i-Tree
Ecosystem Analysis

Central Area Wooded Rights-of-Way

Urban Forest Effects and Values
April 2011

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UFORE
Urban Forest Effects Model

Summary

Understanding an urban forest's structure, function and value can promote management decisions that will improve human health and environmental quality. An assessment of the vegetation structure, function, and value of Seattle's Central Area wooded rights-of-way was conducted during 2010. Data from 30 field plots located throughout Central Area were analyzed using the Urban Forest Effects (UFORE) model developed by the U.S. Forest Service, Northern Research Station.

Key findings

- Total Acres of Central Area Wooded Right-of-Way: 16.36 (2.4% of Central Area total)
- *Number of trees: 3,550*
- *Tree cover: 68.7%*
- *Most common species: Bigleaf maple, Common cherry laurel, Red alder*
- *Percentage of trees less than 6" (15.2 cm) diameter: 46.5%*
- *Pollution removal: 1 ton/year ($7.05 thousand/year)*
- *Carbon storage: 1,510 tons ($27.8 thousand)*
- *Carbon sequestration: 24 tons/year ($438/year)*
- *Building energy savings: $-1,090 / year*
- *Avoided carbon emissions: $-92 / year*
- *Structural values: $2.79 million*

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

For an overview of UFORE methodology, see Appendix I. Data collection quality is determined by the local data collectors, over which i-Tree has no control.

NOTE:

This document has been adapted from the automatic written report generated by the i-Tree Eco software module. Much of the text regarding the results of the study has been left as is and is not the original writing of the author. These sections have been included in italics. Sections written in regular font are the original contribution of the author.

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Introduction

Seattle's Urban Forest Management Plan and the Green Seattle Partnership's 20 Year Strategic Plan provide a comprehensive outline of the actions necessary to achieve a sustainable urban forest. These actions are set forth with the understanding that Seattle needs to maximize the health of its urban forest so the many benefits it provides may be fully realized. As stated in the Urban Forest Management Plan, "Nationally-based studies repeatedly support the fact that the [urban forest] resource deteriorates when human intervention is not a proactive part of urban forest management." [1]

The majority of the proactive human intervention underway in the city focuses on management within delineated management units. These units include private residential, commercial, and industrial properties as well as public properties such as parks and transportation corridors. The Urban Forest Management Plan sets goals to increase canopy cover in each management unit through improved maintenance of existing trees and increased planting of new trees. Additionally, maintenance often includes restoration efforts such as removal of non-native invasive species which inhibit the growth of important canopy trees.

Several surveys have been completed to catalog Seattle's urban forest thus far. One such survey used LIDAR (Light Detection and Ranging) to map the entire canopy of Seattle's urban forest.[2] The LIDAR survey determined percent canopy covers in each management unit of the city. This information was used as a baseline from which to set targets for future canopy cover. The Seattle Urban Nature Project (SUNP) performed an ecological survey of Seattle's remnant forest areas, developing geographic data that represents the various forest types around the city's natural areas. The SUNP study helps the planning and execution of restoration projects through the Green Seattle Partnership.

Building upon these two previous studies of Seattle's urban forest, this study focuses on the undeveloped, or wooded, rights-of-way within the Central

Area of Seattle. Throughout the city's right-of-way network, many areas were left undeveloped due to unfavorable construction conditions, changes in as-built construction plans, or other conditions that were undesirable for development of roadways. The result is a large number of isolated pockets of unused green space on city property. Many of these spaces take the form of unpaved alleyways between residential parcels in city neighborhoods, while others form larger tracts on the borders of parks and other green spaces. Street ends and pedestrian-only routes often fall into this category as well because they exist as wooded portions within the right-of-way. Together, these areas of wooded city right-of-way form a significant portion of Seattle's urban forest. (See image 1 for a complete map of Central Area wooded rights-of-way)

Many of these areas have fallen into a state of poor health due to their existence outside of the normal realm of maintenance either by the city or by private homeowners. As stated on the Seattle Department of Transportation's (SDOT) website, "The department does not maintain areas that were dedicated for streets, but were never improved and opened for travel. Property owners are responsible for any unopened street areas next to their property."[3] There are cases of adjacent property owners taking an active role in the management of these unimproved rights-of-way, sometimes even incorporating them into their own landscape. However, it is often the case that they are fenced off and neglected.

Some portions of the wooded right-of-way, especially street ends and pedestrian corridors, receive attention to mitigate safety concerns from hazard trees, although the state of their ecological health remains low. Large trees covered in English ivy and a ground layer made up of invasive species such as Himalayan blackberry frequently comprise the vegetation in these portions of city right-of-way (see Fig 1).

Figure 1. Degraded urban forest in a wooded right-of-way

An interest exists among both citizens and city officials to address Seattle's wooded rights-of-way and steward them through implementation of the forest restoration best management practices set forth in the GSP's 20 Year Plan. [4] There is a precedent for citizen groups engaging in volunteer restoration activities in wooded rights-of-way for the benefit of their community. Examples can be found near Seattle's Harrison/Denny-Blaine neighborhood where several wooded rights-of-way have been cleared of invasive species and planted with natives. The Harrison Ridge Greenbelt, along the 33rd Ave E right-of-way, is currently listed as a potential restoration area under the Green Seattle Partnership's Forest Steward program. These activities directly correspond to the Urban Forest Management Plan's Community Framework goal of engaging the community in active stewardship of the urban forest. [1]

This study aims to better understand Seattle's wooded rights-of-way through employment of the US Forest Service's i-Tree Eco software module. I-Tree Eco uses many field-collected data inputs to model the urban forest and provide valuable data to planners and policy makers on the value of that resource. Information on forest structure, health, and the economic value of ecosystem services provided by the wooded rights-of-way will be gained through this study. By applying i-Tree Eco specifically to the wooded rights-of-way, interested parties will be able to enhance their understanding of these areas' maintenance needs. Additionally, quantifying the value of these areas will aid in advocating for policy regarding the wooded rights-of-way by giving both policy makers and the public a sense of their economic importance.

Methods

The city of Seattle's geographic data do not make the distinction between wooded rights-of-way (ROW) and paved ROW. Thus, prior to carrying out the i-Tree Eco sampling process, it was necessary to isolate the wooded ROWs from the rest of the ROW property within the city. ArcGIS software was employed to carry out this process using data obtained from the Washington State Geospatial Data Archive (WAGDA). All of the city coverage data including ROW, neighborhood boundaries, and pavement edge were obtained from the City of Seattle data. The aerial photographs were obtained from Puget Sound orthophotography., which is comprised of USGS provided imagery.

