# Argyle Urban Forest Ecosystem Analysis

*March 2019*

*Photo by: Chris Wolfgang - Dallas Observer*

Texas Trees Foundation

Argyle Texas

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# Executive Summary

Argyle's urban forest plays a crucial role in the livability and sustainability of the city. The city's trees impact everything from economic development to the overall health and livelihood of the people that live, work, and play in Argyle every day.

Understanding an urban forests 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 Town of Argyle urban forest was conducted between October 2018 and February 2019. Data from 50 field plots located throughout the Town of Argyle were analyzed using the i-Tree Eco model developed by the U.S. Forest Service, Northern Research Station.

## KEY FINDINGS

The key findings for the 2019 Town of Argyle Urban Forest Resource Assessment are below. This data represent a snapshot of both the structural and functional characteristics and values of the city's urban trees. They are provided to aid in the planning and management of this increasingly important resource. The quantification of the benefits of Argyle's urban forest should serve as a reliable advocacy tool to help educate community leaders and the public about the importance of investing in professional planning and management for Argyle's trees.

- Argyle's 627,500 trees have a structural value of $484 million
- Argyle's tree canopy cover is 31.3 %
- Argyle's trees provide the following in annual average environmental services
    - Pollution Removal: 57.11/year (*$22.7 thousand/year*)
    - Carbon Storage: 91.88 thousand tons (*$835 million*)
    - Carbon Sequestration: 4.895 thousand tons (*$835 thousand/year*)
    - Avoided Runoff: 3.818 million cubic feet/year (*$255 thousand/year*)
- 627,500 trees provide 10.55 thousand tons of Oxygen per year to Argyle
- 60.2% of Argyle's trees are less than 6" (*15.2 cm*) in diameter
- Argyle's trees provide a building energy savings of $7,460/year
- Argyle's most common tree species are Post Oak, Cedar Elm, and Black locust.

*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.*


Photo by: Bill Castleman -
Cross Timbers Gazette

# Introduction

The area of interest (*AOI*) of this study is the Town of Argyle, Texas. The AOI has an area of 11.4 mi² or 7,296 acres. Located in North Texas within the Cross timbers prairie ecoregion at 33°6′59″N 97°11′8″W (33.116422, -97.185461). Argyle's urban forest plays a crucial role in the livability and sustainability of the city. Argyle's 627,500 trees impact everything from economic development to the overall health and livability of the people that live, work, and play in Argyle every day.

Understanding an urban forest's structure, function, and value can promote effective policy decisions, sound management planning, and help to set and anticipate future budgetary requirements. During the Fall of 2018 the Town of Argyle partnered with the Texas Trees Foundation to perform the most detailed and comprehensive study of Argyle's urban forest resource ever conducted.

Over the past decade there has been an increase in both the knowledge of the ecosystem services and social benefits of urban forests as well as the availability of quantitative tools, such as i-Tree, for the measurement and communication of them. In fact, i-Tree is now being promoted and used internationally. To date, there have only been seven (7) other i-Tree Eco studies completed in Texas

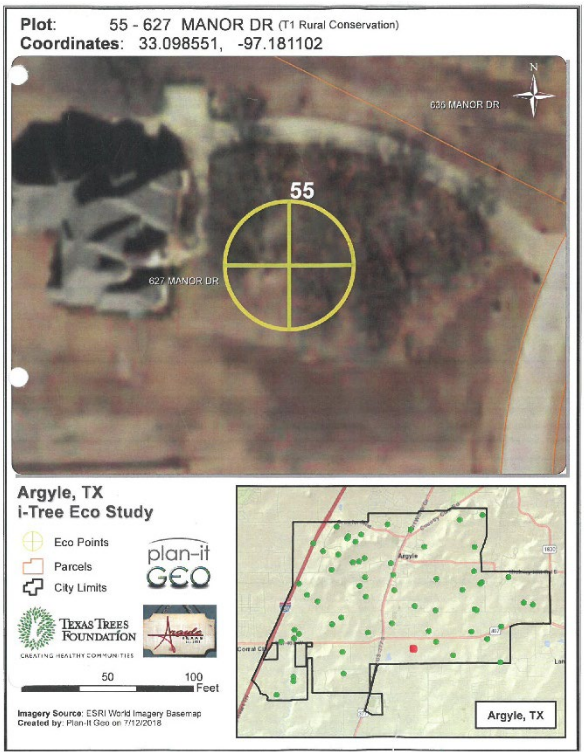
- 2005 Houston Regional UFORE
- 2009 City of Arlington Eco
- 2012 City of Mesquite Eco
- 2013 El Paso Eco
- 2014 City of Plano Eco
- 2015 City of Dallas State of the Urban Forest
- 2016 City of Denton State of the Urban Forest

The Town of Argyle's recognition of the multitude of benefits urban forests provide prompted the development of this resource assessment in order to quantify, and explicitly demonstrate to city officials and the general public alike, the specific services and values attached to Argyle's urban forest. The completion of this study highlights the value Argyle's city leaders have placed on their trees and will enable them to continue promoting and enhancing their urban forestry program.

