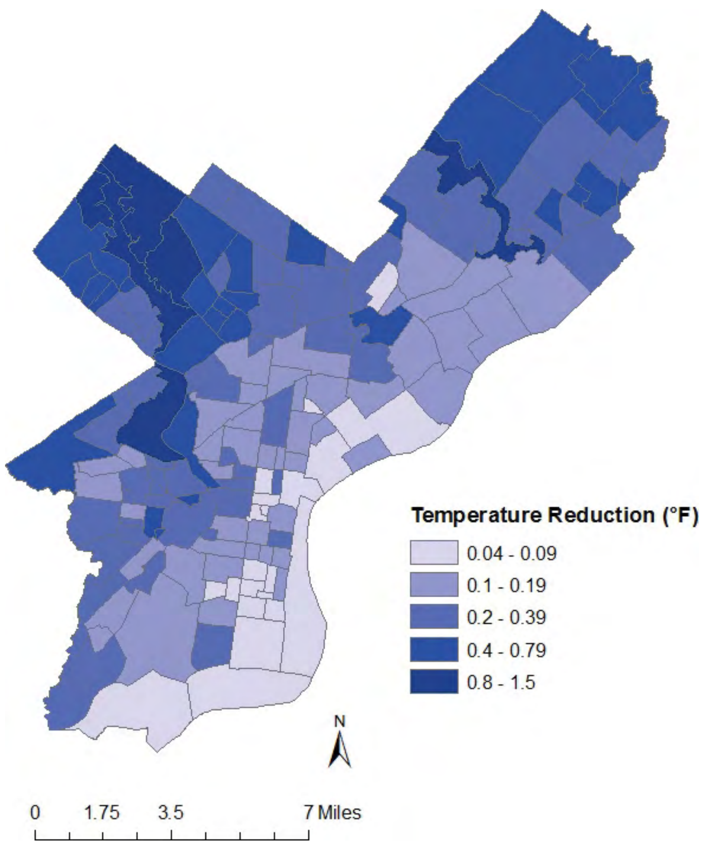

Figure 11.—Daytime (6 a.m. to 5 p.m.) air temperature reductions by trees, by neighborhood for the average temperature summer day, Philadelphia, 2008.

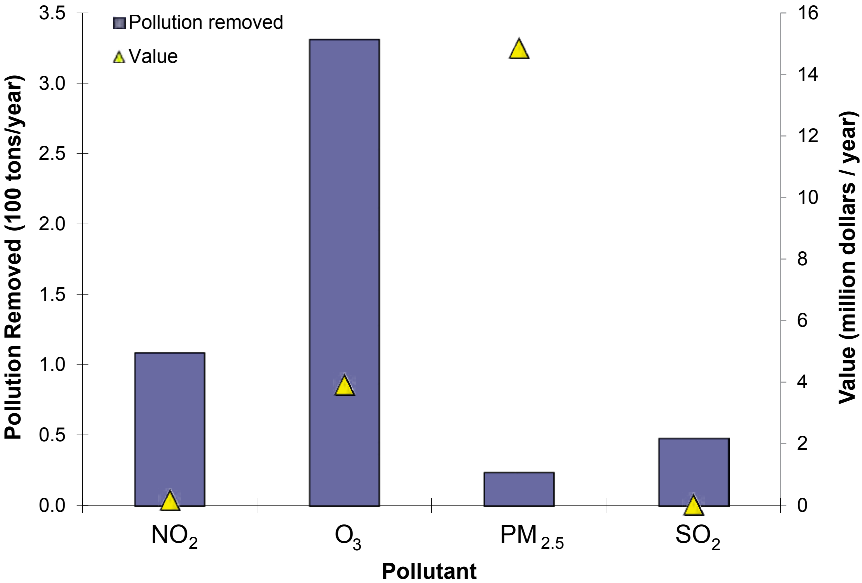

Figure 12.—Annual air pollution removal and value by urban trees, Philadelphia, 2012.

Air Pollution Removal

Poor air quality is a common problem in many urban areas. It can damage landscape materials and ecosystem processes, and reduce visibility. Air pollution is also associated with significant human health effects that impact pulmonary, cardiac, vascular, and neurological systems (e.g., Pope et al. 2002). The urban forest can 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. 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).

Pollution removal by trees in Philadelphia 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 2008. Pollution removal was greatest for ozone (O_3, 332 tons removed per year), followed by nitrogen dioxide (NO_2, 109 tons/year), sulfur dioxide (SO_2, 48 tons/year), and particulate matter less than 2.5 microns in size ($PM_{2.5}$, 24 tons/year) (Fig. 12). By contrast, the value associated with pollution removal was greatest for $PM_{2.5}$ ($14.9 million), followed by O_3 ($3.9 million), NO_2 ($174,000), and SO_2 ($28,000). It is estimated that trees alone remove 513 tons of air pollution (NO_2, O_3, $PM_{2.5}$, and SO_2) per year with an associated value of $19.0 million.

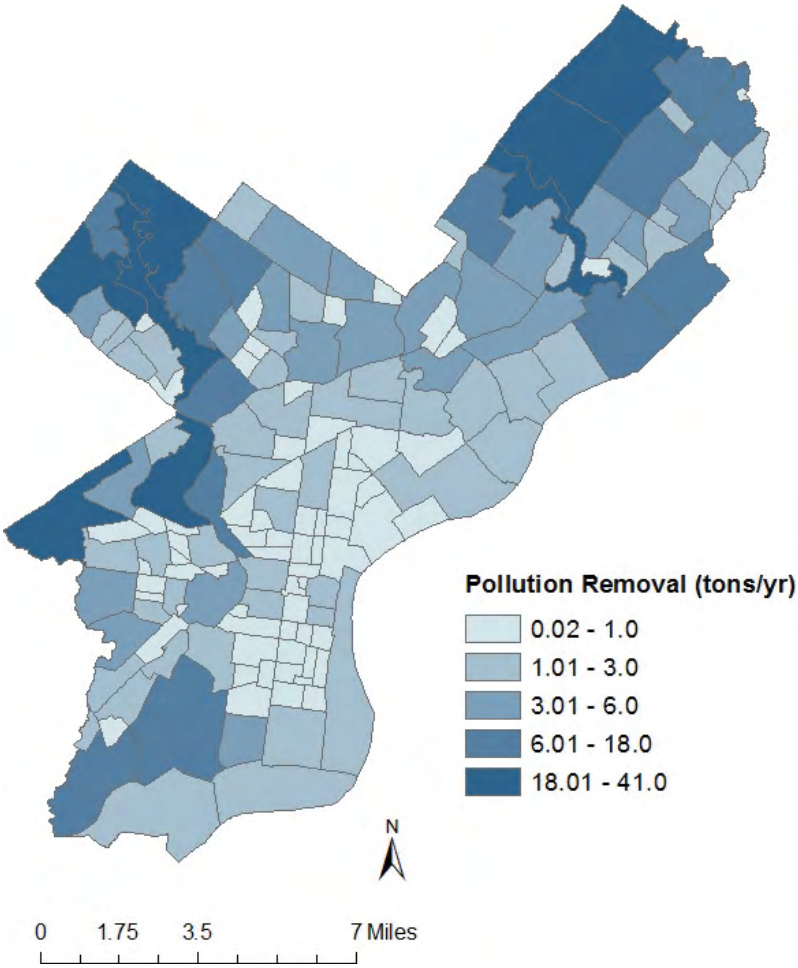

Figure 13.—Pollution removal by trees by neighborhood, Philadelphia, 2012.

Pollution removal by trees in Philadelphia varies among city neighborhoods and is associated with total leaf area (Fig. 13). The area with the greatest pollution removal is Wissahickon Park (41 tons per year), followed by Pennypack Park (35 tons per year) and Chestnut Hill (27 tons per year).

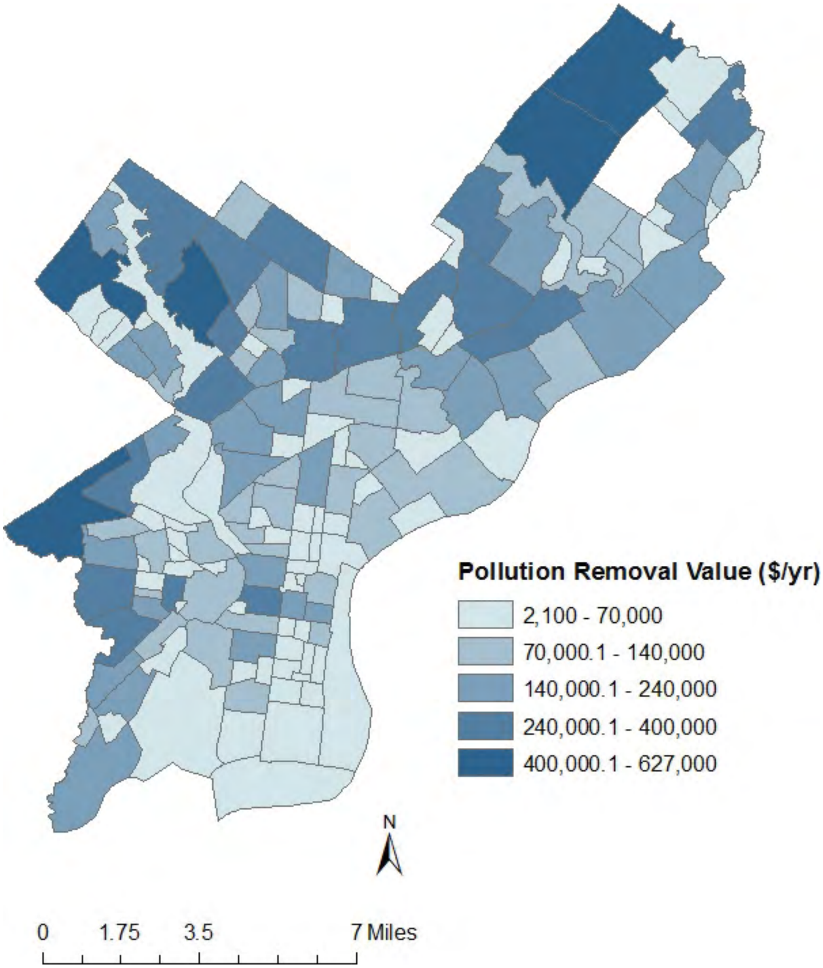

Figure 14.—Pollution removal value by neighborhood, Philadelphia, 2012.

The value of pollution removal also varied by neighborhood (Fig. 14). The maximum pollution removal value was $627,000 per year in the Somerton neighborhood. The Bustleton and Overbrook neighborhoods also had annual pollution removal values over one-half million dollars. The values vary by neighborhood depending upon pollution removal and population totals. Neighborhoods with greater pollution removal and/or more people, tend to have high values as more people receive the health benefits associated with pollution reduction (Nowak et al. 2014). Estimates of pollution removal by neighborhood are given in appendix 3.

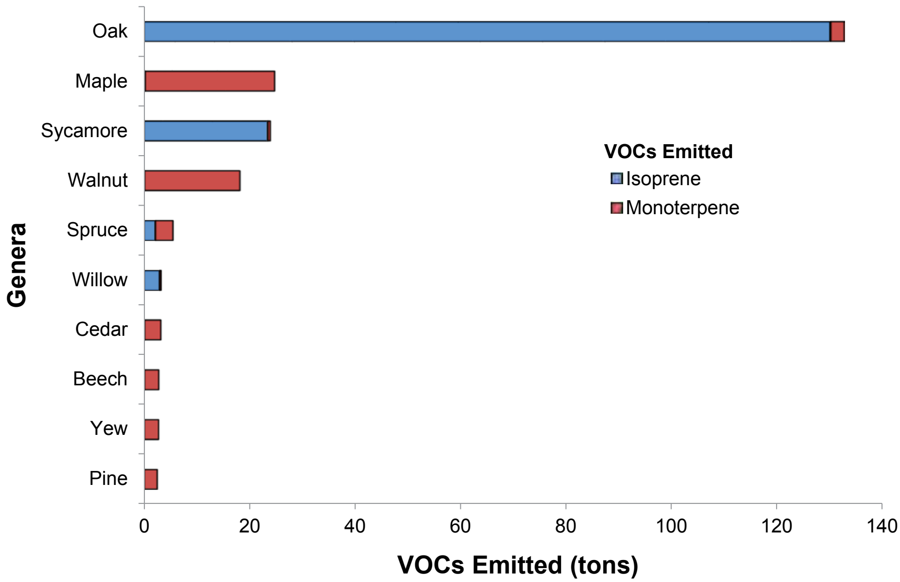

Figure 15.—Annual volatile organic compounds (VOCs) emitted by tree genera with highest total emissions, Philadelphia, 2012.

In 2012, trees in Philadelphia emitted an estimated 228 tons of VOCs (161.3 tons of isoprene and 66.3 tons of monoterpenes). Emissions vary among genera and amount of leaf biomass. Sixty-nine percent of the urban forest's VOC emissions were from the oak and maple genera (Fig. 15). These VOCs are precursor chemicals to ozone formation.[3] General recommendations for improving air quality with trees are given in appendix 9.

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 tissue and by reducing the amount of energy used to heat or cool buildings, thus reducing CO_2 emissions from fossil-fuel based power sources (Abdollahi et al. 2000).

[3] 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.

Carbon storage is one way trees can influence global climate change. 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 production and emissions from fossil-fuel based power sources. Trees in Philadelphia store an estimated 702,000 tons of carbon (2.6 million tons of CO_2 valued at $93.4 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 Philadelphia is about 27,000 tons of carbon per year (99,000 tons per year of CO_2) with an associated value of $3.6 million per year. Net carbon sequestration in Philadelphia is estimated at about 23,000 tons per year (86,000 tons per year of CO_2) by subtracting estimated carbon loss due to tree mortality and decomposition from gross sequestration.

Of all the species sampled, northern red oak stores the most carbon (approximately 8.4 percent of total estimated carbon stored) and annually sequesters the most carbon (9.0 percent of all sequestered carbon) (Figs. 16-17). Trees greater than 30 inches in diameter store the most carbon in the city (Figs. 18-19).

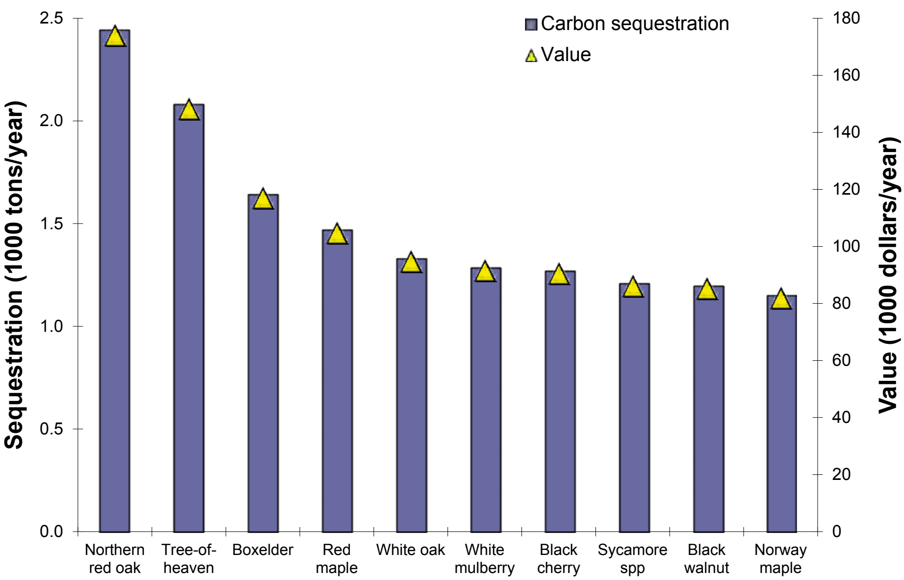

Figure 16.—Estimated annual carbon sequestration and value for urban tree species with the greatest sequestration, Philadelphia, 2012.

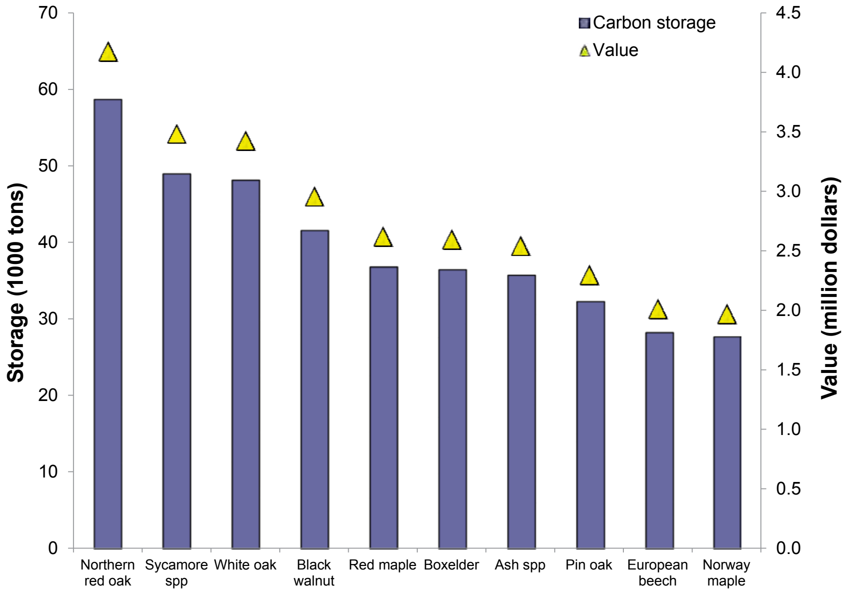

Figure 17.—Estimated annual carbon storage and value for urban tree species with the greatest storage, Philadelphia, 2012.