In order to isolate the wooded ROW from the rest of the ROW layer, both the ROW layer and the pavement edge layer were added to the map in ArcGIS. To avoid incorporating the "parking strip" and other irrelevant portions of the ROW in the study, a 50ft buffer was created around the pavement edge layer. Following this step, the ET Geowizards [5]. Erase tool was used to erase all portions of the ROW layer that intersected with the 50ft buffer around the pavement edge. This process had the effect of 'highlighting' all portions of the ROW layer that are not associated with the paved portion, creating a new layer made up of only the potential unpaved rights-of-way that would be useful in the study. (See Image 2) This allowed a careful evaluation of these 'highlighted' portions of the ROW using aerial photographs and on-the-ground reconnaissance.

Due to the limited timeline of the project and person hours available, the geographic scope was narrowed from the whole city down to a more appropriate size. The Central Area of Seattle, which is encompassed by the six neighborhoods of Harrison/Denny Blaine, Madrona, Leschi, Mann, Atlantic, and Minor, was chosen to be the focus of the study. The Central Area was chosen both for its relatively high number of wooded ROWs and for its proximity to several of Seattle Public Utilities' Green Storm water Infrastructure (GSI) pilot areas. The intent in this regard is to apply the acquired data to the iTree Hydro module in order to gain information relevant to storm water issues in the Central Area.

After clipping the GIS layers to only encompass the Central Area for more efficient computing, the polygons representing wooded ROWs were edited to accurately reflect each perimeter. Each possible sampling site was then checked for relevance to the project. Only wooded right-of-way polygons were kept, while polygons falling on driveways, landscaped areas, or otherwise highly developed areas were deleted from the possible pool of sample sites. Pedestrian routes were retained as long as the surrounding landscape remained unmanaged. (See Appendix I for a complete list of Central Area wooded rights-of-way.)

i-Tree recommends using a .1 acre plot size for sampling. However, it was recognized that using the recommended plot size of .1 acre for the circular sampling sites would create plots that ranged outside of the ROW layer and into private property. To avoid this occurrence plot size was reduced to .05 acres, or circles with a radius of 26.3'.

A certain number of the wooded ROWs targeted in the study were too small to accommodate even a .05 acre plot. In order to generate random points for sampling only within wooded ROWs that were large enough to accommodate the .05 acre plots, a negative buffer of 26.3' was created within each of the polygons representing a wooded ROW. Once this new layer was created, ArcGIS's Create Random Points tool was used to generate 60 random points within the negative buffer layer. This process had the effect of generating sample plot centers far enough away from the wooded ROW edges that the entire circular plot would fit without overlapping with surrounding private property. (See Image 3)

It is recommended by i-Tree that a minimum of thirty sample plots are studied in an i-Tree Eco assessment. Due to limited time and person hours, the minimum of 30 plots was selected as the target while sixty possible plots were generated. The excess plots were generated in order to have backup options in case certain plots were not feasible for study.

Once all of the sample plots were established, sampling was carried out according to the i-Tree Eco protocol (www.itreetools.org) using the paper forms to collect data. Plot centers were established based on aerial photographs of the site, and a measuring tape was used to measure the appropriate distance for the radius. Pin flags and flagging tape were used to mark the perimeter of the circles. The measuring tape was used to measure all horizontal distances such as tree canopy widths, and a clinometer was used to measure vertical distances such as tree height.

If wooded rights-of-way appeared to be closely incorporated into the landscape of surrounding property owners, the property owners were asked for permission to access their adjacent ROW. Plots were skipped if they were deemed to be not feasible for sampling due to extreme terrain, unwelcoming neighbors, or danger from hazardous trees or other concerns. This approach resulted in almost one in two plots being skipped and justified the creation of twice as many sample plots as needed for the study.

Results

Tree Characteristics

The Central Area wooded rights-of-way have an estimated 3,550 trees with a tree cover of 68.7 percent. Trees that have diameters less than 6-inches constitute 46.5 percent of the population. The three most common species are Bigleaf maple (23.70 percent), Common cherry laurel (17.20 percent), and Red alder (6.47 percent).

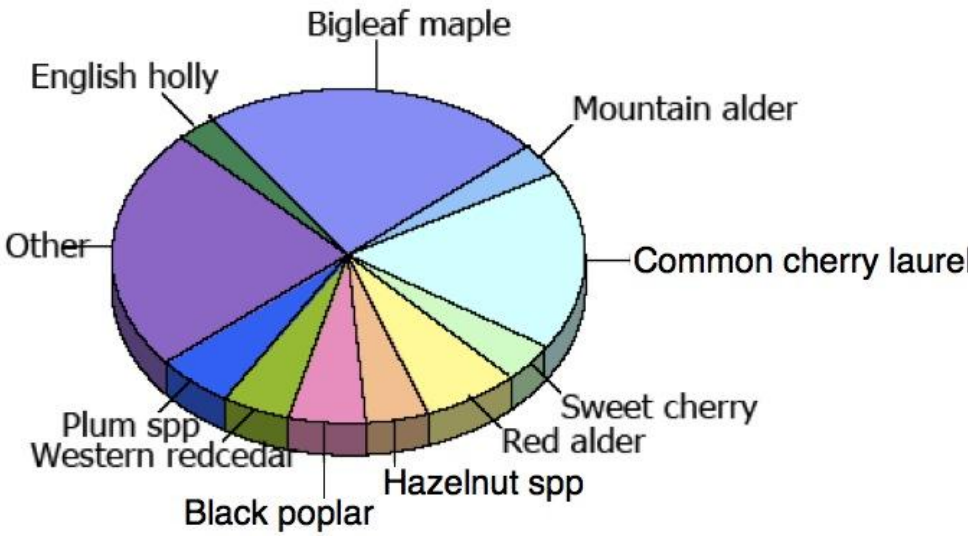


Figure 1. Tree species composition in Central Area

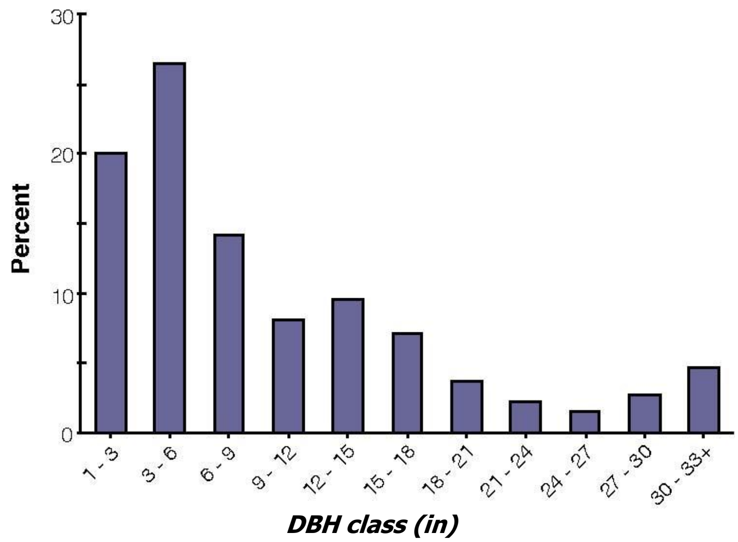


Figure 2. Percent of tree population by diameter class (DBH=stem diameter at 4.5 feet)

Urban forests are composed of a mix of native and exotic tree species. Thus, urban forests often have a tree diversity that is higher than surrounding native landscapes. An increased tree diversity can minimize the overall impact or destruction by a species-specific insect or disease, but it can also pose a risk to native plants if some of the exotic species are invasive plants that can potentially out-compete and displace native species. In the Central Area wooded rights-of-way, about 49 percent of the trees are from species native to North America, while 47 percent are native to the state or district. Species exotic to Washington make up 51 percent of the population. Most exotic tree species have an origin from Eurasia (26.4 percent of the species).

