Greater Gulf-Houston

REGIONAL NATIVE TREE PLANTING POLICY & GUIDELINES MANUAL

Written & Produced by:
Tree Strategy Implementation Group
Greater Houston Region

Facilitated by:

HOUSTON
WILDERNESS
It's Our Nature

July 2021

Background on Tree Strategy Implementation Group (TSIG)
Greater Houston Region

Key Strategy Goals and Guiding Principles

The Tree Strategy Implementation Group (TSIG) came together in early 2020 to create a strategy to accomplish the Resilient Houston Plan's goal to plant *4.6 million new native trees by 2030*. Tree Strategy Implementation Group (TSIG) Members included:

- City of Houston Resilience Office (Marissa Aho)
- Buffalo Bayou Partnership (Anne Olson)
- Civil Engineering - Matthew Smith (ALJ Lindsey)
- Harris County Flood Control District - HCFCD (Nicolas Griffin)
- Harris County, Precinct 2 (Jorge Bustamante)
- Harris County Tollroad Authority - HCTRA (Doug Emery)
- Houston-Galveston Area Council - H-GAC (Justin Bower and Cheryl Mergo)
- Houston Parks & Recreation Dept - HPARD (Kelli Ondracek)
- Houston Parks Board - HPB (Marissa Llosa and Alexis Overdiek)
- Houston Wilderness - HW (Deborah January-Bevers)
- Land Conservation Finance (Ernest Cook)
- Landscape Architects
  - Keiji Asakura (Asakura Robinson)
  - Matt Baumgarten and Rachel Wilkins (SWA)
  - Sheila Condon (Clark Condon)
- Mitigation Banking (represented by Matt Stahman, RES)
- Municipal Utility Districts - MUDs (represented by Alia Vinson, ABHR)
- Nature's Way Resources (John Ferguson)
- TxDOT – Houston District (Ethan Beeson)
- Texas A&M Forest Service (Mickey Merritt & Mac Martin)
- Trees for Houston - TFH (Barry Ward)

GOAL 6 WE WILL ENSURE THAT ALL NEIGHBORHOODS ARE HEALTHY, SAFE, AND CLIMATE READY.

Climate change occurs at a global scale, but its impacts, including extreme heat, flooding from severe storms and heavy rainfall, and prolonged periods of drought, can vary from one neighborhood to the next, with low-income communities and communities of color often disproportionately impacted.

We can apply a neighborhood planning approach to adapt to climate change, with place-based interventions to ensure that all Houstonians live in neighborhoods that are healthy, safe, and climate ready. Place-based interventions include neighborhood Resilience Hubs that cater to the specific needs of the surrounding community, local greening initiatives to enhance open space and combat the urban heat island effect, and community gardens and fruit forests to increase access to fresh food.

(6) Plant 4.6 million new native trees by 2030.

RESILIENT HOUSTON

Based on data analyzed by TSIG members to be most beneficial to the region, a 4-part large-scale tree planting strategy was created based on 40% of the native 4.6 million trees targeted for Urban Heat Island areas with tree species with large leaf canopies, and 60% of the native trees targeted for native 'Super Trees' species (discussed in Chapter 4) that provide high levels of air pollution reduction, water absorption, erosion control and carbon sequestration (See also Appendix J).

The 4-part TSIG Strategy includes:

1. Beginning in 2019, maintaining an average of 400,000 native trees planted each year using three main actions: a) continue large-scale native tree planting with multiple native species by TSIG members, b) create an educational campaign to encourage residential involvement in large-scale native tree plantings (encouraging the equivalent of two new trees for every Houstonian), and c) provide data and tracking of the planting of millions of native trees through 2030, which will be provided via an online City of Houston tracking system.
2. Creation of a *Regional Native Tree Planting Policy & Procedures Manual* – educating decision-makers and the general public on the Best Management Practices of why, how and where to do large-scale native tree plantings, targeting specific native tree species based on location and ecosystem services needed.
3. Tracking where major native tree removals are taking place and encouraging alternatives to deforestation.
4. Supporting regulatory improvements that will assist in reaching the 4.6 million new native trees goal, such as updating county/city native tree lists, and allowing additional green space locations for large-scale tree plantings.

