CITY OF LAKE FOREST PARK

URBAN FOREST ECOSYSTEM SERVICES AND VALUES REPORT

MAY 2024

Acknowledgments

Facet Contributors

Kim Frappier, Project Manager & Author
Sam Payne, Data Analyst & Author
Nathan Burroughs, GIS Analyst
Lars Freeman-Wood, Lead Field Researcher
Sage Yuasa, Field Researcher
Evan Earhart, Field Researcher
Drew Foster, Field Researcher & Analyst
Kenny Booth, Principal

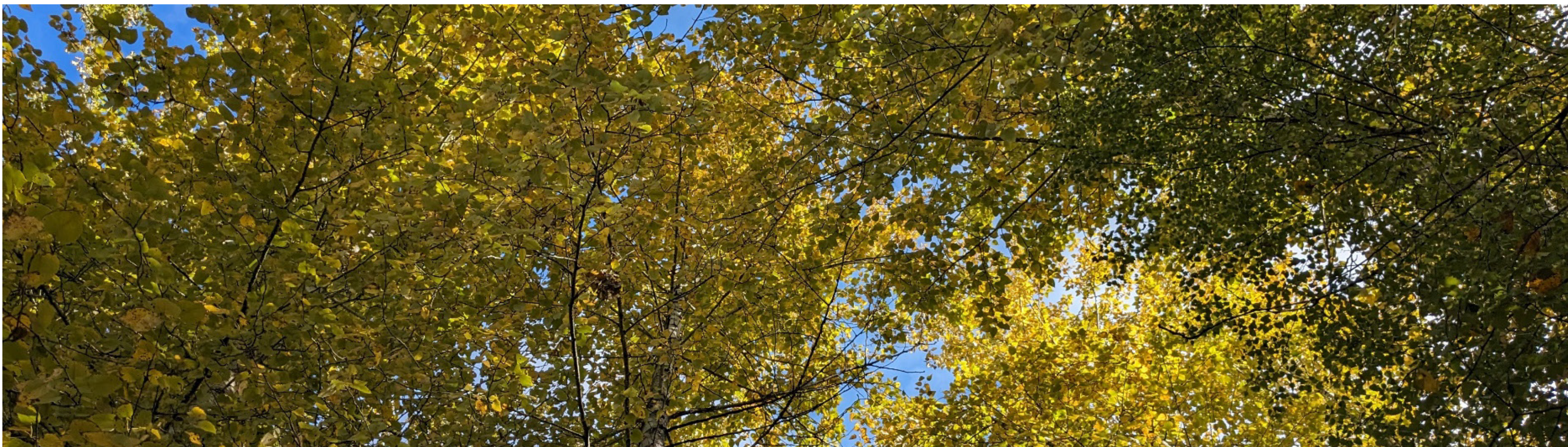
City of Lake Forest Park

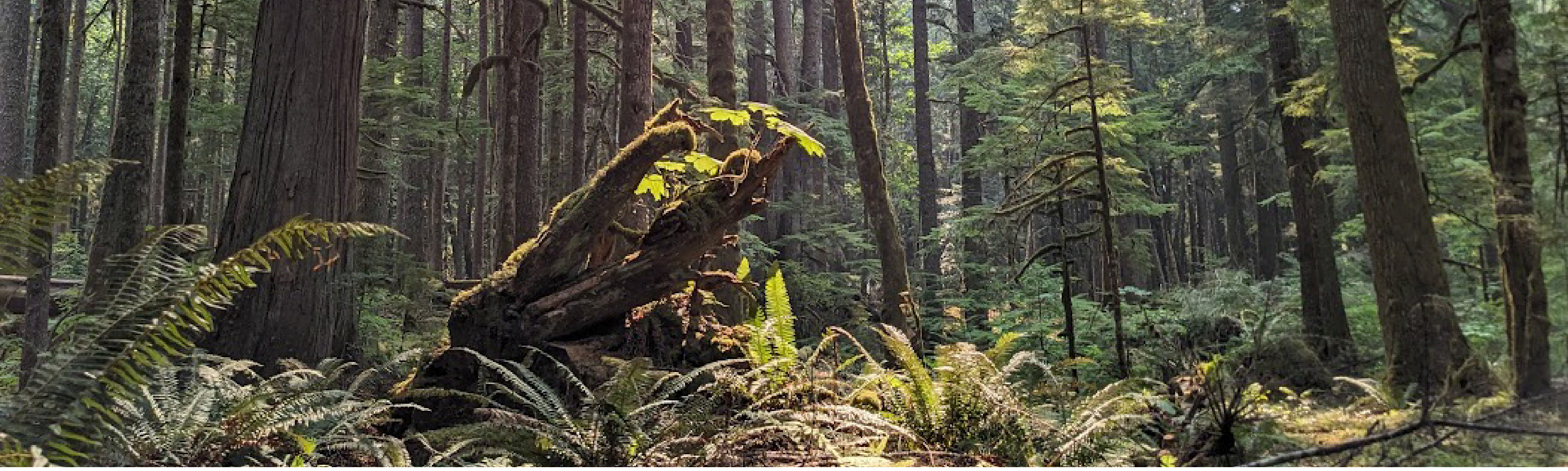
Phillip Hill, City Administrator
Larry Goldman, City Council
Steve Bennett, Planning Director
Hannah Swanson, City Arborist
Richard Olmstead, Tree Board Chair
Doug Sprugel, Tree Board
Marty Byrne, Tree Board
Sandra LeVar, Tree Board
Mark Phillips, Tree Board

We wish to express our gratitude to the i-Tree project team for their invaluable contribution in developing methodologies and software that facilitated the analysis of this study. Contributors to the i-Tree project are listed as the U.S. Forest Service, Davey Tree Expert Company, The Arbor Day Foundation, the Society of Municipal Arborists, the International Society of Arboriculture, and Casey Trees.

Project funding is from the City of Lake Forest Park.

Uncredited photos by Sam Payne, Katy Crandall, and Lexi Ochoa.





Summary

This report presents an evaluation of Lake Forest Park's urban and community forest through an i-Tree Eco plot sample inventory. Utilizing plot data obtained in 2022 and 2023, the i-Tree Eco model provides an assessment of urban forest health, structure, and threats as well as the ecosystem services and values trees provide the community. Additionally, tree canopy height is modeled to evaluate canopy height distribution in the City's tree population. The following list summarizes key findings from this research effort.

- There are 290,000 (± 40,000 SE) trees estimated to be in Lake Forest Park with a mean density of 126 trees per acre (TPA).
- Canopy cover is estimated at 50%.
- The most common tree species are Douglas-fir (16%), bigleaf maple (11%), western red cedar (9%), cherry laurel (8%), bitter cherry (6%), and English holly (6%). Of all trees, 56% are native to Washington.
- Less than 1% of trees are designated as noxious weeds in King County, however, 20% are listed as weeds of concern. The most abundant weeds of concern are cherry laurel, English holly, and sweet cherry.
- The age classification of trees trends youthful, with an abundance of smaller trees that will eventually replace the aging canopy. Trees less than 6 inches DBH account for 49% of the tree population.
- Leaf area density in the Large Residential stratum (parcels >¼ acre) is three times greater than the Small Residential stratum (parcels ≤¼ acre), and seven times greater than the Town Center stratum.
- The Lake Forest Park urban forest provides benefits valued at $4.1 million annually for removing pollution, reducing runoff, sequestering carbon, and lowering energy usage.
- Carbon storage of the total urban forest is valued at $16.2 million, and the replacement value is estimated at $520 million.
- Of the 53 pests and pathogens that i-Tree assessed, 15 are present in King County. The economic impacts of these species are evaluated for each tree species and pest species.
- The canopy height model indicates that the proportion of tall trees, those greater than 135 feet in height, have increased by 21% from 2016 to 2021. The proportion of the tallest trees, those greater than 165 feet increased by 86% during this period, albeit accounting for less than 1% of the total tree population.

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Photo provided by City of Lake Forest Park

Introduction

Lake Forest Park's urban and community forest consists of street trees, forested parks, and open spaces, as well as trees on private residential, commercial, and industrial properties. These urban forest resources provide numerous ecosystem services, public health, and economic benefits to the people who live, work, and recreate here. Jurisdictions across King County and the State of Washington are faced with the need to support smart growth and development, environmental sustainability, and climate change resilience. Protecting green infrastructure such as tree canopies is critical to addressing these public and environmental health issues while ensuring the livability of Lake Forest Park. The first critical step to stewarding and managing this natural resource is understanding what we have.

The City of Lake Forest Park program has invested in tree inventories, canopy cover assessments, and studies investigating urban forest structure and values to guide the urban forestry program. This data has been used to inform and guide management actions, policies, municipal code updates, budget development, and identify additional analysis needs. To date, the City has developed the following urban forest analysis and management plans:

- 2005 and 2016 Canopy Analyses (LiDAR-based studies)
- 2011 Urban Forest Effects and Values (i-Tree Eco Analysis)
- 2010 Community Forest Management Plan

Project Background and Objectives

To build from the previous i-Tree Eco study published in 2011, the City contracted with Facet (formerly DCG/Watershed) in 2022 to conduct a follow-up survey to assess Lake Forest Park's community forest 10 years later. This analysis was first conducted in 2011 by the City arborist and the Lake Forest Park Tree Board, at that time a subset of the Environmental Quality Commission, with community volunteers participating in plot data collection.

The primary objectives of this 2022-2023 i-Tree study are to characterize urban forest structure and composition by collecting data on tree size, species, and health conditions. This data, along with other site-level information within the specific study areas is then used to calculate the environmental and economic benefits at a city scale.

Studying the structure and composition of the urban forest through the i-Tree analysis provides us with a more detailed understanding of Lake Forest Park's city-wide tree canopy, which was assessed in 2005 and again in 2016 using LiDAR analysis. Urban forest structure refers to the horizontal and vertical arrangement of trees, shrubs, and other plants, and their underlying abiotic environments, and is relevant to management because the physical arrangement in three-dimensional space influences the functions and ecosystem services provided by a forest. Composition refers to trees or other plant species that make up a forest.

Lake Forest Park's urban tree canopy covered 43% of the total City area in 2004, which became a baseline for forest management goals established in the City's 2010 Community Forest Management Plan. To reflect the diverse landscapes and development regulations within Lake Forest Park, canopy cover goals were established by land use types to be 50% in suburban residential areas (lots >¼ acres), 25% in urban residential areas (lots <¼ acres), and 15% in business districts. These were informed in part by benchmarks recommended by American Forests. By 2016, total urban forest canopy increased to 50% based on a study by Elm (2016). This is comparable with a recent analysis from i-Tree Landscape using high-resolution data from 2017 which resulted in a canopy cover of 48%.

Canopy cover goals have been refined in Lake Forest Park Municipal Code Section 16.14.070 to represent city zoning designations. As shown in Table 1, canopy cover goals range from 58% in zones with the lowest development intensity to 5% in zones with the greatest development intensity.

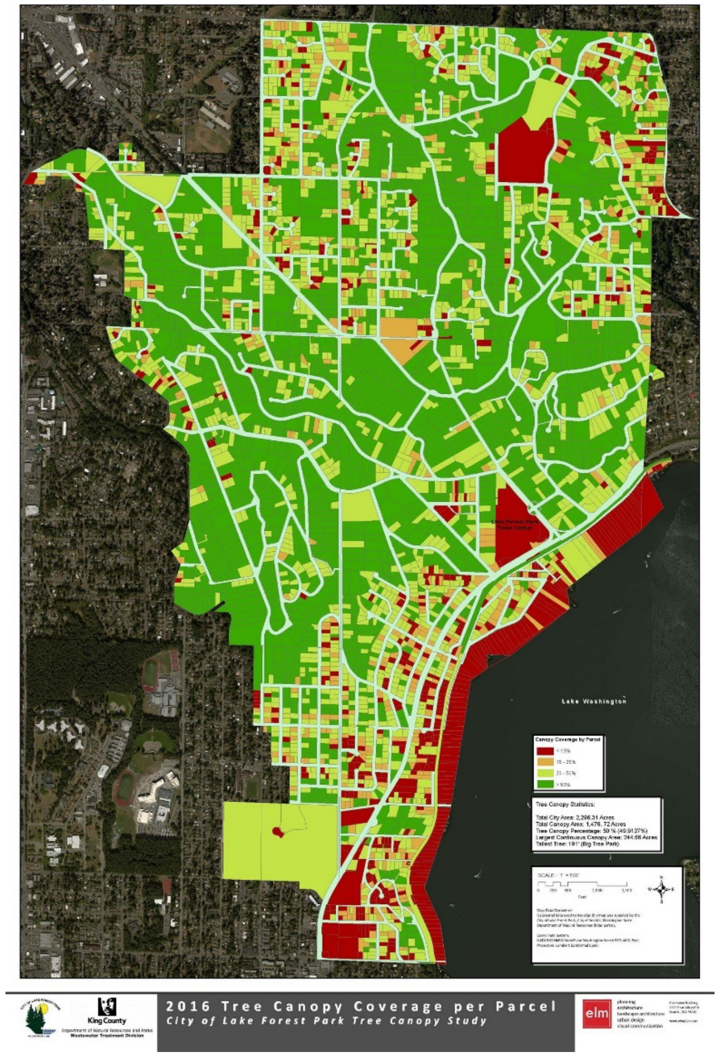


Figure 1. Lake Forest Park Tree Canopy Cover in 2016, reproduced from Elm (2016).

Table 1. Canopy coverage goals by zoning designation.

Zoning Designations	Canopy Coverage Goal
Single-family lots greater than 15,000 square feet	58%
Single-family lots 10,000 – 15,000 square feet	39%
Single-family lots less than 10,000 square feet	28%
Multifamily	15%
Commercial	15%
Southern Gateway Single Family	15%
Southern Gateway Transition	10%
Southern Gateway Corridor	5%

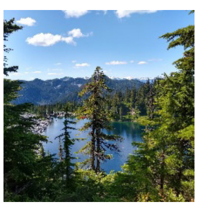
Summary of Urban Forest Benefits

Pollution Abatement: Urban forests serve as natural filters which improve water quality and air quality by trapping, absorbing, and transforming pollutants and excess nutrients, resulting in public health benefits, lower illness rates, and safeguarding ecosystems.

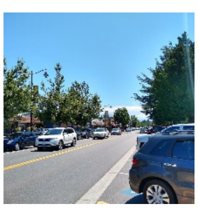
Shade and Cooling: Cities and metropolitan areas experience greater temperatures due to land use changes which alter the energy budget in an urban setting, known as the urban heat island effect. Through shading and evapotranspiration, urban forests mitigate the heat island effect through shading and cooling which lowers air and surface temperatures in densely populated regions.

Stormwater Reduction: Rainfall on impermeable surfaces, like concrete and asphalt, generates stormwater issues in cities, leading to problems such as flooding, water quality impairments, and reduced continuity of streamflow. In natural systems, rainwater interception and evapotranspiration minimize stormwater and reduce the reliance on costly engineered stormwater solutions.