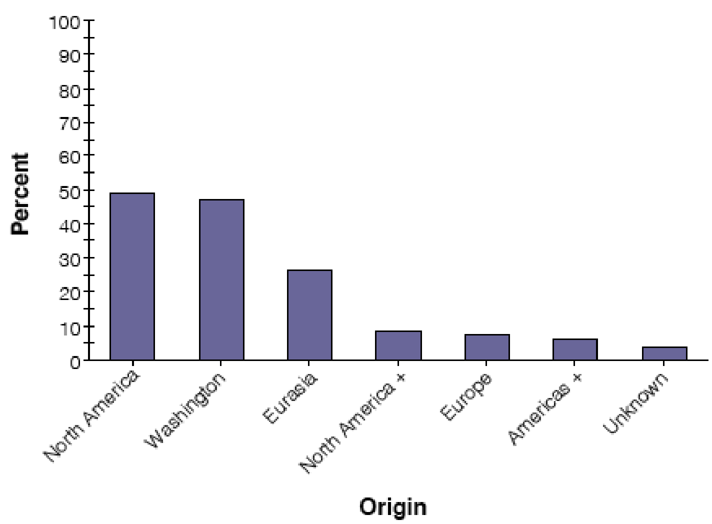


Figure 4. Percent of live trees by species origin

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

Cover and Leaf Area

Many tree benefits equate directly to the amount of healthy leaf surface area of the plant. In Central Area wooded rights-of-way, the three most dominant species in terms of leaf area are Bigleaf maple, Common cherry laurel, and Western redcedar. Trees cover about 68.7 percent of Central Area, and shrubs cover 54.5 percent.

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

Table 1. Most important species in Central Area

Common Name	*Percent Population*	*Percent Leaf Area*	*IV*
Bigleaf maple	*23.7*	*54.2*	*77.9*
Common cherry laurel	*17.2*	*7.1*	*24.4*
Red alder	*6.5*	*5.6*	*12.1*
Western redcedar	*4.6*	*6.2*	*10.8*
Plum spp	*5.2*	*2.3*	*7.5*
Black cottonwood	*1.2*	*5.3*	*6.5*
Black poplar	*5.2*	*0.5*	*5.8*
Sweet cherry	*3.7*	*2.1*	*5.7*
Hazelnut spp	*4.3*	*1.3*	*5.6*
White alder	*2.4*	*2.6*	*5.1*

The two most dominant ground cover types are Herbs (65 percent) and Duff/mulch (17.4 percent).

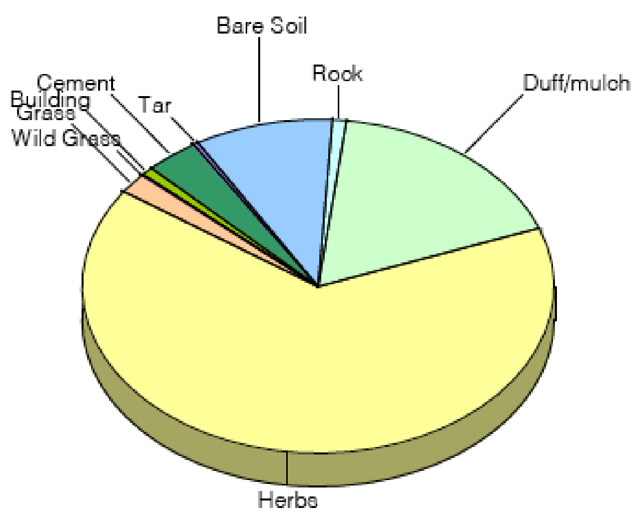
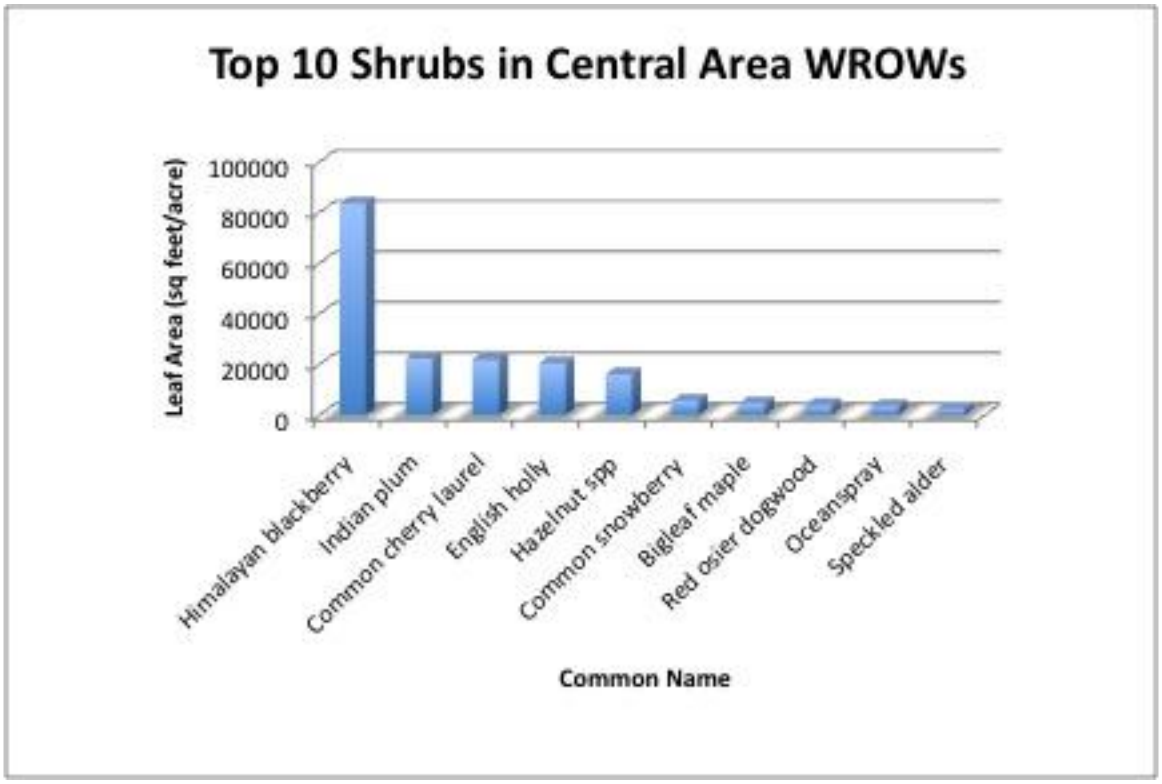


Figure 5. Percent ground cover in Central Area

Shrub composition

The shrub composition of the Central Area wooded rights-of-way can be viewed as an indicator of ecological health. Three of the top five shrubs present in terms of leaf area are known to be invasive species in the pacific northwest. Himalayan Blackberry makes up a significant portion of the total shrub leaf area in the study area with an approximate leaf area density of 81,000 ft^2/acre, while cherry laurel and English holly exist in high concentrations as well with densities of 20,000ft^2 and 19,000ft^2, respectively.



