# Providence's Urban Forest: Structure, Effects and Values

i-Tree Eco System Analysis

February 2014

# Acknowledgements


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# EXECUTIVE SUMMARY

## Providence's Urban Forest

Understanding an urban forest's structure, function and value promotes management decisions that improve human health and environmental quality. The urban forest is compromised of more than just street trees; environmental benefits are also derived from trees in parks, yards, institutional land, natural areas, and other locations. An assessment of the vegetation structure, function, and value of the Providence urban forest was conducted during 2013. Data collected from 250 field plots located throughout Providence were analyzed using the i-Tree Eco model developed by the U.S. Forest Service, Northern Research Station.

**Urban Forest Characteristics**

- Number of trees: 415,000, or 34.4 trees per acre
- Tree cover: 23.9%
- Structural values: $582 million
- Most common species: Norway maple, Northern red oak, Honeylocust
- Percentage of trees less than 6" (15.2 cm) diameter: 49.6%
- Ground Cover: 59% impermeable vs. 41% permeable

**Environmental Benefits**

- Total annual environmental benefits: $4.7 million per year
  - Pollution removal: 91 tons/year ($3.5 million/year)
  - Carbon sequestration: 4,030 tons/year ($287 thousand/year)
  - Avoided runoff: 31.5 million gallons/year ($281 thousand/year)
  - Building energy savings: $591 thousand/year
  - Avoided carbon emissions: 500 tons/year ($35.6 thousand/year)
- Total estimated carbon storage: 124 thousand tons ($8.80 million)

**Threats to our Urban Forest**

- Pest Impacts: Asian Longhorned Beetle has the potential to impact 43.2% of the urban forest, a potential loss of $265 million. Emerald Ash Borer would effect 4.2%, worth $25.4 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. Carbon storage and carbon sequestration values are calculated based on $71 per ton. Structural value: value based on the physical resource itself (e.g., the cost of having to replace a tree with a similar tree). Pollution removal value is calculated based on the prices of $1136 per ton (carbon monoxide), $12938 per ton (ozone),$1488 per ton (nitrogen dioxide), $587 per ton (sulfur dioxide), $63778 per ton (particulate matter less than 10 microns and greater than 2.5 microns), $618260 per ton (particulate matter less than 2.5 microns). Energy saving value is calculated based on the prices of $156.9 per MWH and $15.78 per MBTU. Monetary values ($) are reported in US Dollars throughout the report except where noted. **For an overview of i-Tree Eco models, see Appendix I.**

# BACKGROUND

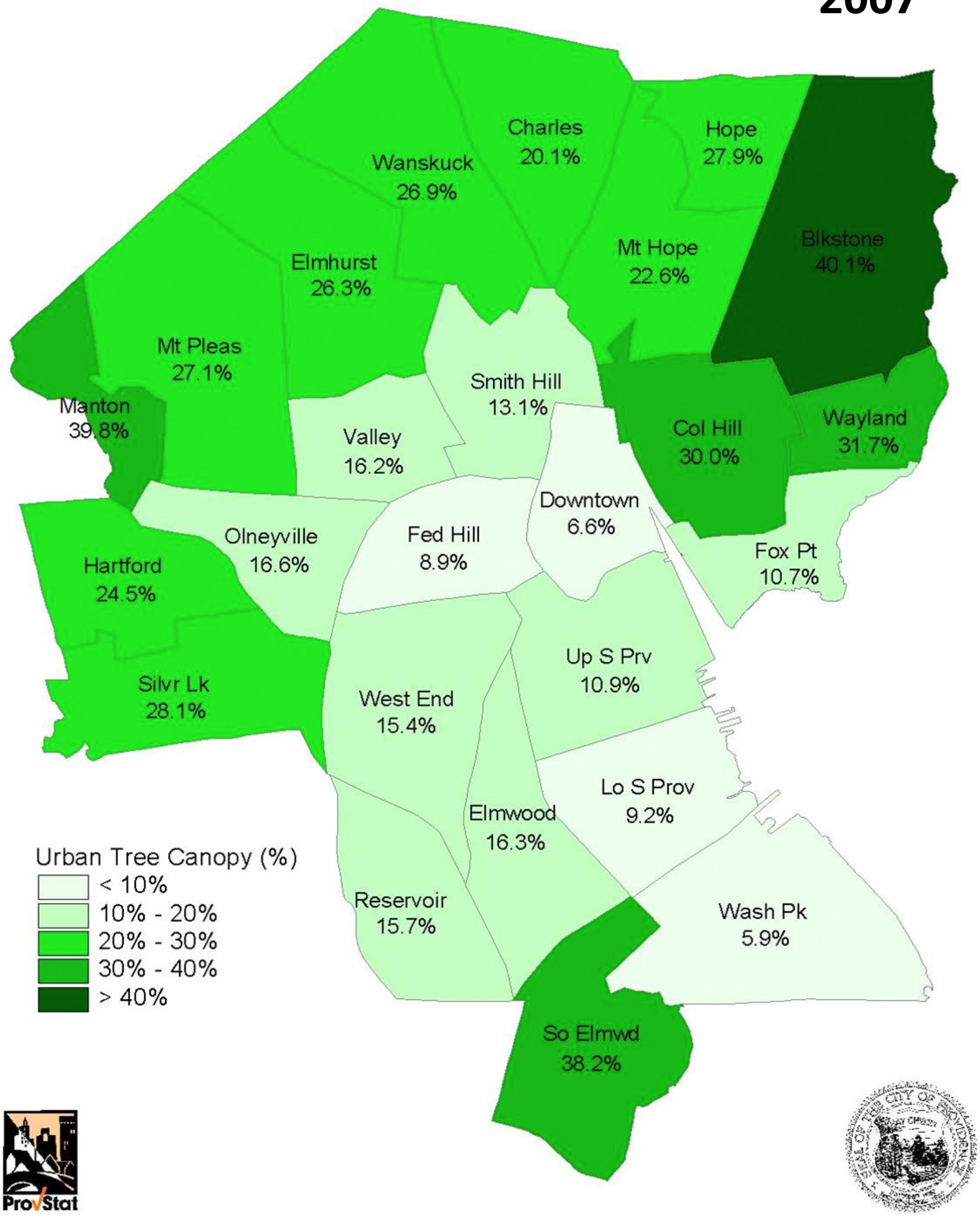
## Providence's Urban Forest

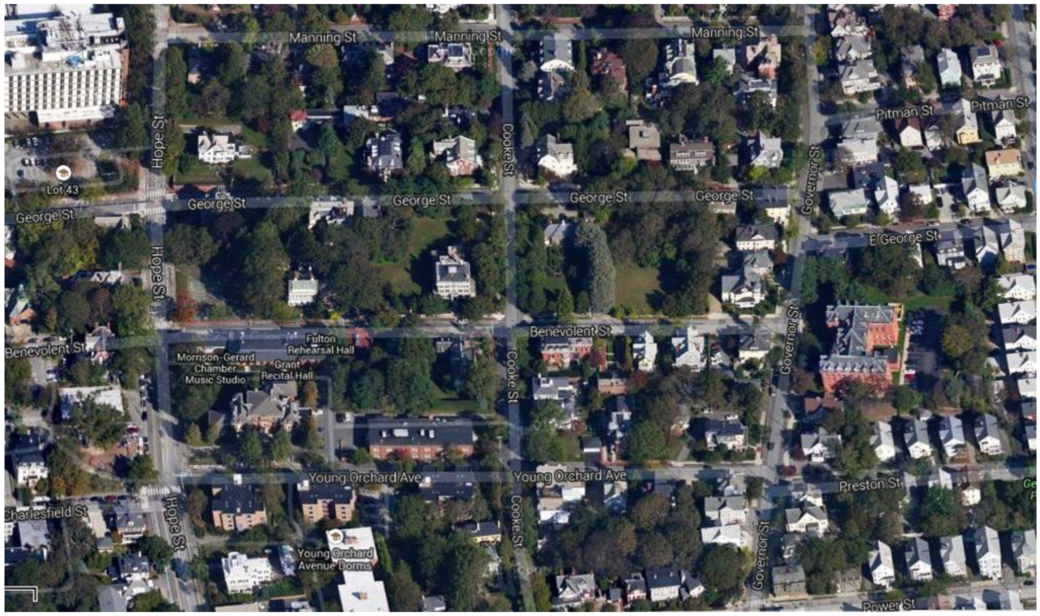
Providence's urban forest – the population of public and private trees that grow along city streets and in parks, backyards, institutional property, natural areas, and other places – is vital to the city's environment and quality of life. A healthy tree canopy provides essential ecological *functions* that can now be quantified. Trees filter the air of pollution; reduce water runoff that affects water quality; moderate urban temperatures in summer; reduce energy consumption and therefore pollution emitted by power plants; and store carbon in their wood. Trees also provide habitat for wildlife, raise the resale value of homes, and help business by making commercial districts attractive and comfortable for shopping. The urban forest also has a *structural value,* or compensatory value, that shows its worth based on its size and composition. In order to know the *structural* and *functional values* of the urban forest, it must be measured.