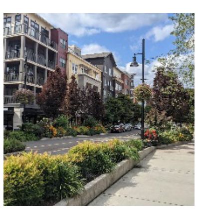
Wildlife Habitat: Urban forests function as crucial wildlife habitats within the urban landscape, supporting a diverse range of species that have adapted to living alongside humans. These flora and fauna communities rely on these forests for essential resources, including refuge, food, water, and shelter, in an otherwise demanding environment.



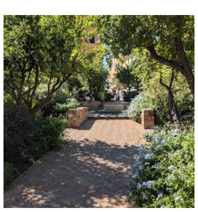
Carbon Sequestration and Storage: Carbon dioxide (CO_2), the primary greenhouse gas driving global warming, is absorbed, and stored by trees during photosynthesis. This sequestered carbon is stored in the plant tissues during the lifetime of a tree.



Noise Buffering: Urban forests and tree canopies serve as natural noise buffers, reducing sound from traffic and other sources. The reduction of nuisance noise is beneficial to human health and well-being and can minimize noise impacts which negatively affect wildlife habitat.



Economic Benefits: Trees bring numerous economic advantages, such as higher property values, increased business traffic, heightened demand, tourism attraction, reduced energy costs, and resident appeal. Research indicates that urban forest programs typically yield substantial returns on investment, believed to be 2:1 or more (Endreny 2018).



Human Health and Wellness: Urban trees provide intangible yet significant societal benefits including recreation, enhancing the aesthetics of city streets, and fostering community pride and identity. Research also shows that trees play a role in improving health outcomes, reducing stress, enhancing mental well-being including cognition, attention, and anxiety, clinical outcomes, and crime reduction (Wolf et al. 2020).

Methods

i-Tree Study Design

The i-Tree Eco study was conducted using pre-stratified protocols to obtain representative samples with randomized 0.1-acre and 0.05-acre plots. Strata are consistent with the 2011 Lake Forest Park i-Tree study design for continuity in management units; these include parcels >¼-acres (Large Residential), parcels ≤¼-acres (Small Residential), and the commercial town center; except that areas now include right-of-way in city limits.

Stratum	Acres	Number of Plots
Town Center	19	10
≤¼ Acres	532	52
>¼ Acres	1750	40

Plots are located on both public and private lands. To secure permission to collect data on private parcels, the City arborist, with support from Facet staff, contacted landowners via mail, email, the City newsletter, and door-knocking. Additional randomly selected plots were generated in instances where permission was not granted until the required number of research plots was reached.

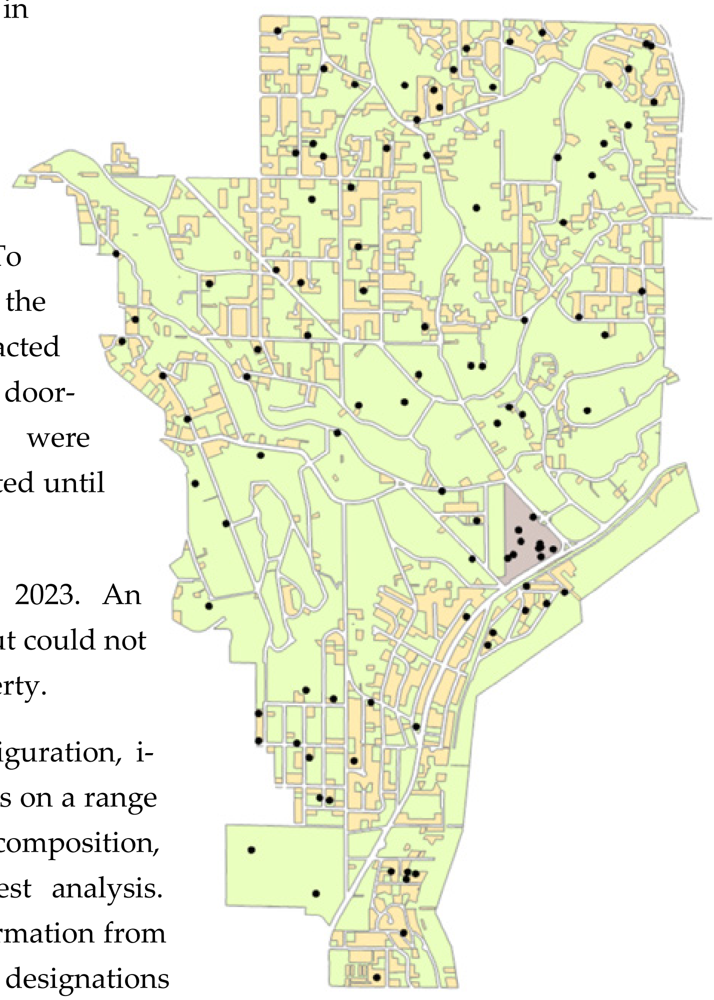


Figure 2. Strata and plot location map.

Data from 102 plots were collected in 2022 and 2023. An additional 58 plots were planned in the study design but could not be collected due to being denied access to private property.

Once processed with the user-defined data and configuration, i-Tree provides statistical analysis and actionable insights on a range of urban forestry topics including structure and composition, benefits and costs, air quality interactions, and pest analysis. Analysis of invasive species was conducted using information from the King County Noxious Weed Board, and species designations recorded in the i-Tree Eco software were disregarded because they are inconsistent with local designations.

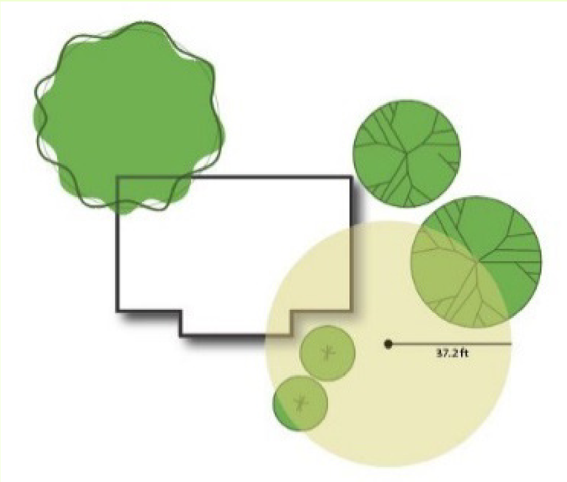
i-Tree is a software suite and a set of tools developed by the USDA Forest Service and various partners to quantify the benefits and values of urban trees and forests. It provides a platform for assessing and managing urban forest ecosystems, focusing on the many environmental, economic, and societal benefits they offer.

i-Tree Manuals and Software Versions

- ❖i-Tree Software Suite v6.0
- ❖i-Tree Eco v6.0 User Manual
- ❖i-Tree Eco v6.0 Field Manual

Urban Forest Measurements

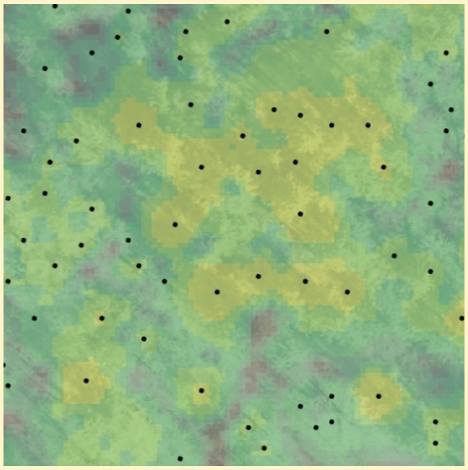
This project utilizes data collection techniques as described in the i-Tree Eco v6.0 Field Manual. Facet field researchers performed a range of measurements for each plot, encompassing both general plot characteristics and tree-specific measurement details. Plot-level and tree-level parameters are outlined in the graphic to the left. A total of 629 trees were assessed; this study includes all trees with a diameter at breast height (DBH) greater than or equal to one inch.



Plot Metrics	Tree Metrics
Plot ID	Tree ID
Date	Date
Field Crew	Status
Plot Center Address Coordinates (Lat/Long)	Distance to Plot Center
	Direction from Plot Center
Tree Cover (%)	Tree Species
Shrub Cover (%)	DBH
Plantable Space (%)	Crown Condition (% Dieback)
Land Use	Tree Height
Ground Cover	Crown Top and Base Height
Comments	Crown Width (Bidirectional)
	Percent of Crown Missing
	Crown Light Exposure
	Nearby Building Distance and Direction
	Street Tree
	Comments

Limitations and Assumptions

Reported data were generated using i-Tree Eco, and therefore, limited by the associated model assumptions. Data provided by i-Tree Eco does not provide standard error or other quantifiable metrics of statistical uncertainty for certain derived metrics. The standard error is reported for certain plot-level metrics which are supported. Studies of the i-Tree sampling methodology suggest that a 102-plot sample has an expected relative standard error (SE) of approximately 17%, however, this will differ by study and among assessed metrics (Nowak et al. 2008). Caution is advised in ascertaining trends between this study and the prior 2011 Lake Forest Park i-Tree Eco and must consider differing study areas. The reported metrics are rounded.



Light Detection and Ranging (LiDAR) can be used to provide highly accurate and spatially explicit models of urban forests. Canopy height models (CHM) are useful as a tool in urban forest management to quantify forest structure. Pictured (left) is a graphic depicting a CHM model of tree canopy height. Other LiDAR applications in forestry include canopy cover analysis, forest health assessment, biomass and carbon estimation, tree inventory mapping, and urban planning and design.

Canopy Height Model

This assessment includes a canopy height model (CHM) to provide information on urban forest structure and insight into the retention of the City's largest and tallest trees. The CHM utilized LiDAR data from the two most recent LiDAR flights on publicly available databases, 2016 and 2021[1].

Modeling was completed in the R Program using the 'lidR' package, an open-source software integrated into the R ecosystem, to manipulate and visualize LiDAR data with applications in forestry. Canopy height model and tree top identification algorithms were used to identify tree heights with a variable search window. Trees overlapping buildings were removed from the model output using land classification data from the Washington Department of Natural Resources Urban Forestry's 2022 King County Land Cover Metrics dataset and outliers below 15 feet in height were removed because they could not reliably be distinguished from other shrubs or infrastructure.

This process yields a tree population point layer with canopy height attribute values that were evaluated for trends in canopy height over time.

[1] LiDAR Data obtained from the Washington Department of Natural Resources LiDAR Portal. Sourced information includes 2016 data from Quantum Spatial and 2021 data from the Washington Geologic Survey.

Results

Tree Characteristics of the Urban Forest

Lake Forest Park is estimated to contain approximately 290,000 (± 40,000 SE) live and dead trees, an increase in the reported population from 2011 of 249,000 trees. Differences in tree population and other city-level metrics are partially attributed to the study areas now including the right-of-way area. Canopy cover is estimated to be 50% of the City area, ranking among the most heavily forested municipalities in the region. This is consistent with other recent Lake Forest Park canopy cover estimates including the study conducted by Elm in 2016, which estimated a canopy cover of 50%, and i-Tree Landscape, which estimated a canopy cover of 48% in 2017 (data obtained from i-Tree Landscape in November 2023). While tree population and canopy cover appear to be increasing, the study methods do not support tests of statistical significance, and the error inherent in comparisons of this type does not permit us to say that there is statistical support for those trends.

Canopy cover is greatest in the Large Residential stratum (57%), followed by the Small Residential stratum (31%), and then the Town Center (10%). The defined strata in the study design do not allow for a direct comparison with the City's canopy cover goals separated by zone, though a side-by-side comparison in Table 2 displays those most closely related. Based on these estimates, the Large Residential and Small Residential strata meet the City's canopy cover goals while the Town Center lags slightly.

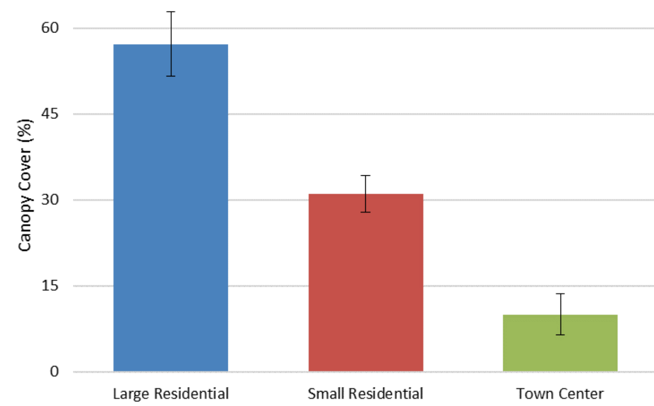


Figure 3. Canopy cover by stratum.

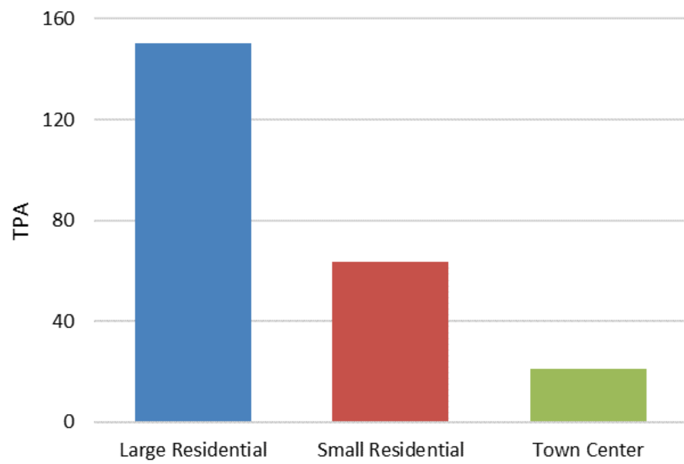


Figure 4. Tree density by stratum.

The average tree density in Lake Forest Park is estimated to be 126 trees per acre (TPA). Large Residential areas have the highest tree density, followed by Small Residential areas, and Town Center as shown in Figure 4.

Table 2. Comparison of canopy cover across i-Tree Eco study strata with city goals. Canopy cover goals for zoning designations do not correspond directly to the strata within the study design, and the nearest type is included for reference.

Stratum	City Goals	Corresponding Zones	Estimated Canopy Cover
Large Residential (>1/4 ac)	50%	Single-family lots 10,000 – 15,000 square feet Single-family lots >15,000 square feet	57%
Small Residential (<1/4 ac)	25%	Single-family lots <10,000 square feet	31%
Town Center	15%	Commercial	10%

There are 72 tree species represented in the study, though many other rare or infrequent species are likely present throughout Lake Forest Park which were not captured in the sampling plots. Since several tree species are not reliably identifiable to species in rapid field assessments, several of these taxa were identified to the genus level including certain apples (*Malus* spp.), plums (*Prunus* spp.), golden chain trees (*Laburnum* spp.), crape myrtles (*Lagerstroemia* spp.), privets (*Ligustrum* spp.), yews (*Taxus* spp.), and willows (*Salix* spp.). Each of these likely represent multiple species or hybrids of multiple species, so overall species richness is assumed to be slightly higher than reported.