# Methods

*i-Tree Eco*

Study design and field data collection protocol were developed by the U.S. Forest Service, Northeast Research Station (*Appendix I*). Using geographical information system (*GIS*) technology and ArcMap 10.x software, 60 0.1-acre circular plots were created and randomly established within the AOI on both public and private property. Study plots were also stratified by land use categories using 2010 National Land Classification Database (*NLCD*) imagery. There was a total of thirteen land use classes identified within Argyle. For logistical planning and operational purposes, the study area was ultimately divided into four quadrants, in which Texas Trees Foundation staff and interns collected data on 50 plots within the Northeast, Northwest, Southeast and Southwestern quadrants.




Study plot centers were located in the field using three map books containing all plots within each respective third. Where plots or portions of plots fell on private property, permission to access private properties for plot measurement was obtained prior to data collection.

Plot and tree level data were recorded on paper forms and archived following data entry. In addition, study plots were designed as permanent measurement locations using global positioning system (*GPS*) units by recording exact plot center locations, the reference point for all measurements. Plot centers can easily be relocated for future measurements using either recorded latitude and longitude values or by triangulating their positions by using the distance and direction of two reference points for each plot center.

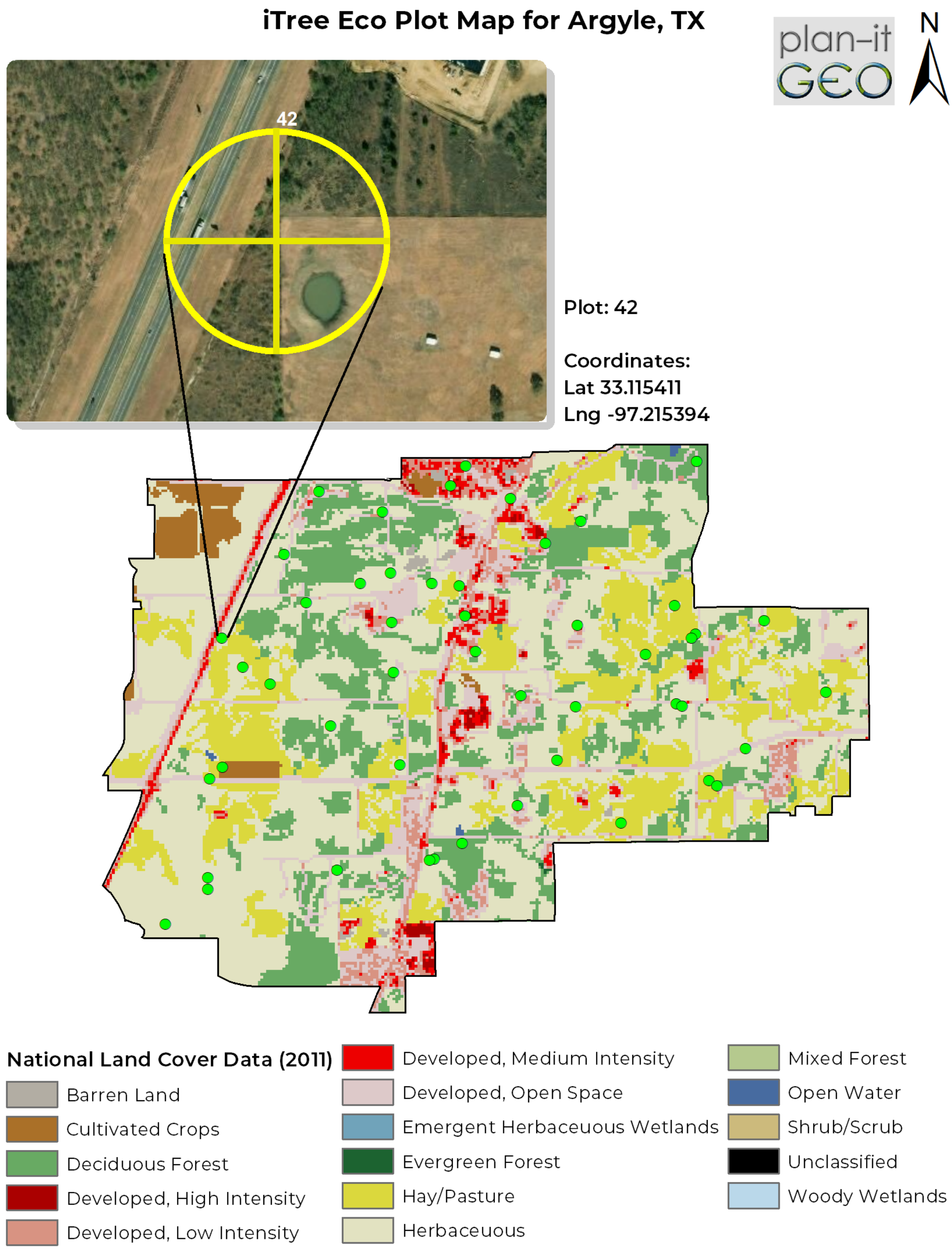



*Figure 1. Study plot design for the Argyle Urban Forest Ecosystem Study*

# i-Tree Eco Assessment Results

*Tree Characteristics of the Urban Forest*

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 the Town of Argyle, about 85 percent of the trees are species native to North America, while 77 percent are native to Texas. Species exotic to North America make up 15 percent of the population. Most exotic tree species have an origin from North America + (*7 percent of the species*). The plus sign (+) indicates the tree species is native to another continent other than the ones listed in the grouping. In the Town of Argyle, the most dominant species in terms of leaf area are Post oak, Cedar elm, and Eastern Cottonwood. 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.