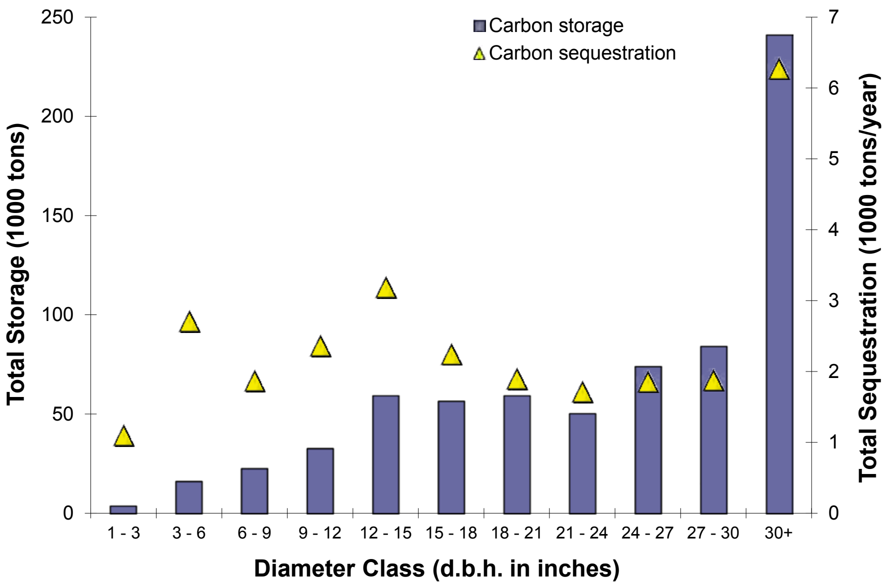

Figure 18.—Estimated total carbon storage and sequestration by diameter class, Philadelphia, 2012. Lower limit of each diameter class is greater than displayed (e.g., 3-6 is actually 3.01-6 inches).

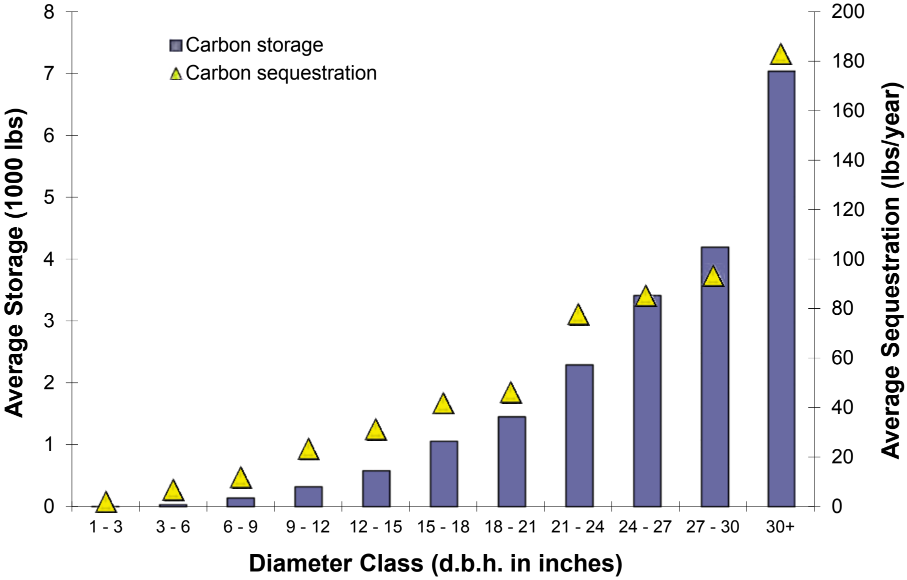

Figure 19.—Estimated average carbon storage and sequestration per tree by diameter class, Philadelphia, 2012. Lower limit of each diameter (d.b.h.) class is greater than displayed (e.g., 3-6 is actually 3.01-6 inches).

Building Energy Use

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).

London planetrees at the Rodin Museum in Philadelphia, PA. Photo by Lara A. Roman, U.S. Forest Service.

Based on average energy costs in 2012 (Energy Information Administration 2012a, 2012b, 2014b, 2014c), trees in Philadelphia reduce energy costs from residential buildings by an estimated $6.9 million annually (Table 7). Trees also provide an additional $1.4 million in value per year by reducing the amount of carbon released by fossil-fuel based power sources (a reduction of 11,000 tons of carbon emissions or 39,000 tons of CO_2) (Table 8).

Table 7.—Annual monetary savings[a] ($) in residential energy expenditures during heating and cooling seasons, Philadelphia, 2012

	Heating	Cooling	Total
MBTU[b] ($)	2,676,000	n/a	2,676,000
MWH[c] ($)	369,000	3,899,000	4,268,000
Carbon avoided ($)	479,000	950,000	1,429,000

[a] Based on 2012 statewide energy costs (Energy Information Administration 2012a, 2012b, 2014b, 2014c) and 2015 social cost of carbon (Interagency Working Group 2013)
[b] MBTU – Million British thermal units (not used for cooling)
[c] MWH – Megawatt-hour

Table 8—Annual energy savings (MBTU, MWH, or tons) due to trees near residential buildings, Philadelphia, 2012

	Heating	Cooling	Total
MBTU[a]	184,000	n/a	184,000
MWH[b]	3,000	30,000	33,000
Carbon avoided (tons)[c]	4,000	7,000	11,000

[a] MBTU – Million British thermal units (not used for cooling)
[b] MWH – Megawatt-hour
[c] To convert carbon estimates to CO2, multiply carbon value by 3.667

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 forest as a structural asset (e.g., how much should one be compensated for the loss of the physical structure of the tree). The compensatory value (Nowak et al. 2002a) of the trees in Philadelphia is about $1.7 billion (Fig. 20). For small trees, a replacement cost can be used. For larger trees, several estimation procedures are used based on species, size, condition and location (Nowak et al. 2002a). 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 species are listed with a high compensatory value because the methods used to estimate compensatory value do not necessary discount invasive species in the species rating.

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., reduction in ultra-violet radiation, aesthetics, and wildlife habitat). Thus the functional values 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.,

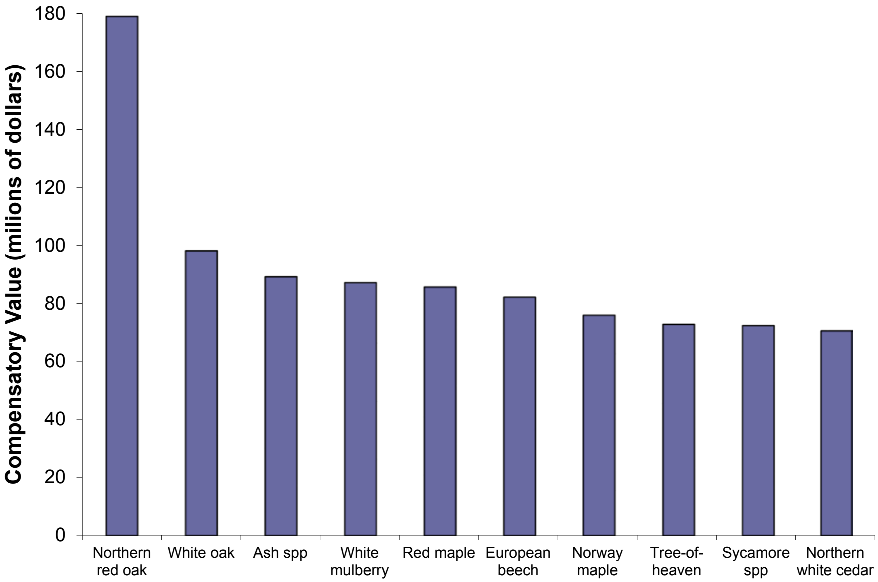

Figure 20.—Tree species with the greatest compensatory value, Philadelphia, 2012.

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 Philadelphia have the following structural values:

- Compensatory value: $1.7 billion
- Carbon storage: $93.4 million

Urban trees in Philadelphia have the following annual functional values:

- Carbon sequestration: $3.6 million
- Pollution removal: $19.0 million
- Reduced energy costs: $6.9 million

Parkland

Parkland areas are an important subset of Philadelphia's urban forest and include forested natural areas as well as neighborhood parks. Parkland comprises 9.3 percent of the city's total land area (Table 2). These publicly managed lands contribute substantially to the environmental benefits provided by the city's urban forest (Table 9). Based on 73 plots, parklands have an estimated 1.1 million trees and store 273,000 tons of carbon, among other environmental benefits. The compensatory value of Philadelphia's parkland is estimated at $350 million. Tree cover in parkland is 64 percent. In total, 72 tree species were sampled in Philadelphia's parkland; these species and their relative abundance are presented in appendix 10.

Table 9.—Summary of urban forest features, Philadelphia parklands, 2012

Feature	Estimate
Number of trees[a]	1,100,000
Tree cover	64%[b]
Most abundant species by:	
Number of trees	ash species, boxelder, spicebush, black cherry, American beech
Leaf surface area	American beech, tulip tree, sycamore species, ash species, black cherry
Trees 1-6 inches d.b.h.	66.7%
Pollution removal	179 tons/year ($6.6 million/year)
VOC emissions	54 tons/year
Carbon storage	273,000 tons ($19.4 million)
Carbon sequestration	6,900 tons/year ($489,000/year)
Value of reduced building energy use	$21,400/year
Value of reduced carbon emissions	$2,400/year
Compensatory value[c]	$350 million

[a] all woody vegetation > 1 inch d.b.h.
[b] assessed using LiDAR in an earlier report (O'Neil-Dunne 2011)
[c] 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)

The most abundant species in parklands are ash species, boxelder, spicebush, black cherry, and American beech (Figs. 21, 22). The two most common invasive tree species in parkland are Norway maple and Japanese angelica tree (both nonnative). Another nonnative invasive, sycamore maple, is also present but comprises less than 1 percent of the population.

The specific assessment of invasive trees, woody shrubs, herbaceous plants, vines, and grasses in parkland revealed that at least one invasive species was found on 79 percent of assessed plots, with 46 percent of plots having greater than five different invasive species. The most common invasive plant species in parklands were garlic mustard (nonnative species present on 53 percent of plots), followed by poison ivy (native, 49 percent), Virginia creeper (native, 37 percent), oriental bittersweet (nonnative, 33 percent), wine raspberry (nonnative, 32 percent), wild grape (native and nonnative species, 32 percent) and multiflora rose (nonnative, 31 percent) (Fig. 23, 24). Invasive species have the potential to outcompete other species, altering both the character of the forest and the habitat of animal and plant species that live there. The capacity of invasive species to dominate an area to the exclusion of other plants is of special concern in parkland areas as it could reduce species diversity and alter many of the functional benefits derived from urban forests.

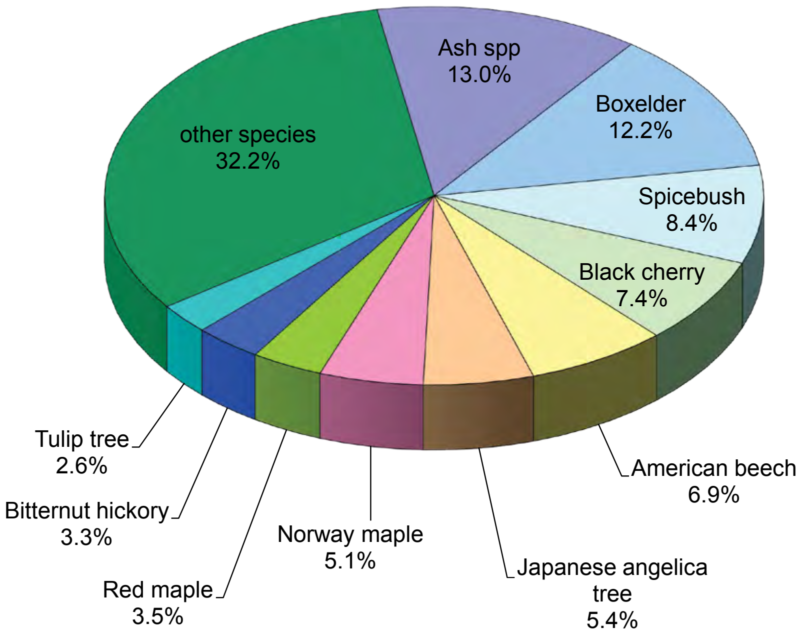

Figure 21.—Species composition as a percentage of all Philadelphia parkland trees, 2012.

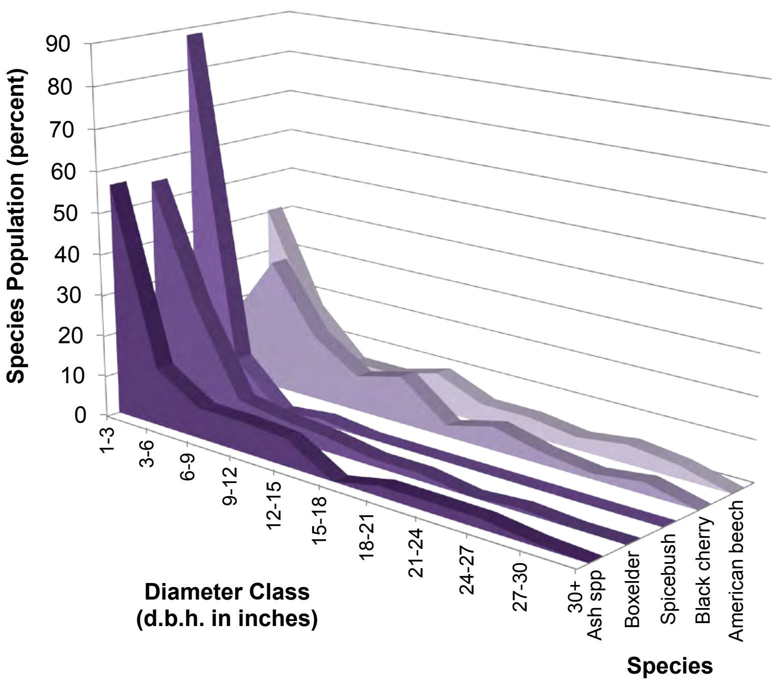

Figure 22.—Percentage of species population by diameter class for five most common species, Philadelphia parkland, 2012. Lower limit of each diameter (d.b.h.) class is greater than displayed (e.g., 3-6 is actually 3.01-6 inches).

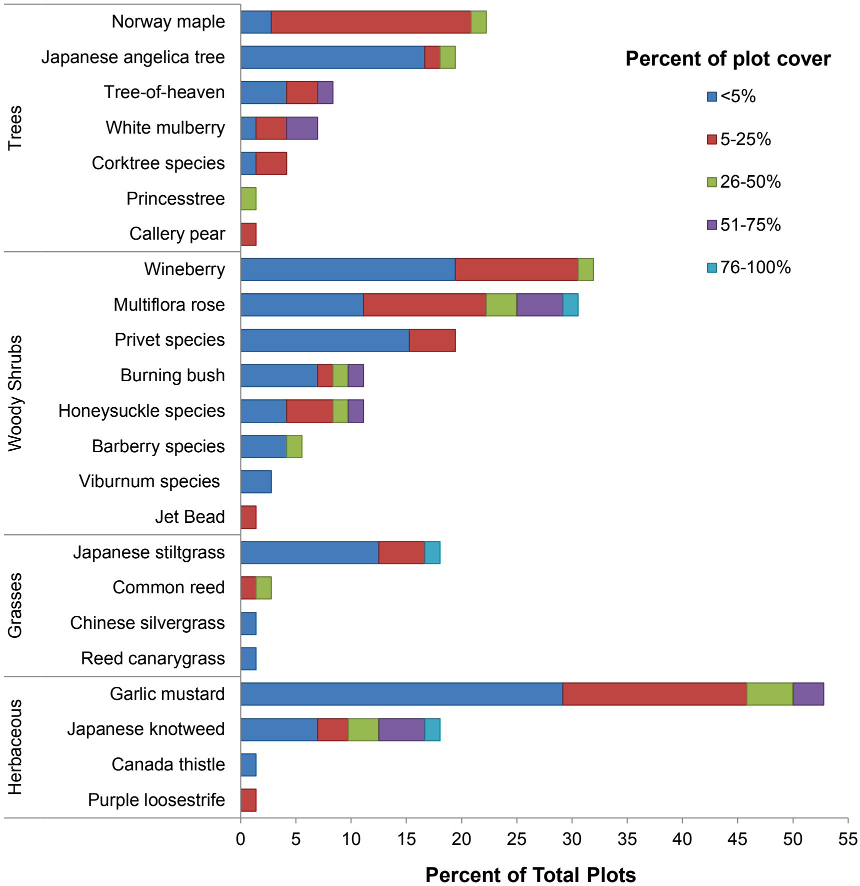

Figure 23.—Percentage of total plots occupied by invasive species (excluding vines; see Fig. 24) subdivided by proportion of plot invaded, Philadelphia parklands, 2012. This figure does not include the invasive species (appendix 2) that were not found on plots.

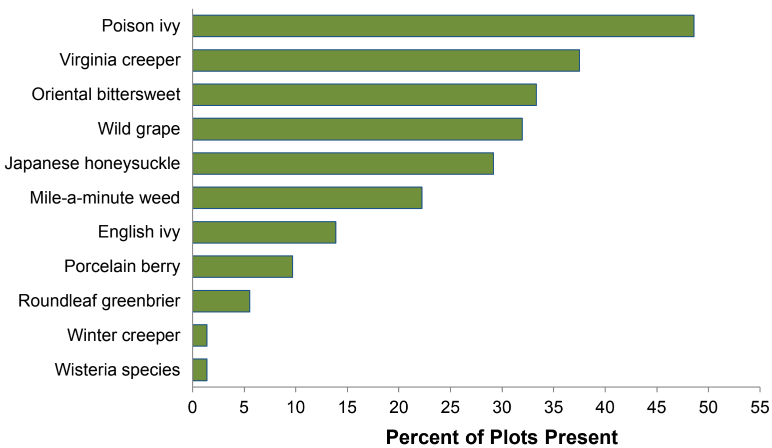

Figure 24.—Percentage of total plots occupied by invasive vines, Philadelphia parklands, 2012. This figure does not include the invasive vine species that were not found (appendix 2).