Species richness at the city scale is greatest in the Small Residential stratum despite having a smaller total area than the Large Residential Stratum, with 54 and 42 species respectively (Figure 5). Conversely, species richness at the local scale is greatest in the Large Residential stratum which has more species per acre than the Small Residential Stratum; with 22 and 11 species respectively. Both metrics of species richness are lowest in the Town Center stratum.

Douglas-fir, bigleaf maple, and western red cedar continue to be the most common trees and are native to the Puget Lowlands Ecoregion. Diversity is key to resiliency in urban forests, particularly regarding impacts from disease and insects, and climate change.

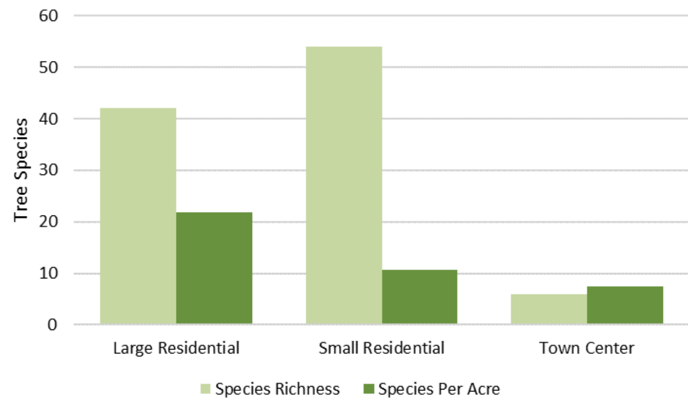


Figure 5. Species richness and species per acres by strata.

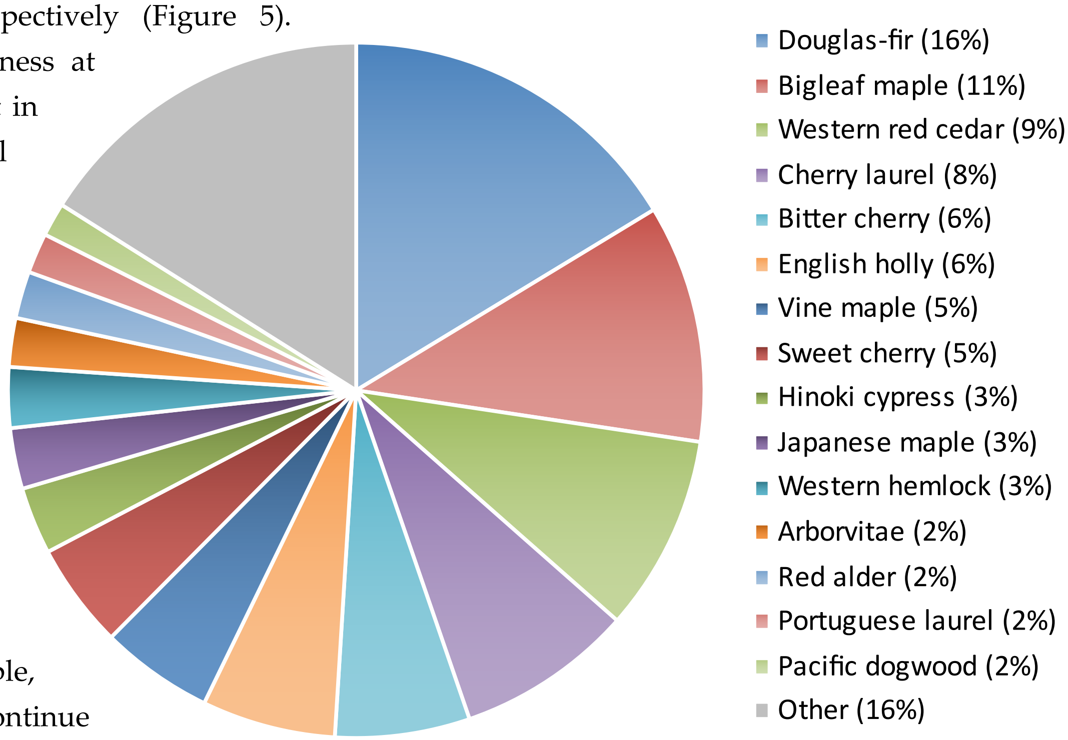


Figure 6. Composition chart of the most abundant tree species.

Lake Forest Park has a greater canopy cover and tree density than any of the cities which i-Tree listed as comparable. Of these, Atlanta is reported to have the greatest tree canopy cover at 37% and Morgantown is reported to have the greatest tree density at 119 TPA.

Tree size class distributions provide a snapshot of forest structure that informs management strategies. Among these, it is useful to know whether a forest has a young or aging population. Currently, 71% of trees in Lake Forest Park are less than 12″ DBH, indicating a skew toward younger or smaller trees.

Despite a youthful population or Type 1 distribution (Morgenroth et al. 2020), the tree size class distribution skews slightly larger than the prior 2011 i-Tree Eco study. The percentage of the largest trees, those above 30″ DBH, has increased since 2011 and now account for 5% of trees. Trees greater than 24″ inches DBH now account for 10% of the total tree population, an increase from 2011.

Trees in Lake Forest Park are estimated to be 56% native to Washington overall, most concentrated in the Large Residential stratum, followed by the Small Residential and Town Center stratum (Figure 7).

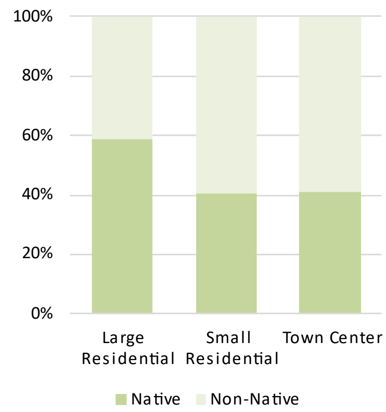


Figure 7. Native status of trees by stratum.

Trees designated by King County or Washington State as noxious weeds comprise less than 1% of the tree population. These are represented by only one species, common hawthorn. However, 20% of trees are species listed by King County as weeds of concern. These include cherry laurel, sweet cherry, European mountain ash, black locust, horse chestnut, and English holly.

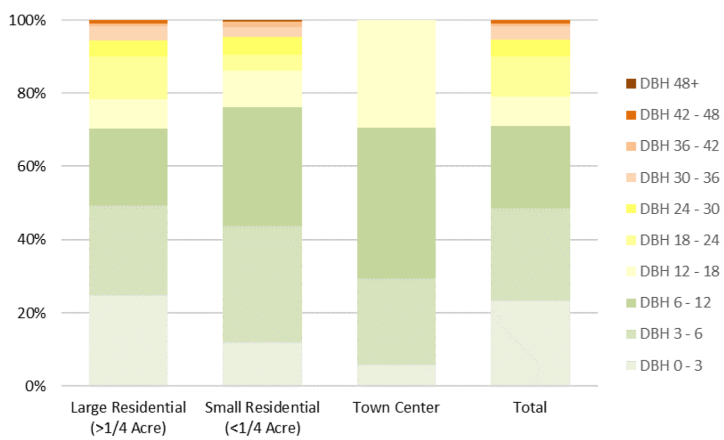


Figure 8. Tree DBH class distribution by stratum.

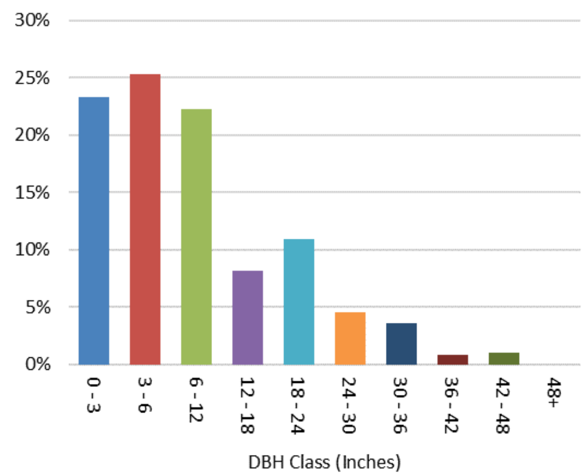


Figure 9. Tree DBH distribution.

Urban Forest Cover and Leaf Area

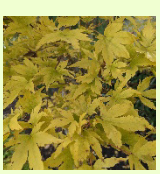
Leaf area density is greatest in the Large Residential stratum compared to other strata due to high tree density and the presence of larger trees. As a result, leaf area density in the Large Residential stratum is three times greater than the Small Residential stratum, and seven times greater than the Town Center stratum (Figure 8). A handful of species contribute most of the leaf area including Douglas-fir, western red cedar, and bigleaf maple (Table 3).

The importance value of each species represents the sum of the percent cover of a specific species and the leaf area percentage. This indicates which species dominate the urban canopy structure but are not always the best species to plant. The leaf area is an informative metric because it directly correlates with many urban forest functions and benefits such as avoided stormwater runoff.

Table 3. Leaf area, importance value, and percent of population by tree

Tree Species	Population (%)	Leaf Area (%)	Importance Value
Douglas-fir (*Pseudotsuga menziesii*)	16.3	35.5	51.8
Bigleaf maple (*Acer macrophyllum*)	11.1	18.9	30.0
Western red cedar (*Thuja plicata)*	9.1	15.5	24.6
Cherry laurel (*Prunus laurocerasus*)*	8.2	0.7	8.9
Red alder (*Alnus rubra*)	2.2	5.8	8.0
English holly (*Ilex aquifolium*)*	6.2	1.3	7.5
Vine maple (*Acer circinatum*)	5.2	1.9	7.1
Bitter cherry (*Prunus emarginata*)	6.3	0.7	6.9
Sweet cherry (*Prunus avium*)*	4.9	0.1	5.0
Deodar cedar (*Cedrus deodara*)	0.3	3.9	4.3
Western hemlock (*Tsuga heterophylla*)	2.8	1.3	4.1
Hinoki cypress (*Chamaecyparis obtusa*)	3.1	0.5	3.7
Japanese maple (*Acer palmatum*)	2.8	0.5	3.3
Western white pine (*Pinus monticola*)	0.4	2.8	3.2
Giant Sequoia (*Sequoiadendron giganteum*)	0.3	2.6	3.0
Arborvitae (*Thuja occidentalis*)	2.3	0.1	2.4
Black poplar (*Populus nigra*)	1.2	1.0	2.2
Portuguese laurel (*Prunus lusitanica*)	1.9	0.3	2.2
Sitka spruce (*Picea sitchensis*)	0.3	1.6	2.0
Pacific dogwood (*Cornus nuttallii*)	1.6	0.3	1.8
Plum (*Prunus* spp.)	1.3	0.1	1.4
Shore pine (*Pinus contorta*)	0.7	0.4	1.1
Blue spruce (*Picea pungens*)	0.4	0.7	1.1

* Designated as weed of concern by King County.



Total leaf area is defined as the one-sided area of all leaves in the study area. This differs from canopy cover because individual leaves may overlap within and among trees.

The total plantable space in Lake Forest Park is estimated to be 22% (±3 SE), which represents opportunities for additional tree planting. This is defined as the amount of land area with suitable soils that are not under existing tree canopies or other overhead or land use restrictions that would prohibit tree planting (e.g., developed park or playfield).

Groundcover composition is a predictor variable for certain tree benefits estimated by i-Tree Eco because of the interaction between these benefits and ground-level processes. Stormwater avoidance, for example, is informed by the amount of impervious surface.

Groundcover composition is consistent with expectations for the land use types, with high-intensity land uses having the most buildings and impervious surfaces, and low-intensity land uses having the most groundcover vegetation, duff/mulch, and bare soil. Impervious surfaces[2] are highest in the Town Center (86%), followed by Small Residential areas (51%), then Large Residential areas (25%). Where shrubs are present in sample plots, groundcover type below the shrub layer is recorded.

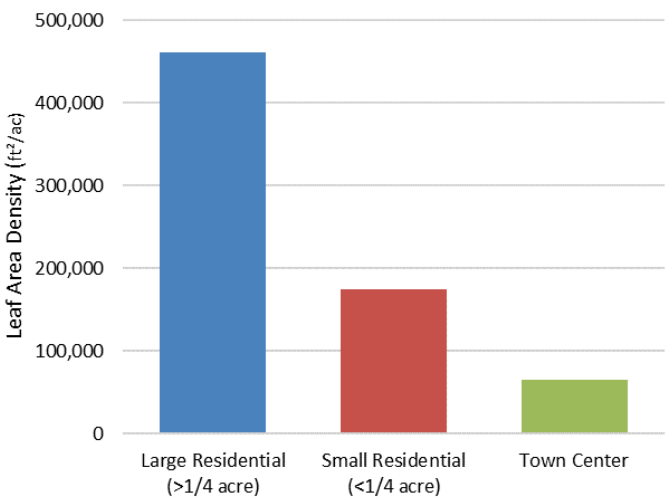


Figure 10. Leaf area density by stratum.

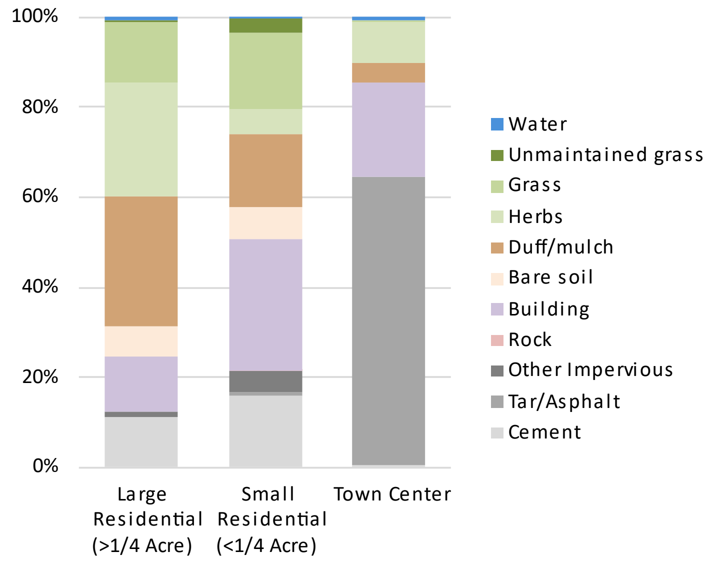
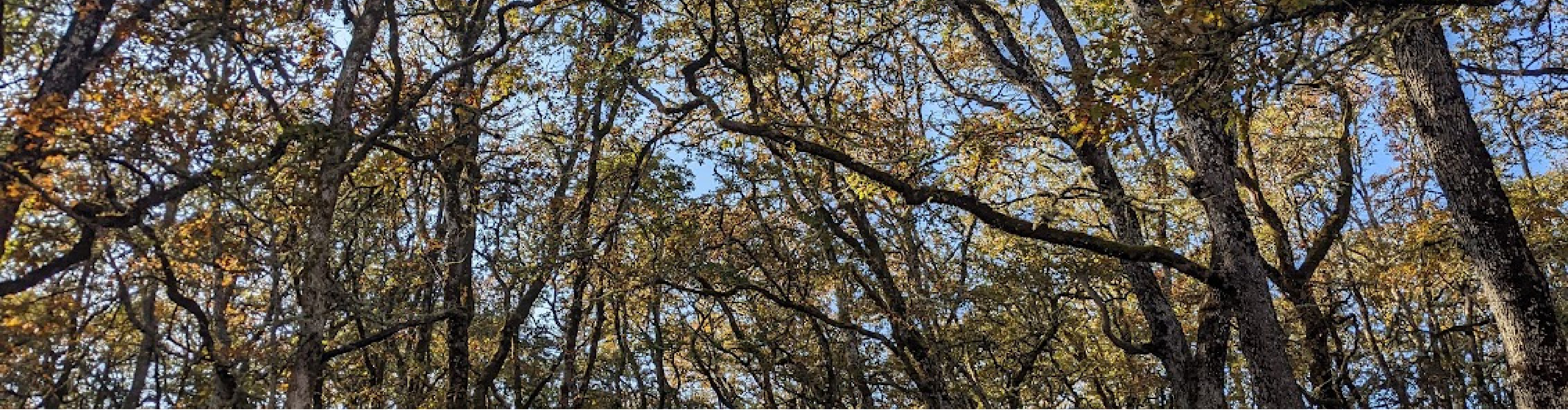


Figure 11. Ground cover composition by stratum.

