HOUSTON'S REGIONAL FOREST

STRUCTURE ▪ FUNCTIONS ▪ VALUES

SEPTEMBER 2005

For more information on this project, please contact:

PETER D. SMITH
Texas Forest Service
psmith@tfs.tamu.edu
979-458-6650

MICHAEL MERRITT
Texas Forest Service
mmerritt@tfs.tamu.edu
713-688-8931

DAVID NOWAK, Ph.D.
U.S. Forest Service
dnowak@fs.fed.us
315-448-3212

DAVID HITCHCOCK
Houston Advanced Research Center
dhitchcock@harc.edu
281-364-4007

HOUSTON'S REGIONAL FOREST

STRUCTURE ▪ FUNCTIONS ▪ VALUES

The population in and around Houston has grown rapidly over the past twenty years, now exceeding five million people. Studies of the area have noted that the loss of trees and changes to the forest makeup have generally accompanied this growth. Trees and urban forestry practices can be used effectively to reduce many of the negative effects of urban growth and other changes occurring in the region. These include reducing urban heat island effects, mitigating negative health and environmental impacts, and improving the overall quality of life.

In 2001, the USDA Forest Service approved funding for a special project to build the tools and systems that will help state and local groups monitor and guide the development of the area's green infrastructure. ***Houston's Regional Forest*** project brought federal and state government researchers together with local planners, policy makers, and managers to analyze the region's tree cover using field research and computer modeling. This report is one of the major outcomes of this project. It provides detailed information on the structure, functions, and values of Houston's regional forest.

ACKNOWLEDGEMENTS

Contributors to this project include:

David J. Nowak, Principal Investigator, USDA Forest Service, Northeastern Research Station (NERS)

Peter D. Smith, Texas Forest Service
Michael Merritt, Texas Forest Service
John Giedraitis, Texas Forest Service
Jeffrey T. Walton, USDA Forest Service, NERS
Robert E. Hoehn, USDA Forest Service, NERS
Jack C. Stevens, USDA Forest Service, NERS
Daniel E. Crane, USDA Forest Service, NERS
Mark Estes, Texas Commission on Environmental Quality
Stephen Stetson, Global Environmental Management, Inc.
Charles Burditt, Burditt Natural Resource Consulting
David Hitchcock, Houston Advanced Research Center
Wendee Holtcamp, Houston Advanced Research Center

Executive Summary

Whether viewed from the pine forests to the northeast, the bottomland hardwoods that line bayous and streams, or the trees that dot the prairie land to the west, tree cover is one of the defining features of the eight-county region surrounding the city of Houston. ***Houston's Regional Forest: Structure • Functions • Values*** examines in detail some of the crucial characteristics of this green infrastructure.

This new understanding of Houston's regional forest is based on satellite imagery, field data, and computer modeling using the Urban Forest Effects Model (UFORE), which analyzes the structure, environmental effects, and values of urban forests.[1] Field surveys completed in 2001 and 2002 provided input into this model and included data from 332 field plots throughout the region located within residential, commercial, forested, and agricultural areas.

A *forest's structure* consists of various tree species, density, health, leaf area, biomass, species diversity, and other elements that make up the forest. This report summarizes the structure of Houston's regional forest, providing a snapshot of the forest resources as well as a detailed examination of where trees are located by species. Using extensive field surveys and satellite data, this analysis provides the most complete understanding of Houston's forest structure to date.

Forest functions include a wide range of environmental, ecosystem, and related services that trees and forests perform, some of which are highly valued by those living in the region. This analysis quantifies some of these functions including air pollution removal, carbon storage, and energy savings. The report does not include other important forest functions such as quality of life services to humans, habitat for wildlife, storm water management, and flood prevention.

Forest values are the quantified economic values of the forest functions mentioned above—air pollution removal, carbon storage, energy savings—plus the replacement value of the forest. Other studies have measured values such as health benefits, property value increases, and floodwater retention.

MAJOR FINDINGS & CONCLUSIONS

Houston's regional forest provides impressive value to its citizens. The replacement cost alone of the 663 million trees found in the region is valued at over $205 billion. The value of the environmental benefits generated by trees each year is estimated at $456 million and forests also store $721 million worth of

> **The replacement cost alone** *of the 663 million trees found in the region is valued at over* **$205 billion.**

Table 1
Summary of Findings[a]

FEATURE	MEASURE
Number of trees	663 million
Trees under five inches in diameter	472 million (71% of trees)
Trees in non-urban land cover classes	579 million (87% of trees)
Most common native tree	loblolly pine (19% of trees)
Most common non-native tree	chinese tallow (23% of trees)
Oak species	15% of trees
Replacement value	$205.8 billion
Carbon storage value	$721 million
Annual environmental value	$456 million
Forest land cover[b]	28.4% of total land area
Forest land cover change: 1992-2000	-486 square miles (-17%)
Primary forest threat	land use change

[a] *All data is year 2001 and 2002, unless indicated otherwise.*
[b] *Forest land cover type = tree canopies plus unforested areas in the immediate vicinity*

total carbon. These benefits are different for rural and urban areas: replacement and carbon storage values are greater in rural areas due to the large number of trees, while energy savings and environmental benefits are greater where the human population is concentrated.

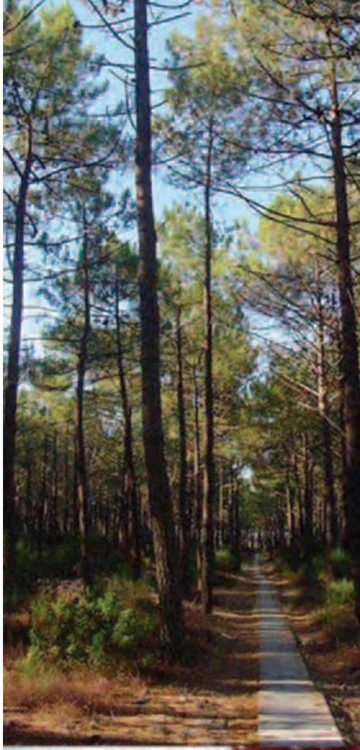
The forests of the Houston area are diverse, but also very different in the northern and southern parts of the region. Area forests contain 67 different tree species. The highly diverse **North Forest** covers a greater area and has larger trees, with loblolly pine the single most common species. The **South Forest** includes forests dominated by cedar elm, sugarberry, and hawthorn as well as remnant tracts of Columbia bottomland hardwood forests. Common to all land cover types, Chinese tallow represents the single most common species, amounting to almost 23 percent of the region's trees.

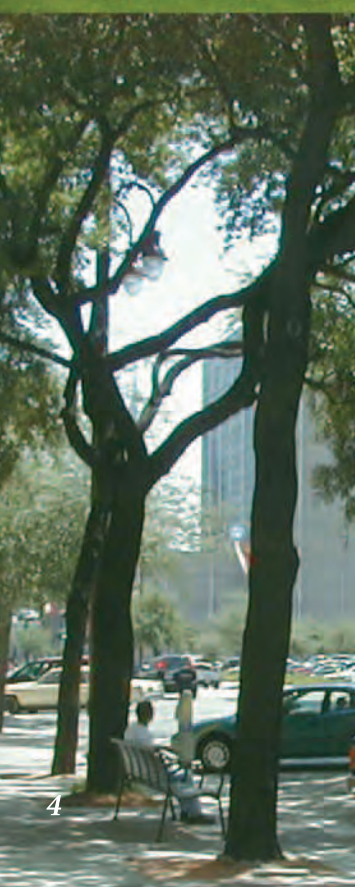
Large trees are disproportionately important in terms of forest benefits. The majority of the region's 663 million trees are small: over 70 percent are less than five inches in diameter. Although trees five inches and greater in diameter make up less than 30 percent of the region's trees, they provide over 60 percent of the environmental benefits. Therefore, protecting the region's large trees is essential for producing future benefits.