Table 10.—Percentage land cover in Philadelphia in 2008 and 2012

Cover type	2008		2012	
	Percent	SE	Percent	SE
tree/shrub	21.2	1.3	21.0	1.3
grass/herb	18.5	1.2	17.9	1.2
impervious - bldg	22.7	1.3	22.8	1.3
impervious - road	14.1	1.1	13.8	1.1
impervious - other	21.2	1.3	22.6	1.3
water	0.2	0.1	0.2	0.1
soil/bare ground	2.0	0.4	1.6	0.4

SE = standard error

Land Cover Change Analysis

Photo interpretation of aerial imagery from different dates provides a method for estimating land cover within a study area (e.g., Nowak and Greenfield 2012). Statistical information on land cover change was derived from a paired point analysis of 2008 and 2012 aerial imagery for the city of Philadelphia. Photo interpretation was conducted on a random sample of 1,000 paired points. From this analysis, tree and shrub cover is estimated at 21.2 percent (standard error (SE) = 1.3 percent) in 2008 and 21.0 percent (SE = 1.3 percent) in 2012 (Table 10).

The 2008 cover estimates provided by the high resolution cover map and photo interpretation cannot be compared as they use different definitions of cover. The cover map defines tree cover based on leaf area at a height of at least 8 feet, while the photo-interpretation of tree cover includes both trees and shrubs (all leaf area not at ground surface). Both photo interpretation and high resolution cover maps have advantages and limitations when estimating cover.

Based on the photo interpretation estimates, tree and shrub cover dropped slightly from 21.2 percent in 2008 to 21.0 percent in 2012. Some tree and shrub cover in 2008 (0.4 percent) was replaced by other impervious cover, while some tree cover (0.2 percent) was gained from the grass/herb class (Table 11). Thus tree and shrub cover changed in Philadelphia between the years, with some tree cover gains (+0.2 percent) and some tree cover losses (-0.4 percent), with the net change (-0.2 percent) not statistically different from zero. However, there was a statistically significant increase in impervious cover with impervious cover increasing from 58.0 percent in 2008 to 59.2 percent in 2012.

Table 11.—Change in percentage of city land area occupied by various land cover class, Philadelphia, 2008-2012

Year	Cover type	2012 Grass/ herb	2012 Tree/ shrub	2012 Imp. Bldg	2012 Imp. Road	2012 Imp. Other	2012 Water	2012 Soil	2008 Total	SE
2008	grass/herb	**17.4**	0.2	0.2	0.0	0.5	0.0	0.2	18.5	1.2
2008	tree/shrub	0.0	**20.8**	0.0	0.0	0.4	0.0	0.0	21.2	1.3
2008	imp. bldg	0.0	0.0	**22.5**	0.0	0.2	0.0	0.0	22.7	1.3
2008	imp. road	0.0	0.0	0.0	**13.8**	0.3	0.0	0.0	14.1	1.1
2008	imp. other	0.0	0.0	0.1	0.0	**21.1**	0.0	0.0	21.2	1.3
2008	water	0.0	0.0	0.0	0.0	0.0	**0.2**	0.0	0.2	0.1
2008	soil	0.5	0.0	0.0	0.0	0.1	0.0	**1.4**	2.0	0.4
2012	total	17.9	21.0	22.8	13.8	22.6	0.2	1.6		
	SE	1.2	1.3	1.3	1.1	1.3	0.1	0.4		
Net Change (2008-12)		-0.6	-0.2	0.1	-0.3	1.4	0.0	-0.4		

Bold values in diagonal indicate amount of class that did not change between 2008 and 2012.
Nonbold values in a row are losses in cover to that row class between the years.
Nonbold values in the columns are gains to the column class between the years.
For example, tree/shrub cover in 2008 = 21.2 percent, 20.8 percent had no change; 0.4 was lost to the impervious (imp.) Other class; and 0.2 was gained from grass/herb class, such that the 2012 tree cover dropped by 0.2 percent to 21.0 percent.

Cobbs Creek Watershed Analysis

The i-Tree Hydro model was calibrated to find the "best fit" between the observed stream flow and the modeled stream flow for the Cobbs Creek 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. (The full report is available at http://nrs.fs.fed.us/data/urban for calibration evaluation and description of scenarios).

Existing Cover Effects

The Philadelphia International Airport weather station used for the i-Tree Hydro simulation of Cobbs Creek watershed recorded 53.8 inches of rainfall during 2011, the year selected for the simulation. It was assumed that this amount fell over the entire 12,676-acre watershed and contributed a total of 2.48 billion cubic feet of rainfall during 2011.

The modeled stream flow in the watershed throughout the simulation period for the existing cover (i.e., no cover change from measured conditions) was 1.07 billion 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 impervious areas and baseflow are the biggest contributors to stream flow with 55.3 and 33.8 percent of total flow generated from impervious runoff and baseflow, respectively. Runoff from pervious areas was estimated to generate 10.9 percent of the total flow.

Table 12—Estimated reduction in chemical constituents due to existing tree cover, Cobbs Creek watershed, 2011

Constituent	Reduction	
	Median	Mean
	tons	*tons*
Total suspended solids	23.4	33.7
Biochemical oxygen demand	4.9	6.1
Chemical oxygen demand	19.2	22.7
Total phosphorus	0.1	0.1
Soluble phosphorus	0.04	0.06
Total Kjeldhal nitrogen	0.6	0.7
Nitrite and nitrate	0.2	0.3
Copper	0.005	0.006

Tree canopies were estimated to intercept about 7.0 percent of the total rainfall, but only 46.8 percent of the watershed was covered by trees, so precipitation interception by trees was only 3.3 percent (81.0 million cubic feet). Areas of non-tree vegetation (i.e., grasses and shrubs) were estimated to intercept about 3.0 percent of the total rainfall, but only 10.5 percent of the watershed was covered by grass and shrubs, so precipitation interception by this vegetation was only 0.3 percent (7.6 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 2011 by around 23.4 tons based on median EMC values. Other chemical constituents were also reduced (Table 12).

Tree Cover Effects

Reducing the existing 46.8 percent tree cover in the Cobbs Creek watershed to 0 percent would increase total stream flow by 44.4 million cubic feet (4.2 percent of total flow under existing conditions) for 2011. Increasing canopy cover from 46.8 percent to 50.0 percent would reduce overall flow by 1.2 million cubic feet (0.1 percent of total flow under existing conditions) for the same period (Fig. 25).

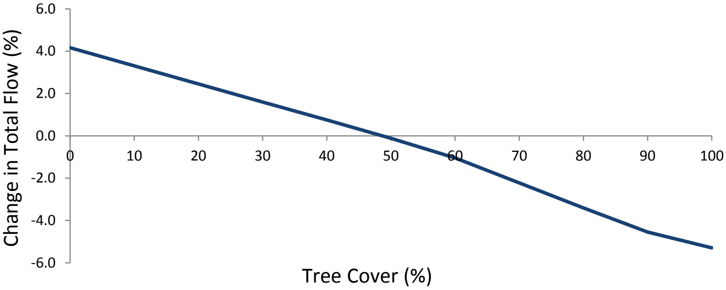

Figure 25.—Percentage change in total annual stream flow by percentage tree cover, Cobbs Creek watershed, 2011.

Impervious Cover Effects

Removing all impervious cover in the Cobbs Creek watershed (currently 54 percent) would reduce total annual flow by 272 million cubic feet (25.6 percent of total flow under existing conditions) for 2011. Increasing impervious cover from 54 percent to 60 percent of the watershed would increase total annual flow by 86.6 million cubic feet (8.1 percent of total flow under existing conditions) for the same period (Fig. 26).

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 a 12 times greater impact on flow than tree cover. Increasing impervious cover by 1 percent averaged a 1.1 percent increase in annual stream flow, while increasing tree cover by 1 percent averaged only a 0.09 percent decrease in stream flow. The interactions between changing both tree and impervious cover are illustrated for changes in percentage flow in Figure 27.

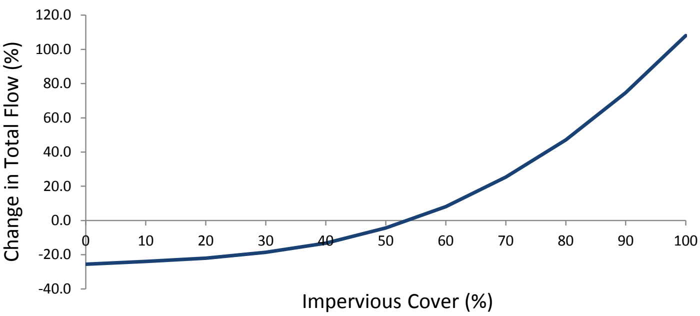

Figure 26.—Percentage change in total annual stream flow by percent impervious cover, Cobbs Creek watershed, 2011.

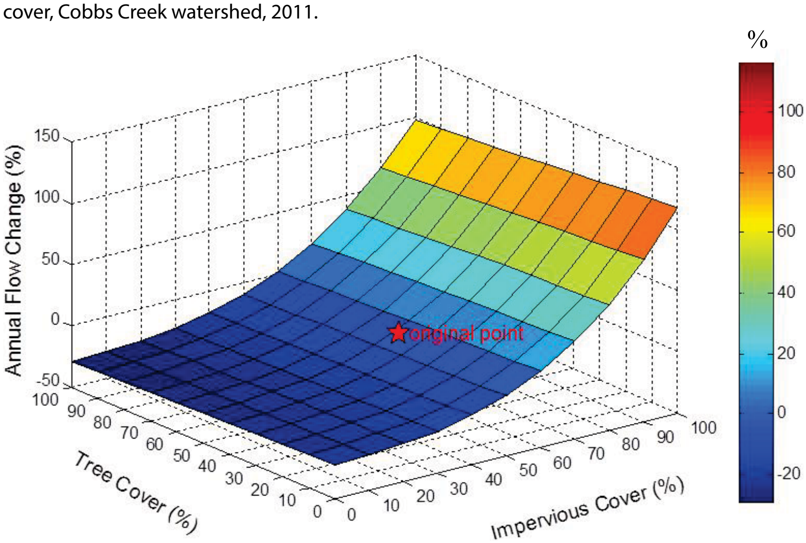

Figure 27.—Percentage change in total flow during simulation period based on percentage impervious and percentage tree cover, Cobbs Creek watershed, 2011. Red star indicates existing conditions. Note: some simulation scenarios (e.g., 100 percent tree cover and 100 percent impervious cover) are not realistic, but included to illustrate the range of possibilities.

MANAGEMENT IMPLICATIONS

The urban forest of Philadelphia 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 of Philadelphia is 20 percent, it ranges from 2.4 percent in the Newbold neighborhood to 83.7 percent in the Wissahickon Park area. 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 Philadelphia. One option for determining priority planting areas is to map tree cover with population density (appendix 11) to identify areas that have low tree cover relative to their population. Using this method, the neighborhoods with the highest planting priority (calculated from population density, tree stocking levels and tree cover per capita) are Dickinson Narrows, McGuire, and Greenwich. Although these neighborhoods have limited plantable space (appendix 3), targeting these areas may enhance benefits to the greatest number of people on a per tree basis. This type of targeted enhancement is just one of many ways to determine priority areas to enhance tree cover. Other methods to target enhancing tree cover 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 8). Based on air temperature data and population, the greatest human impact to reducing air temperatures through tree planting would occur in the Chinatown, Mechanicsville, and Woodland Terrace neighborhoods (appendix 8). 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; c) near buildings to reduce energy use, or any combination of these options.

Current Tree Size Distribution and Potential Species Changes

Change in species composition and tree size structure of Philadelphia's urban forest 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, Philadelphia has more small trees than large trees (which leads to an inverse J-shaped distribution of diameter structure, Fig. 7). 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 is revealed. Other factors that will influence future forest structure include insects, disease, land use changes, climate change, development, and natural resource management. Several of the most common large diameter tree species, particularly pin oak, white oak, and black walnut, are underrepresented among the small diameter trees (Fig. 9), 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 d.b.h. class and appear to be regenerating well (including tree planting by humans) are spicebush, ash species, staghorn sumac, tree-of-heaven, black cherry, honeysuckle species, boxelder, northern white cedar, and apple species. Many of these species tend to be prolific seeders that have become established in open areas and corridors throughout Philadelphia. Some of these species do not attain a large stature at maturity (e.g., spicebush, honeysuckle, and apple). If individual small trees are replacing large trees in the urban landscape, this will likely lead to lower canopy levels and altered size structure. These data suggest that Philadelphia's urban forest maybe shift toward more smaller and often invasive species, which will have impacts on future urban forest structure and value. Long-term monitoring will help better determine how species composition is changing. Additionally, the small ash trees may not reach mature size due to future emerald ash borer infestation.

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, 2013b). This study provides a baseline for future monitoring.

An earlier assessment of Philadelphia's urban forest was conducted based on field data collected in 1996 (Nowak et al. 2007). That assessment and this report are independent and cannot be directly compared due to differing samples and methods. These older plots were not permanently referenced, hence new permanent plots were laid for the current study. However, results from 1996 are mentioned here to help explain potential differences. The 1996 assessment reported 2.1 million trees with tree cover 15.7 percent. Tree cover in 1996 was estimated based on 210 field plots and was estimated within 5 percent categories on each plot. Given this relatively low precision measurement and the fact that the 1996 cover estimate was based on a sample, there is little evidence to show that this cover estimate is different from the more precise 2008 LiDAR tree cover estimate of 20 percent (O'Neil-Dunne 2011). Additionally, "tree" is defined differently in the field plots and LiDAR methods: the 1996 field study had a minimum d.b.h. of 1 inch for tree species and 4 inch for shrub species, the 2012 field study had a minimum d.b.h.

of 1 inch for all woody plants, and the 2008 LiDAR tree cover estimate had a minimum tree height of 8 feet. Therefore, the 1996 sample did not include many species considered shrubs (e.g., spicebush, yew) unless they reached a d.b.h. of 4 inches. Thus, the apparent increase in the number of trees based on 1996 and 2012 field data, particularly shrub species, is likely due to this difference in methods. The 10 most common species for both the 1996 and 2012 plots were similar: eight species were on both lists, while spicebush and yew were in the top 10 for 2012, and apple species and tulip tree were in the top 10 in 1996.

Invasive Species

Invasive species are another concern in Philadelphia and account for 519,000 trees with a leaf area of 697 million square feet. Within parklands, invasive species were found on 79 percent of the sampled plots. The invasive species observed in Philadelphia can alter the urban forest composition through time as they can spread into the surrounding landscape, displacing native species and altering local ecosystems (Pimentel et al. 2000).

Insect and Disease Impacts

Insects and 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. Thirty-one exotic insects/diseases were considered for their potential impact using range maps of the pests in the coterminous United States (U.S. Forest Service 2013, 2014; Worrall 2007). For a complete list of the 31 exotic insects/diseases, see appendix 4.

Although there are numerous pests that could impact Philadelphia's urban forest, Asian longhorned beetle (ALB), gypsy moth (GM), emerald ash borer (EAB), and oak wilt (OW) pose the most serious threats based on their range and the number of trees at risk to infestation.

Of these four insects and diseases, GM and EAB were confirmed present in Philadelphia. Potential loss from GM is 455,000 trees with an associated compensatory value of $394 million; EAB is 207,000 ($90 million). ALB and OW have been found within 250 miles of Philadelphia. Potential loss of trees from ALB is 584,000 ($439 million in compensatory value) and from OW is 193,000 ($321 million) (Fig. 28).

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

These four insects and diseases threaten common trees such as willow, ash, birch, maple, oak, and elm (appendix 4). The two most significant threats to the forest are likely EAB and ALB due to either rapid rate of spread or close proximity to the city. The ALB is currently located in New York City and although not spreading rapidly, this pest can have devastating impacts due to its large host list.

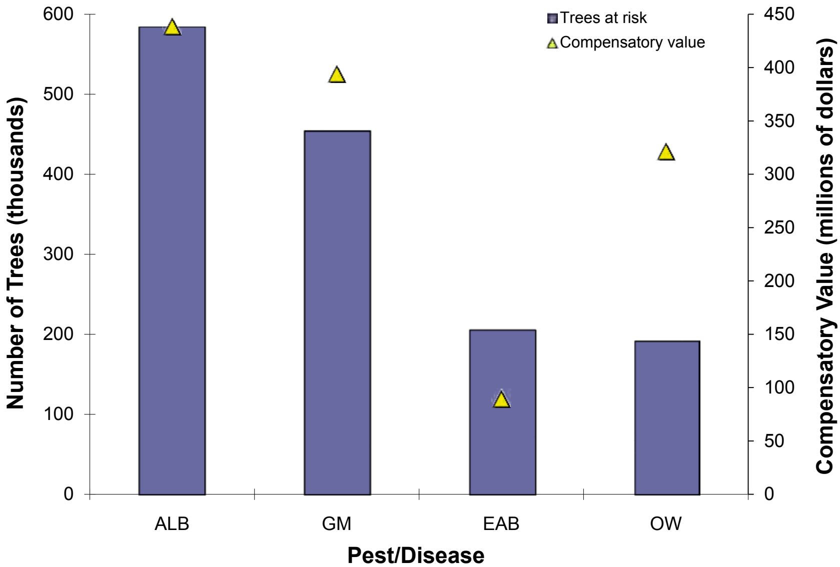

Figure 28.—Number of trees at risk and associated compensatory value for four most threatening insects or diseases, Philadelphia, 2012.

EAB is the pest of most concern and has been recently detected in Philadelphia as of June 2016 (Kannan 2016). Ash is a significant tree in Philadelphia (Table 13) and is found in three of the seven land use categories (Table 14). Citywide, ash ranks second in the number of trees with a d.b.h. between 1 and 3 inches and third in total number of trees and leaf biomass. Ash species also comprise 13 percent of the population in parkland (Fig. 21) and one-quarter of the total tree population in wooded areas.

Table 13.—Ash estimates, Philadelphia, 2012

Parameter	Units	Estimate	Total city	Rank
			percent	
Population	number	206,996	7.1	3
Density	trees/acre	2.3	n/a	3
Carbon stored	tons	35,742	5.1	7
Carbon sequestered	tons/year	1,025	3.8	11
Net carbon sequestered	tons/year	935	4.0	10
Leaf area	acres	4,818	5.2	7
Leaf biomass	tons	1,936	6.3	3
Trees, d.b.h. 1-3 in.	number	111,777	54.1[a]	2
Trees, d.b.h. >18 in.	number	10,557	5.1[a]	12

[a] Percentage of all ash trees

Table 14.—Ash trees by land use, Philadelphia, 2012

Land use[a]	Trees	Density	All trees in land use	Ash trees in land use with d.b.h. > 18 in	Ash trees in land use with d.b.h. 1-3 in
	number	*trees/ac*	*percent*	*percent*	*percent*
Wooded	190,158	13.7	25.0	2.9	58.8
Institutional	10,130	4.7	0.9	50.0	0.0
Comm/Ind/Util	6,708	0.4	0.4	0.0	0.0
Philadelphia	206,996	2.3	7.1	n/a	n/a

[a] No ash trees were found on other, residential, water, or transportation land uses

The expected loss of ash species to EAB will have a significant impact on the forest of Philadelphia. Tree removal costs will be substantial for government agencies and other land owners. It will be necessary to identify other species that can fill the important role that ash has played in Philadelphia's urban forest, including not only the ecosystem services discussed in this report, but also wildlife habitat.

