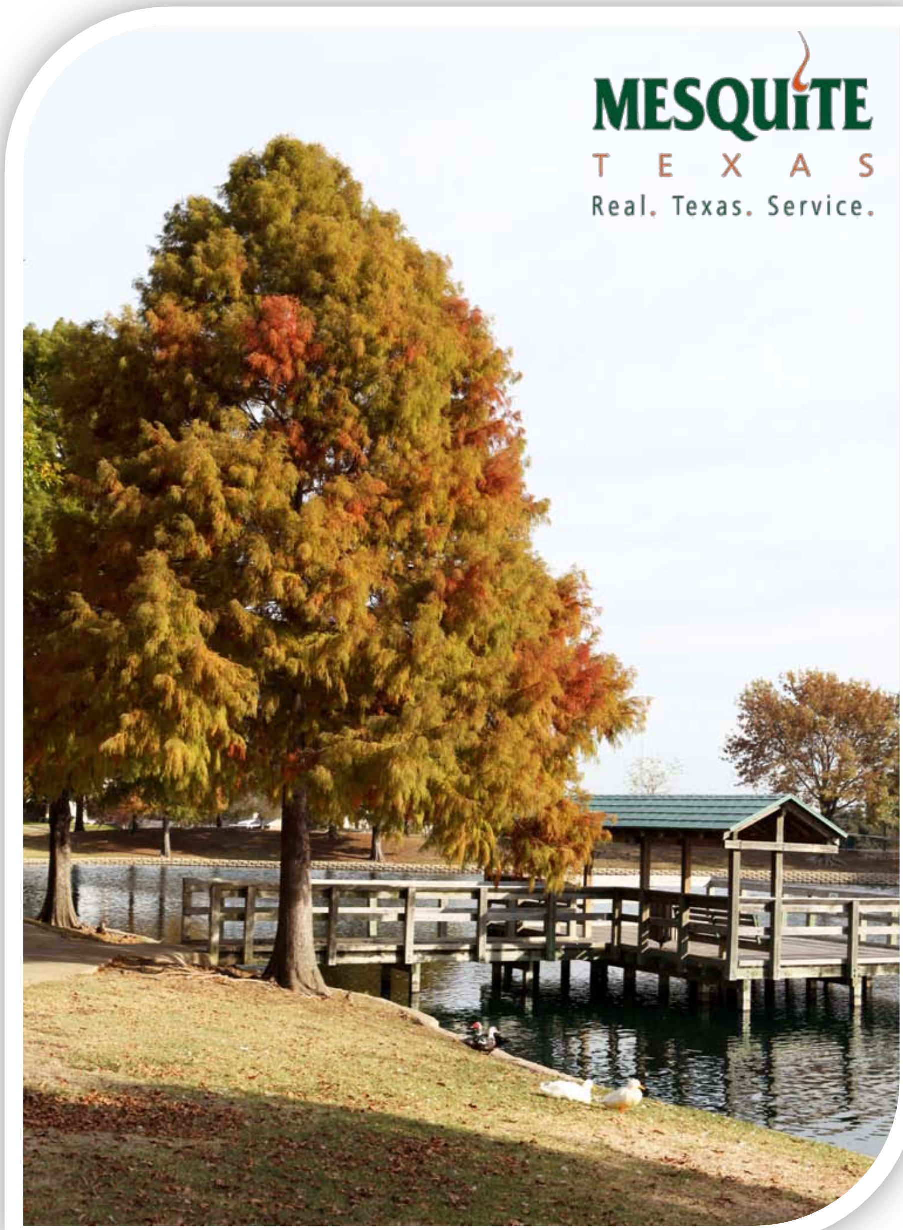
Mesquite Urban Forest Ecosystem Analysis



November 2012

Parks & Recreation

i-Tree

Texas A&M Forest Service

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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 vegetative structure, function, and value of the City of Mesquite urban forest was conducted between February and August 2012. Data from 225 field plots located throughout the City of Mesquite were analyzed using the i-Tree Eco model developed by the U.S. Forest Service, Northern Research Station.

Key findings

- Number of trees: 2,091,000
- Tree cover: 24.4%
- Most common species: Sugarberry, Green ash, Cedar elm
- Percentage of trees less than 6" (15.2 cm) diameter: 75.8%
- Pollution removal: 288 tons/year ($1.54 million/year)
- Carbon storage: 145,000 tons ($10.3 million)
- Carbon sequestration: 13,000 tons/year ($927 thousand/year)
- Oxygen production: 31,900 tons/year ($0 /year)
- Building energy savings: $773 thousand/year
- Avoided carbon emissions: $108 thousand/year
- Annual Rainfall Interception: 30.2 million ft^3/year ($2.01 million/year)
- Structural values: $996 million

Ton: short ton (U.S.) (2,000 lbs) Carbon storage: the amount of carbon bound up in the above-ground and below-ground parts of woody vegetation Carbon sequestration: the removal of carbon dioxide from the air by plants Carbon storage and carbon sequestration values are calculated based on $71 per ton Structural value: value based on the physical resource itself (e.g., the cost of having to replace a tree with asimilar tree) Pollution removal value is calculated based on the prices of $1136 per ton (carbon monoxide), $9110 per ton (PM10). Ozone, sulfur dioxide, nitrogen dioxide and particulate matter less than 2.5 microns are calculated based on US EPA BenMAP model. 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.

Preface

The City of Mesquite began its Urban Forestry Program in 1988 under the direction of the Parks and Recreation Department. At this time, the city set a goal to plant 20,000 trees by the year 2000. Through the efforts of a vigorous, in-house planting schedule, establishment of a landscape ordinance for new development and a tree ordinance designed to replace trees lost during development, the city met this goal in 1999. On April 10, 1999, the City's 20,000th tree, a mesquite (*Prosopis glandulosa*) was planted at the Mesquite Arts Center. Also during this period, the City of Mesquite applied for Tree City USA designation and is currently recertifying for the 23rd consecutive year.

In the Spring of 2012, the Parks & Recreation Department began the effort to further promote the importance of its urban forest by performing an i-Tree ECO study along with the assistance of the Texas A&M Forest Service. The City and Texas A&M Forest Service staff began the process of plotting and mapping 225 random study areas throughout the city. Field studies and data collection began on May 8, 2012 and was completed August 8, 2012.

The result of this project is the Mesquite Urban Forest Ecosystem Analysis. Mesquite is one of only three cities in Texas to complete this process and just one of 773 in the nation and 827 in the world (as of January 2012). The analysis identifies the size of Mesquite's urban forest, the types of tree species most prevalent in the forest and shows the value of this tremendous community asset.

