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Northern Research Station

Resource Bulletin NRS-43

Assessing Urban Forest Effects and Values

Scranton's Urban Forest

Northern Research Station
USDA Forest Service

UFORE Urban Forest Effects Model

Abstract

An analysis of trees in the urbanized portion of Scranton, PA, reveals that this area has about 1.2 million trees with canopies that cover 22.0 percent of the area. The most common tree species are red maple, gray birch, black cherry, northern red oak, and quaking aspen. Scranton's urban forest currently store about 93,300 tons of carbon valued at $1.9 million. In addition, these trees remove about 4,000 tons of carbon per year ($83,000 per year) and about 65 tons of air pollution per year ($514,000 per year). Trees in urban Scranton are estimated to reduce annual residential energy costs by $628,000 per year. The structural, or compensatory, value is estimated at $322 million. Information on the structure and functions of the urban forest can be used to inform urban forest management programs and to integrate urban forests within plans to improve environmental quality in the Scranton area.

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

In 2006, the UFORE model was used to survey and analyze the trees in the urbanized portion of Scranton.

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

Executive Summary

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

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

To help determine the vegetation structure, functions, and values of the urban portion of Scranton, PA, a vegetation assessment was conducted during the summer of 2006. For this assessment, one-tenth acre field plots were sampled and analyzed using the UFORE model. This report summarizes results and values of:

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

Scranton Urban Forest Summary

Feature	Measure
Number of trees	1.2 million
Tree cover	22%
Most common species	red maple, gray birch, black cherry, northern red oak, quaking aspen
Percentage of trees < 6-inches diameter	77.1%
Pollution removal	65 tons/year ($514,000/year)
Carbon storage	93,300 tons ($1.9 million)
Carbon sequestration	4,000 tons/year ($83,000/year)
Building energy reduction	$628,000/year
Increased carbon emissions	$16,700/year
Structural value	$322 million

Ton – short ton (U.S.) (2,000 lbs)

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Benefits provided by urban trees include:

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

Urban Forest Effects Model and Field Measurements

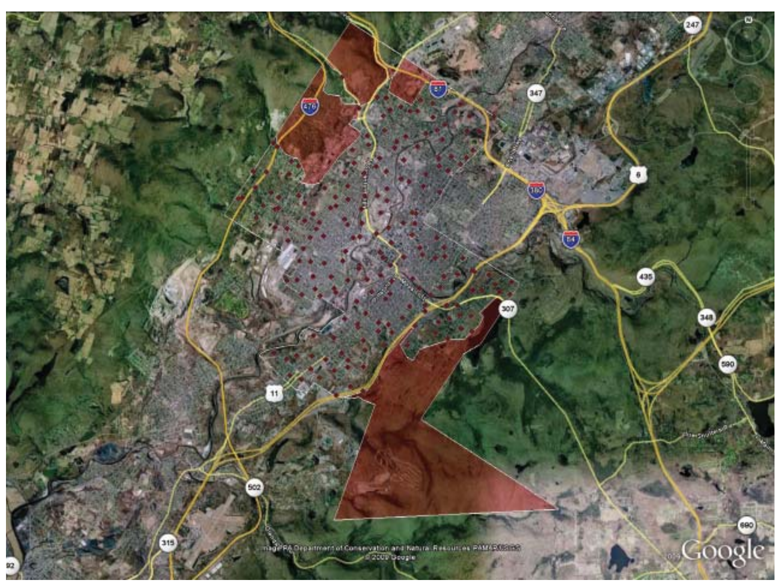
Though urban forests have many functions and values, currently only a few of these attributes can be assessed due to a limited ability to quantify all of these values through standard data analyses. To help assess the city's urban forest, data from 182 field plots located throughout the city were analyzed using the Forest Service's Urban Forest Effects (UFORE) model.[1]

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

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

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

In the field, one-tenth acre plots were selected based on a randomized grid-based pattern at an average density of approximately 1 plot for every 57 acres. The study is broken into smaller areas based on field land use classifications. The plots were divided among the following land uses: residential (91 plots, 50.0% of area), commercial/industrial (30 plots, 16.5%), vacant (28 plots, 15.4%), transportation/utility (12 plots, 6.6%), park/cemetery (11 plots, 6.0%), and institutional (10 plots, 5.5%).



"Urban" Scranton study area. Red dots represent field plots, red shaded areas represent "non-urban" portion of Scranton that was not sampled.

Mark Burns. Used with permission.

Field Survey Data

Plot Information

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

Tree parameters

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

Field data were collected by Northeast Pennsylvania Urban & Community Forestry Program staff, Keystone College interns, Penn State Extension Urban Forester, and DCNR Bureau of Forestry staff; data collection took place during the leaf-on season to properly assess tree canopies. Within each plot, data included land-use, ground and tree cover, shrub characteristics, and individual tree attributes of species, stem-diameter at breast height (d.b.h.; measured at 4.5 ft.), tree height, height to base of live crown, crown width, percentage crown canopy missing and dieback, and distance and direction to residential buildings.[2]

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

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

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

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

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

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

David Nowak, U.S. Forest Service

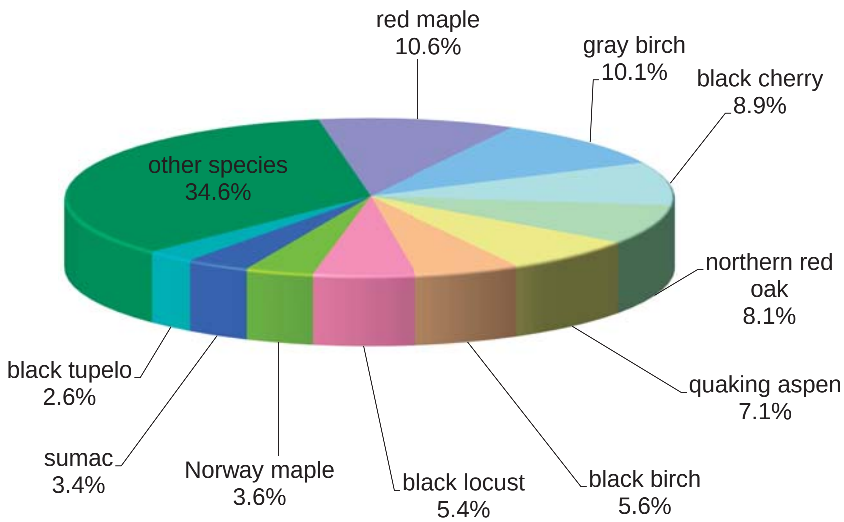
There are an estimated 1.2 million trees in urban Scranton with 22.0 percent tree cover.

