

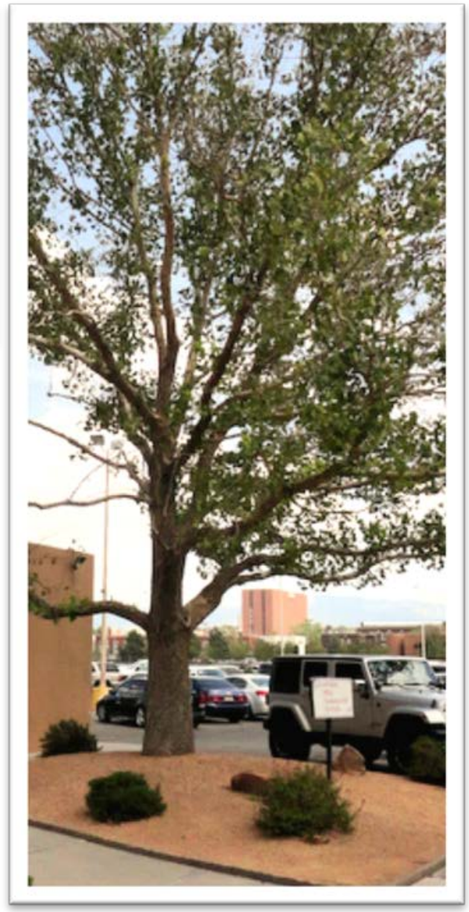

Urban & Community Forest Assessment Project

Southwest Area Summary

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Prepared for:

State of New Mexico Energy, Minerals & Natural Resources Dept.
1220 S St Francis Dr. Santa Fe, New Mexico 87505
(505)476-3330

Prepared by:

Davey Resource Group *A Division of The Davey Tree Expert Company*
Western Region Office 6005 Capistrano Ave. Ste. A Atascadero, CA 93422
Contact: Vince Mikulanis
Vince.Mikulanis@davey.com
(619) 921-2746

DAVEY RESOURCE GROUP
A Division of The Davey Tree Expert Company

This project was developed in partnership with:

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City of Las Cruces

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Tables and Figures

Definitions for **bold** words are available in the Glossary.
Monetary values are reported in US dollars throughout the report.

Executive Summary

In 2013, the New Mexico Energy, Minerals and Natural Resources Department (EMNRD) contracted with Davey Resource Group (DRG) to assess the ecosystem services provided by southwestern urban forests. Field teams collected data to quantify land cover, including tree cover, and perform an analysis of the ecosystem services and benefits of trees on a landscape level for communities in Arizona, Texas and New Mexico. This summary report contains the results of the i-Tree Eco software analysis conducted in four southwest communities: Phoenix, Albuquerque, El Paso, and Las Cruces.

The climate, land area and population, tree species and tree age composition and budget resources of the four communities vary widely, so it is not recommended to use this summary to compare communities to each other. Rather, this summary is intended to provide an overview of the range of values found in the southwest region.

Data were collected in about 200 designated plots in each city, which were randomly distributed across the project areas. The data were analyzed using the i-Tree Eco model developed by the U.S. Forest Service, Northern Research Station.

Based on this sample, average tree canopy in the southwest is estimated to cover 8.6% of the land area. The tree population is mostly young or small statured, with 51% of the population under 6” in **Diameter at Breast Height** (DBH). The tree population provides valuable benefits to the communities in the project areas, valued at over $52 million, and with an average per capita annual value of $6.41, as shown in Table 1.

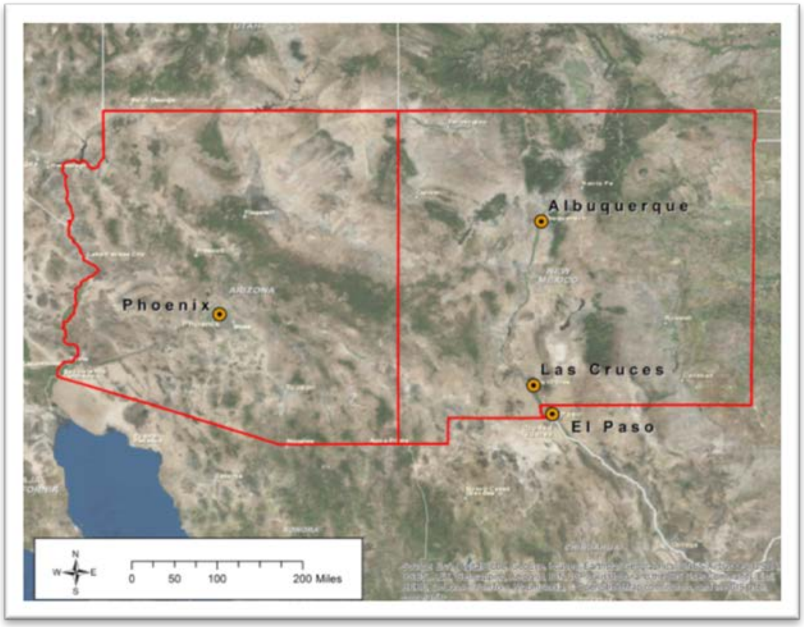
Table 1. Annual Tree Benefit Values ($)

	El Paso	Albuquerque	Phoenix	Las Cruces	Total
Air Pollution Removal	$247,000	$1,100,000	$5,760,000	$235,000	**$7,342,000**
Annual Carbon Sequestration	$529,000	$692,000	$2,520,000	$112,000	**$3,853,000**
Avoided Carbon Emissions	$384,000	$448,000	$2,960,000	$75,000	**$3,867,000**
Building Energy Savings	$2,700,000	$3,310,000	$22,900,000	$563,000	**$29,473,000**
Avoided Storm Water Runoff	$2,190,000	$3,420,000	$6,110,000	$59,800	**$11,779,800**
Total Benefit					

Project area urban forest managers can use the results of the community forest analyses to further understand the composition, species and age distribution, benefits and values, and possible risks in the urban forest. Air Quality and Utility managers can use the data to support planting and maintenance of appropriate tree species to maximize air quality benefits, stormwater runoff, and energy. These data, unique to the project area, can help managers understand the unique attributes of their communities' urban forests.

The data and analysis also provide valuable information about southwest urban forests. The southwest urban forest is under-represented in national urban forestry data, and this project has furthered understanding of its composition and health.

Introduction

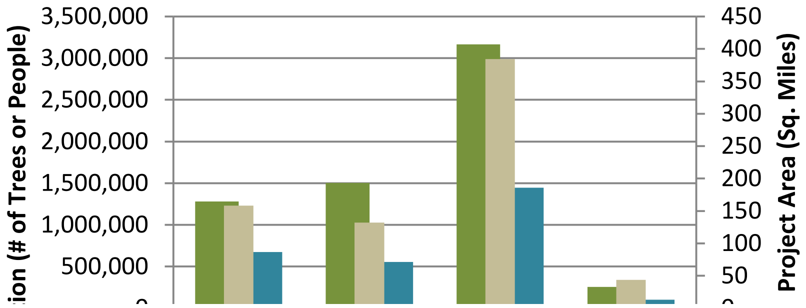


Four southwest communities were studied.

The arid southwest is not known for abundant trees and forests, but the uniquely adapted trees that live in the area provide substantial environmental and economic benefits. In this region, significant effort is required to plant, establish and maintain community trees on both public and private property. Water resources to provide irrigation are limited, and urban forests must compete with other water users. Investment in the urban forest is rewarded with cooling shade, increased air quality, carbon storage, and stormwater runoff reduction, all of which can be modeled and quantified. Costs and benefits of the urban forest in the southwest must be carefully balanced.

The Community Forest Assessments for El Paso, Albuquerque, Phoenix, and Las Cruces can provide benchmarks for the current amount of canopy, leaf surface area, and structure of the urban forest including both public and private trees. They also provide an overview of the ecosystem services of these trees, providing an important perspective on the understanding of the southwest urban forest.