The measurement and study of Providence's urban forest has been an ongoing process. In 2006, a comprehensive *street tree inventory* was conducted and then analyzed using STRATUM software (developed by the U.S. Forest Service, it is now called i-Tree Streets and incorporated into the i-Tree Suite of tree analysis tools). Approximately 25,000 street trees were counted and their environmental benefits calculated, including energy savings, CO2 storage, air quality effects, storm water interception, and effects on property values [60].

In 2007, an Urban Tree Canopy (UTC) study was completed that utilized satellite imagery and computer mapping to determine the percentage canopy cover in Providence. The study determined that the city has 23.3% canopy cover, the amount of ground shaded by trees as viewed from above. The UTC study considers the whole urban forest (not just street trees) and how it is distributed across the city. It provides baseline data for how tree canopy is either increasing or shrinking over time. The study does not measure the environmental benefits of the urban forest, just its location and spread.

# Providence Urban Tree Canopy by Neighborhood 2007





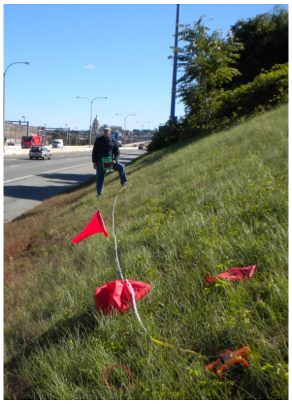

Aerial view of Providence's College Hill neighborhood. (photo courtesy of Google Maps.)

The current study, i-Tree Eco, completes a full analysis of the urban forest begun by the 2006 and 2007 studies. The goal is to quantify the environmental benefits of the whole urban forest – from public street trees and park trees to trees on private lands and in natural areas. i-Tree Eco is part of a suite of software developed by the U.S. Forest Service and partners to analyze and assess urban or community forests. It provides an overall depiction of urban forest structure through field data taken from randomly assigned plots throughout the city, along with local hourly air pollution and meteorological data. The results measure structure, environmental effects and the value to the community. The benefits of having this information help in forest management planning and community decision making.

The findings from this study will be incorporated into strategic planning for Providence's Urban Forest Master Plan, scheduled to be finalized in early 2015. The i-Tree Eco study will help us better understand the urban forest resource and how it improves the environment and human health.

# METHODS AND MATERIALS

## Providence's i-Tree Eco Study Protocol



Harold Monroe, setting up a plot with rulers and flags.

The i-Tree Eco study model was developed through a collaboration of the U.S. Forest Service and The Davey Resource Group. The City of Providence adapted data collection methods from the model to specifically fit the City's needs (See Appendix VII for data sheet).

Plots were assigned through simple random selection of points throughout the city using i-Tree software. Points were randomly chosen. The first 250 random points were used as plots for the study. One plot was inaccessible, and was replaced with the next random plot. Plots fell on both public and private land. Private property owners were sent letters requesting permission (see Appendix VII for letter) and contact was established before entering private grounds.

Data was collected over seven weeks, late August into early October. The surveyors consisted of six paid interns and four volunteers, who were hired with backgrounds in environmental science or were RI Tree Stewards. An Environmental Studies class from Johnson & Wales University also performed data collection. Surveyors received an hour and a half indoor training session, with additional field training. Training was provided by the City Forester, Doug Still, with help from Mark Hengen, Associate Professor of Environmental Science at Johnson and Wales University.  Surveyors worked in pairs, to be able to double check data and estimates. Data was recorded on paper sheets and attached to the coordinating plot map. Surveyors also entered the data into the i-Tree database online via smartphone or home computer.


Survey team badge.

Tree data included species, status (ingrowth or planted), direction (azimuth) and distance to the center point, height, diameter breast height, crown width, crown percent missing, percent dieback, and direction and distance to any building located within 60 feet. Plot data included plot ID number, date, names of surveyors, land use, ground cover, reference objects to center point, and percent tree cover.  A rough sketch was made for each plot to determine general location of reference objects and trees, and photos were taken to show the plot from standing view.

When determining the land use, the predominant use was chosen for each plot. For example, if the plot fell within a neighborhood, but 3 feet were in a cemetery, the land use would fall under residential. Land use choices included Residential, Multi-Family Housing (apartment complex), Commercial/Industrial, Park, Cemetery, Golf Course, Agricultural, Vacant, Institutional (School), Utility, Water/Watershed, Transportation, and an "Other" category.


An example of a survey plot map. The red ring represents the area of the plot, and the red dot is the center point.

Amanda Reposa, an intern, poses for a plot photo to give the viewer perspective.

Reference objects were used to determine the center point of the plot. The distance and direction were taken for each reference object; in most cases there were 2 references objects for each plot. Objects chosen were permanent structures or utilities, such as a building, telephone pole, or street corner.

Tree data was recorder per tree, in the order that they fall from north, clockwise around the center point. Distance and direction were recorded from the center point. Tree height was measured using the “stick method,” calibrating a pen viewed at arm’s length to 10 foot measurements at a specified number of steps away from the tree. Diameter at breast height (DBH) was measured with a forestry DBH tape and measuring at 4.5 feet from the base of each tree when possible, or right under the first branching on smaller trees (making note of height). Crown percent missing was determined by visualizing the shape of the full canopy for the tree species, and estimating how much may be missing from the shape. A tree’s dieback is the percentage of the tree that has missing leaves or dead branches. *For details on i-Tree’s analytical methods, please see Appendix I.*

**Survey Materials**

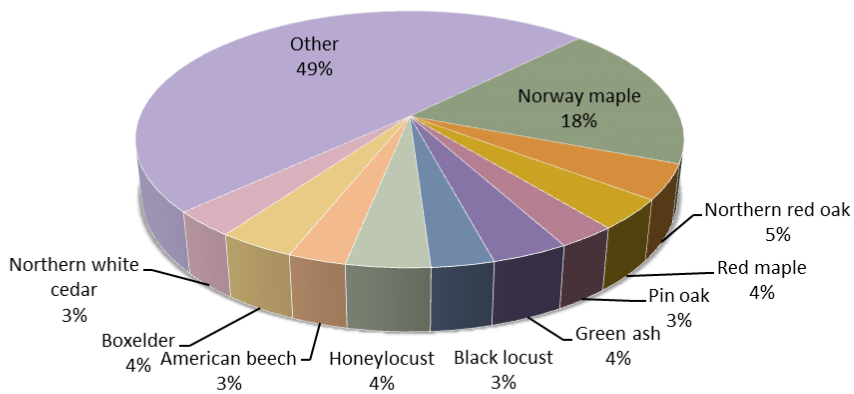
| | |
|---|---|
| Survey Flags | Clipboard |
| Measuring Tape (100 ft) | Data Sheets |
| Baseplate Compass | Maps |
| DBH Measuring Tape | Tree Identification Book |
| Chalk | Identification Badges |

# RESULTS

## Tree Characteristics of Providence's Urban Forest

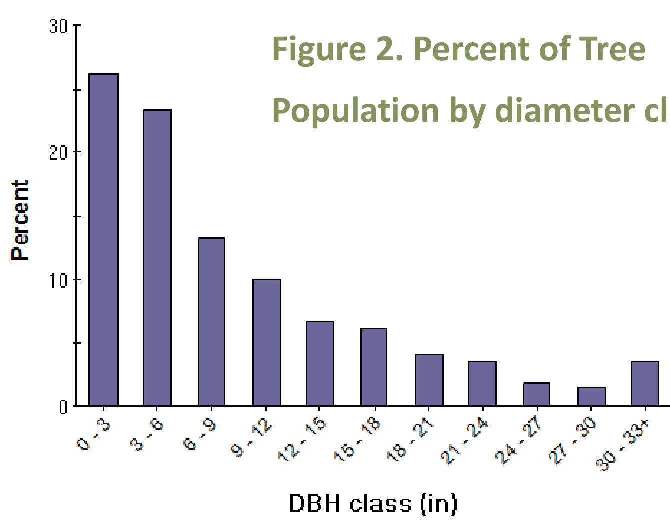
The City of Providence has an estimated 415,000 trees with a tree cover of 23.9 percent. Trees that have diameters less than 6-inches (15.2 cm) constitute 49.6 percent of the population. The three most common species are Norway maple (18.4 percent), Northern red oak (4.4 percent), and Honeylocust (4.2 percent). The overall tree density in Providence is 34.4 trees per acre (see Appendix III for comparable values from other cities).

