i-Tree
Ecosystem Analysis

Austin 2014 Public Trees

Urban Forest Effects and Values
October 2014

Report generated by iTree Eco
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Summary

In June of 2013 City of Austin Council passed resolution CR 20130627-070 requesting a report on ecosystem functions, services, and benefits provided by green infrastructure generally and the urban forest in particular. i-Tree Eco, a program provided by the USDA Forest Service, has been a popular tool for answering the above questions used by many municipalities in the United States as well as globally.

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 Austin urban forest was conducted during 2013-14. Data collected from 80 public field plots located throughout Austin were analyzed using the i-Tree Eco model developed by the U.S. Forest Service, Northern Research Station. Approximately 10 plots occurred on Balcones Canyonland Preserve properties.

- Number of trees: 7,292,000
- Tree cover: 38.0%
- Most common species: Ashe juniper, Plateau live oak, Cedar elm
- Percentage of trees less than 6" (15.2 cm) diameter: 58.0%
- Pollution removal: 781 metric tons/year ($4.17 million/year)
- Carbon storage: 467,000 metric tons ($36.7 million)
- Carbon sequestration: 38,400 metric tons/year ($3.02 million/year)
- Oxygen production: 75,000 metric tons/year ($0 /year)
- Avoided runoff: 1,105,000 cubic meters/year ($2.60 million/year)
- Building energy savings: $721 thousand/year
- Avoided carbon emissions: $97.2 thousand/year
- Structural values: $4.41 billion

Metric Ton: 1000 kilograms
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 $78 per metric 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 $1253 per metric ton (carbon monoxide), $1408 per metric ton (ozone), $314 per metric ton (nitrogen dioxide), $86 per metric ton (sulfur dioxide), $9206 per metric ton (particulate matter less than 10 microns and greater than 2.5 microns), $65320 per metric ton (particulate matter less than 2.5 microns)
Energy saving value is calculated based on the prices of $114.9 per MWH and $10.15 per MBTU
Monetary values ($) are reported in US Dollars throughout the report except where noted

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.

Materials and Methods

80 public plots within City of Austin jurisdiction were pre-stratified and generated using ESRI's ArcGIS program and following the protocol in the i-Tree Eco manual [64]. Of these 80 public plots 10 occurred on 6 Balcones Canyonland Preserve lands.

Plots were visited and assess using methods as described in the i-Tree Eco manual [64].

- 50m Nylon-clad steel tape from CST/berger
- Forestry suppliers Inc. 8m DBH tape
- Red and white ground stakes
- Suunto M3 compass
- TruPulse 200 Laser rangefinder
- ArcGIS 10.0
- I-Tree Eco v5.0

Balcones Canyonland Preserve Plot Locations:

Kent Butler Ecological Reserve

Plot ID: 46*	Latitude:	30 23 19.08115
	Longitude:	97 49 11.04864
Plot ID: 48	Latitude:	30 24 05.99481
	Longitude:	97 48 47.73895
Plot ID: 65	Latitude:	30 23 42.22167
	Longitude:	97 48 25.71323

Forest Ridge/Bull Creek Park

Plot ID: 57	Latitude:	30 23 6.14504
	Longitude:	97 47 5.74763
Plot ID: 60*	Latitude:	30 23 7.27925
	Longitude:	97 46 47.85165

Emma Long Metro Park

Plot ID: 49	Latitude:	30 20 56.96137
	Longitude:	97 50 22.79922

Park West

Plot ID: 54	Latitude:	30 24 5.99481
	Longitude:	97 48 47.73895
Plot ID: 61	Latitude:	30 22 47.22500
	Longitude:	97 50 23.26926

