i-Tree
Ecosystem Analysis

Atlanta

Urban Forest Effects and Values
July 2016

Summary

Understanding an urban forest's structure, function and value can promote management decisions that will improve human health and environmental quality. An assessment of the vegetation structure, function, and value of the Atlanta urban forest was conducted during 2013. Data from 443 field plots located throughout Atlanta were analyzed using the i-Tree Eco model developed by the U.S. Forest Service, Northern Research Station.

- Number of trees: 3,651,000
- Tree cover: 48.0 %
- Most common species of trees: Loblolly pine, Sweetgum, Water oak
- Percentage of trees less than 6" (15.2 cm) diameter: 37.1 %
- Pollution removal: 1,200 tons/year ($8.96 million/year)
- Carbon storage: 1,280,000 tons ($91.1 million)
- Carbon sequestration: 45,200 tons/year ($3.22 million/year)
- Oxygen production: 101,863 tons/year
- Avoided runoff: 94,113,538 cubic feet/year ($6.27 million/year)
- Building energy savings: $13,500,000/year
- Avoided carbon emissions: 23200 tons/year ($1,650,000/year)
- Structural values: $3.85 billion

Ton: short ton (U.S.) (2,000 lbs)
Monetary values $ are reported in US Dollars throughout the report except where noted
Ecosystem service estimates are reported for trees.

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

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I. Tree Characteristics of the Urban Forest

The urban forest of Atlanta has an estimated 3,651,000 trees with a tree cover of 48.0 percent. The three most common species are Loblolly pine (18.0 percent), Sweetgum (10.5 percent), and Water oak (7.1 percent).

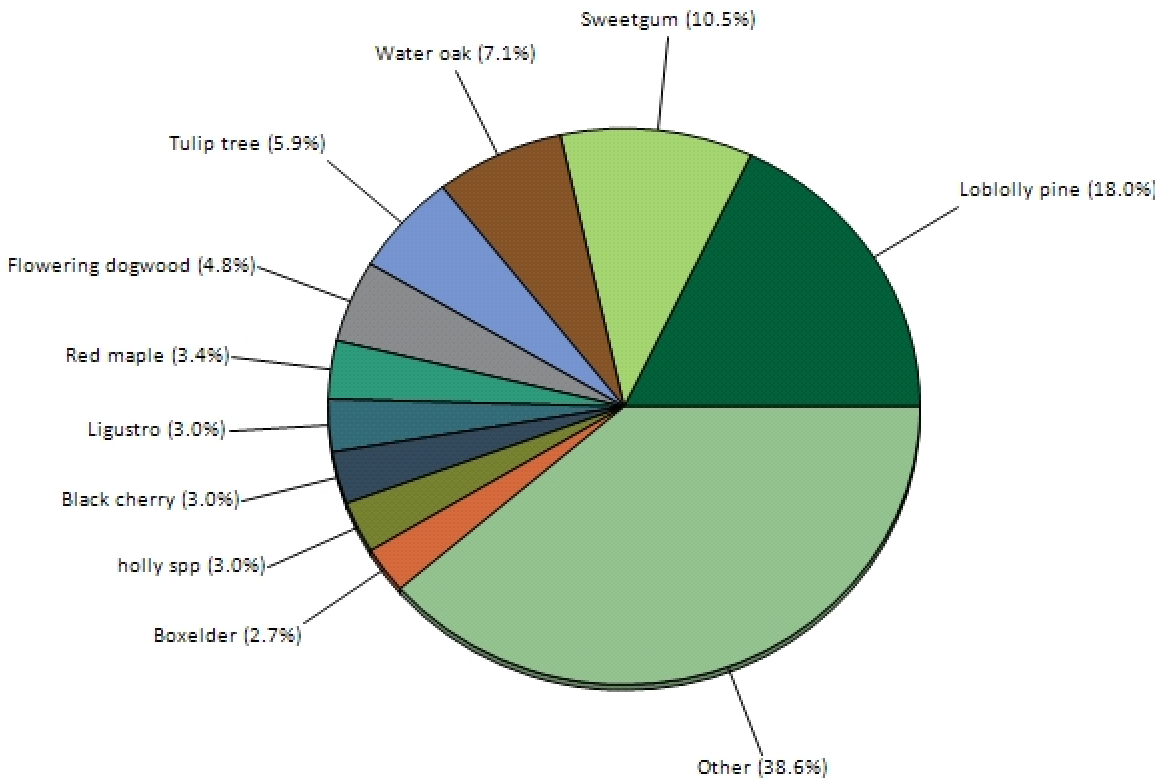


Figure 1. Tree species composition in Atlanta

The overall tree density in Atlanta is 43 trees/acre (see Appendix III for comparable values from other cities). For stratified projects, the highest tree densities in Atlanta occur in 60-100Canopy followed by 40-60%Canopy and 20-40%Canopy.