The Mesquite ECO Study would not have been possible without the support and assistance of the following individuals:

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Introduction

The area of interest (AOI) for this study was the City of Mesquite, Texas. The AOI has an area of 46.2 mi^2 or 29,568 acres in size. Located in north Texas within the blackland prairie ecoregion at 32°46′58″N 96°36′36″W (32.782878, -96.609862), the City of Mesquite was founded on March 14, 1878, on land along the Texas & Pacific line just east of Dallas. The railroad, which ran from Dallas to Shreveport, Louisiana, began stopping at the newly created town shortly thereafter. As a result, the city began to grow around the railroad. The city was officially incorporated on December 3, 1887. Over the next one hundred years the city population and subsequently, its infrastructure grew increasing the need to invest in and care for the community's tree resource. With the creation of the city's urban forestry program in 1988, Mesquite began promoting tree planting and maintenance as well as public education. Today's population of 142,674 now benefits from both the environmental and social benefits the community forest provides them as a result of these early efforts.

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 iTree, for the measurement and communication of them. In fact, iTree is now being promoted and used internationally. To date, there have only been two (2) other iTree Eco studies completed in Texas. In 2005, the Houston Regional UFORE study was completed and in 2009 the City of Arlington completed their Eco project. There have been an estimated 827 international and 773 national Eco projects (as of Jan. 2012), respectively. The city of Mesquite'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 Mesquite's urban forest. The completion of this study highlights the value Mesquite's city leaders have placed on their trees and will enable them to continue promoting and enhancing their urban forestry program.

Methods

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 software, 225 0.1 acre circular plots were created and randomly established within the AOI on both public and private property, representing 7.6% of the total AOI. Study plots were also stratified by land use categories using 2006 National Land Classification Database (NLCD) imagery. There were a total of thirteen land use classes identified within Mesquite. The study area was ultimately divided into thirds, creating northern, central, and southern thirds for logistical planning and operational purposes.

Study plots 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.

All plot-level and tree level data were recorded on paper forms and archived following data entry into the Eco program. In addition, study plots were designed as permanent measurement locations through the use of 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. In addition, a minimum of two (2) photos were taken of plot center for each plot. For an overview of all i-Tree Eco methodology, see Appendix I. or visit http://itreetools.org/eco/resources/UFORE%20Methods.pdf .

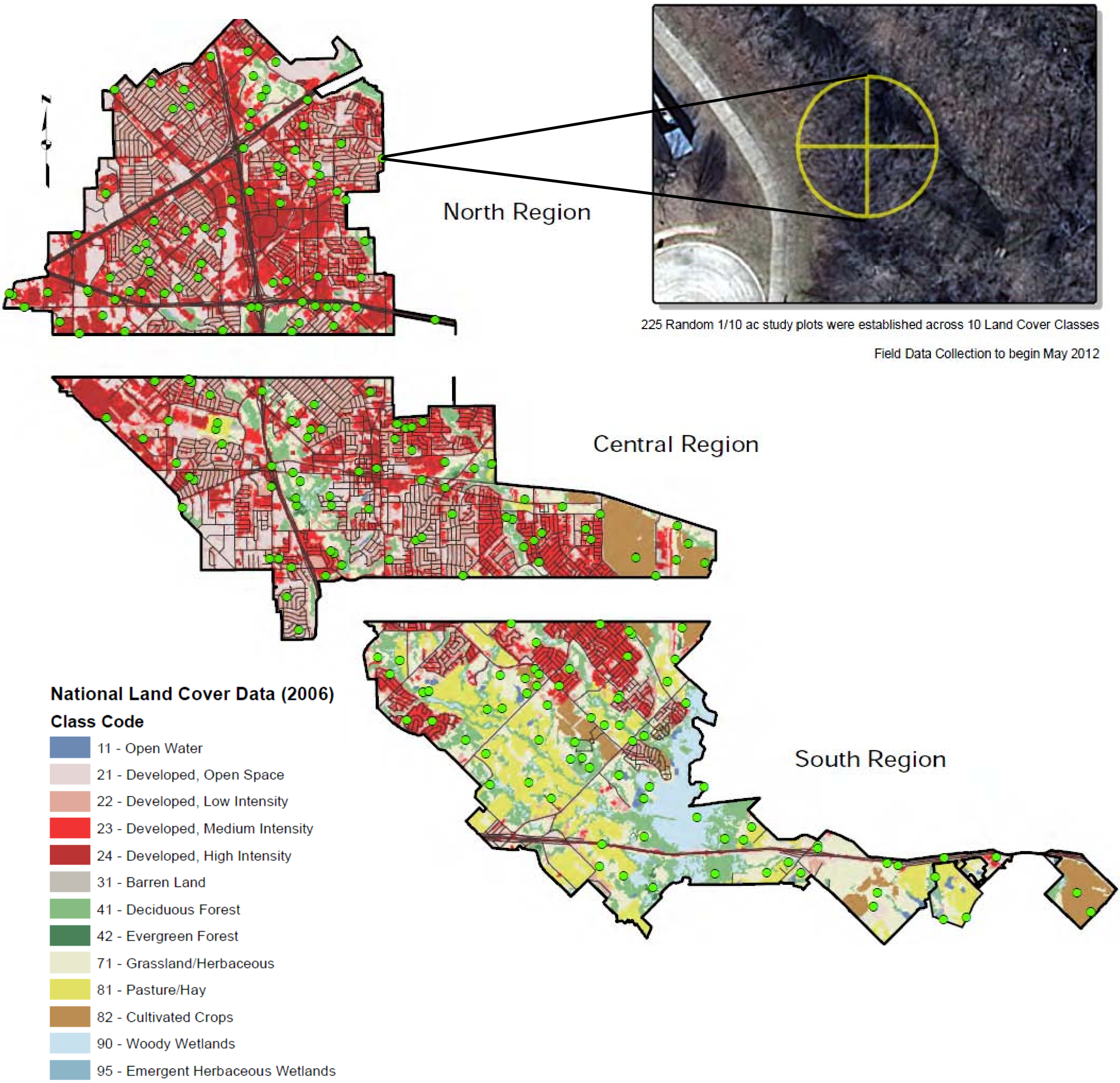

Figure 1. Study plot design for Mesquite Urban Forest Ecosystem Study

Results

I. Tree Characteristics of the Urban Forest

The urban forest of the City of Mesquite has an estimated 2,091,000 trees with a tree cover of 24.4 percent. Trees that have diameters less than 6-inches (15.2 cm) constitute 75.8 percent of the population. The three most common species are sugarberry (*Celtis laevigata*) (27.4 percent), green ash (*Fraxinus pennsylvanica*) (21.2 percent), and cedar elm (*Ulmus crassifolia*) (9.3 percent).