Land use change, non-native tree species, and insect pests pose significant threats to the future of the regional forest. Actions that significantly alter land surfaces have reduced the number and density of trees while providing opportunities for invasive species and pest outbreaks. Land use change continues to pose the biggest threat: between 1992 and 2000, forest land cover types in the region declined by an estimated 17 percent—a decrease of 486 square miles, resulting in a net loss of over 78 million trees. Outbreaks of insect pests represent a potential threat to forests that would cause significant economic and environmental losses.

The Houston metropolitan region includes the City of Houston—the nation's fourth largest city—and the eight surrounding counties:

Brazoria
Chambers
Fort Bend
Galveston
Harris
Liberty
Montgomery
Waller





Urban Forest Effects Model

The Urban Forest Effects Model (UFORE) is a computer model that calculates the structure, environmental effects and values of urban forests. It was developed in the 1990s by researchers at the United States Department of Agriculture (USDA) Forest Service, Northeastern Research Station in Syracuse, New York, and has been used extensively in various places in the U.S. and abroad. Using land cover maps and field survey inputs, the model provides accurate estimates of urban forest effects based on credible scientific research and analysis.

A central computing engine houses an integrated suite of computer programs that make scientifically sound estimates of urban forest effects. These programs are based on peer-reviewed scientific equations to accurately predict environmental and economic benefits.

The UFORE model is currently designed to provide estimates of:

- *Urban forest structure by land cover type. Forest structure data includes such variables as species composition, number of trees, diameter, tree density, tree health, leaf area, and biomass of leaves and trees.*
- *Hourly amount of pollution removed by the urban forest and associated percent air quality improvement throughout the year. Pollution removal is calculated for ozone, sulfur dioxide, nitrogen dioxide, carbon monoxide and particulate matter 10 microns or less in size.*
- *Hourly urban forest volatile organic compound (VOC) emissions and the relative impact of tree species on net ozone and carbon monoxide formation throughout the year.*
- *Total carbon stored and net carbon annually sequestered.*
- *Effects on building energy use and consequent effects on carbon dioxide emissions from power plants.*
- *Replacement value of the forest, as well as the dollar value of air pollution removal and carbon storage and sequestration.*

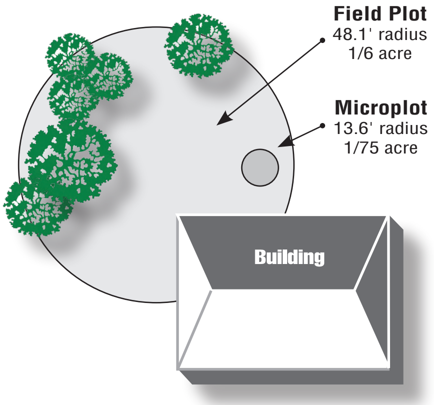


Figure 1
Sample Field Plot Dimensions

Field Survey Data Items

PLOT LOCATION
- Plot Number
- Date
- Crew ID
- Slope/Aspect

PLOT COVER / LAND USE
- Number of actual land uses
- Actual land use
- Percent of plot in each use
- Plot tree cover
- Plot shrub cover
- Percent plantable space
- Ground cover percent (each cover type)
- Number of shrub-genus types
- Shrub layer height (each genus)
- Shrub layer percent of area (each genus)
- Shrub layer percent leaves (each genus)

TREE DATA VARIABLES
- Tree direction
- Tree distance
- Species or genus
- Diameter
- Total height
- Height to crown base
- Percent impervious surface under tree
- Percent shrub cover under tree
- Street tree (Y/N)
- Crown width (two measurements)
- Foliage absent
- Dieback
- Transparency
- Crown light exposure
- Building direction
- Building distance
- Condition (roots, trunk, branches, twigs, leaves)
- Utility conflict
- Leaves condition
- Utility conflict

Field Measurements

An objective view of trees and forests across a region as large as the eight-county Houston region necessitates the use of aerial photography, satellite imagery, or other remote sensing data. But satellites and airborne sensors only see the surface of the region's tree canopy. Field measurements are needed to provide details that satellites miss—for example, the size and species of individual trees or the location of trees with respect to buildings. This detailed information is also essential for the UFORE modeling analysis.

To collect the data, researchers selected sites throughout the region using a sampling pattern similar to one used in the Forest Inventory and Analysis (FIA) program of the USDA Forest Service. This grid pattern divides the region into 6,000-acre cells from which field measurement plots were selected. To get a manageable sample size from the over 800 possible plot locations, two out of every three plots in urban areas were chosen for study, one out of three plots in forested areas, and one out of four plots in agriculture/rangeland areas. This selection process yielded a total of 332 plots.

In 2001 and 2002, field crews visited each of these selected grid points and recorded a series of measurements within a one-sixth acre plot (7,260 square feet—similar in size to a typical residential lot) (Figure 1). Plot measurements included tree species, diameter, height, crown width, foliage parameters, ground cover, and shrub cover.[2] Crews also identified a 1/75th acre microplot (approximately 581 square feet) for measurements of trees between one and five inches in diameter. Unlike trees, data collected on shrubs emphasized the leaf density and crown volume that shrub layers occupied within the plot rather than the dimensions of individual plants.

The Region's Land and Vegetation

A thorough understanding of the region's trees begins with an analysis of surface features that can be identified using satellite imagery and then separating the region into broad categories of vegetation, roads, and zones of urban development. The Houston region has grown at a relatively fast pace and the accompanying development has altered land surfaces dramatically by clearing vegetation, constructing buildings, and paving roads. Shifts in management intensity in agriculture and forestry also affect the region's surface characteristics.

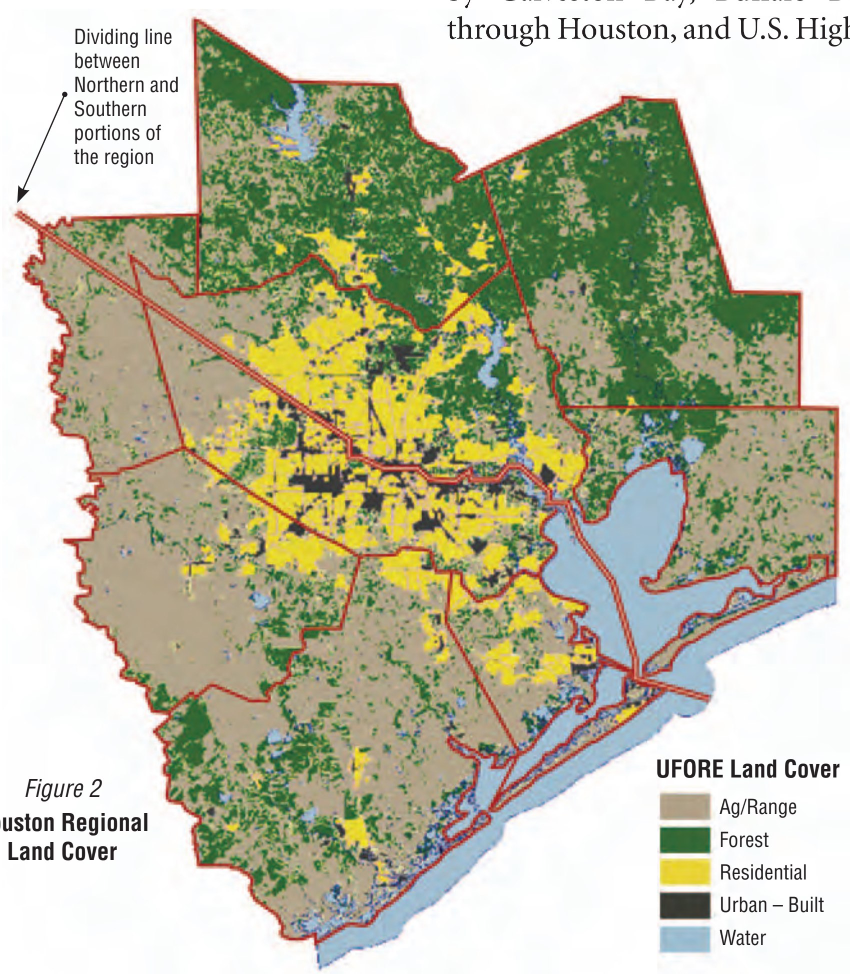


Figure 2
Houston Regional Land Cover

As part of the ***Houston's Regional Forest*** project, Global Environmental Management Inc. developed a comprehensive map of the region using 2000 LANDSAT satellite data, images of field plots, and other remotely-sensed data. The map identified five major categories of *land cover,* including water bodies, forests and urban greenspace, agriculture/range lands, residential areas, and intensely urbanized areas (Figure 2). The Forest and Agriculture/Range categories were further subdivided into two geographic zones to better understand any differences in species composition across the region. These two zones are separated by Galveston Bay, Buffalo Bayou through Houston, and U.S. Highway 290 in Harris and Waller Counties. Excluding water bodies, the total land area studied was 7,581 square miles, divided into seven land cover classes (Table 2).

