Seattle's Forest Ecosystem Values

Analysis of the Structure, Function, and Economic Benefits

August 2012

GREEN CITIES RESEARCH ALLIANCE

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The Green Cities Research Alliance (GCRA) was initiated by the USDA Forest Service, Pacific Northwest Research Station in 2009 to build a program of research about urban ecosystems in the Puget Sound region. GCRA is an integrated social-ecological research program that engages the social and biophysical sciences to meet the practical needs and concerns of local organizations and agencies. It also is an effort to coordinate science and community partners within the Pacific Northwest region, and to link investigations to other U.S. urban areas. The goal of this collaboration is to increase the knowledge necessary to build healthy, sustainable urban environments.

GCRA pairs scientists with practitioners and local decision makers to co-design and implement research efforts that provide relevant and practical information. Studies are being conducted across the urban to rural landscape to learn more about multiple systems, including urban forests, parks, open spaces, and waterways. Results are intended to support better ecological and resources planning, decision making, and ecosystem recovery. Start-up funding for GCRA was provided by the 2009 American Reinvestment and Recovery Act. One set of projects assessed urban forest structure, condition, values, and human interactions across King County, WA. Major collaborators include the University of Washington, King County, Forterra, and the City of Seattle.

For more information, visit www.fs.fed.us/pnw/research/gcra

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Uncredited photos were taken by Lisa Ciecko.

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At the time of publication, a USDA Forest Service General Technical Report was being drafted to provide additional project details. For more information, please contact Lisa Ciecko at lciecko@forterra.org or Dr. Dale Blahna at dblahna@fs.fed.us.

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credit: Charlie Lane

Executive Summary

Across Seattle, in backyards and lush parklands, along parking lots and on college campuses, trees and other vegetation make up a dynamic urban forest. For the first time in history more than 50% of the earth's population lives in urban areas, and in the United States over 80% of the population lives in cities. City residents and visitors benefit from a myriad of services provided by the urban forest. Trees and nature make urban communities more livable and vibrant.

The Forest Ecosystem Values Project began in 2010 using the USDA Forest Service's i-Tree Eco tool to conduct a comprehensive analysis of the current extent and condition of Seattle's urban forest. Tree and shrub size and species information was used to quantify associated ecosystem functions and their public benefits and economic values. This research produced the following findings about Seattle's urban forest:

Urban Forest Structure

- The **number of trees** and tree-like shrubs in Seattle is estimated to be 4.35 million. This equates to a density of nearly 80 trees and tree-like shrubs per acre.
- The three **most common species** measured were red alder, big leaf maple, and beaked hazelnut, which are all native to the region. In total, there were 192 different species identified in the research plots.
- The **replacement value** of the urban forest in Seattle is estimated at $4.9 billion. Though not always recognized as such, the city's trees are an important capital asset.

Ecosystem Functions and Values

- An estimated 2 million metric tons of **carbon** dioxide equivalent is stored in Seattle's trees and tree-like shrubs with an additional 140,000 metric tons of carbon dioxide equivalent sequestered annually. These carbon benefits are estimated to equal $10.9 million in savings from carbon storage and $768,000 annually from carbon sequestration.
- The forest in Seattle removes 725 metric tons of **pollution** from the environment every year, providing a pollution removal value of $5.6 million annually.
- Seattle's urban forest reduces **energy** use in residential buildings by roughly 166,000 million British thermal units of natural gas and 43,000 megawatt hours of electricity, for an annual savings of $5.9 million dollars.

Threats to the Urban Forest

- An assessment of susceptibility to **pest species** indicates Seattle's forest is at risk. As an example, if Asian longhorned beetle were to reach Seattle it could affect 39.5% of urban forest plant population, which has an estimated impact of $2.58 billion dollars.
- **Invasive species** threaten the health and diversity of Seattle's urban forest. This research included additional analysis of two common invasive tree species, cherry laurel and English holly, confirming their escape from cultivation and the need for aggressive removal and management.

Seattle's urban forest is an important resource and a component of the city's infrastructure that offers significant benefits. A better understanding of the values that these trees have on urban livability will encourage and support ongoing resource management, decision making, and funding priorities.

Background

Forest Ecosystem Values Project

The Forest Ecosystem Values Project was initiated by the Green Cities Research Alliance in 2010 to improve knowledge about the structure, function, and value of Seattle's urban forest. The research team began field data collection during the summer of 2010 in Seattle with additional projects undertaken during 2011 and 2012 in King County Parks and the Green-Duwamish River Corridor. This report highlights a unique on-the-ground look at Seattle's forest.

Seattle is part of a rapidly growing metropolitan region that is home to more than 3 million residents. Historically, Seattle's landscape was dominated by lowland coniferous forests, large salt marsh estuaries, and pockets of oak prairies. Today, the region supports a new type of forest where both native and non-native plants, including ornamental and food producing trees, are found throughout the built environments where people live, work, learn, and play.

To protect the health and maintain the benefits provided by the urban forest, the City of Seattle adopted the Urban Forest Management Plan (UFMP) in 2007. The plan calls for an increase in citywide canopy cover from 23% to 30% by 2037. Effective planning and management are dependent on ongoing analysis and monitoring of resources. The information reported here supports Seattle's urban forest management work by providing a snapshot of the current state of the urban forest.

An **urban forest** can be defined as the individual trees and groves that are found in and around the places we live. This includes forested parks and natural areas, as well as the trees along streets and in yards. Looking at an aerial photo can help one to visualize the urban forest; trees and other vegetation create a matrix of green across the city landscape.

Urban Forest Assessment

Urban forest assessment is essential for developing a baseline from which to measure changes and trends. Managing the urban forest includes tree maintenance, policy development, and budgetary decisions - all of which depend on understanding current urban forest conditions. This can be accomplished using indicators of forest health or structure, such as the number of plants, their location, species mix, and age distribution. Cities across the United States have undertaken urban forest assessment projects using both on-the-ground measurements and remote sensing analysis.

Seattle's urban forest has been studied previously. Projects include a satellite imagery analysis in 2009, an urban forest program analysis in 2000, an ecosystem service assessment using the CityGreen tool in 1998, continued development of the Seattle Department of Transportation (SDOT) street tree database, as well as extensive surveys of natural area parks and ongoing monitoring of forested park restoration efforts. The research reported here adds another layer of information, providing more extensive data on current forest conditions.

Ecosystem Services

Why are these studies important? More than 20 years of research has helped communities understand the importance of having a quality urban forest. Assessments of the urban forest can be used to estimate environmental benefits, or ecosystem services, improving our understanding of the role trees play in creating healthy, livable and sustainable cities. Some of the recognized benefits of urban forests include:

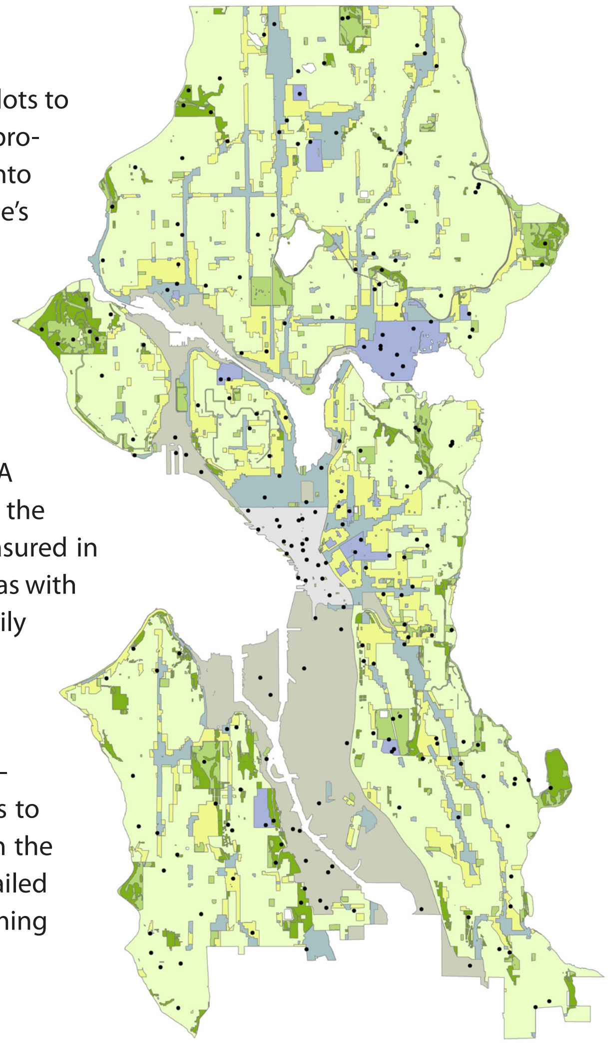
- Reducing stormwater runoff by intercepting rainfall, which reduces impacts to water quality in adjacent lakes and streams
- Lowering energy bills by reducing wind and sun exposure around buildings
- Providing habitat for wildlife
- Capturing and filtering air pollutants
- Improving the appearances of neighborhoods
- Increasing human well-being through recreation and personal restoration opportunities
- Improved public health as a result of services such as increased neighborhood walkability and cleaner air

This report focuses on a subset of recognized ecosystem services, ones that can be easily quantified and converted to dollar values. This report does not serve as a comprehensive assessment of the value of the trees in Seattle, but does provide an economic valuation for some of the quantifiable services provided by the urban forest.

Project Methods

Study Design

Researchers used a system of randomly distributed 1/10-acre plots to capture a representative sample of Seattle's urban forest. To provide results that would be relevant and readily incorporated into Seattle's urban forestry efforts, the study was stratified by Seattle's Urban Forest Management Units, which are based on city zoning. The Transportation Corridor management unit was not included in the sample selection process as these lands are embedded throughout all the other management units.



The table below depicts the percent of the city's land base and the number of completed research plots by management unit. A total of 223 plots were visited within the City of Seattle during the summers of 2010 and 2011. A minimum of 20 plots were measured in each management unit, with additional plots completed for areas with high tree cover and species variability, such as the Single-family Residential management unit.