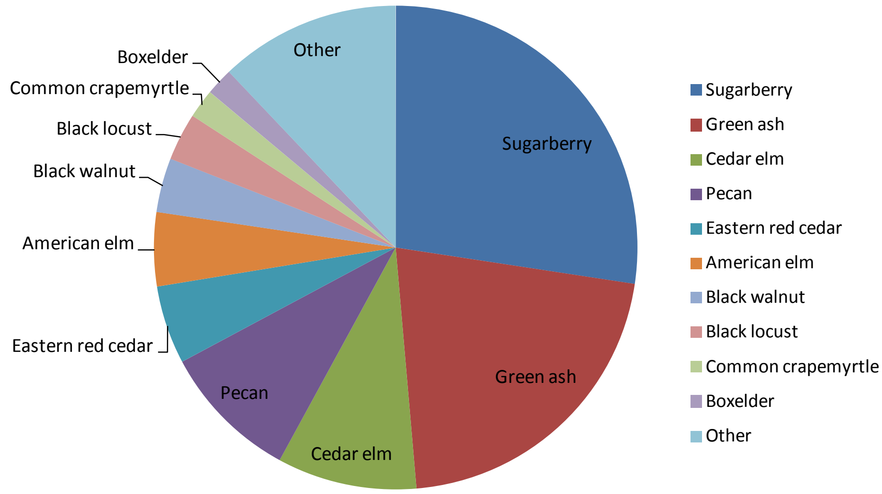

Figure 2. Tree species composition in the City of Mesquite

The overall tree density in the City of Mesquite is 70.7 trees/acre (see Appendix III. for comparable values from other cities). Not surprisingly, the land use classes with the highest forest density were Woody Wetlands and Deciduous Forest, while the land uses categories (other than water) with the fewest trees/ac were Developed, High Intensity and Developed, Medium Intensity.

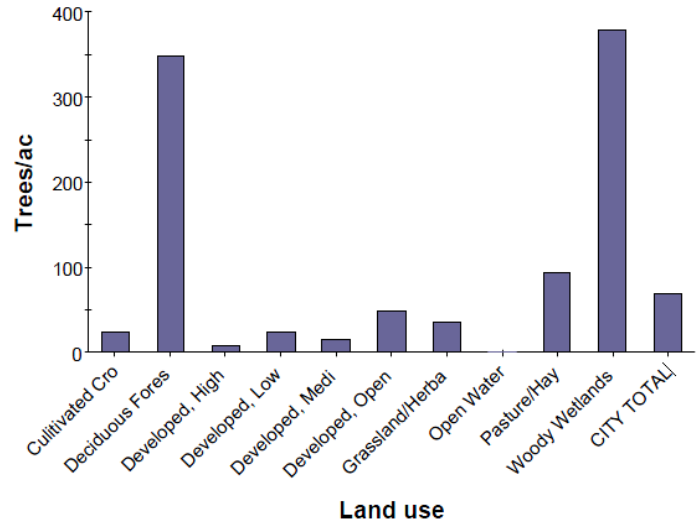

Figure 3. Number of trees/ac in the City of Mesquite by land use

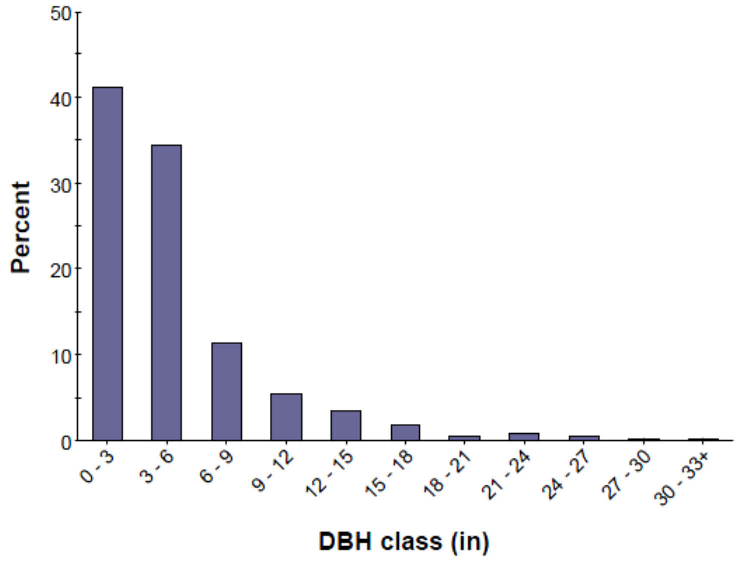

Figure 4. Percent of tree population by diameter class (DBH=stem diameter at 4.5 feet)

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 the City of Mesquite, about 94 percent of the trees are species native to North America, while 80 percent are native to the state. Species exotic to North America make up only 6 percent of the population, with Asia the most common origin (3.9 percent of the species).

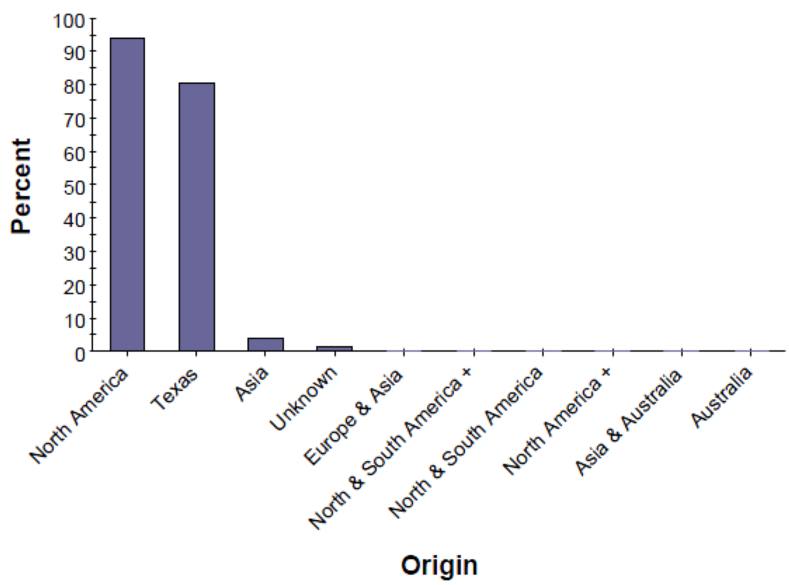

Figure 5. Percent of live trees by species origin

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]. Three of the 54 tree species sampled in the City of Mesquite are identified as invasive on the state invasive species list [2]. These invasive species comprise 0.8 percent of the tree population and thus may only have a minimal level of impact. These three invasive species are Chinese pistache (*Pistacia chinensis*) (0.4 percent of population), white mulberry (*Morus alba*) (0.4 percent), and chinaberry (0.1 percent) (see Appendix V. for details 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 the City of Mesquite, the three most dominant species in terms of leaf area are green ash, sugarberry, and cedar elm. Trees cover about 24.4 percent of the City of Mesquite, and shrubs cover 1.4 percent.

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.