In celebration of Texas Arbor Day 2020, and as a Kick-off for the TSIG's Strategy to plant 4.6 native trees by 2030, a press conference and volunteer native tree planting event was held at Buffalo Bend Nature Park with governmental leaders, community partners and TSIG members (see City of Houston Press Release, November 6, 2020 - Appendix G)

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Resilient Houston Plan
Tree Strategy Implementation Group
Greater Gulf-Houston Regional Native Tree Planting Policy & Guidelines Manual

Using this Manual

To make this Manual as user-friendly as possible, there are a series of video forums that were produced leading up to the final publication of this Manual (See https://houstonwilderness.org/46-million-trees-by-2030-goal). The video TSIG Forums include presentations by experts on large-scale native tree plantings, climate change impacts and adaptive capacity of tree species in the region. At the beginning of each chapter there are YouTube links of the video forums with more information pertaining to that chapter.

Greater Houston's Ecologically Diverse Region

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Chapter 7: Avoiding Deforestation of Native Trees

Chapter 9: Removing Invasive Trees and Diseases

CHAPTER ONE:

Forestation-Style Tree Plantings in 8-County Gulf-Houston Region

BRIEF HISTORY OF LARGE-SCALE FORESTATION IN GULF-HOUSTON REGION

TSIG Video Forum featuring TxDOT-Houston District forestation-style plantings along freeways - See Youtube link: https://youtu.be/Pn8yK928YM8

Large-scale native tree plantings that create forested areas with diverse trees species has been around the Greater Houston area for many years

In 2001, a *Quality of Life Coalition* in Houston, TX, made up of the region's largest business organization, the Greater Houston Partnership, regional environmental nonprofits and local/regional governmental entities, worked closely with the Texas Department of Transportation (TxDOT) Houston District to create a pioneering initiative allowing for large-scale native reforestation along the freeways and large thoroughfares in the Greater Houston Region. The policy initiative was called the *Green Ribbon Freeway Forestation* program. The initiative's goal was to move away from large grass plots along TxDOT's freeway and thoroughfare rights-of-way and replace them with forestation-style tree plantings.

By 2005, Harris County, the City of Houston, Municipal Utility Districts and Master-Planned Communities, non-profit groups were engaging in forestation-style plantings of native trees. At that time, there was not much concentration on the type of native tree species, simply that the trees be native to the region. But the results of those policy changes have been transformative for the freeways and thoroughfares of Greater Houston.

Figure 1.1: TxDOT forestation-style planting along I-69 in Houston

Figure 1.2: Harris County Detention Basin with Forestation-style planting

City of Houston brought many community stakeholders together in 2019 to create a resiliency plan for Greater Houston.

By January of 2020, when the City of Houston's *Resilient Houston Plan* was released with a series of goals to invest in and strengthen the capabilities of neighborhoods, communities and the entire region to address, withstand and quickly recover from physical, social and economic shocks and stresses, it made sense that one of the goals would involve major large-scale tree planting. The result was Goal 6 of the *Resilient Houston Plan* - to plant *4.6 million new native trees by 2030*.

In June of 2020, the City of Houston also debuted its Climate Action Plan that includes the goal to "restore, protect, and enhance Houston's natural ability to capture and store carbon" and adopts the overlapping goal of *4.6 million new native trees planted by 2030*.

BOXELDER

For more information on the Resilient Houston Plan:
https://www.houstontx.gov/mayor/chief-resilience-officer.html

CHAPTER TWO:
Multiple Benefits of Native Trees

TSIG Video Forum featuring Houston Parks Board Forum highlighting a case example of large-scale tree planting along Greens Bayou - See Youtube link: https://youtu.be/ZqJnJIiUCUk

ECOSYSTEM SERVICES

The Gulf-Houston Region is situated in one of the most ecologically diverse major urban areas in the country. The forests, prairies, savannahs, bayous, bottomlands, coastlines and ocean around Gulf-Houston Region comprise ten ecoregions: seven land-based and three water-based.

Contrary to the prevailing image of concrete expanses and glass towers, the expansive Greater Houston Region has 10 distinct ecoregions, including three major rivers—the Trinity, San Jacinto and Brazos—as well as over 40 major bayous and creeks that run like fingers from west to east through the region and into Galveston Bay and the Gulf of Mexico (See Ecoregion Map above). For more detailed information on the 10 distinct ecoregions of the 13+ county region, see the Houston Wilderness Ecosystem Services Primer, 2nd Edition (www.houstonwilderness.org/ecosystem-services).

Below provides an illustration of the ecosystem services of the region's forested areas (upland and riparian) in our region.