Vireo Research Area

Plot ID: 58	Latitude:	30 18 56.90727
	Longitude:	97 49 5.57904

Long Canyon

Plot ID: 59	Latitude:	30 22 42.46992
	Longitude:	97 49 59.57345

***Plots not visited**

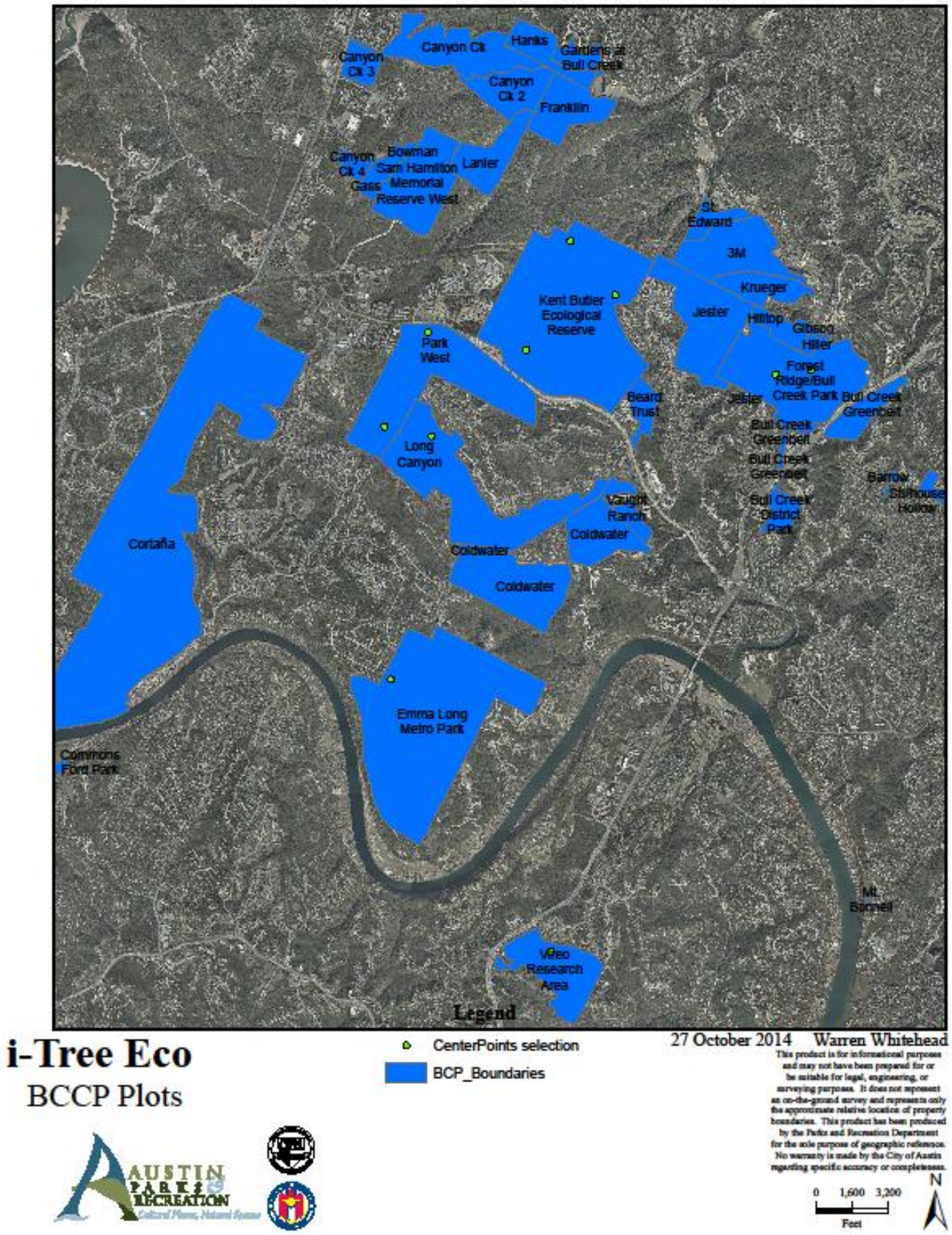

Figure A. Map of 10 Plot locations within Balcones Canyonland Preserves.

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I. Tree Characteristics of the Urban Forest

The public urban forest of Austin has an estimated 7,292,000 trees with a tree cover of 38.0 percent. Trees that have diameters less than 6-inches (15.2 cm) constitute 58.0 percent of the population. The three most common species are Ashe juniper (59.2 percent), Plateau live oak (10.0 percent), and Cedar elm (6.5 percent).

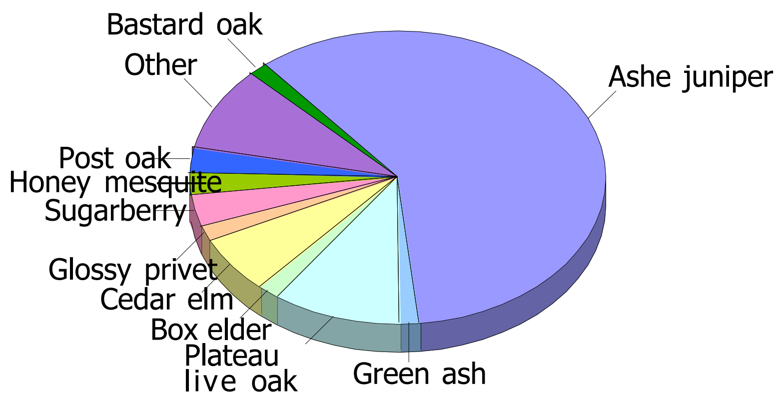

Figure 1. Tree species composition in Austin

The overall tree density in Austin is 319 trees/hectare (see Appendix III for comparable values from other cities).