This project provides a rough estimate of the number of trees, species composition, size, and benefits of trees in the four communities. It is important to note that the data is based on a sample, not a census, or complete tree inventory. To inventory all trees on public and private property would be prohibitively resource intensive. Recognizing this, the USDA Forest Service developed the i-tree Eco sampling methodology and software. The data reported

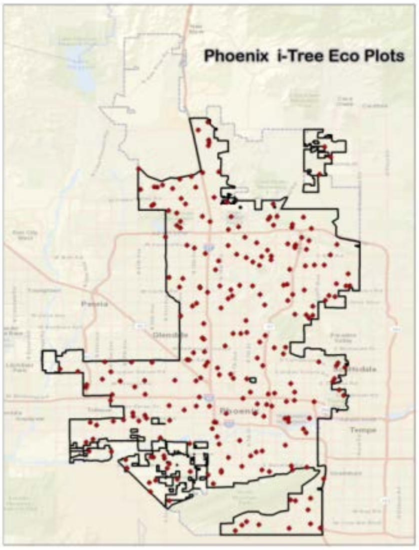


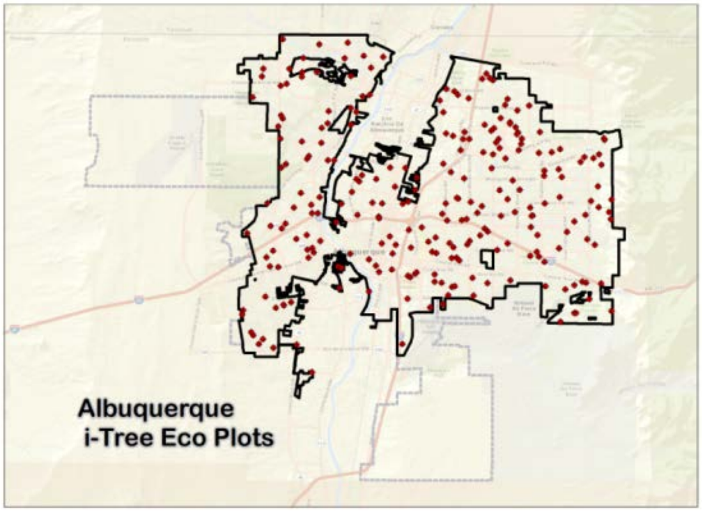
significant error associated with some portions of the data. Error rates are shown where possible to get a sense of the range of values that may be present in the landscape.

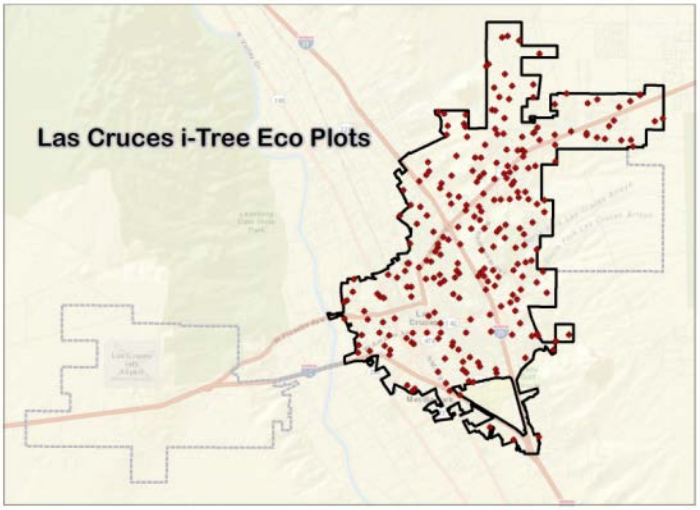
The communities studied vary in size, climate, and financial resources. It is important to consider these factors when reviewing their urban forest composition and benefits. There are also differences in land use composition, elevation, and urban density that impact the urban forest.

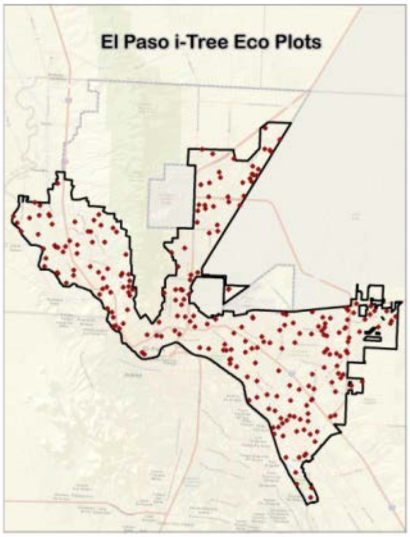
Methods

Project Areas









ecosystem, providing the benefits calculated by the i-Tree Eco model. That is not to say that the trees and shrubs in the excluded areas are not important in providing air quality, stormwater, carbon, and energy benefits, but their influence in the i-Tree Eco model is diminished since they are not in close proximity to urban infrastructure and air conditioned buildings, so their contribution is not likely representative of those in the more urban environment.

For example, a tree in an undeveloped area may provide the same carbon storage benefits as its urban counterpart, but because it is not in close proximity to infrastructure, the residential energy-use benefits are negligible. The pollutant absorption capacity depends on many factors including levels of pollutants, wind and dispersal, and proximity to the source of pollution; thus, the capacity of a tree in an undeveloped area is difficult to calculate with this model which presumes urban infrastructure and activities are nearby. A tree in an undeveloped area is also unlikely to provide substantial property value benefits or have a replacement value since wildland trees that fail are not typically replaced. So, while these trees still have value and provide benefits, those benefits do not fit with the attributes in the i-Tree Eco model, and it was reasonable to exclude them from the study.

The excluded areas provide benefits to the community and if they become more developed should be included in future studies. One factor likely affected by surrounding vegetation but not calculated in the study is the urban heat island effect. Vegetation on land outside the study area may mitigate heat associated with buildings and paved surfaces within the study area, and those benefits are not reflected in this model, which is geared toward understanding tree benefits provided within urbanized areas (Weng et al., 2003).

i-Tree Eco Model and Field Measurements

Model Components

The model selected to calculate urban forest benefits was the i-Tree Eco model. The i-Tree Eco model is designed to use field data collected based on a standardized protocol from randomly located plots and local hourly air pollution and meteorological data to quantify urban forest structure and its numerous effects [Nowak &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. Pollution removal is calculated for ozone, sulfur dioxide, nitrogen dioxide, carbon monoxide and particulate matter (<2.5 microns and <10 microns).

In the field, 0.1-acre plots were randomly distributed across the study site using the ArcView GIS random point generation tool. All field data were collected during the leaf-on season to properly assess tree canopies. Within each plot, typical data collection included 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 and Nowak et al., 2008].

The land uses were determined based on the primary use of the land at the sample site. Land uses varied among the communities, and details are provided in the individual reports.

The i-Tree Eco model uses a local list of invasive plants to determine how many of the trees in the sample are invasive. These lists are not exhaustive and they cover invasive species of varying degrees of invasiveness and distribution. 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.

Urban Tree Benefit and Pathogen and Pest Risk Calculations

To calculate current carbon storage, biomass for each tree was calculated by incorporating measured tree data into equations from the literature. Open-grown, maintained trees tend to have less biomass than predicted by forest-derived biomass equations [Nowak, 1994]. To adjust for this difference, i-Tree Eco multiplies biomass results for open-grown urban trees by 0.8. The i-Tree Eco model converted tree dry-weight biomass to stored carbon by multiplying by 0.5.

To estimate the gross amount of carbon sequestered annually, average diameter growth from the appropriate genera and diameter class and tree condition was added to the existing tree diameter (year x) to estimate tree diameter and carbon storage in year x+1. Carbon storage and carbon sequestration values are based on i-Tree Eco model estimated local carbon values.