[2] Impervious surfaces includes cement, tar/asphalt, other impervious surface, rock, and building.



Air Pollution

Many urban areas have high levels of air pollution which negatively impacts the health of humans and ecosystems. Urban forests mitigate the effects of air pollution through several processes including absorption and particulate matter filtration, air temperature cooling, and reducing the energy consumption of buildings. While trees also emit volatile organic compounds (VOCs) that contribute to the formation of ozone (O_3), studies show that high tree cover is correlated with a reduction in ozone formation (Nowak and Dwyer 2000).

The Lake Forest Park urban forest canopy is estimated to remove 1,600 pounds of carbon monoxide (CO), 33,000 pounds of nitrogen dioxide (NO_2), 69,000 pounds of O_3, 92,000 pounds of particulate matter less than 10 microns and greater than 2.5 microns (PM10), 12,000 pounds of particulate matter less than 2.5 microns (PM2.5), and 3,000 pounds of sulfur dioxide (SO_2) annually. This removal has an associated value of $2.5 million.

Air pollution removal varies temporally, as shown in Figure 10. Some pollutants such as NO_2 and O_3 are removed at greater levels during the summer growing season while PM2.5 and PM10 removal is greatest during the fall and winter. Since some types of air pollution removal correlates with leaf area, the distribution of evergreen and deciduous trees also influences the magnitude of temporal variation. The large spike in PM10 in September and October is due to high concentrations present from wildfire smoke.

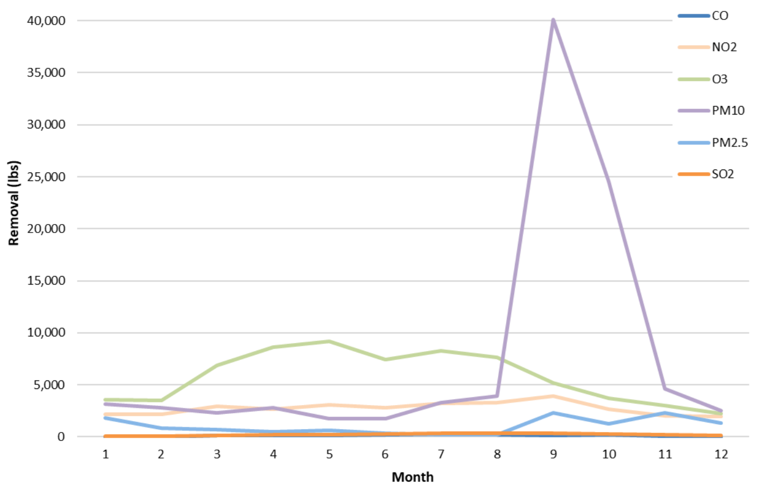


Figure 12. Estimated monthly pollution removal by the Lake Forest Park urban forest.

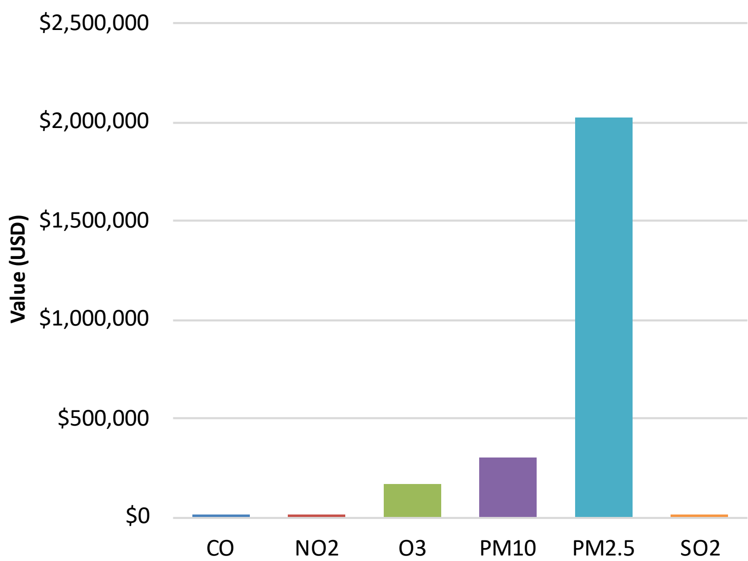
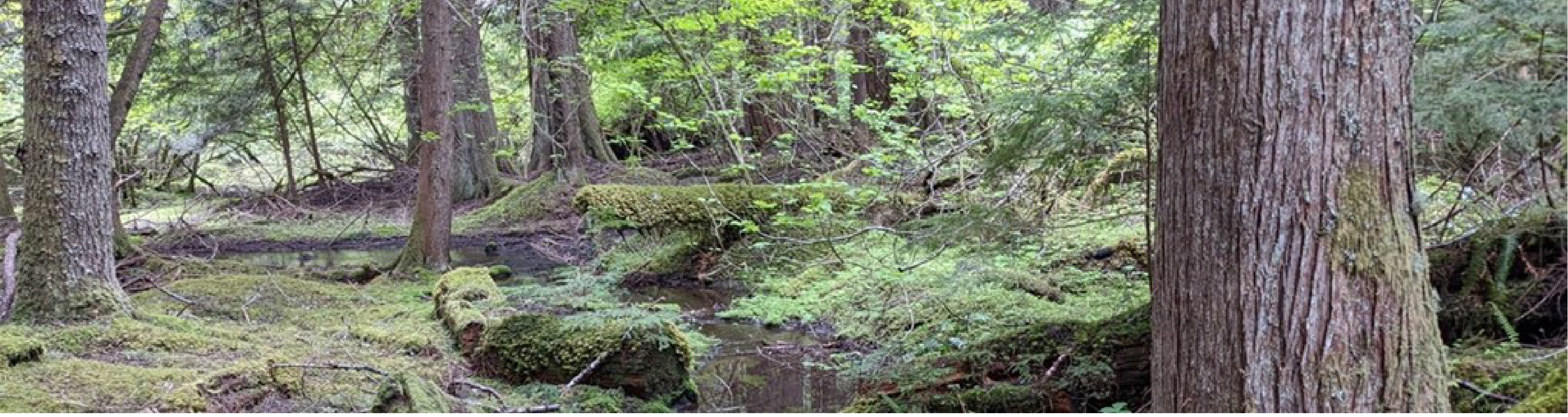


Figure 13. Estimated monetary value of air pollution removal annually.



Carbon Sequestration and Storage

Tree canopy cover in Lake Forest Park is not just a local issue. Global climate change is largely driven by carbon dioxide (CO_2) emissions, a compound that trees uptake and sequester during photosynthesis. Carbon is stored in tree leaves and woody tissues, and therefore, reduces the amount of atmospheric carbon otherwise contributing to climate change. Carbon will remain in a tree until it eventually decomposes, where it may either be released to the atmosphere, returned to the soil, or absorbed by other organisms.

The Lake Forest Park urban forest is estimated to remove 2,600 tons of carbon annually. Areas with the greatest tree cover also provide the greatest levels of CO_2 sequestration, such as the Large Residential stratum, which provides two to six-fold more than the other strata on a per-area basis (Figure 14). The estimated value of this benefit is $440,000 per year. Carbon storage and carbon sequestration values are based on the societal costs of carbon emissions such as climate change impacts on flooding, sea level rise, and agriculture (Appendix I). Carbon storage is also valuable to quantify because a tree that decomposes will eventually release CO_2 back into the atmosphere. Trees in Lake Forest Park collectively store 95,000 tons of carbon, with an estimated value of $16.2 million. Douglas-fir, bigleaf maple, western red cedar, and deodar cedar are the tree species that currently have the greatest amount of carbon storage.

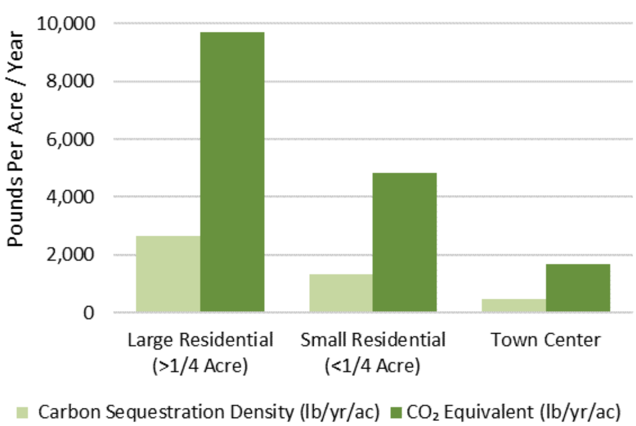


Figure 14. Carbon sequestration each year by stratum.

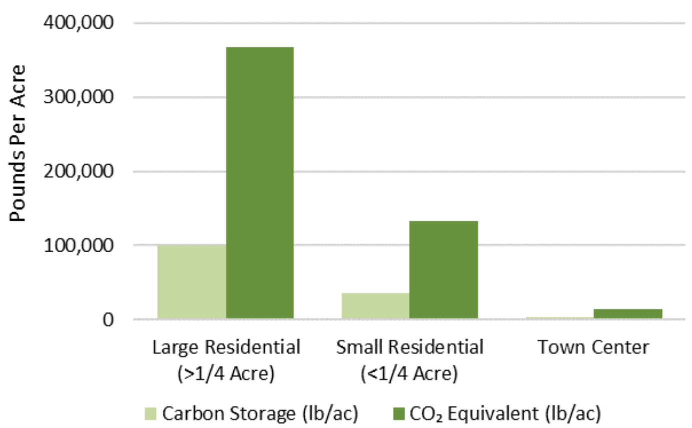


Figure 15. Total carbon storage by stratum.

Climate change is the process of shifting global and regional climate patterns, driven primarily by anthropogenic activities such as fossil fuel emissions and deforestation. These result in increased concentrations of greenhouse gases in the atmosphere which lead to globally rising temperatures, altered weather patterns, and sea level rise, which affect societies, economies, and ecosystems across the planet. Changing climates also mean cities need to manage for resilient forests which can tolerate shifting conditions.

Surface Water Runoff

Runoff from impermeable surfaces is a significant source of water pollution and flooding, posing risks to both human and environmental well-being while imposing substantial economic costs. Trees play a role in mitigating runoff through evapotranspiration, a combination of processes that include the interception of rainwater, evaporation, and transpiration, and thereby, return water to the atmosphere. Additionally, trees enhance the ability of rainwater to infiltrate into soils through inputs of organic matter and improve porosity. The combination of these processes results in the attenuation of pollution-laden runoff and a reduction in the severity of flooding events. Urban forests in Lake Forest Park are estimated to reduce runoff by 50 million gallons per year.

Urban forests also reduce the need for cities to rely on costly built infrastructure to manage water quality and quantity issues. This "green infrastructure" is estimated to provide Lake Forest Park with an estimated economic benefit of $450,000 per year for water quality and flood reduction benefits they provide. The majority of these benefits are provided in the Large Residential stratum, where tree density and leaf area are greatest.

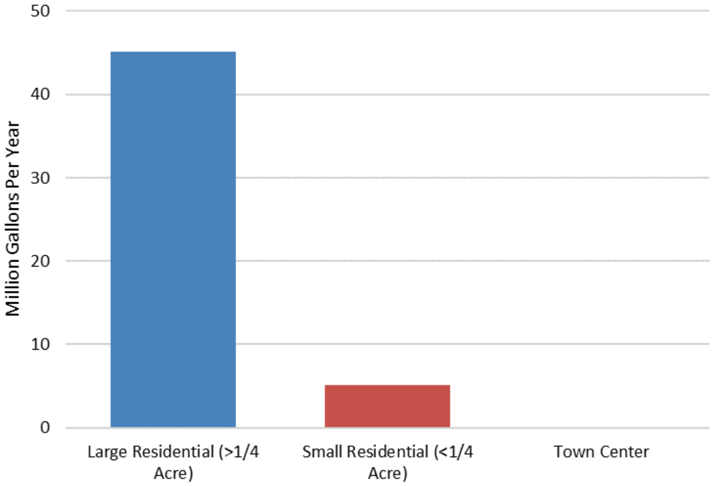


Figure 16. Avoided runoff per annum, by stratum.

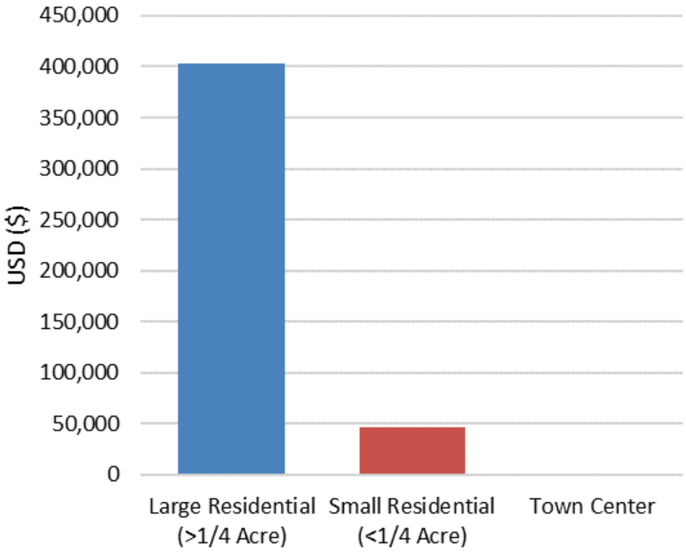


Figure 17. Value of avoided runoff per annum, by stratum.