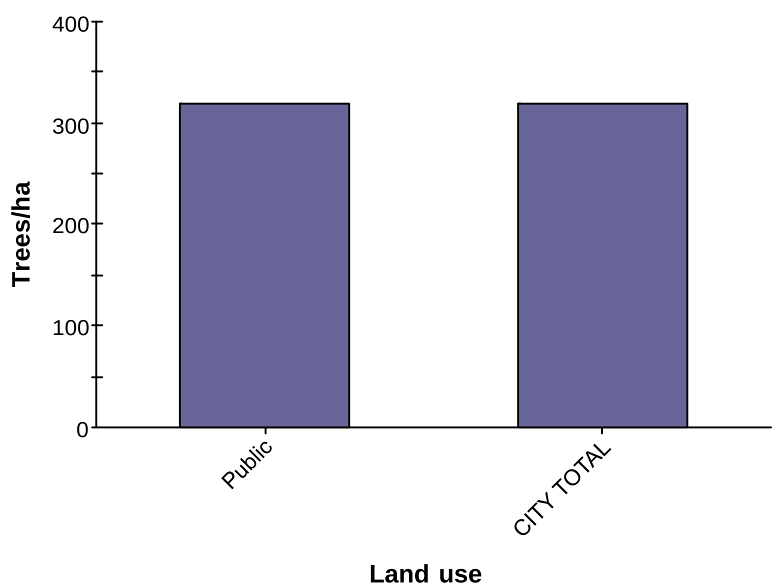

Figure 2. Number of trees/ha in Austin by land use

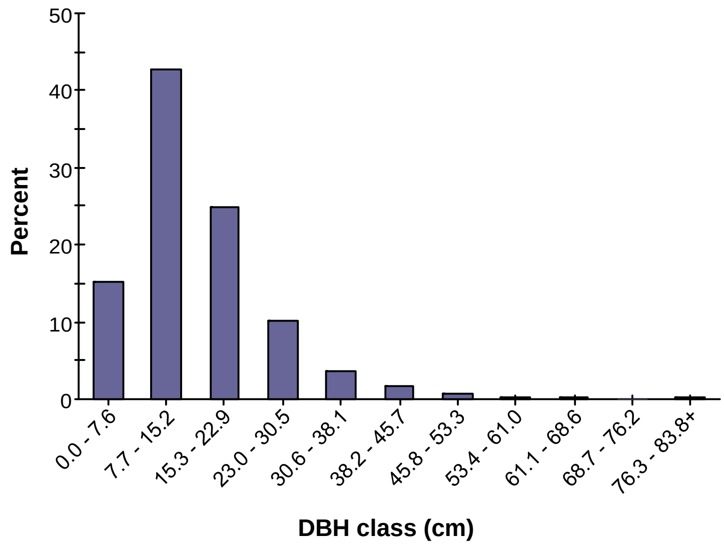

Figure 3. Percent of tree population by diameter class (DBH=stem diameter at 1.37 meter)

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 Austin, about 84 percent of the trees are species native to North America, while 78 percent are native to the state or district. Species exotic to North America make up 17 percent of the population. Most exotic tree species have an origin from Unknown (12.1 percent of the species).

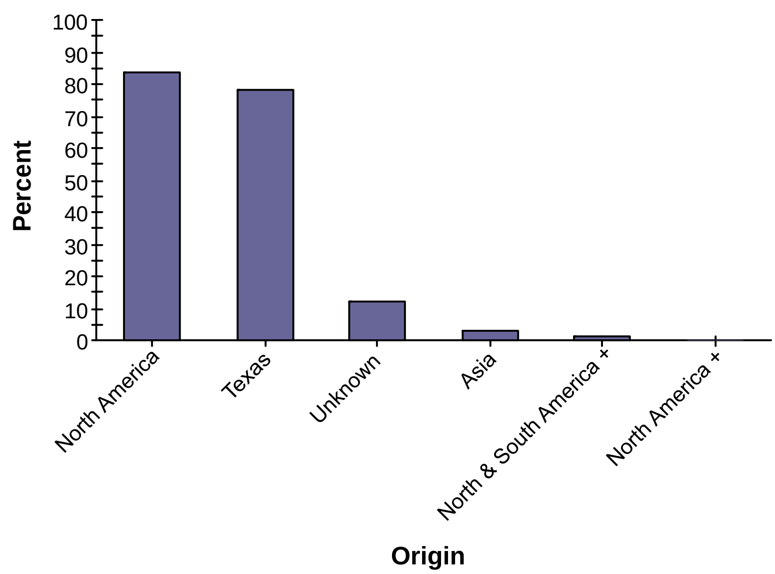

Figure 4. Percent of live trees by species origin

The plus sign (+) indicates the plant 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 [1]. Two of the 34 tree species sampled in Austin are identified as invasive on the state invasive species list [2]. These invasive species comprise 1.7 percent of the tree population though they may only cause a minimal level of impact. These two invasive species are Chinaberry (1.1 percent of population), and Tree of heaven (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. In Austin, the most dominant species in terms of leaf area are Ashe juniper, Plateau live oak, and Cedar elm. Trees cover about 38 percent of Austin based on public land estimates.

The 10 most important species are listed in Table 1. Importance values (IV) are calculated as the sum of relative leaf area and relative composition.

Table 1. Most important species in Austin

Species Name	*Percent Population*	*Percent Leaf Area*	*IV*
Ashe juniper	59.2	49.5	108.7
Plateau live oak	10.0	8.8	18.9
Cedar elm	6.4	8.2	14.6
Sugarberry	3.6	5.5	9.0
Post oak	2.7	4.6	7.3
Pecan	1.1	3.6	4.7
Chinaberry	1.1	2.2	3.3
Glossy privet	1.7	1.4	3.1
Bald cypress	0.2	2.9	3.1
Honey mesquite	2.4	0.6	3.0

The most dominant ground cover types are Tar (24.9 percent) and Grass (22.7 percent).