Air Pollution Removal

Poor air quality is a common problem in many urban areas. It can lead to decreased human health, damage to landscape materials and ecosystem processes, and reduced visibility. The urban forest can help improve air quality by reducing air temperature, directly removing pollutants from the air, and reducing energy consumption in buildings, which consequently reduces air pollutant emissions from the power plants. Trees also emit volatile organic compounds that can contribute to ozone *formation. However, integrative studies have revealed that an increase in tree cover leads to reduced ozone formation[6].*

Pollution removal by trees and shrubs in Central Area wooded rights-of-way was estimated using field data and recent pollution and weather data available. Pollution removal was greatest for particulate matter to 10 microns. It is estimated that trees and shrubs remove 1 ton of air pollution (ozone (O3), carbon monoxide (CO), nitrogen dioxide (NO2), particulate matter less than 10 microns (PM10), and sulfur dioxide (SO2)) per year with an associated value of $7.05 thousand (based on estimated national median externality costs associated with pollutants[7]).

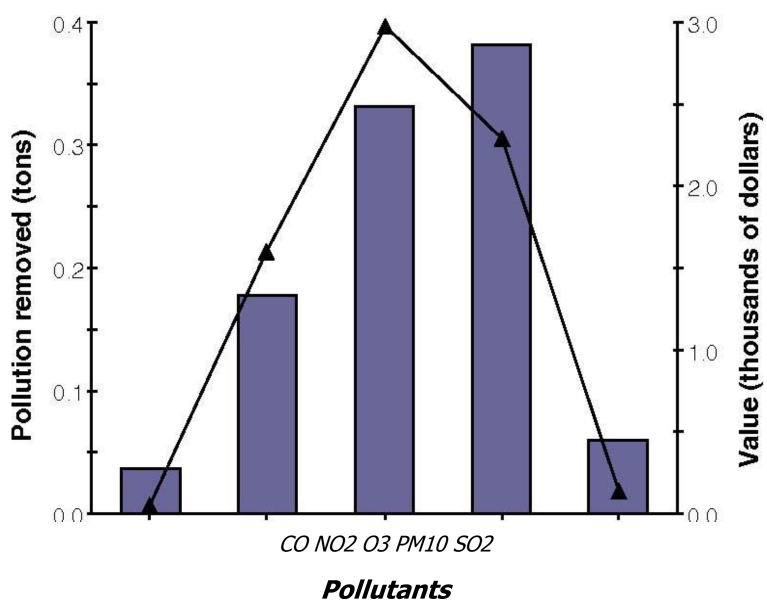


Figure 6. Pollution removal and associated value for trees in Central Area wooded rights-of-way (line graph is value)

Carbon Storage and Sequestration

Climate change is an issue of global concern. Urban trees can help mitigate climate change by sequestering atmospheric carbon (from carbon dioxide) in tissue and by altering energy use in buildings, and consequently altering carbon dioxide emissions from fossil-fuel based power plants [8].

Trees reduce the amount of carbon in the atmosphere by sequestering carbon in new growth every year. The amount of carbon annually sequestered is increased with the size and health of the trees. The gross sequestration of Central Area trees is about 24 tons of carbon per year with an associated value of $438. Net carbon sequestration in the urban forest is about 21 tons.

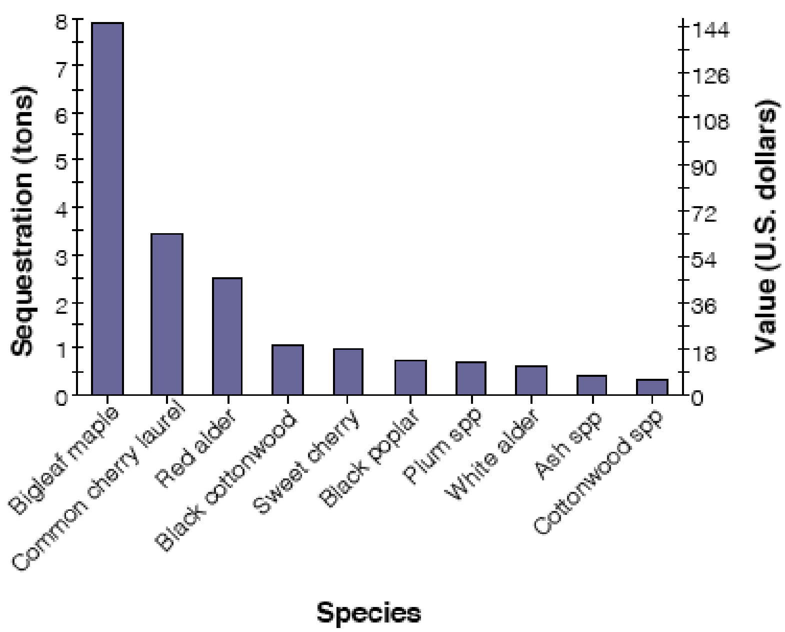


Figure 7. Carbon sequestration and value for species with greatest overall carbon sequestration in Central Area wooded rights-of-way

As trees grow they store more carbon as wood. As trees die and decay, they release much of the stored carbon back to the atmosphere. Thus, carbon storage is an indication of the amount of carbon that can be lost if trees are allowed to die and decompose. Trees in Central Area wooded rights-of-way are estimated to store 1,510 tons of carbon ($27.8 thousand). Of all the species sampled, Bigleaf maple stores and sequesters the most carbon (approximately 50.4% of the total carbon stored and 38.0% of all sequestered carbon.)

Trees and Building Energy Use

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

Based on 2002 prices, trees in Central Area wooded rights-of-way are estimated to reduce energy-related costs from residential buildings by $-1,090 annually. Trees also provide an additional $-92 in value[10] by reducing the amount of carbon released by fossil-fuel based power plants (a reduction of -5 tons of carbon emissions).

Table 2. Annual energy savings due to trees near residential buildings. Note: negative numbers indicate an increased energy use or carbon emission.