The urban forest of the Town of Argyle has an estimated 627,500 trees, with a tree cover of 31.3 percent. The three most common species are Post oak (*30.5 percent*), Cedar elm (*22.6 percent*), and Black locust (*9.3 percent*).

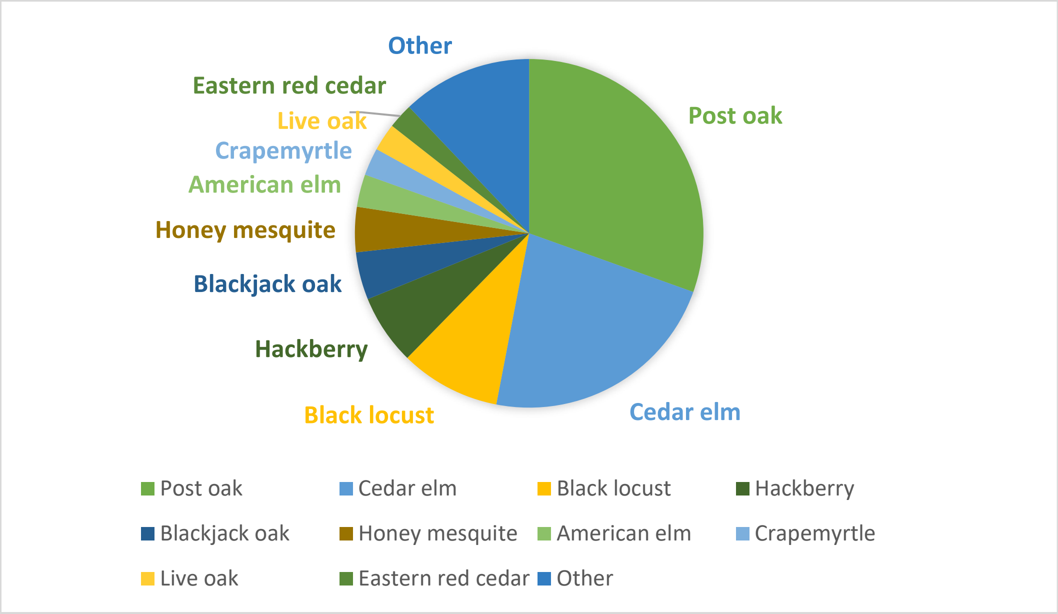



*Figure 2: Tree species composition in the Town of Argyle*

*Importance Values*

In Argyle, TX the most dominant species in terms of leaf area are Post oak, Cedar elm, and Eastern cottonwood. 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.

| *Species Name* | *% Population* | *% Leaf Area* | *IV* |
|---|---|---|---|
| **Post oak** | 30.5 | 41.3 | 71.7 |
| **Cedar elm** | 22.6 | 13.8 | 36.4 |
| **Black locust** | 9.3 | 4.4 | 13.7 |
| **hackberry spp** | 6.5 | 2.9 | 9.4 |
| **Eastern cottonwood** | 1.2 | 7.8 | 8.9 |
| **American elm** | 3 | 5.4 | 8.5 |
| **Live oak** | 2.6 | 4.8 | 7.4 |
| **Siberian elm** | 2.3 | 4.8 | 7.1 |
| **Blackjack oak** | 4.4 | 2.3 | 6.8 |
| **Honey mesquite** | 4.2 | 2.3 | 6.5 |

*Table 1. Argyle's top 10 species based on Importance Values.*

*Relative Tree Age and Size*

The size of Argyle's trees can be a good prediction for future trends in the structure and composition of the urban forest. While larger trees provide more ecosystem benefits, the space to grow and maintain large trees in an urban setting can be limited. In addition, trees will only grow to the size that the current environment conditions will allow. This study revealed that of all of Argyle's trees, 60% had a diameter of less than 6 inches. The relative size/age of trees in a community, combined with other observable species trends, enables more informed management and planning for future planting projects. For example, 60% of the tree population that had less than 6-inches in truck diameter, approximately 52% were species that will attain a relatively large size at maturity if properly protect and cared for.

