i-Tree Ecosystem Analysis

City of Durham

Urban Forest Effects and Values
August 2012

i-Tree

UFORE
Urban Forest Effects Model

Foreword

The City of Durham is known for having abundant, mature tree canopy coverage. There is an emotional connection between residents and the urban forest, and economic values can be easily appreciated as well. Ecological services, however, are not as easily understood and appreciated.

This report provides an overall estimation of the tree canopy in Durham, OR and summarizes how properties of the tree canopy contribute to ecosystem functions. The intended use for this report is to be a reference to aid in comprehensive planning, to foster validation for existing trees, and to connect the concept of the urban forest to a broader function of the city as an ecosystem. This assessment can be useful in determining means of maintaining and improving the value of natural resources in this community, thus enhancing the quality of life for inhabitants.

Purposes of canopy assessment:

- Contribute to overall environmental assessment and planning
- Increase success of tree preservation efforts
- Maximize benefits of trees to maintain as an asset to the city
- Contribute to a vision for the future of Durham's urban forest

Scope and Limitations of Canopy Assessment Report

Newly emerging technology, such as iTree Eco Model (v 4.1.0) used in this assessment, offer means to fulfill the need to better understand existing conditions of community natural assets.

This canopy assessment is based on sample data, as opposed to a complete inventory. Pests, hazard tree risk, and disease have not been assessed in this report. Further survey and assessment work would be necessary to understand the threat or impact of these additional urban forest conditions. This report is not a complete inventory and does not present data on specific locations.

Surveys were conducted to collect field data from thirty randomly located plots throughout Durham. The random sample plots were used in conjunction with local pollution and meteorological data to quantify urban forest structure, environmental effects, and value to communities. The sample design was stratified to exclude industrial areas, and include commercial, residential, institutional, and park properties.

Although limited spatial information is presented about the specific distribution and conditions of urban trees, this has been a cost-effective way to measure the urban tree canopy using free resources. This baseline of data can be useful in demonstrating the value of Durham's urban tree canopy, could aid in making informed management decisions and serve as a foundation for any future monitoring or urban forestry related efforts that may be undertaken. Periodic analysis of the urban tree canopy can be useful for adapting city plans, to direct management strategies, implement protection, and for maintenance of Durham's urban forest. Public awareness of current conditions facilitates acceptance of trees as a worthy investment by quantifying services that demonstrate the functional and structural values of trees – values enhanced by tree maturity when properly managed.

- Heather Reed, 2012 summer intern for the Oregon Department of Forestry in the Urban and Community Forestry Program.

Summary

Understanding an urban forest's structure, function and value can promote management decisions that will improve human health and environmental quality. An assessment of the vegetation structure, function, and value of the City of Durham urban forest was conducted during 2012. Data from 30 random field plots located throughout City of Durham were analyzed using the Urban Forest Effects (UFORE) model developed by the U.S. Forest Service, Northern Research Station.

Key findings

- Number of trees: 17,500
- Tree cover: 44.1%
- Most common species: Douglas fir, Bigleaf maple, Red alder
- Percentage of trees less than 6" (15.2 cm) diameter: 29.6%
- Pollution removal: 2 tons/year ($16.5 thousand/year)
- Carbon storage: 6,300 tons ($116 thousand)
- Carbon sequestration: 202 tons/year ($3.72 thousand/year)
- Structural values: $41.5 million

Ton: short ton (U.S.) (2,000 lbs)
Carbon storage: the amount of carbon bound up in the above-ground and below-ground parts of woody vegetation
Carbon sequestration: the removal of carbon dioxide from the air by plants through photosynthesis
Structural value: value based on the physical resource itself (e.g., the cost of having to replace a tree with a similar tree)
Monetary values($) reported in US Dollar throughout report except where noted

For an overview of UFORE methodology, see Appendix I. Data collection quality is determined by the local data collectors, over which i-Tree has no control. Additionally, some of the plot and tree information may not have been collected, so not all of the analyses may have been conducted for this report.