The 10 most common species account for 65.4 percent of the total number of trees.

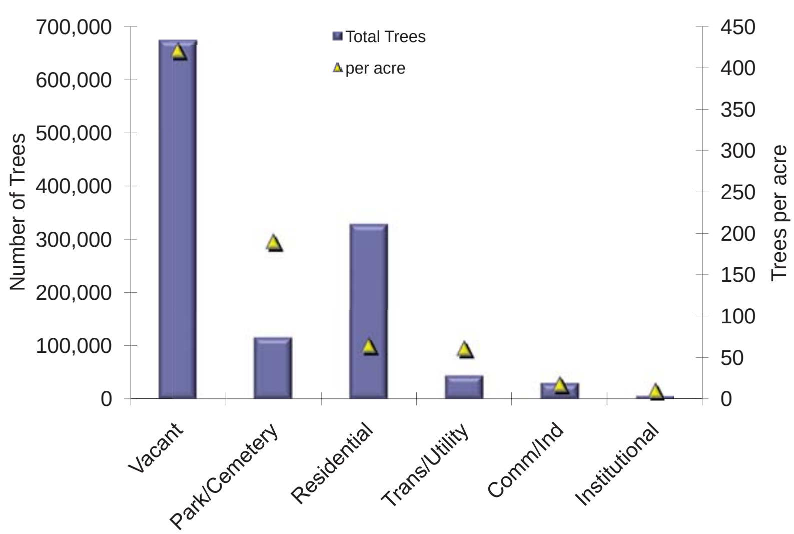
Tree density is highest in vacant lands and lowest in institutional lands.

Tree Characteristics of the Urban Forest

The urban forest of Scranton has an estimated 1.2 million trees with a standard error (SE) of 133,000. Tree cover in urban portion of Scranton is estimated at 22 percent.[12] The four most common species in the urban forest are red maple (10.6 percent), gray birch (10.1 percent), black cherry (8.9 percent), and northern red oak (8.1 percent). The 10 most common species account for 65.4 percent of all trees; their relative abundance is illustrated below. In total, 80 tree species were sampled in urban Scranton; these species and their relative abundance are presented in Appendix IV.



Overall, trees that have diameters less than 6 inches account for 77.1 percent of the population. The highest density of trees occurs in vacant lands (421 trees/acre), followed by park/cemetery (190 trees/acre) and residential land (65 trees/acre). The overall tree density in urban Scranton is 116.3 trees/acre, which is relatively high compared to other city tree densities that range between 14.4 and 119.2 trees/acre (Appendix I). Much of this relatively high tree density can be attributed to the high density of small trees (e.g., gray birch) on vacant lands and most likely are an artifact of forest regeneration on mine lands or harvested forests. About 46 percent of the



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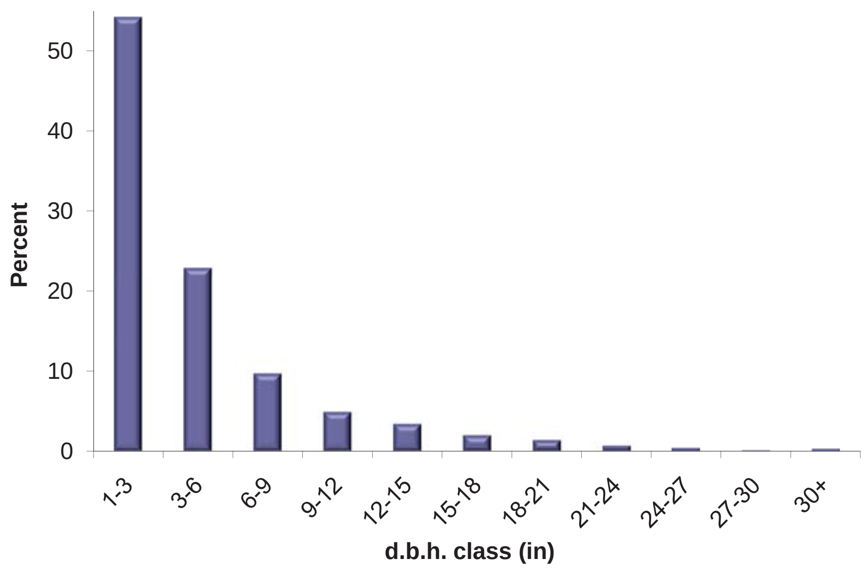
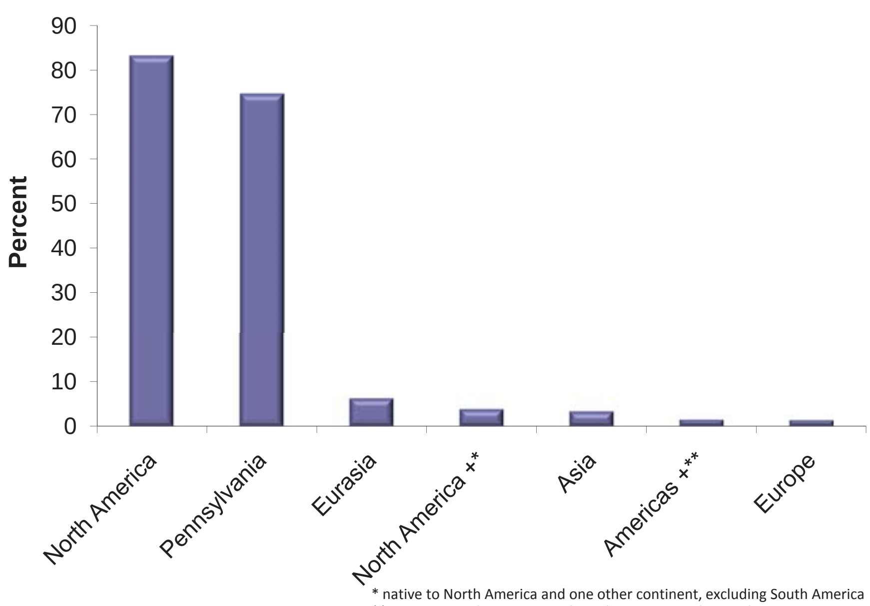
Nearly 74.6 percent of the tree species in urban Scranton are native to Pennsylvania.

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

total tree population in urban Scranton is from trees less than 6 inches in diameter on vacant lands. Land uses that contain the most leaf area are residential (45.3 percent of total tree leaf area) and vacant (37.9 percent).