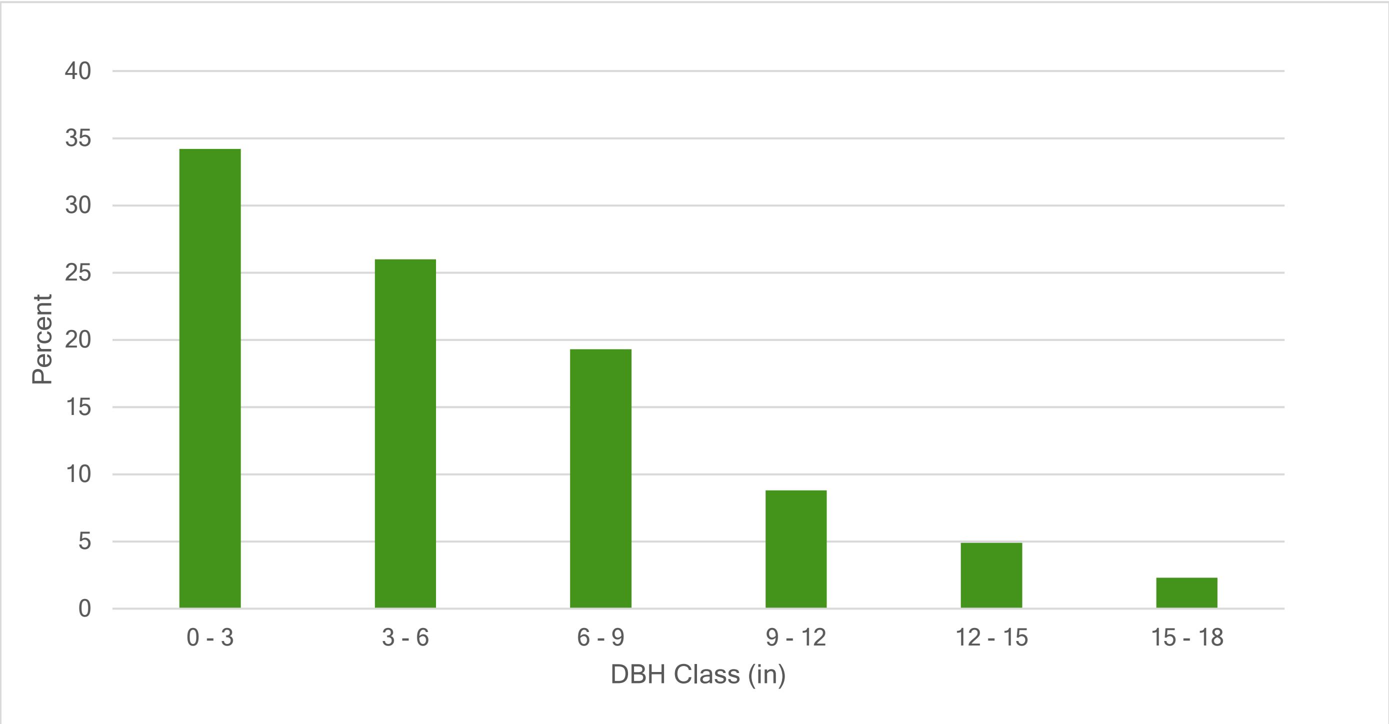



*Figure 3: Percent of tree population by diameter class (DBH - stem diameter at 4.5 ft)*

# The Value of Argyle's Urban Forest

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 by trees and shrubs in the Town of Argyle was estimated using field data and recent available pollution and weather data available. Pollution removal was greatest for ozone (*Figure 4*). It is estimated that trees and shrubs remove 53.811 tons of air pollution (*ozone (O3), carbon monoxide (CO), nitrogen dioxide (NO2), particulate matter less than 2.5 microns (PM2.5), and sulfur dioxide (SO2)*) per year with an associated value of $22.6 thousand*. (*See Appendix I for more details*)

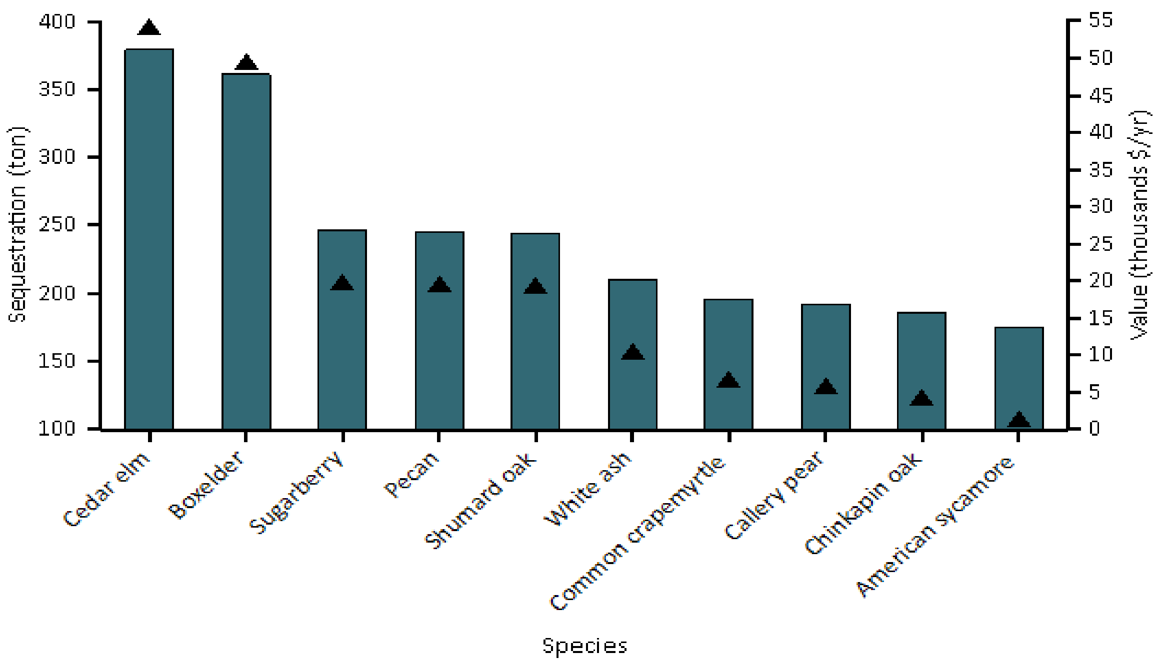



*Figure 4: Estimated carbon storage (points) and values (bars) for urban tree species with the greatest storage*

** 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.*

## 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 the Town of Argyle trees is about 4.895 thousand tons of carbon per year with an associated value of $834 thousand. Net carbon sequestration in the urban forest is about 3.957 thousand tons. See Appendix I for more details on methods.