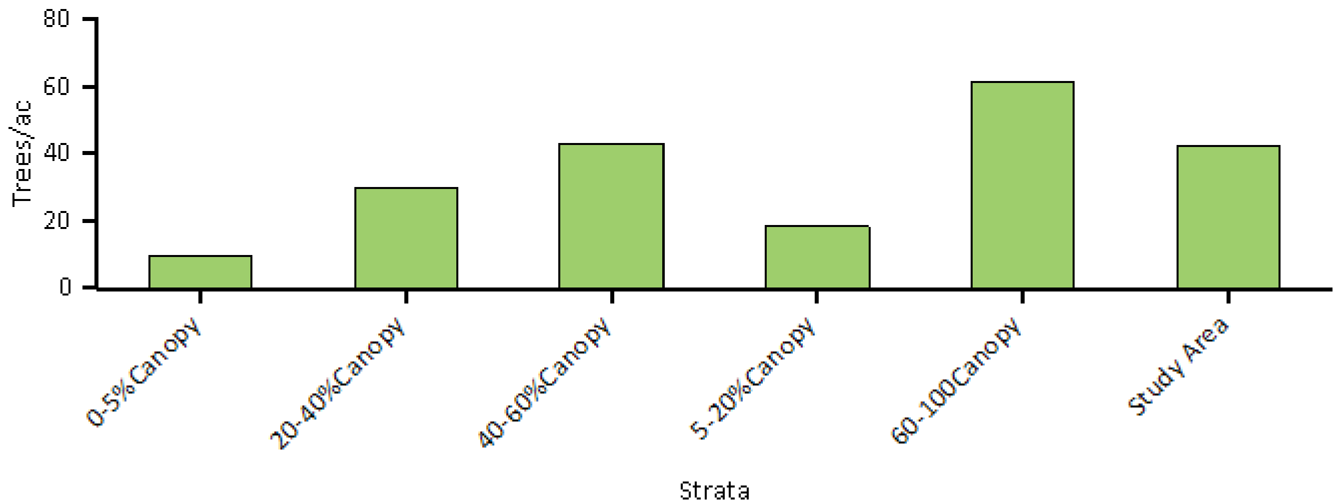


Figure 2. Number of trees/ac in Atlanta by strata

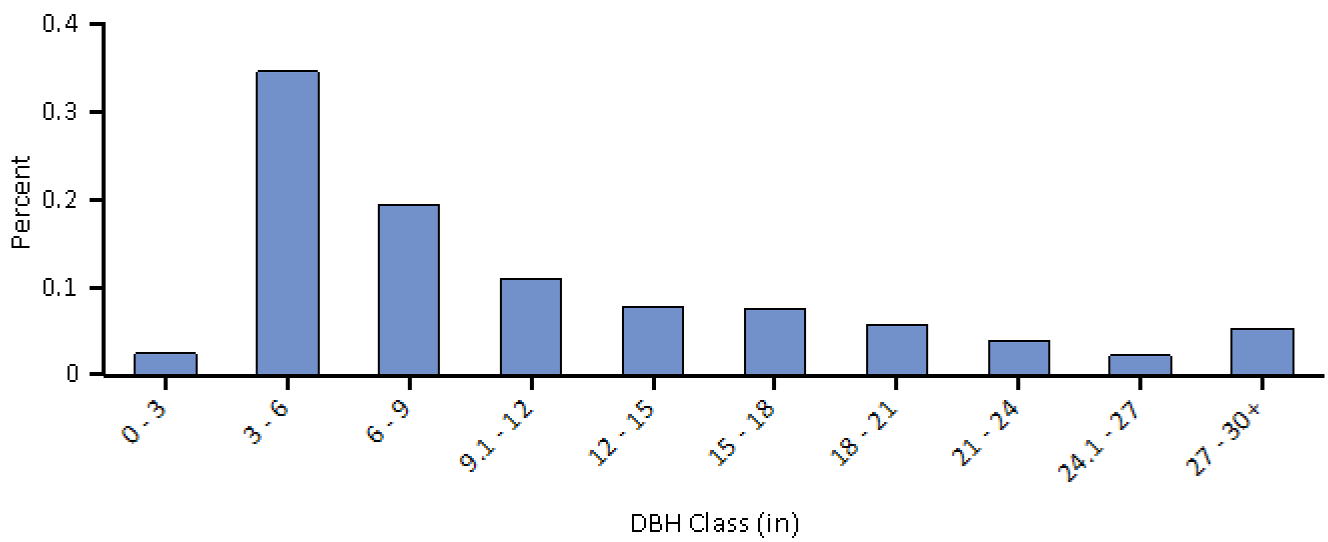


Figure 3. Percent of tree population by diameter class (DBH=stem diameter at 4.5 feet)

Urban forests are composed of a mix of native and exotic tree species. Thus, urban forests often have a tree diversity that is higher than surrounding native landscapes. 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 Atlanta, about 82 percent of the trees are species native to North America, while 76 percent are native to Georgia. Species exotic to North America make up 18 percent of the population. Most exotic tree species have an origin from Asia (12 percent of the species).

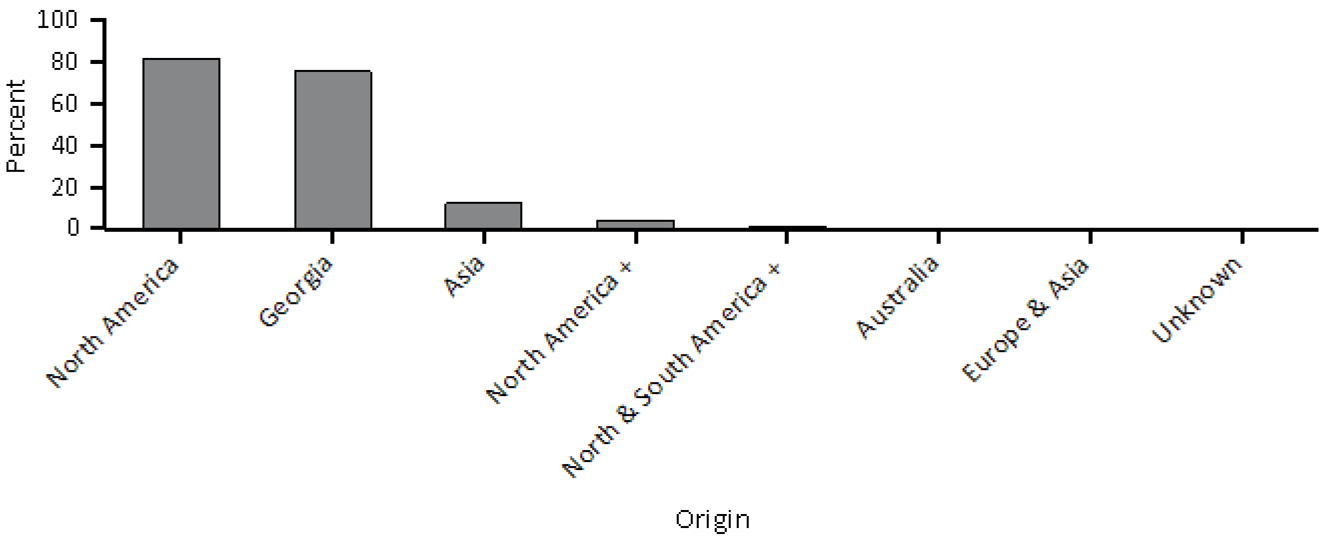


Figure 4. Percent of live tree population by area of native origin, Atlanta

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

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 (National Invasive Species Information Center 2011). Seven of the 100 tree species in Atlanta are identified as invasive on the state invasive species list (Georgia Exotic Pest Plant Council 2006). These invasive species comprise 5.5 percent of the tree population though they may only cause a minimal level of impact. The three most common invasive species are Ligustro (3.0 percent of population), Royal paulownia (0.7 percent), and Chinese privet (0.6 percent) (see Appendix V for a complete list of invasive species).

II. Urban Forest Cover and Leaf Area

Many tree benefits equate directly to the amount of healthy leaf surface area of the plant. Trees cover about 48.0 percent of Atlanta and provide 234.801 square miles of leaf area. Total leaf area is greatest in 40-60%Canopy followed by 60-100Canopy and 20-40%Canopy.

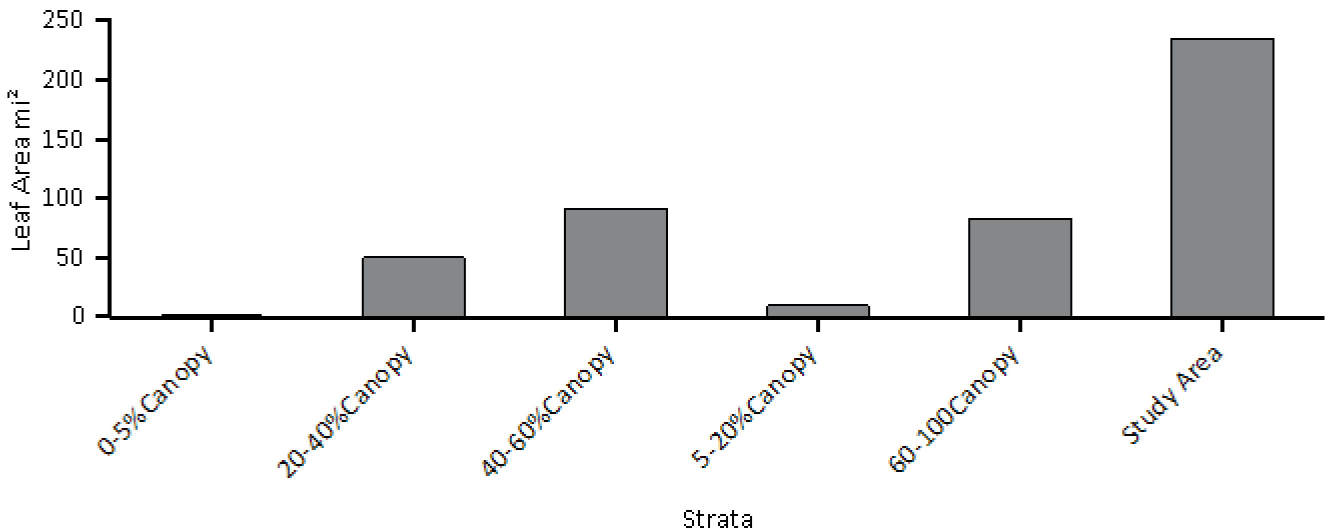


Figure 5. Leaf area by strata, Atlanta

In Atlanta, the most dominant species in terms of leaf area are Loblolly pine, Water oak, and Tulip tree. The 10 species with the greatest importance values are listed in Table 1. Importance values (IV) are calculated as the sum of percent population and percent leaf area. High importance values do not mean that these trees should necessarily be encouraged in the future; rather these species currently dominate the urban forest structure.

Table 1. Most important species in Atlanta

Species Name	*Percent Population*	*Percent Leaf Area*	*IV*
Loblolly pine	18.0	17.6	35.6
Water oak	7.1	15.8	22.9
Sweetgum	10.5	6.1	16.6
Tulip tree	5.9	6.1	12.0
Red maple	3.4	4.7	8.1
Pecan	2.5	5.0	7.6
Flowering dogwood	4.8	2.3	7.0
Southern magnolia	2.1	3.7	5.8
White oak	1.9	3.7	5.7
Black cherry	3.0	1.3	4.3

Common ground cover classes (including cover types beneath trees and shrubs) in Atlanta include buildings, duff/ mulch, rock, bare soil, and water, impervious covers such as tar, cement, and other, and herbaceous covers such as grass, herbs, and wild grass (Figure 6). The most dominant ground cover types are Grass (24.2 percent) and Tar (22.3 percent).