Urban forests are a mix of native tree species that existed prior to the development of the city and exotic species that were introduced by residents or other means. Thus, urban forests often have a tree diversity that is higher than surrounding native landscapes. Increased tree diversity can minimize the overall impact or destruction by a species-specific insect or disease, but the increase in the number of exotic plants can also pose a risk to native plants if some of the exotics species are invasive plants that can potentially out-compete and displace native species. In urban Scranton, about 75 percent of the trees are from species native to Pennsylvania. Trees with a native origin outside of North America are mostly from Eurasia (6.3 percent of the species).





Tom Dobb, wikimedia commons.

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

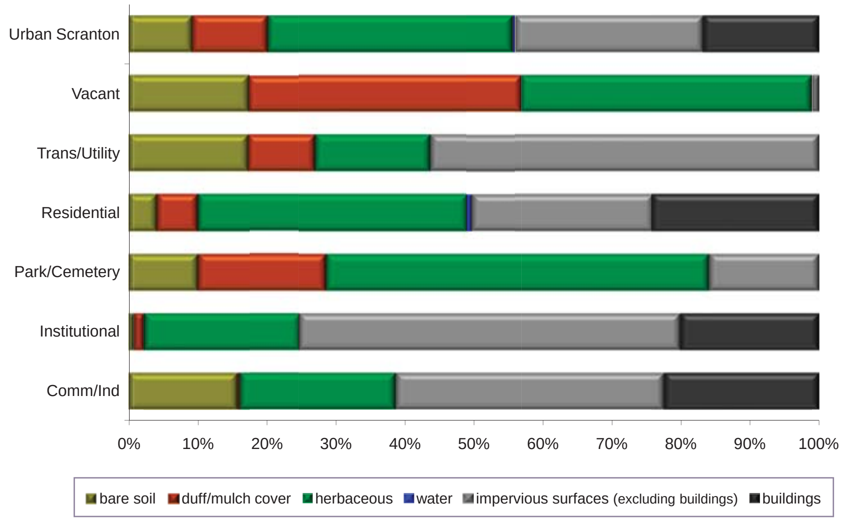
Red maple is currently the most dominant species in the urban Scranton area based on relative leaf area and relative population.

Common Name	% Pop[a]	% LA[b]	IV[c]
red maple	10.6	10.6	21.2
northern red oak	8.1	11.3	19.4
black cherry	8.9	7.3	16.2
Norway maple	3.6	10.8	14.4
gray birch	10.1	2.7	12.8
quaking aspen	7.1	2.5	9.6
black birch	5.6	3.2	8.8
silver maple	1.7	6.7	8.4
black locust	5.4	2.8	8.2
Norway spruce	0.9	6.2	7.1

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

Urban Forest Cover and Leaf Area

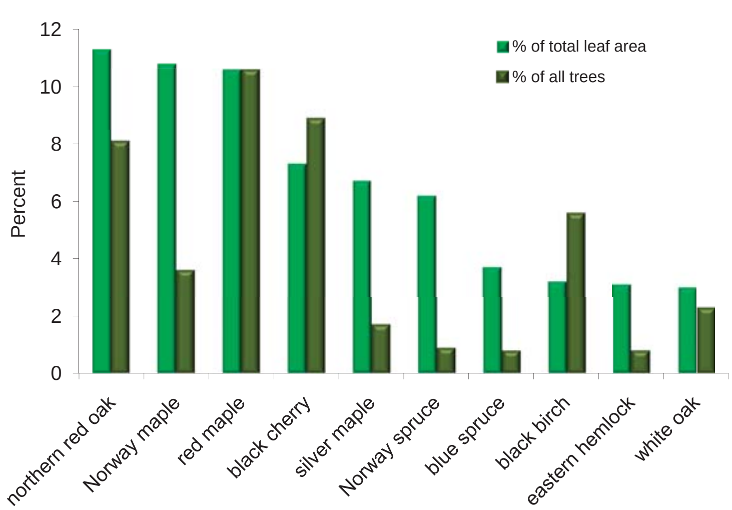
Dominant ground cover types include herbaceous (35.3 percent), impervious surfaces (excluding buildings) (27.5 percent), and buildings (16.7 percent).



Many tree benefits are linked directly to the amount of healthy leaf surface area of the plant. In urban Scranton trees that dominate in terms of leaf area are northern red oak, Norway maple and red maple.

Tree species with relatively large individuals contributing leaf area to the population (species with percent of leaf area much greater than percent of total population) are silver maple, Norway maple, and northern red oak. Smaller trees in the population are sumac, gray birch and witch hazel (species with percent of leaf area much less than percent of total population). A species must also constitute at least 1 percent of the total population to be considered as relatively large or small trees in the population.

The importance values (IV) are calculated using a formula that takes into account the relative leaf area and relative abundance. The most important species in Scranton's urban forest, according to calculated IVs, are red maple, northern red oak, and black cherry. High importance values do not mean that these trees should necessarily be used in the future, rather that these species currently dominate the urban forest structure.



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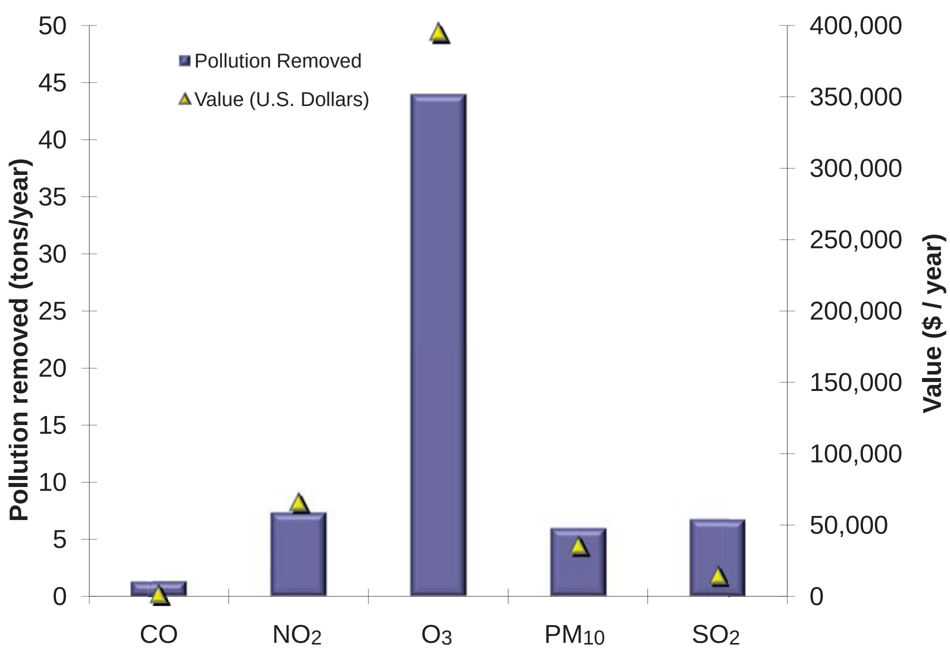
The urban forest of Scranton removes approximately 65 tons of pollutants each year, with a societal value of $514,000 million/ year.