With the goal to capture a sample that represents the full extent of Seattle's urban forest, data collection on private property was an essential component of this research. When access to private property was not granted, the next random plot within the same management unit was selected for data collection. Detailed outreach methods and results will be included in a forthcoming USDA Forest Service General Technical Report.

Urban Forest Management Units	City Area	Completed Plots
Single-family Residential	56%	73
Multi-family Residential	11%	25
Commercial/Mixed Use	8%	23
Downtown	1%	20
Industrial and Manufacturing	11%	21
Major Institutions	2%	21
Developed Parks or Boulevards	4%	20
Natural Area Parks	7%	20

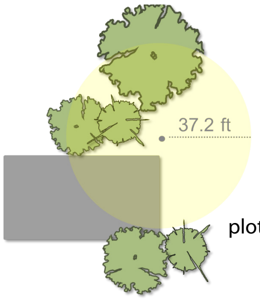
The research reported here used the **i-Tree Eco** tool. i-Tree is a suite of urban forestry tools developed by the USDA Forest Service (USFS) that integrates peer-reviewed field methods and analysis software. Since the release of i-Tree in 2006, over 50 U.S. municipalities, multiple international cities, and numerous individuals have used i-Tree to report on their urban forests. i-Tree Eco was designed to assist with the collection of baseline or periodic data to quantify the structure, environmental effects, and economic values of trees. For more information, visit www.itreetools.org.

Field Measurements

Researchers used field data collection methods outlined by the i-Tree Eco tool. For each plot in Seattle, a field crew completed a series of measurements to capture both general plot and vegetation-specific data (listed at the right). Measurements of the size and condition of each woody plant were recorded for each plot. Data collection occurred while trees were fully leafed out, from May through mid-October, in order to capture accurate canopy characteristics. Over 1,700 trees and tree-like shrubs were measured within the 223 plots.

Data Analysis

Initial field data analysis was prepared by i-Tree Eco scientists with the USDA Forest Service and State University of New York. Additional analysis was undertaken by project researchers to explore information of specific interest in Seattle.



plot layout

DATA COLLECTION

Plot Information	Vegetation Information
date	tree location
crew	tree species
plot identification number	diameter at breast height
plot address	total tree height
reference photos	crown base height
reference object location	crown width
land use	percent crown missing
percent tree cover	crown dieback
percent shrub cover	impervious cover beneath canopy
x,y coordinates	shrub cover beneath canopy
	crown light exposure
	residential building locations
	street tree status

Results

Urban Forest Structure

Assessing the structure of Seattle's urban forest provides a picture of the current extent and condition of the forest. Forest structure refers to the amount and density of plants, the types of plants present (e.g. herbaceous plants, trees, shrubs), the diversity of species, as well as the age diversity . Understanding these characteristics informs urban forest management efforts, in addition to providing information to estimate the benefits and services provided by the urban forest.

To fully capture the value of the urban forest, researchers included trees and other woody vegetation that have a size or function in the environment similar to trees. Trees and tree-like shrubs make up the measured vegetation. Where possible, measured vegetation is divided into:

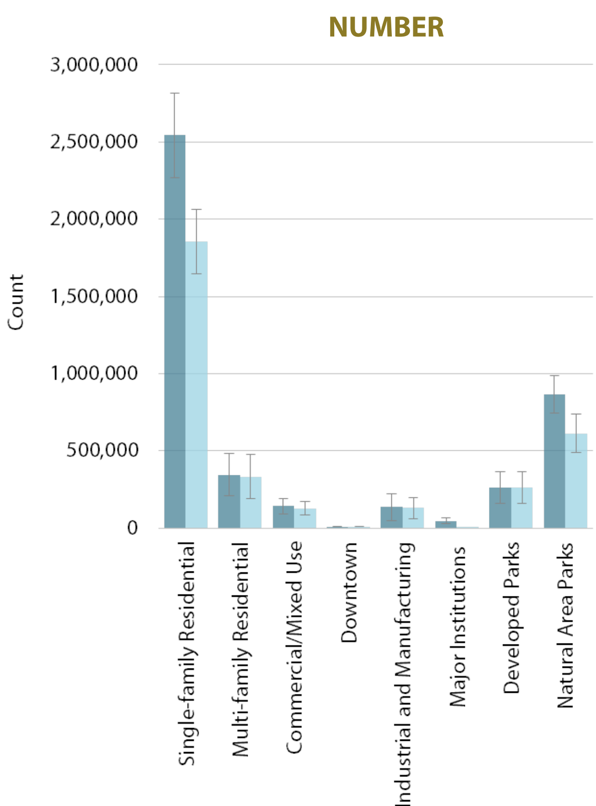
Urban Forest values include estimates for all measured vegetation which includes all woody vegetation with a diameter at breast height (DBH) greater than or equal to one inch.

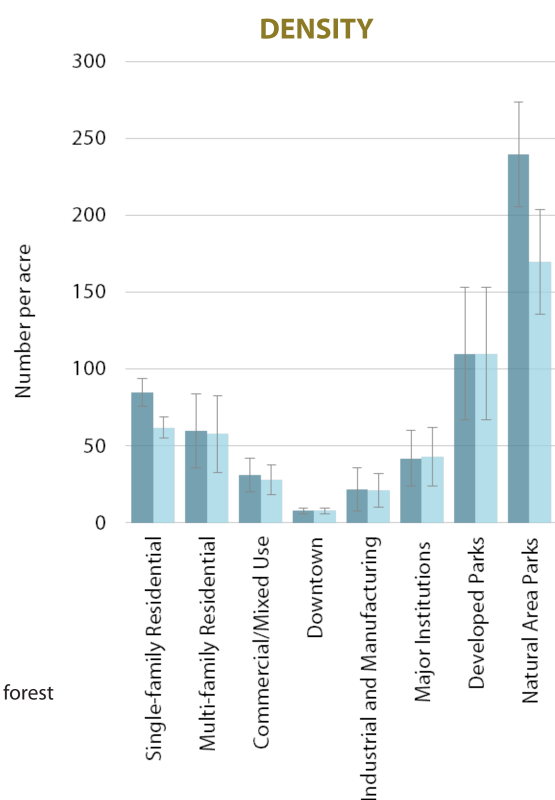
Tree values include species identified by project researchers as trees (see Appendix for more information).

Urban Forest Population

Seattle's urban forest includes an estimated 4.35 million trees and tree-like shrubs. Citywide, this equates to approximately 7 trees and tree-like shrubs per person. As a comparison, Los Angeles has 6 million trees, or about 1.5 trees per person, while Toronto reports 10.2 million trees, or about 4 trees per person.

The abundance of trees differs by management unit. The management unit covering the most land in the city, Single-family Residential, contains the majority of trees and large shrubs, roughly 58%. Natural Area Parks have the highest density of trees, or the average number of trees and tree-like shrubs per acre. While they make up just 7% of the land base, Natural Area Parks are home to the second largest amount of trees, roughly 20% of the total tree population.





Urban Forest Diversity

The diversity of a forest is the measure of the range of different species found in one area. High plant species diversity is a characteristic of forests that function well, making them more capable of withstanding disturbances like weather events, insects or diseases. In urban settings, both native and non-native species can be part of resilient forests as long as efforts are made to plant the right tree in the right place.

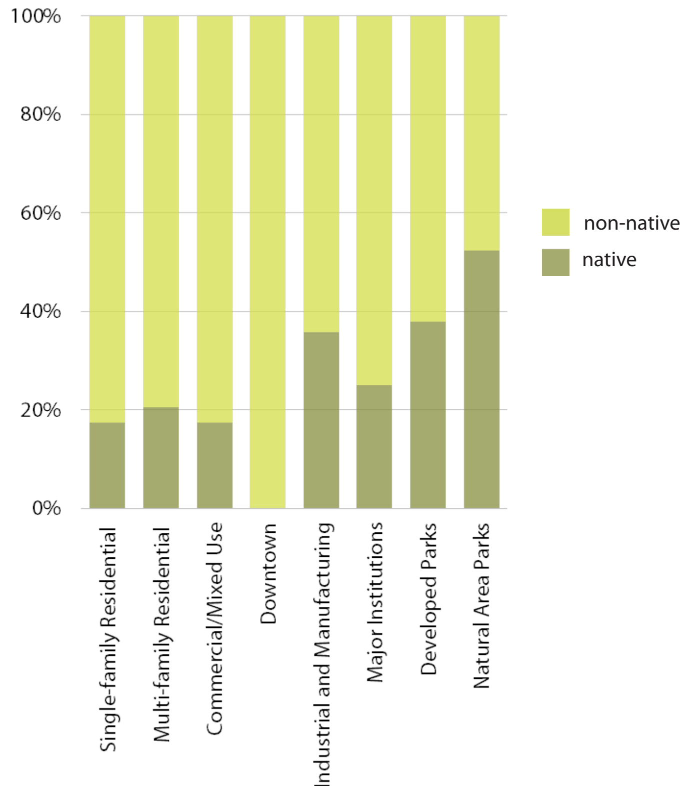
During field data collection, researchers identified 192 species in Seattle, 28 of which are native to the Puget Sound region. Three natives, red alder (*Alnus rubra*), big leaf maple (*Acer macrophyllum)*, and beaked hazelnut (*Corylus cornuta*), are the most common species, accounting for 20% of the urban forest in Seattle. Common in Natural Area Parks, beaked hazelnut is included in the top three because it is a small tree that forms dense thickets, with each above-ground stem being counted as an individual tree.

The forest in the Single-family Residential management unit is by far the most diverse, with more than double the amount of unique species than any other management unit in the city. Parks (both Natural Area and Developed) and Major Institutions are dominated by species native to Washington State while the majority of the trees in Downtown, Commercial, and Single-family Residential management units are not native to the state. The table to the right lists the most prevalent species found citywide.