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I. Tree Characteristics of the Urban Forest

The urban forest of City of Durham has an estimated 17,500 trees with a tree cover of 44.1 percent. Trees that have diameters less than 6-inches (15.2 cm) constitute 29.6 percent of the population. The three most common species are Douglas fir (25.60 percent), Bigleaf maple (13.80 percent), and Red alder (9.85 percent).

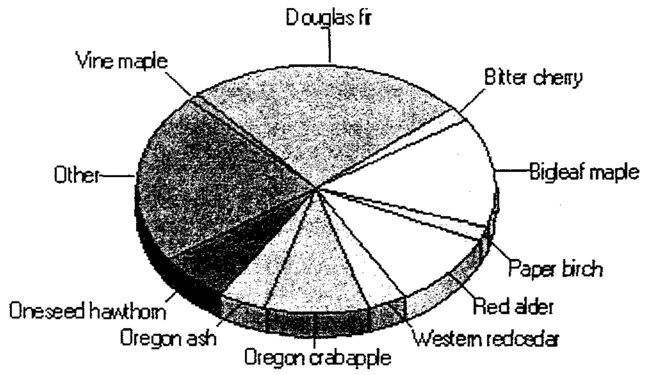
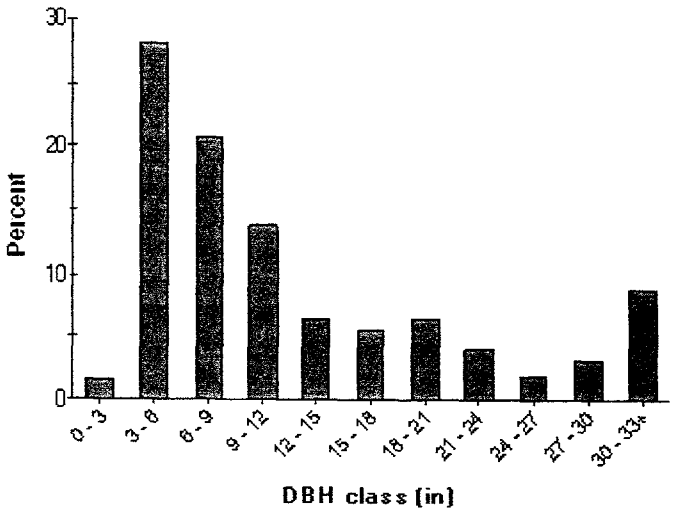


Figure 1. Tree species composition in City of Durham



The overall tree density in City of Durham is 71.2 trees / acre (see Appendix III for comparable values from other cities).

Figure 3. Percent of tree population by diameter class (DBH=stem diameter at 4.5 feet)

Urban forests are composed of a mix of native and exotic tree species. Thus, urban forests often have a tree diversity that is higher than surrounding native landscapes. An increased tree diversity can minimize the overall impact or destruction by a species-specific insect or disease, but it can also pose a risk to native plants if some of the exotic species are invasive plants that can potentially out-compete and displace native species. In City of Durham, about 82 percent of the trees are from species native to North America, while 74 percent are native to the state or district. Species exotic to Oregon make up 18 percent of the population. Most exotic tree species have an origin from Europe & Asia (12.6 percent of the species).

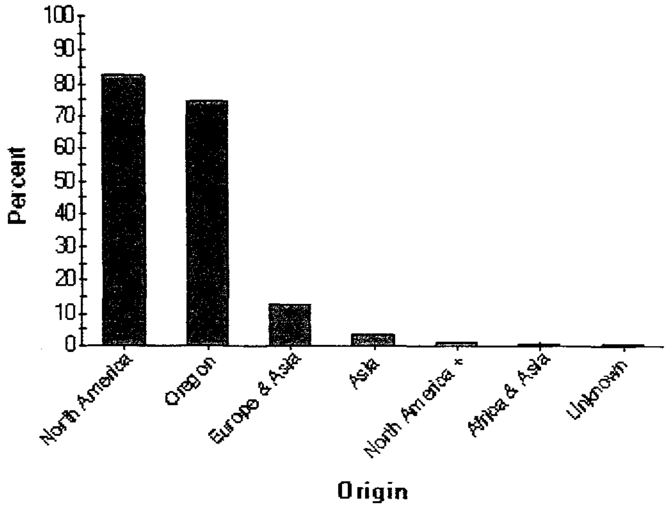


Figure 4. Percent of live trees by species origin

"North America +" = native to North America and at least one other continent except South America