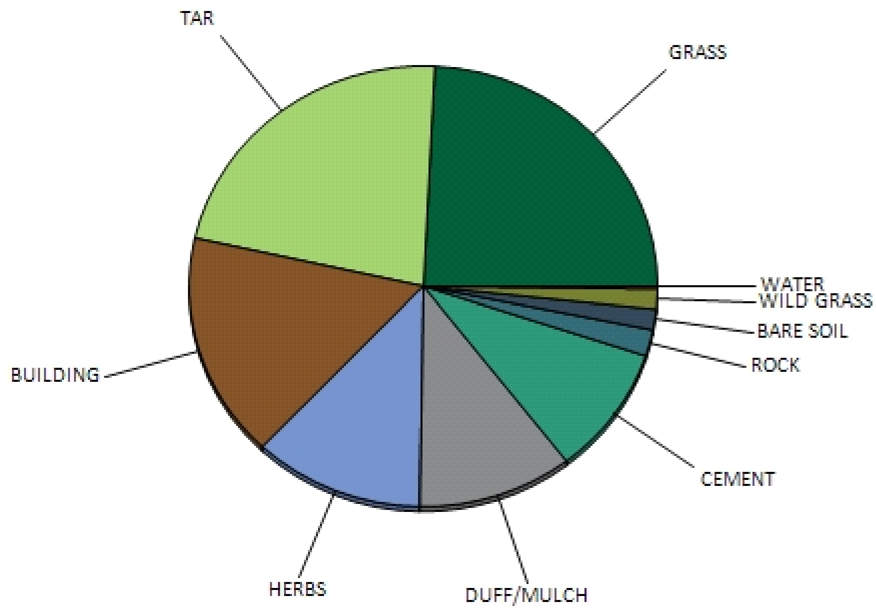


Figure 6. Percent of land by ground cover classes, Atlanta

III. Air Pollution Removal by Urban Trees

Poor air quality is a common problem in many urban areas. It can lead to decreased human health, damage to landscape materials and ecosystem processes, and reduced visibility. The urban forest can help improve air quality by reducing air temperature, directly removing pollutants from the air, and reducing energy consumption in buildings, which consequently reduces air pollutant emissions from the power sources. 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 (Nowak and Dwyer 2000).

Pollution removal[1] by trees and shrubs in Atlanta was estimated using field data and recent available pollution and weather data available. Pollution removal was greatest for ozone (Figure 7). It is estimated that trees and shrubs remove 1,202.959 tons of air pollution (ozone (O3), carbon monoxide (CO), nitrogen dioxide (NO2), particulate matter less than 2.5 microns (PM2.5)[2], and sulfur dioxide (SO2)) per year with an associated value of $8.96 million (see Appendix I for more details).

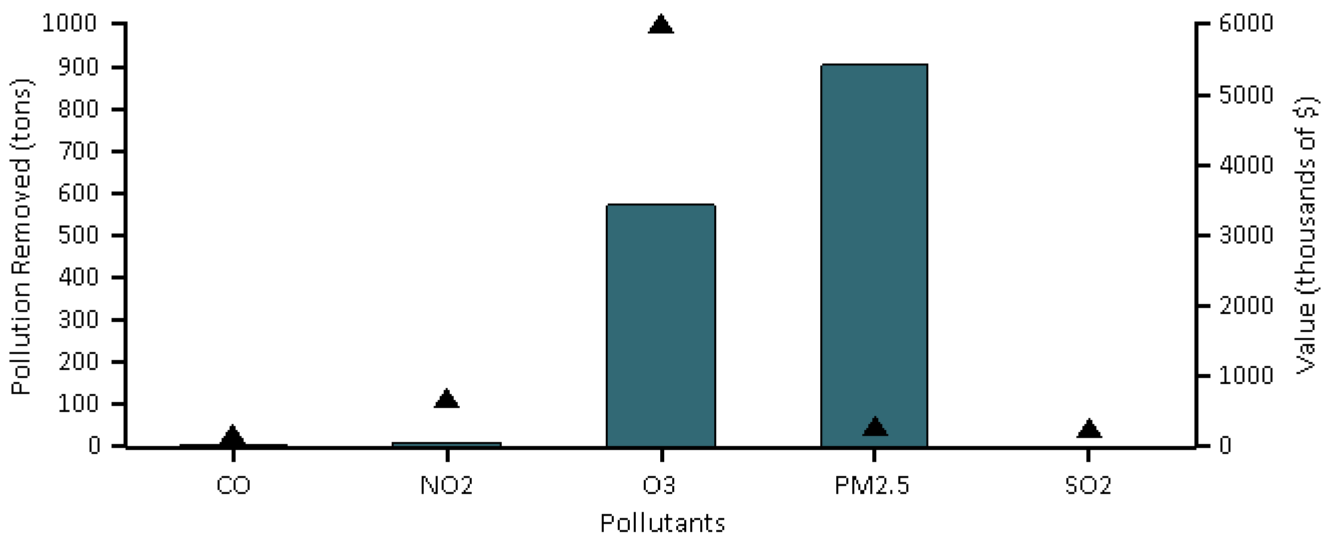


Figure 7. Annual pollution removal (points) and value (bars) by urban trees, Atlanta

[1] Particulate matter less than 10 microns is a significant air pollutant. Given that i-Tree Eco analyzes particulate matter less than 2.5 microns (PM2.5) which is a subset of PM10, PM10 has not been included in this analysis. PM2.5 is generally more relevant in discussions concerning air pollution effects on human health.

[2] Trees remove PM2.5 when particulate matter is deposited on leaf surfaces. This deposited PM2.5 can be resuspended to the atmosphere or removed during rain events and dissolved or transferred to the soil. This combination of events can lead to positive or negative pollution removal and value depending on various atmospheric factors (see Appendix I for more details).

In 2013, trees in Atlanta emitted an estimated 1,185.8 tons of volatile organic compounds (VOCs) (939.4 tons of isoprene and 246.3 tons of monoterpenes). Emissions vary among species based on species characteristics (e.g. some genera such as oaks are high isoprene emitters) and amount of leaf biomass. Fifty-four percent of the urban forest's VOC emissions were from Water oak and Sweetgum. These VOCs are precursor chemicals to ozone formation.[3]

General recommendations for improving air quality with trees are given in Appendix VIII.

[3] Some economic studies have estimated VOC emission costs. These costs are not included here as there is a tendency to add positive dollar estimates of ozone removal effects with negative dollar values of VOC emission effects to determine whether tree effects are positive or negative in relation to ozone. This combining of dollar values to determine tree effects should not be done, rather estimates of VOC effects on ozone formation (e.g., via photochemical models) should be conducted and directly contrasted with ozone removal by trees (i.e., ozone effects should be directly compared, not dollar estimates). In addition, air temperature reductions by trees have been shown to significantly reduce ozone concentrations (Cardelino and Chameides 1990; Nowak et al 2000), but are not considered in this analysis. Photochemical modeling that integrates tree effects on air temperature, pollution removal, VOC emissions, and emissions from power plants can be used to determine the overall effect of trees on ozone concentrations.

IV. Carbon Storage and Sequestration

Climate change is an issue of global concern. Urban trees can help mitigate climate change by sequestering atmospheric carbon (from carbon dioxide) in tissue and by altering energy use in buildings, and consequently altering carbon dioxide emissions from fossil-fuel based power sources (Abdollahi et al 2000).

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 Atlanta trees is about 45,200 tons of carbon per year with an associated value of $3.22 million. Net carbon sequestration in the urban forest is about 38,199 tons. See Appendix I for more details on methods.