**Figure 1. Tree Species Composition in Providence**




The diameter at breast height (DBH) of a tree is a good indication of its size. This diameter measurement is taken at 4.5 feet above the ground. The majority of Providence's trees are less than 12 inches DBH, indicating that most of the population consists of smaller and potentially younger trees.

**Figure 2. Percent of Tree Population by diameter class**

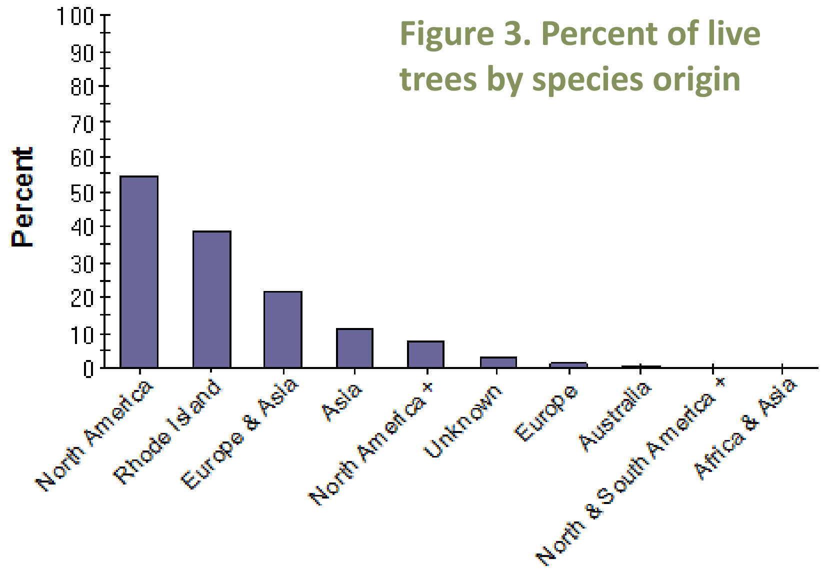


Left: Norway maple leaf and seed.

Below: Volunteers participating in Norway maple removal in an infested woodland in Blackstone Park, a Conservation District.

American Elm, native to eastern North America, has suffered decline from Dutch Elm Disease since the 1930s.

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. 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 Providence, about 55 percent of the trees are species native to North America, while 39 percent are native to the state. Species exotic to North America make up 46 percent of the population. Most exotic tree species originate from Europe & Asia (22.1 percent of all species).




*The plus sign (+) indicates the plant is native to another continent other than the ones listed in the grouping.*

Little-Leaf Linden, native to Europe and Western Asia, is commonly planted as a street tree in the United States.

Invasive plant species are often characterized by their vigor, ability to adapt, reproductive capacity, and general lack of natural enemies. These abilities enable them to displace native plants and make them a threat to natural areas [1]. Five of the 99 tree species sampled in Providence are identified as invasive on the state invasive species list [2]. These invasive species comprise 24.2 percent of the tree population though they may only cause a minimal level of impact. By far, the most common invasive species is Norway maple (18.4 percent of population), followed by Black locust (3.1 percent), and Sycamore maple (2.1 percent) (see Appendix V for a complete list of invasive species).

# RESULTS

## Urban Forest Cover

The leaf area is based on measurements that form a three dimensional view of the canopy of each tree.

Urban tree canopy cover refers to how much ground would be shaded if the sun were directly above in the sky. This study estimates Providence's canopy coverage at 23.9%. This is consistent with the Providence Urban Tree Cover (UTC) study from 2007, utilizing satellite imagery, which estimated 23.3% UTC.

Many environmental benefits of trees also equate directly to the amount of healthy leaf surface area. In Providence, the most dominant species in terms of leaf area are Norway maple, Northern red oak, and Pin oak, which are species with large, broad leaves. This study also factored in canopy height, spread, height from the ground to the lowest branches, missing canopy , and dieback, providing a three dimensional model of each tree affecting the leaf area measurement.

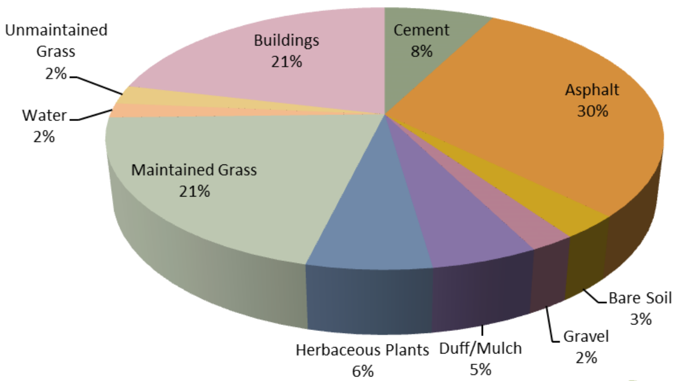
The ten most important species are listed in Table 1. Importance values (IV) are calculated as the sum of relative leaf area and relative composition. Importance values provide an index to how the tree canopy benefits the urban environment.

**Table 1. Most important species in Providence.**

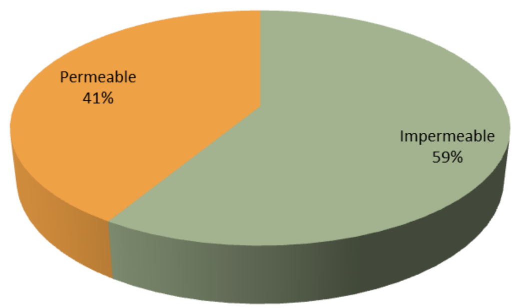
| Species Name | Percent Population | Percent Leaf Area | IV |
|---|---|---|---|
| Norway maple | 18.4 | 24.6 | 43.0 |
| Northern red oak | 4.4 | 8.0 | 12.4 |
| Red maple | 3.8 | 4.9 | 8.8 |
| Pin oak | 2.9 | 5.0 | 7.9 |
| Green ash | 3.8 | 3.7 | 7.6 |
| Black Locust | 3.1 | 3.1 | 6.3 |
| Honeylocust | 4.2 | 1.6 | 5.8 |
| American Beech | 2.9 | 2.4 | 5.3 |
| Boxelder | 3.8 | 1.3 | 5.1 |
| Sycamore maple | 2.1 | 2.3 | 4.4 |

Ground cover types below the tree canopy were measured in each plot. The most dominant ground cover types in Providence are Asphalt (29.9%) and Buildings (21.3%). Permeable and impermeable ground covers can have an impact on many environmental factors from water run-off distribution to available area for vegetation growth. Providence's ground cover is 59% impermeable.

### Figure 4. Percent Ground Cover



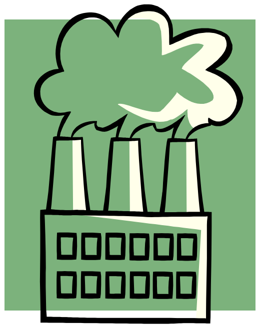

### Percentage of Permeable Ground Cover




In this photograph, you can see many types of ground cover, including mortared brick, cement, grass, and mulch.

# RESULTS

## Air Pollution Removal by Urban Trees



Providence's trees remove an estimated 91 tons of air pollution per year.

Poor air quality is a common problem in many urban areas. It can impair human health, damage plants and ecosystem processes, and reduce visibility. The urban forest improves 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 contribute to ozone formation. However, integrative studies have revealed that an increase in tree cover leads to reduced ozone formation [3].

Pollution removal by trees and shrubs in Providence was estimated using field data and recent available pollution and weather data. Pollution removal was greatest for ozone (47.3 tons). It is estimated that trees and shrubs remove 91 tons of air pollution (ozone (O3), carbon monoxide (CO), nitrogen dioxide (NO2), particulate matter less than 10 microns and greater than 2.5 microns (PM10), particulate matter less than 2.5 microns (PM2.5), and sulfur dioxide (SO2)) per year with an associated value of $3.48 million (see Appendix I for more details).