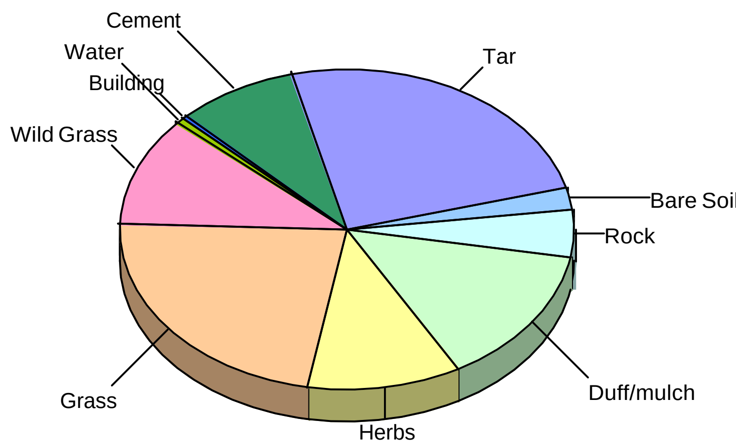

Figure 5. Percent ground cover in Austin

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 plants. Trees also emit volatile organic compounds that can contribute to ozone formation. However, integrative studies have revealed that an increase in tree cover leads to reduced ozone formation [3].

Pollution removal by trees in Austin was estimated using field data and recent pollution and weather data available. Pollution removal was greatest for O3. It is estimated that trees remove 781 metric 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 $4.17 million (see Appendix I for more details).

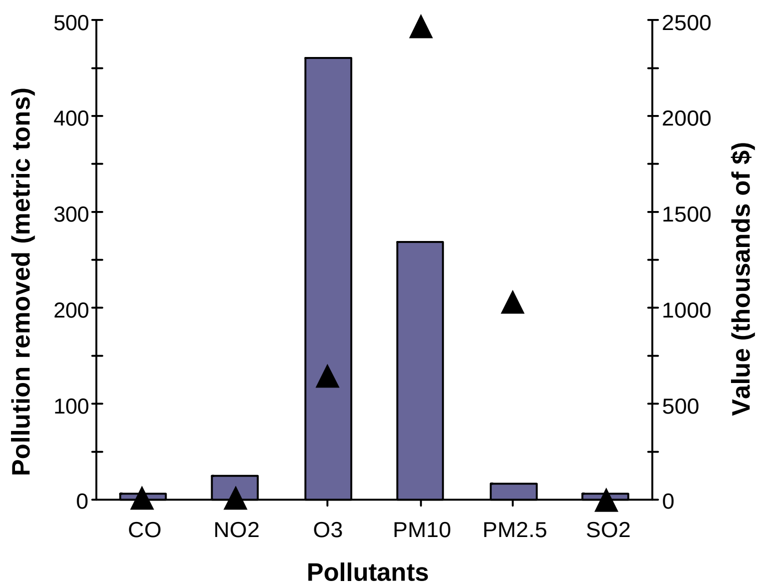

Figure 6. Pollution removal (bars) and associated value (points) for trees in Austin

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 $1253 per metric ton (carbon monoxide), $1408 per metric ton (ozone), $314 per metric ton (nitrogen dioxide), $86 per metric ton (sulfur dioxide), $9206 per metric ton (particulate matter less than 10 microns and greater than 2.5 microns), $65320 per metric ton (particulate matter less than 2.5 microns)

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 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 Austin trees is about 38,400 metric tons of carbon per year with an associated value of $3.02 million. Net carbon sequestration in the urban forest is about 28,100 metric tons. Carbon storage and carbon sequestration values are calculated based on $78 per metric ton (see Appendix I for more details).

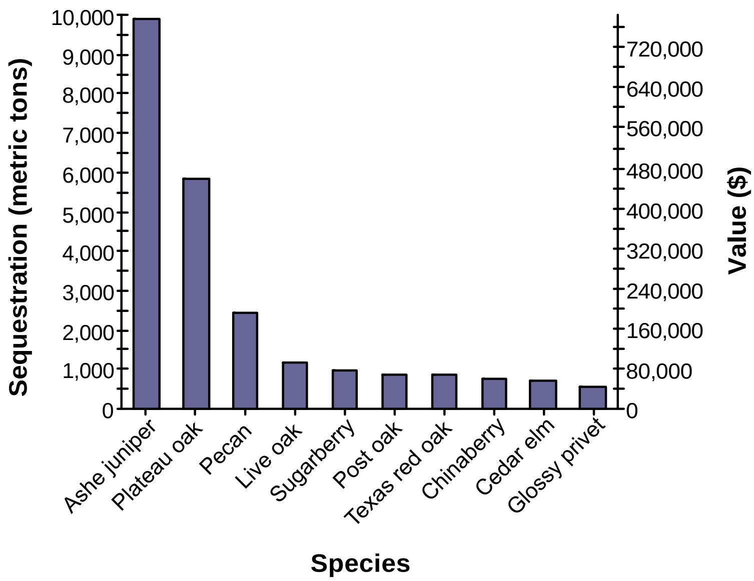

Figure 7. Carbon sequestration and value for species with greatest overall carbon sequestration in Austin

As trees grow they store more carbon as wood. As trees die and decay, they release much of the stored carbon back to the atmosphere. Thus, carbon storage is an indication of the amount of carbon that can be lost if trees are allowed to die and decompose. Trees in Austin are estimated to store 467,000 metric tons of carbon ($36.7 million). Of the species sampled, Ashe juniper stores and sequesters the most carbon (approximately 25.9% of the total carbon stored and 35.1% of all sequestered carbon.)

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 Austin are estimated to produce 75,000 metric 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].

Table 2. The top 20 oxygen producing species in Austin.