Figure 2.1: List of Ecosystem Services Provided by a Forest. Houston Wilderness, The Ecosystem Services in the Greater Gulf-Houston Region Presentation, 2015 (https://houstonwilderness.org/ecosystem-services/)
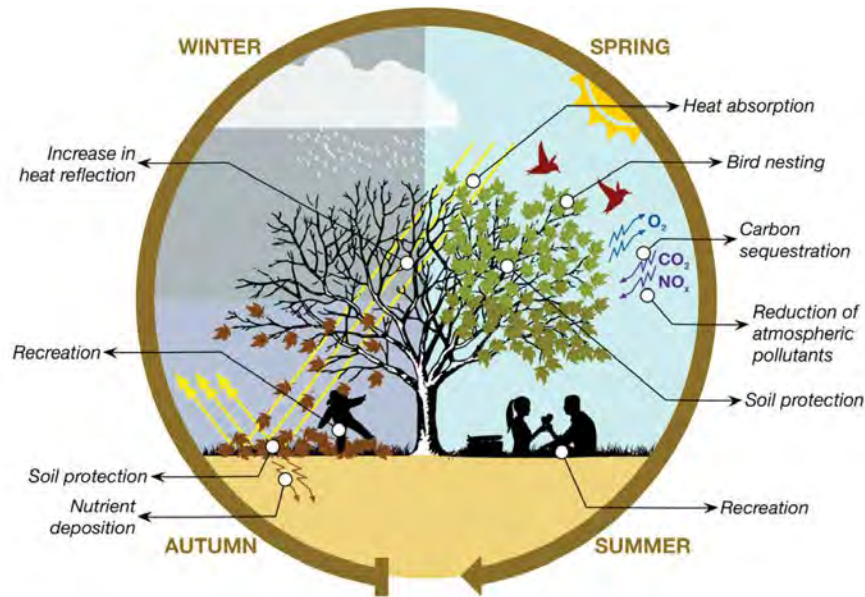
Figure 2.2: Example of a Tree Within-Year Ecosystem Service Supply Cycle. Part of: Burkhard B, Maes J (Eds) (2017) Mapping Ecosystem Services. https://doi.org/10.3897/ab.e12837. This cycle considers a deciduous tree as the focus of ecosystem service supply. Meanwhile, it illustrates that the ecological services of a tree are dynamic, and change with time.

Whether standing in more pedestrian urban settings or in the expanses of the surrounding rural areas, the forests are perhaps the most immediate landscape available to urban citizens - the energy savings afforded to buildings that enjoy the shade from neighboring tree canopies and/or the volume of airborne pollutants— including carbon—removed and sequestered within a tree's biomass.

HEALTH BENEFITS OF NATIVE TREES

Air pollution in Houston is known to pose an increased risk of asthma attacks and cardiac arrest according to researchers at the Houston Health Department, Houston Fire Department, Rice University, and

Baylor College of Medicine. The planting of large-scale native trees provides high levels of air quality benefits, particularly when targeted in high health-risk areas.
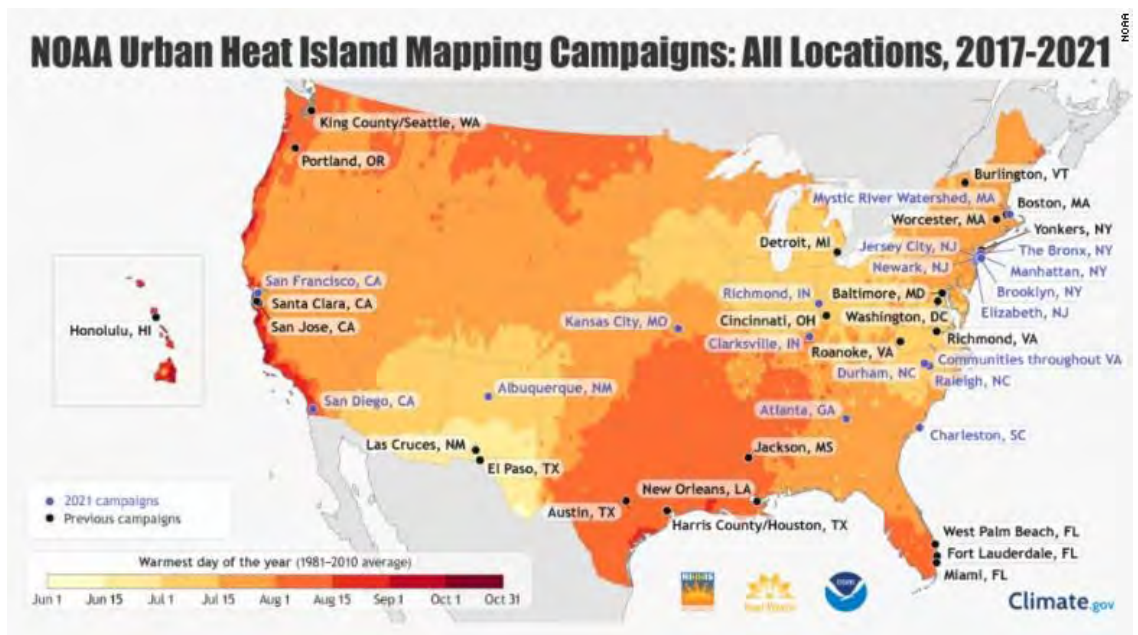
On August 7, 2020, the Houston Harris Heat Action Team (H3AT) -- a collaboration between Houston Advanced Research Center (HARC), the City of Houston, Harris County Public Health (HCPH), and The Nature Conservancy of Texas (TNC) - held a one-day urban heat island mapping effort with the help of 84 community scientists, and funding support from Lowe's and Shell. The effort was part of the 2020 Heat Watch program led by CAPA Strategies and the National Oceanic and Atmospheric Administration (NOAA), and it resulted in a total of 320 square miles of Houston and Harris County being mapped by local residents. (For more information: www.H3AT.org).