II. Urban Forest Cover and Leaf Area

Many tree benefits equate directly to the amount of healthy leaf surface area of the plant. In City of Durham, the three most dominant species in terms of leaf area are Douglas fir, Bigleaf maple, and Oregon ash. Trees cover about 44.1 percent of City of Durham, and shrubs cover 25.1 percent.

The 10 most important species are listed in the table below. Importance values (IV) are calculated as the sum of relative leaf area and relative composition.

Table 1. Most important species in City of Durham

Species Name	*Percent Population*	*Percent Leaf Area*	*IV*
Douglas fir	25.6	44.8	70.4
Bigleaf maple	13.8	10.2	24.0
Red alder	9.9	4.7	14.5
Oregon ash	4.4	9.6	14.1
Oregon crabapple	9.4	3.2	12.6
Black poplar	1.0	8.4	9.4
Oneseed hawthorn	6.4	1.5	7.9
Western redcedar	3.4	2.8	6.2
Bitter cherry	2.0	0.7	2.7
Oregon white oak	1.0	1.4	2.4

The two most dominant ground cover types are Herbs (20 percent) and Grass (17 percent).

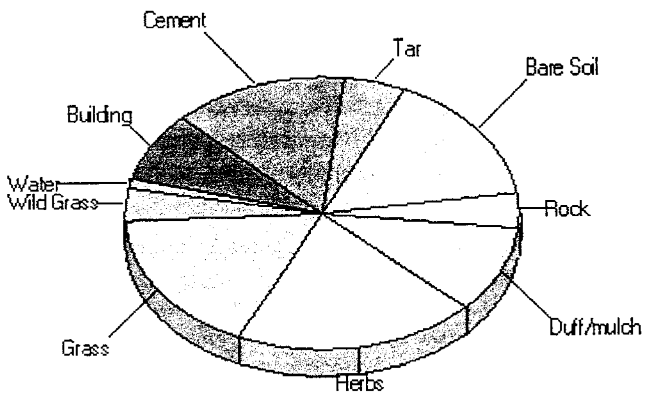


Figure 5. Percent ground cover in City of Durham

III. Air Pollution Removal by Urban Trees

Poor air quality is a common problem in many urban areas. It can lead to decreased human health, 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 reduces air pollutant emissions from the power plants. Trees also emit volatile organic compounds that can contribute to ozone formation. However, integrative studies have revealed that an increase in tree cover leads to reduced ozone formation[1].

Pollution removal by trees and shrubs in City of Durham was estimated using field data and recent pollution and weather data available. Pollution removal was greatest for ozone. It is estimated that trees and shrubs remove 2 tons of air pollution (ozone (O3), carbon monoxide (CO), nitrogen dioxide (NO2), particulate matter less than 10 microns (PM10), and sulfur dioxide (SO2)) per year with an associated value of $16.5 thousand based on estimated national median externality costs associated with pollutants[2]. United States externality pollution values[26] will be substituted for international studies when pollutant values are not available.

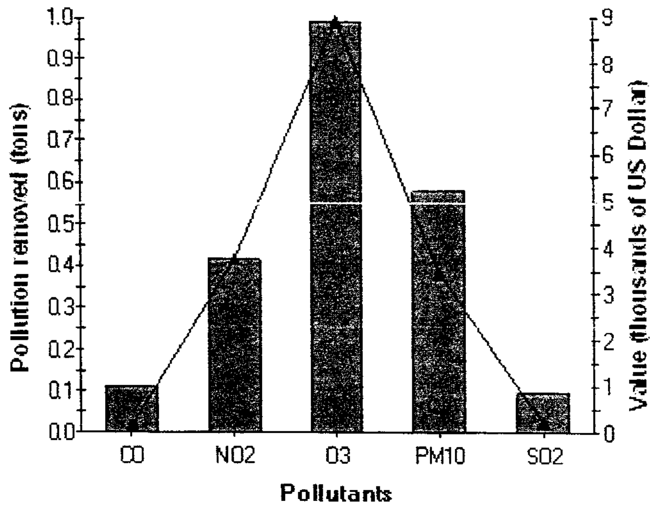


Figure 6. Pollution removal and associated value for trees in City of Durham (line graph is value)