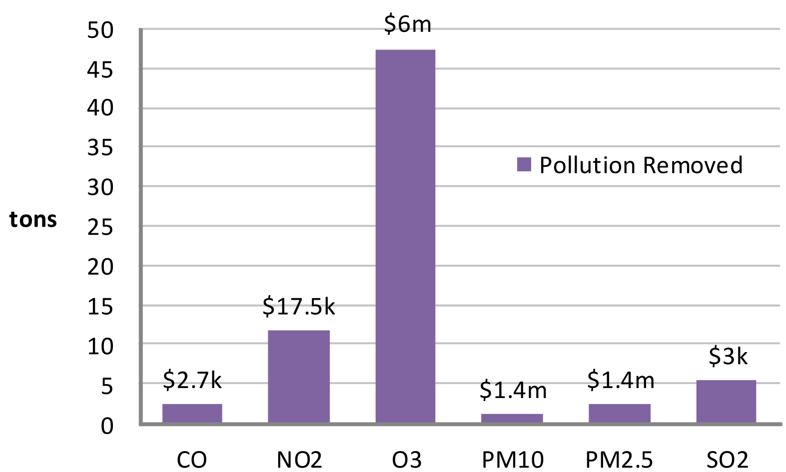



**Figure 5. Pollution removal (bars) and associated value ($) for trees in Providence**

Pollution removal by trees in Providence is greatest for ozone (O3), one of the main pollutants emitted by vehicles.

PM10 consists of particulate matter less than 10 microns and greater than 2.5 microns. As PM2.5 is also estimated, the sum of PM10 and PM2.5 provides the total pollution removal and value for particulate matter less than 10 microns.

Pollution Removal value is calculated based on the prices of $1136 per ton (carbon monoxide), $12938 per ton (ozone),$1488 per ton (nitrogen dioxide), $587 per ton (sulfur dioxide), $63778 per ton (particulate matter less than 10 microns and greater than 2.5 microns), $618260 per ton (particulate matter less than 2.5 microns)

# RESULTS

## Carbon Storage and Sequestration

Providence's trees sequester 4,030 tons of carbon per year. The bulk of carbon is stored in the trunk.

Climate change is an issue of global concern. Urban trees 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 [4].

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 Providence trees is about 4,030 tons of carbon per year with an associated value of $287 thousand. Net carbon sequestration in the urban forest is about 3,480 tons. Carbon storage and carbon sequestration values are calculated based on $71 per ton (see Appendix I for more details).

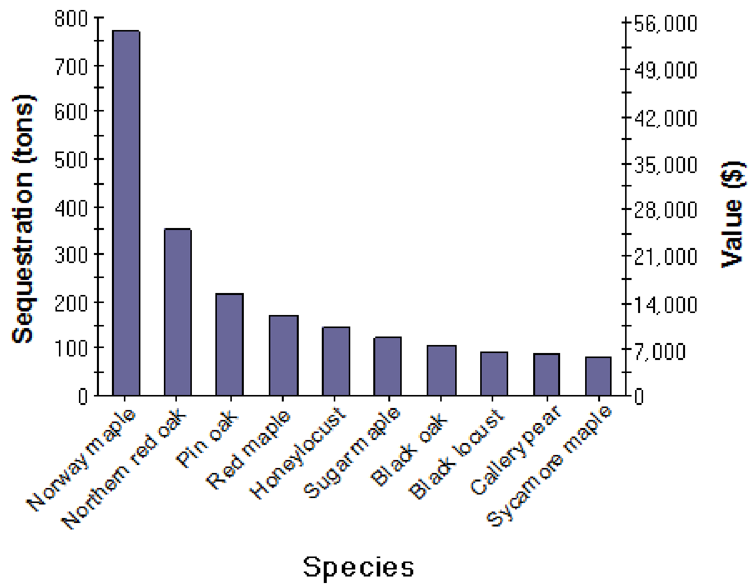
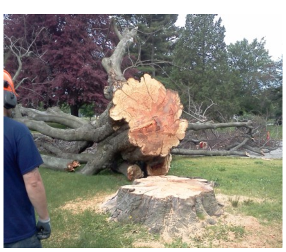



**Figure 6. Carbon sequestration and value for species with greatest overall carbon sequestration in Providence**



Preserving trees helps to store carbon, preventing its release if the tree dies and decomposes.

As trees grow they store increasingly more carbon as wood. As trees die and decay, they release much of the stored carbon back to the atmosphere. Trees in Providence are estimated to store 124,000 tons of carbon ($8.80 million). Of all the species sampled, Norway maple stores and sequesters the most carbon (approximately 21.1% of the total carbon stored and 22.1% of all sequestered carbon.)

## Oxygen Production

Oxygen production is one of the most commonly cited benefits of urban trees. The net annual oxygen production of a tree is directly related to the amount of carbon sequestered by the tree, which is tied to the accumulation of tree biomass.

Trees in Providence are estimated to produce 9,280 tons of oxygen per year. However, this tree benefit is relatively insignificant because of the large and relatively stable amount of oxygen in the atmosphere and extensive production by aquatic systems. Our atmosphere has an enormous reserve of oxygen. If all fossil fuel reserves, all trees, and all organic matter in soils were burned, atmospheric oxygen would only drop a few percent [5].

Providence trees produce 9,280 tons of oxygen per year.

**Table 2. The top 20 oxygen producing species.**

| Species Name | Oxygen (tons) | Net Carbon Sequestration (tons/year) | Number of Trees | Leaf Area (square miles) |
|---|---|---|---|---|
| Norway maple | 2049.39 | 768.52 | 76,172 | 4.56 |
| Northern red oak | 934.41 | 350.40 | 18,320 | 1.48 |
| Pin oak | 576.46 | 216.17 | 12,052 | 0.92 |
| Red maple | 445.95 | 167.23 | 15,909 | 0.91 |
| Honeylocust | 386.16 | 144.81 | 17,356 | 0.30 |
| Sugar maple | 326.28 | 122.36 | 4,339 | 0.47 |
| Black oak | 282.10 | 105.79 | 4,821 | 0.35 |
| Black locust | 243.89 | 91.46 | 13,017 | 0.58 |
| Callery pear | 232.13 | 87.05 | 7,231 | 0.37 |
| Sycamore maple | 217.99 | 81.75 | 8,678 | 0.43 |
| American beech | 216.38 | 81.14 | 12,052 | 0.45 |
| Green ash | 199.42 | 74.78 | 15,909 | 0.69 |
| Silver maple | 193.24 | 72.47 | 6,749 | 0.41 |
| White oak | 171.58 | 64.34 | 3,375 | 0.14 |
| Beech | 165.82 | 62.18 | 2,893 | 0.54 |
| Eastern white pine | 158.65 | 59.54 | 5,785 | 0.32 |
| Kwanzan cherry | 148.65 | 55.74 | 9,642 | 0.26 |
| London planetree | 138.04 | 51.76 | 3,375 | 0.50 |
| Black mulberry | 132.95 | 49.86 | 11,570 | 0.22 |
| Boxelder | 130.63 | 48.99 | 15,909 | 0.23 |

# RESULTS

## Avoided Runoff

Providence trees reduce runoff by an estimated 31.5 million gallons per year.

Surface storm water runoff is a cause for concern in many urban areas. It contributes pollution to streams, wetlands, rivers, lakes, and oceans. During precipitation events, some portion is intercepted by vegetation (trees and shrubs) while the other portion reaches the ground. The portion of the precipitation that reaches the ground and does not infiltrate into the soil becomes surface runoff [6]. In urban areas, the large extent of impervious surfaces increases the amount of surface runoff.

Urban trees, however, are beneficial in reducing surface runoff. Trees intercept precipitation, while their root systems promote infiltration and storage in the soil. The trees of Providence help to reduce runoff by an estimated 4,213,000 cubic feet (31.5 million gallons) per year with an associated value of $281 thousand (see Appendix I for more details).

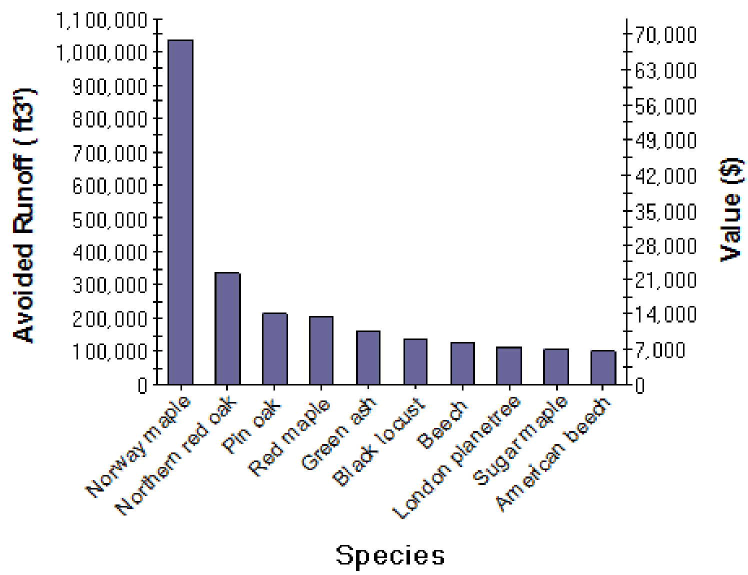



**Figure 7. Avoided runoff value for species with greatest overall impact on runoff in Providence**

Storm water data from the 2006 Providence street tree inventory reported 30.6 million gallons per year of *intercepted* storm water, compared to 31.5 million gallons of *avoided runoff* from the current i-Tree Eco study of the whole urban forest. While one might expect the i-Tree Eco storm water figure to be much higher, the two studies use different analysis models and the results measure different effects. The street tree data (i-Tree Streets/STRATUM) model calculates the amount of water that trees intercept temporarily on the leaf canopy and bark surfaces, which evaporates, drips from leaf surfaces, or flows down the stem to the ground. The i-Tree Eco model is more comprehensive; it considers interception data, ground cover, and other processes that lead to water infiltrating the ground with our without vegetation present. Avoided runoff is a more accurate reflection of the urban forest's benefit to local water quality.