Species Name	*Percent Population*	*Percent Leaf Area*	*IV*
Sugarberry	27.4	18.9	46.3
Green ash	21.2	19.4	40.6
Cedar elm	9.3	14.5	23.8
Pecan	9.2	4.4	13.6
Eastern red cedar	5.2	7.2	12.4
American elm	4.9	5.8	10.8
Live oak	1.4	4.7	6.1
Black walnut	3.6	1.8	5.5
Shumard oak	0.8	4.4	5.2
Black locust	3.2	1.0	4.1

Table 1. Most important tree species in the City of Mesquite

The two most dominant ground cover types are maintained Grass (31.2 percent) and Wild Grass (21 percent).

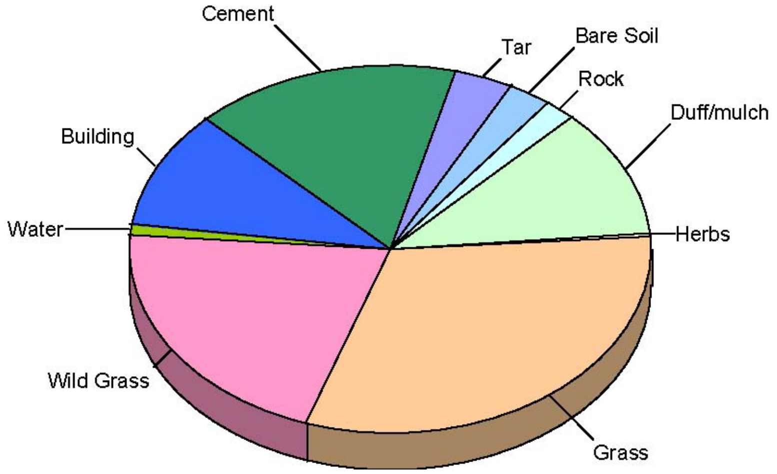

Figure 6. Percent ground cover in the City of Mesquite

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 and shrubs in the City of Mesquite was estimated using field data and recent available pollution and weather data. Pollution removal was greatest for ozone. It is estimated that trees and shrubs remove 288 tons of air pollution (ozone (O3), carbon monoxide (CO), nitrogen dioxide (NO2), particulate matter less than 10 microns (PM10), particulate matter less than 2.5 microns (PM2.5), and sulfur dioxide (SO2)) per year with an associated value of $1.54 million based on estimated local incidence of adverse health effects of the BenMAP model and national median externality costs associated with pollutants [5].

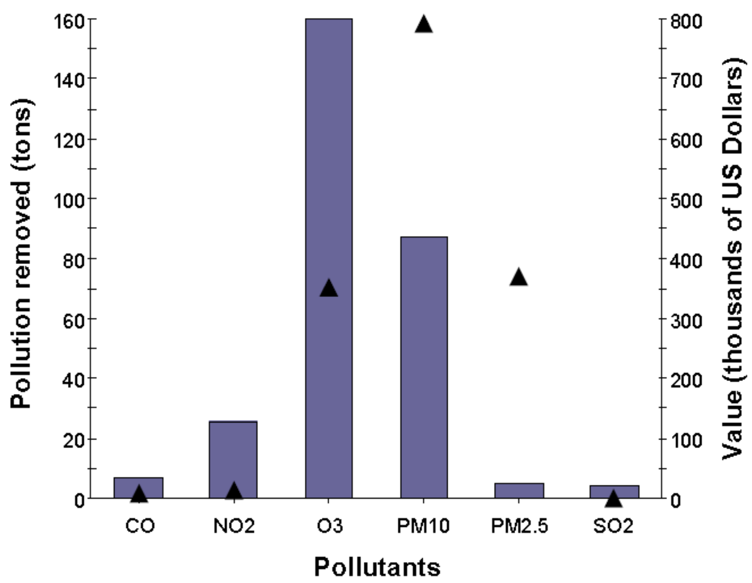

Figure 7. Pollution removal (bars) and associated value (points) for trees in the City of Mesquite Pollution removal and value for PM10 excludes PM2.5 removal and value

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 [7].

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 trees in the City of Mesquite is about 13,000 tons of carbon per year with an associated value of $927 thousand. Net carbon sequestration in the urban forest is about 12,000 tons. Carbon storage and carbon sequestration values are calculated based on $71 per ton.

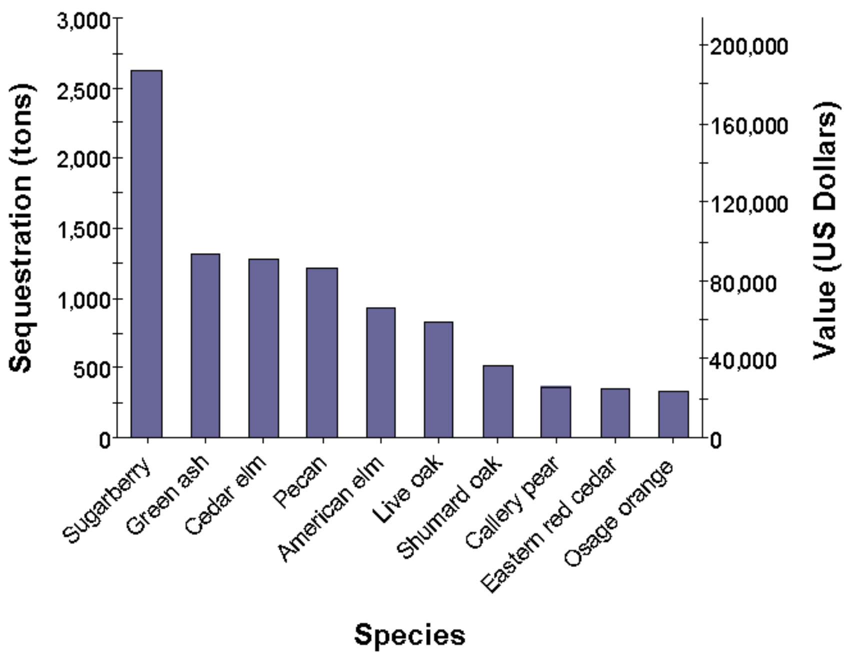

Figure 8. Carbon sequestration and value for species with greatest overall carbon sequestration in the City of Mesquite

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 the City of Mesquite are estimated to store 145,000 tons of carbon ($10.3 million). Of all the species sampled, sugarberry stores and sequesters the most carbon (approximately 13.9% of the total carbon stored and 22.0% 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 the City of Mesquite are estimated to produce 31,900 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 [8].