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

Species Score

Data from this report can be used to help inform species selections for Philadelphia's urban forest. The species scores presented in Table 15 illustrate one way of evaluating existing tree species relative to producing the greatest ecosystem services with minimal pest risks, based on existing composition in Philadelphia. Based on the procedures detailed in the methods, the species with the lowest combined score (low pest risk and high ecosystem service value) are black cherry, northern hackberry, tulip tree, and zelkova. This list does not consider whether the species are native, and there may be other species missing from this list that are suitable for Philadelphia. Species selections should be made by local experts based on knowledge of tree performance, pest risk, and site conditions.

Emerald ash borer infested trees. Photo by Steven Katovich, US Forest Service, from bugwood.org, 1457016.

Table 15.—Species scores based on the current species composition, Philadelphia, 2012. Low combined scores indicate low pest risk and high ecosystem service value.

Common name[a]	Pest score[b]	Service score[c]	Combined score[d]
Black cherry	0	1	1
Northern hackberry	0	1	1
Tulip tree	0	1	1
Zelkova spp.	0	1	1
Common persimmon	0	2	2
Red mulberry	0	2	2
Black locust	0	3	3
Black tupelo	0	3	3
Red maple	3	1	4
Sassafras	2	2	4
Silver maple	3	1	4
Sycamore spp	3	1	4
Yew spp	0	4	4
Black birch	4	1	5
Boxelder	3	2	5
American holly	0	7	7
Atlantic white cedar	0	7	7
Northern catalpa	0	7	7
Honeylocust	0	8	8
Northern white cedar	0	9	9

[a] Invasive species, species not analyzed by i-Tree Species and tree species with pests within Philadelphia were not included.

[b] Pest score (0-4) is a numerical scoring system based on the 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 county, 3 points if within 250 miles, 2 points if within 750 miles, and 1 point if greater than 750 miles away). See Table 19 in appendix 4.

[c] Service score (1-10) is a numerical scoring system based on a relative ranking of species' ability to provide ecosystem services. Lower scores indicate that ecosystem services are better provided.

[d] Combined score is the sum of the pest score and service score. Lower scores indicate more highly recommended species based on their ability to provide ecosystem services and their status as a host to pests.

CONCLUSION

The Philadelphia urban forest contributes significantly to the environment, the economy, and residents' well-being. Throughout the city, an estimated 2.9 million trees, representing more than 69 species, provide a canopy cover of 20 percent. That canopy, particularly leaf surface area, 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 capture, and many others benefits (and costs).

Publicly managed urban forests play a substantial role in providing ecosystem services. Philadelphia's parklands make up 9.3 percent of the city's total land area. The estimated 1.1 million trees in parklands provide a canopy cover of 64 percent and constitute 37.7 percent of the total city tree population. Parkland trees are also responsible for 38.8 percent of carbon storage and 34.8 percent of air pollution removal performed by the city's urban forest.

There are a number of forces for change that will impact Philadelphia's forest structure, health, management costs, and environmental benefits provided to the city's 1.5 million residents. The forces discussed in this report include insects and disease infestation, invasive plants, and aging and loss of larger trees. Additional forces for change that should be considered in urban forest management plans and policies include the overabundance of deer (Rawinski 2014), climate change impacts, the expansion of native, opportunistic species, and future changes due to urban development and changes in the use of the forest. There are numerous forces that have and will alter urban forests. Management needs to determine what type of future forest is desired and then develop and implement management plans that consider these dominant forces for change to help guide the urban forest to sustainable and desirable future state. Managers can use these 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 Philadelphia can be found at: http://nrs.fs.fed.us/data/urban or http://www.nrs.fs.fed.us/philadelphia/

ACKNOWLEDGMENTS

We thank: Philadelphia Parks & Recreation (PPR), the Pennsylvania Horticultural Society (PHS), the University of Pennsylvania, and the Davey Institute for their support of this field study; Joan Blaustein and Thomas Witmer from PPR and Jason Lubar from the University of Pennsylvania's Morris Arboretum for assistance with field crew training; Elizabeth Anderson and Heidi Hiteshue from PHS for assistance with outreach materials; Al Zelaya from Davey for support of i-Tree tools; Phillip Rodbell from the U.S. Forest Service for helping to launch the Forest Service Philadelphia Field Station; interns David Bruhn, Julian Golec, Kathleen Kranich, and Rebecca Lotka for field data collection; and Dana Dentice, Glen Abrams, and Mindy Maslin from PHS and Tim Witmer and Curtis Helm from PPR for report review.

APPENDIX 1

Land Use Category Descriptions

The land use categories used in this report were adapted from definitions used by the Delaware Valley Regional Planning Commission (DVRPC) (Delaware Valley Regional Planning Commission 2010), and are copied here in whole or in part for informational purposes. Some land use categories from DVRPC were combined (e.g., several types of residential were grouped together, along with their associated parking areas).

Littleleaf linden street trees in the University City neighborhood of Philadelphia, PA. Photo by Lara A. Roman, U.S. Forest Service.

Residential: Includes single family detached, multi-family, row home and mobile home areas as well as any associated parking of 10 spaces or more. Single-family detached units are identified including their lots where lot boundaries are evident. In cases where no lot boundaries are evident, their boundaries are estimated. Multi-family dwellings are any multiple residential units, with the exception of row homes and mobile homes. Examples of multi-family units include duplexes, apartments, condominiums, quads, etc. Row home areas are defined as a series of connected single-family houses forming a continuous group usually located in an urban area. Condominiums are identified as multi-family, not row homes. Mobile home areas are those containing a large group of transportable single-family dwellings.

Commercial/Industrial/Utility: Includes commercial, heavy industrial, light industrial, and utility areas as well as any associated parking of 10 spaces or more. Commercial areas contain structures predominantly used for the sale of products and services. Examples include central business districts, malls, strip malls, shopping centers, hotels and motels, and warehousing and distribution centers. All landscaped areas associated with a commercial area are also included in this category. Heavy industrial uses include oil refineries, chemical plants, steel and metal fabrication, shipbuilding, grain elevators, port terminals, manufacturing, and assembly facilities (i.e. automobile production, pharmaceutical). Light industrial uses include industrial parks and small-scale manufacturing and assembly. Light industrial sites are often "cleaner" looking than heavy industrial sites, with uses that create less smoke, dust, and noise. Utility includes power generation and substations, major transmission lines and towers, water filtration and storage tanks, wastewater treatment, landfills, and recycling centers. Reservoirs are identified as water, not utility. Transmission lines take priority only over certain coexisting land uses (agriculture, vacant, and wooded) if present.

Institutional: Includes community services, recreation, and military areas as well as any associated parking of 10 spaces or more. Community services include structures that provide noncommercial services. Examples include educational facilities (schools, but not the recreational fields associated with them), places of worship, cemeteries, hospitals and medical centers, museums, government centers (other than military), correctional facilities, and social clubs. All landscaped areas associated with a community services area are also included in this category. Recreation areas are those developed for recreational activities. This includes recreational parks and playgrounds (including those associated with schools), golf courses, picnic areas, camps, fairgrounds, recreational boat launches, swimming pools, theatres, stadiums and arenas, zoos, amusement parks, and nonmilitary firing ranges. Military includes all military installations, such as bases and camps, armories, air bases, naval bases and air stations, and U.S. Coast Guard bases.

Wooded: Wooded (forested) areas are areas of continuous canopy or solid tree cover, woodlands, and natural lands. Hedgerows (windrows) and wooded areas associated with residences are not interpreted as wooded. If large transmission lines (utility) clearly continue through a wooded area, the utility land use takes priority.

Transportation: Includes transportation areas and any associated parking of 10 spaces or more. Transportation includes areas devoted to rail, air, marine, and highway transportation. Examples include limited-access highways (highways that are at least double lane divided) and their ramps, railroad facilities (stations, roundhouses, and switching yards), airports, and truck and bus terminals. Two lane roads and residential streets are not identified as transportation. The transportation category takes priority over any other coexisting land use that may be present (i.e., highways over rivers or utility rights-of-way).

Other: Includes vacant and agriculture areas. Vacant lands are areas that are not clearly wooded, not agricultural, not developed, not landscaped, or are cleared or unused but not tied to other uses. If large transmission lines (utility) clearly continue through a vacant area, the utility land use takes priority. Agriculture includes land devoted to crops, pastures, orchards, tree farms, or other agricultural uses. Also included are nurseries, greenhouses, sod farms, horse farms, and cattle, pig, poultry, and dairy farms. The farmstead and associated buildings are included as well. If large transmission lines (utility) clearly continue through an agricultural area, the utility land use takes priority.

Water: Water areas are rivers, canals, streams, lakes, reservoirs, and ponds that have two definable boundaries. Single line hydrology is not defined. When coexisting with another land use, other than transportation, the water land use takes priority.

Planted trees along Schuylkill River Trail in Philadelphia. Photo by Sarah Low, U.S. Forest Service.

APPENDIX 2

Invasive Plant Species Assessed in Philadelphia's Parkland Areas

Table 16.—Invasive species[a] assessed in urban forest, Philadelphia parkland, 2012. Species are nonnative unless otherwise indicated.

Functional Type	Common Name	Genus	Species
Trees	Norway maple	*Acer*	*platanoides*
	tree-of-heaven	*Ailanthus*	*altissima*
	Japanese angelica tree	*Aralia*	*elata*
	white mulberry	*Morus*	*alba*
	princesstree	*Paulownia*	*tomentosa*
	corktree species	*Phellodendron*	*species*
	callery pear	*Pyrus*	*calleryana*
	Siberian elm	*Ulmus*	*pumila*
Woody shrubs	barberry species**	*Berberis*	*species*
	Elaeagnus species**	*Elaeagnus*	*species*
	burning bush	*Euonymus*	*alatus*
	privet species	*Ligustrum*	*species*
	honeysuckle species**	*Lonicera*	*species*
	buckthorn species**	*Rhamnus*	*species*
	jet bead	*Rhodotypos*	*scandens*
	multiflora rose	*Rosa*	*multiflora*
	wine raspberry	*Rubus*	*phoenicolasius*
	Viburnum species**	*Viburnum*	*species*
Grasses	Japanese stiltgrass	*Microstegium*	*vimineum*
	Chinese silvergrass	*Miscanthus*	*sinensis*
	reed canarygrass*	*Phalaris*	*arundinacea*
	common reed**	*Phragmites*	*australis*
Herbaceous	garlic mustard	*Alliaria*	*petiolata*
	Canada thistle	*Cirsium*	*arvense*
	Japanese hop	*Humulus*	*japonicus*
	purple loosestrife	*Lythrum*	*salicaria*
	Allegheny-spurge*	*Pachysandra*	*procumbens*
	Japanese knotweed	*Polygonum*	*cuspidatum*
	common periwinkle	*Vinca*	*minor*
Vines	chocolate vine	*Akebia*	*quinata*
	porcelain berry	*Ampelopsis*	*brevipedunculata*
	oriental bittersweet	*Celastrus*	*orbiculatus*
	winter creeper	*Euonymus*	*fortunei*
	English ivy	*Hedera*	*helix*
	Japanese honeysuckle	*Lonicera*	*japonica*
	Virginia creeper*	*Parthenocissus*	*quinquefolia*
	mile-a-minute weed	*Persicaria*	*perfoliata*
	kudzu	*Pueraria*	*montana*
	roundleaf greenbrier*	*Smilax*	*rotundifolia*
	poison ivy*	*Toxicodendron*	*radicans*
	wild grape species**	*Vitis*	*species*
	Wisteria species**	*Wisteria*	*species*

[a] Invasive species list derived from Huebner et al. 2007 and Tom Witmer and Jason Lubar, personal communication, 2012
* native species
** both native and nonnative species

APPENDIX 3

Ecosystem Services by Neighborhood

Ecosystem services are presented by neighborhood for the City of Philadelphia and estimated using the LiDAR urban tree canopy assessment (O'Neil-Dunne 2011) (Table 17). Neighborhoods have been assigned a key identification number so they may be located on the neighborhood key (Branigan 2013) (Fig. 29). Detailed information on ecosystem services by block group can be found at: http://nrs.fs.fed.us/data/urban.

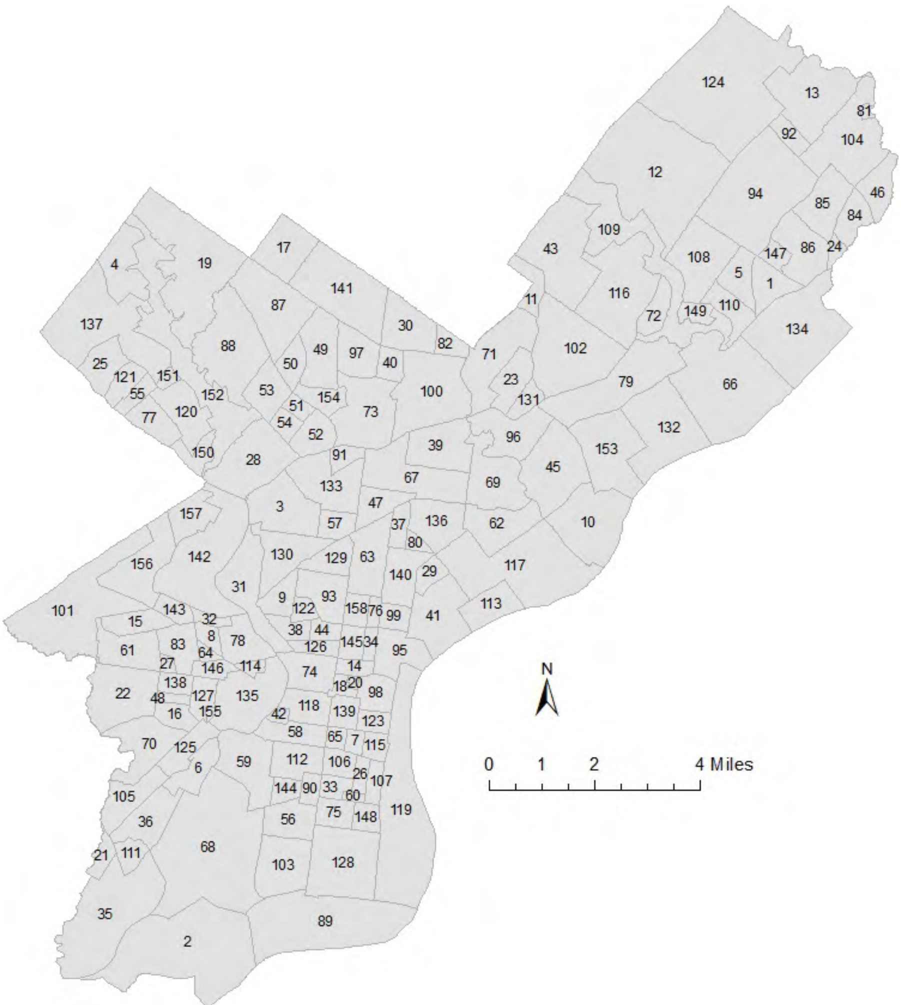

Figure 29.—Neighborhood key, Philadelphia, 2012.