The results of this campaign are being used by the public and private sector in different ways to equitably reduce the impacts of urban heat, including:

- Better understanding heat-related health risks
- Coordinating tree planting, shade structures, and cooling centers
- Informing design of parks, streets, housing, and other built infrastructure

Forested area along Buffalo Bayou

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CHAPTER THREE:
Regional Soils

TSIG Video Forum featuring TxDOT-Houston District forestation-style plantings along freeways - See Youtube link: https://youtu.be/Pn8yK928YM8 and **TSIG Video Forum** Harris County Flood Control District (HCFCD) native forestation-style tree plantings along riparian corridors and use of the 14 Super Trees with high ecosystem services - See Youtube link https://youtu.be/_2xKDfW8WGc

The Gulf-Houston Region's unique clay-based soils play an important role in the health and vitality of the 10 ecoregions and their many ecosystem services

Under both the 8-County *Gulf-Houston Regional Conservation Plan* (https://www.gulfhoustonrcp.org) and the *Resilient Houston Plan*, many stakeholders and communities are working to enhance nature-based infrastructure across the region, including increasing protected/preserved land to 24% of the 8-county region by 2040. A critical part of all nature-based planning and infrastructure needs to involve maintaining and enhancing good soil quality.

The Gulf-Houston Region includes two main clay-based soil types.

All four major urban regions of Texas, including the Gulf-Houston Region, contain Vertisols and Alfisols as their dominant soil orders. The National Resources Conservation Service (NRCS) classifies dominant soil types for the 8-County Gulf-Houston Region as Gulf Coast Prairie Soils.

Global (ice-free) Coverage Area

1. Alfisols: Mod. weathered (clay/sand) **10.1%**
2. Andisols: Volcanic ash — 1.0 %
3. Aridisols: Very dry — 12.0%
4. Entisols: Newly formed — 18.0%
5. Gelisols: Frozen — 9.1%
6. Histosols: Organic, wet — 1.2%
7. Inceptisols: Slightly developed — 15.3%
8. Mollisols: Deep, fertile — 7.0%
9. Oxisols: Very weathered — 7.5%
10. Spodosols: Sandy, acidic — 4.0%
11. Ultisols: Weathered — 8.1%
12. Vertisols: Shrink/swell (mainly clay) — **2.7%**

Texas Soil Is Rare in the World

Dominant Soil Orders Texas

- Alfisols
- Aridisols
- Entisols
- Inceptisols
- Mollisols
- Ultisols
- Vertisols

NRCS: https://www.nrcs.usda.gov/wps/portal/nrcs/detail/tx/home/?cid=nrcs144p2_003094

Figure 3.1: Chart of Dominant Soil Orders in Texas with emphasis on Greater Houston Region soils. Houston Wilderness, Understanding the Soil Content of the 8-County Gulf-Houston Region, 2018 (https://www.gulfhoustonrcp.org/). The U.S. Department of Agriculture identifies twelve soil orders, with Texas containing seven of those twelve orders. From those seven orders, four major urban regions of Texas all contain either Vertisols or Alfisols as their dominant soil orders.