Species	*Oxygen (metric tons)*	*Net Carbon Sequestration (Metric tons/yr.)*	*Number of trees*	Leaf Area (square kilometers)
Ashe juniper	26,341.63	9,878.11	4,318,498.00	233.31
Plateau live oak	15,505.73	5,814.65	730,600.00	41.67
Pecan	6,533.25	2,449.97	79,570.00	16.89
Live oak	3,116.75	1,168.78	28,935.00	7.47
Sugarberry	2,559.31	959.74	260,412.00	25.70
Post oak	2,338.61	876.98	195,309.00	21.65
Texas red oak	2,245.28	841.98	94,038.00	5.98
Chinaberry	2,044.35	766.63	79,570.00	10.30
Cedar elm	1,837.44	689.04	470,188.00	38.62
Glossy privet	1,503.49	563.81	122,972.00	6.62
Bastard oak	1,330.43	498.91	108,505.00	3.16
Bald cypress	1,248.45	468.17	14,467.00	13.46
Box elder	1,136.40	426.15	115,739.00	6.11
Red mulberry	1,084.19	406.57	28,935.00	4.67
American elm	1,078.85	404.57	36,168.00	9.60
Honey mesquite	955.44	358.29	173,608.00	2.92
Lagerstroemia spp	880.85	330.32	28,935.00	1.63
American sycamore	805.41	302.03	21,701.00	6.31
Black willow	456.88	171.33	7,234.00	5.01
Texas ash	441.89	165.71	7,234.00	2.73

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 [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 Austin help to reduce runoff by an estimated 1,105,000 cubic meters a year with an associated value of $2.60 million (see Appendix I for more details).

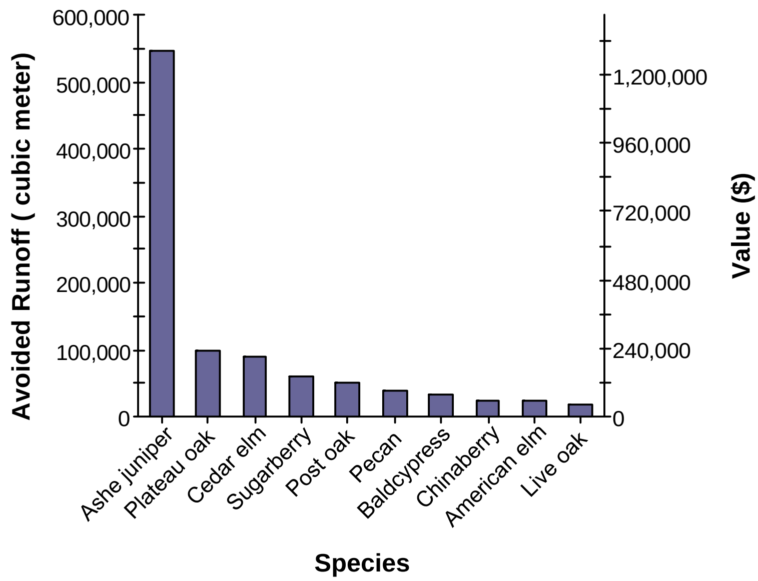

Figure 8. Avoided runoff and value for species with greatest overall impact on runoff in Austin

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 [7].

Trees in Austin are estimated to reduce energy-related costs from residential buildings by $721 thousand annually. Trees also provide an additional $97,183 in value by reducing the amount of carbon released by fossil-fuel based power plants (a reduction of 1,240 metric tons of carbon emissions).

Table 3. Annual energy savings due to trees near residential buildings. Note: negative numbers indicate an increased energy use or carbon emission.

	Heating	*Cooling*	*Total*
MBTU[1]	3,167	n/a	3,167
MWH[2]	169	5,830	5,999
Carbon avoided (mt[3])	77	1,161	1,238

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

Table 4. Annual savings[1] ($) in residential energy expenditure during heating and cooling seasons. Note: negative numbers indicate a cost due to increased energy use or carbon emission.

	Heating	*Cooling*	*Total*
MBTU[2]	32,146	n/a	32,146
MWH[3]	19,418	669,867	689,285
Carbon avoided	6,045	91,139	97,183

[1]Based on the prices of $114.9 per MWH and $10.15 per MBTU (see Appendix I for more details)
[2]One million British Thermal Units
[3]Megawatt-hour

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 [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, urban forest values can be increased; however, the values and benefits also can decrease as the amount of healthy tree cover declines.

Structural values:

- Structural value: $4.41 billion
- Carbon storage: $36.7 million

Annual functional values:

- Carbon sequestration: $3.02 million
- Pollution removal: $4.17 million
- Lower energy costs and carbon emission reductions: $819 thousand (Note: negative value indicates increased energy cost and carbon emission value)