	Heating	Cooling	Total
MBTU[1]	-253	n/a	-253
MWH[2]	-14	31	17
Carbon avoided (t)	-6	1	-5

[1]One million British Thermal Units
[2]Megawatt-hour

Table 3. Annual savings1 (US $) in residential energy expenditure during heating and cooling seasons. Note: negative numbers indicate a cost due to increased energy use or carbon emission.

	Heating	Cooling	Total
MBTU[2]	-2,065	n/a	-2,065
MWH[3]	-806	1,785	979
Carbon avoided (t)	-110	18	-92

[1]Based on state-wide energy costs for Washington.
[2]One million British Thermal Units
[3]Megawatt-hour

Structural and Functional Values

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

The structural value of an urban forest tends to increase with a rise in the number and size of healthy trees [11]. Annual functional values also tend to increase with increased number and size of healthy trees, and are usually on the order of several million dollars per year. Through proper management, urban forest values can be increased; however, the values and benefits also can decrease as the amount of healthy tree cover declines.

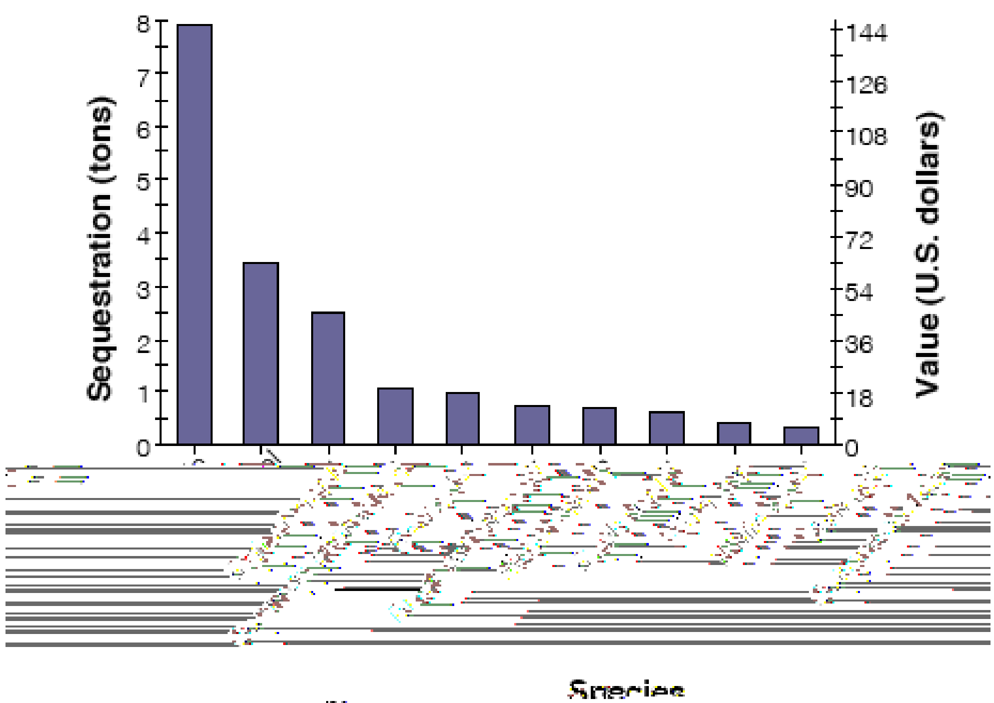
Structural values:

- *Structural value: $2.79 million*
- *Carbon storage: $27.8 thousand*

Annual functional values:

- *Carbon sequestration: $438*
- *Pollution removal: $7.05 thousand*

- *Lower energy costs and carbon emission reductions: $-1,180 (Note: negative value indicates increased energy cost and carbon emission value)*



Potential Pest Impacts

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

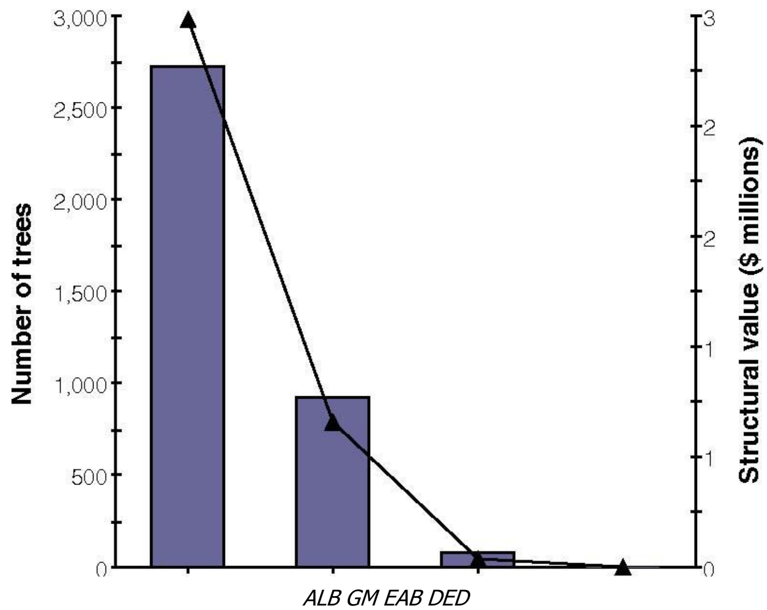


Figure 9. Number of susceptible Central Area trees and structural value by pest (line graph is structural value)

The Asian longhorned beetle (ALB) [12] is an insect that bores into and kills a wide range of hardwood species. ALB poses a threat to 76.6 percent of the trees in the Central Area wooded rights-of-way, which represents a loss of $2.48 million in damage to the structure.

The gypsy moth (GM)[13] is a defoliator that feeds on many species causing widespread defoliation and tree death if outbreak conditions last several years. This pest threatens 25.8 percent of the population, which represents a loss of $657 thousand in structural value.

Emerald ash borer (EAB)[14] has killed thousands of ash trees in parts of the United States. EAB has the potential to affect 2.2 percent of the population ($40.9 thousand in structural damage).

Discussion

The ultimate value in this study is its ability to inform the many stakeholders involved with the wooded rights-of-way. Policy makers, government officials, community members and restoration practitioners all play a role in determining the fate of the wooded rights-of-way. As each of these groups may be interested in certain aspects of the wooded rights-of-way, using this information in a manner that is tailored specifically to the relevant parties will help in advancing progress in the management of these areas.

From a policy perspective, the structural and functional values presented make a strong case for the preservation and enhancement of the forest in the wooded rights-of-way. If the forests in these areas are allowed to degrade and trees are lost, the current value of $2.79 million will decrease and an equivalent amount of money will need to be spent to re-establish these forests. This information is valuable from a policy perspective, as facilitating the permitting process for volunteer labor in wooded rights-of-way through policy is a cost-effective way of promoting maintenance. Through maintenance, the structural and functional values will increase along with forest health.