Knowledge and understanding of our region's unique Vertisols and Alfisols can help guide the discussion on the importance of:

(1) the need to "spread out" protected/preserved lands to naturally hold water necessary to mitigate downstream flooding

(2) creating and maintaining additional detention basins throughout targeted parts of our region that allow for additional storage of water during large rain events

(3) encouraging increased native plants and trees on all available lands in our region, and

(4) targeting measureable carbon sequestration as a major factor in restoration and enhancement efforts.
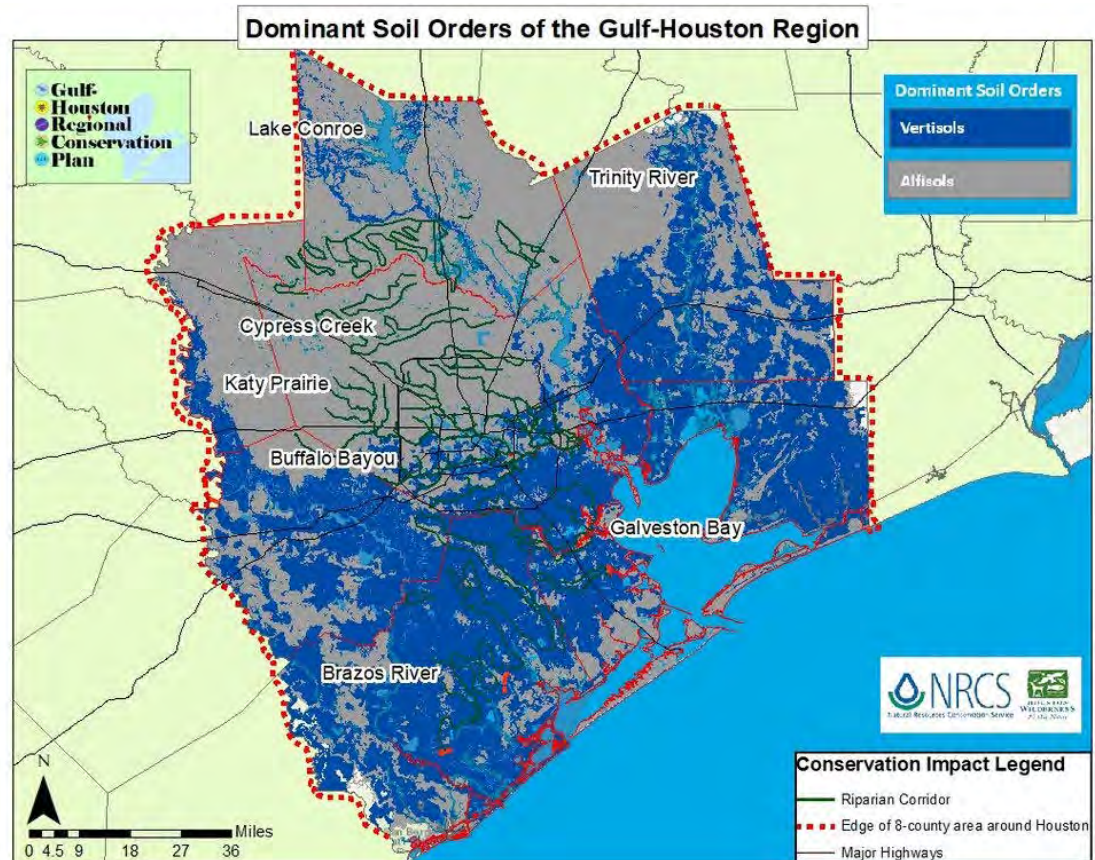
Figure 3.2: Map of the Solid Of the 8-County Gulf-Houston Region. Houston Wilderness, Soil Two-Pager on Regional Soil Orders, 2018 (https://houstonwilderness.org/gulf-houston-regional-conservation-plan). In the Gulf-Houston Region there are two main soil types: Alfisols and Vertisols. The vertisols are mainly distributed in the south, while the alfisols are distributed in the north.

How to prepare the soil before beginning a tree planting site(s)

Existing vegetation on a site

Existing vegetation on a site can be a strong indicator of soil quality and hydrology, which in turn can be suggestive of the potential ease or difficulty of restoration. A comprehensive vegetation survey may also identify: where healthy, rare and/or invasive plant communities exist in relationship to one another, which areas of a site are in greatest need of restoration, and where targeted restoration will most enhance ecosystem services.