# RESULTS

## Trees and Building Energy Use

Providence trees can save an estimated $591 thousand on energy related costs annually.

Trees affect energy consumption by shading buildings, providing evaporative cooling, and blocking winter winds. Trees reduce building energy consumption in the summer months and 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 buildings [7].

Trees in Providence are estimated to reduce energy-related costs from residential buildings by $591 thousand annually. Trees also provide an additional $35,639 in value by reducing the amount of carbon released by fossil-fuel based power plants (a reduction of 500 tons of carbon emissions).

**Table 3. Annual Energy and Cost Savings Due to Trees near Residential Buildings**

| | Heating | | Cooling | | Totals | |
|---|---|---|---|---|---|---|
| | Energy Used | Annual Savings[4] | Energy Used | Annual Savings | Energy Used | Annual Savings |
| MBTU[1] | -8,286 | $-130,751 | n/a | n/a | $-8,286 | -130,751 |
| MWH[2] | -113 | $-17,730 | 4,712 | $739,313 | $4,599 | 721,583 |
| *Carbon Avoided*[3] | -160 | $-11,383 | 660 | $47,022 | $500 | 35,639 |

[1]One Million British Thermal Units: Representing oil, natural gas and other heating fuels.
[2]Megawatt-hour: Representing electricity use.
[3]Short ton
[4]Based on the prices of $156.9 per MWH and $15.78 per MBTU (see Appendix I for more details)

# RESULTS

## Structural and Functional Values

A mature tree removes almost 70 times more pollution than a newly planted tree (Source: *Dr. Nowak, The Effects of Urban Trees on Air Quality*).

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 [8]. 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, the value of Providence's urban forest can be increased; however, the values and benefits also can decrease as the amount of healthy tree cover declines.

Structural values:

- Structural value: $582 million
- Carbon storage: $8.80 million

Annual functional values:

- Total annual environmental benefits: $4.7 million per year
  - ◊ Carbon sequestration: $287 thousand
  - ◊ Pollution removal: $3.5 million
  - ◊ Building energy savings: $591 thousand/year
  - ◊ Avoided carbon emissions: 500 tons/year ($35.6 thousand/year)
  - ◊ Avoided runoff: 31.5 million gallons/year ($281 thousand/year)

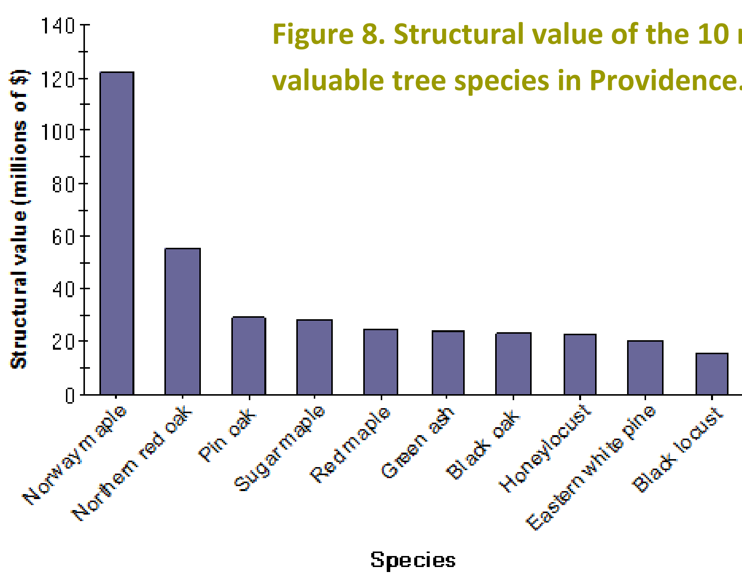



**Figure 8. Structural value of the 10 most valuable tree species in Providence.**

# RESULTS

## Potential Pest Impacts

Asian Longhorned Beetle, a pest with many host species. ALB is found within Worcester MA, about 40 miles away. It is urged to report any possible sightings of this pest in Providence.

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 among cities. Pests were analyzed for their potential impact and compared with pest range maps [9] for the conterminous United States. In the following graph, the pests are color coded according to Providence county's proximity to the pest occurrence in the United States.

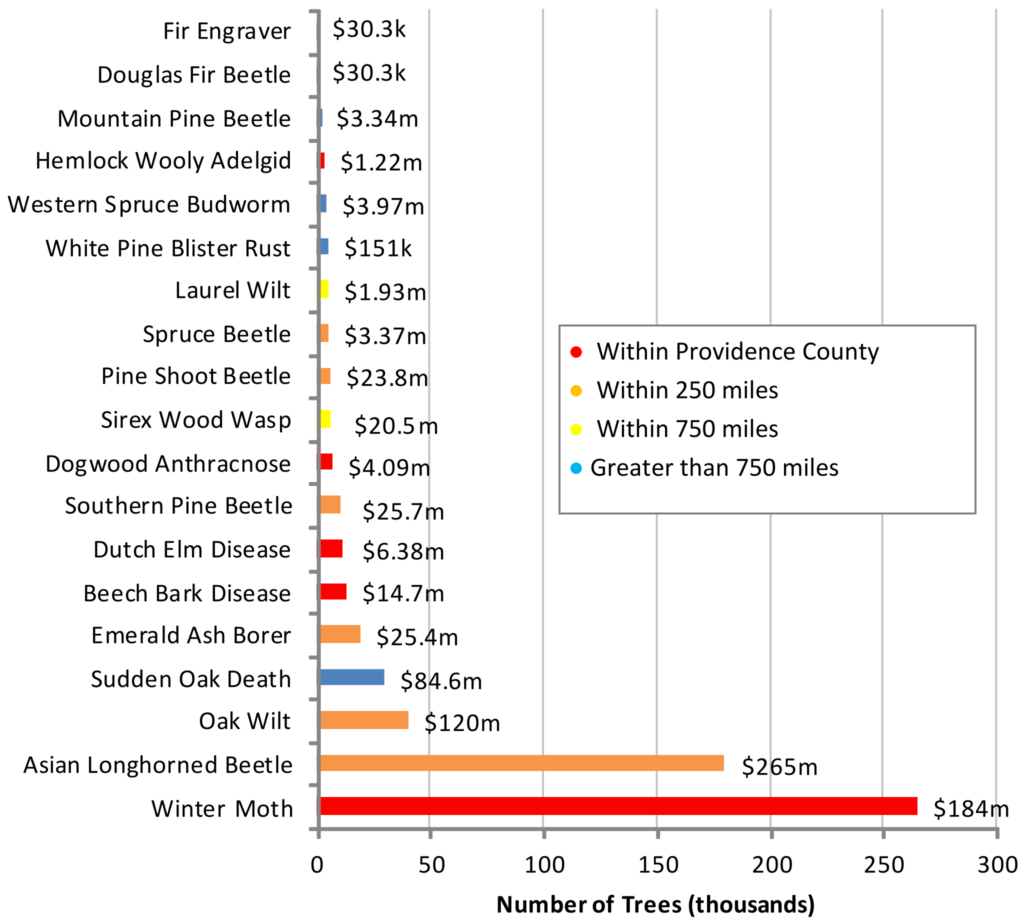



**Figure 10. Number of susceptible Providence Trees and structural value by pest. See following pages for pest descriptions.**

Dutch Elm Disease devastated American Elm trees in North America. A number of new Elm cultivars have shown resistance to the disease.

**Asian Longhorned Beetle** [11] is an insect that bores into and kills a wide range of hardwood species. ALB poses a threat to 43.2 percent of the Providence urban forest, which represents a potential loss of $265 million in structural value.

**Beech Bark Disease** [12] is an insect-disease complex that primarily impacts American beech. This disease threatens 2.9 percent of the population, which represents a potential loss of $14.7 million in structural value.