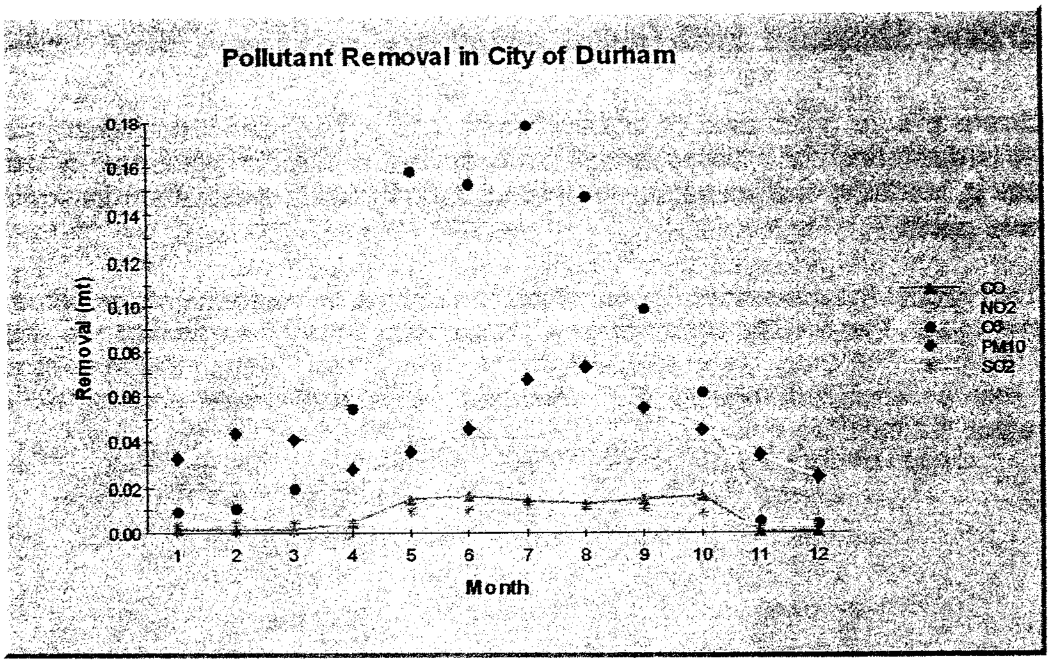


Figure 2. Pollutant Removal by trees in the City of Durham

IV. 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 altering energy use in buildings, and consequently altering carbon dioxide emissions from fossil-fuel based power plants[3].

Trees reduce the amount of carbon in the atmosphere by sequestering carbon in new growth every year. The amount of carbon annually sequestered is increased with the size and health of the trees. The gross sequestration of City of Durham trees is about 202 tons of carbon per year with an associated value of $3.72 thousand. Net carbon sequestration in the urban forest is about 112 tons.

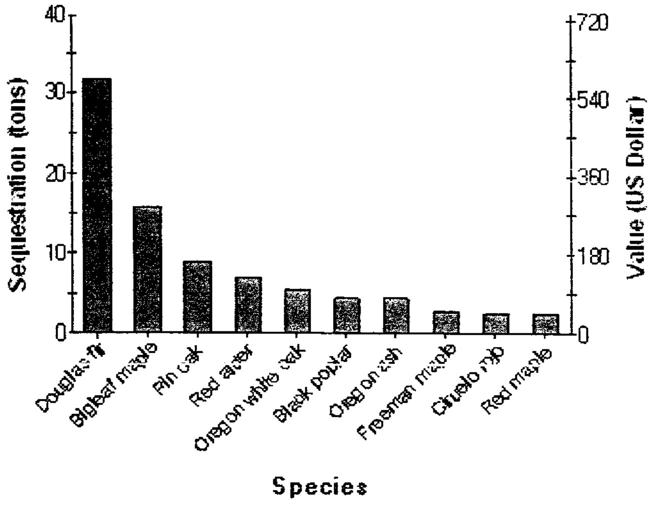


Figure 7. Carbon sequestration and value for species with greatest overall carbon sequestration in City of Durham
(Ciruelo rojo is a common name for purple leaf plum, *Prunus cerasifera* var. *nigra)*