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An expanse of mowed lawn does not possess much habitat value; planting a forest in its place results in habitat enhancements. On the other hand, a coastal grassland that is dominated by native plants may already be providing significant habitat functions as migratory habitat for bees, birds and butterflies, including the Monarch, and other coastal prairie species.

Evaluating Soils

Soil is critical to the success of a forest restoration project. Soil quality is the inherent capacity of the soil to perform its important biological, physical, and chemical functions. Soil health represents the condition of the soil as a result of its management. Soil health can be evaluated using indicators as "baseline assessments." A TxDOT-Houston District example of contract specifications used to evaluate soils can be found in Appendix B.

Baseline Assessments

On the targeted large-scale tree planting site(s), look for organic matter, barren or compacted areas, and the growth habits of existing vegetation, as these are indicators of soil health. For example, stunted growth and sparse vegetation cover might indicate the presence of a soil constraint (e.g. heavy metals, shallow depth to bedrock). More detailed analysis of the soil can be determined by laboratory analysis.
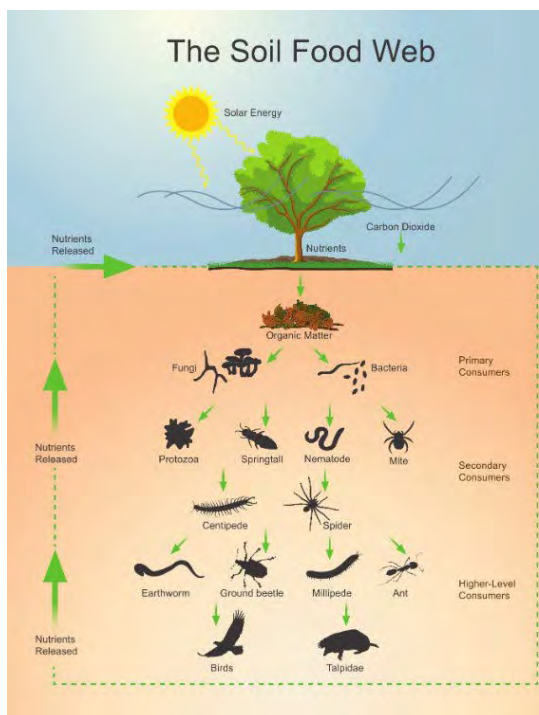
Figure 3.3: Soil Food Web. Smiling Gardener, *The Soil Food Web inhabitants are often classified according to their "trophic level," best translated as "who eats whom."* (https://www.smilinggardener.com/collection/the-soil-food-web/)

• **Texture.** Sandy soils have the largest particles and the fastest drainage rate, due
to their large pores. Clay soils have the finest particles and the slowest drainage
rate. Silt and loamy textured soil characteristics fall in between.

• **Moisture.** Soil moisture is a measure of how much water is in the soil at a given
moment, and it fluctuates with precipitation and plant uptake. Soils with a higher water holding capacity tend to be better for plant growth.

• **Nutrient and Toxin Levels.** The movement and concentrations of nutrients (i.e., nitrogen, phosphorus, potassium) available for plants in the soil will influence the establishment and growth rates of plants. Nutrient levels naturally fluctuate over time due to their sensitivity to these numerous variables. There are ways to enhance the nutrient levels of soils, both Alfisols, Vertisol and other types of soils, by adding organic mulch and/or organic compost (see more below) and/or liquid nutrients directly to the soil before tree plantings.

IMPORTANT NOTE: Most of the soils in our area are deficient in micro-nutrients, hence applying some minerals (also referred to as re-mineralization or rock dust) along with a good organic fertilizer helps trees establish quicker with fewer problems. For more information on how and what type of organic liquid nutrients are available, see https://www.microlifefertilizer.com/about/.

• **Mulch and Compost.** Twigs, leaves, dead flowers, rotten wood, and other debris cover the forest floor, serving as mulch and compost, and are important to add to newly planted forests (tree plantings). Mulch/compost shades and cools the soil, adds organic matter and nutrients to the soil, reduces compaction, and helps keep grass and other plants from growing under and competing with the trees. Shade from surrounding trees also keeps soil and roots cool and moist in the forest.