The amount of oxygen produced is estimated from carbon sequestration based on atomic weights: net O_2 release (kg/yr) = net C sequestration (kg/yr) × 32/12. To estimate the net carbon sequestration rate, the amount of carbon sequestered as a result of tree growth is reduced by the amount lost resulting from tree mortality. Thus, net carbon sequestration and net annual oxygen production of the urban forest account for decomposition [Nowak, Hoehn, & Crane, 2007].

Air pollution removal estimates are derived from calculated hourly tree-canopy resistances for ozone, sulfur, and nitrogen dioxides based on a hybrid of big-leaf and multi-layer canopy deposition models 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, Kroll, & Nowak, 2011, Hirabayashi, Kroll, & Nowak, 2012, and Hirabayashi, 2011].

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 (PM2.5) 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 [Davidson et al., 2007].

National median externality costs were also used to calculate the value of carbon monoxide removal and particulate matter less than 10 microns and greater than 2.5 microns [Murray, Marsh, &Bradford, 1994]. PM10 denotes particulate matter less than 10 microns and greater than 2.5 microns throughout the report. As PM2.5 is also estimated, the sum of PM10 and PM2.5 provides the total pollution removal and value for particulate matter less than 10 microns.

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

The value of avoided runoff is based on estimated or user-defined local values. The U.S. value of avoided runoff is based on the U.S. Forest Service's Community Tree Guide Series [USFS].

Seasonal effects of trees on residential building energy use were calculated based on procedures described in the literature [McPherson & 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.

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., 2002].

Potential pest and pathogen risk is based on their range maps and the known pest and pathogen host species that are likely to experience mortality. Range maps from the Forest Health Technology Enterprise Team (FHTET) [2010] were used to determine the proximity of each pest or pathogen to the

Findings

It is important to note that climate and economic constraints impact each city differently. In addition, each project area has a widely variable number of trees, distribution of land uses, and acreage.

Tree Population Characteristics

This section provides an overview of the species, condition, density, geographic origin, and age (size class) of the tree populations. These values help provide context for the following sections on canopy cover and leaf area, as well as the ecological and economic benefits of the communities' public and private trees. Table 2 provides a summary.

Table 2. Tree Population Characteristics Summary

	El Paso	Albuquerque	Phoenix	Las Cruces	Average
Number of Trees	1,281,000	1,504,000	3,166,000	257,000	
Number of Species Sampled	50	76	60	36	56
Acres of Project Area	101,238	84,626	246,064	28,171	
Tree Cover	5.1%	13.3%	9.0%	3.7%	7.8%
Tree Density (# trees/acre)	12.7	22.2	12.9	9.1	14.2

Species Distribution

The samples identified from 36 to 76 unique tree species, but the urban forest likely has far greater diversity. The most common species are shown in Table 3. Based on this sample, it is estimated that citywide canopy cover ranges from 3.7% to 13.3%, with an average 7.8% canopy cover.

Table 3 shows the most prevalent species in each city, with the corresponding population of the species in the other cities, where applicable. Because of the sampling method used, the species distribution has very high error rates, and species proportions should not be relied on for management decisions. The i-Tree Streets model is more appropriate for determining species composition in the community.

There is a widely accepted rule that no single species should represent more than 10% of the total population [Clark et al., 1997]. Table 3 shows the species that may be overrepresented within the cities

Table 3. Common Tree Species Composition

	% of population			
Species	Las Cruces	Albuquerque	Phoenix	El Paso
Afghan pine	**11.8**		2.8	**10.8**
Austrian pine		3.0		
Black locust	3.9	0.2		0.4
Bottle tree			3.4	
California palm			7.5	
Chaste tree	6.2	0.7		0.7
Chitalpa	3.5	0.8		2.1
Chinaberry				2.4
Chinese elm		0.3	5.7	
Cottonwood	0.5	5.6		0.4
Desert ironwood			3.0	
Desert olive		5.6		
Desert willow	**18.0**	5.3		0.8
Honey locust		3.2		1.2
Honey mesquite	4.9		4.1	1.2
Italian cypress	**15.8**			**25.8**
Mexican fan palm	1.7		5.1	7.3
Oriental arborvitae	2.8	2.0	0.9	1.1
Pecan				4.9
Pinyon pine	1.8	3.1		
Siberian elm	4.0	**24.6**		3.3
Tree of heaven	0.5	2.9		2.6
Sweet acacia			6.7	0.7
Velvet ash	4.5	4.2		4.7
Velvet mesquite			8.3	
White mulberry	1.7	6.0	1.8	5.9
Yellow paloverde			4.1	

Species Richness

The number of species in each Land Use type was included in the sample. This information is provided to show the diversity of trees in the sample, but is not likely a reflection of the full species diversity across the landscape due to the sample size. A complete tree inventory could provide a better understanding of species diversity in a city, but would be prohibitively resource intensive.

The i-Tree Eco model uses established calculations for species diversity indexes, which allow quantitative comparisons of species richness. The individual community reports include the number of species found within each land use type, and several diversity indexes. Of these values, the Menhinick Index may be the most appropriate for comparisons amongst the communities, as it is an indicator of species dominance and has a low sensitivity to sample size. Table 4 shows the Menhinick Index values for the four communities.

The sample plots were distributed randomly across the city, not randomly within the land uses, so it is reasonable to assume there were a higher number of plots in some land uses. This is likely impacting the species richness distribution. In most cities, residential areas have the highest average diversity, and these communities follow this trend. Albuquerque has the highest species diversity with 76 identified species, while Las Cruces has the lowest, with 36. Table 4 shows the land use with the highest amount of species richness in bold text.

Table 4. Species Richness

	Menhinick Index			
Land use	Las Cruces	Albuquerque	Phoenix	El Paso
Commercial/Industrial	1.5	2.4		1.6
Commercial			2.3	
Other/Vacant	0.6	0.4	0.8	2.6
Parks/Open Space	1.1	1.9	1.8	1.4
Residential	**2.6**		**4.2**	
Multi-Family Residential		2.8	2.6	2.5
Single-Family Residential		**3.7**		**3.1**
Citywide	2.4	3.7	3.7	3.0

Trees by Land Use Distribution

Trees in residential areas make up an average of 68% of the trees in the sampled areas. Seventeen percent (17%) of the trees were found in commercial and industrial areas, followed by 11% in vacant/other areas, and 4% in parks/open space (Figure 2).

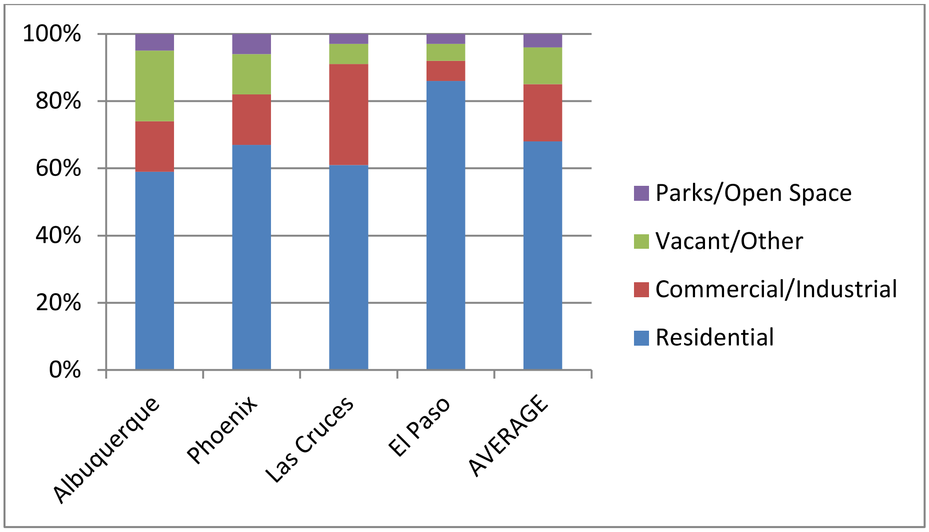


Figure 2. Percent of Trees by Land Use

Tree Density

Another way to consider tree distribution is to show the number of trees per acre, which varies from 9 to 22 trees across the sampled communities (Figure 3). Within each city, trees per acre vary by land use as well, following a trend of higher numbers of trees per acre in residential areas. Table 5 shows the tree density by land use type.