Table 2
Regional Land Cover Categories

LAND COVER TYPE	AREA Sq. Miles	AREA %	TREES Millions	DENSITY[a] Trees/Sq Mi	SPECIES Number
North Forest	1,653	21.8	382.3	231,000	45
South Forest	499	6.6	88.8	178,000	19
Forest subtotal:	***2,152***	***28.4***	***471.1***	***219,000***	***51[b]***
North Agriculture/Range	984	13.0	36.6	37,000	14
South Agriculture/Range	2,643	34.9	71.8	27,000	11
Agriculture/Range subtotal:	***3,627***	***47.9***	***108.4***	***30,000***	***22***
Residential	987	13.0	43.9	44,000	34
Urban Built	402	5.3	5.9	15,000	14
Urban Green	413	5.4	33.9	82,000	26
Urban subtotal:	***1,802***	***23.7***	***83.7***	***46,000***	***46***
Total (excluding Water)	**7,581**	**100.0**	**663.10**	**87,000**	**67[c]**

[a] *Average density, rounded to the nearest thousand.*
[b] *Subtotals for species in major cover classes represent species found in any one of the subcategories*
[c] *Total tree species identified in analysis*

Overall the region is roughly one-fourth urban and three-fourths agriculture/rangeland and forests. While this non-urban land cover dominates the Houston region today, urban development will play an increasing role in changing these land cover percentages as the population of the region continues to grow.

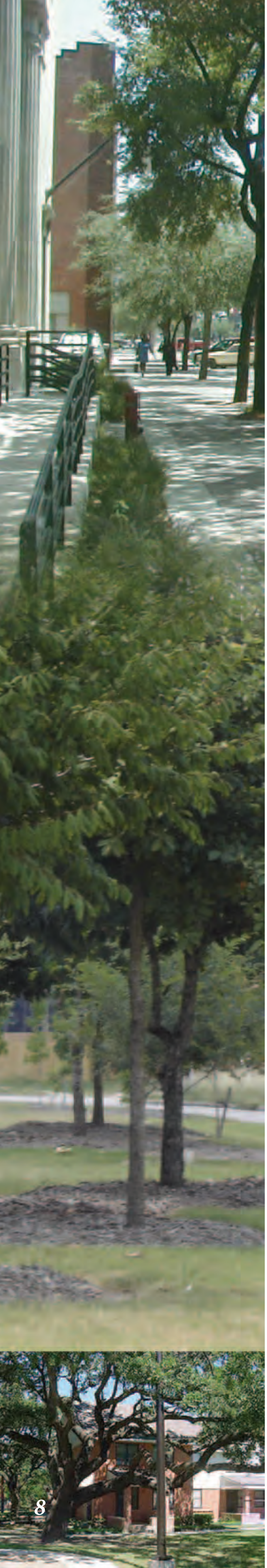
FORESTS

The **North Forest** cover type occupies roughly 1,653 square miles and is located mostly in Montgomery, Waller, and Liberty Counties. It contains 45 tree species, the greatest species diversity of any land cover type. Loblolly pine is most abundant, comprising 24 percent of the tree population. Chinese tallow, the second most common tree, makes up almost 15 percent of the tree population. Combined as a genus, the ten oak species found here represent 16 percent of trees. The next one-fifth of trees is fairly evenly split between sweetgum, baldcypress, green ash, and red maple. With a total of 382 million trees and nearly 231,000 trees per square mile, the **North Forest** has the highest tree density of any of the land cover types, almost three times the regional average.

The **South Forest** contrasts with the heavier forest cover to the north by having fewer trees overall, lower species diversity, and different species. The **South Forest** is 499 square miles in size and extends from Houston to the Gulf of Mexico, increasing in coverage toward the southwest. With 89 million trees (178,000 trees per square mile) and 19 species total, roughly three-quarters are represented by only four species—cedar elm, sugarberry, hawthorn, and Chinese tallow. Other important species found here include pecan, eastern redcedar, and American elm.

AGRICULTURE AND RANGELANDS

South Agriculture/Range is by far the largest land cover type, occupying fully one-third of the region—2,643 square miles. This cover type extends as far north as Waller County and south to the Gulf of Mexico. Its 72 million trees are spread throughout this large area, making tree densities among the lowest of the cover types at 27,000 trees per square mile. This area also possesses the fewest number of species (11) with Chinese tallow comprising nearly 80 percent of all trees. Because of the inherent disturbances and abandonment of agricultural fields and rangeland, the



South Agriculture/Range area provides ample opportunities for the expansion of this invasive species.

The **North Agriculture/Range** cover type is intermixed with the **North Forest** and occupies roughly 984 square miles. It contains 37 million trees (37,000 trees per square mile), made up of 14 species. Loblolly pine is the most prevalent, at 62 percent of all trees, followed by sweetgum, which makes up about 12 percent of trees. Here, Chinese tallow represents only five percent of the total, distinguishing this area from the **South Agriculture/Range.**

URBAN LANDS

Urban land cover types include **Urban Built, Residential,** and **Urban Green.** The **Urban Built** cover type consists of areas dominated by impervious surfaces, such as high-density residential, commercial, and industrial buildings, major roadways, and similar land uses. Only six million total trees are found across the 402 square miles of **Urban Built** land (15,000 trees per square mile). Of these, almost two-thirds are loblolly pine and the next most common is American elm, which makes up 11 percent of trees in this cover type. Fourteen tree species were represented in the sample.

Residential land cover includes low-density development and its associated tree cover. It dominates the central part of the Houston region, emanating out from the central urban core and covering 987 square miles. Tree densities in **Residential** areas vary widely, but on average there are 44,000 trees per square mile (44 million total trees). **Residential** areas contain the second-highest number of tree species (34) of any cover type, many of which have been added over time by homeowners and developers. While the most common tree is again Chinese tallow (30 percent of **Residential** trees), there is a wide diversity of other species. Common trees within **Residential** areas include crape myrtle, loblolly pine, and several species of oak.

While many people consider live oak to be one of the most common trees in the Houston region,

it actually accounts for only

two percent of residential trees.

Urban Green is a cover type associated with major parks, open space, and undeveloped tracts surrounded by or in close proximity to urban development, totaling 413 square miles. It includes large open space areas such as Memorial Park, floodwater retention basins such as Addicks Reservoir, and the vegetated corridors along bayous and streams. Of the three urban land cover types, **Urban Green** areas contain the highest density of trees, at over 82,000 trees per square mile (34 million trees total). Again the most common species is Chinese tallow (43 percent of trees), with hawthorn, water oak, black willow, and green ash making up an additional 40 percent of trees. A total of 26 tree species were found

Tree Population Characteristics

The total population of trees in the Houston area in 2002 is estimated to be 663 million trees. This averages roughly 87,000 trees per square mile, or about 135 trees per person. As might be expected, the majority (71 percent) of trees are located in areas classified as forests. However, urban land cover types also contribute 84 million trees to the region's total, amounting to 13 percent of all trees.

Chinese tallow (23 percent of all trees) and loblolly pine (19 percent) represent the two most common tree species in this study (Table 3). When all oak species are combined, this genus accounts for 15 percent of the trees in the region, and taken together these three tree species/genera account for fully 56 percent of the region's trees. For a complete list of common and scientific names for tree species either found on field plots or discussed in this report, see the Index of Trees on page 22.