Applying mulch across an entire large-scale native tree planting site(s) helps retain soil moisture, deter invasive plants, and keep mowers and other maintenance equipment away from the young and delicate trees. However, if you plan to apply mulch only around individual trees, never mound up the material around trunks, a practice which can rot the trunk, cut off oxygen to roots, cause stem-girdling root growth, prevent water penetration, and, in poorly drained soils, lead to over-saturated roots.

A good mulch bed should extend out at least three feet from a tree's trunk in all directions, though wider is better. Mulch can be anything organic. Plastic sheet "mulches" should never be used under trees or shrubs. Though they keep weeds out for a few years, they kill roots by not allowing oxygen and water into the soil.

Mulching and other organic compost can be done at planting time, but it can also be done around established trees. Just spread a deep layer of mulch right over the existing grass. Before long the shade of the mulch will smother the grass.

High quality regionally-sourced organic mulch from various native tree species is available from a variety of producers/vendors in the region. The same is true for organic compost (Kuhns, n.d.). IMPORTANT NOTE: Native Mulch (sometimes called Native Hardwood), that has been aged (composted) till a deep chocolate brown color is the most effective mulch for tree planting. Avoid raw wood, bark, or dyed mulches as they can be harmful for soils and trees.

Examples of native mulch, compost and tree species vendors can be seen in Appendix C. Further more information on ways to enhance regional soils is available in Appendix D. A
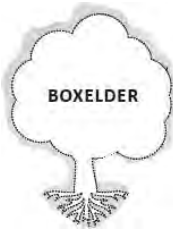
CHAPTER FOUR:
Diversity of Native Tree Species

TSIG Video Forum **featuring Houston Parks & Recreation Department (HPARD) on the region's diverse list of native tree species - See Youtube link** https://www.youtube.com/watch?v=B0YEjzy5dAo

Due to the 10 distinct ecoregions that make up the Greater Gulf-Houston Region, there are many native tree species to choose from when planning a large-scale tree planting/reforestation effort. Invasive and non-native species are discouraged, and often disallowed under county and municipal regulations.

The Greater Houston Region is fortunate to have a long list of native large and small tree species to choose from for large-scale tree plantings in various locations.

The City of Houston's Tree & Shrub Ordinance, which has been adapted by Harris County and other surrounding countries and municipalities, protects Houston's ecoregions by offering incentives to property owners who preserve and care for existing trees on private property, and want to add new native trees to their property or infrastructure projects. Based on the property's size, the ordinance establishes minimum planting requirements for street trees, parking lot trees, shrubs and landscape buffers. These requirements also help achieve the Resilient Houston Plan's 4.6 million trees by 2030 goal. The City of Houston Native Tree list can be found in Appendix E, and here: http://www.houstontx.gov/planning/DevelopRegs/tree_shrub.html

Fourteen (14) Native "Super Tree" Species have been identified for their high levels of ecosystem services in air pollution and water absorption, carbon sequestration and tree canopy size.
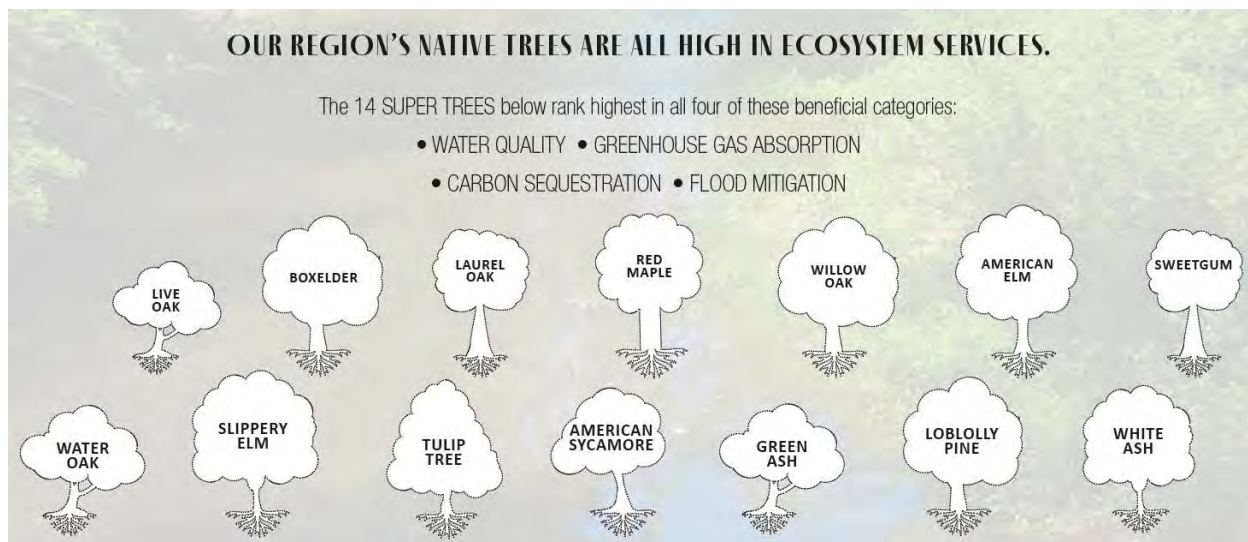
Graphics by JP Duberg