Species	*Oxygen (tons)*	*Net Carbon Sequestration (tons/yr)*	*Number of trees*	Leaf Area (square miles)
Sugarberry	7,005.53	2,627.07	572,918.00	6.99
Green ash	3,482.57	1,305.96	443,819.00	7.18
Cedar elm	3,394.09	1,272.78	194,871.00	5.36
Pecan	3,230.86	1,211.57	193,107.00	1.62
American elm	2,472.56	927.21	102,993.00	2.16
Live oak	2,226.05	834.77	28,247.00	1.75
Shumard oak	1,364.78	511.79	16,216.00	1.64
Callery pear	989.70	371.14	18,867.00	0.71
Eastern red cedar	948.99	355.87	109,529.00	2.66
Osage orange	880.09	330.03	34,108.00	0.59
Common crapemyrtle	848.10	318.04	40,461.00	0.58
Black walnut	618.73	232.03	75,863.00	0.68
Black locust	594.31	222.87	66,422.00	0.36
White mulberry	549.57	206.09	8,114.00	0.69
Post oak	542.01	203.26	6,723.00	0.27
Boxelder	472.32	177.12	38,056.00	0.45
Red mulberry	407.47	152.80	1,345.00	0.28
American sycamore	291.77	109.42	5,439.00	0.52
Arizona ash	211.91	79.47	4,057.00	0.39
Chinese pistache	194.48	72.93	8,166.00	0.30

Table 2. Mesquite's top 20 oxygen-producing species.

VI. Trees and Building Energy Use

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

Based on 2002 prices, trees in the City of Mesquite are estimated to reduce energy-related costs from residential buildings by $773 thousand annually. Trees also provide an additional $107,545 in value [10] by reducing the amount of carbon released by fossil-fuel based power plants (a reduction of 1,510 tons of carbon emissions).

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

	Heating	*Cooling*	*Total*
MBTU[1] MWH[2] Carbon avoided (t[3])	-8,290 -311 -195	n/a 7,772 1,705	-8,290 7,461 1,510

Note: negative numbers indicate an increased energy use or carbon emission.

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

Table 4. Annual savings[1] ($) in residential energy expenditure during heating and cooling seasons.

	Heating	*Cooling*	*Total*
MBTU[2]	-84,147	n/a	-84,147
MWH[3]	-35,734	893,003	857,269
Carbon avoided	-13,895	121,440	107,545

Note: negative numbers indicate a cost due to increased energy use or carbon emission.

[1]Based on the prices of $114.9 per MWH and $10.15 per MBTU. [2]One million British Thermal Units [3]Megawatt-hour

VII. Annual Rainfall Interception

The Federal Clean Water Act regulates municipal stormwater discharge that enters public water sources. Municipal governments are required to outline and submit Best Management Practices for avoiding and reducing pollutant discharge. Fortunately, municipal trees aid in reducing stormwater runoff by intercepting and storing rainfall on their leaves and branches. Reducing the volume of runoff during a storm event helps to minimize both soil erosion potential and peak flow levels. More specifically, healthy urban trees play an important role in stormwater management in three key ways:

1. Reducing the overall volume of water entering the storm system by leaf and branch absorption.
2. Increased soil health and structure due to the process of root growth and decomposition, thus increasing water infiltration rates that ultimately reduce overland water flow.
3. Reduction of rainfall velocity and the soil impact rate of raindrops through tree canopy interception which reduces soil erosion potential and surface transport rates of water.

Land Use Class	Tree Number	Leaf Area (mi^2)	Rainfall Interception (ft^3/yr)	Rainfall Interception Value ($)
Culitivated Crop	31,032	0.3	225,140.7	14,989
Deciduous Forest	918,429	12.6	10,299,085.1	685,679
Developed, High Intensity	21,120	0.4	353,477.3	23,533
Developed, Low Intensity	174,034	6.9	5,636,401.5	375,253
Developed, Medium Inten	86,956	2.7	2,235,010.6	148,799
Developed, Open	180,182	4.4	3,606,666.3	240,120
Grassland/Herbaceous	105,913	1.5	1,237,328.1	82,377
Pasture/Hay	199,153	1.8	1,438,819.6	95,792
Woody Wetlands	374,029	6.4	5,192,426.5	345,694
Total	2,090,848	37.0	30,224,355.8	2,012,236
Water interception value is derived by the price \$0.067/ft^3				

Table 5. Rainfall Interception for Trees in City of Mesquite by Land Use

The Trees of the City of Mesquite provide a total of 30.2 million ft^3/yr of stormwater reduction which has a total monetary savings of \$2.01 million annually. As with all benefits these values will continue to increase as the trees growth and increase their canopy coverage, especially over impervious surfaces such as sidewalks, parking lots and streets. The top three species for rainfall interception are green ash, sugarberry, and cedar elm.

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

Structural values:

- Structural value: $996 million
- Carbon storage: $10.3 million

Annual functional values:

- Carbon sequestration: $927 thousand
- Pollution removal: $1.54 million
- Lower energy costs and carbon emission reductions: $881 thousand (Note: negative value indicates increased energy cost and carbon emission value)

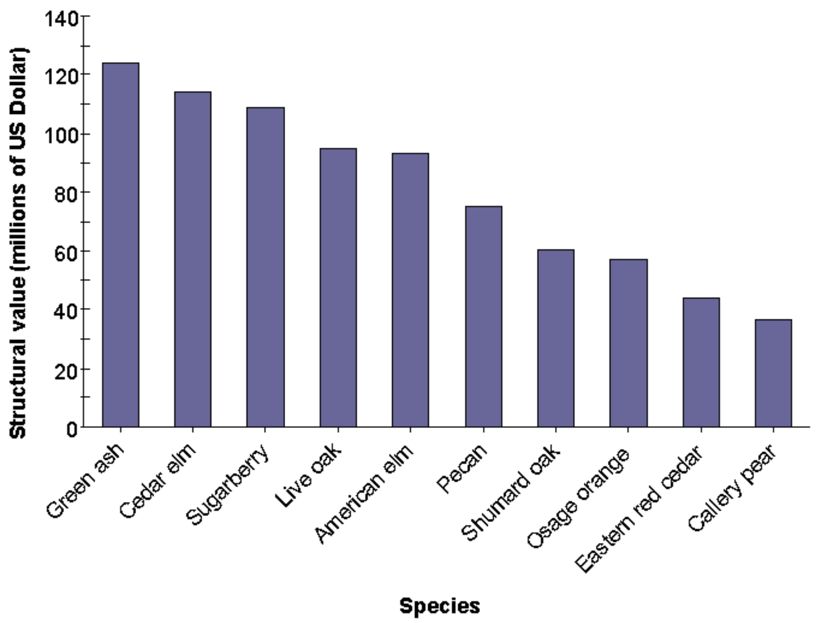

Figure 9. Structural value of the 10 most valuable tree species in the City of Mesquite

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 [12] 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.