Table 3
Most Common Tree Species (10 Million or More Trees)

Tree Species	Number	% of All Trees
Chinese tallow	152,498,000	**23.0**
Loblolly pine	123,974,000	**18.7**
Cedar elm	45,546,000	**6.9**
Water oak	35,608,000	**5.4**
Hawthorn	31,771,000	**4.8**
Sweetgum	30,699,000	**4.6**
Sugarberry	26,788,000	**4.0**
Green ash	24,388,000	**3.7**
Baldcypress	21,628,000	**3.3**
Willow oak	20,993,000	**3.2**
Red maple	17,162,000	**2.6**
American hornbeam	11,809,000	**1.8**
Southern red oak	11,322,000	**1.7**
Black tupelo	10,436,000	**1.6**

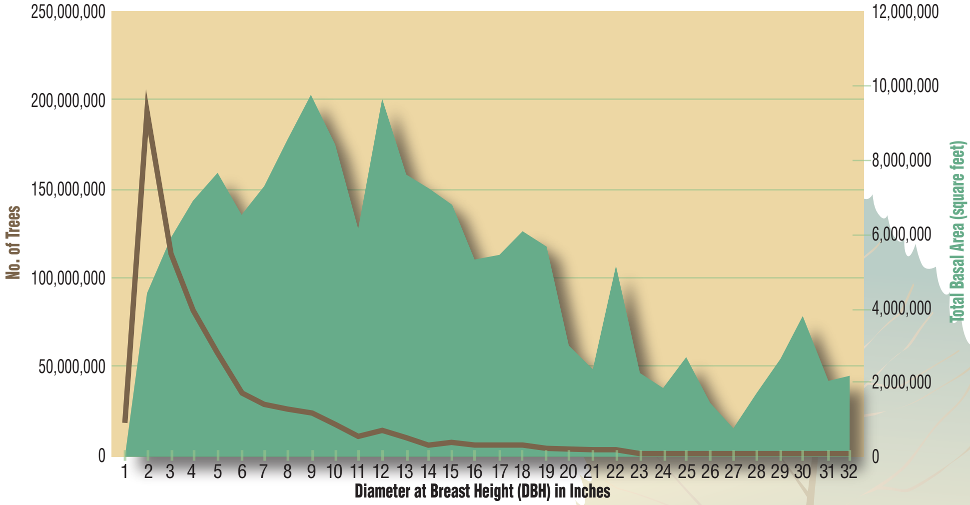
TREE SIZE

The relative size of trees provides important information on the structure, functions and values of the region's forest. Tree size is assessed using trunk diameter and its corresponding cross-section. Diameter is measured at "breast height"—or *DBH,* a point 4.5 feet from the ground—and can then be used to calculate the cross-sectional area of a tree trunk. Called *basal area,* this provides a better measure of total tree volume than tree numbers alone.

Houston's tree population consists of an estimated 191 million trees five inches in diameter or greater, while trees between one and five inches DBH make up 71 percent of the population (472 million trees). Figure 3 shows that although most of the region's trees are less than five inches DBH, the majority of the basal area of Houston's regional forest is found in larger trees (five inches DBH and greater). This 29 percent of trees actually makes up 85 percent of the regional forest's volume.

Leaf area and leaf biomass are other measures used to calculate a tree's functions and values. Leaf surfaces slow rainwater runoff, remove pollutants from the air, and provide shade and cooling effects. Large trees

Figure 3
Number of Trees and Basal Area by Diameter



have more leaves, higher leaf surface areas, and greater leaf biomass than small trees, thus providing substantially greater benefits. On average, a large tree (five inches DBH or greater) removes more pollutants, provides more shade, and has much greater value than a small tree. A single large tree may therefore be the equivalent of hundreds of seedlings or saplings. For instance, urban areas contain 28 million Chinese tallow trees compared to just two million live oaks, yet these oaks possess 16 percent more leaf biomass, thus contributing greater total benefits.

NATIVE AND NON-NATIVE TREES

Species native to the Houston region make up the majority of trees (76 percent) found in the study. Besides the oaks and pines mentioned previously, other common native trees include cedar elm, sweetgum, sugarberry, American elm, baldcypress, and green ash. Native trees are adapted to the region's climate, geography and ecosystems and generally require less maintenance, water, and artificial fertilizers than non-native species in landscape settings. They are also critical components of native ecosystems that provide habitat and food for birds, butterflies, and mammals.

However, non-native species represent a significant component of the region's trees (24 percent), dominated by a single species—Chinese tallow (23 percent). Other common trees that have been introduced to the region include Chinese elm, camphor-tree, crape myrtle, chinaberry, and silver maple. Most of these species remain where they are planted, but certain non-native species become *invasive,* overtaking disturbed areas such as abandoned agricultural and urban lands, coastal prairies, and forests, crowding out native plants in areas where they were not intended. The **South Agriculture/Range** cover type presents a good example of this tendency, with Chinese tallow now accounting for nearly 80 percent of the tree population.

URBAN AND RURAL TREES

Different land cover types contain different tree populations. This study found that urban land cover types contained 84 million trees (13 percent), compared to 579 million trees in rural cover types (87

Table 4
Comparison of Urban and Rural Trees

FEATURE	URBAN	RURAL	TOTAL
Number of Trees (millions)	83.7	579.4	**663.1**
% of Trees	12.6%	87.4%	**100.0%**
Carbon Storage (in million tons)	7.9	31.3	**39.2**
% of Carbon	20.1%	79.9%	**100.0%**
Replacement Value ($ billions)	$41.8	$164.0	**$205.8**
% of Replacement Value	20.3%	79.7%	**100.0%**

percent) (Table 4). However, urban trees provide a greater contribution to key benefits such as carbon storage (20 percent) and replacement value (20 percent).

In urban and urbanizing areas, trees are often cleared from development sites to provide easier access and space for buildings and paved surfaces. Trees and other vegetation that are planted following construction are usually fewer in number and smaller than the trees they replace. Non-native and exotic species may also be introduced as new landscape features.

Urbanization has had different effects on the tree population across the region. For example, urban development in what was previously **South Agriculture/Range** has added some Texas native trees (live oak, loblolly pine) to these landscapes, thus reducing the extent of non-native species such as Chinese tallow. Urban development in **North Forest** areas has altered or replaced the mixed pine/hardwood forests and bottomland forests, in many places providing opportunities for non-native trees and invasive plants to become established.

Forest Functions and Values

Trees and forests provide community, economic, and ecosystem values that have been well documented in research literature. The UFORE analysis in this study calculated the extent and value of three major benefits of trees and forests in the Houston region: pollution removal, carbon storage and sequestration, and energy savings. The study also calculated the value of trees for what they *are,* not just what they *do.* This replacement value corresponds to the estimated worth of each tree as it exists in the landscape.

POLLUTION REMOVAL

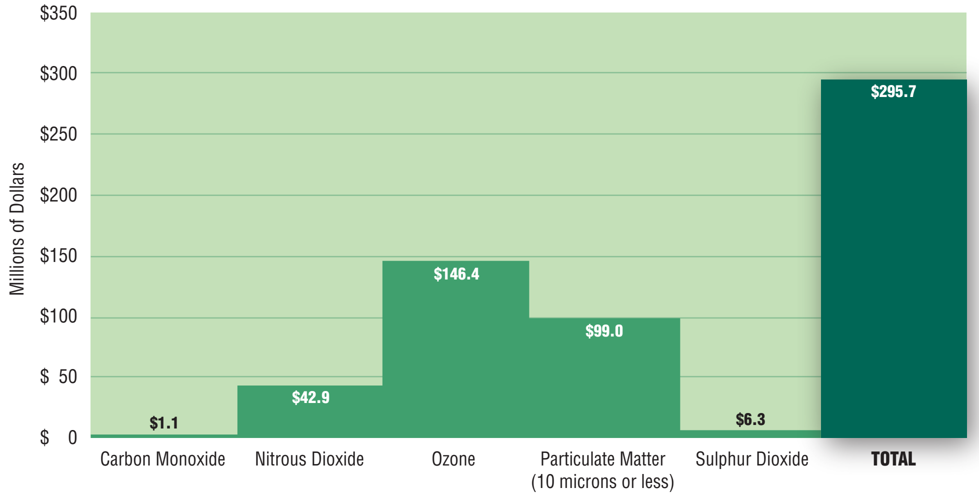
Poor air quality can impair human health, damage crops and other vegetation, and reduce visibility. Under the Clean Air Act, the eight-county Houston region is legally mandated to meet federal air quality standards. Houston's regional forest helps improve air quality by reducing air temperatures, directly removing pollutants from the air, and reducing building energy use and consequent pollutants from power plants.