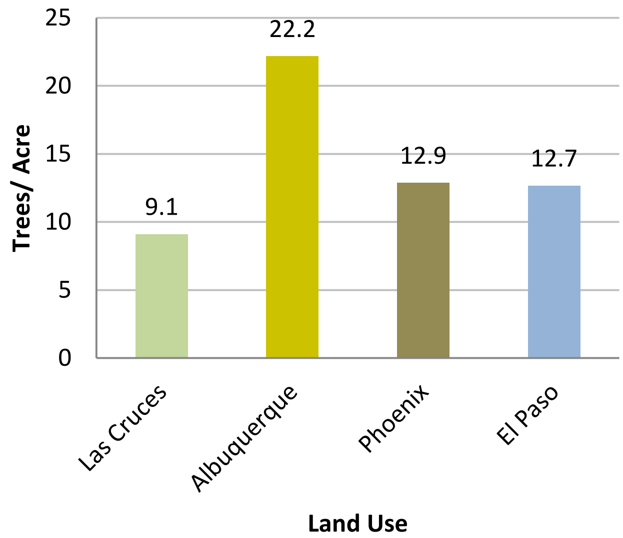


Figure 3. Average Trees per Acre by City

Table 5. Trees per Acre by Land Use

	Trees/acre			
Tree Density	Las Cruces	Albuquerque	Phoenix	El Paso
Commercial			17.5	
Commercial/Industrial	15.1	21.0		3.8
Industrial			5.9	
Other/Vacant	1.9	18.6	18.0	4.8
Parks/Open Space	4.9	6.4	10.8	11.3
Residential	18.7		16.3	
Multi-Family Residential		11.4	19.3	20.9
Single-Family Residential		29.5		25.1
City Total	**9.1**	**22.2**	**12.9**	**12.7**

Relative Age Distribution

For woody plants, the diameter at breast height (DBH) increases incrementally annually, so it may be used to estimate the age of the population. However, in the arid southwest, climate may cause trees to remain smaller than they might in other climates.

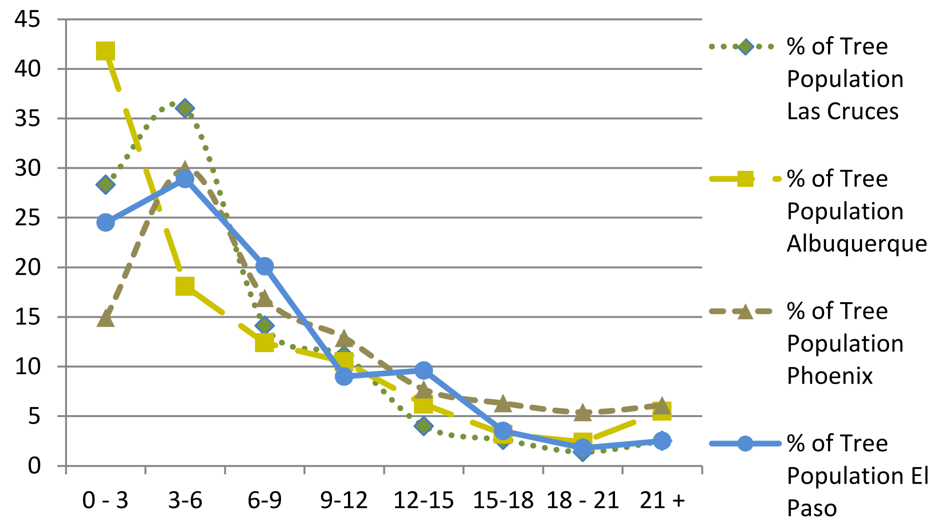
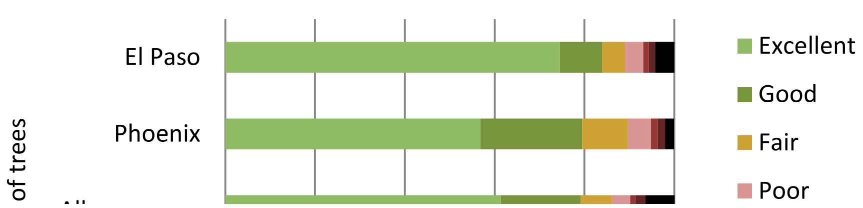


Figure 4. Relative Age Distribution by Percent

The relative DBH distribution of the sampled trees indicates a young or small-growth population with 44.8% to 64.3% of the populations under 6” DBH (Figure 4). Although there is some variation in the populations, the important thing that these data describe is that all the cities studied have a large number of smaller trees. The management implications of this fact are that trees in the arid southwest tend to be smaller, so managers who wish to increase tree benefits might encourage tree planting plans that have spacing requirements appropriate for small-statured trees. Another implication of these data could be that trees are dying at younger ages, and managers should examine tree planting and maintenance practices.

Tree Condition

Tree condition can be related to species fitness, tree age, environmental stressors, and maintenance. An average of 80% of trees in the sample are in good to excellent condition (Figure 5). This is unusually high, and an indication that the trees are either receiving appropriate maintenance, or trees in decline do not linger in the landscape. Communities with more large-statured trees tend to have more trees in decline, so this condition distribution makes



Tree Species Origin Distribution

Urban forests are composed of a mixture 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 of the urban forest resource by a species-specific pest or pathogen, but it can also pose a risk to native plants if exotic species spread beyond planting sites and aggressively suppress the establishment of native species in both the urban and wildland areas. Those species, called 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 [USDA, 2011]. The sample indicates a significant portion of the cities' trees are native to the state, averaging 20% of the populations. Table 6 shows the common species origins, and the other category includes unknown, and continents that comprised less than 2% of the total.

Table 6. Percent of Live Trees by Species Origin

Origin	% of trees			
	Las Cruces	Albuquerque	Phoenix	El Paso
Arizona	-	-	21.8	-
New Mexico	24.4	19.8	-	-
Texas	-	-	-	15.3
Asia & Europe	33.5	50.5	21.7	48.9
North & South America	44.4	35.8	57.5	34.1
Other	22.1	13.7	21.4	17.6

Cover and Leaf Area

Importance Value and Leaf Area

The level of benefits provided by the urban forest correlates with the amount of healthy leaf area. In the project areas, the most impactful species in terms of leaf area and population are listed in Table 7. Three of the four communities are heavily reliant on Afghan pine, representing 11% - 26% of the leaf area. Albuquerque is heavily reliant on Siberian elm for canopy. For three of the four communities, the species with the highest importance value represents more than 10% of the population, which is the recommended threshold for a single species to facilitate optimal species diversity.

Table 7. Most Important Species by City

Species	Percent Population	Percent Leaf Area	Importance Value
Las Cruces			
Afghan pine	11.8	26.3	38.1
Desert willow	18.0	11.7	29.7
Italian cypress	15.8	1.5	17.3
Albuquerque			
Siberian elm	24.6	28.5	53.1
Fremont cottonwood	5.0	10.7	15.7
White mulberry	4.8	14.4	19.3
Phoenix			
Velvet mesquite	8.3	8.7	17.0
Afghan pine	2.8	10.6	13.4
California palm	7.5	5.6	13.1
El Paso			
Afghan pine	10.8	18.1	28.9
Italian cypress	25.8	2.6	28.5
White mulberry	5.9	19.7	25.6

Groundcover and Canopy

Groundcover types impact stormwater runoff and availability of planting sites, and indicate the degree of urban density. The most dominant ground cover type varies among project areas (Figure 6). Las Cruces has a high portion (54%) of bare soil, as does El Paso, with 33%. Albuquerque and Phoenix have high portions of tar and bare soil, while the most common ground cover in Phoenix was rock at 25%.