Tree Benefits Summary

The total economic benefit of trees in Lake Forest Park is estimated to be $4.1 million per year, when accounting for energy savings, gross carbon sequestration, pollution removal, and avoided runoff (Table 4). On an individual basis, this amounts to $13.79 per tree on average.

Tree replacement values are another useful measure when managing forests since it is more expensive to replace trees than to preserve existing trees. The collective replacement value of all trees in Lake Forest Park is estimated to be $520 million in addition to the $16.2 million provided by carbon storage. The high cost of tree removal can inform public policy and management decisions regarding tree preservation and replacement on public and private land.

Trees in Lake Forest Park also generate 5,200 tons of oxygen every year, however, this benefit is believed to be relatively insignificant due to the vast reserves of oxygen in the atmosphere and production from oceanic systems (Broecker 1970; i-Tree 2023).

Table 4. Total Lake Forest Park tree benefits summary.

Benefits	Annual Value	Annual Value Per Tree
Energy & Carbon Emission Reduction	$635,000	$2.17
Gross Carbon Sequestration	$450,000	$1.53
Pollution Removal	$2,550,000	$8.57
Avoided Runoff	$450,000	$1.52
Total Benefits	**$4,085,000**	**$13.79**

Urban forests result in a net reduction in energy use through shading, evaporative cooling, and blocking of winter winds which are estimated to save Lake Forest Park residents $533,000 per year. Additionally, the value of reduced carbon emissions resulting from energy savings is valued at $102,000 per year.

Pests and Pathogens

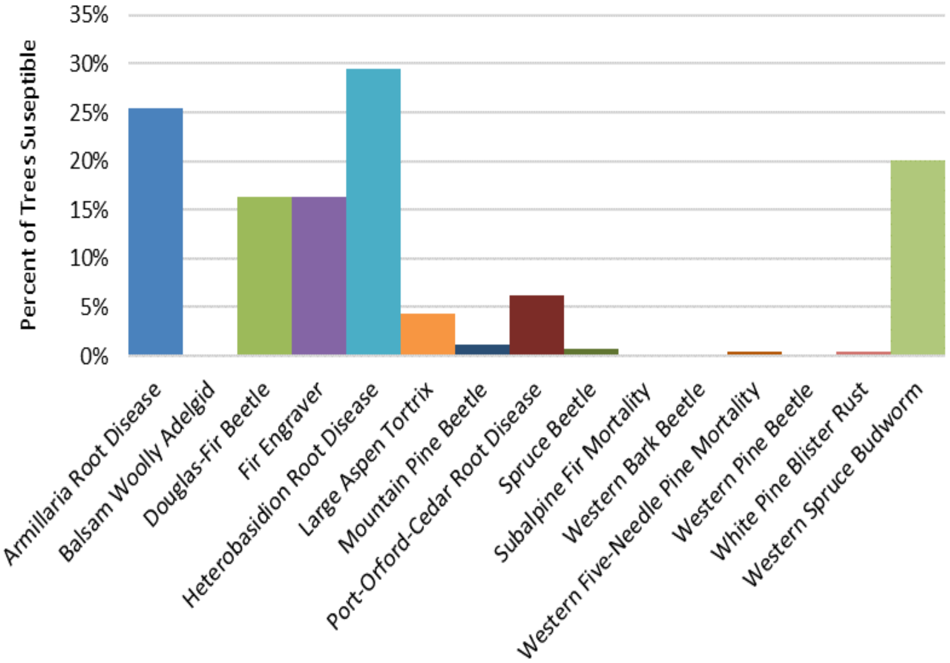


Figure 18. Susceptibility by trees to the 15 evaluated pests and pathogens which are currently known to be present in King County.

Trees are susceptible to pests and pathogens that are capable of impacting tree viability, resulting in reduced lifespan, hazard conditions, and sometimes mortality. The i-Tree Eco model includes an analysis of the susceptibility of Lake Forest Park's urban forests to 53 common pests and pathogens to evaluate risks and management priorities. While some pests and pathogens are naturally occurring and play an important role in forest ecological processes, others may have significant negative ecological and economic impacts. This section introduces the types of pests and pathogens identified through the i-Tree analysis based on data from the Forest Health Technology Enterprise Team (i-Tree 2023). See Appendix V for the complete list of pests and pathogens assessed through i-Tree. As described in Figure 18, the three species that could impact the highest percentage of canopy species in Lake Forest Park are two fungal pathogens and one insect commonly found in Pacific Northwest forests (Armillaria root disease, Heterobasidion root disease, and western spruce budworm).

Armillaria Root Disease (*Armillaria sp.*) refers to a group of fungi that causes reduced leader growth and foliage discoloration and thinning, spreading through a tree's root system (Allen et al. 1996).

Pests and pathogens included in the i-Tree analysis have been documented within King County limits but does not confirm their presence in the trees surveyed within the study plots. This research did not include an advanced level of tree health analysis beyond the standard i-Tree data collection protocols.

Heterobasidion Root Disease (HRD; *Heterobasidion annosum, H. occidentale*), also called Annosus root and butt rot, is a fungus known to impact native conifers as well as bigleaf maple and red alder. In younger trees, symptoms include a reduction in the leader and branch growth, chlorotic foliage, and a distressed cone crop. (Allen et al. 1996).

Photo by USDA Forest Service; fruiting body of H. occidentale.

Western spruce budworm (*Choristoneura occidentalis, C. freemani*) is an insect native to western North America and is a widespread defoliator of several native conifer species. It feeds upon and defoliates Douglas-firs, spruce, and true firs (e.g., white fir and subalpine fir). The larvae feed on the current year's needles and buds giving the canopy a red-brown or grayish appearance with thinning foliage and produce a new generation annually.

Photo by: Montana State University Extension;

Emerging Threats in Western Washington

Disease and pest outbreaks have increased in number and frequency in recent years due to international trade, travel, and climatic changes. New pests are introduced outside of their native range into ecosystems that have not evolved with the pest to develop any resistance. The effects of climate change, such as increases in seasonal and average air temperatures, increases in extreme heat, and prolonged drought, add abiotic stressors, weakening a tree's ability to defend against these diseases and pest pressures (Mauger et al. 2015). Additional pests and pathogens that could have an impact on canopy trees within Lake Forest Park include sooty bark disease, bronze birch borer, emerald ash borer, and non-native long-horned beetle species.

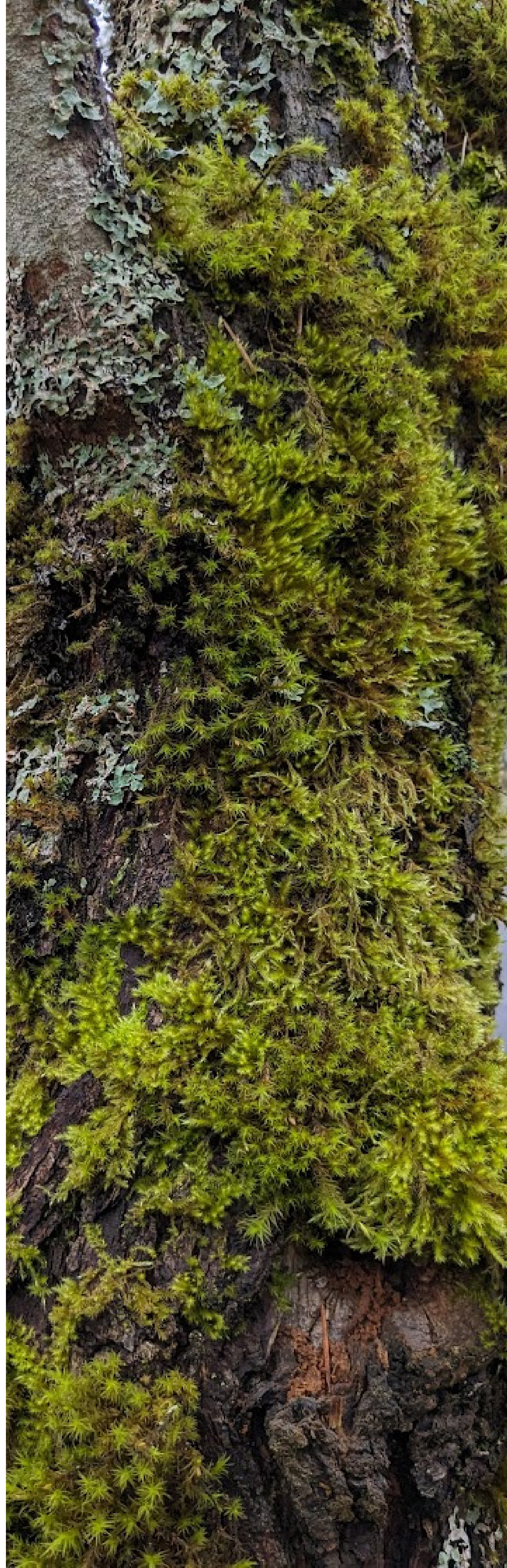
Sooty bark disease (*Cryptostroma corticale*) causes dieback primarily in maple species. To date, the fungus has been found to cause damage in sycamore maples (*Acer pseudoplatanus*), red maple (*A. rubrum*), Japanese maple (*A. palmatum*), vine maple (*A. circinatum*), and bigleaf maple (*A. macrophyllum*) in the Puget Sound region. The fungus infects the tree's vascular system and thrives during hot summers, proliferating in drought-stressed trees (Brooks et al. 2022).

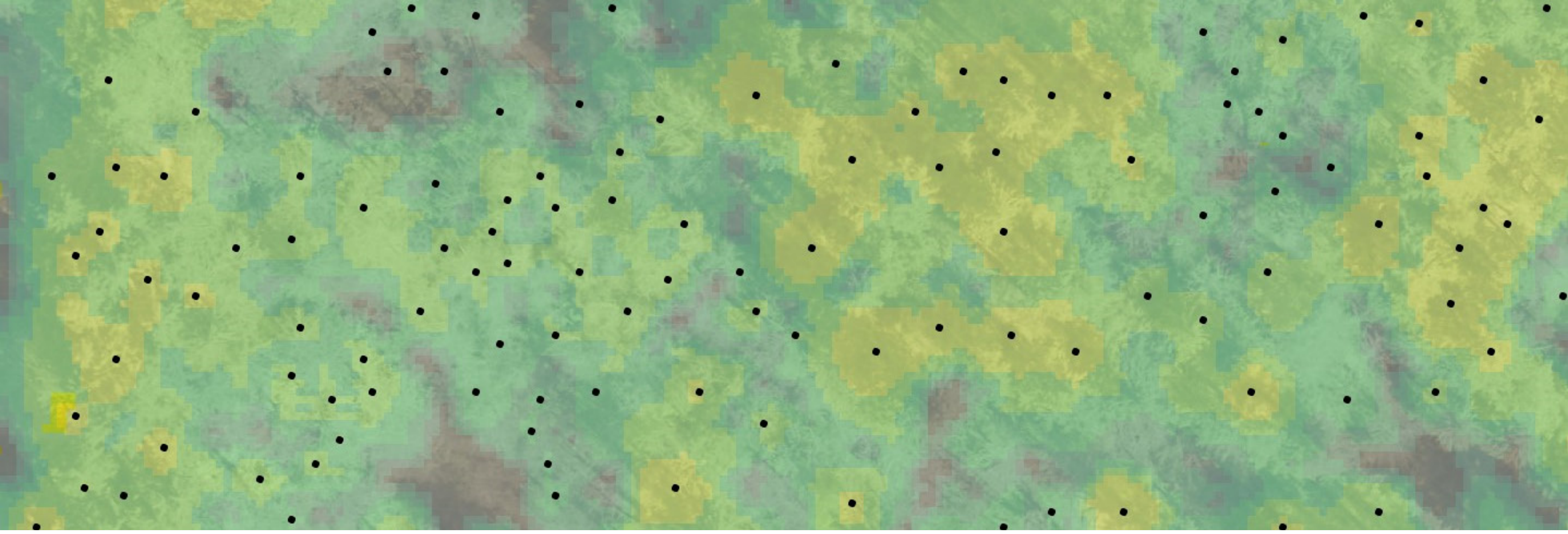
Bronze birch borer (*Agrilus anxius*) is a beetle whose larvae tunnel into live wood, creating extensive galleries leading to branch or trunk girdling, ultimately cutting the rest of the branch off from resources. Bronze birch borers are attracted to trees weakened by environmental stressors, age, or other diseases and pests (Antonelli 2008).

Emerald ash borer (*Agrilus planipennis*) has been present in the United States since 2002 but only recently has been confirmed in the Pacific Northwest Region as of 2022, where it was discovered in Oregon. While it has not yet been sighted in the Puget Sound region, its spread into Washington State is expected. The emerald ash borer infects native and non-native ash trees (*Fraxinus* spp.). Like other borers, its larvae create extensive galleries, causing limb and trunk dieback leading to decline and eventual tree death (Bliss-Ketchum et al. 2021). Although ash trees were found to only compose a tiny fraction of the tree population (<0.1%), it is possible that more are present and were not represented in the samples. Oregon ash (*Fraxinus latifolia*) is a native tree that can be found near water or in wetland areas. Ashes are also commonly planted as street trees and as ornamentals in yards and gardens.


Photo by Leah Bauer, USDA Forest Service, Northern Research Center Station; Emerald ash borer

Asian, citrus, and red-necked long-horned beetles (*Anoplophora glabripennis, A. chinenses, and Aromia bungii* respectively) feed on the wood of hardwood trees. Although there are no known established populations of these beetles in Washington, they have reached local nurseries where they were eradicated. With continued global movement within the nursery trade, Washington will need to continually monitor these species. The beetles typically feed on both healthy and dying trees and are known to impact 40 host species including maples, horse chestnuts, willows, birches, and elms. There are locally known native look-a-likes which present a challenge to identification for nonprofessionals (WISC 2017). The Washington Invasive Species Council has resources for identifying the potentially invasive versus native beetles in King County.





Canopy Height Model Results

The distribution of tree heights in Lake Forest Park reveals that the proportion of tall trees, those greater than 135 feet in height, has increased by 21% in 2021 compared to 2016 (Figure 19). The proportion of the tallest trees, those greater than 165 feet has increased by 86% during this period, albeit accounting for less than 1% of the total tree population. This suggests that most tall trees are being retained and that other small and moderate size trees are aging into the larger height classifications. The tallest tree is estimated to be 195 feet tall.

Trends of smaller trees vary by height class, although the proportion of trees in the moderate height classes have tended to decrease while the smallest, those between 15-30 feet, are approximately equal. Since trees below 15 feet were removed in this analysis, plot samples collected as part of the i-Tree Eco inventory provide better insight into age distribution and forest regeneration. The canopy height model is less selective than the plot sampling method in finding smaller trees and subcanopy trees, so interpretations of age and regeneration are not as precise as other sampling methods. However, this analysis provides us with additional insight into the distribution of trees within the assessed range between 15 and 195 feet.