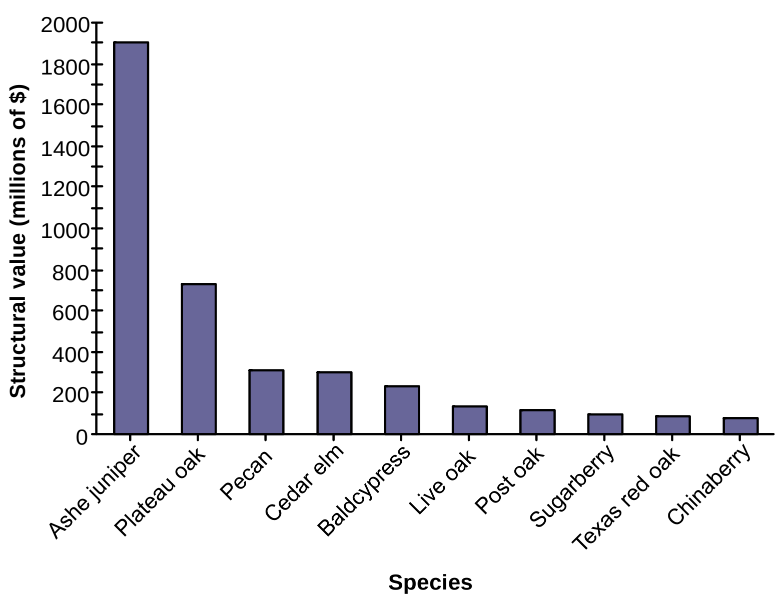

Figure 9. Structural value of the 10 most valuable tree species in Austin

IX. Potential Pest Impacts

Various insects and diseases can infest urban forests, potentially killing trees and reducing the health, value and sustainability of the urban forest. As pests tend to have differing tree hosts, the potential damage or risk of each pest will differ among cities. Thirty- one 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 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.

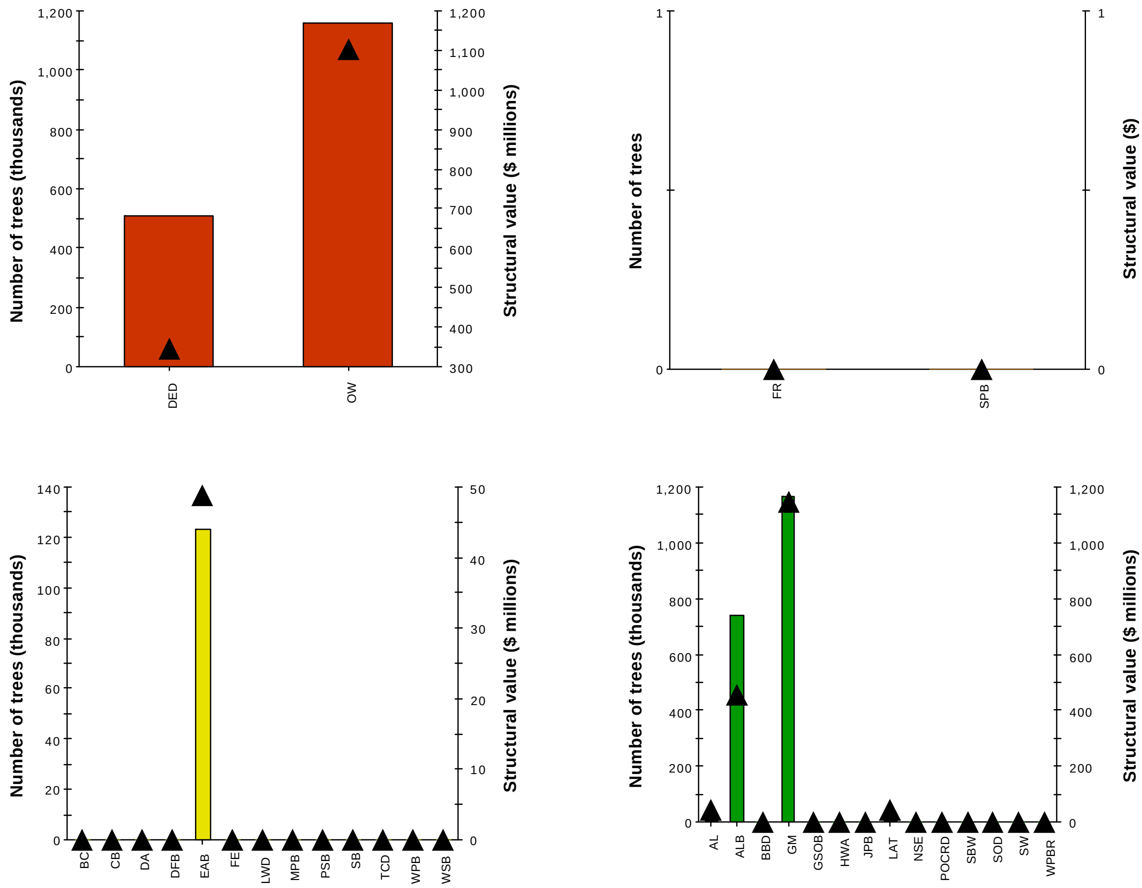

Figure 10. Number of susceptible Austin trees and structural value by pest (points)

Aspen Leafminer (AL) [10] is an insect that causes damage primarily to trembling or small tooth aspen by larval feeding of leaf tissue. AL has the potential to affect 0.1 percent of the population ($45.7 million in structural value).

Asian Longhorned Beetle (ALB) [11] is an insect that bores into and kills a wide range of hardwood species. ALB poses a threat to 10.1 percent of the Austin_2013_Public urban forest, which represents a potential loss of $455 million in structural value.

Beech Bark Disease (BBD) [12] is an insect-disease complex that primarily impacts American beech. This disease threatens 0.0 percent of the population, which represents a potential loss of $0 in structural value.

Butternut Canker (BC) [13] is caused by a fungus that infects butternut trees. The disease has since caused significant declines in butternut populations in the United States. Potential loss of trees from BC is 0.0 percent ($0 in structural value).