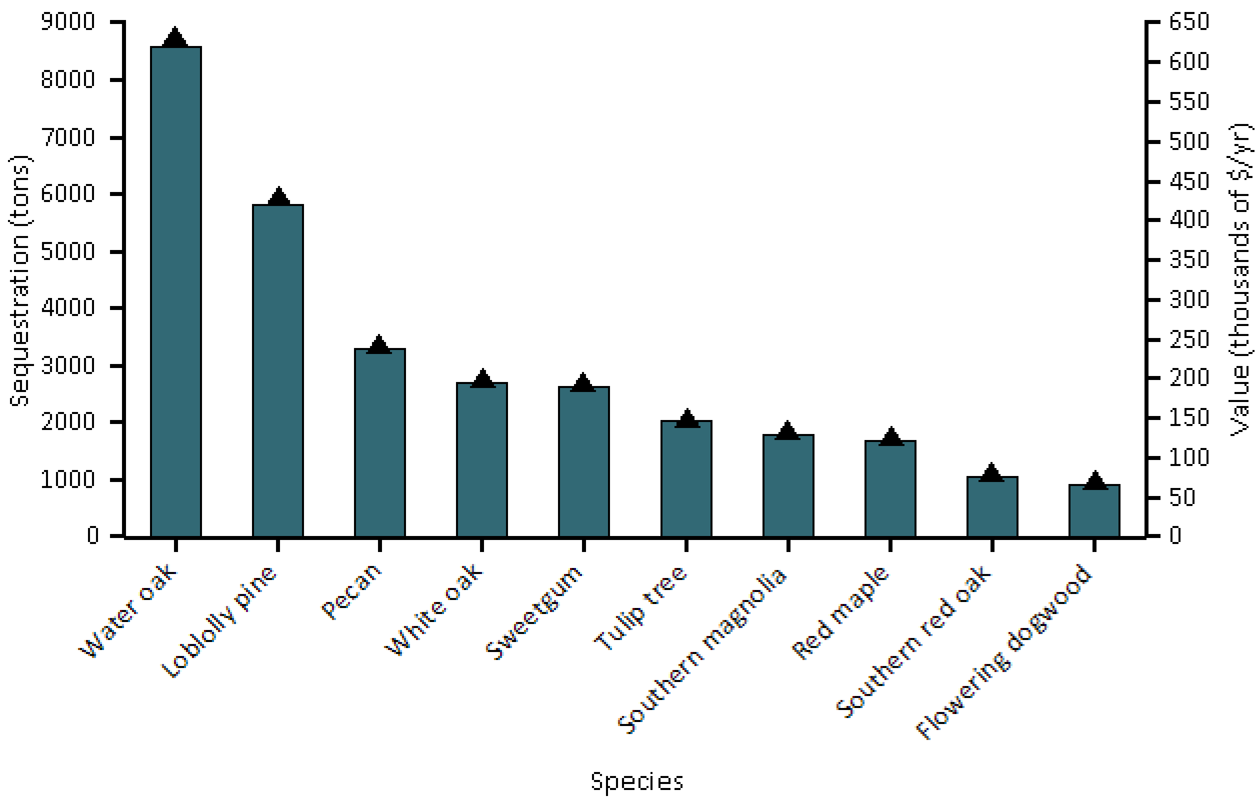


Figure 8. Estimated annual gross carbon sequestration (points) and value (bars) for urban tree species with the greatest sequestration, Atlanta

Carbon storage is another way trees can influence global climate change. As a tree grows, it stores more carbon by holding it in its accumulated tissue. As a tree dies and decays, it releases much of the stored carbon back into the atmosphere. Thus, carbon storage is an indication of the amount of carbon that can be released if trees are allowed to die and decompose. Maintaining healthy trees will keep the carbon stored in trees, but tree maintenance can contribute to carbon emissions (Nowak et al 2002c). When a tree dies, using the wood in long-term wood products, to heat buildings, or to produce energy will help reduce carbon emissions from wood decomposition or from fossil-fuel or wood-based power plants.

Trees in Atlanta are estimated to store 1,280,000 tons of carbon ($91.1 million). Of the species sampled, Water oak stores and sequesters the most carbon (approximately 27.4% of the total carbon stored and 19.2% of all sequestered carbon.)

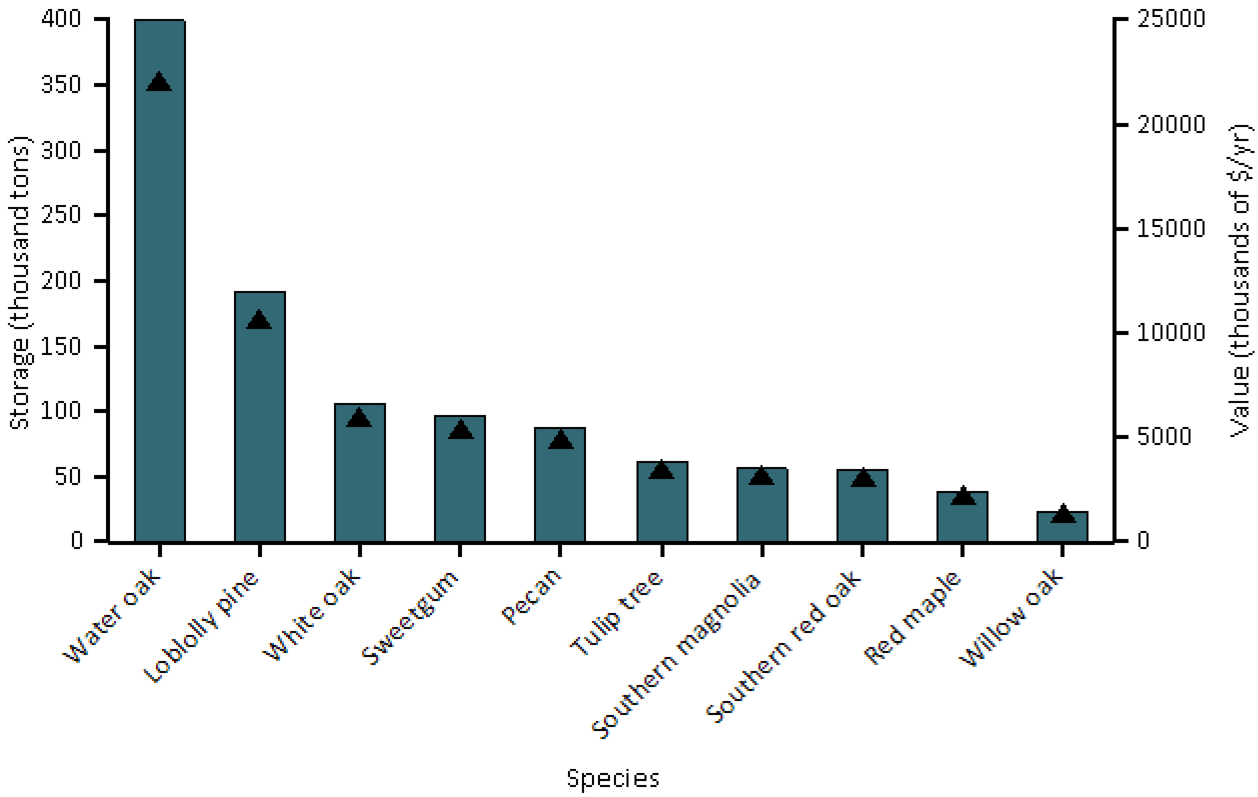


Figure 9. Estimated carbon storage (points) and values (bars) for urban tree species with the greatest storage, Atlanta

V. 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 Atlanta are estimated to produce 102,000 tons of oxygen per year.[4] 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 (Broecker 1970).

Table 2. The top 20 oxygen production species.