Trees in Argyle, TX are estimated to store 91,876 tons of carbon (*$15.67 million*). Of the species sampled, Post oak stores the most carbon (*approximately 61.2% of the total carbon stored*) as well as sequesters the most (*approximately 54.3% of all sequestered carbon*).

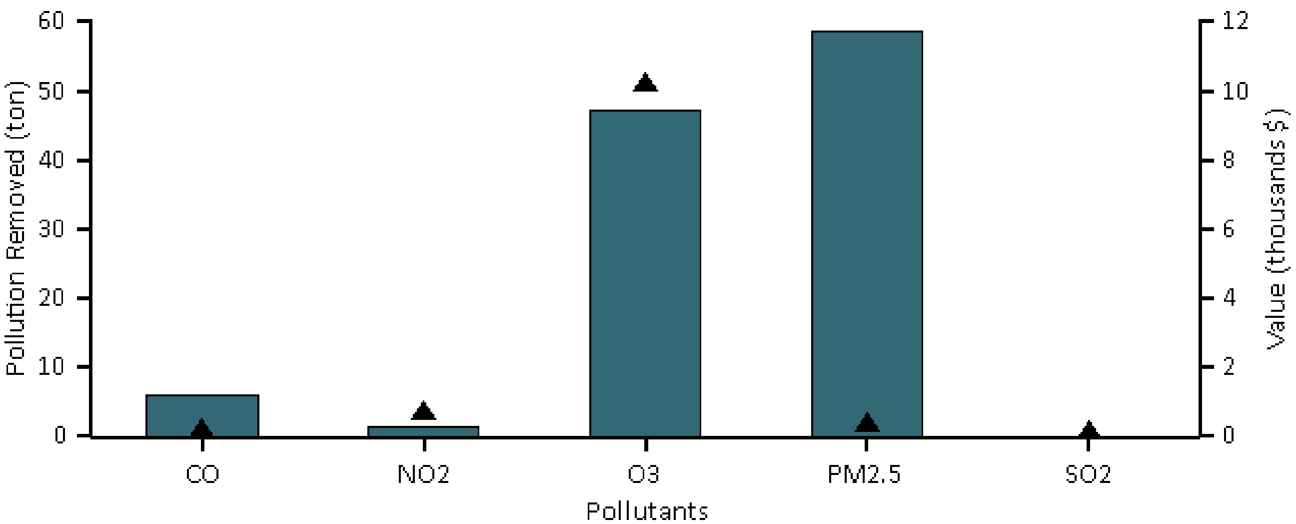



*Figure 5: Annual pollution removal (points) and values (bars) by urban trees, Argyle TX.*

*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.

*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).

## 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 Argyle, TX are estimated to produce 10.554 thousand 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 (*Broecker 1970*).

| *Species* | *Oxygen* | *Net Carbon Sequestration* | *Number of Trees* | *Leaf Area* |
|---|---|---|---|---|
| | *(ton)* | *(ton/yr)* | | *(acre)* |
| Post oak | 5,672.03 | 2,127.01 | 191,155 | 2,839.99 |
| Cedar elm | 980.72 | 367.77 | 141,542 | 949.68 |
| Black locust | 553.48 | 207.55 | 58,368 | 300.59 |
| Siberian elm | 549.51 | 206.07 | 14,592 | 331.03 |
| Live oak | 479.67 | 179.88 | 16,051 | 333.28 |
| Honey mesquite | 465.61 | 174.60 | 26,266 | 159.64 |
| Blackjack oak | 409.82 | 153.68 | 27,725 | 160.80 |
| American elm | 316.32 | 118.62 | 18,970 | 373.60 |
| hackberry spp | 247.12 | 92.67 | 40,858 | 198.86 |
| Common crapemyrtle | 207.44 | 77.79 | 16,051 | 37.35 |
| Eastern cottonwood | 177.40 | 66.53 | 7,296 | 534.68 |
| Eastern red cedar | 120.66 | 45.25 | 14,592 | 215.13 |
| Mesquite | 91.43 | 34.29 | 10,214 | 72.26 |
| Pecan | 63.66 | 23.87 | 4,378 | 28.13 |
| Native Hackberry | 43.56 | 16.33 | 8,755 | 31.48 |
| Eastern redbud | 43.55 | 16.33 | 2,918 | 7.84 |
| Honeylocust | 35.01 | 13.13 | 2,918 | 22.55 |
| Chinese pistache | 31.52 | 11.82 | 1,459 | 18.61 |
| Mexican plum | 30.84 | 11.56 | 7,296 | 10.89 |
| Chinese elm | 23.05 | 8.64 | 1,459 | 14.26 |

*Table 2. Argyle's top 20 oxygen production species.*

* 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.

## 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 the Town of Argyle help to reduce runoff by an estimated 3.82 million cubic feet a year with an associated value of $255 thousand (*see Appendix I for more details*). Avoided runoff is estimated based on local weather from the user-designated weather station. In the Town of Argyle, the total annual precipitation in 2015 was 55.6 inches.