The most common hosts of the fungus that cause Chestnut Blight (CB) [14] are American and European chestnut. CB has the potential to affect 0.0 percent of the population ($0 in structural value).

Dogwood Anthracnose (DA) [15] is a disease that affects dogwood species, specifically flowering and Pacific dogwood. This disease threatens 0.0 percent of the population, which represents a potential loss of $0 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) [16]. 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, Austin could possibly lose 6.9 percent of its trees to this pest ($343 million in structural value).

Douglas-Fir Beetle (DFB) [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 $0 ($0 in structural value).

Emerald Ash Borer (EAB) [18] has killed thousands of ash trees in parts of the United States. EAB has the potential to affect 1.7 percent of the population ($48.8 million in structural value).

One common pest of white fir, grand fir, and red fir trees is the Fir Engraver (FE) [19]. FE poses a threat to 0.0 percent of the Austin urban forest, which represents a potential loss of $0 in structural value.

Fusiform Rust (FR) [20] 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).

The Gypsy Moth (GM) [22] is a defoliator that feeds on many species causing widespread defoliation and tree death if outbreak conditions last several years. This pest threatens 16.0 percent of the population, which represents a potential loss of $1.15 billion in structural value.

Infestations of the Goldspotted Oak Borer (GSOB) [21] have been a growing problem in southern California. Potential loss of trees from GSOB is $0 ($0 in structural value).

As one of the most damaging pests to eastern hemlock and Carolina hemlock,

Hemlock Woolly Adelgid (HWA) [23] has played a large role in hemlock mortality in the United States. HWA has the potential to affect 0.0 percent of the population ($0 in structural value).

The Jeffrey Pine Beetle (JPB) [24] is native to North America and is distributed across California, Nevada, and Oregon where its only host, Jeffrey pine, also occurs. This pest threatens 0.0 percent of the population, which represents a potential loss of $0 in structural value.

Quaking aspen is a principal host for the defoliator, Large Aspen Tortrix (LAT) [25]. LAT poses a threat to 7.23 thousand percent of the Austin urban forest, which represents a potential loss of $45.7 million in structural value.

Laurel Wilt (LWD) [26] is a fungal disease that is introduced to host trees by the redbay ambrosia beetle. This pest threatens 0.0 percent of the population, which represents a potential loss of $0 in structural value.

Mountain Pine Beetle (MPB) [27] is a bark beetle that primarily attacks pine species in the western United States. MPB has the potential to affect 0.0 percent of the population ($0 in structural value).

The Northern Spruce Engraver (NSE) [28] has had a significant impact on the boreal and sub-boreal forests of North America where the pest's distribution overlaps with the range of its major hosts. Potential loss of trees from NSE is $0 ($0 in structural value).

Oak Wilt (OW) [29], which is caused by a fungus, is a prominent disease among oak trees. OW poses a threat to 15.9 percent of the Austin urban forest, which represents a potential loss of $1.10 billion in structural value.

Port-Orford-Cedar Root Disease (POCRD) [30] is a root disease that is caused by a fungus. POCRD threatens 0.0 percent of the population, which represents a potential loss of $0 in structural value.

The Pine Shoot Beetle (PSB) [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 0.0 percent of the population ($0 in structural value).

Spruce Beetle (SB) [32] is a bark beetle that causes significant mortality to spruce species within its range. Potential loss of trees from SB is $0 ($0 in structural value).

Spruce Budworm (SBW) [33] is an insect that causes severe damage to balsam fir. SBW poses a threat to 0.0 percent of the Austin urban forest, which represents a potential loss of $0 in structural value.

Sudden Oak Death (SOD) [34] is a disease that is caused by a fungus. Potential loss of trees from SOD is $0 ($0 in structural value).

Although the Southern Pine Beetle (SPB) [35] will attack most pine species, its preferred hosts are loblolly, Virginia, pond, spruce, shortleaf, and sand pines. This pest threatens 0.0 percent of the population, which represents a potential loss of $0 in structural value.

The Sirex Wood Wasp (SW) [36] is a wood borer that primarily attacks pine species. SW poses a threat to 0.0 percent of the Austin urban forest, which represents a potential loss of $0 in structural value.

Thousand Canker Disease (TCD) [37] is an insect-disease complex that kills several species of walnuts, including black walnut. Potential loss of trees from TCD is $0 ($0 in structural value).

The Western Pine Beetle (WPB) [38] is a bark beetle and aggressive attacker of ponderosa and Coulter pines. This pest threatens 0.0 percent of the population, which represents a potential loss of $0 in structural value.

Since its introduction to the United States in 1900, White Pine Blister Rust (Eastern U.S.) (WPBR) [39] has had a detrimental effect on white pines, particularly in the Lake States. WPBR has the potential to affect 0.0 percent of the population ($0 in structural value).