**Dogwood Anthracnose** [15] is a disease that affects dogwood species, specifically flowering and Pacific dogwood. This disease threatens 1.4 percent of the population, which represents a potential loss of $4.09 million in structural value.

**Dutch Elm Disease** [16] has devastated the American elm, one of the most important street trees in the twentieth century. Since first reported in the 1930s, it has killed over 50 percent of the native elm population in the United States. Although some elm species have shown varying degrees of resistance, Providence could possibly lose 2.3 percent of its trees to this pest ($6.38 million in structural value).

**Douglas-Fir Beetle** [17] is a bark beetle that infests Douglas-fir trees throughout the western United States, British Columbia, and Mexico. Potential loss of trees from DFB is 482 ($30.3 thousand in structural value).

**Emerald Ash Borer** [18] has killed thousands of ash trees in parts of the United States. EAB has the potential to affect 4.2 percent of the population ($25.4 million in structural value).


Emerald Ash Borer is moving its way through the Northeast, posing a threat to Providence's Ash trees. *Photo credit: bugwood.org.*

**Fir Engraver** [19] is a common pest of white fir, grand fir, and red fir trees . FE poses a threat to 0.1 percent of the Providence urban forest, which represents a potential loss of $30.3 thousand in structural value.

**Hemlock Woolly Adelgid** [23] is one of the most damaging pests to eastern hemlock and Carolina hemlock, and has played a large role in hemlock mortality in the United States. HWA has the potential to affect 0.3 percent of the population ($1.22 million in structural value).

**Laurel Wilt** [26] is a fungal disease that is introduced to host trees by the redbay ambrosia beetle. This pest threatens 1.0 percent of the population, which represents a potential loss of $1.93 million in structural value.


Gypsy Moth first came to Rhode Island in the early 1900's, but heavy defoliation occurred in the 1980's throughout New England.

**Mountain Pine Beetle** [27] is a bark beetle that primarily attacks pine species in the western United States. MPB has the potential to affect 0.3 percent of the population ($3.34 million in structural value).

**Oak Wilt** [29], which is caused by a fungus, is a prominent disease among oak trees. OW poses a threat to 9.5 percent of the Providence urban forest, which represents a potential loss of $120 million in structural value.

**The Pine Shoot Beetle** [31] is a wood borer that attacks various pine species, though Scotch pine is the preferred host in North America. PSB has the potential to affect 1.9 percent of the population ($23.8 million in structural value).

**Spruce Beetle** [32] is a bark beetle that causes significant mortality to spruce species within its range. Potential loss of trees from SB is 3.37 thousand ($3.89 million in structural value).

**Sudden Oak Death** [34] is a disease that is caused by a fungus. Potential loss of trees from SOD is 30.4 thousand ($84.6 million in structural value).

**Southern Pine Beetle** [35] will attack most pine species, but its preferred hosts are loblolly, Virginia, pond, spruce, shortleaf, and sand pines. This pest threatens 2.7 percent of the population, which represents a potential loss of $25.7 million in structural value.

Hemlock Wooly Adelgid has spread throughout the East Coast leading to significant Hemlock decline.

**The Sirex Wood Wasp** [36] is a wood borer that primarily attacks pine species. SW poses a threat to 1.5 percent of the Providence urban forest, which represents a potential loss of $20.5 million in structural value.

**Winter Moth** [Added by City of Providence staff] has a wide variety of host species, and is most notably a problem with oak and fruit bearing trees. This pest threatens 64 percent of the population. Severe outbreaks and defoliation cause decline, resulting in a potential loss of $184 million in structural value.

**White Pine Blister Rust** (Eastern U.S.) [39] has had a detrimental effect on white pines Since its introduction to the United States in 1900, particularly in the Lake States. WPBR has the potential to affect 1.4 percent of the population ($20.4 million in structural value).

**Western Spruce Budworm** (WSB) [40] is an insect that causes defoliation in western conifers. This pest threatens 0.8 percent of the population, which represents a potential loss of $3.97 million in structural value.

# DISCUSSION

The results of this study show that Providence's urban forest is a vital environmental resource that significantly improves air quality, water quality, and the well-being of residents. It has long been acknowledged that the tree canopy contributes to the city's character and attractiveness, and that trees help create a unique sense of place. But looking past important intangible values, this i-Tree Eco study takes a scientific approach toward measuring a range of environmental benefits. For the first time, the function and structure of the *whole* urban forest have been quantified, adding to previous studies on the street tree population and the amount of canopy cover using remote sensing methods. We now have a more complete view of the resource using random sampling combined with on-the-ground assessments of trees, canopy density, ground cover, and the relationship of trees to buildings. Environmental benefits are delivered by trees on both public and private land: it is important to include and consider trees beyond the public right-of-way.

Most importantly, these study results demonstrate the importance of *large trees* to Providence. Large trees are the "heavy lifters" environmentally, with exponentially greater leaf area and biomass than small trees. According to U.S. Forest Service researchers, a large mature tree can remove up to 70 times more pollution from the air than a small or newly planted tree [61]. This is reflected in much larger "importance values" given in this study to species that are not only common in Providence, but that grow big such as oaks and maples (see Table 1, page 17). We must protect our large shade trees, and create adequate space for them to grow and live with long, healthy life-spans. Additionally, with approximately half (49.6%) of the city's trees measuring 6 inches or less in diameter, most trees are relatively young. Simply caring for and protecting these trees will lead to increased canopy coverage over time. This is not completely desirable, however. With 46% of the tree population consisting of invasive species, steps must be taken to encourage the growth of native trees.

Estimates on the number of trees in Providence (415,000), canopy cover (23.9%), species composition and size, structural value ($582 million), and annual environmental benefits provide baseline data for comparison purposes in the future, which will help managers understand if tree canopy and associated benefits are increasing or decreasing over time. Repeat studies should be conducted every 10 years to identify trends. The i-Tree methodology is now widely used in cities across the United States and Canada, allowing comparisons between Providence and other municipalities (see Appendix III).

Information derived from this study can be used to make informed management decisions and zoning policy relating to trees and preserving tree canopy. Understanding the benefits and their associated values can lead to policies that improve the quality of the urban forest, leading to increased benefits for Providence residents. With 23.9% canopy cover, there is clearly an opportunity for continued growth. Sound management must also include planning to address significant pest threats to the city's trees, such as the potential of infestation by Asian longhorned beetle or emerald ash borer. Specific goals and strategies will be developed through the upcoming planning process for the Urban Forest Master Plan, to be completed by early 2015. Potential management strategies will revolve around the following topics:

*Species selection* – plant diverse and appropriate species; plant non-invasive species; plant native trees near natural areas; remove invasive species from public woodlands.

*Foster large shade trees* – plant large species wherever space allows; strengthen and enforce tree protection standards during construction; enforce Providence Zoning Ordinance requirements for providing minimum tree cover on developments, and enforce "significant tree" regulations.

*Plant for greatest environmental impact* – plant trees along transportation corridors, especially in "low canopy" neighborhoods; utilize more conifer species to create windbreaks for savings on winter heating costs and year-round removal of pollutants; encourage tree planting in energy-conserving locations, in highly polluted areas, or in heavily populated areas; develop strategies to address the quality of tree populations in "abandoned" landscapes such as empty lots and unmanaged easements and roadsides.

*Public stewardship* – continue and increase involvement of residents in tree planting (Providence Neighborhood Planting Program) and tree care; increase cooperation with neighborhood groups through Partnership for Providence Parks and other means of outreach; educate and involve citizens on the importance of trees through public events and social media; develop innovative ways to encourage hands-on public involvement.

*Pest planning* - develop action plans to deal with possible insect or disease outbreaks; plant for diversity to create resiliency to possible pest problems; collaborate with organizations that function beyond the city's borders, i.e. state and federal agencies, the Rhode Island Tree Council, and other regional groups.

Providence Mayor Angel Taveras aids in a Providence Neighborhood Planting Program event on Lorimer Street.

# 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 [41], 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 (<2.5 microns and <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 pests, such as Asian longhorned beetle, emerald ash borer, gypsy moth, and Dutch elm disease.

In the field 0.10 acre plots were randomly distributed. Typically, all field data are collected during the leaf-on season to properly assess tree canopies. Within each plot, typical data collection (actual data collection may vary depending upon the user) includes land use, ground and tree cover, individual tree attributes of species, stem diameter, height, crown width, crown canopy missing and dieback, and distance and direction to residential buildings [42, 43].

Invasive species are identified using an invasive species list [2] 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.

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 [44]. 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. 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 [45] and converted to local currency with user-defined exchange rates.

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 [46].