MOST COMMON SPECIES

Urban Forest Species		Tree Species	
red alder	12%	red alder	15%
big leaf maple	9%	big leaf maple	11%
beaked hazelnut	5%	western red cedar	4%
indian plum	4%	Douglas fir	4%
western red cedar	3%	arborvitae	4%
Douglas fir	3%	cherry laurel	3%
arborvitae	3%	cherry species	3%
cherry laurel	3%	English holly	3%
rhododendron species	3%	Japanese maple	2%
cherry species	2%	willow species	2%

NATIVE VS NON-NATIVE



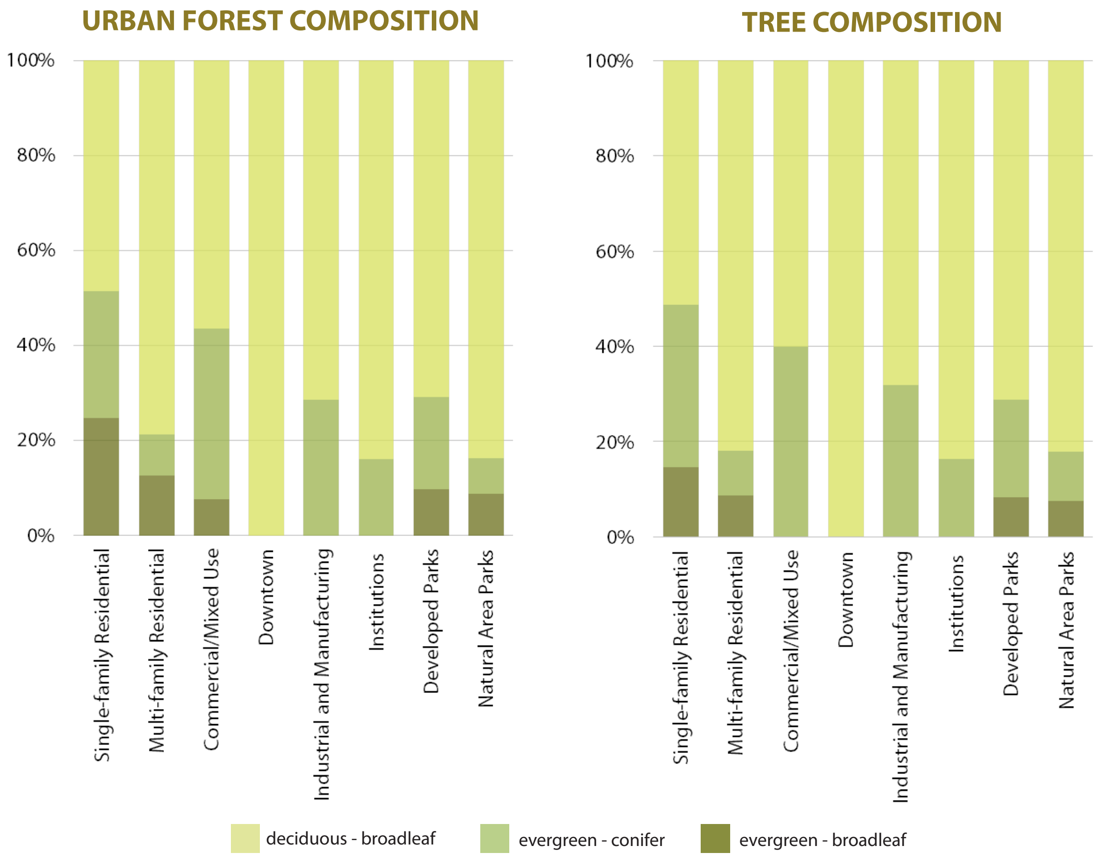
Urban Forest Trends: Evergreen vs Deciduous

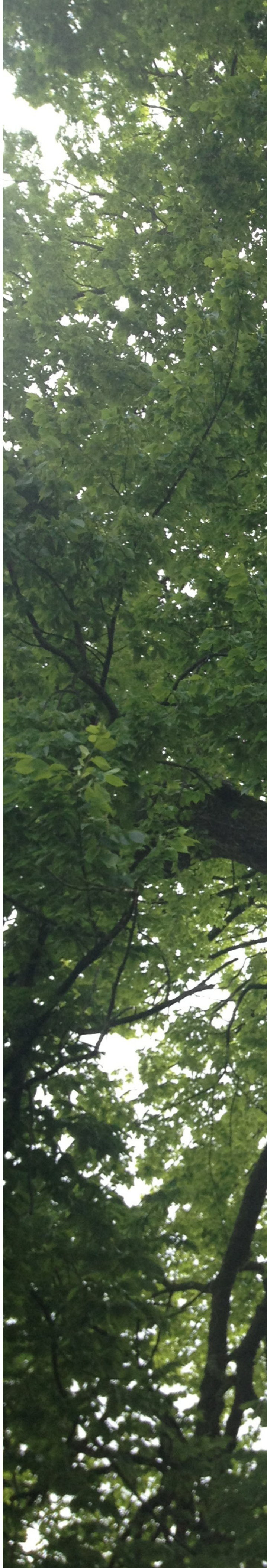
Evergreens play a key role in Seattle's urban forest because they provide ecosystem benefits year-round. With 39% of Seattle's rainfall occurring during winter months (December through February), evergreens are especially important in managing stormwater. They help reduce surface water flow, thereby reducing soil erosion, pollutant loads, and sewage overflows in water bodies throughout the region.

Large evergreen conifer species, such as western red cedar (*Thuja plicata*) and Douglas fir (*Pseudotsuga mensiezii*), are iconic of the Pacific Northwest. Urbanization has left little room for these giants. In Natural Area Parks where we would expect to see these large trees, very few conifers have naturally reestablished after being logged at the turn of the 20th century.

The terms **evergreen** and **deciduous** refer to whether a plant retains its foliage year round. Deciduous species, such as maples, alders, and ashes, shed their leaves annually. Evergreen trees are true to their name and keep their foliage for more than one season. Both evergreen and deciduous species can be characterized as **coniferous** or **broadleaf**. Broadleaf evergreen species have leaves as opposed to conifers which have needles. Broadleaf evergreen species are especially common in temperate climates and include pacific madrone, cherry laurel, holly, and rhododendrons. Deciduous conifers are less common, but Seattle is home to larches, dawn redwoods, and bald cypress that shed their needles annually.

To better understand the composition of deciduous and evergreen species in Seattle's urban forest, additional analysis was completed. Vegetation within each of the sampled plots was identified as evergreen or deciduous, as well as broadleaf or coniferous. The graph below shows the percent distribution of deciduous and evergreen species by urban forest management unit.





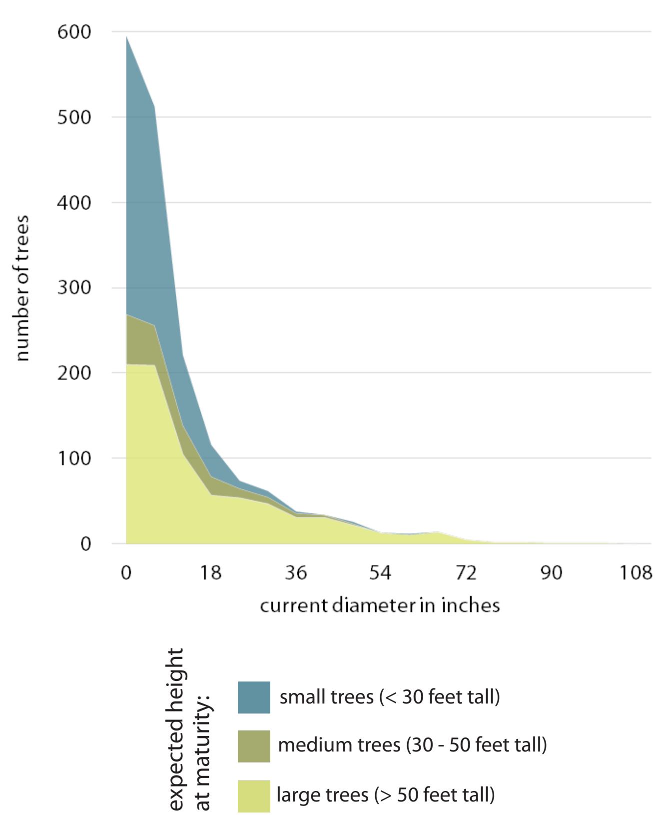
Age and Size

The current size of trees and tree-like shrubs is a good predictor of future trends in urban forest composition and structure. Because age cannot be accurately measured without intrusive methods such as tree coring, size (in this case trunk diameter) paired with species-specific growth curves is used as a proxy for age. Trunk diameter is recorded at 4.5 feet above the ground.

Larger trees provide substantially more ecosystem services (like air quality and water quality protection) than smaller trees. However, the space to grow and maintain large trees in the city is limited and small trees collectively play an important role in improving urban habitats. It is important to remember that some small trees today are young while others are simply smaller species.

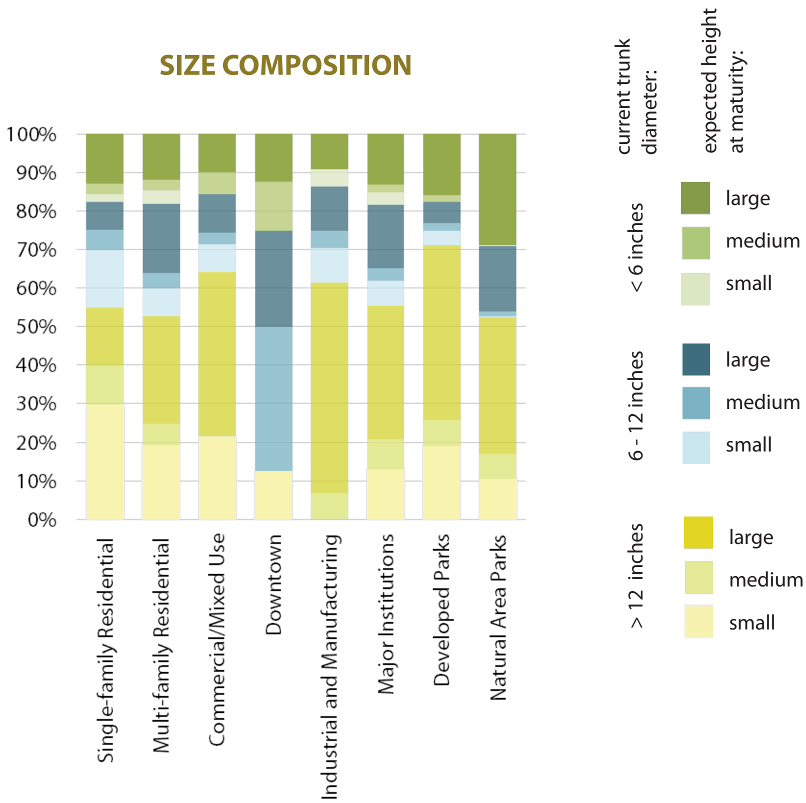
To help illustrate the size potential of the urban forest, tree species were organized into three groups according to their maximum height potential. In this classification system, small trees are those that do not grow taller than 30 feet, medium trees can reach heights between 30 and 50 feet, while large trees exceed 50 feet in height at maturity.