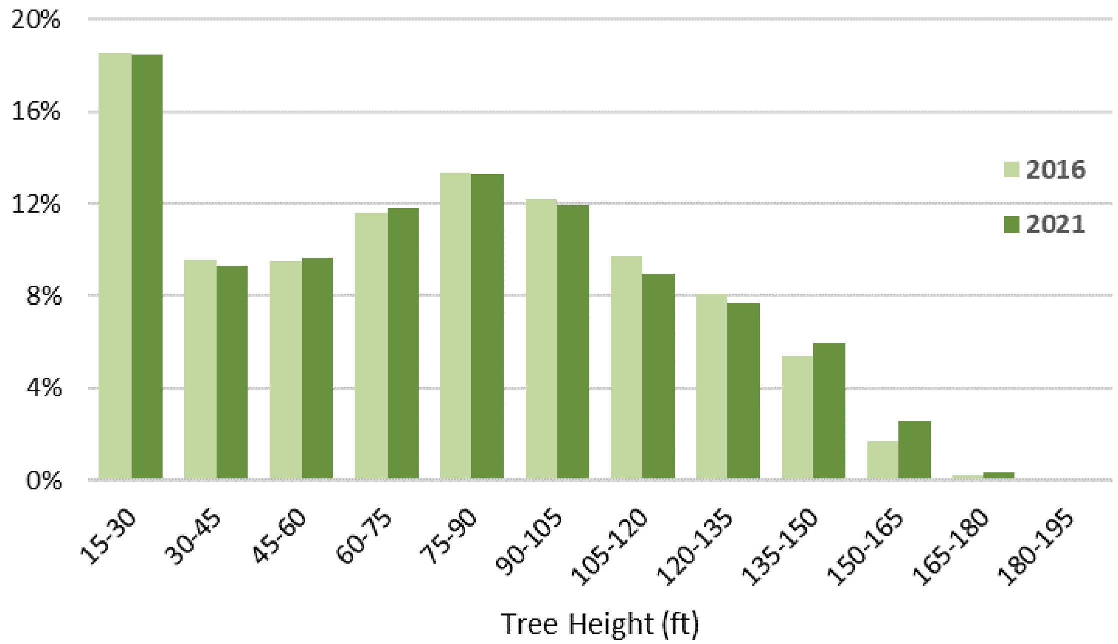


Figure 19. Histogram of tree heights in 2016 and 2021 based on the CHM.

Photo by Cori Whitaker

Discussion

The results of this i-Tree Eco study and canopy height model provide insight into the current composition and structure of Lake Forest Park's urban and community forest as well as quantify ecosystem service benefits and values. The results suggest a net increase in urban tree canopy cover and tree density during the last ten years and an increasing trend in the presence of large canopy trees, primarily comprised of Pacific Northwest native species.

The data obtained by this study provides City urban forest managers with practical information that is useful to develop urban forest management strategies and policies. Cities across the Puget Sound region and the Pacific Northwest face several challenges to steward resilient, regenerative, and viable urban forests. These include shifts in climate conditions, threats from current and emerging pests and pathogens, the potential for increases in urban wildfires, and continued development needed to meet regional housing needs. Urban forest managers are also tasked with ensuring that tree canopy remains equitably distributed throughout the City and that more densely developed land use zones have adequate green infrastructure to manage stormwater, minimize urban heat islands, provide shade, and foster both ecological health as well as human health and wellness.

Climate Adaptation and Resilience

Within the field of urban forest management, arborists, ecologists, foresters, and land managers continue to evaluate best management practices and adapt arboricultural strategies to the on-the-ground conditions impacting the resilience of urban forests.

Western Washington is expected to experience increasingly drier conditions and higher temperatures during the summer months, with potential increases in precipitation during the winter months (Mauger et al. 2015). This will present new and exacerbate current stressors on existing urban forests such as drought, insect and tree disease outbreaks, competition with invasive plant species, habitat loss and fragmentation, erosion, and wildfires. These stressors also create challenges for establishing the next generation of urban forest canopy, especially coupled with development pressures and the need to respond to the rising necessity for sustainable and affordable housing.

One strategy for establishing resilience within the urban forest is to increase tree diversity (at the family, genus, and species level) and ensure installed trees are climate-adapted to current and future stressors, such as drought. Since most biotic and abiotic stressors exhibit variable effects among tree species, a diverse forest acts as an insurance

policy that minimizes risk from impacts to individual taxa.

The City of Lake Forest Park currently has an approved tree list which includes species that are appropriate for the built environment in LFP and that are drought tolerant. This is an important educational and management tool that should be periodically evaluated and updated to account for updated research and recommendations from the arboriculture and horticultural trades and account for climate resilience.

Protection of Significant and Large Trees

The tree size class distributions outlined in this study tell us that 71% of the City's forests are less than 12" diameter-at-breast-height (DBH), but that the percentage of large diameter trees (those greater than 24" DBH) has continued to increase during the last decade. Tree diameter correlates with tree height and volume and can be used as a metric to describe overall tree size and identify large trees, which are a management priority for the City. Large trees provide greater levels of ecosystem services such as stormwater capture and infiltration, cooling, and water quality improvements compared to small trees; therefore, societal benefits are optimized when they are retained.

Since the majority of Lake Forest Park's urban forest is located on private residential, commercial, and industrial property, protection of significant and large-diameter trees on privately owned property will be an important strategy as the City seeks to protect its existing tree canopy. The City currently regulates trees during the development of private property through its tree ordinance – Chapter 16.14 *Tree Canopy Preservation and Enhancement* - as well as trees within shoreline jurisdiction through Chapter 16.18 *Shoreline Master Program*. These regulations prioritize the retention and protection of existing

trees and groves as well as replanting with new trees when removal is unavoidable due to tree risks, site development design, and storm damage.

The findings within this report can be used as a tool to educate and engage community members, private landowners, and the development community to encourage early assessment and integration of existing significant and exceptional trees in the pre-design or early design phase of new development. Another critical component is ensuring not only the long-term viability of a retained tree but ensuring that replacement trees are chosen using the “right plant, right place” approach, and have adequate growing conditions (e.g., soil volumes, planter strip widths, etc.) to reach maturity without impacting required infrastructure such as sidewalks, driveways, and utilities.

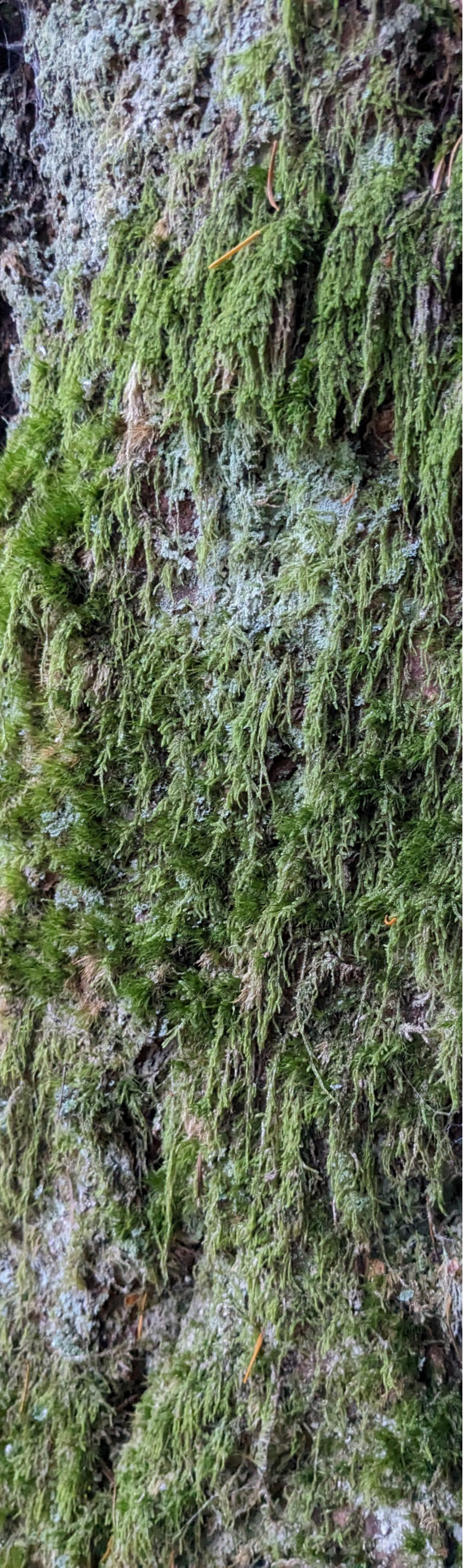
Invasive Species Management

Invasive plants are self-propagating and aggressive introduced species that are known to outcompete our native flora. They present significant challenges to urban forest health and management, including the economic investment for control and eradication as well as the costs to replace the ecosystem service benefits, they provided. This study provides an inventory of invasive trees, although shrub and understory components of the urban forest are not a part of the study design.

It is advantageous, both ecologically and economically, to control invasive plants before they become widely established in urban forests. Once a forest is overrun by invasive species, there is often an associated drop in wildlife richness, as they do not support the same level of habitat structure or food availability as native ecosystems.

For example, two shrub species that are heavily impacting Lake Forest Park’s urban forest are Himalayan blackberry (*Rubus bifrons*) and English ivy (*Hedera helix*). Both species are Class C non-regulated weeds on the King County Noxious Weed List, are widely distributed throughout the Puget Sound region, and are recommended for control where feasible due to their impacts (King County Noxious Weed Control Board 2023).

Himalayan blackberry is a woody shrub that forms dense brambles in clearings and forest understories that become so thick that no other plants will grow. Seed distribution is bird-facilitated which provides a constant source to new areas, so it is difficult to eliminate. English ivy forms an expansive mat through the trunks and canopies of trees, and on the forest floor, that competes with native plants for nutrients and light. English ivy can significantly reduce a tree's lifespan through this direct competition, by girdling the stem and increasing limb and tree failure from the extra weight. Once invasive plants take hold, native tree seedling establishment is suppressed, halting the cycle of forest regeneration. Existing trees eventually senesce and fall, leaving gaps in the canopy that can be quickly filled in by the established invasive plants.



Of the trees surveyed, 20% are either listed as a Class C noxious weed (common hawthorn) or a Weed of Concern (sweet cherry, black locust, cherry laurel, English holly, and European mountain ash) by the King County Noxious Weed Program. Cherry laurel and English holly, black locust, and European mountain ash are widely used as ornamental landscape plants. However, these species compete with our native flora and naturalize in open spaces and critical areas. Stokes et al (2014) examined the dispersal, spread, and impact of English holly in St. Edwards State Park and found that native vegetation was greatly reduced under the holly canopy. The study also reports that the holly population was spreading rapidly both through seed dispersal and vegetatively through the expansion of tree clumps.

A potential strategy to address this problem could be for the City to develop a prohibited species list and other educational materials to discourage property owners and developers from introducing invasive shrub and tree species into new plantings. In addition, the City could consider implementing the removal of both invasive shrub and tree species from public open spaces, replacing them with native tree and shrub species.

Additional Considerations

Scientific studies as well as programmatic and policy audits provide important data to evaluate the success of urban forest resource management strategies. In addition to the continuation of tree benefit analyses, the evaluation of other policies and regulations can inform municipal code updates, the effectiveness of current community education and outreach efforts, and additional support needed from community members in managing trees on their properties. Continued study of on-the-ground conditions coupled with evaluation of existing policies and best practices will provide the City with the tools and information needed to manage the valuable urban forest resource effectively and adaptively.

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Appendix I. i-Tree Eco Model and Field Measurements

i-Tree Eco 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 (Nowak and Crane 2000), 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.
- 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 sources.
- Replacement value of the forest, as well as the value for air pollution removal and carbon storage and sequestration.
- Potential impact of infestations by pests, such as Asian longhorned beetle, emerald ash borer, gypsy moth, and Dutch elm disease.

Typically, all field data are collected during the leaf-on season to properly assess tree canopies. 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 (Nowak et al 2005; Nowak et al 2008).

During data collection, trees are identified to the most specific taxonomic classification possible. Trees that are not classified to the species level may be classified by genus (e.g., ash) or species groups (e.g., hardwood). In this report, tree species, genera, or species groups are collectively referred to as tree species.

<u>Tree Characteristics:</u>

Leaf area of trees was assessed using measurements of crown dimensions and percentage of crown canopy missing. In the event that these data variables were not collected, they are estimated by the model.

An analysis of invasive species is not available for studies outside of the United States. For the U.S., invasive species are identified using an invasive species list (Oregon Invasive Species Council 2014)for the state in which the urban forest is located. These lists are not exhaustive and they cover invasive species of varying degrees of invasiveness and distribution. In instances where a state did not have an invasive species list, a list was created based on the lists of the adjacent states. Tree species that are identified as invasive by the state invasive species list are cross-referenced with native range data. This helps eliminate species that are on the state invasive species list, but are native to the study area.

<u>Air Pollution Removal:</u>

Pollution removal is calculated for ozone, sulfur dioxide, nitrogen dioxide, carbon monoxide, particulate matter less than 2.5 microns, and particulate matter less than 10 microns and greater than 2.5 microns. PM2.5 is generally more relevant in discussions concerning air pollution effects on human health.

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 (Baldocchi 1988; Baldocchi et al 1987). 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 (Bidwell and Fraser 1972; Lovett 1994) that were adjusted depending on leaf phenology and leaf area. Particulate removal incorporated a 50 percent resuspension rate of particles back to the atmosphere (Zinke 1967). 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 (Hirabayashi et al 2011; Hirabayashi et al 2012; Hirabayashi 2011).

Trees remove PM2.5 and PM10* when particulate matter is deposited on leaf surfaces (Nowak et al 2013). This deposited PM2.5 and PM10* can be resuspended to the atmosphere or removed during rain events and dissolved or transferred to the soil. This combination of events can lead to positive or negative pollution removal and value depending on various atmospheric factors. Generally, PM2.5 and PM10* removal is positive with positive benefits. However, there are some cases when net removal is negative or resuspended particles lead to increased pollution concentrations and negative values. During some months (e.g., with no rain), trees resuspend more particles than they remove. Resuspension can also lead to increased overall PM2.5 and PM10* concentrations if the boundary layer conditions are lower during net resuspension periods than during net removal periods. Since the pollution removal value is based on the change in pollution concentration, it is possible to have situations when trees remove PM2.5 and PM10* but increase concentrations and thus have negative values during periods of positive overall removal. These events are not common, but can happen.

For reports in the United States, default air pollution removal value is calculated based on local incidence of adverse health effects and national median externality costs. The number of adverse health effects and associated economic value is calculated for ozone, sulfur dioxide, nitrogen dioxide, and particulate matter less than 2.5 microns using data from the U.S. Environmental Protection Agency's Environmental Benefits Mapping and Analysis Program (BenMAP) (Nowak et al 2014). The model uses a damage-function approach that is based on the local change in pollution concentration and population. National median externality costs were used to calculate the value of carbon monoxide removal (Murray et al 1994).