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 [47, 48]. 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 [49, 50] that were adjusted depending on leaf phenology and leaf area. Removal estimates of particulate matter less than 10 microns incorporated a 50 percent resuspension rate of particles back to the atmosphere [51]. 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 [52, 53, and 54].

Air pollution removal value was 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 <2.5 microns using the U.S. Environmental Protection Agency's Environmental Benefits Mapping and Analysis Program (BenMAP). The model uses a damage-function approach that is based on the local change in pollution concentration and population [55].

National median externality costs were used to calculate the value of carbon monoxide removal and particulate matter less than 10 microns and greater than 2.5 microns [56]. PM10 denotes particulate matter less than 10 microns and greater than 2.5 microns throughout the report. As PM2.5 is also estimated, the sum of PM10 and PM2.5 provides the total pollution removal and value for particulate matter less than 10 microns.

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 [57].

If appropriate field data were collected, seasonal effects of trees on residential building energy use were calculated based on procedures described in the literature [7] 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.

Structural values were based on valuation procedures of the Council of Tree and Landscape Appraisers, which uses tree species, diameter, condition, and location information [58]. Structural value may not be included for international projects if there is insufficient local data to complete the valuation procedures.

Potential pest risk is based on pest range maps and the known pest host species that are likely to experience mortality. Pest range maps from the Forest Health Technology Enterprise Team (FHTET) [9] 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 [9].

# APPENDIX II

## Relative Tree Effects

The urban forest in Providence 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 [59], average passenger automobile emissions [60], and average household emissions [61].

Carbon storage is equivalent to:
- Amount of carbon emitted in Providence in 42 days
- Annual carbon (C) emissions from 74,100 automobiles
- Annual C emissions from 37,200 single-family houses

Carbon monoxide removal is equivalent to:
- Annual carbon monoxide emissions from 9 automobiles
- Annual carbon monoxide emissions from 39 single-family houses

Nitrogen dioxide removal is equivalent to:
- Annual nitrogen dioxide emissions from 739 automobiles
- Annual nitrogen dioxide emissions from 493 single-family houses

Sulfur dioxide removal is equivalent to:
- Annual sulfur dioxide emissions from 7,890 automobiles
- Annual sulfur dioxide emissions from 132 single-family houses

Particulate matter less than 10 micron (PM10) removal is equivalent to:
- Annual PM10 emissions from 65,000 automobiles
- Annual PM10 emissions from 6,270 single-family houses

Annual carbon sequestration is equivalent to:
- Amount of carbon emitted in Providence in 1.4 days
- Annual C emissions from 2,400 automobiles
- Annual C emissions from 1,200 single-family houses

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

# APPENDIX III

## Comparison of Urban Forests

A common question asked is, "How does this city compare to other cities?" Although comparison among cities should be made with caution as there are many attributes of a city that affect urban forest structure and functions, summary data are provided from other cities analyzed using the 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)* |
|---|---|---|---|---|---|
| Calgary, Canada | 7.2 | 11,889,000 | 445,000 | 21,422 | 326 |
| Atlanta, GA | 36.8 | 9,415,000 | 1,345,000 | 46,433 | 1,662 |
| Toronto, Canada | 20.5 | 7,542,000 | 992,000 | 40,345 | 1,212 |
| New York, NY | 21.0 | 5,212,000 | 1,351,000 | 42,283 | 1,677 |
| Baltimore, MD | 21.0 | 2,627,000 | 596,000 | 16,127 | 430 |
| Philadelphia, PA | 15.7 | 2,113,000 | 530,000 | 16,115 | 576 |
| Washington, DC | 28.6 | 1,928,000 | 523,000 | 16,148 | 418 |
| Boston, MA | 22.3 | 1,183,000 | 319,000 | 10,509 | 284 |
| Woodbridge, NJ | 29.5 | 986,000 | 160,000 | 5561.00 | 210 |
| Minneapolis, MN | 26.5 | 979,000 | 250,000 | 8,895 | 305 |
| Syracuse, NY | 23.1 | 876,000 | 173,000 | 5,425 | 109 |
| Morgantown, WV | 35.9 | 661,000 | 94,000 | 2,940 | 66 |
| Moorestown, NJ | 28.0 | 583,000 | 117,000 | 3,758 | 118 |
| **Providence, RI** | **23.9** | **415,000** | **124,000** | **4,030** | **91** |
| Jersey City, NJ | 11.5 | 136,000 | 21,000 | 890 | 41 |
| Freehold, NJ | 34.4 | 48,000 | 20,000 | 545 | 21 |

**II. Per acre values of tree effects**

| *City* | *No. of trees* | *Carbon storage (tons)* | *Carbon sequestration (lbs/yr)* | *Pollution removal (lbs/yr)* |
|---|---|---|---|---|
| Calgary, Canada | 66.7 | 2.5 | 0.120 | 3.6 |
| Atlanta, GA | 111.6 | 15.9 | 0.550 | 39.4 |
| Toronto, Canada | 48.3 | 6.4 | 0.258 | 15.6 |
| New York, NY | 26.4 | 6.8 | 0.214 | 17.0 |
| Baltimore, MD | 50.8 | 11.5 | 0.312 | 16.6 |
| Philadelphia, PA | 25.0 | 6.3 | 0.190 | 13.6 |
| Washington, DC | 49.0 | 13.3 | 0.410 | 21.2 |
| Boston, MA | 33.5 | 9.0 | 0.297 | 16.0 |
| Woodbridge, NJ | 66.5 | 10.8 | 0.375 | 28.4 |
| Minneapolis, MN | 26.2 | 6.7 | 0.238 | 16.4 |
| Syracuse, NY | 54.5 | 10.8 | 0.338 | 13.6 |
| Morgantown, WV | 119.7 | 17.0 | 0.532 | 23.8 |
| Moorestown, NJ | 62.0 | 12.5 | 0.400 | 25.2 |
| **Providence, RI** | **34.44** | **10.2** | **0.335** | **15.12** |
| Jersey City, NJ | 14.3 | 2.2 | 0.094 | 8.6 |
| Freehold, NJ | 38.5 | 16.0 | 0.437 | 33.6 |

# APPENDIX IV

## General Recommendations for Air Quality Improvement

Urban vegetation can directly and indirectly affect local and regional air quality by altering the urban atmosphere environment. Four main ways that urban trees affect air quality are [62]:

- 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 [63]. Local urban management decisions also can help improve air quality.

Urban forest management strategies to help improve air quality include [63]:

| ***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

## Invasive Species of the Urban Forest

The following inventoried species were listed as invasive on the Rhode Island invasive species list [2]:

| *Species Name* | *Number of trees* | *% Tree Number* | *Leaf Area (mi2)* | *% Leaf Area* |
|---|---|---|---|---|
| Norway maple | 76,172 | 18.35 | 4.56 | 24.64 |
| Black locust | 13,017 | 3.14 | 0.58 | 3.14 |
| Sycamore maple | 8,678 | 2.09 | 0.43 | 2.30 |
| Tree of heaven | 1,446 | 0.35 | 0.01 | 0.07 |
| English oak | 964 | 0.23 | 0.00 | 0.03 |
| **TOTAL** | **100,277** | **24.16** | **5.59** | **30.18** |

[1]Species are determined to be invasive if they are listed on the state's invasive species list.

# APPENDIX VI

## Potential Risk of Pests

Based on the host tree species for each pest and the current range of the pest [13], it is possible to determine what the risk is that each tree species sampled in the urban forest could be attacked by an insect or disease.

| | | | Pest | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Spp. Risk | Risk | Species Name | AL | ALB | BBD | BC | CB | DA | DED | DFB | EAB | FE | FR | GM | GSOB | HWA | JPB | LAT | LWD | MPB | NSE | OW | POCRD | PSB | SB | SBW | SOD | SPB | SW | TCD | WPB | WPBR | WSB |
| | 11 | Norway spruce | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 10 | Scotch pine | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 9 | Quaking aspen | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 9 | Willow spp | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 9 | Eastern white pine | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 8 | Northern red oak | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 8 | Pin oak | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 8 | River birch | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 7 | American elm | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 7 | Black oak | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 7 | Chinese elm | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 7 | Eastern hemlock | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 7 | Elm spp | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 7 | English oak | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 7 | Slippery elm | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 7 | White oak | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 7 | Blue spruce | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 6 | Black spruce | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 6 | Green ash | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 6 | Spruce spp | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 6 | Douglas fir | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 4 | American basswood | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 4 | American beech | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 4 | American chestnut | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 4 | Apple spp | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 4 | Basswood spp | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 4 | Callery pear | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 4 | Carolina poplar | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 4 | Common linden | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 4 | Cottonwood spp | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 4 | Crabapple | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 4 | Dogwood spp | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 4 | Flowering dogwood | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 4 | Kousa dogwood | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 4 | Littleleaf linden | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 4 | Poison sumac | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 4 | Sweetgum | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

| | |
|---|---|
| 4 | Birch spp |
| 3 | Ash spp |
| 3 | Boxelder |
| 3 | Crimson king norway maple |
| 3 | Eastern cottonwood |
| 3 | Japanese maple |
| 3 | London planetree |
| 3 | Mimosa |
| 3 | Norway maple |
| 3 | Paperbark maple |
| 3 | Red maple |
| 3 | Silver maple |
| 3 | Sugar maple |
| 3 | Sycamore maple |
| 3 | White ash |
| 2 | Sassafras |