CITYWIDE TREE SIZE



In Seattle's Natural Area Parks management unit 29% of the trees are greater than 12 inches in diameter, while 53% have a diameter of 6 inches or less. Of these small diameter trees, 68% are species that are large at maturity (taller than 50 feet). So while they are small today, they have the potential to increase in size over time.

Meanwhile, within the Single-family Residential management unit, 18% of the urban forest trees are over 12 inches in diameter and 55% are less than 6 inches diameter. On average, 46% of the tree species that will be large at maturation currently have a trunk diameter less than 12 inches.



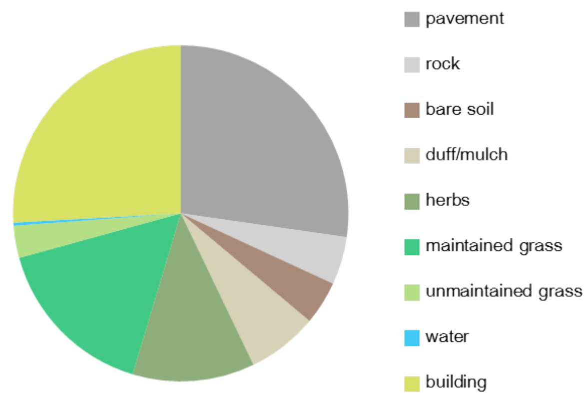
Ground Cover

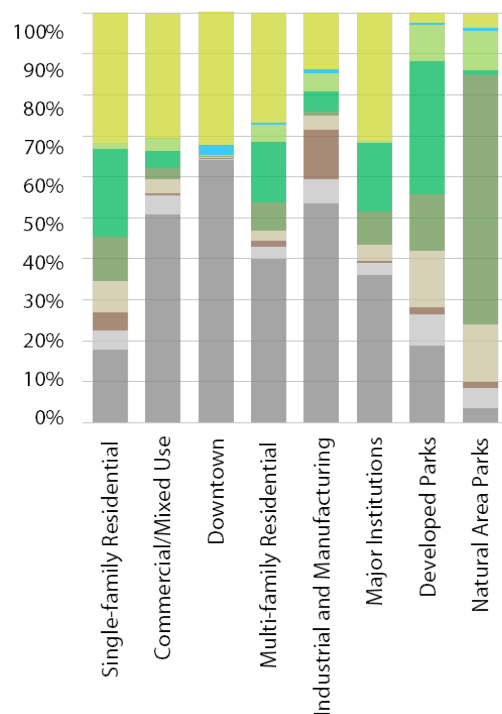
The urban forest softens the impact of impervious surfaces, like roads, buildings, and to a lesser degree maintained grass. Impervious surfaces reduce water infiltration and increase runoff, affecting regional water quality. By measuring ground cover we can assess the distribution of impervious surfaces.

Tree cover reduces stormwater impacts by intercepting rainfall, slowing water movement, and increasing infiltration in the ground. Previous research in Seattle suggests that an evergreen conifer canopy that hangs over an impervious surface can reduce runoff by approximately 27%.

The field crew measured ground cover type at each plot. The chart to the right represents citywide cover estimates. The amount of each cover type varied by management unit. Downtown plots were dominated by pavement (64%) and buildings (32%), while Single-family Residential plots had similar building cover (31%), but lower pavement cover (17%) and maintained grass (23%).

CITYWIDE GROUND COVER





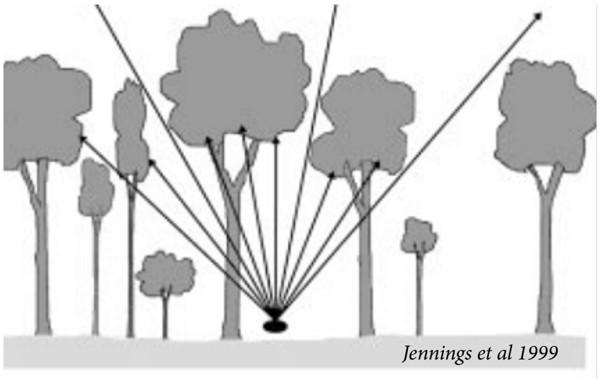
Canopy Cover Analysis

Canopy cover is an indicator of the extent, distribution, and health of the urban forest. As such, canopy cover is used frequently in urban forestry planning to represent forest conditions and as a performance benchmark to evaluate progress towards meeting urban forest management goals. Seattle's Urban Forest Management Plan calls for an increase in citywide canopy cover from 23% to 30% percent by 2037.

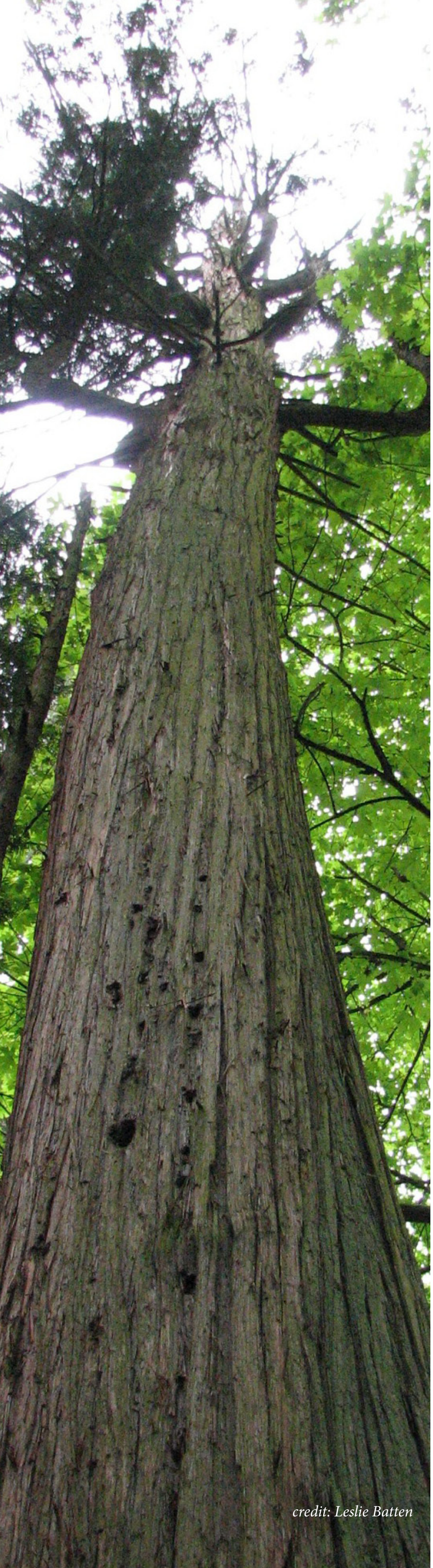
Canopy estimates can be produced using on-the-ground methods or by interpretation of aerial imagery, such as satellite data. Research reported here used ocular methods defined by i-Tree Eco. An ocular estimate is a visual assessment of tree cover from different locations around the research plot. These values were then interpolated to estimate canopy cover values citywide and per management unit.

In 2009, City of Seattle conducted canopy mapping that used 2002 and 2007 satellite imagery, differentiating woody vegetation from other ground cover to tally both citywide canopy cover values and values per management unit.

ocular estimate



satellite analysis

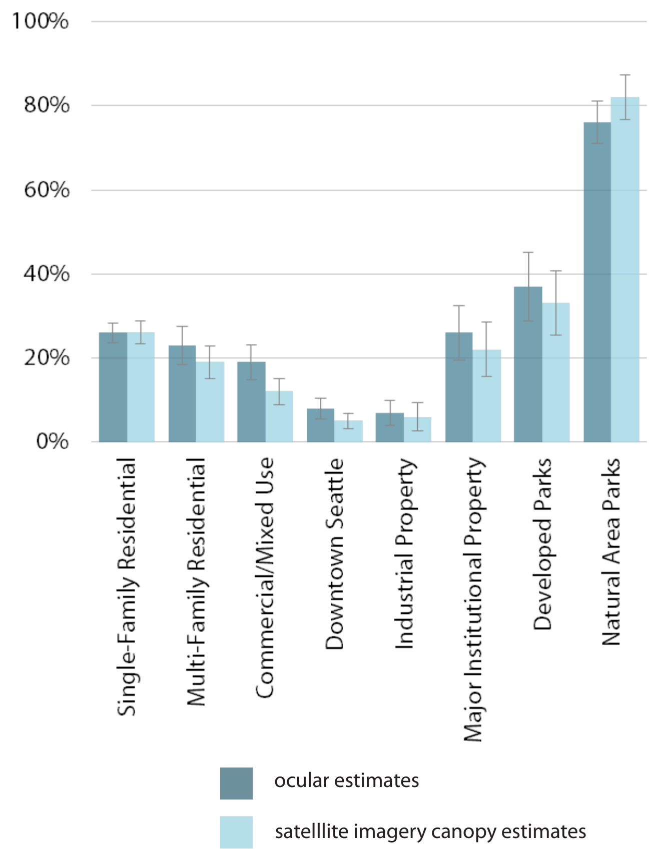


credit: Leslie Batten

Because canopy cover values are important to urban forest management efforts in Seattle, additional analysis to compare these two canopy cover data sets, the earlier remotely sensed measures and the more recent ocular estimates, is essential.