Table 17.—Current tree cover, planting index values, and available space for planting by neighborhood, Philadelphia, 2012

Key ID	Neighborhood	Tree cover	Pollution removal		Avg.[a]	PPI[b]	TPI[c]	Plantable space[d]	Temp. reduction[e]
		percent	*tons/yr*	*$/yr*				*acres*	*°F*
1	Academy Gardens	15.9	1.79	54,500	40.3	70.5	10.2	149.98	0.3
2	Airport	4.2	2.65	100	17.5	34.9	0.0	688.73	0.1
3	Allegheny West	14.6	2.92	168,300	34.4	65.5	3.3	187.09	0.3
4	Andorra	54.4	9.76	143,400	25.5	45.5	5.5	136.89	1.0
5	Aston-Woodbridge	29.1	3.07	134,500	35.3	58.2	12.3	93.99	0.5
6	Bartram Village	20.3	2.02	62,800	30.0	55.0	4.9	97.24	0.3
7	Bella Vista	6.9	0.22	42,700	47.7	66.6	28.7	6.18	0.1
8	Belmont	11.7	0.42	44,800	43.8	69.6	17.9	25.71	0.2
9	Brewerytown	10.8	0.78	99,100	40.0	70.3	9.7	41.30	0.2
10	Bridesburg	7.5	1.46	34,000	37.5	72.1	2.9	214.67	0.1
11	Burholme	27.1	1.66	56,500	35.4	60.0	10.8	68.27	0.5
12	Bustleton	22.7	19.34	595,000	32.2	62.6	1.8	836.05	0.4
13	Byberry	23.4	7.43	17,900	31.7	61.8	1.6	513.79	0.4
14	Callowhill	2.5	0.11	6,400	46.5	66.2	26.9	6.28	<0.1
15	Carroll Park	10.7	0.90	125,500	39.2	72.0	6.4	55.52	0.2
16	Cedar Park	19.1	1.29	193,300	37.8	64.9	10.6	38.47	0.3
17	Cedarbrook	14.2	2.07	118,500	37.6	70.5	4.6	181.73	0.3
18	Center City East	4.2	0.13	12,300	59.1	53.4	64.7	3.18	0.1
19	Chestnut Hill	48.5	26.83	363,100	24.8	47.9	1.7	507.76	0.9
20	Chinatown[c]	2.6	0.03	3,100	140.8	66.5	215.2	1.07	0.1
21	Clearview	21.8	1.26	78,900	44.9	63.6	26.2	49.65	0.4
22	Cobbs Creek	12.9	3.56	393,700	36.0	69.2	2.8	131.70	0.2
23	Crescentville	5.1	0.48	7,700	36.9	68.1	5.7	85.74	0.1
24	Crestmont Farms	46.3	1.07	36,800	63.8	59.1	68.6	26.52	0.8
25	Dearnley Park	41.3	4.64	52,400	28.7	50.7	6.7	116.28	0.7
26	Dickinson Narrows	4.1	0.15	36,500	53.9	81.0	26.7	11.38	0.1
27	Dunlap	13.1	0.23	31,900	51.3	69.8	32.8	9.12	0.2
28	East Falls	32.8	8.10	312,700	29.5	55.1	3.8	242.97	0.6
29	East Kensington	6.0	0.28	28,300	48.6	75.2	22.0	28.86	0.1
30	East Oak Lane	28.3	3.91	209,000	31.7	58.5	5.0	134.44	0.5
31	East Park	42.1	6.72	4,500	22.5	43.2	1.9	201.52	0.6
32	East Parkside	10.5	0.29	35,700	46.0	70.2	21.9	21.03	0.2
33	East Passyunk	3.0	0.14	33,600	41.6	64.4	18.8	2.72	0.1
34	East Poplar	13.2	0.40	27,600	45.6	67.9	23.3	17.18	0.2
35	Eastwick	18.9	10.68	173,500	25.5	49.9	1.1	601.61	0.3
36	Elmwood	9.4	1.68	153,000	39.4	72.5	6.2	102.63	0.2
37	Fairhill	6.7	0.29	23,900	44.5	74.2	14.9	32.76	0.1
38	Fairmount	9.7	0.49	105,400	42.0	71.1	13.0	23.29	0.2
39	Feltonville	11.0	1.80	106,600	37.6	69.3	5.9	138.83	0.2
40	Fern Rock	14.3	0.70	46,400	37.9	61.7	14.1	31.16	0.3
41	Fishtown - Lower Kensington	5.8	0.98	108,300	37.5	71.8	3.3	97.36	0.1
42	Fitler Square	18.8	0.35	50,100	49.7	59.2	40.2	6.80	0.3

continued

Table 17.—continued

Key ID	Neighborhood	Tree cover	Pollution removal		Avg.[a]	PPI[b]	TPI[c]	Plantable space[d]	Temp. reduction[e]
		percent	*tons/yr*	*$/yr*				*acres*	*°F*
43	Fox Chase	20.3	7.67	313,100	33.5	64.7	2.3	403.42	0.4
44	Francisville	10.4	0.39	44,500	46.3	71.0	21.6	29.10	0.2
45	Frankford	9.5	2.28	165,300	36.3	69.5	3.2	163.88	0.2
46	Franklin Mills	14.7	1.45	16,200	36.7	60.0	13.4	41.33	0.2
47	Franklinville	7.4	0.62	44,500	37.3	66.1	8.4	41.33	0.1
48	Garden Court	21.6	0.51	80,200	50.3	66.0	34.6	11.95	0.4
49	Germantown, East	25.7	3.86	159,600	32.2	60.5	3.9	155.62	0.5
50	Germantown, Morton	16.2	0.96	72,900	37.1	64.4	9.9	49.59	0.3
51	Germantown, Penn Knox	25.4	0.76	50,400	39.2	55.8	22.6	21.69	0.4
52	Germantown, Southwest	24.8	2.17	181,200	34.7	61.1	8.4	71.10	0.4
53	Germantown, West Central	36.6	3.82	295,300	30.0	54.3	5.7	86.20	0.7
54	Germantown, Westside	22.4	0.92	96,700	38.0	61.7	14.2	33.67	0.4
55	Germany Hill	31.5	1.54	66,100	35.3	57.0	13.5	39.98	0.5
56	Girard Estates	7.5	0.99	118,600	35.9	65.1	6.7	41.78	0.1
57	Glenwood	5.9	0.36	35,200	44.6	70.1	19.1	31.28	0.1
58	Graduate Hospital	9.1	0.92	135,600	39.0	68.0	10.1	40.02	0.2
59	Grays Ferry	7.5	1.71	107,700	34.8	65.9	3.8	131.89	0.1
60	Greenwich	5.9	0.09	16,900	78.8	77.9	79.8	6.52	0.1
61	Haddington	8.7	1.33	186,800	38.9	73.2	4.6	87.37	0.2
62	Harrowgate	5.9	0.88	49,000	36.2	67.9	4.5	55.26	0.1
63	Hartranft	11.4	1.85	187,400	37.9	69.5	6.3	109.13	0.2
64	Haverford North	12.2	0.26	20,900	47.7	67.9	27.4	13.65	0.2
65	Hawthorne	6.5	0.20	29,900	53.0	67.8	38.2	7.70	0.1
66	Holmesburg	12.0	6.10	234,800	38.0	71.7	4.2	504.01	0.2
67	Hunting Park	9.0	2.03	88,600	34.1	64.0	4.3	171.19	0.2
68	Industrial	7.4	6.32	28,400	19.5	38.9	0.1	474.94	0.1
69	Juniata Park	12.8	2.40	111,000	35.7	66.9	4.5	117.01	0.2
70	Kingsessing	17.1	3.67	267,400	35.6	68.1	3.1	163.47	0.3
71	Lawndale	16.9	3.75	247,200	33.9	64.7	3.1	173.58	0.3
72	Lexington Park	12.5	1.06	43,100	41.9	71.1	12.8	82.11	0.2
73	Logan	17.3	3.94	247,000	32.6	61.6	3.6	179.30	0.3
74	Logan Square	12.4	1.64	166,200	35.7	62.3	9.0	54.74	0.2
75	Lower Moyamensing	2.8	0.22	51,400	41.1	67.0	15.2	6.27	0.1
76	Ludlow	7.9	0.18	14,000	55.2	75.9	34.4	22.98	0.1
77	Manayunk	18.1	1.87	150,700	35.0	63.2	6.8	64.37	0.3
78	Mantua	18.3	2.04	95,800	30.5	57.1	3.9	70.79	0.3
79	Mayfair	9.4	3.23	247,400	38.2	73.9	2.5	308.14	0.2
80	McGuire	4.1	0.09	10,000	62.5	78.9	46.1	10.98	0.1
81	Mechanicsville[c]	34.2	0.37	3,800	96.7	61.8	131.6	17.06	0.6
82	Melrose Park Gardens	18.0	0.76	58,000	44.8	67.0	22.6	47.18	0.3
83	Mill Creek	13.5	1.43	121,000	38.4	68.9	7.8	99.25	0.2
84	Millbrook	20.7	1.72	70,500	39.2	63.5	14.9	97.87	0.3
85	Modena	17.9	2.89	152,200	37.2	68.5	5.8	183.26	0.3

continued

Table 17.—continued

Key ID	Neighborhood	Tree cover	Pollution removal		Avg.[a]	PPI[b]	TPI[c]	Plantable space[d]	Temp. reduction[e]
		percent	*tons/yr*	*$/yr*				*acres*	*°F*
86	Morrell Park	23.7	4.23	151,100	35.8	63.2	8.5	194.26	0.4
87	Mount Airy, East	28.8	7.26	386,300	30.8	59.3	2.3	266.59	0.5
88	Mount Airy, West	47.1	16.01	493,600	25.5	49.0	2.0	301.42	0.9
89	Navy Yard	6.3	2.11	2,200	28.3	56.5	0.0	334.35	0.1
90	Newbold	2.4	0.10	24,600	43.3	64.4	22.2	1.51	<0.1
91	Nicetown	11.5	0.46	23,500	43.1	66.0	20.2	35.32	0.2
92	Normandy Village	27.1	1.49	41,600	38.1	61.9	14.3	60.46	0.5
93	North Central	10.1	1.29	121,700	40.6	73.8	7.3	107.72	0.2
94	Northeast Philadelphia Airport	15.1	9.23	1,000	8.6	17.1	0.0	822.17	0.3
95	Northern Liberties	5.8	0.73	51,500	40.3	70.7	9.9	68.68	0.1
96	Northwood	33.3	5.39	162,400	30.6	56.7	4.6	183.05	0.6
97	Ogontz	13.3	1.40	121,100	36.2	66.1	6.4	71.09	0.2
98	Old City	11.1	1.03	115,300	34.7	54.2	15.2	20.59	0.2
99	Old Kensington	6.6	0.31	25,900	44.2	72.6	15.8	31.20	0.1
100	Olney	15.7	4.57	357,500	35.0	67.2	2.9	216.55	0.3
101	Overbrook	31.1	18.82	569,100	24.1	46.9	1.4	485.67	0.6
102	Oxford Circle	9.2	3.22	275,700	39.4	76.5	2.3	333.73	0.2
103	Packer Park	17.0	3.41	62,400	34.1	63.2	5.0	279.11	0.3
104	Parkwood Manor	23.3	7.57	246,800	33.8	63.5	4.1	412.20	0.4
105	Paschall	14.7	2.34	166,300	37.0	66.8	7.1	89.15	0.3
106	Passyunk Square	4.4	0.28	53,900	43.4	69.4	17.5	12.68	0.1
107	Pennsport	8.1	0.39	60,500	41.3	66.6	16.0	10.04	0.1
108	Pennypack	17.2	4.48	117,200	34.5	62.5	6.5	217.66	0.3
109	Pennypack Park	81.0	34.96	128,000	16.2	31.4	1.0	194.87	1.4
110	Pennypack Woods	21.7	2.20	79,300	37.9	64.5	11.2	107.59	0.4
111	Penrose	10.5	0.71	51,800	48.7	73.6	23.9	64.81	0.2
112	Point Breeze	7.8	0.98	140,700	39.2	73.0	5.5	51.98	0.1
113	Port Richmond	16.2	0.86	2,900	35.9	67.8	4.1	78.03	0.2
114	Powelton	22.3	0.55	45,000	53.5	66.5	40.4	14.58	0.4
115	Queen Village	10.6	0.52	97,800	42.1	66.2	18.1	20.72	0.2
116	Rhawnhurst	10.5	4.45	232,300	37.3	71.8	2.7	384.78	0.2
117	Richmond	5.2	2.02	98,500	35.4	69.7	1.1	237.16	0.1
118	Rittenhouse	9.6	1.02	273,200	38.0	66.8	9.2	19.37	0.2
119	Riverfront	3.2	1.26	18,100	29.6	58.6	0.5	180.28	<0.1
120	Roxborough	17.7	2.71	214,000	35.3	66.1	4.5	150.96	0.3
121	Roxborough Park	33.1	2.29	51,400	31.5	53.2	9.7	56.25	0.6
122	Sharswood	13.0	0.45	44,300	46.2	70.1	22.4	29.40	0.2
123	Society Hill	21.9	1.11	181,100	36.2	53.2	19.2	14.34	0.4
124	Somerton	22.2	20.61	627,000	32.6	63.4	1.9	985.06	0.4
125	Southwest Schuylkill	9.9	0.99	82,100	38.2	69.9	6.5	55.71	0.2
126	Spring Garden	12.1	0.57	122,800	44.1	68.7	19.6	19.43	0.2
127	Spruce Hill	22.5	1.53	251,200	40.3	64.5	16.1	30.28	0.4
128	Stadium District	2.9	1.01	39,400	27.0	53.4	0.7	186.07	0.1

continued

Table 17.—continued

Key ID	Neighborhood	Tree cover	Pollution removal		Avg.[a]	PPI[b]	TPI[c]	Plantable space[d]	Temp. reduction[e]
		percent	*tons/yr*	*$/yr*				*acres*	*°F*
129	Stanton	10.4	0.84	104,400	39.9	70.9	8.9	48.17	0.2
130	Strawberry Mansion	10.7	1.76	175,600	37.1	69.7	4.5	123.72	0.2
131	Summerdale	10.8	0.46	31,400	44.5	74.4	14.7	31.21	0.2
132	Tacony	8.1	2.09	132,200	37.4	73.2	1.6	255.31	0.1
133	Tioga	10.1	1.97	167,200	35.1	66.3	3.8	134.64	0.2
134	Torresdale	18.0	6.68	211,900	35.9	66.8	5.0	450.16	0.3
135	University City	12.2	3.18	116,300	32.2	59.7	4.7	124.99	0.2
136	Upper Kensington	6.8	0.91	103,000	40.0	73.8	6.2	65.44	0.1
137	Upper Roxborough	42.3	20.77	449,300	28.2	54.1	2.4	554.23	0.7
138	Walnut Hill	8.6	0.43	62,800	43.0	70.9	15.1	23.55	0.1
139	Washington Square West	9.5	0.65	171,400	38.0	59.3	16.6	8.95	0.2
140	Kensington, West	6.4	0.78	75,800	39.1	73.5	4.7	81.34	0.1
141	West Oak Lane	12.1	3.71	319,400	36.5	71.1	1.9	298.34	0.2
142	West Park	52.5	19.37	43,600	22.1	43.3	1.0	388.96	0.9
143	West Parkside	5.6	0.27	4,100	39.3	71.3	7.3	39.39	0.1
144	West Passyunk	5.2	0.25	55,600	43.2	64.6	21.8	4.56	0.1
145	West Poplar	4.6	0.24	23,900	46.0	73.7	18.4	41.04	0.1
146	West Powelton	12.6	0.64	55,900	45.5	69.5	21.6	40.68	0.2
147	West Torresdale	35.0	1.51	34,200	51.7	60.7	42.6	68.01	0.6
148	Whitman	5.3	0.29	56,400	48.4	75.9	21.0	15.80	0.1
149	Winchester Park	19.0	0.94	30,700	40.5	64.8	16.3	57.78	0.4
150	Wissahickon	18.4	1.00	88,200	36.0	61.7	10.3	44.44	0.3
151	Wissahickon Hills	28.0	0.65	30,600	45.8	59.8	31.8	22.32	0.5
152	Wissahickon Park	83.7	40.76	46,400	1.6	3.0	0.2	183.59	1.5
153	Wissinoming	10.6	2.44	154,200	37.2	72.2	2.3	227.38	0.2
154	Wister	34.8	2.13	93,500	33.7	55.3	12.1	47.08	0.6
155	Woodland Terrace	25.7	0.24	20,900	78.9	57.9	100.0	5.20	0.5
156	Wynnefield	19.4	4.04	267,200	34.2	64.8	3.5	197.26	0.3
157	Wynnefield Heights	19.2	1.94	201,700	36.6	63.3	9.8	98.27	0.3
158	Yorktown	9.8	0.49	41,200	48.8	72.9	24.7	36.01	0.2

[a] Average PPI and TPI value
[b] PPI = priority planting index (see appendix 6)
[c] TPI = temperature planting index (see appendix 8)
[d] Plantable space is the area of grass/shrub and bare soil as estimated using the LiDAR urban tree canopy assessment (O'Neil-Dunne 2011)
[e] Temperature reduction was based on daytime hours (6 a.m. to 5 p.m.) for average temperature summer day (8/4/08)

APPENDIX 4

Potential Insect and Disease Impacts

Thirty-one insects and 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 Philadelphia will vary by pest. The number of trees at risk (Table 18) reflects only the known host species that are likely to experience mortality. The species host lists used for these insects/diseases can be found at http://nrs.fs.fed.us/data/urban.

Table 18.—Potential risk to trees by insect or disease, Philadelphia, 2012

Code	Scientific name	Common name	Trees at risk	Compensatory value
			number	*$ millions*
AL	*Phyllocnistis populiella*	Aspen leafminer	19,000	8
ALB	*Anoplophora glabripennis*	Asian longhorned beetle	584,000	439
BBD	*Cryptococcus fagisuga*	Beech Bark disease	69,000	114
BC	*Sirococcus clavigignenti-juglandacearum*	Butternut canker	0	0
CB	*Cryphonectria parasitica*	Chestnut blight	0	0
DA	*Discula destructive*	Dogwood anthracnose	29,000	4
DED	*Ophiostoma novo-ulmi*	Dutch elm disease	58,000	15
DFB	*Dendroctonus pseudotsugae*	Douglas-fir beetle	0	0
EAB	*Agrilus planipennis*	Emerald ash borer	207,000	90
FE	*Scotylus ventralis*	Fir engraver	0	0
FR	*Cronartium fusiforme*	Fusiform rust	0	0
GSOB	*Agrilus auroguttatus*	Goldspotted oak borer	0	0
GM	*Lymantria dispar*	Gypsy moth	455,000	394
HWA	*Adelges tsugae*	Hemlock woolly adelgid	22,000	11
JPB	*Dendroctonus jeffreyi*	Jeffrey pine beetle	0	0
LAT	*Choristoneura conflictana*	Large aspen tortrix	50,000	30
LWD	*Raffaelea lauricola*	Laurel wilt	265,000	8
MPB	*Dendroctonus ponderosae*	Mountain pine beetle	0	0
NSE	*Ips perturbatus*	Northern spruce engraver	7,000	8
OW	*Ceratocystis fagacearum*	Oak wilt	193,000	321
POCRD	*Phytophthora lateralis*	Port-Orford-Cedar root disease	0	0
PSB	*Tomicus piniperda*	Pine shoot beetle	29,000	21
SB	*Dendroctonus rufipennis*	Spruce beetle	7,000	8
SBW	*Choristoneura fumiferana*	Spruce budworm	0	0
SOD	*Phytophthora ramorum*	Sudden oak death	123,000	198
SPB	*Dendroctonus frontalis*	Southern pine beetle	58,000	40
SW	*Sirex noctilio*	Sirex woodwasp	29,000	21
TCD	*Pityophthorus juglandis & Geosmithia spp.*	Thousand canker disease	58,000	58
WPB	*Dendroctonus brevicomis*	Western pine beetle	0	0
WPBR	*Cronartium ribicola*	White pine blister rust	14,000	11
WSB	Choristoneura occidentalis	Western spruce budworm	7,000	8

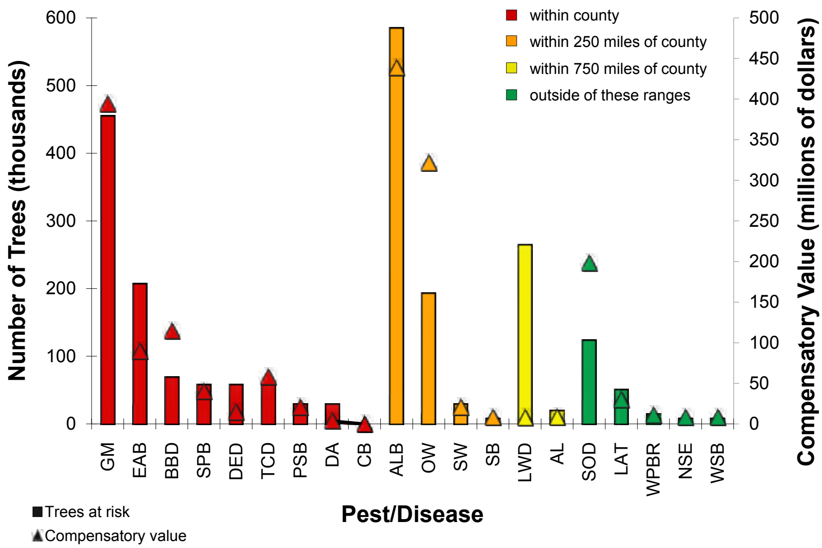

Figure 30.—Number of trees at risk and associated compensatory value of insect/disease effects, Philadelphia, 2012. This figure does not include the pests and diseases that were not a threat to any of the species sampled in the city. For a complete list of the pests and diseases assessed, see Table 18.