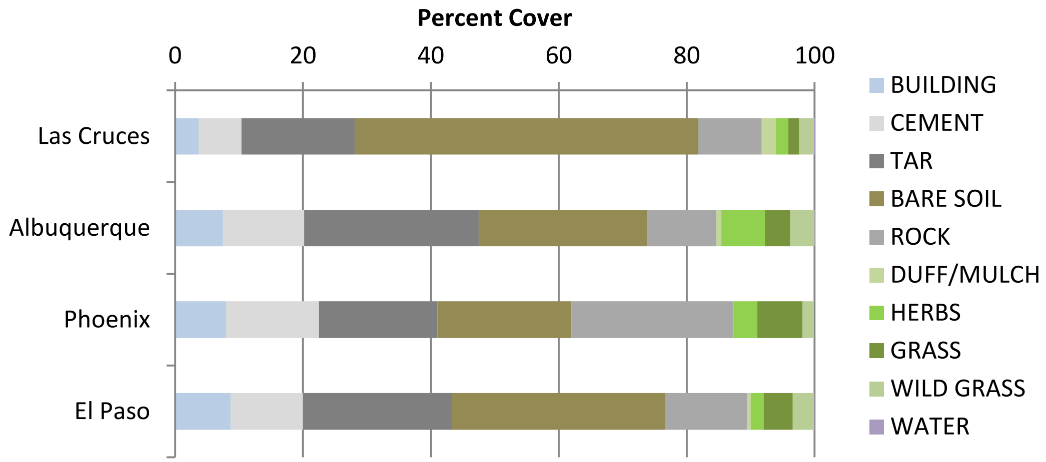
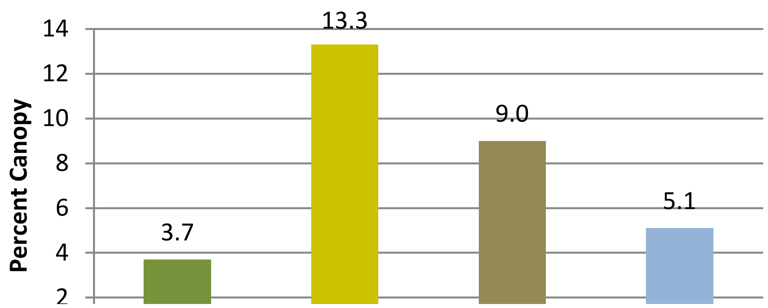


Figure 6. Ground Cover Type Distribution by City

Percent canopy varied from 13.3% in Albuquerque to 3.7% in Las Cruces (Figure 7). The largest canopy covers were found in residential areas in all communities except Albuquerque, where heavily-treed utility sample plots had 27% canopy cover (the high number of trees per acre in the utility land use is likely an outlier based on a heavily vegetated plot). Commercial, industrial, and other/vacant land areas had the lowest canopy covers, ranging from 0.5% to 2.7%.



Economic and Ecological Benefits

Functional and Structural Values

Urban forests have structural value based on the trees themselves (e.g., the cost of having to replace a tree with a similar tree). The structural value of an urban forest tends to increase with a rise in the number and size of healthy trees [Nowak, Crane, & Dwyer, 2002]. Structural values are provided for each city in Table 9 by millions of dollars, and on a per-tree basis.

Table 8. Structural Values (Tree Replacement Values)

	El Paso	Albuquerque	Phoenix	Las Cruces	**Average**
Replacement Value (Millions of $)	1,020	1,930	3,820	205	
Per-tree Replacement Value ($/tree)	$796	$1,283	$1,207	$798	**$1,124**

Trees also have a functional value (either positive or negative) based on the functions the trees perform (e.g., removing pollution, reducing energy use). 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 can decrease if the amount of healthy tree cover declines. Table 10 shows the functional values by city.

Table 9. Tree Benefit Amounts and Values

Lifetime Tree Benefit Amount

	El Paso	Albuquerque	Phoenix	Las Cruces	**Total**
Lifetime Carbon Storage (tons)	92,800	226,000	305,000	17,800	**641,600**

Annual Tree Benefit Amounts

	El Paso	Albuquerque	Phoenix	Las Cruces	**Total**
Air Pollution Removal (tons)	318	366	1,770	92	**2,546**
Carbon Sequestration (tons)	7,430	9,710	35,400	1,580	**54,120**
Oxygen Production (tons)	14,100	21,300	89,200	3,290	**127,890**
Avoided Carbon Emissions (tons)	5,394	6,289	41,565	1,054	**54,302**
Avoided Storm Water Runoff (cubic feet)	32,867,000	51,386,000	91,700,000	898,000	**176,851,000**

Annual Tree Benefit Values ($)

	El Paso	Albuquerque	Phoenix	Las Cruces	**Total**
Air Pollution Removal	$247,000	$1,100,000	$5,760,000	$235,000	**$7,342,000**
Annual Carbon Sequestration	$529,000	$692,000	$2,520,000	$112,000	**$3,853,000**
Avoided Carbon Emissions	$384,000	$448,000	$2,960,000	$75,000	**$3,867,000**
Building Energy Savings	$2,700,000	$3,310,000	$22,900,000	$563,000	**$29,473,000**
Avoided Storm					

Functional Tree Benefit Comparisons

Local climate and tree species and size distributions impact the tree benefits provided. The levels of tree benefits provided are closely related to tree size and population size. Figure 8 shows the portion of the benefits in each city and Figure 9 shows the monetary values of the same benefits. A large portion, and maybe one of the more important of functional benefits in the southwest, is energy savings due to the location of the trees around residential buildings. These trees provide shade and thus lower air-conditioning usage. This is very important in the Southwest as temperatures are high and summers long.

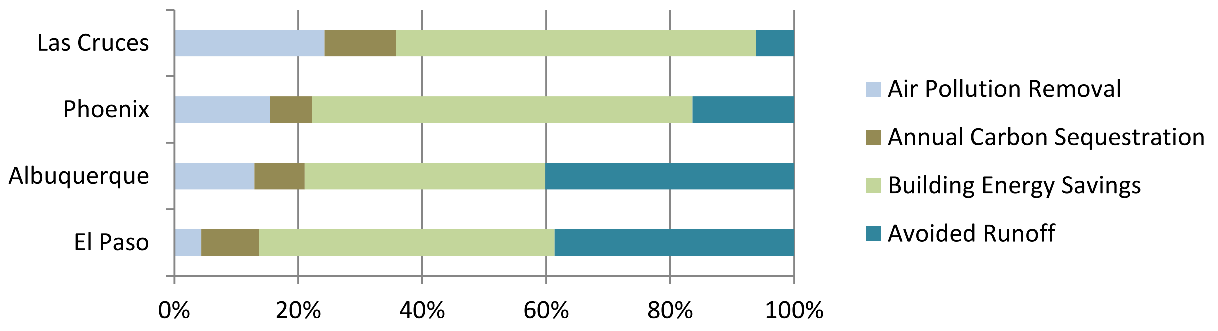
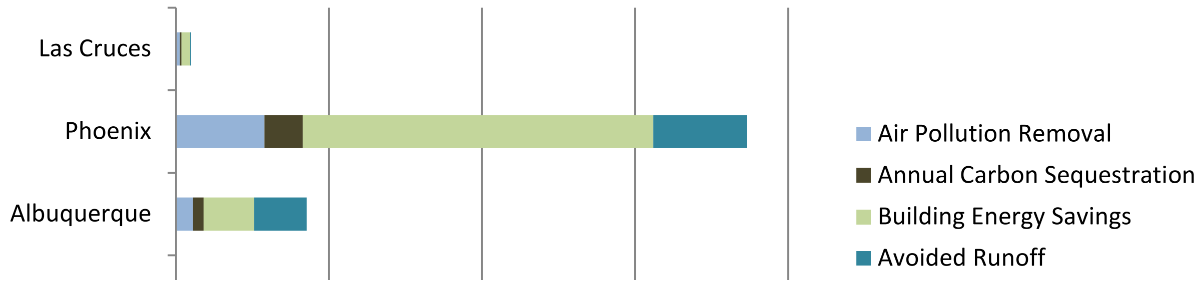


Figure 8. Proportions of Functional Tree Benefits

The large contribution of Phoenix's tree benefits in Figure 9 cannot be completely explained by the larger tree population in Phoenix, as those values are roughly twice those for Albuquerque, while tree benefits are almost four times as great. A large portion of this difference is the higher energy savings realized due to Phoenix's hotter climate. The remainder of the difference is realized in air pollution and carbon sequestration, and is related to species distribution, climate, and tree size distribution within the i-Tree Eco model.