Statistical tests were used to compare ocular canopy estimates at each of the 223 i-Tree Eco research plots with canopy values derived from satellite imagery analysis for the same plot areas. The statistical comparisons take into account natural variation and data errors. Results generally show no significant differences between the two canopy cover measurement methods either across the city, or in most of the management units. However, significant differences between the two measurements were found in both the Commercial and Multi-family Residential management units.

CANOPY ANALYSIS COMPARISONS



Observed differences between these two datasets could be due to either canopy growth and loss that occurs over time or the differences in the methods used to derive the canopy estimates. Canopy trends are better assessed by comparing previous and current conditions using the same measurement methods.

For these reasons, the canopy values determined during this project using the ocular methods should not replace the results of the satellite imagery analysis. Urban forest management decisions based on canopy values need to consider the inherent error and adapt as more information becomes available over time.

Urban Forest Functions and Values

The urban forest is a key component of Seattle's infrastructure, providing essential services with environmental and economic benefits. Characterizing the city's urban forest structure enables us to explore and quantify a subset of these benefits, specifically air pollution removal values, carbon sequestration and storage, and energy savings, in addition to the replacement value of Seattle's urban forest.

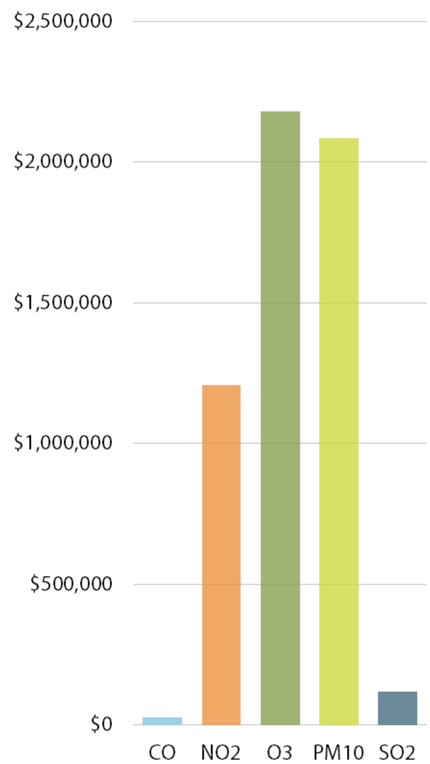
Pollution Removal

Trees play a vital role in reducing the impacts of pollution generated by common human activities. The physical processes of plants that help improve air quality include intercepting particulate matter on leaf surfaces and absorbing pollutants.

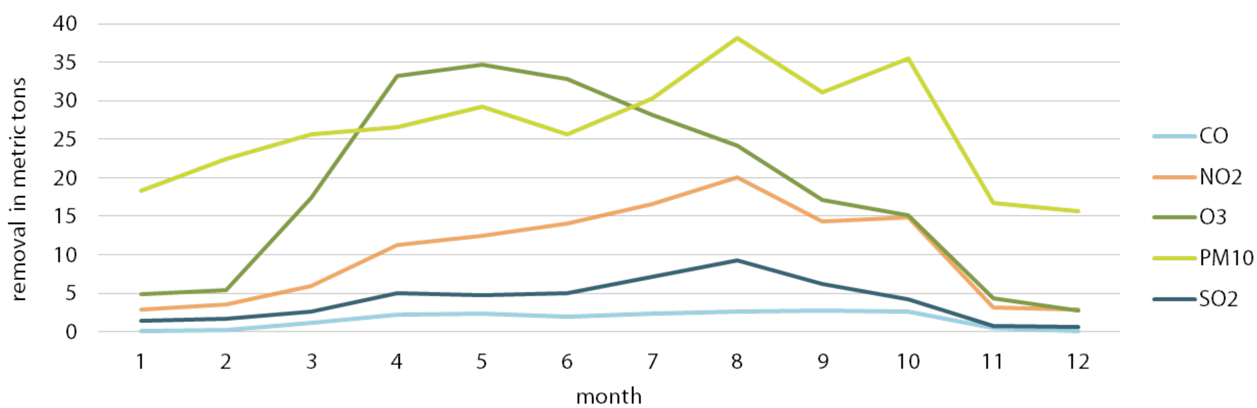
Analysis of research plot data suggests that Seattle's urban forest removes 725 metric tons of pollutants annually, valued at $5.62 million. The i-Tree model estimates included five common pollutants: ozone (O3), sulfur dioxide (SO2), nitrogen dioxide (NO2), carbon monoxide (CO), and particulate matter less than 10 microns (PM10).

i-Tree Eco uses local pollution concentration data, local weather data, and leaf area estimates derived from tree measurements. Economic valuation uses national median costs for each pollutant. Some vegetation produces volatile organic compounds (VOC) that can increase ozone pollution. To account for this, the i-Tree model includes both reduction and production values. As is common with urban forests, Seattle's trees have a positive overall effect on ozone levels.

POLLUTION REMOVAL VALUES



ANNUAL POLLUTION REMOVAL



Carbon Storage and Sequestration

Carbon dioxide (CO_2) is a greenhouse gas that is associated with global climate change. Trees reduce CO_2 concentrations through two different processes – carbon storage and carbon sequestration.

Carbon storage refers to the carbon bound in above- and below-ground plant tissues, including roots, stems, and branches. Once plants die and begin decomposing, carbon is slowly released back to the system. For example, stored carbon can be released into the atmosphere as CO_2 or stored as organic matter in the soil.

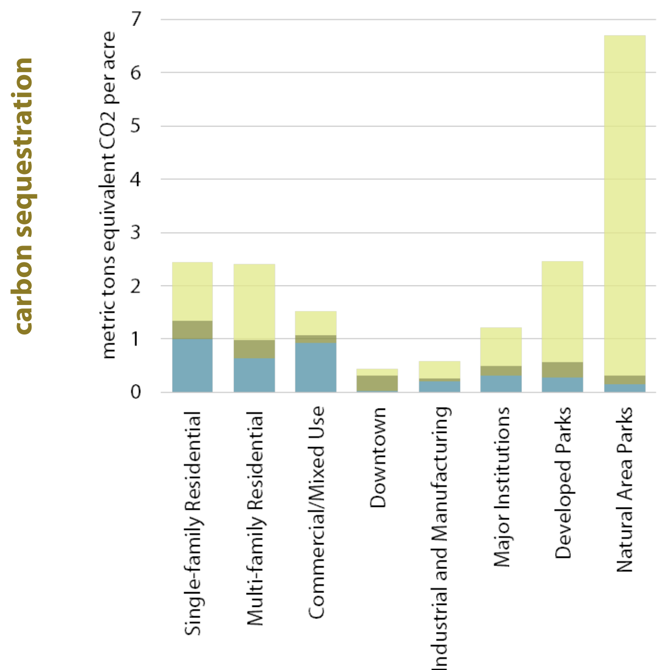
Carbon sequestration is the annual removal of CO_2 through photosynthesis by plants. Photosynthesis is the process where plants use sunlight to convert CO_2 to plant tissues.

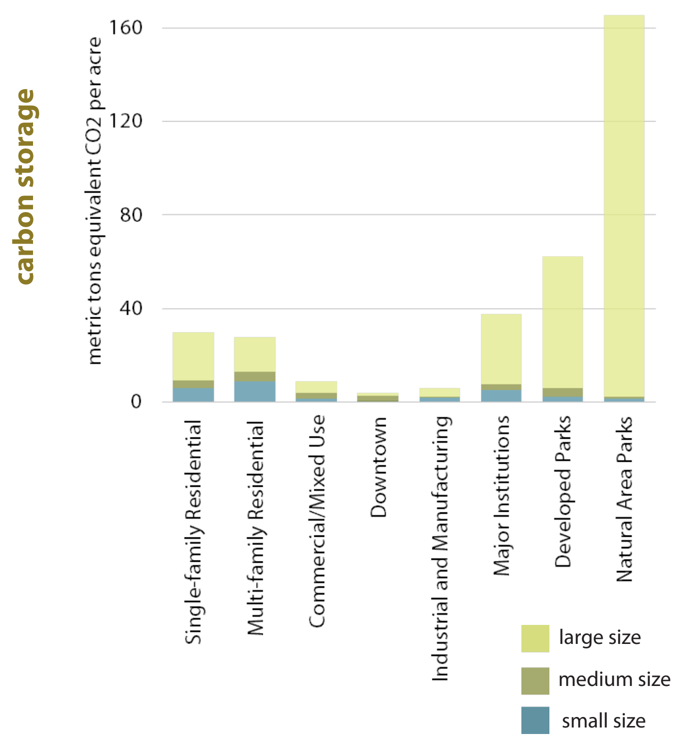
Seattle's urban forest stores approximately 36 metric tons of CO_2 equivalent (or 9.9 metric tons of carbon) per acre and sequesters approximately 2.6 metric tons of CO_2 equivalent (or 0.7 metric tons of carbon) per acre. Across Seattle, carbon storage in urban forest biomass amounts to almost 2 million metric tons of CO_2 equivalent, with an additional 141,000 metric tons of CO_2 equivalent sequestered in 2011.

This equates to a citywide savings of $10.9 million from carbon storage and an annual savings of $768,000 from carbon sequestration. The urban forest CO_2 removal rate per year is 2%, or 7 days, of the city's total annual emissions.

The species and size of a tree impacts the amount of carbon storage and sequestration. As illustrated in the graph of carbon storage, mature large trees in Seattle store the bulk of carbon in the urban forest. However, the majority of the carbon sequestration in each management unit varies depending on the forest composition and tree maturity. Large species are sequestering most of the carbon in the Natural Area Parks and Developed Parks.

Carbon values are determined using estimates of biomass based on field-collected data and equations that show the relationship between tree size and biomass. Biomass is the calculation of the tissue mass of a tree – and carbon storage is approximately half the biomass of the tree. Metric tons carbon dioxide equivalent is the international reporting standard metric for CO_2 emissions that are reduced or removed from our environment.