Pest range maps from the Forest Health Technology Enterprise Team (FHTET) (U.S. Forest Service 2013, 2014; Worrall 2007) were used to determine the proximity of each pest to the county. For Philadelphia, proximity was classified for insects/diseases within Philadelphia County, within 250 miles, between 250 and 750 miles, or greater than 750 miles. FHTET did not have pest range maps for Dutch elm disease and chestnut blight. The range of these pests was based on known occurrence and the host range, respectively (U.S. Forest Service 2013, 2014; Worrall 2007).

In Figure 30, the bars representing each pest are color coded according to Philadelphia County's proximity to the pest occurrence in the United States (U.S. Forest Service 2013, 2014; Worrall 2007).

Based on the host tree species for each pest and the current range of the pest, it is possible to determine the potential risk to insects and diseases for each tree species sampled in Philadelphia. In Table 19, species risk is designated as one of the following:

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

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

Table 19.—Potential insect and disease risk for tree species, Philadelphia, 2012

			Pests[c]																														
Spp. risk[a]	Pest score[b]	Common name	GM	EAB	BBD	SPB	DED	TCD	PSB	DA	HWA	BC	CB	ALB	OW	SW	SB	FR	SBW	LWD	AL	SOD	LAT	WPBR	NSE	WSB	DFB	FE	GSOB	JPB	MPB	POCRD	WPB
	12	eastern white pine																															
	11	Austrian pine																															
	10	black willow																															
	9	white spruce																															
	8	eastern hemlock																															
	8	gray birch																															
	8	northern red oak																															
	8	pin oak																															
	8	river birch																															
	7	black oak																															
	7	blackjack oak																															
	7	chestnut oak																															
	7	Chinese elm																															
	7	English elm																															
	7	scarlet oak																															
	7	**Siberian elm**[d]																															
	7	slippery elm																															
	7	white oak																															
	5	bigtooth aspen																															
	4	ash species																															
	4	American basswood																															
	4	American beech																															
	4	apple spp																															
	4	beech spp																															
	4	black walnut																															
	4	**callery pear**																															
1	4	European beech																															
	4	flowering dogwood																															

continued

Table 19.—continued

			Pests[c]																														
Spp. risk[a]	Pest score[b]	Common name	GM	EAB	BBD	SPB	DED	TCD	PSB	DA	HWA	BC	CB	ALB	OW	SW	SB	FR	SBW	LWD	AL	SOD	LAT	WPBR	NSE	WSB	DFB	FE	GSOB	JPB	MPB	POCRD	WPB
red	4	hawthorn spp	red																														
red	4	red osier dogwood								red																							
red	4	staghorn sumac	red																														
red	4	witch hazel	red																														
orange	4	black birch												orange									green										
orange	3	boxelder												orange																			
orange	3	horsechestnut												orange																			
orange	3	Japanese maple												orange																			
orange	3	**Norway maple**												orange																			
orange	3	red maple												orange																			
orange	3	silver maple												orange																			
orange	3	**sycamore maple**												orange																			
orange	3	sycamore spp												orange																			
yellow	2	sassafras																		yellow													
yellow	2	spicebush																		yellow													

[a] Species risk

Red indicates that the tree species is at risk to at least one pest within Philadelphia County

Orange indicates that the tree species has no risk to pests within Philadelphia County, but has a risk to at least one pest within 250 miles of the county

Yellow indicates that the tree species has no risk to pests within 250 miles of Philadelphia County, but has a risk to at least one pest that is 250 to 750 miles from the county

Green indicates that the tree species has no risk to pests within 750 miles of Philadelphia County, but has a risk to at least one pest that is greater than 750 miles from the county

[b] Pest score: 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 Philadelphia County

Orange indicates pest is within 250 miles of Philadelphia County

Yellow indicates pest is within 750 miles of Philadelphia County

Green indicates pest is outside of these ranges

[d] Species in **bold** text indicate that species is on the state or park invasive species list

APPENDIX 5

Species Sampled in the Philadelphia Urban Forest

Table 20.—Species sampled in the urban forest, Philadelphia, 2012

Genus	Species[a]	Common name	Trees	Population	Leaf area	IV[b]	Stem d.b.h. median	Stem d.b.h. avg.	Basal area[c]	Compensatory value	Pest score[d]
			number	*percent*	*percent*		*inches*	*inches*	*ft²*	*$ millions*	
Acer	*negundo*	boxelder	176,400	6.0	5.0	11.0	6.0	8.3	112,107	56.6	3
Acer	*palmatum*	Japanese maple	21,610	0.7	0.6	1.3	3.5	5.2	4,910	7.9	3
Acer	*platanoides*	Norway maple*	73,580	2.5	5.4	7.9	4.7	8.4	77,076	76.3	3
Acer	*pseudoplatanus*	Sycamore maple*	29,570	1.0	1.9	2.9	7.4	13.0	48,630	44.0	3
Acer	*rubrum*	red maple	101,220	3.5	5.6	9.1	7.7	10.6	100,503	86.1	3
Acer	*saccharinum*	silver maple	5,590	0.2	0.0	0.2	20.5	20.5	13,453	0.0	3
Aesculus	*hippocastanum*	horsechestnut	17,860	0.6	1.8	2.4	6.5	14.9	44,706	48.5	3
Ailanthus	*altissima*	tree-of-heaven*	183,180	6.3	4.2	10.5	4.8	7.6	97,393	73.2	0
Aralia	*elata*	Japanese angelica tree*	5,070	0.2	0.0	0.2	2.5	2.5	249	0.2	0
Berberis	*species*	barberry spp*	5,070	0.2	0.0	0.2	2.5	2.5	249	0.6	0
Betula	*lenta*	black birch	5,590	0.2	0.0	0.2	4.5	4.5	763	2.3	4
Betula	*nigra*	river birch	7,200	0.2	1.0	1.2	15.5	15.5	10,056	13.8	8
Betula	*populifolia*	gray birch	12,800	0.4	0.3	0.7	9.1	6.0	4,050	4.3	8
Buddleja	*species*	butterflybush spp	14,400	0.5	0.1	0.6	3.0	3.5	1,336	3.4	0
Buxus	*species*	boxwood spp	16,780	0.6	0.1	0.7	3.7	3.8	1,739	4.2	0
Catalpa	*speciosa*	northern catalpa	19,010	0.7	0.3	1.0	13.4	15.4	28,576	16.5	0
Celtis	*occidentalis*	northern hackberry	7,200	0.2	1.8	2.0	29.0	33.5	45,409	46.5	0
Chamaecyparis	*thyoides*	Atlantic white cedar	21,610	0.7	1.4	2.1	9.5	9.8	14,180	20.8	0
Cornus	*florida*	flowering dogwood	7,200	0.2	0.0	0.2	2.5	2.5	354	0.7	4
Cornus	*sericea*	red osier dogwood	21,610	0.7	0.2	0.9	3.3	2.8	1,415	3.1	4
Crataegus	*species*	hawthorn spp	5,590	0.2	0.0	0.2	1.5	1.5	122	0.1	4
Diospyros	*virginiana*	common persimmon	5,070	0.2	0.0	0.2	2.5	2.5	249	0.7	0

continued

Table 20.—continued

Genus	Species[a]	Common name	Trees	Population	Leaf area	IV[b]	Stem d.b.h. median	Stem d.b.h. avg.	Basal area[c]	Compensatory value	Pest score[d]
Fagus	*grandifolia*	American beech	55,930	1.9	3.2	5.1	5.0	10.1	55,396	31.2	4
Fagus	*species*	beech spp	5,590	0.2	0.3	0.5	5.5	5.5	1,098	0.7	4
Fagus	*sylvatica*	European beech	7,200	0.2	4.7	4.9	29.0	38.5	59,746	82.5	4
Fraxinus	*species*	ash spp	207,000	7.1	5.2	12.3	2.9	5.8	108,172	89.6	3
Gleditsia	*triacanthos*	honeylocust	68,160	2.3	0.9	3.2	4.7	7.4	43,279	39.0	0
Hamamelis	*virginiana*	witch hazel	16,780	0.6	0.2	0.8	4.5	4.5	2,349	1.8	4
Hardwood	*species*	hardwood	45,590	1.6	0.0	1.6	4.8	3.7	5,288	0.4	n/a
Hibiscus	*syriacus*	rose-of-sharon	7,200	0.2	0.0	0.2	4.5	4.5	982	2.8	0
Ilex	*opaca*	American holly	16,780	0.6	0.1	0.7	1.5	1.6	427	0.4	0
Juglans	*nigra*	black walnut	57,540	2.0	6.3	8.3	12.1	15.0	98,850	58.0	4
Lindera	*benzoin*	spicebush	253,360	8.7	1.5	10.2	2.0	2.1	9,954	6.2	2
Liriodendron	*tulipifera*	tulip tree or yellow-poplar	27,960	1.0	5.2	6.2	9.5	13.1	40,265	17.5	0
Lonicera	*species*	honeysuckle spp*	61,520	2.1	0.3	2.4	1.8	2.0	2,380	1.9	0
Malus	*species*	apple spp	67,120	2.3	0.5	2.8	3.2	3.1	5,154	3.5	4
Morus	*alba*	white mulberry*	92,410	3.2	2.5	5.7	5.8	8.9	72,986	87.6	0
Morus	*rubra*	red mulberry	5,590	0.2	0.0	0.2	1.5	1.5	122	0.1	0
Nyssa	*sylvatica*	black tupelo	50,340	1.7	0.7	2.4	7.3	7.8	22,787	10.9	0
Paulownia	*species*	princesstree spp*	22,370	0.8	1.3	2.1	8.0	16.0	59,729	49.6	0
Phellodendron	*species*	corktree spp*	33,560	1.1	0.5	1.6	4.0	4.0	4,240	3.1	0
Picea	*glauca*	white spruce	7,200	0.2	0.5	0.7	11.5	11.5	5,656	8.1	9
Pinus	*nigra*	Austrian pine	15,200	0.5	0.3	0.8	13.5	13.5	16,299	9.5	11
Pinus	*strobus*	eastern white pine	13,910	0.5	0.4	0.9	7.0	11.3	12,498	11.1	12
Platanus	*species*	sycamore spp	42,990	1.5	8.7	10.2	15.5	17.7	103,682	72.8	3
Populus	*grandidentata*	bigtooth aspen	5,590	0.2	0.1	0.3	9.5	9.5	3,051	1.1	5
Prunus	*serotina*	black cherry	241,290	8.3	3.6	11.9	4.4	5.9	75,712	40.2	0
Prunus	*species*	plum spp	25,330	0.9	0.5	1.4	2.8	2.9	1,740	1.1	0

continued

Table 20.—continued

Genus	Species[a]	Common name	Trees	Population	Leaf area	IV[b]	Stem d.b.h. median	Stem d.b.h. avg.	Basal area[c]	Compensatory value	Pest score[d]
Pyrus	*calleryana*	callery pear*	5,070	0.2	0.2	0.4	11.5	11.5	3,978	6.0	4
Quercus	*alba*	white oak	20,000	0.7	3.7	4.4	29.0	24.1	90,022	98.5	7
Quercus	*coccinea*	scarlet oak	27,960	1.0	1.0	2.0	15.5	11.7	33,158	18.7	7
Quercus	*marilandica*	blackjack oak	11,190	0.4	0.1	0.5	4.0	4.5	1,586	0.7	7
Quercus	*palustris*	pin oak	16,780	0.6	1.2	1.8	25.5	23.2	57,014	19.1	8
Quercus	*prinus*	chestnut oak	5,070	0.2	0.0	0.2	2.5	2.5	249	0.4	7
Quercus	*rubra*	northern red oak	106,340	3.6	7.6	11.2	8.2	12.2	149,099	179.1	8
Quercus	*velutina*	black oak	5,590	0.2	0.6	0.8	17.5	17.5	9,884	5.1	7
Rhus	*hirta*	staghorn sumac	87,920	3.0	0.3	3.3	1.6	1.7	2,447	2.0	4
Robinia	*pseudoacacia*	black locust	11,190	0.4	0.0	0.4	0.0	1.2	153	0.4	0
Salix	*nigra*	black willow	19,010	0.7	0.5	1.2	10.6	13.8	31,371	8.3	10
Sassafras	*albidum*	sassafras	11,190	0.4	0.3	0.7	7.0	11.5	10,311	1.5	2
Taxus	*species*	yew spp	110,960	3.8	0.8	4.6	5.7	6.5	34,672	64.5	0
Thuja	*occidentalis*	northern white-cedar	142,060	4.9	1.9	6.8	4.0	5.5	40,424	71.0	0
Tilia	*americana*	American basswood	21,610	0.7	1.6	2.3	5.7	10.2	18,526	28.6	4
Tsuga	*canadensis*	eastern hemlock	21,610	0.7	0.4	1.1	3.5	5.8	7,424	11.4	8
Ulmus	*parvifolia*	Chinese elm	13,420	0.5	0.3	0.8	3.0	3.0	915	3.2	7
Ulmus	*procera*	English elm	22,370	0.8	0.1	0.9	2.0	3.1	2,013	4.6	7
Ulmus	*pumila*	Siberian elm*	7,200	0.2	0.9	1.1	16.5	16.5	11,352	8.3	7
Ulmus	*rubra*	slippery elm	27,960	1.0	0.4	1.4	3.8	4.7	4,698	1.7	7
Zelkova	*species*	Zelkova spp	7,200	0.2	0.3	0.5	6.5	6.5	1,925	4.3	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 county, 3 points if within 250 miles, 2 points if within 750 miles, and 1 point if greater than 750 miles away). See Table 19 in appendix 4.
* Invasive species

APPENDIX 6

Tree Species Distribution

This appendix illustrates various species distributions in Philadelphia's urban forest. 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 designations of "other hardwood" include the sampled hardwood trees that could not be identified as a more specific species or genera classification.

The species distributions for each land use are illustrated for the 20 most common species or all species if there are less than 20 species in the land use category (Figs. 31-38).

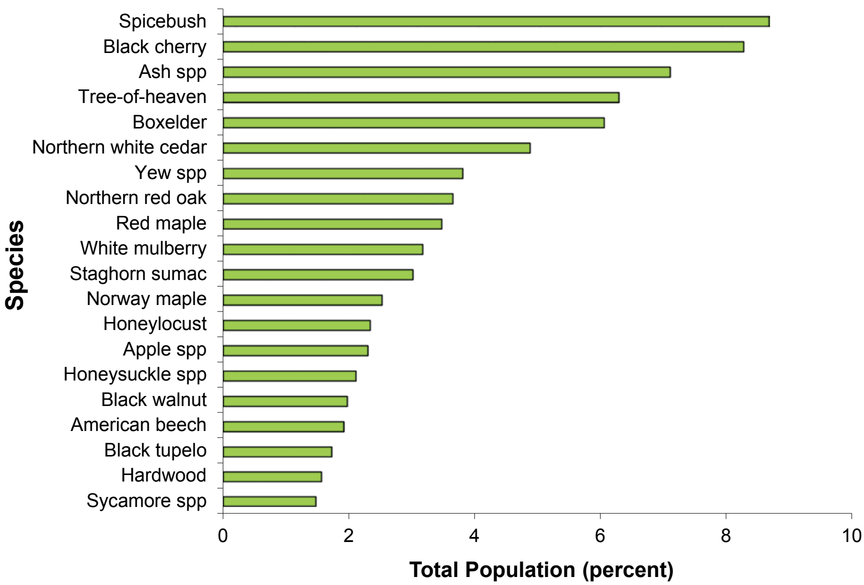

Figure 31.—The 20 most common tree species as a percent of the total urban tree population, Philadelphia, 2012.

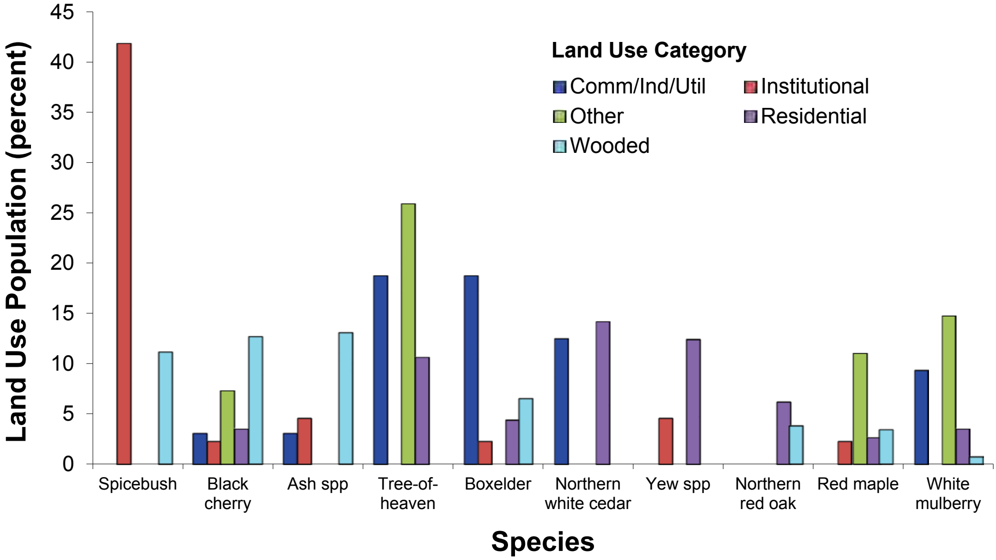

Figure 32.—The percent land-use population occupied by the 10 most common tree species, Philadelphia, 2012. For example, spicebush comprises 42 percent of the Institutional tree population.