Species	*Oxygen (tons)*	*Net Carbon Sequestration (tons/yr)*	*Number of Trees*	*Leaf Area (square miles)*
Water oak	18,818.75	7,057.03	257,963	37.08
Loblolly pine	14,080.74	5,280.28	655,899	41.37
Pecan	7,913.38	2,967.52	91,928	11.84
Sweetgum	6,308.89	2,365.84	383,364	14.27
Tulip tree	4,838.56	1,814.46	215,355	14.33
White oak	4,500.33	1,687.63	71,171	8.76
Southern magnolia	4,242.72	1,591.02	77,043	8.57
Red maple	4,095.52	1,535.82	123,825	10.95
Southern red oak	2,315.98	868.49	33,589	4.10
Flowering dogwood	2,086.13	782.30	173,613	5.28
Common crapemyrtle	1,859.70	697.39	74,727	2.45
hickory spp	1,798.87	674.57	62,196	1.76
Willow oak	1,601.20	600.45	27,932	4.32
holly spp	1,561.36	585.51	109,858	1.46
Black cherry	1,559.47	584.80	110,604	2.98
River birch	1,481.33	555.50	22,876	3.35
Callery pear 'bradford'	1,424.40	534.15	24,420	1.86
Boxelder	1,388.37	520.64	98,557	3.39
Cherrybark oak	996.44	373.67	14,653	1.09
Northern red oak	889.32	333.49	12,089	1.58

[4] A negative estimate, or oxygen deficit, indicates that trees are decomposing faster than they are producing oxygen. This would be the case in an area that has a large proportion of dead trees.

VI. Avoided Runoff

Surface runoff can be a cause for concern in many urban areas as it can contribute pollution to streams, wetlands, rivers, lakes, and oceans. During precipitation events, some portion of the precipitation 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 (Hirabayashi 2012). In urban areas, the large extent of impervious surfaces increases the amount of surface runoff.

Urban trees and shrubs, however, are beneficial in reducing surface runoff. Trees and shrubs intercept precipitation, while their root systems promote infiltration and storage in the soil. The trees and shrubs of Atlanta help to reduce runoff by an estimated 94,100,000 cubic feet a year with an associated value of $6.3 million (see Appendix I for more details).

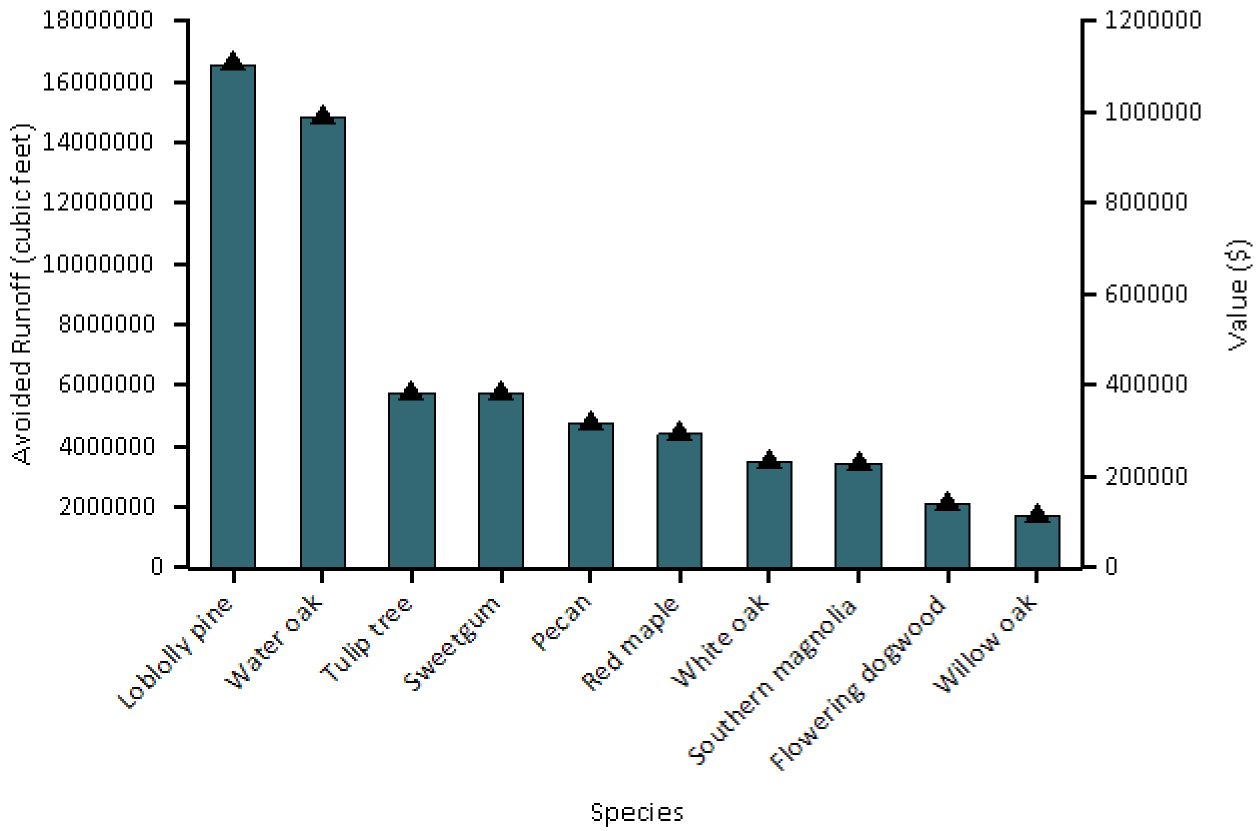


Figure 10. Avoided runoff (points) and value (bars) for species with greatest overall impact on runoff, Atlanta

VII. 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 (McPherson and Simpson 1999).

Trees in Atlanta are estimated to reduce energy-related costs from residential buildings by $13,500,000 annually. Trees also provide an additional $1,650,000 in value by reducing the amount of carbon released by fossil-fuel based power plants (a reduction of 23200 tons of carbon emissions).

Note: negative numbers indicate that there was not a reduction in carbon emissions and/or value, rather carbon emissions and values increased by the amount shown as a negative value.[5]

Table 3. Annual energy savings due to trees near residential buildings,Atlanta

	Heating	*Cooling*	*Total*
MBTU[a]	266,316	n/a	266,316
MWH[b]	5,166	87,129	92,295
Carbon avoided (ton)	5,095	18,072	23,167

[a]MBTU = one million British Thermal Units

[b]MWH = megawatt-hour

Table 4. Annual savings[a] ($) in residential energy expenditure during heating and cooling seasons, Atlanta

	Heating	*Cooling*	*Total*
MBTU[b]	3,709,872	n/a	3,709,872
MWH[c]	548,118	9,244,388	9,792,506
Carbon avoided	362,864	1,286,965	1,649,829

[b]Based on the prices of $106.10 per MWH and $13.93 per MBTU (see Appendix I for more details)

[c]MBTU = one million British Thermal Units

[c]MWH = megawatt-hour

[5] Trees modify climate, produce shade, and reduce wind speeds. Increased energy use or costs are likely due to these tree-building interactions creating a cooling effect during the winter season. For example, a tree (particularly evergreen species) located on the southern side of a residential building may produce a shading effect that causes increases in heating requirements.

VIII. 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 (Nowak et al 2002a). Annual functional values also tend to increase with increased number and size of healthy trees. 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.

Urban trees in Atlanta have the following structural values:

- Structural value: $3.85 billion
- Carbon storage: $91.1 million

Urban trees in Atlanta have the following annual functional values:

- Carbon sequestration: $3.22 million
- Avoided runoff: $6.27 million
- Pollution removal: $8.96 million
- Energy costs and carbon emission values: $15,200,000.00

(Note: negative value indicates increased energy cost and carbon emission value)