As trees grow they store more carbon as wood. As trees die and decay, they release much of the stored carbon back to the atmosphere. Thus, carbon storage is an indication of the amount of carbon that can be lost if trees are allowed to die and decompose. Trees in City of Durham are estimated to store 6,300 tons of carbon ($116 thousand). Of all the species sampled, Douglas fir stores and sequesters the most carbon (approximately 61.3% of the total carbon stored and 28.4% of all sequestered carbon.)

V. Structural and Functional Values

Urban forests have a structural value based on the trees themselves (e.g., the cost of having to replace a tree with a similar tree); they also have functional values (either positive or negative) based on the functions the trees perform.

The structural value of an urban forest tends to increase with a rise in the number and size of healthy trees [6]. 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. 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.

<u>Structural values:</u>

- Structural value: $41.5 million
- Carbon storage: $116 thousand

<u>Annual functional values:</u>

- Carbon sequestration: $3.72 thousand
- Pollution removal: $16.5 thousand

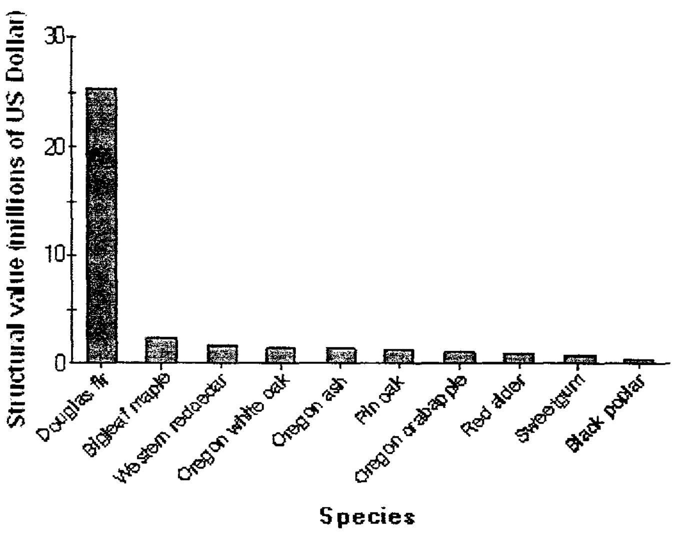


Figure 8. Structural value of the 10 most valuable tree species in City of Durham

VI. Potential Pest Impacts

Various insects and diseases can infest urban forests, potentially killing trees and reducing the health, value and sustainability of the urban forest. As pests tend to 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 (ALB), gypsy moth (GM), emerald ash borer (EAB), and Dutch elm disease (DED).

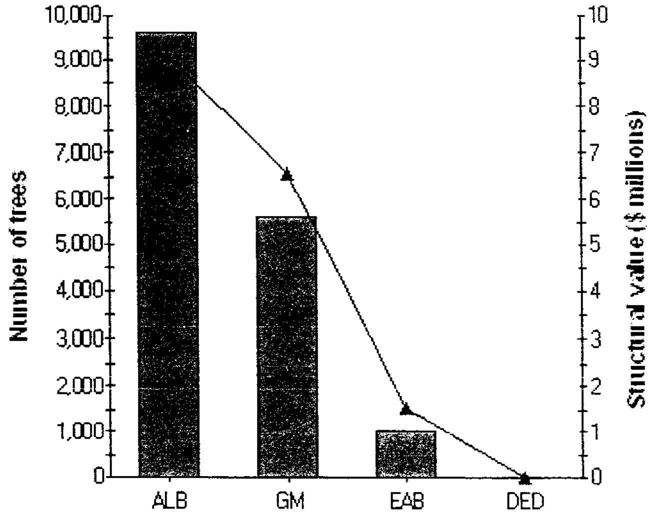


Figure 9. Number of susceptible City of Durham trees and structural value by pest (line graph is structural value)