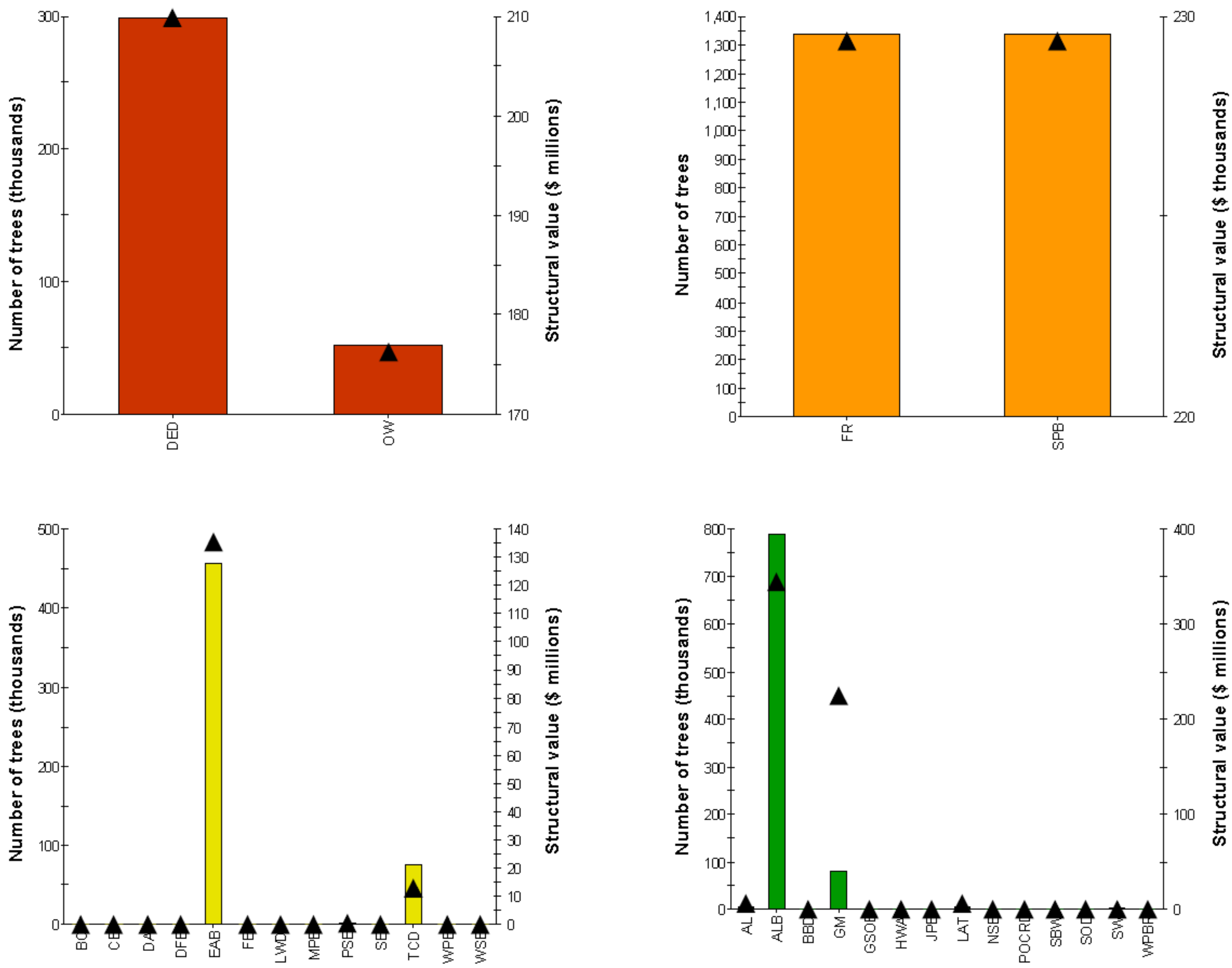

Figure 10. Susceptibility of the City of Mesquite trees and structural value by pest (▲)

In the City of Mesquite, by far the most potential for loss related to pests and associated diseases are from Dutch Elm Disease (DED) and Oak Wilt Disease (OW), with 14.3% and 2.5% of the total population worth $210 million and $176 million, respectively. Other potential risk includes fusiform rust disease and southern pine beetle (SPB) infestations associated with pines. Emerald ash borers have caused the death of millions of ash trees in the Midwest and should be a future concern for tree managers in Mesquite and the rest of the Metroplex as the pests continue to migrate south and west, especially considering green ash is the second most populous species with 21% of all trees. See Appendix VI. for more potential risk of pests information.

Discussion

The Mesquite 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. With 24% canopy cover across the city there is a clear opportunity for continued growth. In fact, since a majority of the city's trees are 6" or less in diameter most trees are relatively young and with proactive care should grow, expanding the coverage of canopy over the community and providing heightened benefits over time. However, the city should be conscious of which trees make up their canopy since some trees are less desirable either due to higher susceptibility to pest and disease or because they are relatively short lived. Furthermore, nearly 58% of all trees were represented by only three species. Thus, diversifying species selection in future planting initiatives is recommended in order to enhance the forest's quality and resilience.

Ultimately, an inventory of all city owned trees should be conducted to facilitate management decisions that may improve the health and condition of the trees as well as to reduce risk in the event of tree loss/failure during storm events. It is recommended that the city of Mesquite develop an Urban Forest Management Plan that outlines goals and the tasks necessary to reach them. Establishing measureable goals will allow the urban forest program staff to establish work priorities, monitor progress and develop appropriate budgets annually.

Mesquite represents only the third community in the state to complete an iTree Eco study and only the second in the DFW Metroplex. So, how does the urban forest of Mesquite compare to other Texas communities? 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 iTree software versions.

Converting benefit results to per tree and per acre values allows for the best comparison. Mesquite enjoys an average tree density with 71 trees per acre (tpa). The City of Arlington, however only had 45 tpa while the Houston region measured 137 tpa. In contrast, Mesquite has a slightly lower diversity of trees with only 54 distinct species encountered as compared to 77 species in Arlington and 67 species in Houston. Mequite's canopy coverage is representative of other communuties in Texas and the Metroplex. In fact, a 16-county regional icanopy coverage analyis for north Texas found the region to have approximately 23% coverage. In terms of average benefits values, Mesquite has relatively higher amounts of benefits on both a per tree and per acre basis. However, as a result of fewer trees the structural value of Mesquite's urban forest was slightly less than that found in both the City of Arlington and the Houston region studies. See Appendix III. for a comparison of Mesquite's urban forest with other North American cities.