The UFORE model calculated pollution removal by Houston's regional forest using hourly pollution data and weather data (George Bush Intercontinental Airport weather station) collected in 2000. The year 2000 was used because the study results needed to match Texas Commission on Environmental Quality (TCEQ) air quality modeling protocols for that time period.

Model results reveal that Houston's regional forest removes 60,575 tons of *criteria air pollutants* (substances designated in the Clean Air Act) per year, which has an annual economic

Figure 4

Value of Air Pollution Removed



value to the region of nearly $300 million dollars (Figure 4). These estimates are based on the national median externality costs associated with air pollution.[3]

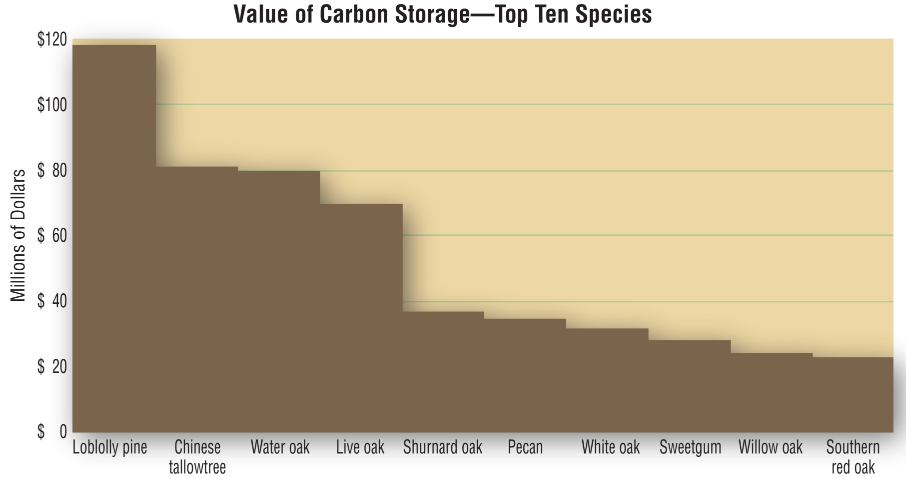
However, the overall effect of trees on air quality involves complex relationships between the pollution trees remove, biogenic emissions, and air temperature and moisture regimes. While trees do emit volatile organic compounds (VOCs) that contribute to ground-level ozone formation, many studies have shown that increasing tree cover over an area can actually reduce these ozone levels.[4] Sophisticated modeling is required to calculate the net effects of trees, which will be documented as a companion report on *Air Quality and Houston's Regional Forest.*

CARBON STORAGE AND SEQUESTRATION

Trees play an important role with regard to the carbon cycle and associated climate variability. Trees moderate the amount of carbon dioxide in the atmosphere through the process of photosynthesis. Carbon that remains locked up in trees from year to year is referred to as *carbon storage.* As trees grow larger each year, they *sequester* additional carbon and add it to the carbon already stored in trunks, branches, and leaves. Unlike deciduous trees, evergreens retain their leaves for more than one season, thus adding to their stored carbon.

Figure 5

Value of Carbon Storage—Top Ten Species



Based on the UFORE model analysis, trees in Houston's regional forest store 39.2 million tons of carbon, valued at $721 million.[5] Of this amount, 15 percent is stored by one species alone—loblolly pine (Figure 5). In addition, the regional forest sequesters 1.6 million tons of carbon each year, at a value of $29 million.

Trees vary significantly in their carbon storage and sequestration rates based on species, size, health, and site conditions. Young, healthy trees in the prime of life have higher sequestration rates than older trees, but due to their stature large trees store more carbon. For example, live oak represents less than 0.5 percent of the region's tree population but accounts for over nine percent of the total carbon stored.

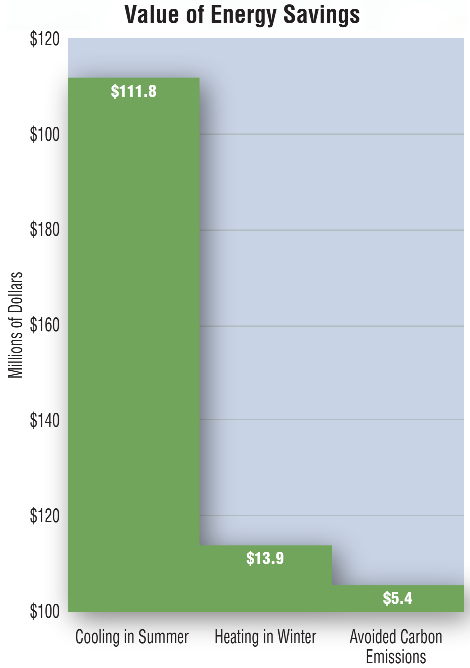
ENERGY SAVINGS

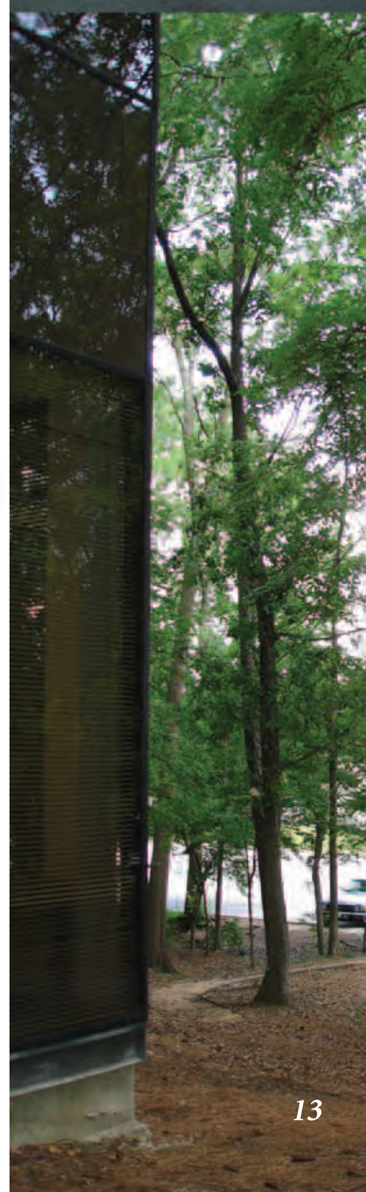
Trees affect the amount of energy that homes and buildings use by providing shade, by the evaporative cooling effect of their leaves, and by blocking winter winds. Trees are particularly beneficial in areas like Houston that rely on air conditioning in summer months. In this analysis, trees located within sixty feet of one- or two-story residential buildings were evaluated to calculate their effect on energy usage.

The UFORE model calculated energy savings from trees using tree size, distance and direction from buildings, leaf type (deciduous or evergreen), and the percent cover of buildings and trees as recorded on field survey plots. Values are derived from the average regional costs for electricity and fuel.

Results show that the regional forest saves energy in both the heating and cooling seasons, with the largest savings in summer when trees shade buildings and reduce the need for air conditioning. During the winter, trees protect buildings from cold north winds, reducing the need for heating. By reducing energy consumption, trees also reduce carbon emissions from power plants that would have occurred had the trees not been present.[6] The estimated total value of energy savings and avoided carbon emissions for the Houston region amounts to $131 million annually (Figure 6).

Figure 6
Value of Energy Savings





REPLACEMENT VALUE

Trees have an intrinsic value based on their presence and contribution to the landscape setting that can be measured in dollars. This *replacement value* is calculated using procedures set forth by the Council of Tree and Landscape Appraisers[7] and can be used to determine monetary settlements for damage or death of plants through litigation, insurance claims, loss of property value for income tax deductions, and real estate assessments. Values derived from these procedures estimate the amount of money a tree owner should be compensated for the loss of a particular tree. The value is based on the market cost of planting a replacement tree and four characteristics of the original tree: size, species, condition, and location.