For international reports, user-defined local pollution values are used. For international reports that do not have local values, estimates are based on either European median externality values (van Essen et al 2011) or BenMAP regression equations (Nowak et al 2014) that incorporate user-defined population estimates. Values are then converted to local currency with user-defined exchange rates.

For this analysis, pollution removal value is calculated based on the prices of $1,397 per ton (carbon monoxide), $4,926 per ton (ozone), $613 per ton (nitrogen dioxide), $181 per ton (sulfur dioxide), $330,079 per ton (particulate matter less than 2.5 microns), $6,565 per ton (particulate matter less than 10 microns and greater than 2.5 microns).

Carbon Storage and Sequestration:

Carbon storage is the amount of carbon bound up in the above-ground and below-ground parts of woody vegetation. 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 (Nowak 1994). 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.

Carbon sequestration is the removal of carbon dioxide from the air by plants. 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.

Carbon storage and carbon sequestration values are based on estimated or customized local carbon values. For international reports that do not have local values, estimates are based on the carbon value for the United States (U.S. Environmental Protection Agency 2015, Interagency Working Group on Social Cost of Carbon 2015) and converted to local currency with user-defined exchange rates.

For this analysis, carbon storage and carbon sequestration values are calculated based on $171 per ton.

Oxygen Production:

The amount of oxygen produced is estimated from carbon sequestration based on atomic weights: net O2 release (kg/yr) = net C sequestration (kg/yr) × 32/12. To estimate the net carbon sequestration rate, the amount of carbon sequestered as a result of tree growth is reduced by the amount lost resulting from tree mortality. Thus, net carbon sequestration and net annual oxygen production of the urban forest account for decomposition (Nowak et al 2007). For complete inventory projects, oxygen production is estimated from gross carbon sequestration and does not account for decomposition.

Avoided Runoff:

Annual avoided surface runoff is calculated based on rainfall interception by vegetation, specifically the difference between annual runoff with and without vegetation. Although tree leaves, branches, and bark may intercept precipitation and thus mitigate surface runoff, only the precipitation intercepted by leaves is accounted for in this analysis.

The value of avoided runoff is based on estimated or user-defined local values. For international reports that do not have local values, the national average value for the United States is utilized and converted to local currency with user-defined exchange rates. The U.S. value of avoided runoff is based on the U.S. Forest Service's Community Tree Guide Series (McPherson et al 1999; 2000; 2001; 2002; 2003; 2004; 2006a; 2006b; 2006c; 2007; 2010; Peper et al 2009; 2010; Vargas et al 2007a; 2007b; 2008).

For this analysis, avoided runoff value is calculated based on the price of $0.01 per gallon.

Building Energy Use:

If appropriate field data were collected, seasonal effects of trees on residential building energy use were calculated based on procedures described in the literature (McPherson and Simpson 1999) using distance and direction of trees from residential structures, tree height and tree condition data. To calculate the monetary value of energy savings, local or custom prices per MWH or MBTU are utilized.

For this analysis, energy saving value is calculated based on the prices of $96.70 per MWH and $10.65 per MBTU.

Replacement Values:

Replacement value is the value of a tree based on the physical resource itself (e.g., the cost of having to replace a tree with a similar tree). Replacement values were based on valuation procedures of the Council of Tree and Landscape Appraisers, which uses tree species, diameter, condition, and location information (Nowak et al 2002a; 2002b). Replacement value may not be included for international projects if there is insufficient local data to complete the valuation procedures.

Potential Pest Impacts:

The complete potential pest risk analysis is not available for studies outside of the United States. The number of trees at risk to the pests analyzed is reported, though the list of pests is based on known insects and disease in the United States.

For the U.S., potential pest risk is based on pest range maps and the known pest host species that are likely to experience mortality. Pest range maps for 2012 from the Forest Health Technology Enterprise Team (FHTET) (Forest Health Technology Enterprise Team 2014) were used to determine the proximity of each pest to the county in which the urban forest is located. For the county, it was established whether the insect/disease occurs within the county, is within 250 miles of the county edge, is between 250 and 750 miles away, or is greater than 750 miles away. FHTET did not have pest range maps for Dutch elm disease and chestnut blight. The range of these pests was based on known occurrence and the host range, respectively (Eastern Forest Environmental Threat Assessment Center; Worrall 2007).

Relative Tree Effects:

The relative value of tree benefits reported in Appendix II is calculated to show what carbon storage and sequestration, and air pollutant removal equate to in amounts of municipal carbon emissions, passenger automobile emissions, and house emissions.

Municipal carbon emissions are based on 2010 U.S. per capita carbon emissions (Carbon Dioxide Information Analysis Center 2010). Per capita emissions were multiplied by city population to estimate total city carbon emissions.

Light duty vehicle emission rates (g/mi) for CO, NOx, VOCs, PM10, SO2 for 2010 (Bureau of Transportation Statistics 2010; Heirigs et al 2004), PM2.5 for 2011-2015 (California Air Resources Board 2013), and CO2 for 2011 (U.S. Environmental Protection Agency 2010) were multiplied by average miles driven per vehicle in 2011 (Federal Highway Administration 2013) to determine average emissions per vehicle.

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

- CO2, SO2, and NOx power plant emission per KWh are from Leonardo Academy 2011. CO emission per kWh assumes 1/3 of one percent of C emissions is CO based on Energy Information Administration 1994. PM10 emission per kWh from Layton 2004.
- CO2, NOx, SO2, and CO emission per Btu for natural gas, propane and butane (average used to represent LPG), Fuel #4 and #6 (average used to represent fuel oil and kerosene) from Leonardo Academy 2011.
- CO2 emissions per Btu of wood from Energy Information Administration 2014.
- CO, NOx and SOx emission per Btu based on total emissions and wood burning (tons) from (British Columbia Ministry 2005; Georgia Forestry Commission 2009).

Appendix II. Relative Tree Effects

The urban forest in Lake Forest Park 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, average passenger automobile emissions, and average household emissions. See Appendix I for methodology.

Carbon storage is equivalent to:
- Amount of carbon emitted in Lake Forest Park in 481 days
- Annual carbon (C) emissions from 67,300 automobiles
- Annual C emissions from 27,600 single-family houses

Carbon monoxide removal is equivalent to:
- Annual carbon monoxide emissions from 7 automobiles
- Annual carbon monoxide emissions from 21 single-family houses

Nitrogen dioxide removal is equivalent to:
- Annual nitrogen dioxide emissions from 2,350 automobiles
- Annual nitrogen dioxide emissions from 1,060 single-family houses

Sulfur dioxide removal is equivalent to:
- Annual sulfur dioxide emissions from 14,500 automobiles
- Annual sulfur dioxide emissions from 38 single-family houses

Annual carbon sequestration is equivalent to:
- Amount of carbon emitted in Lake Forest Park in 13.0 days
- Annual C emissions from 1,800 automobiles
- Annual C emissions from 700 single-family houses

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 i-Tree Eco model.

I. City totals for trees

City	*% Tree Cover*	*Number of Trees*	*Carbon Storage (tons)*	*Carbon Sequestration (tons/yr)*	*Pollution Removal (tons/yr)*
Toronto, ON, Canada	26.6	10,220,000	1,221,000	51,500	2,099
Atlanta, GA	36.7	9,415,000	1,344,000	46,400	1,663
Los Angeles, CA	11.1	5,993,000	1,269,000	77,000	1,975
New York, NY	20.9	5,212,000	1,350,000	42,300	1,676
London, ON, Canada	24.7	4,376,000	396,000	13,700	408
Chicago, IL	17.2	3,585,000	716,000	25,200	888
Phoenix, AZ	9.0	3,166,000	315,000	32,800	563
Baltimore, MD	21.0	2,479,000	570,000	18,400	430
Philadelphia, PA	15.7	2,113,000	530,000	16,100	575
Washington, DC	28.6	1,928,000	525,000	16,200	418
Oakville, ON , Canada	29.1	1,908,000	147,000	6,600	190
Albuquerque, NM	14.3	1,846,000	332,000	10,600	248
Boston, MA	22.3	1,183,000	319,000	10,500	283
Syracuse, NY	26.9	1,088,000	183,000	5,900	109
Woodbridge, NJ	29.5	986,000	160,000	5,600	210
Minneapolis, MN	26.4	979,000	250,000	8,900	305
San Francisco, CA	11.9	668,000	194,000	5,100	141
Morgantown, WV	35.5	658,000	93,000	2,900	72
Moorestown, NJ	28.0	583,000	117,000	3,800	118
Hartford, CT	25.9	568,000	143,000	4,300	58
Jersey City, NJ	11.5	136,000	21,000	890	41
Casper, WY	8.9	123,000	37,000	1,200	37
Freehold, NJ	34.4	48,000	20,000	540	22

II. Totals per acre of land area

City	*Number of Trees/ac*	*Carbon Storage (tons/ac)*	*Carbon Sequestration (tons/ac/yr)*	*Pollution Removal (lb/ac/yr)*
Toronto, ON, Canada	64.9	7.8	0.33	26.7
Atlanta, GA	111.6	15.9	0.55	39.4
Los Angeles, CA	19.6	4.2	0.16	13.1
New York, NY	26.4	6.8	0.21	17.0
London, ON, Canada	75.1	6.8	0.24	14.0
Chicago, IL	24.2	4.8	0.17	12.0
Phoenix, AZ	12.9	1.3	0.13	4.6
Baltimore, MD	48.0	11.1	0.36	16.6
Philadelphia, PA	25.1	6.3	0.19	13.6
Washington, DC	49.0	13.3	0.41	21.2
Oakville, ON , Canada	78.1	6.0	0.27	11.0
Albuquerque, NM	21.8	3.9	0.12	5.9
Boston, MA	33.5	9.1	0.30	16.1
Syracuse, NY	67.7	10.3	0.34	13.6
Woodbridge, NJ	66.5	10.8	0.38	28.4
Minneapolis, MN	26.2	6.7	0.24	16.3
San Francisco, CA	22.5	6.6	0.17	9.5
Morgantown, WV	119.2	16.8	0.52	26.0
Moorestown, NJ	62.1	12.4	0.40	25.1
Hartford, CT	50.4	12.7	0.38	10.2
Jersey City, NJ	14.4	2.2	0.09	8.6
Casper, WY	9.1	2.8	0.09	5.5
Freehold, NJ	38.3	16.0	0.44	35.3

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 (Nowak 1995):

- 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 (Nowak 2000). Local urban management decisions also can help improve air quality.

Urban forest management strategies to help improve air quality include (Nowak 2000):

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

Appendix V. Tree Population

Species	Number of Trees	Percent of Population
Douglas fir (Pseudotsuga menziesii)	47,352	16.3%
Bigleaf maple (Acer macrophyllum)	32,086	11.1%
Western red cedar (Thuja plicata)	26,564	9.1%
Cherry laurel (Prunus laurocerasus)	23,834	8.2%
Bitter cherry (Prunus emarginata)	18,156	6.3%
English holly (Ilex aquifolium)	17,990	6.2%
Vine maple (Acer circinatum)	15,190	5.2%
Sweet cherry (Prunus avium)	14,770	5.1%
Hinoki cypress (Chamaecyparis obtusa)	9,048	3.1%
Japanese maple (Acer palmatum)	8,224	2.8%
Western hemlock (Tsuga heterophylla)	8,164	2.8%
Arborvitae (Thuja occidentalis)	6,698	2.3%
Red alder (Alnus rubra)	6,301	2.2%
Portugal laurel (Prunus lusitanica)	5,408	1.9%
Pacific dogwood (Cornus nuttallii)	4,524	1.6%
Plum spp (Prunus)	3,910	1.3%
Black poplar (Populus nigra)	3,535	1.2%
Swiss mountain pine (Pinus mugo)	2,651	<1%
Camellia (Camellia japonica)	2,397	<1%
Paper birch (Betula papyrifera)	1,977	<1%
Shore pine (Pinus contorta)	1,977	<1%
English hawthorn (Crataegus monogyna)	1,872	<1%
California laurel (Umbellularia californica)	1,768	<1%
Cherry plum (Prunus cerasifera)	1,723	<1%
Port orford cedar (Chamaecyparis lawsoniana)	1,618	<1%
Kousa dogwood (Cornus kousa)	1,513	<1%
Leyland cypress (x Hesperotropsis leylandii)	1,469	<1%
Western white pine (Pinus monticola)	1,199	<1%
Blue spruce (Picea pungens)	1,094	<1%
Callery pear (Pyrus calleryana)	1,094	<1%
Deodar cedar (Cedrus deodara)	989	<1%
Sitka spruce (Picea sitchensis)	989	<1%
Giant Sequoia (Sequoiadendron giganteum)	989	<1%
Flowering dogwood (Cornus florida)	922	<1%
Red maple (Acer rubrum)	884	<1%
Japanese angelica tree (Aralia elata)	884	<1%
Atlas cedar (Cedrus atlantica)	884	<1%
Katsura tree (Cercidiphyllum japonicum)	884	<1%
Blue chinese fir (Cunninghamia lanceolata)	884	<1%
Chinese parasoltree (Firmiana simplex)	884	<1%
Cucumber tree (Magnolia acuminata)	884	<1%
Babylon weeping willow (Salix babylonica)	884	<1%
Pacific yew (Taxus brevifolia)	884	<1%

Apple spp (Malus)	839	<1%
Sweet cherry (Prunus avium)	315	<1%
European white birch (Betula pendula)	315	<1%
Southern magnolia (Magnolia grandiflora)	315	<1%
Japanese flowering cherry (Prunus serrulata)	210	<1%
Common apple (Malus domestica)	210	<1%
Black locust (Robinia pseudoacacia)	210	<1%
European mountain ash (Sorbus aucuparia)	210	<1%
Subalpine fir (Abies lasiocarpa)	105	<1%
Trident maple (Acer buergerianum)	105	<1%
Eastern redbud (Cercis canadensis)	105	<1%
Oregon ash (Fraxinus latifolia)	105	<1%
Honeylocust (Gleditsia triacanthos)	105	<1%
Black walnut (Juglans nigra)	105	<1%
Golden Chain Tree spp (Laburnum)	105	<1%
Lagerstroemia spp (Lagerstroemia)	105	<1%
Privet spp (Ligustrum)	105	<1%
Norway spruce (Picea abies)	105	<1%
Scots pine (Pinus sylvestris)	105	<1%
Black cottonwood (Populus balsamifera ssp. trichocarp)	105	<1%
Common plum (Prunus domestica)	105	<1%
Sargent cherry (Prunus sargentii)	105	<1%
Umbrella pine (Sciadopitys verticillata)	105	<1%
Coast redwood (Sequoia sempervirens)	105	<1%
Yew spp (Taxus)	105	<1%
Mountain hemlock (Tsuga mertensiana)	105	<1%
Sweetgum (Liquidambar styraciflua)	76	<1%
River birch (Betula nigra)	57	<1%
Willow spp (Salix)	19	<1%
Total	**290,403**	**100%**