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

Air Pollution Removal by Urban Trees

Poor air quality is a common problem in many urban areas. It can lead to human health problems, damage to landscape materials and ecosystem processes, and reduced visibility. The urban forest can help improve air quality by reducing air temperature, directly removing pollutants from the air, and reducing energy consumption in buildings, which consequently reduce air pollutant emissions from power plants. Trees also emit volatile organic compounds that can contribute to ozone formation. However, integrative studies have revealed that an increase in tree cover leads to reduced ozone formation.[13]

Pollution removal by trees in urban Scranton was estimated using the UFORE model in conjunction with field data and hourly pollution and weather data for the year 2000. Pollution removal was greatest for ozone (O_3), followed by nitrogen dioxide (NO_2), sulfur dioxide (SO_2), particulate matter less than ten microns (PM_{10}), and carbon monoxide (CO). It is estimated that trees remove 65 tons of air pollution (CO, NO_2, O_3, PM_{10}, SO_2) per year with an associated value of $514,000 (based on estimated 2007 national median externality costs associated with pollutants[14]).



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Carbon storage:

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

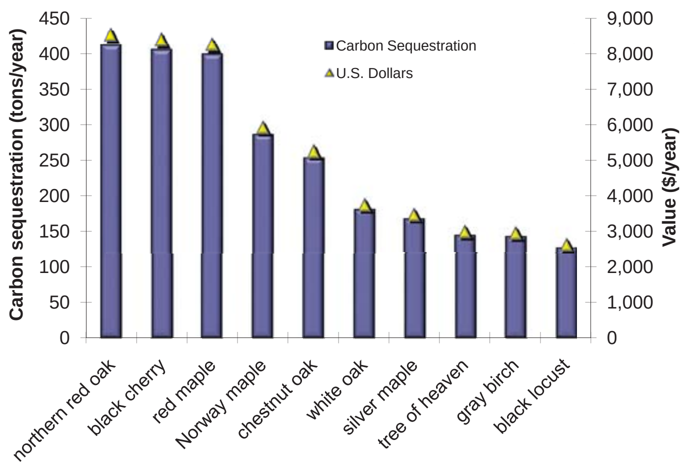
Carbon sequestration:

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

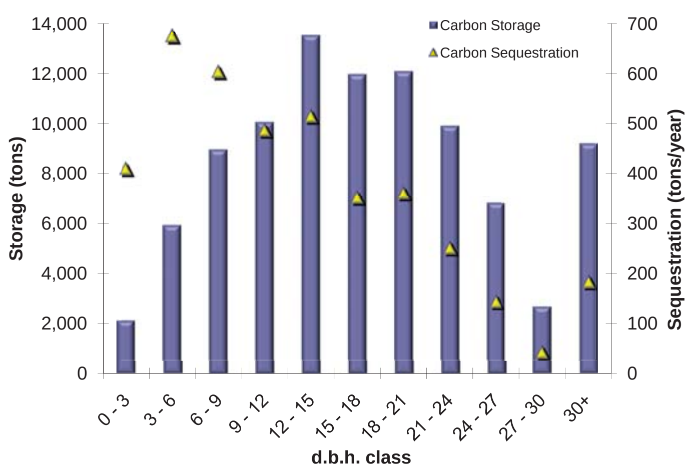
Carbon Storage and Sequestration

Climate change is an issue of global concern. Urban trees can help mitigate climate change by sequestering atmospheric carbon (from carbon dioxide) in tissue and by reducing energy use in buildings, and consequently reducing carbon dioxide emissions from fossil-fuel based power plants.[15]

Trees reduce the amount of carbon in the atmosphere by sequestering carbon in new tissue growth every year. The amount of carbon annually sequestered is increased with healthier trees and larger diameter trees. Gross sequestration by trees in urban Scranton is about 4,000 tons of carbon per year with an associated value of $83,000. Net carbon sequestration in the urban Scranton is estimated at about 3,000 tons and is lower than gross sequestration based on the estimated loss of carbon due to tree mortality.



Carbon storage by trees is another way trees can influence global climate change. As trees grow, they store more carbon by holding it in their accumulated tissue. As trees die and decay, they release much of the stored carbon back to the atmosphere. Thus, carbon storage is an indication of the amount of carbon that can be released if trees are allowed to die and decompose. Maintaining healthy trees will keep the carbon stored in trees and when trees die, utilizing the wood in long-term wood products or to help heat buildings or produce energy will help reduce carbon emissions from wood decomposition or from power plants. Trees in urban Scranton are estimated to store 93,300 tons of carbon ($1.9 million). Of all the species sampled, northern red oak stores and sequesters the most carbon (approximately 13.2% of the total carbon stored and 10.2% of all sequestered carbon).



Jeffrey from Dunmore PA. wikimedia commons.

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

Interactions between buildings and trees are estimated to reduce residential heating and cooling costs by $628,000 per year.

Trees Affect Energy Use in Buildings

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

Based on average state energy costs in 2007, trees in urban Scranton are estimated to reduce energy costs from residential buildings by $628,000 annually. Trees also provide an additional $16,700 in value per year by reducing amount of carbon released by fossil-fuel based power plants (a reduction of 700 tons of carbon emissions).

Richard Webb, Self-employed horticulurist, Bugwood.org

Annual energy savings due to trees near residential buildings

	Heating	Cooling	Total
MBTU[a]	32,000	n/a	32,000
MWH[b]	300	1200	1,500
Carbon avoided (t)	500	200	700

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

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

	Heating	Cooling	Total
MBTU[a]	463,000	n/a	463,000
MWH[b]	30,000	135,000	165,000
Carbon avoided	12,200	4,500	16,700

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

Joseph O'brien, US Forest Service, forestryimages.com

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

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

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

A map of priority planting locations for the City of Scranton is found in Appendix V.

A list of tree species found in the City of Scranton is in Appendix IV.

Structural and Functional Values

Urban forests have a structural value based on the tree itself (e.g., the cost of having to replace the tree with a similar tree). The structural value[10] of the trees and forests in urban Scranton is about $322 million. The structural value of an urban forest tends to increase with a rise in the number and size of healthy trees.