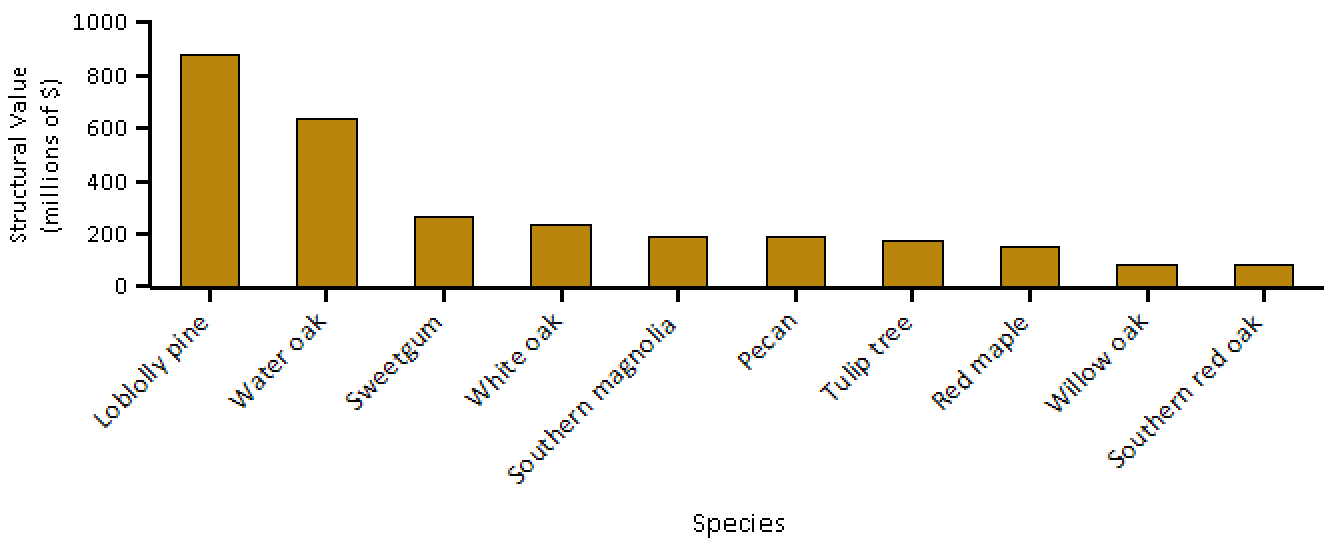


Figure 11. Tree species with the greatest structural value, Atlanta

IX. Potential Pest Impacts

Various insects and diseases can infest urban forests, potentially killing trees and reducing the health, structural 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. Thirty-six pests were analyzed for their potential impact and compared with pest range maps (Forest Health Technology Enterprise Team 2014) for the conterminous United States to determine their proximity to DeKalb County. Six of the thirty-six pests analyzed are located within the county. For a complete analysis of all pests, see Appendix VII.

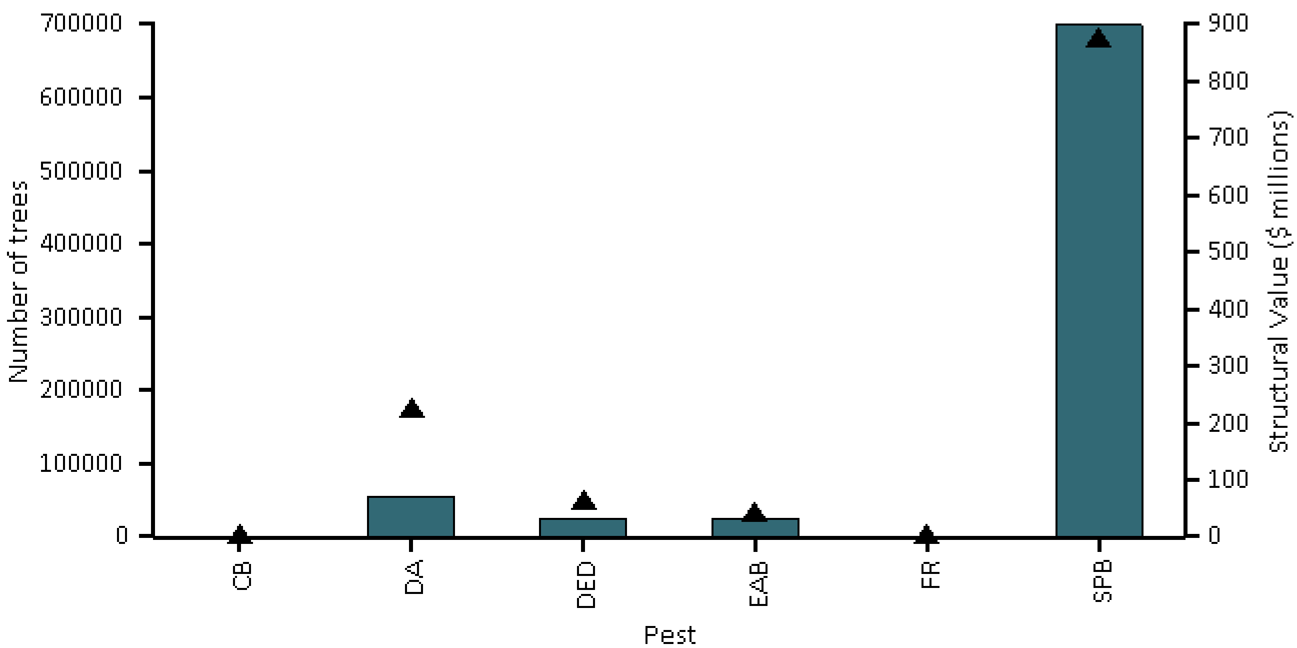


Figure 12. Number of trees at risk (points) and associated compensatory value (bars) for most threatening pests located in the county, Atlanta

The most common hosts of the fungus that cause chestnut blight (CB) (Diller 1965) are American and European chestnut. CB has the potential to affect 0.0 percent of the population ($0 in structural value).

Dogwood anthracnose (DA) (Mielke and Daughtrey) is a disease that affects dogwood species, specifically flowering and Pacific dogwood. This disease threatens 4.8 percent of the population, which represents a potential loss of $70.6 million in structural value.

American elm, one of the most important street trees in the twentieth century, has been devastated by the Dutch elm disease (DED) (Northeastern Area State and Private Forestry 1998). 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, Atlanta could possibly lose 1.3 percent of its trees to this pest ($31.3 million in structural value).

Emerald ash borer (EAB) (Michigan State University 2010) has killed thousands of ash trees in parts of the United States. EAB has the potential to affect 0.8 percent of the population ($31.7 million in structural value).

Fusiform rust (FR) (Phelps and Czabator 1978) is a fungal disease that is distributed in the southern United States. It is particularly damaging to slash pine and loblolly pine. FR has the potential to affect 0.0 percent of the population ($0 in structural value).

Although the southern pine beetle (SPB) (Clarke and Nowak 2009) will attack most pine species, its preferred hosts are loblolly, Virginia, pond, spruce, shortleaf, and sand pines. This pest threatens 18.6 percent of the population, which represents a potential loss of $899 million in structural value.

Appendix I. i-Tree Eco Model and Field Measurements

i-Tree Eco is designed to use standardized field data from randomly located plots and local hourly air pollution and meteorological data to quantify urban forest structure and its numerous effects (Nowak and Crane 2000), including:

- Urban forest structure (e.g., species composition, tree health, leaf area, etc.).
- Amount of pollution removed hourly by the urban forest, and its associated percent air quality improvement throughout a year.
- Total carbon stored and net carbon annually sequestered by the urban forest.
- Effects of trees on building energy use and consequent effects on carbon dioxide emissions from power sources.
- 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.

Typically, all field data are collected during the leaf-on season to properly assess tree canopies. Typical data collection (actual data collection may vary depending upon the user) includes land use, ground and tree cover, individual tree attributes of species, stem diameter, height, crown width, crown canopy missing and dieback, and distance and direction to residential buildings (Nowak et al 2005; Nowak et al 2008).

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

<u>Tree Characteristics:</u>

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

An analysis of invasive species is not available for studies outside of the United States. For the U.S., invasive species are identified using an invasive species list (Georgia Exotic Pest Plant Council 2006)for the state in which the urban forest is located. These lists are not exhaustive and they cover invasive species of varying degrees of invasiveness and distribution. In instances where a state did not have an invasive species list, a list was created based on the lists of the adjacent states. Tree species that are identified as invasive by the state invasive species list are cross-referenced with native range data. This helps eliminate species that are on the state invasive species list, but are native to the study area.

<u>Air Pollution Removal:</u>

Pollution removal is calculated for ozone, sulfur dioxide, nitrogen dioxide, carbon monoxide and particulate matter less than 2.5 microns. Particulate matter less than 10 microns (PM10) is another significant air pollutant. Given that i-Tree Eco analyzes particulate matter less than 2.5 microns (PM2.5) which is a subset of PM10, PM10 has not been included in this analysis. PM2.5 is generally more relevant in discussions concerning air pollution effects on human health.