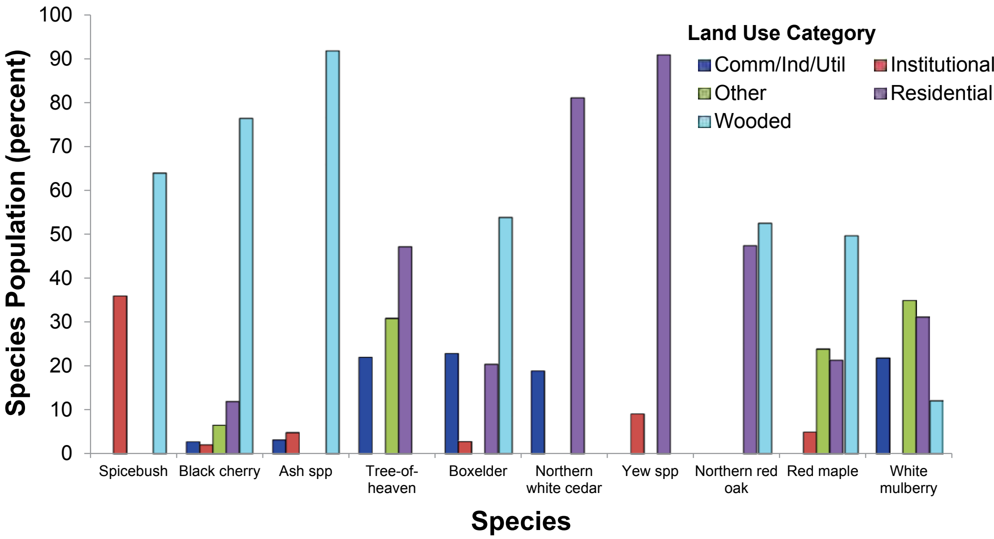

Figure 33.—The percentage of species population in each land use category, Philadelphia, 2012. For example, 64 percent of spicebush is found within Wooded land use.

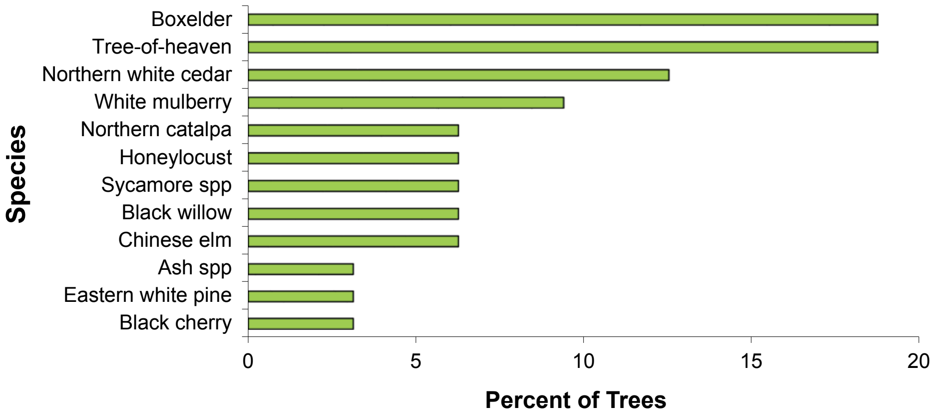

Figure 34.—Percentage of trees in Commercial/Industrial/Utility category of land use, Philadelphia, 2012.

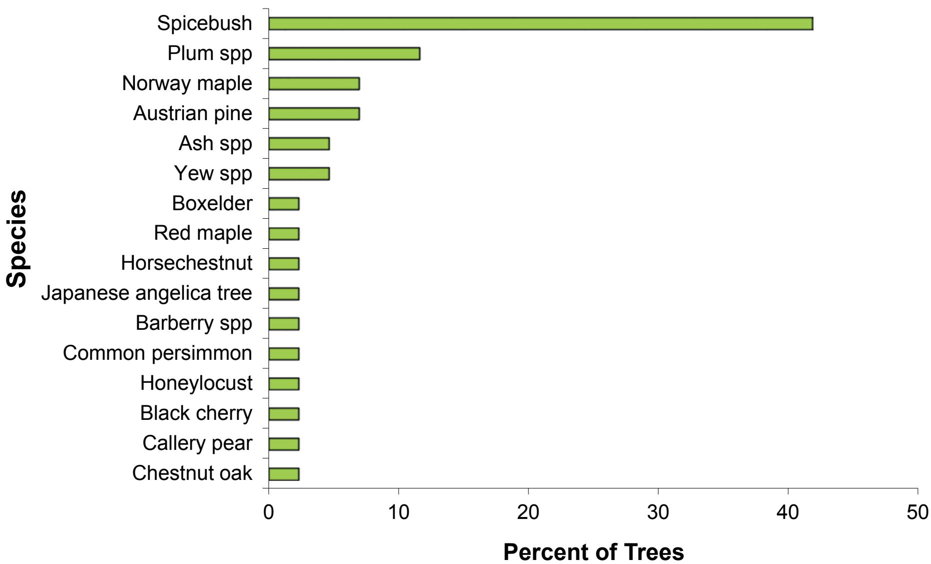

Figure 35.—Percentage of trees in Institutional category of land use, Philadelphia, 2012.

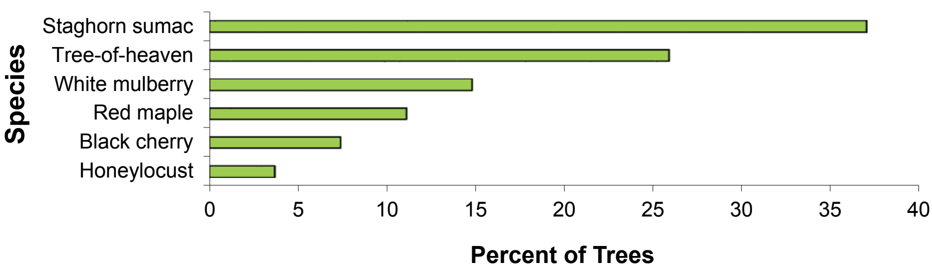

Figure 36.—Percentage of trees in Other category of land use, Philadelphia, 2012.

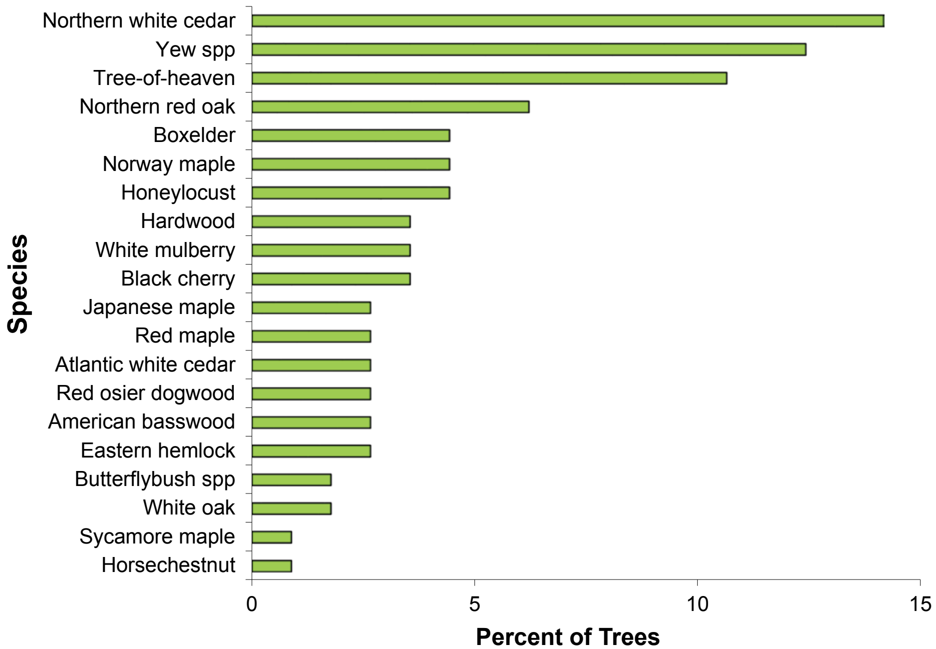

Figure 37.—Percentage of trees in Residential category of land use, Philadelphia, 2012.

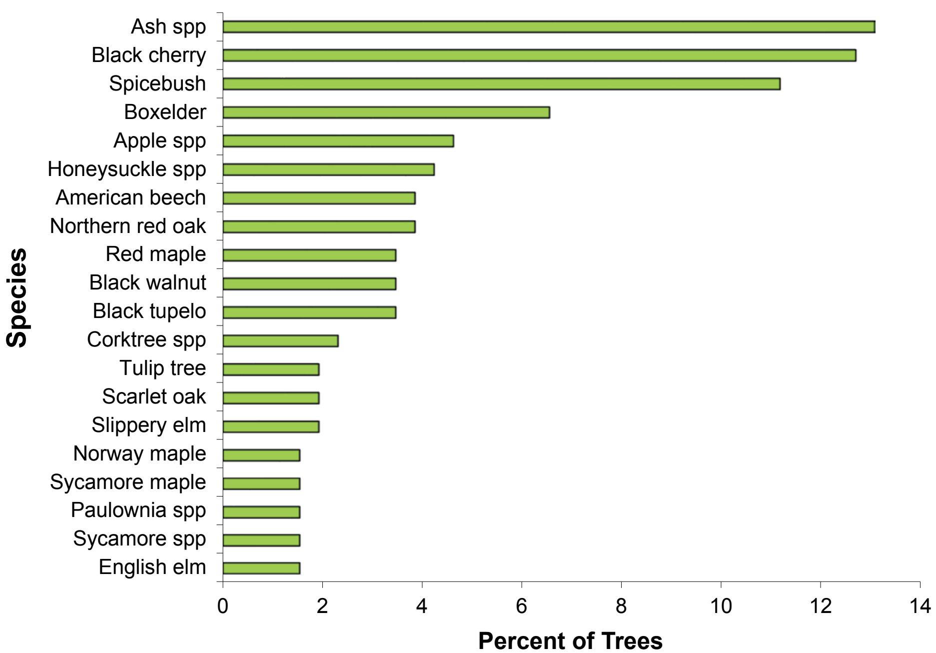

Figure 38.—Percentage of trees in Wooded category of land use, Philadelphia, 2012.

APPENDIX 7

Relative Tree Effects

The urban forest in Philadelphia provides benefits that include carbon storage and sequestration and air pollutant removal. These benefits vary across d.b.h classes (Table 21). 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 (NOx), VOCs, particulate matter less than 10 microns (PM_{10}), and SO_2 in 2010 (Bureau of Transportation Statistics 2010, Heirigs et al. 2004), and CO_2 in 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 NOx power plant emission per KWh are from Leonardo Academy (2011). CO emission per kWh assumes 1/3 of 1 percent of C emissions is CO based on Energy Information Administration (1994).

CO_2, NOx, 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, NOx and sulfur oxides (SOx) emission per Btu based on total emissions and wood burning (tons) from British Columbia Ministry (2005) and Georgia Forestry Commission (2009).

General tree information:

Average tree diameter = 7.4 inches

Median tree diameter = 4.3 inches

Number of trees sampled = 451

Number of species sampled = 69

Table 21.—Average tree effects by tree diameter class (d.b.h.), Philadelphia, 2012

d.b.h.[a]	Carbon storage			Carbon sequestration			Pollution removal	
inches	*lbs*	*$*	*miles*[b]	*lbs/yr*	*$/yr*	*miles*[b]	*lbs/yr*	*$/yr*
1-3	8	0.28	10	2.2	0.08	2	0.05	0.94
3-6	41	1.48	50	6.8	0.24	7	0.11	2.01
6-9	146	5.19	160	11.9	0.42	13	0.22	4.16
9-12	328	11.67	360	23.5	0.84	26	0.40	7.40
12-15	584	20.81	640	31.3	1.11	34	0.59	10.89
15-18	1,060	37.74	1,160	42.0	1.50	46	0.83	15.36
18-21	1,454	51.78	1,590	46.3	1.65	51	0.86	15.84
21-24	2,295	81.75	2,510	77.9	2.77	85	1.38	25.52
24-27	3,415	121.62	3,730	85.5	3.04	93	1.30	24.12
27-30	4,196	149.44	4,580	93.4	3.33	102	2.13	39.50
30+	7,039	250.69	7,690	183.2	6.52	200	3.73	69.07

[a] lower limit of each diameter (d.b.h.) 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 Philadelphia provide:

Carbon (C) storage equivalent to:

Amount of C emitted in region in 32 days or

Annual C emissions from 497,000 automobiles or

Annual C emissions from 203,600 single family houses

Nitrogen dioxide (NO_2) removal equivalent to:

Annual NO_2 emissions from 7,800 automobiles or

Annual NO_2 emissions from 3,500 single family houses

Sulfur dioxide (SO_2) removal equivalent to:

Annual SO_2 emissions from 7,300 automobiles or

Annual SO_2 emissions from 0 single family houses

Annual C sequestration equivalent to:

Amount of C emitted in region in 1 day or

Annual C emissions from 19,200 automobiles or

Annual C emissions from 7,900 single family home

APPENDIX 8

Temperature Index Map

Air temperature is an important climatic variable in urban areas. The air temperature model (Heisler et al. 2006, 2007, 2015) was run to determine the average temperature between noon and 5 p.m. for four different days between June 1, 2008, and August 31, 2008. Average temperature was also modeled for the hour with the warmest air temperature. The representative days and hour were as follows:

- Windiest day (day with the highest average wind speed): June 1, 2008
- Least windy day (day with the lowest average wind speed): August 21, 2008
- Average day (day with the average temperature closest to the summer average temperature): August 4, 2008 (Fig. 39)
- Warmest temperature day (day with the highest average summer daytime temperature): June 10, 2008
- Warmest temperature hour (hour with the warmest air temperature): 4 p.m. on June 9, 2008.

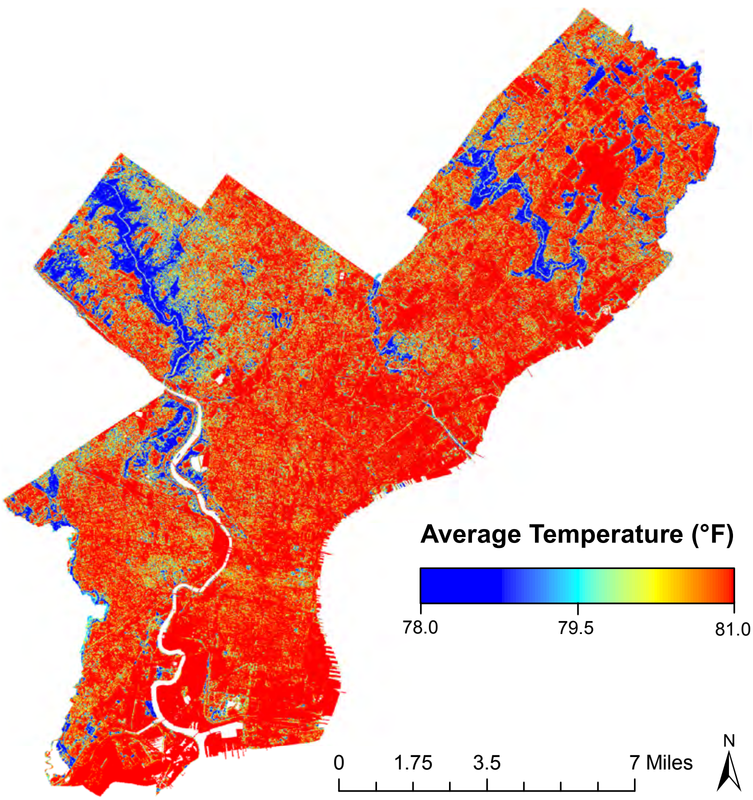

Figure 39.—Average temperature distribution (noon to 5 p.m.) for the average summer day, Philadelphia, 2012.

Tree cover can help reduce air temperatures in urban areas. The air temperature estimates modeled here present one option that can be used in urban areas to determine areas to target tree cover enhancements. That is, 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. This process provides an air temperature planting index (TPI) for each of the representative days. Standardized value the TPI was calculated as:

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

Where TPI is the value (0-1), n is the value (temperature × 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 produce the same TPI index map as the relative temperature difference among block groups was the same, though the actual temperatures would differ. The results of the block groups were averaged within each neighborhood (weighted average proportional to block area within neighborhood) and standardized a second time on a scale of 0 to 100 to produce neighborhood temperature index maps. Because two neighborhoods (Mechanicsville and Chinatown) had high population densities and temperatures (high index values relative to others), the index values dropped to very small values for many other neighborhoods. To avoid this skew in the index, these two neighborhoods were removed from the standardization. All other neighborhoods were standardized between 0 and 100, and these two neighborhoods had their index values calculated subsequently such that their index values were greater than 100. This adjusted index was only done for the neighborhood index only (not block groups) due to these outliers causing most neighborhoods toward index values close to zero. 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. 40).