Residential Building Energy Effects

The urban forest moderates local climate, which can translate to reduced energy costs for homeowners. Depending on their size, proximity to a house, and whether they are evergreen or deciduous, trees can affect residential heating and cooling needs. Trees in urban areas can influence temperatures by providing evaporative cooling, acting as wind blocks, and offering shade.

In Seattle, an estimated **1.6 million British thermal units** (MBTU) of natural gas and **43,000 megawatt-hours** (MWh) of electricity are saved annually because of the urban forest. This equates to roughly **$5.9 million dollars** in annual savings in Seattle.

The energy estimates rely on field-collected data, including distance and direction from residential buildings, species, tree height, and building percent cover. Cost savings reflect statewide average prices per kWh and per MBTU, adjusted from 2002 pricing. Energy savings from cooling and heating use a statewide estimate for energy costs, which likely means that the residential energy effects are high estimates for Seattle's moderate climate.

Because 88% of Seattle's energy is generated using hydroelectric power, this report does not include a value for avoided carbon emissions from fossil-fuel power generation, as is often provided by i-Tree Eco reports.

Replacement Value

Infrastructure systems are essential for supporting human health and well-being in cities. While grey infrastructure is made up of drains, pipes, and wires that deliver water and energy and carry away waste, trees and vegetation make up a green infrastructure. This report demonstrates that the urban forest in Seattle is part of a green infrastructure system that works to provide a wide array of services and benefits.

To get a sense of the costs to reestablish Seattle's urban forest, i-Tree Eco estimates the replacement value. This equates to the cost of physically replanting trees and nurturing them to the size and extent of Seattle's current forest.

> The replacement value of Seattle's current urban forest is estimated to be **$4.99 billion dollars.**

This value is estimated using methods established by the Council of Tree and Landscape Appraisers. Much like houses can be appraised, the replacement value of trees can be assessed. Field-collected size, species, condition, and location data, as well as literature-based replacement costs, transplantable size information, and local species factors are used in this estimate.

Threats to the Urban Forest

When assessing the value of the urban forest, it is important to consider potential current and future threats. Major threats to Seattle's urban forest include insects and disease pests, as well as invasive species.

Susceptibility to Pests

While there is a rich diversity in Seattle's urban forest, this research suggests that pests still have the potential to wreak havoc on our urban forest. Field collected data was analyzed to better understand the threat of four major pest species: Asian long-horned beetle, gypsy moth, emerald ash borer, and Dutch elm disease.

Asian Longhorned Beetle

Anoplophora glabripennis (ALB)

ALB is native to China and Korea, but has been found on the east coast of the United States. The beetle's preferred host species include maples (*Acer spp.*), horsechesnut (*Aesculus hippocastanum*), elms (*Ulmus spp.*), willows (*Salix spp.*), and birches (*Betula spp.*). The long list of host trees means that ALB can have devastating impact in any corner of the United States. A related species, the citrus longhorned beetle, was found in a nursery in Tukwila, WA in 2001, requiring removal of about 1,000 trees in the vicinity of the nursery . This research suggests that close to **39.5%** of the urban forest is at risk, representing a potential loss of over **$2.58 billion dollars**.


Kenneth R. Law, USDA APHIS PPQ, Bugwood.org

Gypsy Moth

Lymantria dispar (GM)

Larvae eat the leaves of many common hardwoods, including oak (*Quercus spp.*), birch (*Betula spp.*), and willow (*Salix spp.*). Infestations on the east coast have also impacted hemlock (*Tsuga spp.*), pine (*Pinus spp.*), and spruce (*Picea spp.*), each of which are prevalent in Seattle. The impact to the host tree depends on how much of the tree is defoliated and what other stressors (drought, disease, etc.) are impacting the tree. Trees commonly die after 2-3 years of larvae defoliation. If gypsy moth were to establish in Seattle, **17.3%** of the population would be at risk of defoliation and eventual dieback, totaling **$938 million dollars** in structural damage.


http://www.entomart.be/

Emerald Ash Borer

Agrilus planipennis (EAB)

As the name suggests, EAB targets ash species (*Fraxinus spp.*) and has caused tens of millions of dollars in damage throughout the northeastern U.S. and as far west as Minnesota. Originally from Asia, the wood-boring beetle is thought to have arrived in the U.S. on wood packing crates. Seattle's ash population is small, representing **0.2%** of the population. Still, **$43.6 million dollars** in structural damage would occur if EAB finds its way west.


David Cappaert
Michigan State University, Bugwood.org

Dutch Elm Disease

Ophiostoma ulmi (DED)

DED is a fungus that effects the vascular system of the tree, making it difficult for the tree to access water, eventually causing the tree to wilt and die. DED was first found in Seattle in 2001. Although we have fewer elm trees (just **0.1%** of the urban forest population) compared to east coast cities that have been devastated by DED, a loss of just over **$8 million dollars** is predicted. This is future loss, and does not account for trees that have been lost to DED prior to this research.


Joseph O'Brien,
USDA Forest Service, Bugwood.org

Invasive Plant Species

Invasive species are non-native plants that thrive when introduced to foreign environments. These plants have destructive impacts on existing vegetation and associated ecosystems. The extent and distribution of two invasive species, cherry laurel (*Prunus laurocerasus*) and English holly (*Ilex aquifolium*), were analyzed further to identify potential management needs.

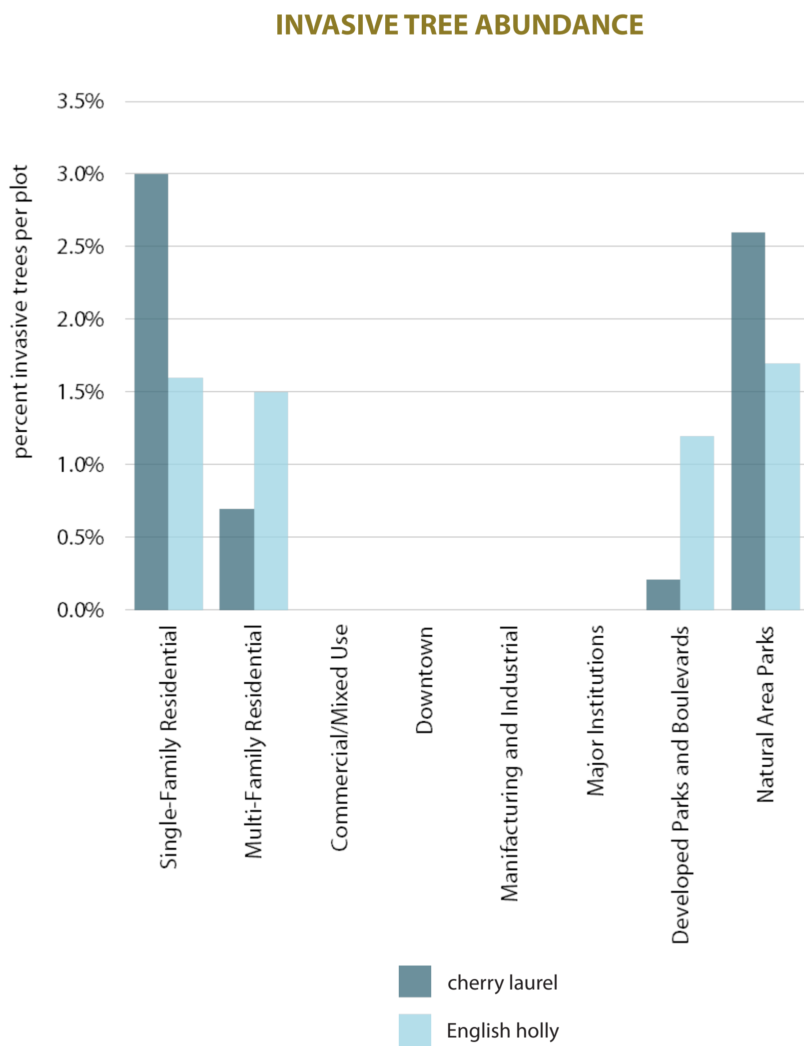
Cherry laurel (also known as English laurel) and English holly are both considered invasive species in Seattle and are recognized by the King County Noxious Weed Board as Weeds of Concern. Removal is recommended in natural areas and residents are discouraged from introducing new plantings. Both were originally horticultural species, available for purchase and planted widely in yards. Because the seeds of both species are dispersed by birds, volunteer seedlings establish readily around the city. Both species are fast growing and thrive in a variety of conditions, often outcompeting native vegetation and changing the structure of Seattle's forested parklands.

Cherry laurel and English holly each make up 3% of the urban forest population. Their presence in residential areas (both Single-family Residential and Multi-family Residential) and Natural Area Parks suggests that seeds from cultivated trees on private lands are making their way into forested parklands. Given their aggressive spreading nature, it is important to continue to manage these species and monitor their spread over time.

English holly

credit: Norah Kates

Cherry laurel



Conclusion

This Forest Ecosystem Values Project captured the current structure of Seattle's urban forest and quantified a subset of the ecosystem functions and economic values provided to city residents. Results suggest that the urban forest is a vital resource and a component of the city's infrastructure that offers significant benefits and must be managed as such to increase effectiveness and minimize threats.

Stewardship

The urban forest ecosystem is inextricably tied to people - people are part of the urban forest. With a better understanding of its value, residents may be more likely to support programs and act to sustain and increase the urban forest in Seattle. Fortunately, Seattle is home to hundreds of non-profit and community organizations, as well an established municipal urban forest team and an Urban Forest Commission that all work to improve the urban forest and its benefits. Resident involvement is encouraged through the Seattle reLeaf program, which works with neighborhoods to increase tree cover and maintain existing trees. On forested parklands, Green Seattle Partnership is a unique collaboration between the City, individuals, and organizations to re-establish and protect native conifer cover and reduce the spread of invasive species. The continued work of these stewardship programs and the establishment of new innovative efforts will be vital in protecting the urban forest and the life sustaining ecosystem services it provides.

Equity

Scientific studies confirm that having trees in communities can make places more walkable, reduce crime, ease feelings of stress and depression, and boost property values. Such services and benefits contribute to public health and urban sustainability. All residents of the city should have equitable access to these benefits. The City of Seattle's commitment to equity as part of the Race and Social Justice Initiative provides a foundation for addressing socio-economic differences across the city, enhancing both social and environmental benefits for all residents of the city.