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 to 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 Providence county
- Orange indicates pest is within 250 miles of Providence county
- Yellow indicates pest is within 750 miles of Providence county
- Green indicates pest is outside of these ranges

# APPENDIX VII

## i-Tree Eco Data Sheet

| PLOT ID= | DATE= | CREW= | GPS COOR | PHOTO ID= |
|---|---|---|---|---|
| | | | X | |
| | | | Y | |

### PLOT SKETCH AND NOTES FOR PLOT RELOCATION

(Note distance and direction from plot center to fixed objects; sketch fixed objects in relation to plot center)

Plot address=
Notes:

Plot contact info:
Name and Title:_______________
Phone #______________________

**LOCATING REFERENCE OBJECTS/LANDMARKS** (Identify at least 1 object)
Measure Reference Object (1) description________________________________
Distance to Reference Object (1)_____________
Direction to Reference Object (1)_____________
Measured Reference Object (2) description________________________________
Distance to Reference Object (2) _____________
Direction to Reference Object (2)_____________
Tree Measurement Point (TMP): Reference Object (1) used Y/N
Reference Object (2) used Y/N
Measurement Unit: M/E

Percent Measured________

| ACTUAL LAND USE= | PERCENT IN= | PLOT TREE COVER (%)= | SHRUB COVER (%)= | PLANTABLE SPACE (%)= |
|---|---|---|---|---|
| ACTUAL LAND USE= | PERCENT IN= | | | |
| ACTUAL LAND USE= | PERCENT IN= | | | |
| ACTUAL LAND USE= | PERCENT IN= | | | |

| GROUND COVER | %BLDG | %CMNT | %TAR | %ROCK | %SOIL | %DUFF/ MULCH | %HERB/ IVY | %MAIN. GRASS | %UNMAIN GRASS | %H2O |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | |

| SHRUBS | SPECIES | HEIGHT | % AREA | % MISSING | SPECIES | HEIGHT | % AREA | % MISSING | SPECIES | HEIGHT | % AREA | % MISSING |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
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| PLOT ID= | | | | TREE SPECIES | | | DBH | | | | | | HEIGHT | | | CROWN WIDTH | | | | | | | TREES NEAR BUILDINGS | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TREE ID | STAT | DR | DS | LAND | USE | HT DBH | 1 | 2 | 3 | 4 | 5 | 6 | TOT | LIVE TOP | CROWN BASE | N-S | E-W | % MISS | DB | % IMP | % SHRUB | CLE | D1 | S1 | D2 | S2 | D3 | S3 | TREE SITE |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
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# APPENDIX VIII

## Permission Letter for Private Residences

CITY OF PROVIDENCE
Angel Taveras, Mayor

September 3, 2013

Dear Property Owner,

The Providence Forestry Division is conducting a study of the city's urban forest this September and October. The study utilizes research and software developed by the U.S. Forest Service called i-Tree Eco (www.itreetools.org/eco) that will provide us with important information about our trees and environment: the structure of our urban forest, the environmental benefits it provides such as energy use reduction and air quality benefits, how many of our trees are at risk from exotic pests and diseases, and the overall value of our trees.

The study considers ALL trees in Providence, not just city-owned trees. A group of paid staff and volunteers are surveying 250 randomly assigned study plots, each 1/10 acre in size. Many of these survey plots fall on private land, including one that happens to be located on your property.

**We are requesting permission to access your yard** to collect information on trees and other vegetation within the sample plot, including tree type (if there are any), size, and spread. The measurements will not harm the trees or your property in any way, and the specific information will not be shared with anyone outside of the study. In general, it takes the surveyors about 1 hour to collect the data. Even if there are no trees or vegetation on your property, we would like to visit the site to complete the survey scientifically.

**To indicate your permission or denial for city forestry personnel to enter your property for this specific purpose, please email me at dstill@providenceri.com, or return the attached page with your signature.** If we do not hear from you by September 13, a forestry employee may contact you to request permission to access the property as well. Please contact me at 401-785-9450 x270 if you have any questions or concerns.

I very much appreciate your consideration in helping us with this important study!

Sincerely,

Douglas Still
City Forester

DEPARTMENT OF PARKS + RECREATION
Roger Williams Boathouse | 1000 Elmwood Avenue Providence, Rhode Island 02905
401 785 9450 ph | 401 941 5920 fax
www.providenceri.com

CITY OF PROVIDENCE
Angel Taveras, Mayor

# i-Tree Eco Tree Study
# Providence Forestry Division

**Name** __________________________________________

**Address** __________________________________________

☐ Yes, I hereby authorize City of Providence forestry personnel to access my property during September-October of 2013 for the purpose of collecting inventory data from trees on or adjoining my property.

☐ No, I do not want my trees or property included in this study.

**For further questions regarding the i-Tree Eco study, please call the Providence Forestry Division at 785-9450 x254.**

DEPARTMENT OF PARKS + RECREATION
Roger Williams Boathouse | 1000 Elmwood Avenue Providence, Rhode Island 02905
401 785 9450 ph | 401 941 5920 fax
www.providenceri.com

# APPENDIX IX

## Results: Providence's State of the Urban Forestry Report (2008)

**Providence Tree Tally, 2006**
**Key Findings**

- **24,999 street trees** (includes 409 dead trees)
- **The species are diverse** – over 95 different tree species
- Top species – Norway maple (18.8%), Callery Pear (11.6%), Green Ash (8.6%), Honeylocust (7.4%), London Planetree (7.0%), Red Maple (5.6%), Zelkova (4.4%)
- **More than 2/3 of street trees are in either excellent (23.2%) or good (48.9%) condition,** with 18.9% fair, 7.3% poor, and 1.6% dead.
- The trees are weighted toward the smaller size classes, **with 2/5 (39.9%) 6" in diameter or less, and nearly 2/3 (65.1%) 12" in diameter or less.** 27.6% of trees were 13-24" in diameter, and 7.2% were greater than 24" diameter.
- 41.5% of trees had utility wires located above (or through) them.
- 52.4% of planting spaces were sidewalk pits, while 47.6% were lawn strips or lawn areas.
- **The avg. size tree pit was 16.5 sf., and the avg. lawn strip width was 3.89 ft.**
- 16.2% of trees had some sort of infrastructure conflict threatening their health, led by close sidewalk pavement (12.0%).

- Providence's street trees provide **$2,932,731 in benefits annually.** ($118.23/tree)

| Total Annual Benefits of Street Trees, City of Providence | | | |
|---|---|---|---|
| **Benefit** | **Amount** | **Sub-Value** | **Total Value** |
| **Energy** | | | |
| Electricity saved | 1684 MWh | $202,132 | |
| Natural Gas saved | 633,812 therms | $1,026,528 | **$1,228,660** |
| **CO2** | | | |
| CO2 stored | 2,180 tons | $14,564 | |
| CO2 avoided | 2,527 tons | $16,945 | |
| CO2 released | 504 tons | ($3,367) | **$28,143** |
| **Air Quality** | | | |
| Pollution intercepted | 29 tons | $101,096 | |
| Pollution avoided | 12 tons | $101,863 | |
| BVOC pollution emitted | 2 tons | ($8,627) | **$194,334** |
| **Stormwater** | | | |
| Stormwater intercepted | 30.6 m. gallons | | **$244945** |
| **Aesthetic/Other** | | | |
| Incr. property values | | | **$1,236,649** |
| | | **TOTAL** | **$2,932,731** |

(Calculations obtained using STRATUM analysis software, U.S. Forest Service)

- **38,899 tons of carbon are stored** in Providence's street tree population.
- **For every dollar the City spends on trees, we are "paid back" $3.33 in benefits each year!!**
- **The replacement value** of Providence's street trees is **$81,855,622,** or $3,274 tree
- **Providence has 23% Urban Tree Canopy (UTC), and 52% Possible UTC**

Prepared by Douglas Still, January 15, 2008

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