The UFORE model estimated a total replacement value of $205.8 billion for Houston's regional forest.

Summary of Values

Houston's regional forest has a total estimated structural value of $206.5 billion. *Structural value* combines replacement values of trees and carbon storage values, and represents the total value of the trees as they stand. But because trees live and grow each year, the regional forest provides annual *functional values* (air pollution removal, carbon sequestration, and energy savings) that total an additional $456 million. These values are summarized in Table 5.

Table 5

Structural Value	Amount
Replacement Value	$205.8 billion
Carbon storage	$ 0.7 billion
Total Structural Value	**$206.5 billion**
Annual Functional Value	**Annual Amount**
Carbon Sequestration	$ 29.0 million
Air Pollution Removal	$295.7 million
Energy Savings	$131.1 million
Total Annual Functional Value	**$455.8 million**

Threats to the Region's Forest

Forests and trees are faced with many factors that can adversely affect tree populations and their associated values to people, the economy, and ecosystems. These threats include extreme weather events, wildfire, insect pests, and land cover changes. This report provides an analysis of several of these factors.

PESTS

Because the region's forests are dominated by certain tree species—Chinese tallow, pine, oak, maple and ash—the structural and functional values of the forest as a whole are at risk from pests that target these potential hosts. The UFORE model estimated the effects of four insect pests of particular concern to the forests of the Houston area: gypsy moth, southern pine beetle, Asian longhorned beetle, and emerald ash borer. The total value of losses sustained during a serious outbreak of any one of these pests could be in the billions of dollars (Figure 7). These losses do not include costs that would be incurred to control such pests.

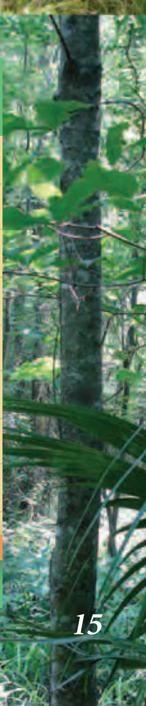
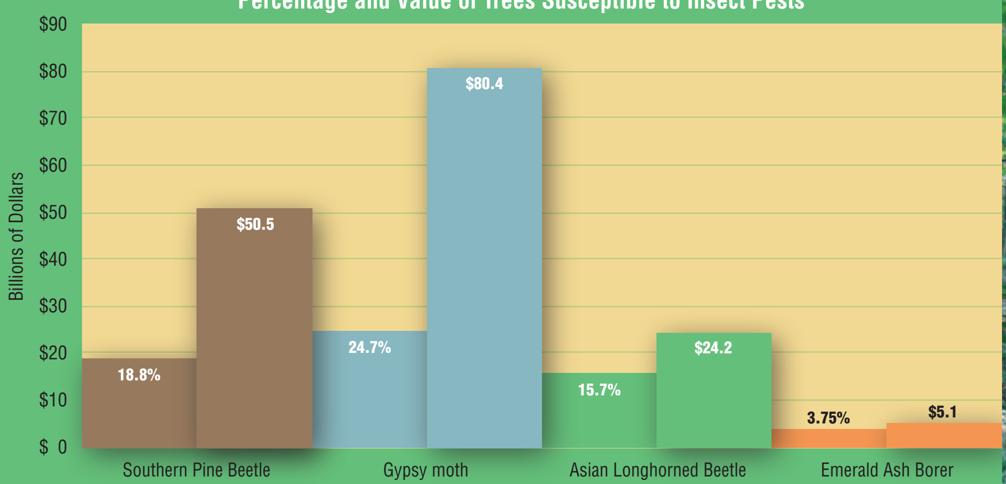
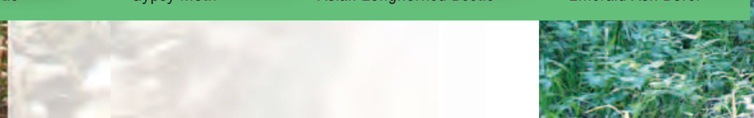


Figure 7

Percentage and Value of Trees Susceptible to Insect Pests





Gypsy moth[8] represents the single greatest pest threat to Houston's regional forest due to the large range of suitable host species found here. This non-native insect has become established in other parts of the U.S., notably the northeast and the southern Appalachians. It defoliates many species—particularly oaks—during the growing season, causing widespread tree mortality if the outbreak is repeated several years in succession. Should it become established in the Houston region, losses of ten percent of susceptible trees would amount to approximately $8.0 billion.

Southern pine beetle[9] is a native insect pest that has destroyed thousands of acres of pine forests in the southern U.S. in recent years. In 1995 alone, timber losses were estimated at over $300 million. Infestations are cyclic, with outbreaks reaching epidemic proportions about every six to ten years. Though the Houston area has been spared such an outbreak over the past decade, an infestation affecting ten percent of the region's pine trees would cause more than $5 billion in structural value losses.

Asian longhorned beetle[10] is another pest from Southeast Asia that could have serious impact on the region's forest cover, since it bores into and kills a wide range of hardwood species. Although not yet established in the region, it has been recorded at the Port of Houston on shipping crates. If an outbreak of this insect were to occur, the loss of just ten percent of susceptible host trees would total $2.4 billion.

Emerald ash borer[11] is a recently introduced pest that currently affects several U.S. states (Michigan, Indiana, Ohio) and southern Ontario, Canada. All ash species are susceptible to attack and multi-county quarantine zones within affected states have been established to limit the movement of ash logs and firewood. Control measures currently involve eliminating infected and potential host ash trees within three miles of an outbreak, meaning that the discovery of even one infested tree can impact a much greater area of the region's forest. Currently, 3.8 percent of Houston's tree population is made up of ash trees.

Chinese tallow easily invades *areas disturbed by* **human activity.**

INVASIVE TREE SPECIES

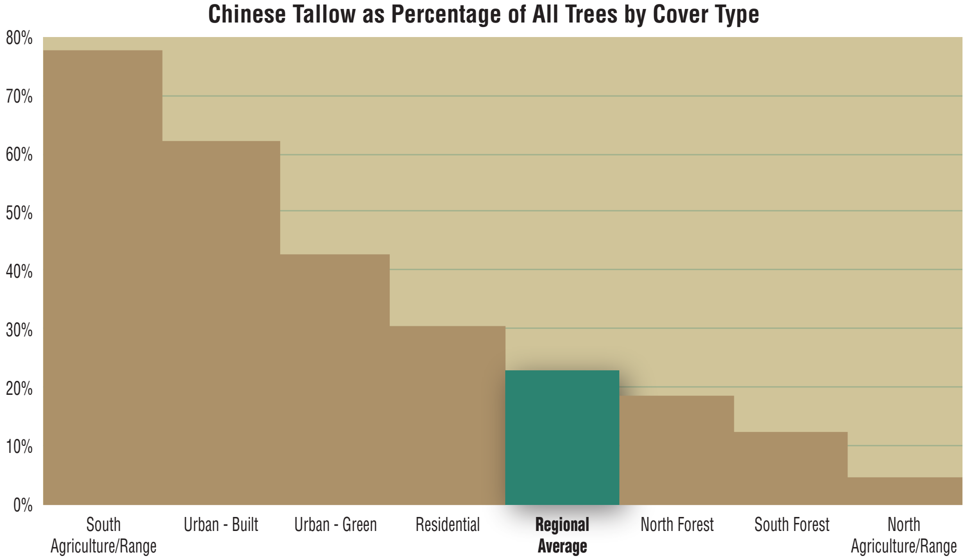
The movement of trees and plants across the globe for horticultural and agricultural purposes has dramatically affected ecosystems in the southern U.S. Some plants were chosen for their aesthetic qualities or to perform some particular function, while others are simply "stowaways" that arrived in shipments of other plants or animals. A small number of species introduced to the U.S. escape cultivation and become established in a variety of unplanned settings. With few natural pests or diseases in their new home, these escaped plants can become invasive over the course of a few decades and begin to alter native ecosystems.