Per Tree Benefit Values for Several iTree Eco Studies in Texas

Location	Year	Scale	# of Trees	Acres	Tree/Acre	# of Species	Canopy Cover (%)	Carbon Storage ($)	Carbon Sequestration ($/yr)	Energy Savings ($/yr)	Air Quality ($/yr)	Rainfall Interception ($/yr)	Average of All Benefits ($)	Structural / Replacement Value ($)
Houston	2005	Region (8 County)	663,000,000	4,851,840	137	67	28	1.87	0.04	0.20	0.45	NA	0.64	311
Arlington	2009	City	2,965,000	65,889	45	77	22	2.87	0.15	0.99	0.98	1.44	1.29	944
Mesquite	2012	City	2,091,000	29,568	71	54	24	4.92	0.44	0.37	0.74	0.96	1.49	476

Per Acre Benefit Values for Several iTree Eco Studies in Texas

Location	Year	Scale	# of Trees	Acres	Tree/Acre	# of Species	Canopy Cover (%)	Carbon Storage ($)	Carbon Sequestration ($/yr)	Energy Savings ($/yr)	Air Quality ($/yr)	Rainfall Interception ($/yr)	Average of All Benefits ($)	Structural / Replacement Value ($)
Houston	2005	Region (8 County)	663,000,000	4,851,840	137	67	28	148.60	5.98	27.00	61.00	NA	60.65	42,458
Arlington	2009	City	2,965,000	65,889	45	77	22	129.00	6.94	44.54	44.00	65.36	57.97	42,496
Mesquite	2012	City	2,091,000	29,568	71	54	24	348.35	31.35	26.14	52.08	67.98	105.18	33,685

Table 5. Per tree and per acre benefit values for iTree Eco studies in Texas

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 [10], including:

- Urban forest structure (e.g., species composition, tree health, leaf area, etc.).
- Amount of pollution removed hourly by the urban forest, and its associated percent air quality improvement throughout a year. Pollution removal is calculated for ozone, sulfur dioxide, nitrogen dioxide, carbon monoxide and particulate matter (<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, 225 0.10 acre circular plots (radius = 37.2 feet) were randomly distributed throughout the study area and stratified by land use categories. 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 [44, 6].

Invasive species were 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 [45]. 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.

The amount of oxygen produced is estimated from carbon sequestration based on atomic weights: net O2 release (kg/yr) = net C sequestration (kg/yr) × 32/12. To estimate the net carbon sequestration rate, the amount of carbon sequestered as a result of tree growth is reduced by the amount lost resulting from tree mortality. Thus, net carbon sequestration and net annual oxygen production of the urban forest account for decomposition [46].

Air pollution removal estimates are derived from calculated hourly tree-canopy resistances for ozone, and sulfur and nitrogen dioxides based on a hybrid of big-leaf and multi-layer canopy deposition models [47, 48]. As the removal of carbon monoxide and particulate matter by vegetation is not directly related to transpiration, removal rates (deposition velocities) for these pollutants were based on average measured values from the literature [49, 50] that were adjusted depending on leaf phenology and leaf area. Removal estimates of particulate particulate matter less than 10 microns incorporated a 50 percent resuspension rate of particles back to the atmosphere [51]. Recent updates (2011) to air quality modeling are based on improved leaf area index simulations, weather and pollution processing and interpolation, and updated pollutant monetary values [52, 53, and 54].

Air pollution removal value was calculated based on local incidence of adverse health effects and national median externality costs. The number of adverse health effects and associated economic value is calculated for ozone, sulfur dioxide, nitrogen dioxide, and particulate matter <2.5 microns using the U.S. Environmental Protection Agency's Environmental Benefits Mapping and Analysis Program (BenMAP). The model uses a damage-function approach that is based on the local change in pollution concentration and population [5].

National median externality costs were used to calculate the value of carbon monoxide removal. As particulate matter <10 microns is inclusive of particulate matter <2.5 microns, the pollution removal value for particulate matter <10 microns utilizes both local incidence values from particulate matter <2.5 microns and national median externality costs from particulate matter <10 microns to estimate the air pollution removal values. Thus the value for particulate matter <10 microns = ((PM10 (mt/yr)-PM2.5 (mt/yr))*median externality)+PM2.5 ($/yr).

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

Structural values were based on valuation procedures of the Council of Tree and Landscape Appraisers, which uses tree species, diameter, condition, and location information [55].

Potential pest risk was 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) [12] 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 [12].

Appendix II. Relative Tree Effects

The urban forest in the City of Mesquite 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 [56], average passenger automobile emissions [57], and average household emissions [58].

Carbon storage is equivalent to:

- Amount of carbon emitted in the City of Mesquite in 61 days
- Annual carbon (C) emissions from 86,900 automobiles
- Annual C emissions from 43,600 single-family houses

Carbon monoxide removal is equivalent to:

- Annual carbon monoxide emissions from 26 automobiles
- Annual carbon monoxide emissions from 109 single-family houses

Nitrogen dioxide removal is equivalent to:

- Annual nitrogen dioxide emissions from 1,600 automobiles
- Annual nitrogen dioxide emissions from 1,070 single-family houses

Sulfur dioxide removal is equivalent to:

- Annual sulfur dioxide emissions from 6,390 automobiles
- Annual sulfur dioxide emissions from 107 single-family houses

Particulate matter less than 10 micron (PM10) removal is equivalent to:

- Annual PM10 emissions from 244,000 automobiles
- Annual PM10 emissions from 23,600 single-family houses

Annual carbon sequestration is equivalent to:

- Amount of carbon emitted in the City of Mesquite in 5.5 days
- Annual C emissions from 7,800 automobiles
- Annual C emissions from 3,900 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.

City	*% Tree Cover*	*Number of trees*	*Carbon storage (tons)*	*Carbon Sequestration (tons/yr)*	*Pollution removal (tons/yr)*
Calgary, Canada	7.2	11,889,000	445,000	21,422	326
Atlanta, GA	36.8	9,415,000	1,345,000	46,433	1,662
Toronto, Canada	20.5	7,542,000	992,000	40,345	1,212
New York, NY	21.0	5,212,000	1,351,000	42,283	1,677
Baltimore, MD	21.0	2,627,000	596,000	16,127	430
Philadelphia, PA	15.7	2,113,000	530,000	16,115	576
Mesquite, TX	24.4	2,091,000	145,000	13,000	288
Washington, DC	28.6	1,928,000	523,000	16,148	418
Boston, MA	22.3	1,183,000	319,000	10,509	284
Woodbridge, NJ	29.5	986,000	160,000	5561.00	210
Minneapolis, MN	26.5	979,000	250,000	8,895	305
Syracuse, NY	23.1	876,000	173,000	5,425	109
Morgantown, WV	35.9	661,000	94,000	2,940	66
Moorestown, NJ	28.0	583,000	117,000	3,758	118
Jersey City, NJ	11.5	136,000	21,000	890	41
Freehold, NJ	34.4	48,000	20,000	545	21