Continued Assessment

Scientific data is essential to achieve effective planning and management of urban forest systems. This assessment of the urban forest provides a baseline from which future studies can track trends or changes in the forest. Repeating this research on a regular basis, such as every five years, using the same plot locations would provide a comparison to help managers determine if goals are being met and inform how to adapt management practices.

Considerations

Scientific studies indicate that urban forests provide far more benefits than have been reported here. Of particular interest in Seattle is the evaluation of urban forest effects on stormwater management. Current urban forestry models do not include suitable measures for application in the Pacific Northwest. In addition, human health and well-being metrics were left out of this assessment. It is well documented that the experience of nature in cities improves public health. Expanding future assessments to include socio-cultural benefits would further support urban forest planning and management that improves quality of life.

Ongoing knowledge development about urban forest conditions and structure can encourage and support more effective resource management, decision making, and funding allocations. This report of baseline conditions is an important contribution in support of citywide strategies to create and maintain a quality urban forest.

credit: Chris Gilliand

Appendix

Index of Sampled Species

Native Status: species native to Washington State
Management Units: DEV= developed parks, P = Natural Area Parks, SF = Single-family Residential, MF = Multi-family Residential, MJRI = Institutions, MFGI = Industrial and Manufacturing, C = Commercial/Mixed Use
Percent of Population: percent of the species present in urban forest sample plots
Size: represents expected height at maturity, small = less than 30 feet tall, medium = between 30 - 50 feet tall, large = greater than 50 feet tall
Tree Status: yes = classified by research staff as a tree species

Species	Native Status	Management Unit Presence	% of Pop.	Size	Tree Status
Abies grandis	yes	DEV, P, SF	1%	large	yes
Abies lasiocarpa	yes	SF	0%	large	yes
Acer campestre	no	DEV, SF	0%	large	yes
Acer circinatum	yes	DEV, MFGI, MJRI, SF	2%	small	yes
Acer griseum	no	SF	0%	small	yes
Acer japonicum	no	C	0%	small	yes
Acer macrophyllum	yes	DEV, MF, MFGI, P, SF	9%	large	yes
Acer palmatum	no	C, DT, MF, MFGI, MJRI, SF	2%	small	yes
Acer platanoides	no	C, DT, MF, MFGI, MJRI	1%	medium	yes
Acer pseudoplatanus	no	DEV, MF	0%	large	yes
Acer rubrum	no	MF, SF	0%	medium	yes
Acer saccharinum	no	C, DEV, MF, MJRI	1%	large	yes
Acer species	no	MF, MJRI	0%	medium	yes
Acer tataricum	no	MF	0%	medium	yes
Acer x freemanii	no	DT	0%	large	yes
Aesculus hippocas-tanum	no	DEV, MF, P	0%	large	yes
Aesculus x carnea	no	DEV	0%	medium	yes
Alnus rubra	yes	DEV, MF, MFGI, MJRI, P, SF	12%	large	yes
Amelanchier laevis	no	MF	0%	small	yes
Aralia elata	no	SF	0%	small	yes
Araucaria araucana	no	SF	0%	large	yes
Arbutus menziesii	yes	DEV, P, SF	1%	large	yes
Arbutus unedo	no	SF	0%	small	no
Aucuba japonica	no	SF	0%	small	no
Betula alleghaniensis	no	DEV	0%	medium	yes
Betula papyrifera	yes	C, MJRI, SF	1%	large	yes
Betula pendula	no	SF	0%	medium	yes
Betula populifolia	no	MJRI	0%	medium	yes
Buddleja davidii	no	MJRI, SF	0%	small	no
Buxus sempervirens	no	SF	0%	small	no

Species	Native Status	Management Unit Presence	% of Pop.	Size	Tree Status
Calocedrus decurrens	no	MJRI	0%	large	yes
Camellia japonica	no	SF	0%	small	no
Camellia species	no	SF	1%	small	no
Carpinus betulus	no	SF	0%	medium	yes
Castanea dentata	no	DEV	0%	large	yes
Catalpa species	no	SF	0%	large	yes
Ceanothus species	no	SF	0%	small	no
Cedrus atlantica	no	SF	0%	large	yes
Cedrus deodara	no	MF, MJRI, SF	1%	large	yes
Cercidiphyllum japonicum	no	C, MF	0%	large	yes
Cercis canadensis	no	MJRI, SF	0%	small	yes
Chamaecyparis lawsoniana	no	C, SF	0%	medium	yes
Chamaecyparis noot-katensis	yes	C, SF	0%	large	yes
Chamaecyparis obtusa	no	SF	0%	large	yes
Chamaecyparis pisifera	no	DEV	0%	large	yes
Chamaecyparis species	no	MFGI, MJRI, SF	1%	large	yes
Choisya species	no	SF	0%	small	no
Clerodendrum tricho-tomum	no	MF, SF	0%	small	yes
Cornus florida	no	MF, SF	0%	small	yes
Cornus kousa	no	SF	0%	small	yes
Cornus nuttallii	yes	DEV, P, SF	1%	medium	yes
Cornus sericea	yes	MFGI, P	0%	small	no
Cornus species	no	SF	0%	small	yes
Corylus avellana	no	SF	0%	small	yes
Corylus colurna	no	P	0%	medium	yes
Corylus cornuta	yes	DEV, P, SF	5%	small	no
Corylus species	no	SF	0%	medium	no
Cotinus coggygria	no	SF	0%	small	no
Cotinus obovatus	no	SF	0%	small	yes
Cotoneaster pannosus	no	SF	0%	small	no
Crataegus douglasii	yes	SF	0%	medium	yes
Crataegus laevigata	no	MF	0%	medium	yes

Species	Native Status	Management Unit Presence	% of Pop.	Size	Tree Status
Crataegus monogyna	no	DEV, P, SF	1%	medium	yes
Crataegus species	no	MF, SF	0%	medium	yes
Cupressocyparis leylandii	no	SF	0%	large	yes
Cupressus semper-virens	no	SF	0%	medium	yes
Cupressus species	no	SF	0%	medium	yes
Cydonia oblonga	no	SF	0%	small	yes
Diospyros virginiana	no	SF	0%	medium	yes
Escallonia species	no	SF	0%	small	no
Euonymus japonica	no	SF	0%	small	yes
Fagus sylvatica	no	C, DEV	0%	large	yes
Fatsia japonica	no	SF	0%	small	no
Ficus carica	no	SF	0%	small	yes
Ficus species	no	MF	0%	small	yes
Forsythia species	no	SF	0%	small	no
Forsythia x intermedia	no	SF	0%	small	no
Frangula purshiana	yes	DEV	0%	medium	yes
Fraxinus americana	no	SF	0%	large	yes
Fraxinus angustifolia	no	MF, MJRI	0%	large	yes
Fraxinus latifolia	yes	DEV	0%	large	yes
Fraxinus species	no	MJRI	0%	large	yes
Ginkgo biloba	no	SF	0%	medium	yes
Gleditsia triacanthos	no	DT, MFGI, MRJI	0%	medium	yes
Hamamelis virginiana	no	C, SF	0%	small	yes
Holodiscus discolor	no	P	0%	small	no
Holodiscus species	no	SF	0%	small	no
Hydrangea species	no	SF	0%	small	no
Ilex aquifolium	no	DEV, MF, P, SF	2%	medium	yes
Juglans major	no	MJRI	0%	large	yes
Juniperus californica	no	SF	0%	medium	no
Juniperus chinensis	no	SF	0%	medium	yes
Juniperus communis	no	SF	0%	small	no
Juniperus species	no	SF	0%	medium	yes
Juniperus virginiana	no	SF	1%	medium	no
Kalmia angustifolia	no	P	0%	small	no
Laburnum anagy-roides	no	DEV, SF	1%	small	yes
Laurus nobilis	no	SF	0%	small	yes
Ligustrum species	no	MF, SF	1%	small	no
Liquidambar styraci-flua	no	C, DEV, DT, MJRI	0%	large	yes
Lonicera species	no	SF	0%	small	no
Magnolia grandiflora	no	MF, SF	1%	medium	yes
Magnolia species	no	MF, SF	0%	medium	yes
Magnolia stellata	no	MF, SF	0%	small	yes
Magnolia x soulan-giana	no	SF	0%	small	yes

Species	Native Status	Management Unit Presence	% of Pop.	Size	Tree Status
Mahonia species	no	MF, SF	0%	small	no
Malus species	no	DEV, P, SF	1%	small	yes
Musa species	no	SF	0%	small	yes
Oemleria cerasiformis	no	DEV, MF, P, SF	4%	small	no
Philadelphus species	no	SF	0%	small	no
Photinia species	no	SF	0%	small	yes
Photinia x fraseri	no	SF	0%	small	yes
Picea abies	no	MF, SF	0%	large	yes
Picea glauca	no	SF	0%	large	yes
Picea pungens	no	SF	0%	large	yes
Pieris japonica	no	SF	0%	small	no
Pieris species	no	MF, SF	0%	small	no
Pinus contorta	yes	MFGI, SF	0%	medium	yes
Pinus contorta var. latifolia	no	DEV, SF	0%	medium	yes
Pinus parviflora	no	SF	0%	medium	yes
Pinus ponderosa	yes	SF	0%	large	yes
Pinus resinosa	no	MF, SF	0%	large	yes
Pinus rigida	no	SF	0%	medium	yes
Pinus species	no	SF	0%	medium	yes
Pinus strobus	no	SF	0%	large	yes
Pinus virginiana	no	C, MFGI	0%	medium	yes
Platanus hybrida	no	MJRI	0%	large	yes
Platanus occidentalis	no	C	0%	large	yes
Platycladus orientalis	no	C, DEV	0%	large	yes
Populus balsamifera trichocarpa	yes	C, DEV, MF, MJRI, P, SF	1%	large	yes
Populus nigra	no	MJRI	0%	large	yes
Populus species	no	SF	0%	large	yes
Populus tremuloides	yes	DEV, MF	1%	large	yes
Prunus alabamensis	no	SF	0%	small	yes
Prunus alleghaniensis	no	MF	0%	small	yes
Prunus americana	no	SF	1%	small	yes
Prunus avium	no	SF	0%	small	yes
Prunus cerasifera	no	C, MFGI, SF	1%	small	yes
Prunus domestica	no	MF, SF	1%	small	yes
Prunus emarginata	yes	DEV, MF, P, SF	2%	small	yes
Prunus laurocerasus	no	DEV, MF, P, SF	3%	small	yes
Prunus lusitanica	no	MF, SF	0%	small	yes
Prunus persica	no	SF	0%	small	yes
Prunus serrulata	no	C, DEV, SF	1%	small	yes
Prunus species	no	MF, MJRI, P, SF	2%	small	NA
Prunus subhirtella	no	SF	0%	small	yes
Pseudotsuga men-ziesii	yes	DEV, MF, P, SF	3%	large	yes
Pyracantha species	no	SF	0%	small	no
Pyrus communis	no	SF	0%	small	yes
Pyrus pyrifolia	no	SF	0%	small	yes