Air pollution removal estimates are derived from calculated hourly tree-canopy resistances for ozone, and sulfur and nitrogen dioxides based on a hybrid of big-leaf and multi-layer canopy deposition models (Baldocchi 1988; Baldocchi et al 1987). As the removal of carbon monoxide and particulate matter by vegetation is not directly related to transpiration, removal rates (deposition velocities) for these pollutants were based on average measured values from the literature (Bidwell and Fraser 1972; Lovett 1994) that were adjusted depending on leaf phenology and leaf area.

Particulate removal incorporated a 50 percent resuspension rate of particles back to the atmosphere (Zinke 1967). Recent updates (2011) to air quality modeling are based on improved leaf area index simulations, weather and pollution processing and interpolation, and updated pollutant monetary values (Hirabayashi et al 2011; Hirabayashi et al 2012; Hirabayashi 2011).

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

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

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

For this analysis, pollution removal value is calculated based on the prices of $1,469 per ton (carbon monoxide), $3,450 per ton (ozone), $655 per ton (nitrogen dioxide), $194 per ton (sulfur dioxide), $129,505 per ton (particulate matter less than 2.5 microns).

<u>Carbon Storage and Sequestration:</u>

Carbon storage is the amount of carbon bound up in the above-ground and below-ground parts of woody vegetation. To calculate current carbon storage, biomass for each tree was calculated using equations from the literature and measured tree data. Open-grown, maintained trees tend to have less biomass than predicted by forest-derived biomass equations (Nowak 1994). To adjust for this difference, biomass results for open-grown urban trees were multiplied by 0.8. No adjustment was made for trees found in natural stand conditions. Tree dry-weight biomass was converted to stored carbon by multiplying by 0.5.

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

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

For this analysis, carbon storage and carbon sequestration values are calculated based on $71.2 per ton.

Oxygen Production:

The amount of oxygen produced is estimated from carbon sequestration based on atomic weights: net O_2 release (kg/yr) = net C sequestration (kg/yr) × 32/12. To estimate the net carbon sequestration rate, the amount of carbon sequestered as a result of tree growth is reduced by the amount lost resulting from tree mortality. Thus, net carbon sequestration and net annual oxygen production of the urban forest account for decomposition (Nowak et al 2007). For complete inventory projects, oxygen production is estimated from gross carbon sequestration and does not account for decomposition.

Avoided Runoff:

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

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

Building Energy Use:

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

For this analysis, energy saving value is calculated based on the prices of $106.10 per MWH and $13.93 per MBTU.

Structural Values:

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

Potential Pest Impacts:

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

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

Relative Tree Effects:

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

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

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

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

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

Appendix II. Relative Tree Effects

The urban forest in Atlanta provides benefits that include carbon storage and sequestration, and air pollutant removal. To estimate the relative value of these benefits, tree benefits were compared to estimates of average municipal carbon emissions, average passenger automobile emissions, and average household emissions. See Appendix I for methodology.

Carbon storage is equivalent to:

- Amount of carbon emitted in Atlanta in 210 days
- Annual carbon (C) emissions from 905,000 automobiles
- Annual C emissions from 371,000 single-family houses

Carbon monoxide removal is equivalent to:

- Annual carbon monoxide emissions from 216 automobiles
- Annual carbon monoxide emissions from 596 single-family houses

Nitrogen dioxide removal is equivalent to:

- Annual nitrogen dioxide emissions from 15,300 automobiles
- Annual nitrogen dioxide emissions from 6,890 single-family houses

Sulfur dioxide removal is equivalent to:

- Annual sulfur dioxide emissions from 398,000 automobiles
- Annual sulfur dioxide emissions from 1,050 single-family houses

Annual carbon sequestration is equivalent to:

- Amount of carbon emitted in Atlanta in 7.4 days
- Annual C emissions from 32,000 automobiles
- Annual C emissions from 13,100 single-family houses

Appendix III. Comparison of Urban Forests

A common question asked is, "How does this city compare to other cities?" Although comparison among cities should be made with caution as there are many attributes of a city that affect urban forest structure and functions, summary data are provided from other cities analyzed using the i-Tree Eco model.

I. City totals for trees

City	% Tree Cover	Number of trees	Carbon Storage (tons)	Carbon Sequestration (tons/yr)	Pollution removal (tons/yr)
Calgary, Canada	7.2	11,889,000	445,333	21,385	326
Atlanta, GA	36.8	9,415,000	1,344,818	46,407	1,662
Toronto, Canada	20.5	7,542,000	992,079	40,345	1,213
New York, NY	21.0	5,212,000	1,351,432	42,329	1,677
Baltimore, MD	21.0	2,627,000	596,350	16,094	430
Philadelphia, PA	15.7	2,113,000	530,211	16,094	577
Washington, DC	28.6	1,928,000	522,495	16,094	418
Boston, MA	22.3	1,183,000	318,568	10,472	284
Woodbridge, NJ	29.5	986,000	159,835	5,512	211
Minneapolis, MN	26.5	979,000	250,224	8,929	305
Syracuse, NY	23.1	876,000	173,063	5,401	109
Morgantown, WV	35.9	661,000	93,696	2,976	66
Moorestown, NJ	28.0	583,000	116,845	3,748	118
Jersey City, NJ	11.5	136,000	20,944	882	41
Freehold, NJ	34.4	48,000	19,842	551	21

II. Per acre values of tree effects

City	No. of trees/acre	Carbon Storage (tons/acre)	Carbon Sequestration (tons/yr/acre)	Pollution removal (tons/yr/acre)
Calgary, Canada	66.7	2.50	0.06	1.8
Atlanta, GA	111.6	15.90	0.28	19.7
Toronto, Canada	48.3	6.40	0.13	7.8
New York, NY	26.4	6.80	0.11	8.5
Baltimore, MD	50.8	10.43	0.14	7.5
Philadelphia, PA	25.0	6.30	0.09	6.8
Washington, DC	49.0	13.30	0.21	10.6
Boston, MA	33.5	9.00	0.15	8.0
Woodbridge, NJ	66.5	10.80	0.19	14.2
Minneapolis, MN	26.2	6.70	0.12	8.2
Syracuse, NY	54.5	10.80	0.17	6.8
Morgantown, WV	119.7	17.00	0.27	11.9
Moorestown, NJ	62.0	12.50	0.20	12.6
Jersey City, NJ	14.3	2.20	0.05	4.3
Freehold, NJ	38.5	16.00	0.22	16.8

Appendix IV. General Recommendations for Air Quality Improvement

Urban vegetation can directly and indirectly affect local and regional air quality by altering the urban atmosphere environment. Four main ways that urban trees affect air quality are (Nowak 1995):

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

The cumulative and interactive effects of trees on climate, pollution removal, and VOC and power plant emissions determine the impact of trees on air pollution. Cumulative studies involving urban tree impacts on ozone have revealed that increased urban canopy cover, particularly with low VOC emitting species, leads to reduced ozone concentrations in cities (Nowak 2000). Local urban management decisions also can help improve air quality.

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

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

Appendix V. Invasive Species of the Urban Forest

The following inventoried tree species were listed as invasive on the Georgia invasive species list (Georgia Exotic Pest Plant Council 2006):

Species Name[a]	*Number of trees*	*% Tree Number*	*Leaf Area (mi^2)*	*% Leaf Area*
Ligustro	111,302	3.05	0.62	0.26
Royal paulownia	25,827	0.71	0.64	0.27
Chinese privet	22,516	0.62	0.37	0.16
Mimosa	19,409	0.53	0.67	0.29
Tree of heaven	16,382	0.45	0.64	0.27
Callery pear	3,401	0.09	0.22	0.09
Chinaberry	1,086	0.03	0.07	0.03
Total	**199,923**	**5.48**	**3.24**	**1.38**