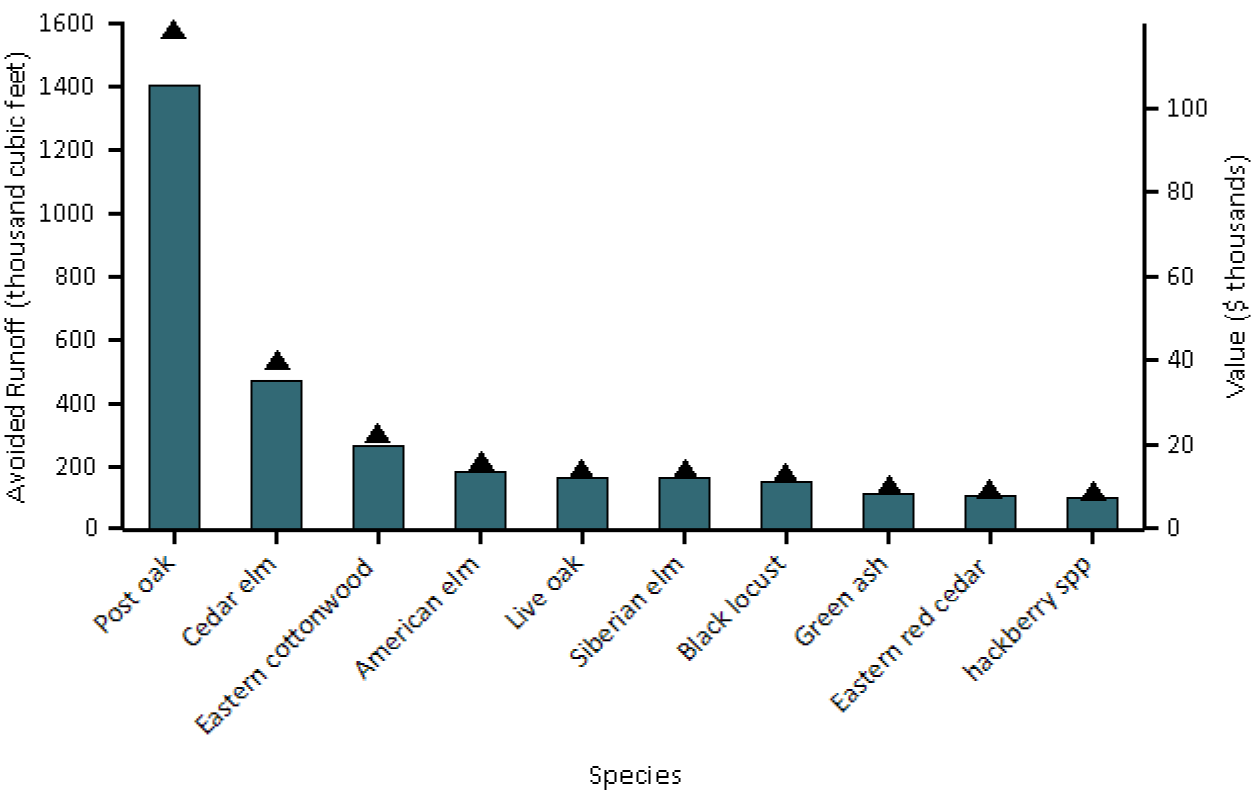



*Figure 6: Avoided runoff (points) and value (bars) for species with the greatest overall impact on runoff, Argyle, TX.*

# 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 Town of Argyle Eco are estimated to reduce energy-related costs from residential buildings by $7,460 annually. Trees also provide an additional $358 in value by reducing the amount of carbon released by fossil-fuel based power plants (*a reduction of 2.1 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]

| | *Heating* | *Cooling* | *Total* |
|---|---:|---:|---:|
| MBTU[a] | -2,045 | N/A | -2,045 |
| MWH[b] | -85 | 350 | 265 |
| Carbon Avoided (tons) | -61 | 63 | 2 |

*Table 3. Annual energy savings due to trees near residential buildings, Argyle, TX*

| | *Heating* | *Cooling* | *Total* |
|---|---:|---:|---:|
| MBTU[b] | -22,110 | N/A | -22,110 |
| MWH[c] | -9,483 | 39,050 | 29,567 |
| Carbon Avoided | -10,450 | 10,808 | 358 |

*Table 4. Annual savings ($) in residential energy expenditure during heating and cooling seasons, Argyle, TX*

[*] *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.*

# 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.

<u>Urban trees in Argyle, TX have the following structural values:</u>

- Structural value: $484 million
- Carbon storage: $15.7 million

<u>Urban trees in Argyle, TX have the following annual functional values:</u>

- Carbon sequestration: $835 thousand
- Avoided runoff: $255 thousand
- Pollution removal: $22.7 thousand
- Energy costs and carbon emission values: $7.82 thousand