Potential Urban Forest Health Impacts

Pathogen and Pest Proximity and Risk

Pathogens and pests can infest urban forests, potentially killing trees and reducing the health, value and sustainability of the urban forest. As pathogens and pests have differing tree hosts, the potential damage or risk of each pest will differ among cities. Thirty-one pathogens and pests were analyzed for their potential impact and compared with range maps [FHTET, 2010] for the contiguous United States.

Predicting emergent pest infestations may be more accurately done by local area experts, but the i-Tree Eco model does provide some data about pests that may become a concern. These should be considered in conjunction with the opinions of local pest and disease experts. Based on the i-Tree Eco model, the pests and pathogens most likely to influence the urban forests, if they ever migrate to the project areas are as follows:

- Las Cruces: southern pine beetle, sirex wood wasp, and pine shoot beetle
- Phoenix: gypsy moth and Asian longhorned beetle
- El Paso: chalcid wasp, sirex wood wasp, and pine shoot beetle
- Albuquerque: Asian longhorned beetle and Dutch elm disease

The most susceptible tree species were pines, oaks, elms, cottonwoods and ashes. When considering the resilience of the urban forest, continued planting of these species may not be the most strategic approach. Instead, shifting planting palettes to include more species that have few current known pathogens may be wise. However, managers should still consider existing species composition, using the best management practice of avoiding reliance of any one species for more than 10% of the urban forest population or benefits.

Appendix I. Glossary and Calculations

Carbon dioxide emissions from automobile assumed six pounds of carbon per gallon of gasoline if energy costs of refinement and transportation are included (Graham, Wright, & Turhollow, 1992)

Carbon emissions Total city carbon emissions were based on 2003 US per capita carbon emissions – calculated as total US emissions (EIA, 2003) divided by the 2003 US total population (Census.gov). This value was multiplied by the population of Phoenix (1.49 million) to estimate total city carbon emissions.

Carbon storage The amount of carbon bound up in the above-ground and below-ground parts of woody vegetation. Carbon storage and carbon sequestration values are calculated based on $71.21 per ton.

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.

Diameter at Breast Height (DBH) Is the diameter of the tree measured 4'6" above grade.

Energy saving Value is calculated based on local energy the prices per MWH and per MBTU.

Household emissions (average) 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 (EIA, 2001)

CO2, SO2, and NOx power plant emission per KWh (EPA)

CO emission per kWh assumes 1/3 of one percent of C emissions is CO (EIA, 1994)

PM10 emission per kWh (Layton, 2004, 2005)

CO2, NOx, SO2, PM10, 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) (Abraxas Energy Consulting)

CO2 and fine particle emissions per Btu of wood (Houck et al., 1998)

CO, NOx and SOx emission per Btu based on total emissions and wood burning (tons) (www.env.bc.ca, 2005)

Emissions per dry ton of wood converted to emissions per Btu based on average dry weight per cord of wood and average Btu per cord (ianrpubs.unl.edu).

Monetary values ($) are reported in US Dollars throughout the report.

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

Pollution removal Value is calculated based on the prices of $1,136 per ton (carbon monoxide), $1,260 per ton (ozone), $226 per ton (nitrogen dioxide), $110 per ton (sulfur dioxide), $5,840 per ton (particulate matter less than 10 microns and greater than 2.5 microns), $17,993 per ton (particulate matter less than 2.5 microns).

Trees remove PM2.5 when particulate matter is deposited on leaf surfaces. This deposited PM2.5 can be re-suspended to the atmosphere or removed during rain events and dissolved or transferred to the soil. This combination of events can lead to interesting results depending on various atmospheric factors. Generally, pollution removal is positive with positive benefits. However, there are some cases when net removal is negative or re-suspended particles lead to increased pollution concentrations and negative values. During some months (e.g., with no rain), trees re-suspend more particles than they remove. Re-suspension can also lead to increased overall PM2.5 concentrations if the boundary layer conditions are lower during net re-suspension 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.

Structural value Value based on the physical resource itself (e.g., the cost of having to replace a tree with a similar tree).

Ton Short ton (U.S.) (2,000 lbs).

Appendix II. Comparison of Urban Forests

Sometimes it is useful to determine how a city compares to other areas (Tables 11 & 12). 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. This comparison information is provided by the i-Tree Eco model and reporting.

Table 10. Total Tree Benefits in Other Areas

Area	Number of trees	Carbon Storage (tons)	Carbon Sequestration (tons/year)	Pollution Removal (tons/year)
Calgary, Canada	11,889,000	445,000	21,422	326
Atlanta, GA	9,415,000	1,345,000	46,433	1,662
Toronto, Canada	7,542,000	992,000	40,345	1,212
New York, NY	5,212,000	1,351,000	42,283	1,677
Phoenix, AZ	3,166,000	305,000	35,400	1,770
Baltimore, MD	2,627,000	596,000	16,127	430
Philadelphia, PA	2,113,000	530,000	16,115	576
Washington, DC	1,928,000	523,000	16,148	418
Albuquerque, NM	1,504,000	226,000	9,710	366
El Paso, TX	1,281,000	92,800	7,430	318
Boston, MA	1,183,000	319,000	10,509	284
Woodbridge, NJ	986,000	160,000	5,561	210
Minneapolis, MN	979,000	250,000	8,895	305
Syracuse, NY	876,000	173,000	5,425	109
Morgantown, WV	661,000	94,000	2,940	66
Moorestown, NJ	583,000	117,000	3,758	118
Las Cruces, NM	257,000	17,800	1,580	92
Eastern Colorado	251,000	71,900	2,200	77
Jersey City, NJ	136,000	21,000	890	41
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Table 11. Per-Acre Values of Tree Effects in Other Areas

Area	Number of Trees	Carbon Storage (tons)	Carbon Sequestration (tons/year)
Morgantown, WV	119.7	17.0	0.53
Atlanta, GA	111.6	15.9	0.55
Calgary, Canada	66.7	2.5	0.12
Woodbridge, NJ	66.5	10.8	0.38
Moorestown, NJ	62.0	12.5	0.40
Syracuse, NY	54.5	10.8	0.34
Baltimore, MD	50.8	11.5	0.31
Washington, DC	49.0	13.3	0.41
Toronto, Canada	48.3	6.4	0.26
Freehold, NJ	38.5	16.0	0.44
Boston, MA	33.5	9.0	0.30
New York, NY	26.4	6.8	0.21
Minneapolis, MN	26.2	6.7	0.24
Philadelphia, PA	25.0	6.3	0.19
Albuquerque, NM	17.8	2.7	0.11
Jersey City, NJ	14.3	2.2	0.09
Phoenix, AZ	12.9	1.2	0.14
El Paso, TX	12.7	0.9	0.07
Eastern Colorado	12.1	3.5	0.11
Las Cruces, NM	9.1	0.6	0.06

Appendix III. 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 (Table 13).