Such is the case of Chinese tallow in the Houston region. Originally established in Texas in the early 1900s as a potential agricultural source of seed oil to make soap, it quickly escaped cultivation. It grows rapidly and matures at an early age; birds spread its seeds widely; and it favors the climate and soil conditions over a vast portion of the lower Texas coastal plain. It appears highly adapted to areas disturbed by human activity, including agriculture, forestry, and land development. And once established, Chinese tallow tends to dominate areas by outcompeting native plants.

This single species now accounts for over 152 million trees, almost one-fourth of all trees in the region. It is considered common in all of the cover types sampled in this study, but the highest concentration occurs in the **South Agriculture/Range** cover type where the species represents nearly 80 percent of all trees. Some of these lands may ultimately represent new forests in areas where trees historically did not dominate the landscape, meaning that Chinese tallow is providing benefits in terms of new tree cover. However, it now makes up from 13 to 19 percent of trees in the **Forest** cover types, which hints at the effect on native plant populations (Figure 8).

Figure 8

Chinese Tallow as Percentage of All Trees by Cover Type



Horticulturists, urban foresters, and nursery and landscape professionals all share a responsibility to consider the potential negative effects of introducing new species to the region. Future surveys of the regional forest will help monitor the populations of exotic species and their impact on the environment.

Several other non-native tree or shrub species warrant careful consideration, either because they have already escaped cultivation in the Houston region, are being promoted as landscape plants, or because their effects elsewhere have been highly negative. This first group includes tree-of-heaven, chinaberry, Chinese privet, and mimosa. All of these species can be found occasionally in native or disturbed areas throughout the region, though not in numbers comparable to Chinese tallow.

The second group includes Chinese pistache, Chinese elm, Mexican white oak, and sawtooth oak. These species are now commonly found in nurseries throughout the region and have been promoted as landscape trees highly adapted to Houston's climate and soils. It is this very adaptation, however, that presents the potential for escaping cultivation and becoming an invasive species.

The third group is the most problematic because it is impossible to completely predict how a species will adapt to a new environment simply based on its habits elsewhere. However, some species have caused such environmental degradation in other parts of the U.S. that any proposed or accidental introduction in the Houston region should be viewed with extreme caution. Though not discovered on field plots in this study, experiences with trees such as Brazilian pepper in Florida, saltcedar in the desert southwest, or eucalyptus in California offer cautionary tales of allowing these plants to become established here—either through accident or some well-meaning landscape design.

Horticulturists, urban foresters, and nursery and landscape professionals all share a responsibility to consider the potential negative effects of introducing new species to the region. Future surveys of the regional forest will help monitor the populations of exotic species and their impact on the environment.

LAND COVER CHANGES—1992 TO 2000

Urban development and other human activities in the Houston region have had significant effects on the regional forest's extent and composition. Previous studies have

Table 6
Land Cover Change 1992-2000[a]

LAND COVER TYPE	1992 Sq. Miles	2000 Sq. Miles	CHANGE Sq. Miles	% CHANGE
Forest	2,798	2,312	-485.6	-17.4%
Agriculture/Rangeland	3,840	3,846	6.0	0.2%
Residential	659	989	329.5	50.0%
Urban Built	275	425	149.8	54.5%
Total Land Cover	**7,572**	**7,572**	**-00.3**[a]	**0.0%**

[a] *Changes in land cover should be considered approximate due to differences in methodologies used for the two study periods. Urban Green areas for 2000 redistributed across cover types to match 1992 cover classification system. Water areas not included.*

indicated that urban expansion over the past thirty years has resulted in forest cover losses of approximately six percent per decade.[12] The current study compared LANDSAT satellite data for 2000 and U.S. Geological Survey land cover data for 1992 to estimate land cover changes that occurred over this more recent eight-year period (Table 6).

The **Forest** land cover types declined by a total of 17.4 percent over this eight-year period, an annual loss of 2.2 percent. Since the area occupied by **Agriculture/Range** lands stayed roughly the same, the primary source of change in land cover was the expansion of **Residential** areas by 330 square miles, a growth rate of 6.3 percent per year. The associated **Urban Built** land cover type increased by 55 percent during this time period, occupying an additional 150 square miles.

These land cover changes had a dramatic effect on the total number of trees in the region. Assuming that the density of trees within a cover type would be similar from 1992 to 2000, the net effect of land cover change was a loss of over 78 million trees (almost 10 million trees per year), with a structural value of approximately $24 billion ($310 per tree). The environmental benefits from trees declined by an average of $56 million per year, or $448 million. Unmitigated losses at this rate will continue to erode the benefits that trees provide to citizens in the region.

The Future of Houston's Regional Forest

Houston's regional forest represents a vital part of the region's identity and provides many benefits to Houston's people, environment, and economy. This project has quantified and illustrated some of these features. But these trees and forests don't exist in a vacuum; they are affected by the cumulative daily activity of the region's five million people. To ensure that the benefits of trees will be experienced by future generations, local and regional leaders of today must begin to develop long-range policies for maintaining and expanding tree cover.

The greatest threat to the overall tree population remains the land development process. Based on current practices, forest changes that are likely to occur include: decreased numbers, densities, and varieties of native trees, combined with a potential for an increased presence of pests and non-native trees. This report also demonstrates the dominant contribution larger trees make to the overall value of the regional forest, making it important for regional leaders to consider policies that adequately protect this key portion of the resource. Examples of strategies to preserve trees currently in use in the region include: conservation easements, parkland dedication, land purchases for parks or flood control, conservation subdivision design, tree preservation ordinances, and a variety of educational opportunities for developers.

Mortality of existing trees is not generated by development pressures alone. Natural mortality rates of forests have been studied extensively, but only limited urban forest mortality rates exist.[13] A study of Baltimore's trees estimated that net losses averaged 4.2 percent annually, which included the effects of land use change. Using a comparable rate for the Houston region, net tree losses could total as many as 28 million trees per year. Besides

To ensure that the benefits of trees will be experienced by future generations,

local and regional leaders of today must begin to develop

long-range policies for maintaining and expanding tree cover.

affecting the rate or impact of land use change in the region, one way to minimize these annual losses is to reduce tree mortality rates, which could be accomplished through improved landscape care and maintenance programs. Matching species to suitable locations is also critical to survival of trees in planting programs.

But ultimately, large scale tree planting and other programs are needed if any increase in tree cover is to be realized. And it will be important to match these programs with the benefits expected from trees, since different species provide different values to the region. For air quality improvement it may be important to consider species that generate lower emissions of volatile organic compounds (VOCs) as a key factor, while planting programs for energy conservation or heat island mitigation might favor species that generate maximum shade over a longer lifespan. Other factors include whether trees are to be planted on public or private property; whether the area is urban or rural; whether a species is native or non-native; what the maintenance requirements are; availability for planting; and cost.

Houston neighborhood with mature tree canopy coverage.