Surrounding property owners and community members are important stakeholders as well in the consideration of wooded rights-of-way. These are the people who will be most directly affected by changes in the wooded rights-of-way, as they are in close proximity to them during their day-to-day lives. There may be opposition to restoration from this group of stakeholders due to privacy or other concerns. Therefore, it is important to conduct education and outreach to give these individuals a sense of the importance that exists in healthy wooded rights-of-way. For example, citizens with elderly relatives or small children may be influenced by the air pollution removal figures, while citizens who are concerned with global climate change may value the data on carbon sequestration or energy savings.

Restoration and urban forestry practitioners will be interested in the tree characteristics information, which will aid in planning efforts. Much of this information bares similarities to the findings of the Seattle Urban Nature Project (SUNP). SUNP indicates that shorter-lived and over-mature deciduous trees such as big-leaf maple dominate the canopy in much of Seattle's remnant forests, while invasive species such as Himalayan blackberry dominate the understory. This is also the case in many of the wooded rights-of-way. Therefore, many of the same restoration approaches involving the removal of invasive species and the establishment of a conifer-dominated canopy can be taken in the wooded rights-of-way just as they are in parks and other wooded areas.

Through the Green Seattle Partership, efforts are already well underway to improve the health of forests in park woodlands. The same BMPs used in this context could be applied to the wooded rights-of-way, yielding a variety of extra advantages. For example, invasive seed rain from unmanaged wooded rights-of-way is a setback to GSP forest restoration efforts that could be mitigated through restoration of the wooded rights-of-way. Additionally, many wooded rights-of-way provide habitat corridors for urban wildlife. Thus, preserving the ecological integrity of these areas will benefit the city's fauna as well.

By modeling the urban forest within the Central Area's wooded rights-of-way, important information on value and structure has been obtained. This information acts as a valuable tool in advocating for and managing this portion of Seattle's urban forest, and should encourage the relevant city departments to work together in this pursuit. Adapting this information for specific stakeholder interests will aid in making the case for restoration activities in the Central Area's wooded rights-of-way.

Image 1

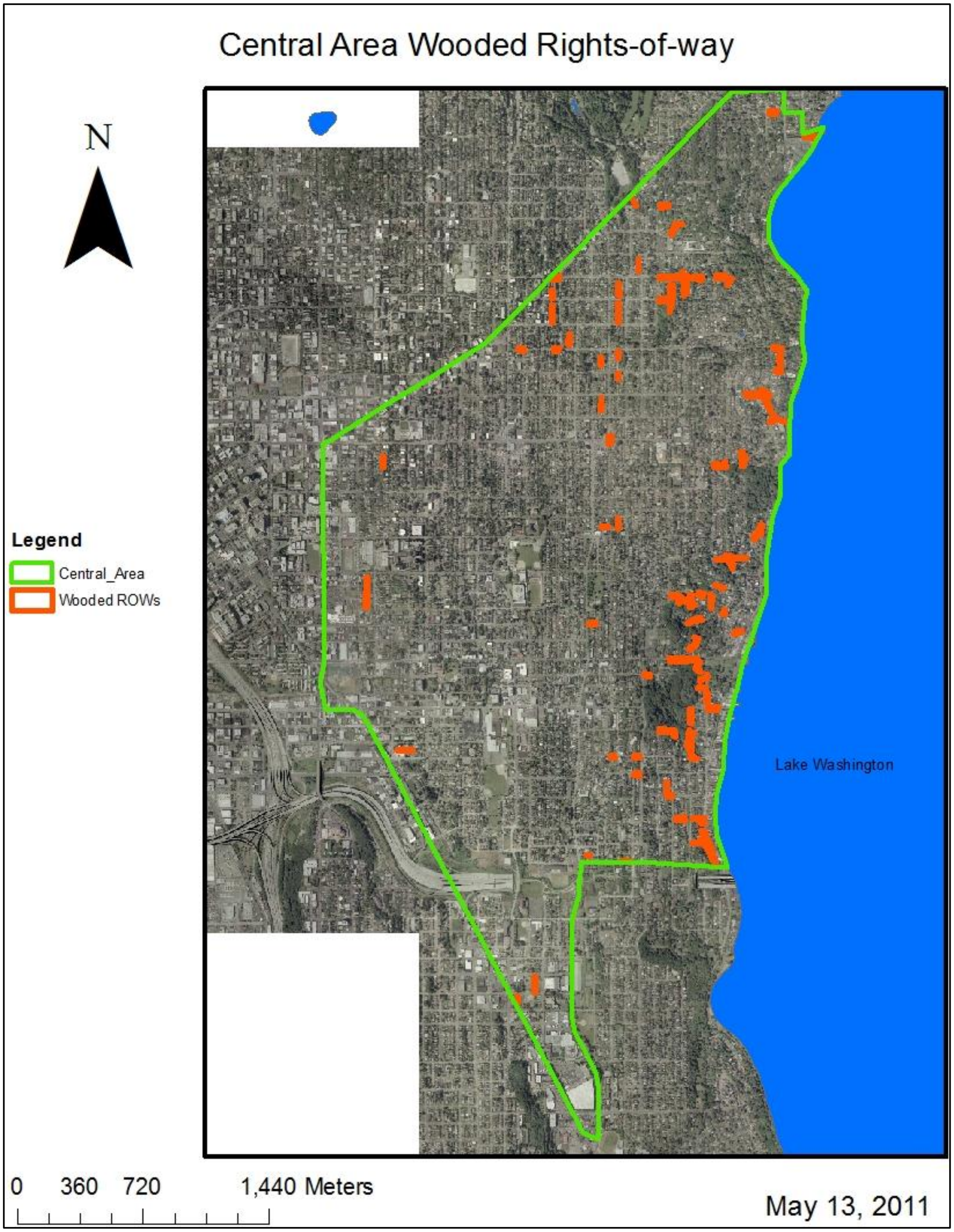

Central Area Wooded Rights-of-way
N
Legend
Central_Area
Wooded ROWs
Lake Washington
0 360 720 1,440 Meters
May 13, 2011

Image 2:

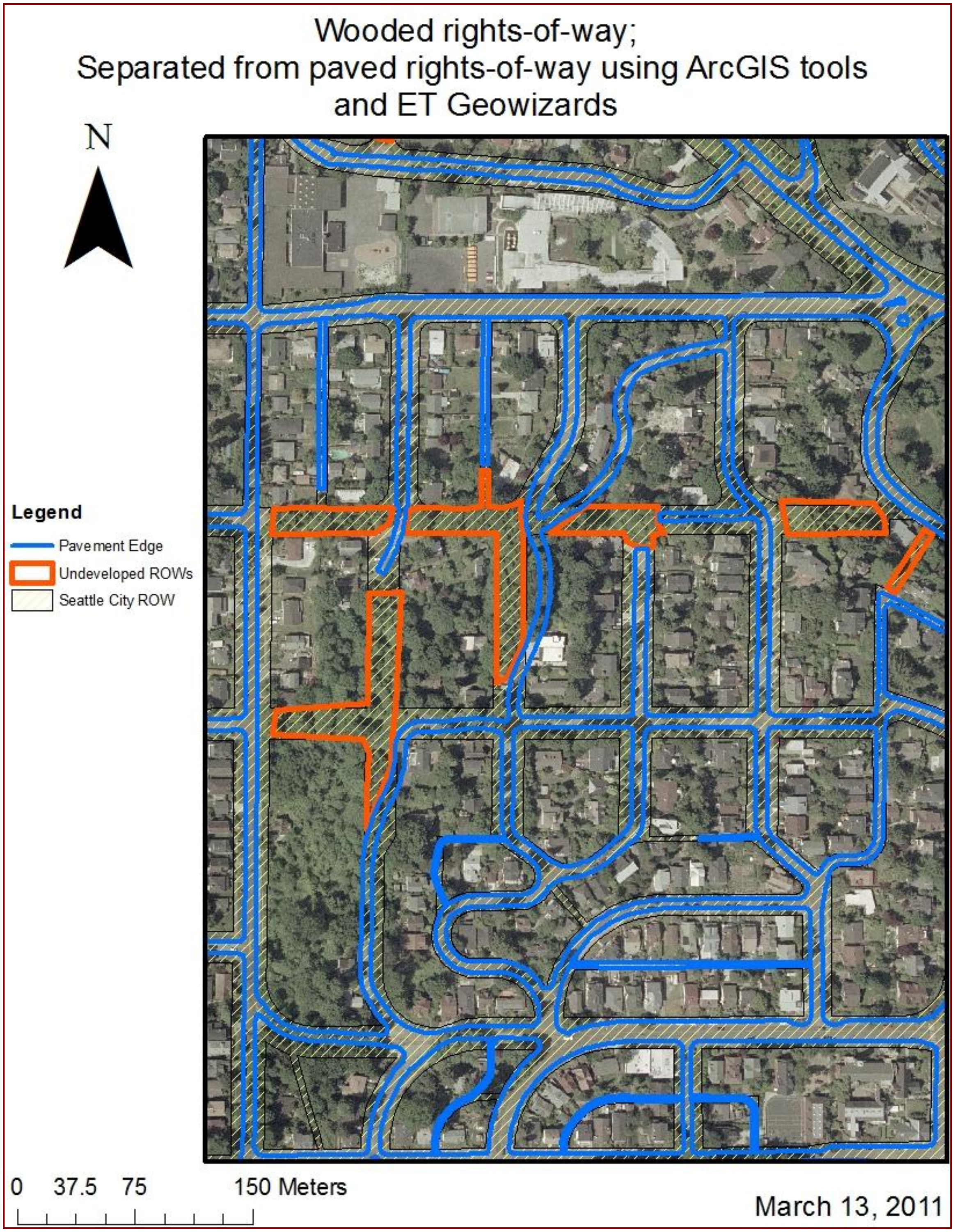
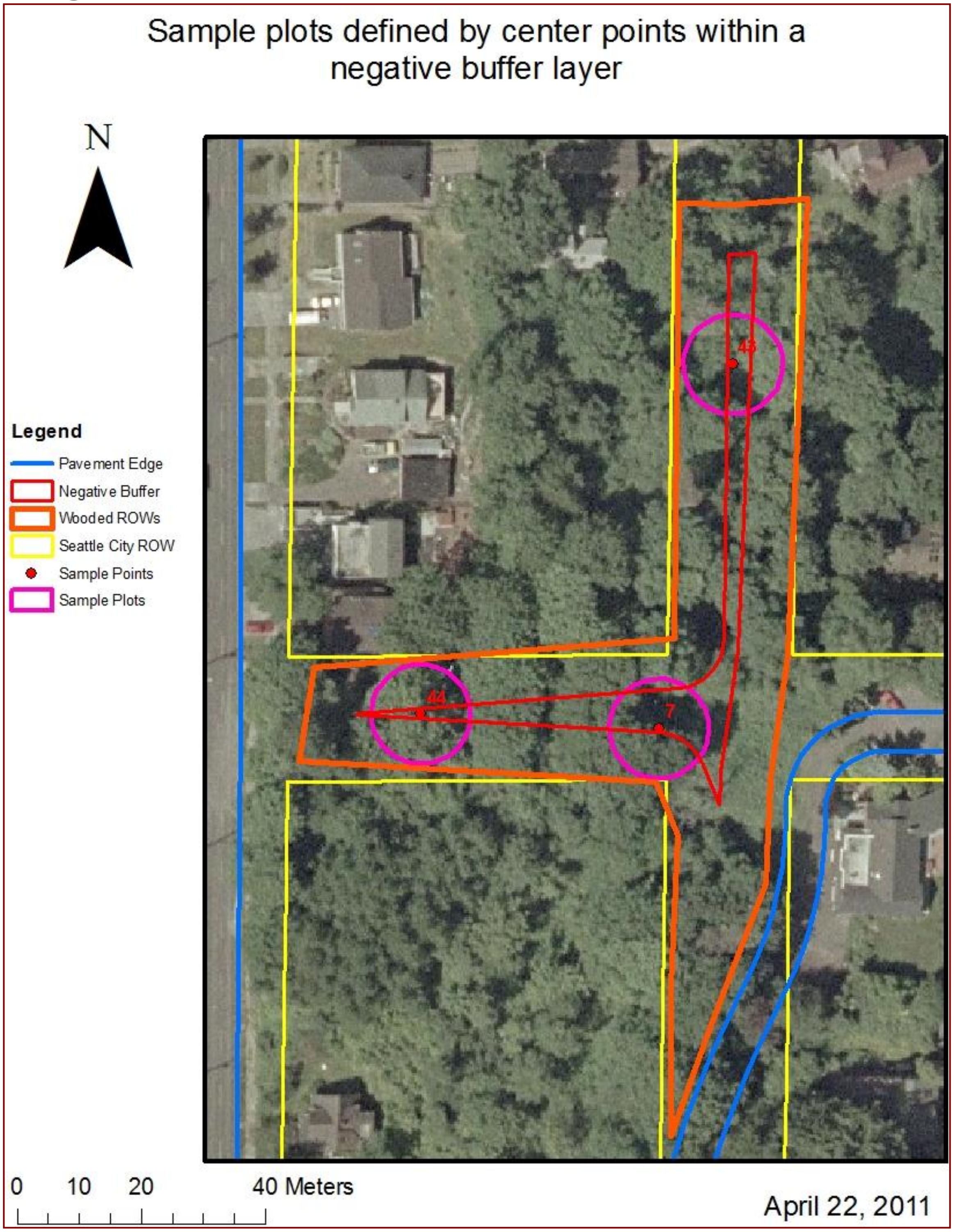