Species	Native Status	Management Unit Presence	% of Pop.	Size	Tree Status
Pyrus species	no	SF	0%	medium	yes
Quercus nigra	no	SF	0%	large	yes
Quercus rubra	no	C, DT	0%	large	yes
Quercus species	no	DEV	0%	large	yes
Quercus velutina	no	MJRI	0%	large	yes
Rhododendron macrophyllum	no	P	1%	small	no
Rhododendron species	no	C, DEV, MF, P, SF	3%	small	no
Rhus species	no	C, SF	0%	small	no
Robinia pseudoacacia	no	MF, SF	0%	large	yes
Rosa species	no	SF	0%	small	no
Salix hookeriana	yes	MF	0%	small	yes
Salix lucida ssp. lasiandr	yes	MJRI	1%	small	yes
Salix matsudana	no	SF	0%	medium	yes
Salix scouleriana	yes	MJRI, P	0%	medium	yes
Salix sitchensis	no	DEV	0%	medium	yes
Salix species	no	DEV, MFGI, MJRI, P, SF	2%	large	yes
Sambucus racemosa	no	P, SF	1%	small	yes
Sciadopitys verticillata	no	SF	0%	small	yes
Sequoia sempervirens	no	MFGI, MJRI, SF	0%	large	yes
Sorbus aucuparia	no	DEV, P, SF	0%	medium	yes
Sorbus species	no	MF, SF	0%	medium	yes
Syringa species	no	MF, SF	0%	small	no
Syringa vulgaris	no	SF	2%	small	no
Tamarix species	no	SF	0%	small	yes
Taxodium distichum	no	DEV	0%	large	yes
Taxus baccata	no	SF	0%	medium	yes
Taxus brevifolia	yes	P	0%	large	no
Taxus species	no	SF	0%	medium	no
Thuja occidentalis	no	C, MFGI, SF	3%	large	yes
Thuja plicata	yes	C, DEV, MF, MFGI, MJRI, P, SF	3%	large	yes
Thuja species	no	SF	0%	large	yes
Tilia cordata	no	C, MF	0%	large	yes
Tilia platyphyllos	no	C	0%	large	yes
Tsuga heterophylla	yes	DEV, P, SF	0%	large	yes
Tsuga mertensiana	yes	SF	0%	large	yes
Ulmus species	no	MJRI, SF	0%	large	yes
Viburnum opulus	no	SF	0%	small	no
Viburnum plicatum	no	SF	0%	small	yes
Zelkova serrata	no	C	0%	large	yes

References

Alliance for Community Trees. 2011. **Benefits of Trees and Urban Forests: A Research List.** URL: http://www.actrees.org/files/Research/benefits_of_trees.pdf

American Forests. 1998. **Regional Ecosystem Analysis Puget Sound Metropolitan Area.** URL: http://www.systemecology.com/4_Past_Projects/AF_PugetSound.pdf

Bradley, G. 1995. **Urban Forest Landscapes: Integrating Multidisciplinary Perspectives.** In: Bradley, G.A (editor), Urban Forest Landscapes: Integrating Multidisciplinary Perspectives. University of Washington Press, USA: 1 – 11.

Brinkley, W., K.L. Wolf, and D.J. Blahna. 2010. **Stewardship Footprints and Potential Ecosystem Recovery: Preliminary Data for Seattle and Puget Sound.** In: D.N. Laband (editor), Linking Science and Society: Proceedings of Emerging Issues Along Urban/Rural Interfaces III. Atlanta GA.

Cascadia Consulting Group. 2000. S**eattle Urban Forest Assessment: Sustainability Matrix**. URL: http://www.seattle.gov/environment/documents/sustainability%20matrix.pdf

City of Seattle Race and Social Justice Initiative. URL: http://www.seattle.gov/rsji/

City of Seattle. 2007. **Urban Forest Management Plan**. URL http://www.seattle.gov/environment/documents/Final_UFMP.pdf

City of Seattle. 2008. **Seattle Community Greenhouse Gas Inventory**. URL: http://www.seattle.gov/environment/documents/2008-community-inventory-fullreport.pdf

Council of Tree and Landscape Appraisers (CTLA). 1992. **Guide for Plant Appraisal (8th ed.)**. International Society of Arboriculture, Champaign, IL.

Elman, E. and N. Salisbury. 2009. **The State of Seattle's Conifers**. URL: http://www.seattleurbannature.org/projects/2009_state_of_conifers.pdf

Franklin, J. F. and C. T. Dyrness. 1988. **Natural Vegetation of Oregon and Washington**. Oregon State University Press: Corvallis, OR.

Green Seattle Partnership. URL: http://greenseattle.org/

Green Seattle Partnership Monitoring Program. URL: http://greenseattle.org/forest-steward-resources-1/monitoring/monitoring

Herrera Environmental Consultants, Inc. 2008. **The Effects of Trees on Stormwater Runoff.**

King County Noxious Weed Control Board. **2012 King County Noxious Weed List**. URL: http://your.kingcounty.gov/dnrp/library/water-and-land/weeds/WeedLists/2012-King-County-Noxious-Weed-List.pdf

Moll, G. 1995. **Urban Forestry: A National Initiative**. In: Bradley, G.A (editor), Urban Forest Landscapes: Integrating Multidisciplinary Perspectives. University of Washington Press, USA: 12 – 16.

National Oceanic and Atmospheric Administration, National Climate Data Center. **Normal Monthly Precipitation**. URL: http://lwf.ncdc.noaa.gov/oa/climate/online/ccd/nrmlprcp.html

Nowak, D. J., D. E. Crane, and J. F. Dwyer. 2002. **Compensatory Value of Urban Trees in the United States**. Journal of Arboriculture 28(4): July 2002

Nowak, D. J. 2010. **Every Tree Counts: A Portrait of Toronto's Urban Forest**. URL: http://www.itreetools.org/resources/reports/Toronto_Every_Tree_Counts.pdf

Nowak, D. J., R. E. Hoehn, D. E. Crane, L. Weller, A. Davilia. 2010. **Assessing Urban Forest Effects and Values: Los Angeles' Urban Forest**. URL: http://www.nrs.fs.fed.us/pubs/rb/rb_nrs47.pdf

Nowak, D. J., D. E. Crane, J. C. Stevens, R. E. Hoehn, J. T. Walton, and J. Bond. 2008. **A ground based method of assessing urban forest structure and ecosystem services**. Arboriculture and Urban Forestry, 34(6): 347-358.

McManus, M., N. Schneeberger, R. Reardon, and G. Mason. 1989. **Forest Insect and Disease Leaflet 162: Gypsy Moth**. URL: http://na.fs.fed.us/spfo/pubs/fidls/gypsymoth/gypsy.htm

Miller, J. R. and R. J. Hobbs. 2002. **Conservation Where People Live and Work**. Conservation Biology, 16(2): 330-337. doi: 10.1046/j.1523-1739.2002.00420.x.

Parlin, Michaela. 2009. **Seattle, Washington Urban Tree Canopy Analysis Project Report: Looking Back and Moving Forward**. URL: http://www.seattle.gov/trees/docs/NCDC_Final_Project_Report.pdf

Seattle City Light. 2010. Fuel Mix: **How Seattle City Light electricity is generated**. URL: http://www.seattle.gov/light/fuelmix/

Seattle Department of Transportation. 2011. **Stop That Beetle!** URL: http://sdotblog.seattle.gov/2011/12/08/stop-that-beetle/

Seattle Department of Transportation. **SDOT Tree Inventory**. URL: http://www.seattle.gov/transportation/treeinventory.htm

Seattle Department of Transportation. **Citizens's Alert!! Watch for DED Trees!** URL: http://www.seattle.gov/transportation/dutchelm.htm

Seattle reLeaf. URL: www.seattle.gov/trees/

Seattle Urban Nature Project. 2006. **Citywide Habitat Assessment Interim Report**. URL: http://www.seattleurbannature.org/Projects/CHAInterimReport.pdf

Vargas, Kelaine (editor). 2011. **I-Tree Eco User's Manual** v.4.1.0. URL: http://www.itreetools.org/resources/manuals/i-Tree%20Eco%20Users%20Manual.pdf

United States Conference of Mayors. 2008. **Protecting and Developing the Urban Tree Canopy.** URL: http://www.usmayors.org/trees/treefinalreport2008.pdf

USDA Forest Service Northeastern Area State and Private Forestry. 2008. **Pest Alert: Asian Longhorned Beetle**. URL: http://www.na.fs.fed.us/pubs/palerts/alb/alb_pa.pdf

USDA Forest Service. **Emerald Ash Borer**. URL: http://www.emeraldashborer.info

Wolf, K. L. 2004. **Economics and Public Value of Urban Forests**. Urban Agriculture Magazine, Special Issue on Urban and Periurban Forestry, 13: 31-33.

Wolf, K. L. 2012. **Green Cities: Good Health**. URL: http://depts.washington.edu/hhwb/

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