I. City totals for trees

City	*No. of trees*	*Carbon storage (tons)*	*Carbon sequestration (lbs/yr)*	*Pollution removal (lbs/yr)*
Morgantown, WV	119.7	17	0.532	23.8
Atlanta, GA	111.6	15.9	0.55	39.4
Mesquite, TX	70.7	4.9	0.44	19.48
Calgary, Canada	66.7	2.5	0.12	3.6
Woodbridge, NJ	66.5	10.8	0.375	28.4
Moorestown, NJ	62	12.5	0.4	25.2
Syracuse, NY	54.5	10.8	0.338	13.6
Baltimore, MD	50.8	11.5	0.312	16.6
Washington, DC	49	13.3	0.41	21.2
Toronto, Canada	48.3	6.4	0.258	15.6
Freehold, NJ	38.5	16	0.437	33.6
Boston, MA	33.5	9	0.297	16
New York, NY	26.4	6.8	0.214	17
Minneapolis, MN	26.2	6.7	0.238	16.4
Philadelphia, PA	25	6.3	0.19	13.6

II. Per acre values of tree effects

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 [59]:

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

Urban forest management strategies to help improve air quality include [61]:

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]:

[1]*Species Name*	*Number of trees*	*% Tree Number*	*Leaf Area (mi2)*	*% Leaf Area*
Chinese pistache	8,166	0.39	0.30	0.82
White mulberry	8,114	0.39	0.69	1.87
Chinaberry	1,338	0.06	0.08	0.21
TOTAL	**17,618**	**0.84**	**1.08**	**2.91**

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

Appendix VI. Potential risk of pests

Based on the host tree species for each pest and the current range of the pest [12], 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
Orange	9	Slash pine											Orange											Yellow				Orange	Green				
Red	5	American elm		Green					Red																								
Red	5	Bur oak												Green								Red											
Red	5	Cedar elm		Green					Red																								
Red	5	Live oak												Green								Red											
Red	5	Post oak												Green								Red											
Red	5	Shumard oak												Green								Red											
Red	5	Winged elm		Green					Red																								
Green	4	Black willow	Green	Green										Green				Green															
Green	4	Silky willow	Green	Green										Green				Green															
Yellow	3	Green ash		Green							Yellow																						
Yellow	2	Arizona ash									Yellow																						
Yellow	2	Black walnut																												Yellow			
Yellow	2	Patmore ash									Yellow																						
Yellow	2	Pumpkin ash									Yellow																						
Green	2	Chinese elm		Green										Green																			
Green	1	Boxelder		Green																													
Green	1	Callery pear												Green																			
Green	1	Japanese maple		Green																													
Green	1	Sweetgum												Green																			

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

Potential Pest List

Aspen Leafminer (AL) [13] 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 0.2 percent of the population ($5.92 million in structural value).

Asian Longhorned Beetle (ALB) [14] is an insect that bores into and kills a wide range of hardwood species. ALB poses a threat to 37.7 percent of the City of Mesquite urban forest, which represents a potential loss of $345 million in structural value.

Beech Bark Disease (BBD) [15] 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) [16] 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).

Chestnut Blight (CB) [17] are American and European chestnut. CB has the potential to affect 0.0 percent of the population ($0 in structural value).

Dogwood Anthracnose (DA) [18] 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.

Dutch Elm Disease (DED) [19] has devastated American elm trees, one of the most important street tree species in the twentieth century. Since first reported in the 1930s, it has killed over 50 percent of the native elm population in the United States. Although some elm species have shown varying degrees of resistance, the City of Mesquite could possibly lose 14.3 percent of its trees to this pest ($210 million in structural value).

Douglas-Fir Beetle (DFB) [20] 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) [21] has killed thousands of ash trees in parts of the United States. EAB has the potential to affect 21.9 percent of the population ($135 million in structural value).

Fir Engraver (FE) [22] is a common pest of white fir, grand fir, and red fir trees. FE poses a threat to 0.0 percent of the City of Mesquite urban forest, which represents a potential loss of $0 in structural value.

Fusiform Rust (FR) [23] 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 0.1 percent of the population ($229 thousand in structural value).

The Gypsy Moth (GM) [25] is a defoliator that feeds on many species causing widespread defoliation and tree death if outbreak conditions last several years. This pest threatens 3.8 percent of the population, which represents a potential loss of $225 million in structural value.

Goldspotted Oak Borer (GSOB) [24] infestations have been a growing problem in southern California. Potential loss of trees from GSOB is $0 ($0 in structural value).

Hemlock Woolly Adelgid (HWA) [26] is one of the most damaging pests to eastern hemlock and Carolina hemlock, and has played a large role in hemlock mortality in the United States. HWA has the potential to affect 0.0 percent of the population ($0 in structural value).

The Jeffrey Pine Beetle (JPB) [27] 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.

Large Aspen Tortrix (LAT) [28] is a concern for quaking aspen and other trees in the Populus genus. LAT poses a threat to 4.07 thousand percent of the City of Mesquite urban forest, which represents a potential loss of $5.92 million in structural value.

Laurel Wilt (LWD) [29] 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) [30] 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) [31] 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) [32], which is caused by a fungus, is a prominent disease among oak trees. OW poses a threat to 2.5 percent of the City of Mesquite urban forest, which represents a potential loss of $176 million in structural value.

Port-Orford-Cedar Root Disease (POCRD) [33] 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) [34] 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 0.1 percent of the population ($229 thousand in structural value).

Spruce Beetle (SB) [35] 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) [36] is an insect that causes severe damage to balsam fir. SBW poses a threat to 0.0 percent of the City of Mesquite urban forest, which represents a potential loss of $0 in structural value.

Sudden Oak Death (SOD) [37] is a disease that is caused by a fungus. Potential loss of trees from SOD is $0 ($0 in structural value).

Southern Pine Beetle (SPB) [38] will attack most pine species, however its preferred hosts are loblolly, Virginia, pond, spruce, shortleaf, and sand pines. This pest threatens 0.1 percent of the population, which represents a potential loss of $229 thousand in structural value.

The Sirex Wood Wasp (SW) [39] is a wood borer that primarily attacks pine species. SW poses a threat to 0.1 percent of the City of Mesquite urban forest, which represents a potential loss of $229 thousand in structural value.

Thousand Canker Disease (TCD) [40] is an insect-disease complex that kills several species of walnuts, including black walnut. Potential loss of trees from TCD is 75.9 thousand ($13.1 million in structural value).

The Western Pine Beetle (WPB) [41] 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.

White Pine Blister Rust (Eastern U.S.) (WPBR) [42] has had a detrimental effect on white pines, particularly in the Lake States, since its introduction to the United States in 1900. WPBR has the potential to affect 0.0 percent of the population ($0 in structural value).

Western spruce budworm (WSB) [43] 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.

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Average annual passenger automobile emissions per vehicle were based on dividing total 2002 pollutant emissions from light-duty gas vehicles by total number of passenger cars in 2002 (National Transportation Statistics http://www.bts.gov/publications/national_transportation_statistics/2004/).

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