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

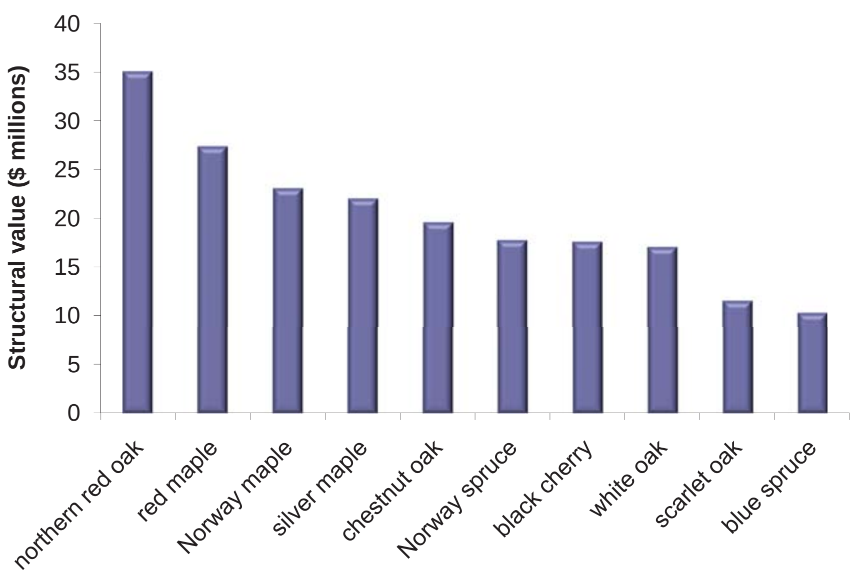
Structural values:

- Structural value: $322 million
- Carbon storage: $1.9 million

Annual functional values:

- Carbon sequestration: $83,000
- Pollution removal: $514,000
- Reduced energy costs: $628,000

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



Asian longhorned beetle

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

Gypsy moth

USDA Forest Service Archives
(www.invasive.org)

Emerald ash borer

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

Dutch elm disease

USDA Forest Service

Potential Insect and Disease Impacts

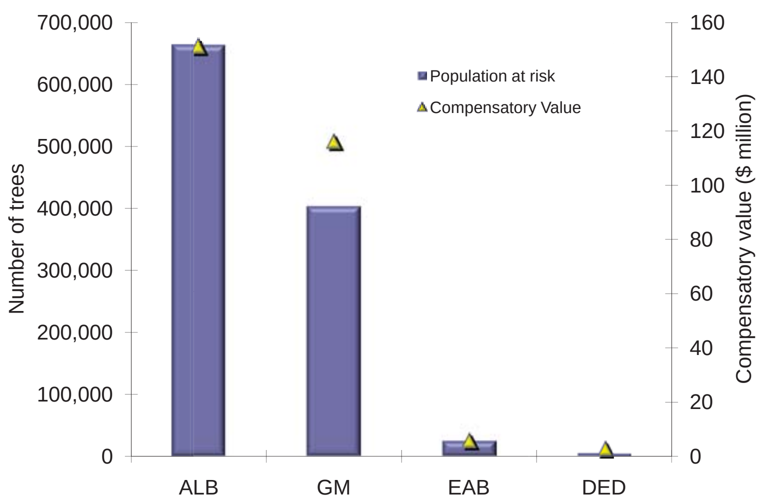
Various insects and diseases can infest urban forests, potentially killing trees and reducing the health, value and sustainability of the urban forest. As various pests have differing tree hosts, the potential damage or risk of each pest will differ. Four exotic pests were analyzed for their potential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

The Asian longhorned beetle (ALB)[16] is an insect that bores into and kills a wide range of hardwood species. This beetle was discovered in 1996 in Brooklyn, NY and has subsequently spread to Long Island, Queens and Manhattan. In 1998, the beetle was discovered in the suburbs of Chicago, IL. Beetles have also been found in Jersey City, NJ (2002), Toronto/Vaughan, Ontario (2003), and Middlesex/Union Counties, NJ (2004). In 2007, the beetle was found on Staten and Prall's Island, NY. Most recently, beetles were detected in Worcester, MA (2008). In urban Scranton, this beetle represents a potential loss of $151 million in structural value (65.2 percent of live tree population).

The gypsy moth (GM)[17] is a defoliator that feeds on many species causing widespread defoliation and tree death if outbreak conditions last several years. This pest could potentially result in damage to or a loss of $116 million in structural value of urban Scranton's trees (39.7 percent of live tree population).

Since being discovered in Detroit in 2002, emerald ash borer (EAB)[18] has killed millions of ash trees in Illinois, Indiana, Kentucky, Maryland, Michigan, Minnesota, Missouri, New York, Ohio, Ontario, Pennsylvania, Quebec, Virginia, West Virginia, and Wisconsin. EAB has the potential to affect 2.4 percent of urban Scranton's live tree population ($5.8 million in structural value).

American elm, one of the most important street trees in the 20th century, has been devastated by Dutch elm disease (DED). Since first reported in the 1930s, it has killed more than 50 percent of the native elm population in the United States.[19] Although some elm species have shown varying degrees of resistance, urban Scranton possibly could lose 0.4 percent of its live trees to this disease ($2.8 million in structural value).



Appendix I. Comparison of Urban Forests

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

I. City totals, trees only

City	% Tree cover	Number of trees	Carbon storage (tons)	Carbon sequestration (tons/yr)	Pollution removal (tons/yr)[1]	Pollution removal value U.S. $[2]
Calgary, Alberta[a]	7.2	11,889,000	445,000	21,400	326	2,357,000
Toronto, Ontario[a*]	19.9	10,220,000	1,221,000	51,500	1,283	10,474,000
Atlanta, GA[b]	36.7	9,415,000	1,344,000	46,400	1,663	12,213,000
Sacramento, CA[c*]	17.0	6,889,000	1,487,000	71,700	2,914	21,730,000
New York, NY[b]	20.9	5,212,000	1,350,000	42,300	1,677	11,834,000
Chicago, IL[d]	17.2	3,585,000	716,000	25,200	888	6,398,000
Baltimore, MD[e]	21.0	2,627,000	597,000	16,200	430	3,123,000
Philadelphia, PA[b]	15.7	2,113,000	530,000	16,100	576	4,150,000
Washington, DC[f]	28.6	1,928,000	526,000	16,200	418	2,858,000
Oakville, Ontario[g]	29.1	1,908,000	147,000	6,600	190	1,421,000
Scranton, PA[h]	22.0	1,198,000	93,000	4,000	72	514,000
Boston, MA[b]	22.3	1,183,000	319,000	10,500	284	2,092,000
Woodbridge, NJ[i]	29.5	986,000	160,000	5,600	210	1,525,000
Minneapolis, MN[j]	26.4	979,000	250,000	8,900	306	2,242,000
Syracuse, NY[e]	23.1	876,000	173,000	5,400	109	836,000
San Francisco, CA[a]	11.9	668,000	194,000	5,100	141	1,018,000
Morgantown, WV[k]	35.5	658,000	93,000	2,900	72	485,000
Moorestown, NJ[i]	28.0	583,000	117,000	3,800	118	841,000
Jersey City, NJ[i]	11.5	136,000	21,000	890	41	292,000
Casper, WY[a]	8.9	123,000	37,000	1,200	37	275,000
Freehold, NJ[i]	34.4	48,000	20,000	550	22	162,000