The Asian longhorned beetle (ALB) [7] is an insect that bores into and kills a wide range of hardwood species. ALB poses a threat to 54.7 percent of the City of Durham urban forest, which represents a loss of $9.08 million in damage to the structure.

The gypsy moth (GM)[8] is a defoliator that feeds on many species causing widespread defoliation and tree death if outbreak conditions last several years. This pest threatens 32 percent of the population, which represents a loss of $6.57 million in structural value.

Emerald ash borer (EAB)[9] has killed thousands of ash trees in parts of the United States. EAB has the potential to affect 5.9 percent of the population ($1.51 million in structural damage).

American elm, one of the most important street trees in the twentieth century, has been devastated by the Dutch elm disease (DED)[10]. Since first reported in the 1930s, it has killed over 50 percent of the native elm population in the United States. Although some elm species have shown varying degrees of resistance, City of Durham could possibly lose 0 percent of its trees to this pest ($0 in structural value).

VII. Stewardship Recommendations

The presence of true-laminated root rot, *Phellinus weirii* (also known as *P. sulphurascens*), should have a significant impact on species selection for future tree plantings in the city of Durham. Laminated root rot is named for its action on decayed roots, which separate like pages in a book. This fungal pathogen is known to be the worst disease to affect mature Douglas-fir, the predominant species of Durham's tree canopy, and can persist in stumps and soil for decades. Healthy seedlings and tree roots can be infected upon contact with this lingering root pathogen, leading to death, decay, hazardous and pest-prone trees.

Trees resistant to laminated root rot (such as cedar, pine, or hardwoods) should be favored when planting new trees, instead of attempting to restore Douglas-fir trees losses. Another factor to consider when selecting trees to plant in the future would be the substantial amount of shade cast by the mature tree canopy, and tolerance capacity for added tree species to thrive in this understory. Species diversity would be a beneficial goal to adopt in tree planting efforts. These goals would collectively help to reduce maintenance costs and tree-related problems. Promoting the benefits of trees to enhance stewardship of private land, and identifying public sites to plant new trees would also be advantageous for maximizing the value of Durham's urban forest.

VIII. List of Recommended Tree Species for Durham, OR

Acer griseum	Paperbark maple
Acer japonicum 'Aconitifolium'	Full moon maple
Acer palmatum 'Sango-kaku'	Japanese coral bark maple
Amelanchier alnifolia	Serviceberry, Saskatoon
Betula nigra 'Cully'	Heritage® River Birch
Carpinus betulus	Hop hornbeam
Carpinus betulus 'Fastigiata'	Pyramidal hop hornbeam
Celtis occidentalis	Hackberry
Cercidiphyllum japonicum	Katsuratree
Cercis canadensis	Eastern redbud (many ornamental varieties available)
Cladrastis lutea	Yellowwood
Cornus alternifolia	Pagoda dogwood
Cornus mas	Cornelian cherry
Davidia involucrata	Dovetree
Fagus sylvatica	European beech (other ornamental varieties available)
Franklinia alatamaha	Franklin tree
Fraxinus americana	white ash (many ornamental varieties available)
Fraxinus pennsylvanica Summit'	Summit green ash
Ginkgo biloba 'Magyar'	Magyar maidenhair tree
Ginkgo biloba 'Fairmount'	Fairmount maidenhair tree
Ginkgo biloba 'PNI 2720'	Princeton Sentry® maidenhair tree
Halesia carolina	Carolina silverbell
Hamamellis spp.	Witch hazel (many ornamental varieties available)
Heptacodium miconioides	Seven-sons tree
Laburnum watereri	Golden-chain tree
Larix kaempferi	Japanese larch
Magnolia denudata	Yulan magnolia
Magnolia grandiflora 'Edith Bogue'	Edith Bogue Southern magnolia
Magnolia grandiflora 'Victoria'	Victoria Southern magnolia
Magnolia stellata 'Royal Star'	Royal Star magnolia
Magnolia x *soulangiana*	Saucer magnolia (many ornamental varieties available)
Malus Sentinel'	Sentinel crabapple
Malus 'Spring Snow'	Spring snow crabapple
Metasequoia glyptostroboides	Dawn redwood
Nyssa sylvatica	Tupelo
Oxydendrum arboreum	Sourwood
Parrotia persica	Ironwood
Picea omorika 'Nana'	Dwarf Serbian spruce
Picea sitchensis 'Papoose'	Dwarf sitka spruce