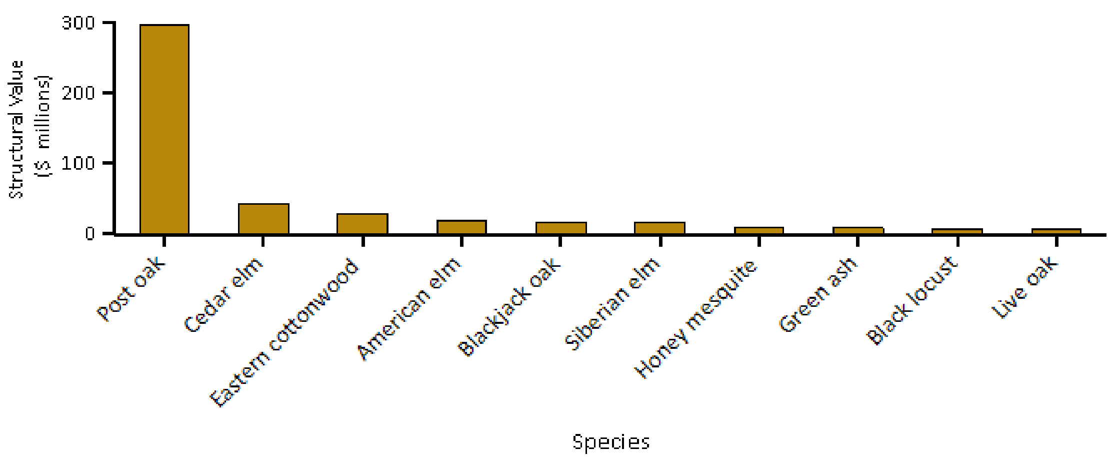



*Figure 7: Tree species with the greatest structural value in the town of Argyle*

## 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 Dallas County. Two of the thirty-six pests analyzed are located within the county. For a complete analysis of all pests, see Appendix VII.

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.

In the Town of Argyle, the greatest opportunity for loss related to pests and associated diseases is from Dutch elm disease and oak wilt disease, potentially affecting 3% and 2.6% of the total population worth $19.1 million and $6.8 million, respectively.

Emerald ash borers have caused the death of tens of millions of ash trees in the Midwest and should be a serious concern for tree managers in the DFW region, as the presence of the pest was recently confirmed in East Texas (*Harrison County*) in early 2016. Fortunately, Green ash only make up >1% of the total tree population of Argyle. The potential loss of value, should Argyle lose its ash trees, was estimated to be approximately $8.4 million. Thus, protecting high value landscape specimens of this species should be a priority.

## Discussion

The Argyle urban forest provides multiple benefits to the residents of the city and creates a sense of community. An increase in the understanding of these benefits and their associated economic values can improve both local planning and management and ultimately improve the overall condition or quality of the forest leading to increased benefits.

31.3% is generally a good canopy coverage of a city in the DFW area. Although as Argyle continues to develop and expand it is important to implement good tree mitigation and preservation practices to protect and maintain a sustainable urban forest. With a majority of the town's trees being 6" or less in diameter most trees are relatively young and with proactive care should grow, expanding the canopy coverage over the community and providing heightened benefits over time. With nearly 70% of all trees represented by only four species, diversifying species selection in future planting initiatives is recommended to enhance the forest's quality and resilience.

This study also shows that Post oaks are a vital component of Argyle's urban forest making up 30.5% of the canopy coverage and accounting for $298.7 million of the overall value of Argyle's tree population. Post oaks also sequester and store the most carbon of any species in Argyle. It is recommended that due to the importance of Post oaks strict tree preservation ordinances protecting these trees would be highly recommended.

While a direct comparison to other communities is interesting on an empirical basis it is important to recognize the many physical (*e.g. types of infrastructure, level/extent of development etc*….), social (*e.g. political support for program etc*….), and natural (*e.g. species availability and growth rates, climate etc*….) attributes that control the level and quality of any community's urban forest. Furthermore, the year each study is completed does impact the results to a small degree since regression equations that provide leaf area estimates and benefit values, as well as other local inputs such as energy costs, are sometimes adjusted with the release of new i-Tree software versions.

See Appendix III. for a comparison of Argyle's urban forest with other North American cities.

# Appendix

## 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.

Tree Characteristics:

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 (*Watershed Protection Development Review*) 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.

Air Pollution Removal:

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 $1,380 per ton (*carbon monoxide*), $185 per ton (*ozone*), $89 per ton (*nitrogen dioxide*), $21 per ton (*sulfur dioxide*), $7,488 per ton (*particulate matter less than 2.5 microns*).

Carbon Storage and Sequestration:

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

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

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

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

Oxygen Production:

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

Avoided Runoff:

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

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

For this analysis, avoided runoff value is calculated based on the price of $0.07 per ft³.

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 $111.59 per MWH and $10.81 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 the Town of Argyle 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 Town of Argyle Eco in 1,931 days
- Annual carbon (C) emissions from 65,000 automobiles
- Annual C emissions from 26,600 single-family houses

Carbon monoxide removal is equivalent to:

- Annual carbon monoxide emissions from 8 automobiles
- Annual carbon monoxide emissions from 22 single-family houses

Nitrogen dioxide removal is equivalent to:

- Annual nitrogen dioxide emissions from 472 automobiles
- Annual nitrogen dioxide emissions from 213 single-family house

Sulfur dioxide removal is equivalent to:

- Annual sulfur dioxide emissions from 4,590 automobiles
- Annual sulfur dioxide emissions from 12 single-family houses

Annual carbon sequestration is equivalent to:

- Amount of carbon emitted in Town of Argyle Eco in 100.0 days
- Annual C emissions from 3,500 automobiles
- Annual C emissions from 1,400 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 | Carbon Sequestration | Pollution Removal |
|---|---|---|---|---|---|
| | | | (tons) | (tons/yr) | (tons/yr) |
| Toronto, ON, Canada | 26.6 | 10,220,000 | 1,221,000 | 51,500 | 2,099 |
| Atlanta, GA | 36.7 | 9,415,000 | 1,344,000 | 46,400 | 1,663 |
| Los Angeles, CA | 11.1 | 5,993,000 | 1,269,000 | 77,000 | 1,975 |
| New York, NY | 20.9 | 5,212,000 | 1,350,000 | 42,300 | 1,676 |
| London, ON, Canada | 24.7 | 4,376,000 | 396,000 | 13,700 | 408 |
| Chicago, IL | 17.2 | 3,585,000 | 716,000 | 25,200 | 888 |
| Baltimore, MD | 21.0 | 2,479,000 | 570,000 | 18,400 | 430 |
| Philadelphia, PA | 15.7 | 2,113,000 | 530,000 | 16,100 | 575 |
| Washington, DC | 28.6 | 1,928,000 | 525,000 | 16,200 | 418 |
| Oakville, ON, Canada | 29.1 | 1,908,000 | 147,000 | 6,600 | 190 |
| Boston, MA | 22.3 | 1,183,000 | 319,000 | 10,500 | 283 |
| Syracuse, NY | 26.9 | 1,088,000 | 183,000 | 5,900 | 109 |
| Woodbridge, NJ | 29.5 | 986,000 | 160,000 | 5,600 | 210 |
| Minneapolis, MN | 26.4 | 979,000 | 250,000 | 8,900 | 305 |
| San Francisco, CA | 11.9 | 668,000 | 194,000 | 5,100 | 141 |
| Morgantown, WV | 35.5 | 658,000 | 93,000 | 2,900 | 72 |
| Moorestown, NJ | 28.0 | 583,000 | 117,000 | 3,800 | 118 |
| Hartford, CT | 25.9 | 568,000 | 143,000 | 4,300 | 58 |
| Jersey City, NJ | 11.5 | 136,000 | 21,000 | 890 | 41 |
| Casper, WY | 8.9 | 123,000 | 37,000 | 1,200 | 37 |
| Freehold, NJ | 34.4 | 48,000 | 20,000 | 540 | 22 |

II. Totals per acre of land area

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

# APPENDIX IV. GENERAL RECOMMENDATIONS FOR AIR QUALITY IMPROVEMENT

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

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

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

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

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

## APPENDIX V. INVASIVE SPECIES OF THE URBAN FOREST

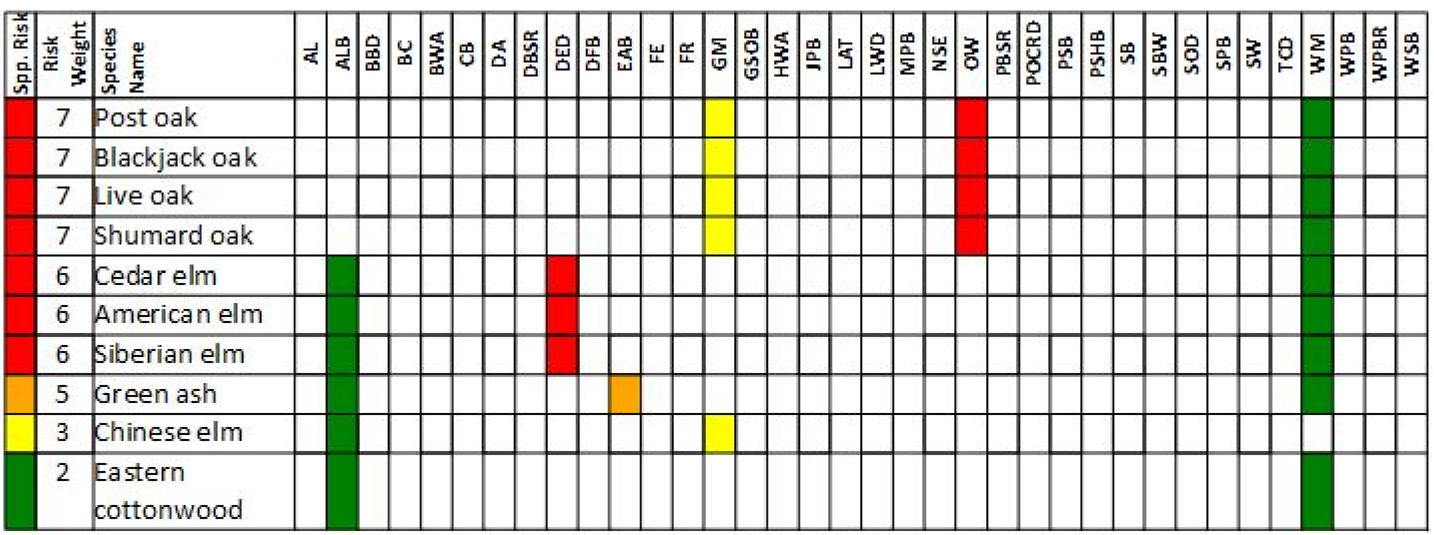
The following inventoried tree species were listed as invasive on the Texas invasive species list (*Watershed Protection Development Review*):

| Species Name[a] | *Number of Trees* | *% of Trees* | *Leaf Area (ac)* | *Percent Leaf Area* |
|---|---|---|---|---|
| Chinese pistache | 1,459 | 0.2 | 18.6 | 0.3 |
| **Total** | **1,459** | **0.23** | **18.61** | **0.27** |

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

## APPENDIX VI. POTENTIAL RISK OF PESTS

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:

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

Species Risk:

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

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

Pest Color Codes:

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

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