II. Per acre values of tree effects

City	No. of trees	Carbon Storage (tons)	Carbon sequestration (tons/yr)	Pollution removal (lbs/yr)	Pollution removal value U.S. $[1]
Calgary, Alberta[a]	66.7	2.5	0.12	3.7	13.2
Toronto, Ontario[a*]	64.9	7.8	0.33	16.3	66.5
Atlanta, GA[b]	111.6	15.9	0.55	39.4	144.8
Sacramento, CA[c*]	21.3	4.6	0.22	18.0	67.3
New York, NY[b]	26.4	6.8	0.21	17.0	59.9
Chicago, IL[d]	24.3	4.8	0.17	12.0	43.3
Baltimore, MD[e]	50.8	11.6	0.31	16.6	60.4
Philadelphia, PA[b]	25.1	6.3	0.19	13.6	49.2
Washington, DC[f]	49.0	13.4	0.41	21.2	72.7
Oakville, Ontario[g]	55.6	4.3	0.19	11.0	41.4
Scranton, PA[h]	116.4	9.1	0.39	13.9	49.9
Boston, MA[b]	33.5	9.1	0.30	16.1	59.3
Woodbridge, NJ[i]	66.5	10.8	0.38	28.4	102.9

continued

Appendix I.—continued

City	% Tree cover	Number of trees	Carbon storage (tons)	Carbon sequestration (tons/yr)	Pollution removal (tons/yr)[1]	Pollution removal value U.S. $[1]
Minneapolis, MN[j]	26.2	6.7	0.24		16.3	60.1
Syracuse, NY[e]	54.5	10.8	0.34		13.6	52.0
San Francisco, CA[a]	22.5	6.6	0.17		9.5	34.4
Morgantown, WV[k]	119.2	16.8	0.52		25.9	87.8
Moorestown, NJ[i]	62.1	12.4	0.40		25.1	89.5
Jersey City, NJ[i]	14.4	2.2	0.09		8.6	30.8
Casper, WY[a]	9.1	2.8	0.09		5.5	20.4
Freehold, NJ[i]	38.3	16.0	0.44		35.3	130.1

[1] Pollution removal and values are for carbon monoxide, sulfur and nitrogen dioxide, ozone, and particulate matter less than 10 microns (PM_{10}).

[2] Pollution values updated to 2007 values.

* includes shrub cover in tree cover estimate based on photo-interpretation

<u>Data collection group</u>

[a] City personnel
[b] ACRT, Inc.
[c] Sacramento Tree Foundation
[d] Various Departments of the City of Chicago
[e] U.S. Forest Service
[f] Casey Trees Endowment Fund
[g] City personnel, urban boundary of city
[h] Northeast Pennsylvania Urban & Community Forestry Program staff, Keystone College interns, Penn State Extension Urban Forester, and DCNR Bureau of Forestry staff
[i] New Jersey Department of Environmental Protection
[j] Davey Resource Group
[k] West Virginia University

Appendix II. General Recommendations for Air Quality Improvement

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

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

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

Urban forest management strategies to help improve air quality include:

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

Appendix III. Relative Tree Effects

The urban forest in Scranton provides benefits that include carbon storage and sequestration, and air pollutant removal. To estimate a relative value of these benefits, tree benefits were compared to estimates of average carbon emissions in the city[20], average passenger automobile emissions[21], and average household emissions.[22]

General tree information:

Average tree diameter (d.b.h.) = 4.6 in.
Median tree diameter (d.b.h.) = 2.8 in.
Number of live trees sampled = 1,798
Number of species sampled = 80

Average tree effects by tree diameter:

D.b.h.	Carbon storage			Carbon sequestration			Pollution removal	
Class (inch)	(lbs)	($)	(miles) [a]	(lbs/yr)	($/yr)	(miles)[a]	(lbs)	($)
3-6	7	0.07	20	1.3	0.01	5	0.02	0.06
6-9	43	0.45	160	4.9	0.05	18	0.1	0.22
9-12	154	1.60	570	10.4	0.11	38	0.2	0.66
12-15	342	3.54	1,250	16.6	0.17	61	0.3	1.17
15-18	665	6.88	2,430	25.3	0.26	93	0.5	2.00
18-21	1,031	10.66	3,770	30.3	0.31	111	0.6	2.38
21-24	1,428	14.78	5,230	42.6	0.44	156	0.8	3.06
24-27	2,173	22.48	7,960	54.9	0.57	201	0.8	3.10
27-30	2,703	27.96	9,900	56.9	0.59	208	1.1	4.38
30+	4,579	47.37	16,770	72.4	0.75	265	0.9	3.40
30+	5,502	56.92	20,150	109.8	1.14	402	1.6	6.44

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

The trees in urban Scranton provide:

Carbon storage equivalent to:
Amount of carbon (C) emitted in city in 78 days or
Annual carbon emissions from 56,000 automobiles or
Annual C emissions from 28,100 single family houses

Carbon monoxide removal equivalent to:
Annual carbon monoxide emissions from 5 automobiles or
Annual carbon monoxide emissions from <1 single family houses

Nitrogen dioxide removal equivalent to:
Annual nitrogen dioxide emissions from 500 automobiles or
Annual nitrogen dioxide emissions from 300 single family houses

Sulfur dioxide removal equivalent to:
Annual sulfur dioxide emissions from 9,900 automobiles or
Annual sulfur dioxide emissions from 200 single family houses

Particulate matter less than 10 micron (PM_{10}) removal equivalent to:
Annual PM_{10} emissions from 15,900 automobiles or
Annual PM_{10} emissions from 1,500 single family houses

Annual C sequestration equivalent to:
Amount of C emitted in city in 3.3 days or
Annual C emissions from 2,400 automobiles or
Annual C emissions from 1,200 single family homes