Index of Trees in UFORE Analysis

Common Name	Scientific Name	Native ?	Found in Land Cover Types[1]
American elm	*Ulmus americana*	Y	NF, SF, SA, NA, R, UG, UB
American holly	*Ilex opaca*	Y	NF, R
American hornbeam	*Carpinus caroliniana*	Y	NF
American sycamore	*Platanus occidentalis*	Y	NF
Baldcypress	*Taxodium distichum*	Y	NF
Black cherry	*Prunus serotina*	Y	NF
Black hickory	*Carya texana*	Y	NF
Black tupelo	*Nyssa sylvatica*	Y	NF, NA
Black walnut	*Juglans nigra*	Y	NF
Black willow	*Salix nigra*	Y	NF, NA, UG, UB
Boxelder	*Acer negundo*	Y	UG
Brazilian pepper	*Schinus terebinthifolius*		Discussed in report
Bur oak	*Quercus macrocarpa*	Y	R
California palm	*Washingtonia filifera*		R
Camphor-tree	*Cinnamomum camphora*		R
Cedar elm	*Ulmus crassifolia*	Y	NF, SF, SA, R, UG, UB
Cherrybark oak	*Quercus falcata var. pagodifolia*	Y	NF, UG
Chinaberry	*Melia azedarach*		SF
Chinese elm	*Ulmus parvifolia*		R
Chinese pistache	*Pistacia chinensis*		Discussed in report
Chinese privet	*Ligustrum sinense*		Discussed in report
Chinese tallow	*Sapium sebiferum*		NF, SF, SA, NA, R, UG, UB
Chittamwood (Gum bumelia)	*Bumelia lanuginosa*	Y	SF, SA, UG
Common fig	*Ficus carica*		UG
Common persimmon	*Diospyros virginiana*	Y	NF
Crape myrtle	*Lagerstroemia indica*		R
Eastern cottonwood	*Populus deltoides*		YR, UG
Eastern hophornbeam	*Ostrya virginiana*	Y	NF, R
Eastern redcedar	*Juniperus virginiana*	Y	NF, SF, R, UB
Eucalyptus	*Eucalyptus spp.*		Discussed in report
Flowering dogwood	*Cornus florida*	Y	NF
Green ash	*Fraxinus pennsylvanica*	Y	NF, SF, SA, UG
Hawthorn	Crataegus spp.	Y	NF, SF, SA, R, UG
Hercules-club	*Zanthoxylum clava-herculis*	Y	NA
Hickory	*Carya spp.*	Y	NF
Huisache	*Acacia farnesiana*	Y	R, SA
Laurel oak	*Quercus laurifolia*	Y	NF, SF
Live oak	*Quercus virginiana*	Y	SF, SA, R, UG, UB
Loblolly pine	*Pinus taeda*	Y	NF, SA, NA, R, UG, UB
Mexican white oak	*Quercus polymorpha*		Discussed in report
Mimosa	*Albizia julibrissin*		Discussed in report
Oriental arborvitae	*Thuja orientalis*		UB
Osage-orange (Bois-d'Arc)	*Maclura pomifera*	Y	SF, R
Overcup oak	*Quercus lyrata*	Y	NF
Pecan	*Carya illinoensis*	Y	NF, SF, SA, R, UG, UB

Common Name	Scientific Name	Native ?	Found in Land Cover Types[1]
Post oak	*Quercus stellata*	Y	NF, SF, NA, R, UG
Red maple	*Acer rubrum*	Y	NF, NA
Red mulberry	*Morus rubra*	Y	NF, R, UG
Redbay	*Persea borbonia*	Y	NF
Rusty blackhaw	*Viburnum rufidulum*	Y	R
Saltcedar (Tamarisk)	*Tamarix spp.*		Discussed in report
Sawtooth oak	*Quercus accutissima*		Discussed in report
Shortleaf pine	*Pinus echinata*	Y	NF
Shumard oak	*Quercus shumardii*	Y	NF, R
Silver maple	*Acer saccharinum*		R
Slash pine	*Pinus elliottii*		R, UB
Slippery elm	*Ulmus rubra*	Y	NF, UG
Southern catalpa	*Catalpa bignonioides*		R
Southern magnolia	*Magnolia grandiflora*	Y	NF, NA, R
Southern red oak	*Quercus falcata*	Y	NF, SF, NA, R, UG
Sugarberry	*Celtis laevigata*	Y	NF, SF, SA, R, UG, UB
Swamp chestnut oak	*Quercus michauxii*	Y	NF
Sweetgum	*Liquidambar stryaciflua*	Y	NF, NA, R, UG, UB
Texas hawthorn	*Crataegus texana*	Y	SF
Tree-of-heaven	*Ailanthus altissima*		Discussed in report
Unknown	*Spp.*		NF, UG
Velvet (Arizona) ash	*Fraxinus velutina*		NF, R, UG
Water-elm	*Planera aquatica*	Y	NF
Water hickory	*Carya aquatica*	Y	NF, UG
Water oak	*Quercus nigra*	Y	NF, SF, NA, R, UG, UB
Western soapberry	*Sapindus drummondii*	Y	SF, R
White ash	*Fraxinus americana*	Y	NF
White oak	*Quercus alba*	Y	NF, NA, R
Willow	*Salix spp.*		UB
Willow oak	*Quercus phellos*	Y	NF, R, UG
Winged elm	*Ulmus alata*	Y	NF, SF, NA, UG

[1] Codes for land cover types: **NF**=North Forest, **SF**=South Forest, **NA**=North Ag/Range, **SA**=South Ag/Range, **R**=Residential, **UG**=Urban Green, **UB**=Urban Built.

Photography: *David Hitchcock, Wendee Holtcamp, Alex MacLean, Michael Merritt, Quality of Life Coalition, John Warner*

TFS Communications/Urban & Community Forestry
9/05-5000

Footnotes/References

[1] Nowak, D.J., and D.E. Crane. 2000. "The Urban Forest Effects (UFORE) Model: quantifying urban forests structure and functions" in: Hansen, M. and T. Burk (Eds) *Integrated Tools for Natural Resources Inventories in the 21st Century.* Proceedings of the IUFRO Conference. USDA Forest Service General Technical Report NC-212. North Central Research Station, St. Paul, MN. Pp. 714 - 720.

[2] For detailed methods, see: Nowak, D. J., D. E. Crane, J. C. Stevens, and M. Ibarra. 2002. Brooklyn's Urban Forest. USDA Forest Service Gen. Tech. Rep. NE-290; and Urban Forest Health Monitoring Manual at: http://www.fs.fed.us/ne/syracuse/Tools/UFORE.htm

[3] F. J. Murray, L. March, P.A. Bradford, New York State Energy Plan (New York State energy Office, Albany, NY, 1994. Economic values to society are based on median monetized dollars per ton externality values used in energy decision making from various studies. Values per ton in this study include: NO_2 = $6,752, PM10 = $4,508, SO2 = $1,653, and CO = $959.

[4] For more information, visit: http://www.fs.fed.us/ne/syracuse/TREE%20Air%20Qual.pdf

[5] Carbon values are multiplied by $20.3 per metric ton, which is based on the estimated marginal social costs of CO_2 emission. Fanhauser, A., 1994. The social costs of greenhouse gas emissions: an expected value approach. The Energy Journal 15(2), 157-184.

[6] For more information, see: Abdollahi, K. K., Z. H. Ning, and A. Appeaning (Eds.) 2000. *Global climate change and the urban forest.* GCRCC and Franklin Press, Baton Rouge, LA.

[7] Based on Council of Tree and Landscape Appraisers guidelines. For more information, see Nowak, D. J., D. E. Crane, and J. F. Dwyer. 2002. *Compensatory value of urban trees in the United States.* J. Arboric. 28 (4): 194-199.

[8] For more information, visit: http://na.fs.fed.us/spfo/pubs/fidls/gypsymoth/gypsy.htm

[9] For more information, visit: http://www.barkbeetles.org/spb/Index.HTML

[10] For more information, visit: http://na.fs.fed.us/fhp/alb/index.shtm

[11] For more information, visit: http://na.fs.fed.us/fhp/eab/index.shtm or http://www.emeraldashborer.info/

[12] American Forests' *Urban Ecosystem Analysis For the Houston Gulf Coast Region.* For more information, visit: http://americanforests.org/downloads/rea/AF_Houston.pdf

[13] Nowak, D.J., M. Kuroda, and D.E. Crane. 2004. Tree mortality rates and tree population projections in Baltimore, Maryland, USA. Urban Forestry and Urban Greening, 2:139-147. http://www.elsevier-deutschland.de/artikel/649602#

For further information on Urban Forest Health Monitoring, UFORE, or urban forest effects, please visit: http://fhm.fs.fed.us/; http://www.fs.fed.us/ne/syracuse; or http://www.ufore.org

HOUSTON'S REGIONAL FOREST

STRUCTURE ▪ FUNCTIONS ▪ VALUES

HOUSTON'S REGIONAL FOREST

STRUCTURE ▪ FUNCTIONS ▪ VALUES

U.S. FOREST SERVICE ■ TEXAS FOREST SERVICE
SEPTEMBER 2005