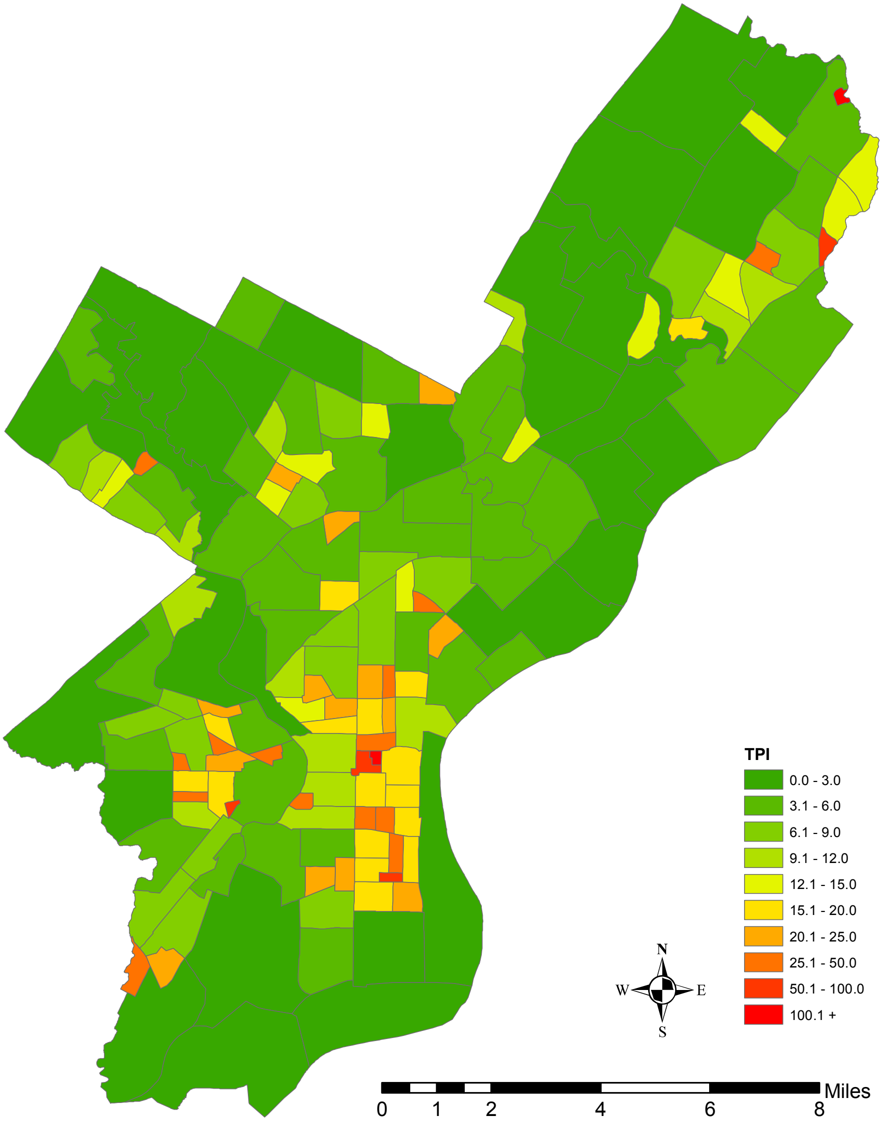

Figure 40.—Temperature planting index (TPI) by neighborhood for average summer day, Philadelphia, 2012. Higher index scores indicate higher priority areas for planting. Note: two neighborhoods (Mechanicsville and Chinatown) have values greater than 100 (see text; these outlier neighborhoods were excluded from standardized index to avoid most neighborhoods having very small index values).

APPENDIX 9

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 10

Species Sampled in the Philadelphia Parkland Areas

Table 22.—Species[a] sampled in the urban forest, Philadelphia parklands, 2012

Genus	Species	Common name	Trees	Population	Leaf area	IV[b]	Stem d.b.h.		Basal area[c]	Compensatory value
							median	avg.		
			number	*percent*	*percent*		*inches*	*inches*	*ft²*	*$ millions*
Acer	*negundo*	boxelder	131,400	12.2	6.4	18.6	2.7	4.4	31,103	8.0
Acer	*palmatum*	Japanese maple	3,490	0.3	0.3	0.6	4.5	4.8	571	0.4
Acer	*platanoides*	Norway maple*	54,660	5.1	5.6	10.7	3.7	5.0	16,121	8.9
Acer	*pseudoplatanus*	sycamore maple*	4,650	0.4	0.2	0.6	5.0	5.3	932	0.5
Acer	*rubrum*	red maple	38,380	3.5	5.6	9.1	6.8	9.4	31,975	18.1
Acer	*saccharinum*	silver maple	13,950	1.3	4.1	5.4	16.0	19.6	39,068	15.7
Acer	*saccharum*	sugar maple	5,810	0.5	0.8	1.3	6.5	6.9	2,112	3.1
Aesculus	*hippocastanum*	horsechestnut*	1,160	0.1	0.0	0.1	4.5	4.5	159	0.1
Aesculus	*species*	buckeye spp	1,160	0.1	0.1	0.2	15.5	15.5	1,624	0.4
Ailanthus	*altissima*	tree-of-heaven*	22,090	2.0	0.7	2.7	5.3	5.0	4,325	2.8
Alnus	*species*	alder spp	2,330	0.2	0.1	0.3	2.0	2.0	82	0.0
Aralia	*elata*	Japanese angelica tree	58,140	5.4	0.7	6.1	1.9	2.1	2,391	1.7
Betula	*lenta*	black birch	6,980	0.6	0.8	1.4	5.0	5.5	1,610	1.0
Betula	*populifolia*	gray birch	1,160	0.1	0.1	0.2	1.5	1.5	25	0.0
Carpinus	*caroliniana*	American hornbeam	1,160	0.1	0.1	0.2	3.5	3.5	101	0.1
Carya	*alba*	mockernut hickory	3,490	0.3	0.3	0.6	14.5	18.8	10,339	4.4
Carya	*cordiformis*	bitternut hickory	36,050	3.3	1.2	4.5	2.1	3.7	6,796	4.1
Catalpa	*speciosa*	northern catalpa	2,330	0.2	0.2	0.4	12.0	17.0	4,269	0.9
Celtis	*occidentalis*	northern hackberry	1,160	0.1	0.0	0.1	0.0	0.8	6	0.0
Cornus	*florida*	flowering dogwood	9,300	0.9	0.4	1.3	4.0	3.9	1,097	0.8
Crataegus	*species*	hawthorn spp	1,160	0.1	0.0	0.1	1.5	1.5	25	0.0
Diospyros	*virginiana*	common persimmon	2,330	0.2	0.2	0.4	3.0	9.5	1,890	2.4

continued

Table 22.—continued

Genus	Species	Common name	Trees	Population	Leaf area	IV[b]	Stem d.b.h.		Basal area[c]	Compensatory value
							median	avg.		
			number	*percent*	*percent*		*inches*	*inches*	*ft²*	*$ millions*
Fagus	*grandifolia*	American beech	74,420	6.9	14.3	21.2	3.9	8.4	57,952	32.3
Fraxinus	*species*	ash spp	140,710	13.0	8.7	21.7	2.7	5.8	62,168	36.3
Ginkgo	*biloba*	ginkgo	3,490	0.3	0.3	0.6	21.3	20.2	8,196	13.6
Gleditsia	*triacanthos*	honeylocust	6,980	0.6	0.5	1.1	8.0	12.7	9,379	6.6
Hardwood	*species*	hardwood	19,770	1.8	0.0	1.8	5.5	7.7	12,024	0.0
Ilex	*opaca*	American holly	3,490	0.3	0.0	0.3	1.5	1.6	89	0.1
Juglans	*nigra*	black walnut	6,980	0.6	0.3	0.9	5.0	5.5	1,587	0.9
Juglans	*species*	walnut spp	1,160	0.1	0.4	0.5	14.5	14.5	1,427	0.4
Ligustrum	*species*	privet spp	1,160	0.1	0.0	0.1	3.5	3.5	101	0.1
Lindera	*benzoin*	spicebush	90,700	8.4	1.5	9.9	1.7	2.0	4,017	2.2
Liquidambar	*styraciflua*	sweetgum	1,160	0.1	0.3	0.4	14.5	14.5	1,427	1.9
Liriodendron	*tulipifera*	tulip tree or yellow-poplar	27,910	2.6	12.7	15.3	23.0	23.6	104,393	40.3
Lonicera	*species*	honeysuckle spp	16,280	1.5	0.3	1.8	1.8	2.1	647	0.5
Malus	*species*	apple spp	11,630	1.1	0.8	1.9	3.4	4.9	3,882	5.3
Morus	*alba*	white mulberry*	10,470	1.0	2.0	3.0	8.8	9.3	6,495	8.5
Morus	*rubra*	red mulberry	4,650	0.4	0.2	0.6	10.3	8.3	2,327	0.6
Nyssa	*sylvatica*	black tupelo	9,300	0.9	0.7	1.6	5.5	6.9	4,294	2.6
Ostrya	*virginiana*	eastern hophornbeam	5,810	0.5	0.1	0.6	1.8	2.3	292	0.3
Paulownia	*species*	princesstree spp*	3,490	0.3	0.4	0.7	9.5	12.2	3,578	1.3
Phellodendron	*species*	corktree spp*	23,260	2.2	0.9	3.1	3.3	3.9	3,254	1.9
Pinus	*strobus*	eastern white pine	1,160	0.1	0.0	0.1	6.5	6.5	311	0.0
Pinus	*sylvestris*	scotch pine	3,490	0.3	0.1	0.4	7.3	6.8	1,040	1.9
Platanus	*species*	sycamore spp	15,120	1.4	8.9	10.3	27.5	24.7	68,345	42.9
Populus	*grandidentata*	bigtooth aspen	1,160	0.1	0.1	0.2	9.5	9.5	634	0.2
Populus	*tremuloides*	quaking aspen	3,490	0.3	0.0	0.3	2.5	2.8	241	0.1
Prunus	*serotina*	black cherry	80,240	7.4	7.9	15.3	6.5	8.8	58,220	27.6

continued

Table 22.—continued

Genus	Species	Common name	Trees	Population	Leaf area	IV[b]	Stem d.b.h.		Basal area[c]	Compensatory value
							median	avg.		
			number	*percent*	*percent*		*inches*	*inches*	*ft²*	*$ millions*
Prunus	*species*	plum spp	16,280	1.5	0.6	2.1	3.3	4.1	2,594	0.9
Quercus	*alba*	white oak	2,330	0.2	1.1	1.3	20.0	26.5	9,870	4.7
Quercus	*coccinea*	scarlet oak	5,810	0.5	0.6	1.1	15.5	11.7	6,894	3.9
Quercus	*imbricaria*	shingle oak	1,160	0.1	0.2	0.3	8.5	8.5	514	0.7
Quercus	*marilandica*	blackjack oak	2,330	0.2	0.1	0.3	4.0	4.5	330	0.1
Quercus	*palustris*	pin oak	4,650	0.4	1.5	1.9	26.0	26.5	20,535	13.3
Quercus	*phellos*	willow oak	2,330	0.2	0.1	0.3	2.0	3.5	254	0.4
Quercus	*prinus*	chestnut oak	1,160	0.1	0.0	0.1	2.5	2.5	57	0.1
Quercus	*rubra*	northern red oak	17,440	1.6	3.0	4.6	5.5	11.6	25,155	8.9
Quercus	*velutina*	black oak	2,330	0.2	0.6	0.8	18.0	27.5	11,215	4.6
Rhus	*hirta*	staghorn sumac	1,160	0.1	0.0	0.1	1.5	1.5	25	0.1
Robinia	*pseudoacacia*	black locust	2,330	0.2	0.3	0.5	17.0	18.0	4,370	1.1
Salix	*nigra*	black willow	1,160	0.1	0.0	0.1	4.5	4.5	159	0.1
Sassafras	*albidum*	sassafras	23,260	2.2	1.4	3.6	8.0	9.0	14,175	5.3
Tilia	*americana*	American basswood	2,330	0.2	0.4	0.6	8.0	16.5	4,694	1.8
Tsuga	*canadensis*	eastern hemlock	3,490	0.3	0.1	0.4	5.5	8.5	2,011	0.1
Ulmus	*alata*	winged elm	3,490	0.3	0.0	0.3	1.5	1.5	76	0.0
Ulmus	*americana*	American elm	1,160	0.1	0.1	0.2	7.5	7.5	406	0.1
Ulmus	*rubra*	slippery elm	9,300	0.9	0.4	1.3	3.5	4.4	1,744	1.5
Ulmus	*species*	elm spp	1,160	0.1	0.0	0.1	2.5	2.5	57	0.0
Viburnum	*dilatatum*	linden arrowwood	1,160	0.1	0.0	0.1	1.5	1.5	25	0.1
Viburnum	*prunifolium*	black haw	2,330	0.2	0.0	0.2	2.0	2.0	82	0.0
Viburnum	*sieboldii*	Siebold's arrowwood	1,160	0.1	0.0	0.1	2.5	2.5	57	0.0
Viburnum	*species*	viburnum spp	2,330	0.2	0.1	0.3	2.0	2.0	82	0.0

[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.

* Nonnative invasive species

APPENDIX 11

Tree Planting Index Map

To determine the best locations to plant trees, tree canopy and impervious cover identified from high resolution land cover maps (O'Neil-Dunne 2011) were used in conjunction with 2010 U.S. Census data to produce an index of priority planting areas for Philadelphia. Index values were produced for each Census block group; the higher the index value, the higher the priority of the area for tree planting. This index is a type of "environmental equity" index with areas with higher human population density and lower tree cover tending to get the higher index value. The criteria used to make the index were:

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

Each criteria was standardized on a scale of 0 to 1 with 1 representing the Census block group with the highest value in relation to priority of tree planting (i.e., the Census block group with highest population density, lowest stocking density or lowest tree cover per capita were standardized to a rating of 1).

Standardized value for population density (PD) was calculated as:

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

Where PD is the value (0-1), n is the value for the Census block (population/km2), m is the minimum value for all census blocks, and r is the range of values among all Census blocks (maximum value – minimum value).

Standardized value for tree stocking (TS) was calculated as:

$$TS = [1 - (t/(t+g)]$$

Where TS is the value (0-1), t is percent tree cover, and g is percent grass cover.

Standardized value for tree cover per capita (TPC) was calculated as:

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

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

Individual scores were combined and standardized based on the following formula to produce an overall priority planting index (PPI) value between 0 and 100:

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

Where PPI = index value, PD is standardized population density, TS is standardized tree stocking, and TPC is standardized tree cover per capita.

In the formula, criteria (PD, TS, and TPC) were each weighted with a slight increased weighting to population density to produce a type of "environmental equity" index. The Tree Planting Index gives the highest priority to tree planting in the City of Philadelphia where population density tends to be highest and tree cover the lowest. Priority planting index values were applied to the neighborhoods of Philadelphia by calculating an area weighted average for each neighborhood (Fig. 41).

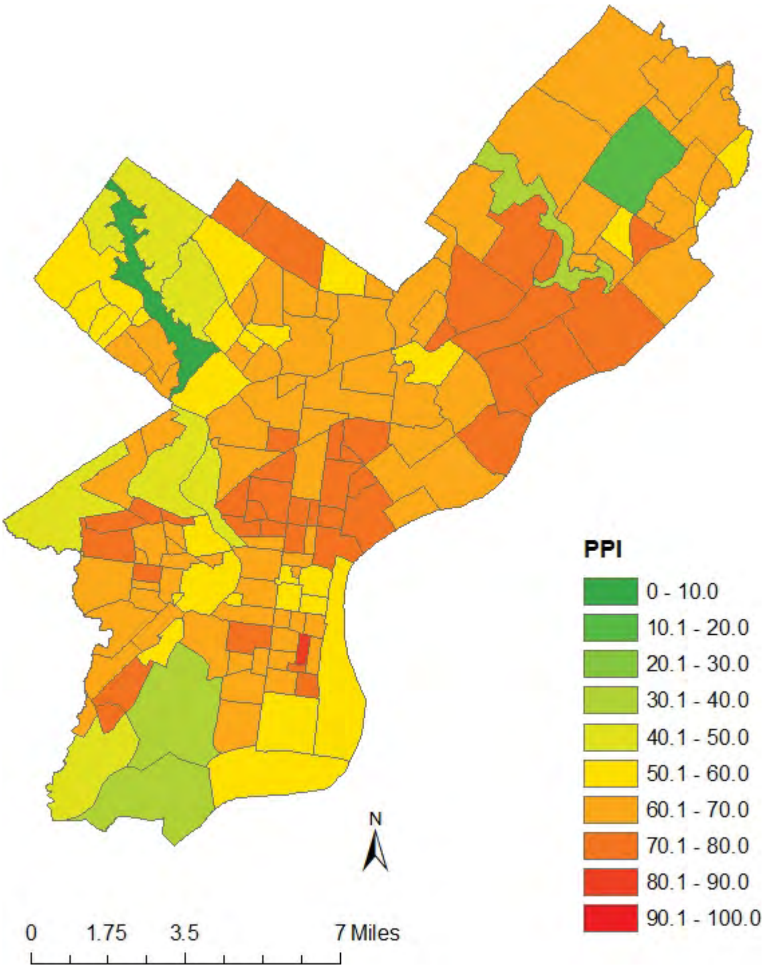

Figure 41.—Priority planting index (PPI) by neighborhood, Philadelphia, 2012. Higher index scores indicate higher priority areas for planting.

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An analysis of the urban forest in Philadelphia, Pennsylvania, reveals that this city has an estimated 2.9 million trees (encompassing all woody plants greater than 1 inch diameter at breast height [d.b.h]) with tree canopy that covers 20 percent of the city. The most common tree species are spicebush, black cherry, ash, tree-of-heaven, and boxelder, but the most dominant species in terms of leaf area are sycamore spp. (including London planetree), northern red oak, black walnut, red maple, and Norway maple. Trees in Philadelphia currently store about 702,000 tons of carbon (2.6 million tons of carbon dioxide [CO_2]) valued at $93.4 million. In addition, these trees remove about 27,000 tons of carbon per year (99,000 tons CO_2/year) ($3.6 million per year) and about 513 tons of air pollution per year ($19.0 million per year). Philadelphia's urban forest is estimated to reduce annual residential energy costs by $6.9 million per year. The compensatory value of the trees is estimated at $1.7 billion. The city's parklands constitute 9.3 percent of the total land area, have an estimated 1.1 million trees, 64 percent canopy cover, and account for 38.8 percent of carbon storage and 34.8 percent of air pollution removal performed by the city's urban forest. 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 Philadelphia.

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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