Appendix IV. List of Species Sampled in Scranton

Genus	Species	Common Name	% Population	% Leaf Area	IV[a]
Abies	*concolor*	White fir	0.1	0.2	0.3
Acer	*negundo*	Boxelder	0.4	0.4	0.8
Acer	*palmatum*	Japanese maple	0.2	0.2	0.4
Acer	*platanoides*	Norway maple	3.6	10.8	14.4
Acer	*rubrum*	red maple	10.6	10.6	21.2
Acer	*saccharinum*	Silver maple	1.7	6.7	8.4
Aesculus	*hippocastanum*	Horsechestnut	0	0	0
Ailanthus	*altissima*	Tree of heaven	1.5	2	3.5
Amelanchier	species	Serviceberry	0	0	0
Betula	*lenta*	Black birch	5.6	3.2	8.8
Betula	*nigra*	River birch	0.1	0.5	0.6
Betula	*papyrifera*	Paper birch	0.1	0.1	0.2
Betula	*pendula*	European white birch	0.2	0.1	0.3
Betula	*populifolia*	Gray birch	10.1	2.7	12.8
Betula	species	Birch	0	0	0
Carya	species	Hickory	1.6	0.9	2.5
Castanea	*dentata*	American chestnut	0	0	0
Catalpa	species	Catalpa	0.5	1	1.5
Chionanthus	*virginicus*	Fringe tree	0	0.1	0.1
Cornus	*alternifolia*	Alternateleaf dogwood	0	0	0
Cornus	*florida*	Flowering dogwood	0.2	0.4	0.6
Cornus	*kousa*	Kousa dogwood	0	0	0
Crataegus	*species*	Hawthorn	0.7	0.1	0.8
Elaeagnus	*umbellata*	Autumn olive	0.4	0.2	0.6
Euonymus	*alatus*	Winged burningbush	0	0	0
Fagus	*grandifolia*	American beech	0	0	0
Fagus	*sylvatica*	European beech	0	0	0
Fraxinus	*americana*	White ash	1.9	1.8	3.7
Fraxinus	*pennsylvanica*	Green ash	0.2	0	0.2
Gleditsia	*triacanthos*	Honeylocust	0.1	0.3	0.4
Hamamelis	*virginiana*	Witch hazel	1.2	0.4	1.6
Juglans	*nigra*	Black walnut	0.6	1.4	2
Juniperus	*chinensis*	Chinese juniper	0.1	0	0.1
Juniperus	*species*	Juniper	0	0	0
Kalmia	*latifolia*	Mountain laurel	0.3	0	0.3
Larix	*decidua*	European larch	0	0	0
Lonicera	*tatarica*	Tartarian honeysuckle	0	0	0

Continued

Appendix IV continued.

Genus	Species	Common Name	% Population	% Leaf Area	IV[a]
Malus	*species*	Crabapple	1.3	0.9	2.2
Malus	*tschonoskii*	Tschonoskii crabapple	0.2	0.2	0.4
Morus	*alba*	White mulberry	0	0	0
Nyssa	*sylvatica*	Black tupelo	2.6	1	3.6
Philadelphus	*coronarius*	Sweet mock orange	0	0	0
Picea	*abies*	Norway spruce	0.9	6.2	7.1
Picea	*pungens*	Blue spruce	0.8	3.7	4.5
Pinus	*nigra*	Austrian pine	0	0	0
Pinus	*sylvestris*	Scotch pine	0.6	0.2	0.8
Platanus	*occidentalis*	American sycamore	0	0.7	0.7
Populus	*deltoides*	Eastern cottonwood	0.1	0.1	0.2
Populus	*grandidentata*	Bigtooth aspen	2.2	1.7	3.9
Populus	*tremuloides*	Quaking aspen	7.1	2.5	9.6
Prunus	*americana*	American plum	0	0	0
Prunus	*avium*	Sweet cherry	0.7	0.1	0.8
Prunus	*cerasifera*	Cherry plum	0.2	0.2	0.4
Prunus	*pensylvanica*	Pin cherry	1.9	0.8	2.7
Prunus	*serotina*	Black cherry	8.9	7.3	16.2
Prunus	*virginiana*	Common chokecherry	0.7	0.4	1.1
Prunus	*yedoensis*	Yoshino flowering cherry	0	0	0
Pseudotsuga	*menziesii*	Douglas fir	0.1	0.1	0.2
Pyrus	*calleryana*	Callery pear	0.2	0.6	0.8
Pyrus	species	Pear	0.1	0.2	0.3
Quercus	*alba*	White oak	2.3	3	5.3
Quercus	*coccinea*	Scarlet oak	1.2	1.5	2.7
Quercus	*ilicifolia*	Bear oak	1.4	0.6	2
Quercus	*palustris*	Pin oak	0.3	0.5	0.8
Quercus	*prinus*	Chestnut oak	2.6	2.9	5.5
Quercus	*rubra*	Northern red oak	8.1	11.3	19.4
Quercus	*velutina*	Black oak	0.8	0.6	1.4
Rhamnus	*species*	Buckthorn	0	0	0
Rhododendron	*azalea*	Azalea	0.1	0	0.1
Rhododendron	species	Rhododendron	0	0	0
Rhus	species	Sumac	3.4	0.2	3.6
Robinia	*pseudoacacia*	Black locust	5.4	2.8	8.2
Rosa	*banksiae*	Banksian rose	0	0	0
Salix	*nigra*	Black willow	0	0.3	0.3

Continued

Appendix IV continued.

Genus	Species	Common Name	% Population	% Leaf Area	IV[a]
Sassafras	*albidum*	Sassafras	0.8	0.2	1
Syringa	species	Lilac	0	0	0
Taxus	*baccata*	English yew	0.2	0.4	0.6
Taxus	*cuspidata*	Japanese yew	0.1	0.1	0.2
Thuja	*occidentalis*	Northern white cedar	0.1	0	0.1
Tsuga	*canadensis*	Eastern hemlock	0.8	3.1	3.9
Ulmus	*americana*	American elm	0.4	0.9	1.3
Ulmus	*pumila*	Siberian elm	0.1	0.4	0.5
Ulmus	species	Elm	0.1	0	0.1