Table 12. Urban Forest Management Strategies to Improve Air Quality

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

Appendix IV. Species Distributions and Botanical Names

Phoenix

Common Name	Species	Percent Population	Percent Leaf Area	Importance Value
Velvet mesquite	*Prosopis velutina*	8.25	8.71	16.95
Afghan pine	*Pinus eldarica*	2.75	10.64	13.39
California palm	*Washingtonia filifera*	7.52	5.56	13.08
Bottle tree	*Brachychiton occulneuem*	3.44	8.76	12.20
Sweet acacia	*Acacia farnesiana*	6.69	5.42	12.10
Chinese elm	*Ulmus parvifolia*	5.71	5.30	11.01
Honey mesquite	*Prosopis glandulosa*	4.13	6.84	10.97
Mexican fan palm	*Washingtonia robusta*	5.10	2.71	7.81
Blue paloverde	*Parkinsonia florida*	2.43	3.74	6.18
Yellow paloverde	*Parkinsonia microphylla*	4.13	1.71	5.83
Aleppo pine	*Pinus halepensis*	1.68	4.05	5.73
Citrus spp	*Citrus*	4.01	1.64	5.65
Olive	*Olea europaea*	2.28	2.93	5.21
Indian rosewood	*Dalbergia sissoo*	2.44	2.12	4.56
Willow acacia	*Acacia salicina*	0.93	3.35	4.28
Desert Ironwood	*Olneya tesota*	3.02	0.92	3.94
Texas ebony	*Ebenopsis ebano*	0.89	2.37	3.26
Jerusalem thorn	*Parkinsonia aculeata*	1.34	1.79	3.13
Queen palm	*Arecastrum romanzoffianum*	1.81	0.93	2.74
Coolabah	*Eucalyptus coolabah*	0.47	2.23	2.70
Feather bush	*Lysiloma watsonii*	2.13	0.42	2.55
Juniper spp	*Juniperus*	2.34	0.13	2.47
Mexican ash ash	*Fraxinus berlandieriana*	1.34	1.06	2.40
Ceratonia spp	*Ceratonia*	0.45	1.83	2.27
Silk oak	*Grevillea robusta*	0.47	1.73	2.20
Orchid tree	*Bauhinia purpurea*	1.78	0.38	2.16

Common Name	Species	Percent Population	Percent Leaf Area	Importance Value
Leadtree spp	*Leucaena*	0.89	1.08	1.97
Red gum eucalyptus	*Eucalyptus camaldulensis*	0.47	1.32	1.79
Pygmy date palm	*Phoenix roebelenii*	1.34	0.42	1.75
Bird of paradise tree	*Strelitzia nicolai*	1.05	0.63	1.68
Saguaro	*Carnegia gigantea*	1.48	0.10	1.58
Mediterranean fan palm	*Chamaerops humilis*	0.89	0.47	1.36
Oriental arborvitae	*Platycladus orientalis*	0.89	0.47	1.36
Date palm	*Phoenix dactylifera*	0.45	0.87	1.31
African sumac	*Rhus lancea*	0.61	0.69	1.30
Live oak	*Quercus virginiana*	1.05	0.14	1.20
Oleander	*Nerium oleander*	0.89	0.19	1.08
Shoestring acacia	*Acacia stenophylla*	0.45	0.49	0.94
Ocotillo	*Fouquieria splendens*	0.45	0.41	0.86
Acacia spp	*Acacia*	0.76	0.02	0.79
King palm	*Archontophoenix cunninghamiana*	0.45	0.32	0.77
Olive spp	*Olea*	0.45	0.28	0.72
Mimosa	*Albizia julibrissin*	0.45	0.19	0.64
Ficus macrocarpa	*Ficus macrocarpa*	0.45	0.11	0.56
Indian laurel fig	*Ficus retusa ssp nitida*	0.45	0.10	0.55
Argentine mesquite	*Prosopis alba*	0.45	0.10	0.55
Mescalbean	*Sophora secundiflora*	0.45	0.09	0.54
Glossy privet	*Ligustrum lucidum*	0.45	0.07	0.52
Luckynut	*Thevetia peruviana*	0.45	0.05	0.50
Aloe yucca	*Yucca aloifolia*	0.45	0.05	0.49
Purpleleaf plum	*Prunus pissardii*	0.45	0.03	0.48
Saltbush spp	*Atriplex*	0.29	0.15	0.44
Lotebush	*Ziziphus obtusifolia*	0.29	0.06	0.35
Laurel-leafed snailseed	*Cocculus laurifolius*	0.16	0.12	0.28
Paloverde spp	*Parkinsonia*	0.16	0.12	0.28
Desert broombush	*Templetonia egena*	0.16	0.09	0.25
Hackberry spp	*Celtis*	0.15	0.05	0.20

Las Cruces

Common Name	Species	Percent Population	Percent Leaf Area	Importance Value
Afghan pine	*Pinus eldarica*	11.81	26.27	38.08
Desertwillow	*Chilopsis linearis*	17.98	11.72	29.70
Italian cypress	*Cupressus sempervirens*	15.80	1.53	17.33
Arizona ash	*Fraxinus berlandieriana*	4.48	12.76	17.24
White mulberry	*Morus alba*	1.67	11.36	13.03
Siberian elm	*Ulmus pumila*	4.03	8.16	12.19
Black locust	*Robinia pseudoacacia*	3.94	4.61	8.55
Honey mesquite	*Prosopis glandulosa*	4.88	3.47	8.35
Chaste tree	*Vitex agnus-castus*	6.22	2.11	8.33
Chitalpa	*Chitalpa tashkentensis*	3.45	3.90	7.35
Oriental arborvitae	*Platycladus orientalis*	2.78	1.28	4.06
Live oak	*Quercus/live virginiana*	1.79	2.08	3.87
Purpleleaf plum	*Prunus pissardii*	2.24	0.96	3.20
London plane	*Platanus x acerifolia*	0.76	2.34	3.11
Pinyon pine	*Pinus edulis*	1.79	0.58	2.37
Willow spp	*Salix*	0.45	1.78	2.23
Neomexican elderberry	*Sambucus caerulea v mexicana*	1.79	0.39	2.18
Ocotillo	*Fouquieria splendens*	1.34	0.73	2.07
Texas red oak	*Quercus texana*	1.52	0.49	2.01
Mexican fan palm	*Washingtonia robusta*	1.66	0.23	1.88
Common crapemyrtle	*Lagerstroemia indica*	1.52	0.06	1.59
Cottonwood spp	*Populus*	0.45	0.94	1.39
Yaupon	*Ilex vomitoria*	0.90	0.31	1.20
Torrey yucca	*Yucca torreyi*	0.90	0.26	1.15
Raywood ash	*Fraxinus angustifolia 'Raywood'*	0.90	0.15	1.04
Soaptree yucca	*Yucca elata*	0.97	0.07	1.04
Northern white cedar	*Thuja occidentalis*	0.45	0.53	0.98
Oak spp	*Quercus*	0.76	0.10	0.86
Creosote bush	*Larrea tridentata*	0.45	0.36	0.80
Bur oak	*Quercus macrocarpa*	0.45	0.16	0.61
Eve's needle	*Yucca faxoniana*	0.45	0.12	0.57
Tree of heaven	*Ailanthus altissima*	0.45	0.08	0.53