Wooded rights-of-way;
Separated from paved rights-of-way using ArcGIS tools
and ET Geowizards
N
Legend
Pavement Edge
Undeveloped ROWs
Seattle City ROW
0 37.5 75 150 Meters
March 13, 2011

Image 3:


Sample plots defined by center points within a negative buffer layer
N
Legend
Pavement Edge
Negative Buffer
Wooded ROWs
Seattle City ROW
Sample Points
Sample Plots
43
44
7
0 10 20 40 Meters
April 22, 2011

Appendix I: Central Area Wooded Right-of-Way Index

E Highland Drive @ 39th Ave E
E Prospect St @ 41st Ave E
E Ford Pl @ Lake Washington Blvd E
E Thomas St @ 33rd
E Thomas St @ 36th Ave E
33rd Ave E @ E John St
E Howell St @ 26th Ave
E Howell St @ Lake Washington Blvd
E Pine St @ Grand Ave
E Spruce St @ 26th Ave
E Yesler Way @ Euclid Ave
34th Ave S @ Jackson
34th Ave S @ King
S Norman St @ 33rd Ave S
30th Ave E @ E Mercer St
39th Ave @ E Pine St
40th Ave @ E Olive Ln
Between 30th Ave E, 31st Ave E, Harrison, and Thomas
E Thomas St @ 35th Ave
E Thomas St @ 34th Ave
Between E Pine, E Pike, MLK JR way, and 29th Ave
29th Ave @ E Union St
S Jackson @ 35th Ave S
S King St @ 33rd
S Norman St @ Lakeside Ave
S Judkins St @ Lakeside Ave S
E Thomas @ 26th Ave E
37th Ave E @ E High Lane
36th Ave @ Newport Way
E Spring St @ 37th Ave
E Spring St @ 36th Ave
Wellington Ave @ Lake Washington Blvd
E James St @ 37th Ave
E Alder St @ 34th Ave
E Mercer St @ 32nd Ave E
Between E Thomas, E John, 29th Ave E, and 30th Ave E
Between 25th Ave E, E John, and 26th Ave E
Between E John St, E Denny Way, 25th, and 26th
E Howell St @ 24th Ave
Between E Denny Way, E Howell, 26th, and 27th
Between E Howell, E Olive, MLK Jr Way, and 29th Ave
Between E Howell, E Olive, MLK Jr Way, and 29th Ave
Between E Pine, E Olive, 29th, and 30th
Between E Spring St E Union St 15th Ave and 16th Ave

Between E Alder St, E Jefferson St, 14th Ave, and 15th Ave
Between 16th Ave S, 18th Ave S, S Weller St, and S lane St
Between S Hill, S Plum, 24th Ave S, and 25th Ave S
BetweenS Walker St, S Hill St, 23rd Ave S, 24th Ave S
S Irving St between Yakima and 30th
Between S Irving S Judkins MLK Jr S and Brandner Pl S
S Lane @ 29th
S Lane @ 31st
S Dearborn @ 30th
S Charles St @ 33rd Ave S
S Washington St @ 31St Ave S
Lake Washington Blvd South of E Yesler Way
Lake Washington Blvd @ 36th Ave S
S Main between Lake Washington Blvd & 35th
35th Ave S @ S Leschi Pl
Euclid Ave @ E Superior St
E Superior St @ Lake Washington Blvd
Randolph Ave E @ E Alder St
E Spruce St @ Euclid Ave
36th Ave @ E Alder St
35th Ave E @ E Alder St
E Terrace St @ 36th Ave E
Between 29th 30th E Columbia St E Cherry St
Between E Columbia E Cherry @ MLK Jr Way
Between E John E Denny 29th and 30th
29th Ave @ E Union

Appendix II. UFORE Model and Field Measurements

UFORE is designed to use standardized field data from randomly located plots and local hourly air pollution and meteorological data to quantify urban forest structure and its numerous effects [10], including:

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

In the field 0.05 acre plots were randomly distributed throughout the Central

Area wooded rights-of-way. Typically, all field data are collected during the leaf-on season to properly assess tree canopies. Within each plot, typical data collection (actual data collection may vary depending upon the user) includes land use, ground and tree cover, individual tree attributes of species, stem diameter, height, crown width, crown canopy missing and dieback, and distance and direction to residential buildings[16].

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[17]. To adjust for this difference, biomass results for open-grown urban trees were multiplied by 0.8. No adjustment was made for trees found in natural stand conditions. Tree dry-weight biomass was converted to stored carbon by multiplying by 0.5.

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

Air pollution removal estimates are derived from calculated hourly tree-canopy resistances for ozone, and sulfur and nitrogen dioxides based on a hybrid of big-leaf and multi-layer canopy deposition models[18,19]. 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[20,21] that were adjusted depending on leaf phenology and leaf area. Particulate removal incorporated a 50 percent resuspension rate of particles back to the atmosphere[22].

If appropriate field data were collected, seasonal effects of trees on residential building energy use were calculated based on procedures described the literature[9] using distance and direction of trees from residential structures, tree height and tree condition data.

Structural values were based on valuation procedures of the Council of Tree and Landscape Appraisers[13], which uses tree species, diameter, condition and location information[23].

Appendix III. Relative Tree Effects

The urban forest in Central Area wooded rights-of-way 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[24], average passenger automobile emissions[25], and average household emissions[26].

Carbon storage is equivalent to:

. • *Amount of carbon emitted in Central Area wooded rights-of-way in 0 days*
. • *Annual carbon (C) emissions from 905 automobiles*
. • *Annual C emissions from 455 single-family houses*

.*Carbon monoxide removal is equivalent to:*

. • *Annual carbon monoxide emissions from automobiles*
. • *Annual carbon monoxide emissions from 1 single-family houses*

.*Nitrogen dioxide removal is equivalent to:*
. • *Annual nitrogen dioxide emissions from 11 automobiles*
. • *Annual nitrogen dioxide emissions from 8 single-family houses*

.*Sulfur dioxide removal is equivalent to:*
. • *Annual sulfur dioxide emissions from 87 automobiles*
. • *Annual sulfur dioxide emissions from 1 single-family houses*

.*Particulate matter less than 10 micron (PM10) removal is equivalent to:*
- *Annual PM10 emissions from 1,020 automobiles*
- *Annual PM10 emissions from 98 single-family houses*

.*Annual carbon sequestration is equivalent to:*
. • *Amount of carbon emitted in Central Area wooded rights-of-way in days*
. • *Annual C emissions from automobiles*
. • *Annual C emissions from single-family houses*

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

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[27]:

. *• 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[28]. Local urban management decisions also can help improve air quality.

Urban forest management strategies to help improve air quality include[29]:

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

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