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

Note: 0% indicates a value less than 0.05% but greater than 0

Appendix V. Tree Planting Index Map

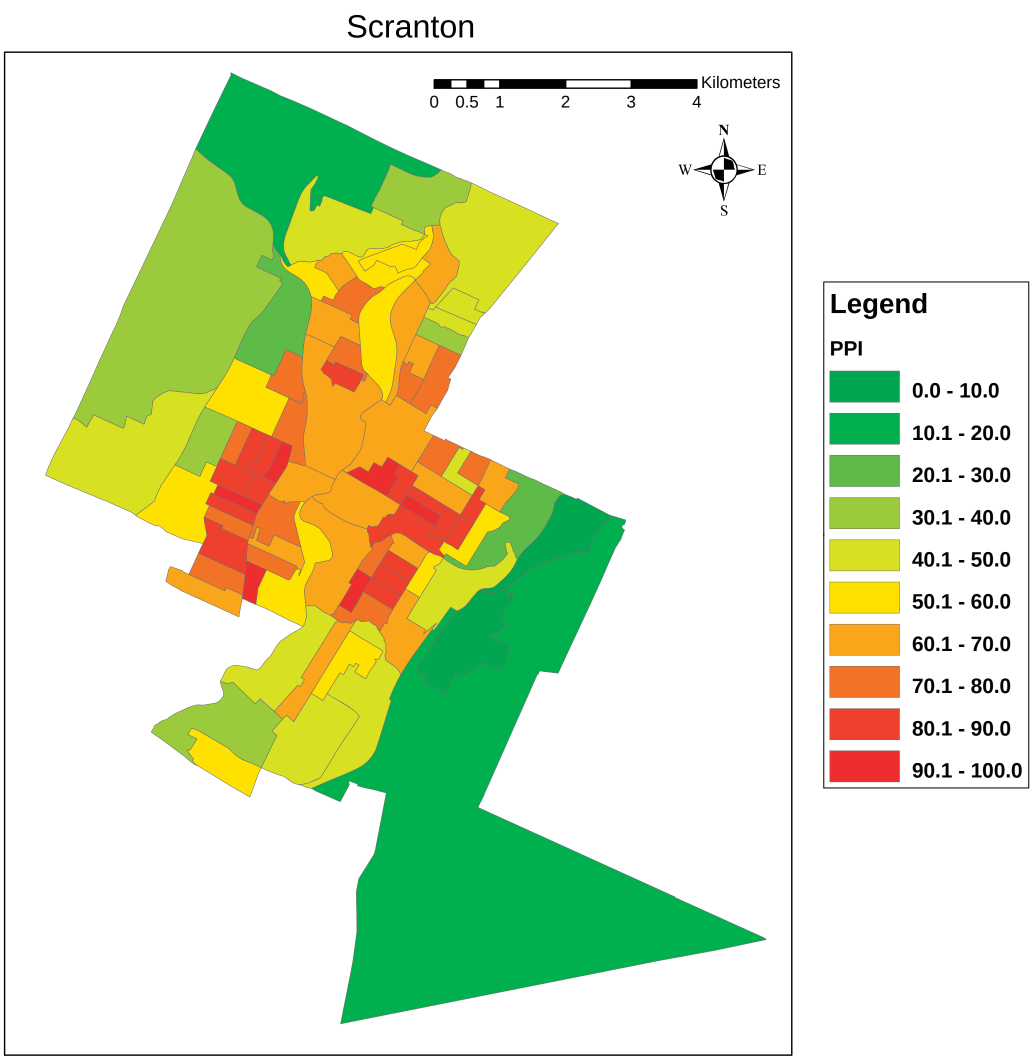
To determine the best locations to plant trees, tree canopy and impervious cover maps from National Land Cover Data[23] were used in conjunction with 2000 U.S. Census data to produce an index of priority planting areas. Index values were produced for each census block group with the higher the index value, the higher the priority of the area for tree planting. This index is a type of "environmental equity" index with areas with higher human population density and lower tree cover tending to get the higher index value. The criteria used to make the index were:

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

Each criteria was standardized[24] 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). 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.



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Explanation of Calculations of Appendix III and IV

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

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

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

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

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CO_2, SO_2, and NOx power plant emission per KWh from:

U.S. Environmental Protection Agency. U.S. power plant emissions total by year www.epa.gov/cleanenergy/egrid/samples.htm.

CO emission per kWh assumes one-third of 1 percent of C emissions is CO based on:

Energy Information Administration. 1994. Energy use and carbon emissions: non-OECD countries. DOE/EIA-0579(94). Washington, DC: Department of Energy, Energy Information Administration. http://tonto.eia.doe.gov/bookshelf

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CO_2, NOx, SO_2, PM_{10}, 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:

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Residential Wood Burning Emissions in British Columbia. 2005. http://www.env.gov.bc.ca/air/airquality/pdfs/wood_emissions.pdf.

Emissions per dry tonne of wood converted to emissions per Btu based on average dry weight per cord of wood and average Btu per cord from:

Kuhns, M.; Schmidt, T. 1988. Heating with wood: species characteristics and volumes I. NebGuide G-88-881-A. Lincoln, NE: University of Nebraska, Institute of Agriculture and Natural Resources, Cooperative Extension.

23 National Land Cover Data are available at: www.epa.gov/mrlc/nlcd-2001.html

24 Standardized value for population density was calculated as PD = (n – m)/r, where PD is the value (0-1), n is the value for the census block (population / km^2), m is the minimum value for all census blocks, and r is the range of values among all census blocks (maximum value – minimum value). Standardized value for tree stocking was calculated as TS = 1 – [t/(t+g)], where TS is the value (0-1), t is percent tree cover, and g is percent grass cover. Standardized value for tree cover per capita was calculated as TPC = 1 – [(n – m)/r], where TPC is the value (0-1), n is the value for the census block (m^2/capita), m is the minimum value for all census blocks, and r is the range of values among all census blocks (maximum value – minimum value).

Nowak, David J.; Hoehn, Robert E. III; Crane, Daniel E.; Stevens, Jack C.; Cotrone, Vincent. 2010. **Assessing urban forest effects and values, Scranton's urban forest.** Resour. Bull. NRS-43. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 23 p.

An analysis of trees in the urbanized portion of Scranton, PA, reveals that this area has about 1.2 million trees with canopies that cover 22.0 percent of the area. The most common tree species are red maple, gray birch, black cherry, northern red oak, and quaking aspen. Scranton's urban forest currently store about 93,300 tons of carbon valued at $1.9 million. In addition, these trees remove about 4,000 tons of carbon per year ($83,000 per year) and about 65 tons of air pollution per year ($514,000 per year). Trees in urban Scranton are estimated to reduce annual residential energy costs by $628,000 per year. The structural, or compensatory, value is estimated at $322 million. Information on the structure and functions of the urban forest can be used to inform urban forest management programs and to integrate urban forests within plans to improve environmental quality in the Scranton area.

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

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