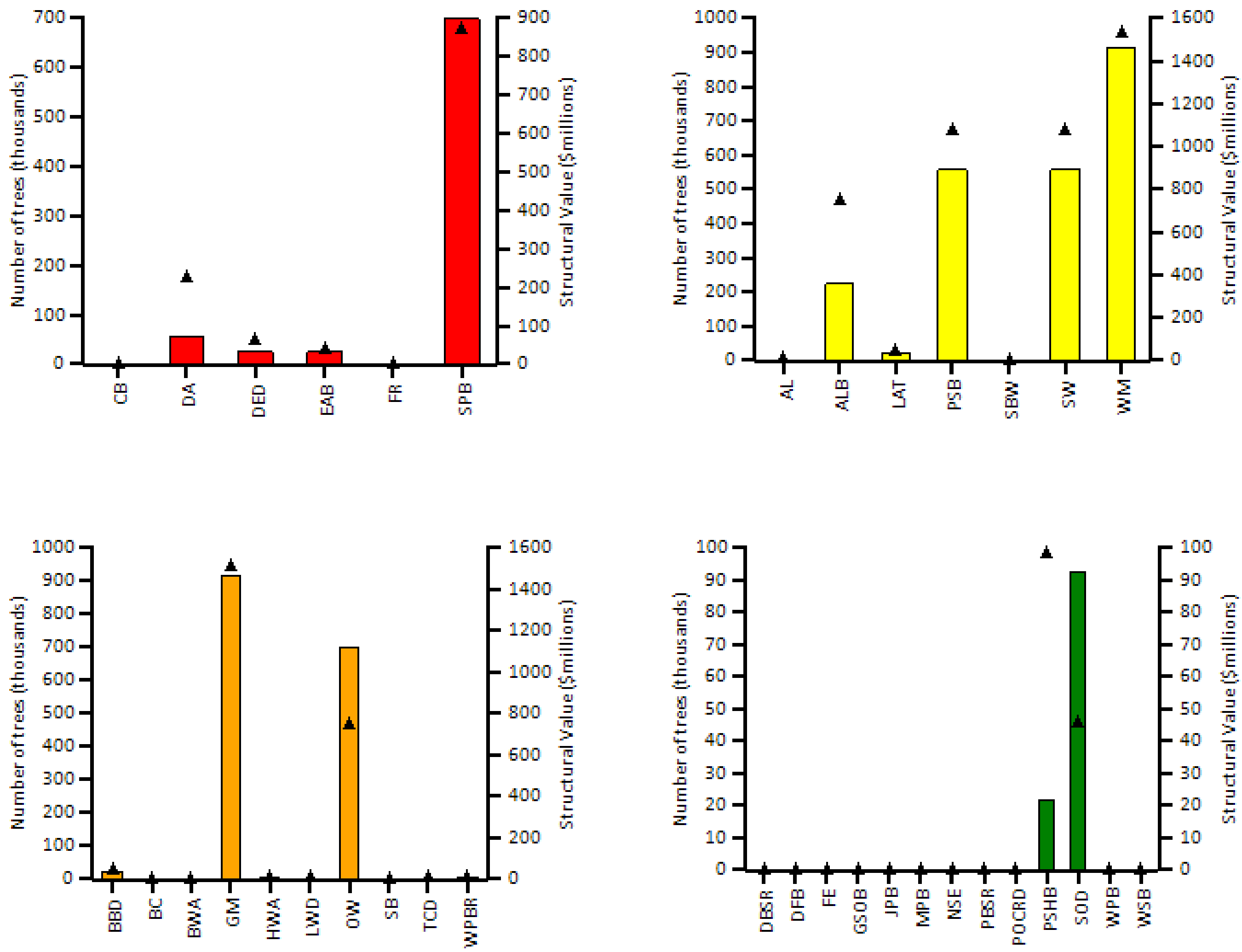
[a]Species are determined to be invasive if they are listed on the state's invasive species list

Appendix VI. Potential Risk of Pests

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

Code	Scientific Name	Common Name	Trees at Risk (#)	Value ($ millions)
AL	Phyllocnistis populiella	Aspen Leafminer	3,663	3
ALB	Anoplophora glabripennis	Asian Longhorned Beetle	468,835	357
BBD	Neonectria faginata	Beech Bark Disease	28,757	36
BC	Sirococcus clavigignenti juglandacearum	Butternut Canker	0	0
BWA	Adelges piceae	Balsam Woolly Adelgid	0	0
CB	Cryphonectria parasitica	Chestnut Blight	0	0
DA	Discula destructiva	Dogwood Anthracnose	173,613	71
DBSR	Leptographium wageneri var. pseudotsugae	Douglas-fir Black Stain Root Disease	0	0
DED	Ophiostoma novo-ulmi	Dutch Elm Disease	47,776	31
DFB	Dendroctonus pseudotsugae	Douglas-Fir Beetle	0	0
EAB	Agrilus planipennis	Emerald Ash Borer	29,123	32
FE	Scolytus ventralis	Fir Engraver	0	0
FR	Cronartium quercuum f. sp. Fusiforme	Fusiform Rust	0	0
GM	Lymantria dispar	Gypsy Moth	943,345	1,467
GSOB	Agrilus auroguttatus	Goldspotted Oak Borer	0	0
HWA	Adelges tsugae	Hemlock Woolly Adelgid	7,431	6
JPB	Dendroctonus jeffreyi	Jeffrey Pine Beetle	0	0
LAT	Choristoneura conflictana	Large Aspen Tortrix	26,539	37
LWD	Raffaelea lauricola	Laurel Wilt	7,326	1
MPB	Dendroctonus ponderosae	Mountain Pine Beetle	0	0
NSE	Ips perturbatus	Northern Spruce Engraver	0	0
OW	Ceratocystis fagacearum	Oak Wilt	465,412	1,119
PBSR	Leptographium wageneri var. ponderosum	Pine Black Stain Root Disease	0	0
POCRD	Phytophthora lateralis	Port-Orford-Cedar Root Disease	0	0
PSB	Tomicus piniperda	Pine Shoot Beetle	670,918	893
PSHB	Euwallacea nov. sp.	Polyphagous Shot Hole Borer	98,557	22
SB	Dendroctonus rufipennis	Spruce Beetle	0	0
SBW	Choristoneura fumiferana	Spruce Budworm	0	0
SOD	Phytophthora ramorum	Sudden Oak Death	45,678	92
SPB	Dendroctonus frontalis	Southern Pine Beetle	678,349	899
SW	Sirex noctilio	Sirex Wood Wasp	670,918	893
TCD	Geosmithia morbida	Thousand Canker Disease	5,416	4
WM	Operophtera brumata	Winter Moth	956,482	1,466
WPB	Dendroctonus brevicomis	Western Pine Beetle	0	0
WPBR	Cronartium ribicola	White Pine Blister Rust	3,663	10
WSB	Choristoneura occidentalis	Western Spruce Budworm	0	0

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



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

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

Spp. Risk	Risk Weight	Species Name	AL	ALB	BBD	BC	BWA	CB	DA	DBSR	DED	DFB	EAB	FE	FR	GM	GSOB	HWA	JPB	LAT	LWD	MPB	NSE	OW	PBSR	POCRD	PSB	PSHB	SB	SBW	SOD	SPB	SW	TCD	WM	WPB	WPBR	WSB
	11	Eastern white pine																																				
	9	Southern red oak																																				
	9	River birch																																				
	9	Northern red oak																																				
	9	Weeping willow																																				
	8	Loblolly pine																																				
	8	Water oak																																				
	8	White oak																																				
	8	Willow oak																																				
	8	Winged elm																																				
	8	Cherrybark oak																																				
	8	American elm																																				
	8	Shortleaf pine																																				
	8	Shumard oak																																				
	8	Post oak																																				
	8	Live oak																																				
	8	Slippery elm																																				
	8	Scarlet oak																																				
	7	Eastern hemlock																																				
	6	White ash																																				
	6	Texas red oak																																				
	6	elm spp																																				
	6	oak spp																																				
	6	Sawtooth oak																																				
	5	Boxelder																																				
	5	Chinese elm																																				
	5	American basswood																																				
	4	Flowering dogwood																																				
	4	Red maple																																				
	4	Florida maple																																				
	4	Sugar maple																																				
	4	Silver maple																																				
	4	Black maple																																				
	4	ash spp																																				
	3	Sweetgum																																				
	3	American beech																																				

	3	Callery pear 'Bradford'
	3	Eastern hophornbeam
	3	Sassafras
	3	Black walnut
	3	Parsley hawthorn
	3	Callery pear
	3	European beech
	3	Smooth sumac
	3	crabapple
	2	Black cherry
	2	Trident maple
	2	Japanese maple
	2	Mimosa

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

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