Pinus lambertiana	Sugar pine
Pinus nigra	Austrian black pine
Pyrus calleryana	Callery Pear
Quercus frainetto	Hungarian Oak
Quercus imbricaria	Shingle Oak
Quercus phellos	Willow Oak
Quercus robur 'Fastigiata'	Columnar English oak
Quercus rubra	Red oak
Sambucus racemosa	Elderberry (several varieties)
Sciadopitys verticillata	Japanese umbrella pine
Stewartia pseudocamellia	Japanese stewartia
Styrax japonicus	Japanese snowbell
Styrax obassia	Bigleaf snowbell
Taxodium distichum	Bald cypress
Thuja occidentalis 'Emerald'	American arborvitae, Eastern white cedar
Thuja plicata	Western redcedar
Tilia cordata	Little leaf linden
Zelkova serrata	Japanese Zelkova

For more tree information *http://oregonstate.edu/dept/ldplants/*
www.greatplantpicks.org/
http://rainyside.com/

Appendix I. UFORE Model and Field Measurements

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 [5], including:

- Urban forest structure (e.g., species composition, tree health, leaf area, 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.
- Structural value of the forest, as well as the value for air pollution removal and carbon storage and sequestration.
- Potential impact of infestations by Asian longhorned beetles, emerald ash borers, gypsy moth, and Dutch elm disease.

In the field 0.10 acre plots were randomly distributed. Typically, all field data are collected during the leaf-on season to properly assess tree canopies. Within each plot, typical data collection (actual data collection may vary depending upon the user) includes land use, ground and tree cover, individual tree attributes of species, stem diameter, height, crown width, crown canopy missing and dieback, and distance and direction to residential buildings[11,26].

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[12]. To adjust for this difference, biomass results for open-grown urban trees were multiplied by 0.8. 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.

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[13,14]. 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[15,16] that were adjusted depending on leaf phenology and leaf area. Particulate removal incorporated a 50 percent resuspension rate of particles back to the atmosphere[17]. Recent updates (2011) to air quality modeling are based on improved leaf area index simulations, weather and pollution processing and interpolation, and updated pollutant monetary values[27,28,29].

If appropriate field data were collected, seasonal effects of trees on residential building energy use were calculated based on procedures described in the literature[4] using distance and direction of trees from residential structures, tree height and tree condition data.

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.

Structural values were based on valuation procedures of the Council of Tree and Landscape Appraisers, which uses tree species, diameter, condition and location information[18].

Appendix II. Relative Tree Effects

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

Carbon storage is equivalent to:
- Amount of carbon emitted in City of Durham in 281 days
- Annual carbon (C) emissions from 3,780 automobiles
- Annual C emissions from 1,900 single-family houses

Carbon monoxide removal is equivalent to:
- Annual carbon monoxide emissions from automobiles
- Annual carbon monoxide emissions from 2 single-family houses

Nitrogen dioxide removal is equivalent to:
- Annual nitrogen dioxide emissions from 26 automobiles
- Annual nitrogen dioxide emissions from 18 single-family houses

Sulfur dioxide removal is equivalent to:
- Annual sulfur dioxide emissions from 138 automobiles
- Annual sulfur dioxide emissions from 2 single-family houses