El Paso

Species	Species	Percent Population	Percent Leaf Area	Importance Value
Italian cypress	*Cupressus sempervirens*	25.8	2.6	28.5
Afghan pine	*Pinus eldarica*	10.8	18.1	28.9
Mexican fan palm	*Washingtonia robusta*	7.3	2.7	10.0
White mulberry	*Morus alba*	5.9	19.7	25.6
Pecan	*Carya illinoinensis*	4.9	9.0	13.9
Velvet ash	*Fraxinus velutina*	4.7	12.3	17.0
Siberian elm	*Ulmus pumila*	3.3	2.8	6.0
Tree of heaven	*Ailanthus altissima*	2.6	0.7	3.3
Chinaberry	*Melia azedarach*	2.4	2.7	5.1
Juniper spp	*Juniperus*	2.1	3.4	5.5
Chitalpa	*Chitalpa tashkentensis*	2.1	0.5	2.6
Mimosa	*Albizia julibrissin*	2.1	0.2	2.3
Chinese pistache	*Pistacia chinensis*	1.3	0.5	1.7
Honeylocust	*Gleditsia triacanthos*	1.2	1.5	2.6
Honey mesquite	*Prosopis glandulosa*	1.2	2.4	3.6
Oriental arborvitae	*Platycladus orientalis*	1.1	0.7	1.8
Pear spp	*Pyrus*	1.1	0.5	1.6
Redbud spp	*Cercis*	1.1	0.6	1.6
Elderberry spp	*Sambucus*	1.1	0.3	1.4
Aleppo pine	*Pinus halepensis*	1.0	5.9	6.9
Red cedar spp	*Thuja*	1.0	1.5	2.4
Yucca spp	*Yucca*	1.0	0.4	1.4
Jerusalem thorn	*Parkinsonia aculeata*	0.9	0.1	1.0
Desertwillow	*Chilopsis linearis*	0.8	0.5	1.4
Sweet acacia	*Acacia farnesiana*	0.7	1.4	2.1
Chaste tree	*Vitex agnus-castus*	0.7	1.3	2.0
Western redcedar	*Thuja plicata*	0.7	0.7	1.4
Canary island date palm	*Phoenix canariensis*	0.7	0.6	1.3
Privet spp	*Ligustrum*	0.7	0.1	0.8
Eucalyptus	*Eucalyptus urophylla*	0.7	0.1	0.8
Soaptree yucca	*Yucca elata*	0.7	0.1	0.8
Live oak	*Quercus/live virginiana*	0.7	0.0	0.8

Species	Species	Percent Population	Percent Leaf Area	Importance Value
Peach	*Prunus persica*	0.4	0.4	0.8
Black locust	*Robinia pseudoacacia*	0.4	0.2	0.6
Callery pear	*Pyrus calleryana*	0.4	0.2	0.5
Torrey yucca	*Yucca torreyi*	0.4	0.1	0.5
Soapberry spp	*Sapindus*	0.4	0.1	0.5
Mediterranean fan palm	*Chamaerops humilis*	0.4	0.1	0.4
Desert museum palo verde	*Parkinsonia hybrid Desert Museum*	0.4	0.1	0.4
Eve's needle	*Yucca faxoniana*	0.4	0.1	0.4
Common crapemyrtle	*Lagerstroemia indica*	0.4	0.1	0.4
Apple spp	*Malus*	0.4	0.0	0.4
Oak spp	*Quercus*	0.4	0.0	0.4
Neomexican elderberry	*Sambucus caerulea v mexicana*	0.4	0.0	0.4
Oleander	*Nerium oleander*	0.4	0.0	0.4
Screwbean mesquite	*Prosopis pubescens*	0.2	0.1	0.3

Albuquerque

Common Name	Species	Percent Population	Percent Leaf Area	Importance Value
Siberian elm	*Ulmus pumila*	24.57	28.51	53.08
White mulberry	*Morus alba*	5.97	15.15	21.09
Cottonwood	*Populus spp.*	5.64	10.73	16.37
Desert olive	*Forestiera shrevei*	5.62	0.58	6.21
Desertwillow	*Chilopsis linearis*	5.32	1.87	7.20
Firethorn spp	*Pyracantha*	4.32	0.54	4.82
Velvet ash	*Fraxinus velutina*	4.16	5.70	9.86
Honeylocust	*Gleditsia triacanthos*	3.16	2.64	5.79
Pinyon pine	*Pinus edulis*	3.12	2.35	5.46
Austrian pine	*Pinus nigra*	2.95	2.95	5.90
Tree of heaven	*Ailanthus altissima*	2.88	1.77	4.65
Purpleleaf plum	*Prunus ceracifera*	2.67	1.72	4.39
Callery pear	*Pyrus calleryana*	2.05	2.54	4.59
Oriental arborvitae	*Platycladus orientalis*	1.98	0.53	2.51
Mimosa	*Albizia julibrissin*	1.54	1.53	3.07
Raywood ash	*Fraxinus angustifolia 'Raywood'*	1.42	2.00	3.43
Arizona cypress	*Cupressus arizonica*	1.35	3.75	5.10
Ponderosa pine	*Pinus ponderosa*	1.10	0.75	1.85
London plane	*Platanus hybrida*	0.98	1.39	2.37
White ash	*Fraxinus americana*	0.88	1.61	2.49
Chinese pistache	*Pistacia chinensis*	0.88	0.55	1.42
Common crapemyrtle	*Lagerstroemia indica*	0.88	0.17	1.05
Chitalpa	*Chitalpa tashkentensis*	0.79	1.31	2.07
Yucca spp	*Yucca*	0.66	0.10	0.76
Almond	*Prunus amygdalus*	0.66	0.08	0.74
Chaste tree	*Vitex agnus-castus*	0.65	0.36	1.01
Aleppo pine	*Pinus halepensis*	0.65	0.24	0.89
Crabapple	*Malus tschonoskii*	0.64	0.24	0.88
Texas red oak	*Quercus texana*	0.64	0.11	0.74
Cherry plum	*Prunus cerasifera*	0.62	0.10	0.72
Live oak	*Quercus virginiana*	0.54	0.17	0.71
Boxelder	*Acer negundo*	0.50	0.16	0.66

Common Name	Species	Percent Population	Percent Leaf Area	Importance Value
Plum spp	*Prunus*	0.44	0.07	0.51
Chir pine	*Pinus roxburghii*	0.40	0.42	0.82
Pine spp	*Pinus*	0.40	0.13	0.53
Soaptree yucca	*Yucca elata*	0.37	0.17	0.54
Cupressocyparis spp	*Cupressocyparis*	0.30	0.26	0.55
Chinese elm	*Ulmus parvifolia*	0.25	0.05	0.30
Northern red oak	*Quercus rubra*	0.25	0.02	0.27
Japanese maple	*Acer palmatum*	0.25	0.02	0.27
Scotch pine	*Pinus sylvestris*	0.22	0.84	1.06
Texas pistache	*Pistacia mexicana*	0.22	0.58	0.80
Black locust	*Robinia pseudoacacia*	0.22	0.52	0.73
Black cottonwood	*Populus trichocarpa*	0.22	0.49	0.71
Northern catalpa	*Catalpa speciosa*	0.22	0.19	0.41
Russian olive	*Elaeagnus angustifolia*	0.22	0.07	0.29
Chokeberry spp	*Photinia*	0.22	0.06	0.28
Swampprivet spp	*Forestiera*	0.22	0.06	0.28
Blue spruce	*Picea pungens*	0.22	0.06	0.28
Freeman maple	*Acer x freemanii*	0.22	0.05	0.27
Eastern redbud	*Cercis canadensis*	0.22	0.02	0.24
Spindletree spp	*Euonymus*	0.22	0.02	0.24
Hawthorn spp	*Crataegus*	0.22	0.02	0.24
Locust spp	*Gleditsia*	0.22	0.02	0.24
Ash spp	*Fraxinus*	0.20	0.19	0.39
Mexican pinyon	*Pinus cembroides*	0.20	0.03	0.23
Goldenrain tree	*Koelreuteria paniculata*	0.15	0.06	0.20
Rocky mountain juniper	*Juniperus scopulorum*	0.15	0.02	0.16
Other species		1.60	2.30	4.00

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