Western spruce budworm (WSB) [40] is an insect that causes defoliation in western conifers. This pest threatens 0.0 percent of the population, which represents a potential loss of $0 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 [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 0.040 hectare 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 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 [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 re-suspension 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 Austin 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 Austin in 37 days
- Annual carbon (C) emissions from 309,000 automobiles
- Annual C emissions from 155,000 single-family houses

Carbon monoxide removal is equivalent to:
- Annual carbon monoxide emissions from 27 automobiles
- Annual carbon monoxide emissions from 110 single-family houses

Nitrogen dioxide removal is equivalent to:
- Annual nitrogen dioxide emissions from 1,780 automobiles
- Annual nitrogen dioxide emissions from 1,190 single-family houses

Sulfur dioxide removal is equivalent to:
- Annual sulfur dioxide emissions from 10,100 automobiles
- Annual sulfur dioxide emissions from 170 single-family houses

Particulate matter less than 10 micron (PM10) removal is equivalent to:
- Annual PM10 emissions from 834,000 automobiles
- Annual PM10 emissions from 80,500 single-family houses

Annual carbon sequestration is equivalent to:
- Amount of carbon emitted in Austin in 3.0 days
- Annual C emissions from 25,400 automobiles
- Annual C emissions from 12,800 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 (metric tons)*	*Carbon Sequestration (metric*	*Pollution removal (metric tons/yr.*
Calgary, Canada	7.2	11,889,000	404,000	19,400	296
Atlanta, GA	36.8	9,415,000	1,220,000	42,100	1,508
Toronto, Canada	20.5	7,542,000	900,000	36,600	1,100
New York, NY	21	5,212,000	1,226,000	38,400	1,521
Baltimore, MD	21	2,627,000	541,000	14,600	390
Philadelphia, PA	15.7	2,113,000	481,000	14,600	523
Washington, DC	28.6	1,928,000	474,000	14,600	379
Boston, MA	22.3	1,183,000	289,000	9,500	258
Woodbridge, NJ	29.5	986,000	145,000	5,000	191
Minneapolis, MN	26.5	979,000	227,000	8,100	277
Syracuse, NY	23.1	876,000	157,000	4,900	99
Morgantown, WV	35.9	661,000	85,000	2,700	60
Moorestown, NJ	28	583,000	106,000	3,400	107
Jersey City, NJ	11.5	136,000	19,000	800	37
Freehold, NJ	34.4	48,000	18,000	500	19

II. Per hectare values of tree effects

City	*No. of trees*	*Carbon Storage (metric tons)*	*Carbon sequestration (metric*	*Pollution removal (metric tons/yr.)*
Calgary, Canada	164.8	5.60	0.13	4.0
Atlanta, GA	275.8	35.64	0.62	44.2
Toronto, Canada	119.4	14.35	0.29	17.5
New York, NY	65.2	15.24	0.24	19.1
Baltimore, MD	125.5	25.78	0.35	18.6
Philadelphia, PA	61.8	14.12	0.21	15.2
Washington, DC	121.1	29.81	0.46	23.8
Boston, MA	82.8	20.18	0.33	17.9
Woodbridge, NJ	164.3	24.21	0.42	31.8
Minneapolis, MN	64.7	15.02	0.27	18.4
Syracuse, NY	134.7	24.21	0.38	15.2
Morgantown, WV	295.8	38.11	0.60	26.7
Moorestown, NJ	153.2	28.02	0.45	28.2
Jersey City, NJ	35.3	4.93	0.11	9.6
Freehold, NJ	95.1	35.87	0.49	37.7

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 Texas invasive species list [2]:

Species Name[1]	*Number of trees*	*% Tree Number*	*Leaf Area (km2)*	*% Leaf Area*
Chinaberry	79,570	1.09	10.30	2.18
Tree of heaven	43,402	0.60	0.46	0.10
TOTAL	**122,972**	**1.69**	**10.76**	**2.28**

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

Appendix VII. 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 Weight	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
	5	American elm																															
	5	Bastard oak																															
	5	Cedar elm																															
	5	Live oak																															
	5	Plateau live oak																															
	5	Post oak																															
	5	Texas red oak																															
	4	Black willow																															
	3	Green ash																															
	2	Ash spp																															
	2	Texas ash																															
	1	Box elder																															

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

Appendix VIII. Species list

Tree Common Name	***Scientific Name***
Boxelder	*Acer negundo*
Tree of Heaven	*Ailanthus altissima*
Pecan	*Carya Illinoinensis*
Sugarberry	*Celtis laevigata*
Texas persimmon	*Diospyros texana*
Carolina buckthorn	*Frangula caroliniana*
Ash spp.	*Fraxinus (Genus)*
Green ash	*Fraxinus pennsylvanica*
Texas ash	*Fraxinus texensis*
Possum haw holly	*Ilex decidua*
Yaupon holly	*Ilex vomitoria*
Ashe juniper	*Juniperus ashei*
Mountain laurel	*Kalmia latifolia*
lagerstroemia spp(Genus)	*Lagerstroemia(Genus)*
Glossy privet	*Ligustrum lucidum*
Chinaberry	*Melia azedarach*
Red mulberry	*Morus rubra*
American sycamore	*Platanus occidentalis*
Honey mesquite	*Prosopis glandulosa*
Mexican plum	*Prunus mexicana*
Plateau live oak	*Quercus/live fusiformis*
Southern live oak	*Quercus/live virginiana*
Bastard oak	*Quercus sinuata*
Post oak	*Quercus stellata*
Texas red oak	*Quercus texana*
Prairie sumac	*Rhus lanceolata*
Western soapberry	*Sapindus saponaria drummondii*
Black willow	*Salix nigra*
Baldcypress	*Taxodium distichum*
American elm	*Ulmus americana*
Cedar elm	*Ulmus crassifolia*
Hercules club	*Zanthoxylum clava-herculis*

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