Particulate matter less than 10 micron (PM10) removal is equivalent to:
- Annual PM10 emissions from 1,540 automobiles
- Annual PM10 emissions from 149 single-family houses

Annual carbon sequestration is equivalent to:
- Amount of carbon emitted in City of Durham in 9 days
- Annual C emissions from 100 automobiles
- Annual C emissions from 100 single-family houses

Note: estimates above are partially based on the user-supplied information on human population total for study area

Appendix III. Comparison of Urban Forests

A common question asked 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 for trees

City	*% Tree Cove*	*Number of trees*	*Carbon storage (tons)*	*Carbon Sequestration (tons/yr)*	*Pollution removal (tons/yr)*	*Pollution Value (USD)*
Calgary, Canada	7.2	11,889,000	445,000	21,422	326	1,611,000
Atlanta, GA	36.8	9,415,000	1,345,000	46,433	1,662	2,534,000
Toronto, Canada	20.5	7,542,000	992,000	40,345	1,212	6,105,000
New York, NY	21.0	5,212,000	1,351,000	42,283	1,677	8,071,000
Baltimore, MD	21.0	2,627,000	596,000	16,127	430	2,129,000
Philadelphia, PA	15.7	2,113,000	530,000	16,115	576	2,826,000
Washington, DC	28.6	1,928,000	523,000	16,148	418	1,956,000
Boston, MA	22.3	1,183,000	319,000	10,509	284	1,426,000
Woodbridge, NJ	29.5	986,000	160,000	5561.00	210	1,037,000
Minneapolis, MN	26.5	979,000	250,000	8,895	305	1,527,000
Syracuse, NY	23.1	876,000	173,000	5,425	109	268,000
Morgantown,	35.9	661,000	94,000	2,940	66	311,000
Moorestown, NJ	28.0	583,000	117,000	3,758	118	576,000
Jersey City, NJ	11.5	136,000	21,000	890	41	196,000
Freehold, NJ	34.4	48,000	20,000	545	21	133,000

II. Per acre values of tree effects

City	*No. of trees*	*Carbon storage (tons)*	*Carbon sequestration (lbs/yr)*	*Pollution removal (lbs/yr)*	*Pollution Value (USD)*
Calgary, Canada	66.7	2.5	0.120	3.6	9.0
Atlanta, GA	111.6	15.9	0.550	39.4	30.0
Toronto, Canada	48.3	6.4	0.258	15.6	39.1
New York, NY	26.4	6.8	0.214	17.0	40.9
Baltimore, MD	50.8	11.5	0.312	16.6	41.2
Philadelphia, PA	25.0	6.3	0.190	13.6	33.5
Washington, DC	49.0	13.3	0.410	21.2	49.7
Boston, MA	33.5	9.0	0.297	16.0	40.4
Woodbridge, NJ	66.5	10.8	0.375	28.4	70.0
Minneapolis, MN	26.2	6.7	0.238	16.4	40.9
Syracuse, NY	54.5	10.8	0.338	13.6	16.7
Morgantown, WV	119.7	17.0	0.532	23.8	56.3
Moorestown, NJ	62.0	12.5	0.400	25.2	61.3
Jersey City, NJ	14.3	2.2	0.094	8.6	20.7
Freehold, NJ	38.5	16.0	0.437	33.6	106.6

Appendix IV. General Recommendations for Air Quality Improvement

Urban vegetation can directly and indirectly affect local and regional air quality by altering the urban atmosphere environment. Four main ways that urban trees affect air quality are[22]:

- Temperature reduction and other microclimate effects
- Removal of air pollutants
- Emission of volatile organic compounds (VOC) and tree maintenance emissions
- Energy effects on buildings

The cumulative and interactive effects of trees on climate, pollution removal, and VOC and power plant emissions determine the 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[23]. Local urban management decisions also can help improve air quality.

Urban forest management strategies to help improve air quality include[24]:

Strategy	***Result***
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

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

20. Average passenger automobile emissions per mile were based on dividing total 2002 pollutant emissions from light-duty gas vehicles (National Emission Trends http://www.epa.gov/ttn/chief/trends/index.html) divided 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/).

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