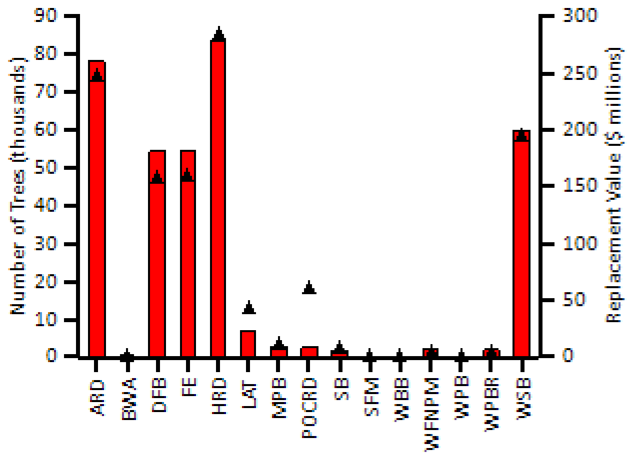
Appendix VI. Potential Risk of Pests

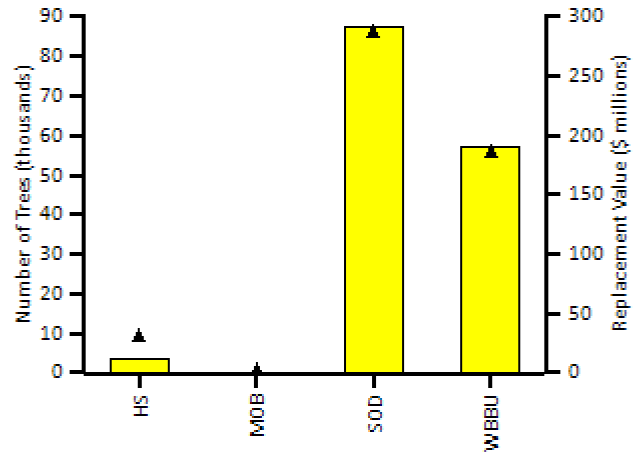
Fifty-three insects and diseases were analyzed to quantify their potential impact on the urban forest. As each insect/ disease is likely to attack different host tree species, the implications for {0} will vary. The number of trees at risk reflects only the known host species that are likely to experience mortality.

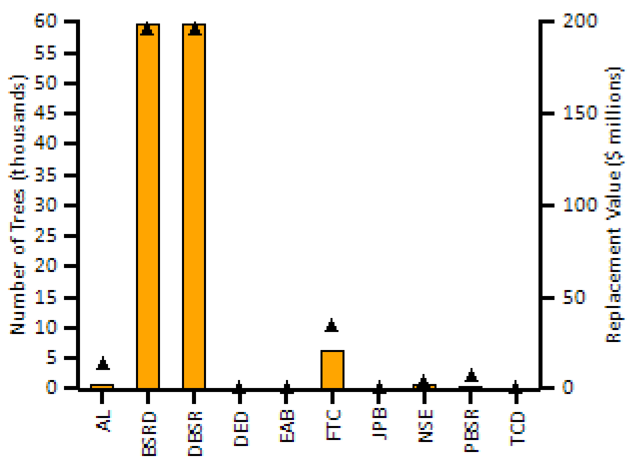
Code	Scientific Name	Common Name	Trees at Risk (#)	Value ($ millions)
AL	Phyllocnistis populiella	Aspen Leafminer	4,034	2.32
ALB	Anoplophora glabripennis	Asian Longhorned Beetle	64,701	122.94
ARCA	Neodothiora populina	Aspen Running Canker	0	0.00
ARD	Armillaria spp.	Armillaria Root Disease	74,022	260.62
BBD	Neonectria faginata	Beech Bark Disease	0	0.00
BC	Sirococcus clavigignenti juglandacearum	Butternut Canker	105	0.02
BLD	Litylenchus crenatae mccannii	Beech Leaf Disease	0	0.00
BM	Euproctis chrysorrhoea	Browntail Moth	6,746	3.73
BOB	Tubakia iowensis	Bur Oak Blight	0	0.00
BSRD	Leptographium wageneri	Black Stain Root Disease	58,797	198.51
BWA	Adelges piceae	Balsam Woolly Adelgid	210	1.26
CB	Cryphonectria parasitica	Chestnut Blight	0	0.00
DA	Discula destructiva	Dogwood Anthracnose	6,959	2.22
DBSR	Leptographium wageneri var. pseudotsugae	Douglas-fir Black Stain Root Disease	58,797	198.51
DED	Ophiostoma novo-ulmi	Dutch Elm Disease	0	0.00
DFB	Dendroctonus pseudotsugae	Douglas-Fir Beetle	47,352	181.69
EAB	Agrilus planipennis	Emerald Ash Borer	105	0.23
FE	Scolytus ventralis	Fir Engraver	47,562	181.85
FR	Cronartium quercuum f. sp. Fusiforme	Fusiform Rust	0	0.00
FTC	Malacosoma disstria	Forest Tent Caterpillar	10,231	21.17
GSOB	Agrilus auroguttatus	Goldspotted Oak Borer	0	0.00
HRD	Heterobasidion irregulare/ occidentale	Heterobasidion Root Disease	85,466	278.55
HS	Neodiprion tsugae	Hemlock Sawfly	9,257	11.89
HWA	Adelges tsugae	Hemlock Woolly Adelgid	0	0.00
JPB	Dendroctonus jeffreyi	Jeffrey Pine Beetle	0	0.00
JPBW	Choristoneura pinus	Jack Pine Budworm	4,734	1.41
LAT	Choristoneura conflictana	Large Aspen Tortrix	12,685	23.54
LWD	Raffaelea lauricola	Laurel Wilt	1,768	0.54
MOB	Xyleborus monographus	Mediterranean Oak Borer	629	0.38
MPB	Dendroctonus ponderosae	Mountain Pine Beetle	3,386	8.78
NSE	Ips perturbatus	Northern Spruce Engraver	989	2.62
OW	Ceratocystis fagacearum	Oak Wilt	0	0.00
PBSR	Leptographium wageneri var. ponderosum	Pine Black Stain Root Disease	1,977	1.27
POCRD	Phytophthora lateralis	Port-Orford-Cedar Root Disease	18,248	8.45
PSB	Tomicus piniperda	Pine Shoot Beetle	53,389	190.60

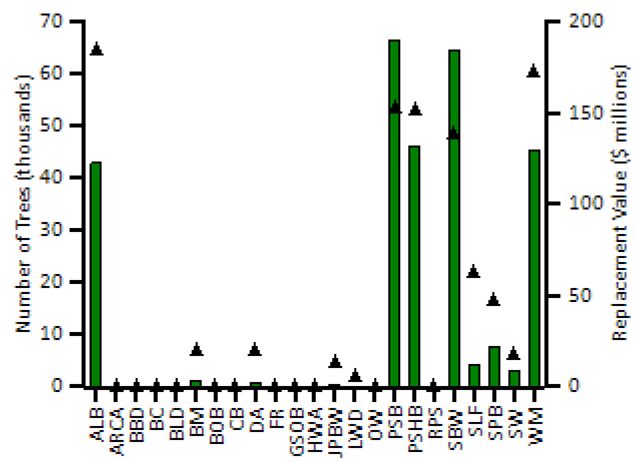
Code	Scientific Name	Common Name	Trees at Risk (#)	Value ($ millions)
PSHB	Euwallacea nov. sp.	Polyphagous Shot Hole Borer	53,196	131.65
RPS	Matsucoccus resinosae	Red Pine Scale	0	0.00
SB	Dendroctonus rufipennis	Spruce Beetle	2,187	5.49
SBW	Choristoneura fumiferana	Spruce Budworm	48,551	184.56
SFM	subalpine fir mortality summary	Subalpine Fir Mortality	105	0.05
SLF	Lycorma delicatula	Spotted Lanternfly	22,041	11.87
SOD	Phytophthora ramorum	Sudden Oak Death	85,835	291.62
SPB	Dendroctonus frontalis	Southern Pine Beetle	16,388	22.45
SW	Sirex noctilio	Sirex Wood Wasp	6,037	8.91
TCD	Geosmithia morbida	Thousand Canker Disease	105	0.02
WBB	Dryocoetes confusus	Western Bark Beetle	0	0.00
WBBU	Acleris gloverana	Western Blackheaded Budworm	55,621	190.96
WFNPM	western five-needle pine mortality summary	Western Five-Needle Pine Mortality	1,199	6.29
WM	Operophtera brumata	Winter Moth	60,501	129.74
WPB	Dendroctonus brevicomis	Western Pine Beetle	0	0.00
WPBR	Cronartium ribicola	White Pine Blister Rust	1,199	6.29
WSB	Choristoneura occidentalis	Western Spruce Budworm	58,228	200.17

In the following graph, the pests are color coded according to the county's proximity to the pest occurrence in the United States. Red indicates that the pest is within the county; orange indicates that the pest is within 250 miles of the county; yellow indicates that the pest is within 750 miles of the county; and green indicates that the pest is outside of these ranges.









Note: points - Number of trees, bars - Replacement value

Based on the host tree species for each pest and the current range of the pest (Forest Health Technology Enterprise Team 2014), it is possible to determine what the risk is that each tree species in the urban forest could be attacked by an insect or disease.

Spp. Risk	Risk Weight	Species Name	AL	ALB	ARCA	ARD	BBD	BC	BLD	BM	BOB	BSRD	BWA	CB	DA	DBSR	DED	DFB	EAB	FE	FR	FTC	GSOB	HRD	HS	HWA	JPB	JPBW	LAT	LWD	MOB	MPB	NSE	OW	PBSR
	32	Douglas fir																																	
	29	Western white pine																																	
	24	Subalpine fir																																	
	24	Norway spruce																																	
	21	Shore pine																																	
	19	Western hemlock																																	
	19	Mountain hemlock																																	
	13	Willow spp																																	
	12	Plum spp																																	
	12	Scots pine																																	
	11	Sitka spruce																																	
	10	Blue spruce																																	
	9	Black cottonwood																																	
	8	Western red cedar																																	
	8	Paper birch																																	
	7	Red alder																																	
	7	European white birch																																	
	7	River birch																																	
	5	Bigleaf maple																																	
	5	Arborvitae																																	
	5	Black walnut																																	
	4	Hinoki cypress																																	
	4	Swiss mountain pine																																	
	4	California laurel																																	
	4	Port orford cedar																																	
	4	Pacific yew																																	
	4	Sweet cherry																																	
	4	Oregon ash																																	
	3	Japanese maple																																	
	3	Pacific dogwood																																	
	3	Red maple																																	
	3	Apple spp																																	
	3	Trident maple																																	
	2	Black poplar																																	
	2	Chinese parasoltree																																	
	2	Japanese flowering cherry																																	
	2	Coast redwood																																	
	1	Bitter cherry																																	
	1	Vine maple																																	
	1	Camellia																																	

Spp. Risk	Risk Weight	Species Name	AL	ALB	ARCA	ARD	BBD	BC	BLD	BM	BOB	BSRD	BWA	CB	DA	DBSR	DED	DFB	EAB	FE	FR	FTC	GSOB	HRD	HS	HWA	JPB	JPBW	LAT	LWD	MOB	MPB	NSE	OW	PBSR
green	1	English hawthorn																																	
green	1	Kousa dogwood													green																				
green	1	Callery pear																																	
green	1	Flowering dogwood													green																				
green	1	Japanese angelica tree																																	
green	1	Atlas cedar																																	
green	1	Katsura tree		green																															
green	1	Babylon weeping willow																																	
green	1	Southern magnolia																																	
green	1	Black locust																																	
green	1	European mountain ash		green																															
green	1	Honeylocust																																	
green	1	Common plum																																	
green	1	Sweetgum																																	

Spp. Risk	Risk Weight	Species Name	POCRD	PSB	PSHB	RPS	SB	SBW	SFM	SLF	SOD	SPB	SW	TCD	WBB	WBBU	WFNPM	WM	WPB	WPBR	WSB
red	32	Douglas fir		green				green			yellow					yellow					red
red	29	Western white pine		green								green	green				red			red	red
red	24	Subalpine fir							red												red
red	24	Norway spruce		green			red	green				green	green								red
red	21	Shore pine		green								green	green								
red	19	Western hemlock										green				yellow					red
red	19	Mountain hemlock										green				yellow					red
red	13	Willow spp								green											
red	12	Plum spp																			
red	12	Scots pine		green								green	green								red
red	11	Sitka spruce					red					green						green			
red	10	Blue spruce					red	green				green									red
red	9	Black cottonwood			green													green			
red	8	Western red cedar																			
red	8	Paper birch								green								green			
red	7	Red alder																			
red	7	European white birch			green					green											
red	7	River birch								green								green			
yellow	5	Bigleaf maple			green						yellow							green			
red	5	Arborvitae	red							green											
orange	5	Black walnut			green									orange							
red	4	Hinoki cypress	red																		
green	4	Swiss mountain pine		green								green	green								
yellow	4	California laurel			green						yellow										
red	4	Port orford cedar	red																		
red	4	Pacific yew	red																		
yellow	4	Sweet cherry								green								green			

Spp. Risk	Risk Weight	Species Name	POCRD	PSB	PSHB	RPS	SB	SBW	SFM	SLF	SOD	SPB	SW	TCD	WBB	WBBU	WFNPM	WM	WPB	WPBR	WSB
Orange	4	Oregon ash																Green			
Green	3	Japanese maple			Green					Green											
Yellow	3	Pacific dogwood									Yellow										
Green	3	Red maple								Green								Green			
Green	3	Apple spp								Green											
Green	3	Trident maple			Green					Green											
Green	2	Black poplar			Green													Green			
Green	2	Chinese parasoltree			Green					Green											
Green	2	Japanese flowering cherry			Green					Green											
Yellow	2	Coast redwood									Yellow										
Green	1	Bitter cherry																Green			
Green	1	Vine maple																			
Green	1	Camellia			Green																
Green	1	English hawthorn																Green			
Green	1	Kousa dogwood																			
Green	1	Callery pear			Green																
Green	1	Flowering dogwood																			
Green	1	Japanese angelica tree								Green											
Green	1	Atlas cedar			Green																
Green	1	Katsura tree																			
Green	1	Babylon weeping willow			Green																
Green	1	Southern magnolia			Green																
Green	1	Black locust								Green											
Green	1	European mountain ash																			
Green	1	Honeylocust			Green																
Green	1	Common plum																Green			
Green	1	Sweetgum			Green																

Note:
Species that are not listed in the matrix are not known to be hosts to any of the pests analyzed.

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

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

Pest Color Codes:

- Red indicates pest is within King county
- Red indicates pest is within 250 miles county
- Yellow indicates pest is within 750 miles of King county
- Green indicates pest is outside of these ranges

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