In 2019, Houston Wilderness worked with TSIG partners to research, calculate and rank the ecosystem services values associated with native tree species in our region and identified fourteen (14) of those native species with high absorption levels in carbon sequestration, greenhouse gases and flood mitigation through rainfall interception and water absorption. Called the native "Super Trees," these 14 tree species are targeted for large-scale plantings along riparian corridors, freeways and thoroughfares, park natural areas, and urban hot spots. Due to their high absorption levels, planting these tree species provide a multitude of ecosystem services - increased air & water quality, water absorption, erosion control, carbon sequestration, increased outdoor recreation, and habitat creation. The Houston Wilderness' native tree species ranking list can be found in Appendix F & J.

There are many examples of diverse plantings of different native tree species on different size acreage all around the Greater Gulf-Houston Region, including examples of large-scale Super Tree plantings.

Forestation Example along Buffalo Bayou (near Buffalo Bayou Park):

In Buffalo Bayou trails, a large number of Red Maple trees, Redbuds, American Elms and Sycamores, Loblolly Pines, natives species of Live, Laurel, Post, Water, Willow Oaks, Green Ash, Boxelders, Tuliptree, Sweetgum and Sugarberry trees are planted. This tree species is a typical example of the Super Trees in the Houston Region. Red maple is capable of storing about 139 lbs of carbon dioxide per year and up to 859 lbs within 10-years. Red maple also performs well in flood control and air purification. It absorbs 2,592 gallons of water and 1.6 lbs of GHG per year. In Houston, the sunshine lasts longer in autumn, and the red maple trees can receive more sunshine, which accelerates the leaves to turn red in autumn (Garcia, 2019). Further more information on *Fourteen (14) Native "Super Tree" Species*, see Appendix F.

Reforestation Example along Bayport Berm (near Bayport Container Terminal)
All types of lands in Greater Houston lend themselves to large-scale tree plantings, even in more industrial areas, such as the Houston ship channel**.** Along the Bayport Berm, near Bayport Container Terminal in Pasadena/Seabrook, thousands of the 13 of the Super Tree species have been planted along the Berm and will be available for the public to visit the reforested area by 2024.

Reforestation Example along Will Clayton Parkway (near Bush International Airport)

Strips of rights-of-way along Will Clayton Parkway leading in and out of Bush International Airport were planted over 15 years ago and are now reforested with a variety of tree species, enjoyed by travelers from all over the world and used as habitat by a variety of wildlife and migratory bird species.

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Reforestation Example in Clay Family Eastern Glades @Memorial Park
Renovated with new native trees and grasses in 2019, the Eastern Glades in Memorial Park provide a peaceful environment that will grow into a forested area within the next 10 years. Use of Cypress trees, Loblolly Pines and Oak trees were planted throughout the park.

Reforestation Example in MUD No. 230 - Mandolin Gardens Park
There are regulatory and state-allowed funding tools available for municipal utility districts (MUDs), master-planned communities, and other special districts to use to add green space to their neighborhoods and enhance the green space with large-scale tree planting. These "tools in the resilience toolbox" are particularly important for older districts who need to expand green space for their residents. MUD No. 23's enhancement of a previous detention ditch into an oasis of native trees and grasses with a walking trail for residents to enjoy is one example. (For more information on Tools

in the Resilience Toolbox, see Gulf-Houston RCP one-pagers at
https://houstonwilderness.org/gulf-houston-regional-conservation-plan).

Before

After

Reforestation Example in Milby Park
A 100-ft wide riparian buffer was created along Sims Bayou in Milby Park, with the planting of a diverse mix of over 2,000 native trees and shrubs. The site began as mowed park land dominated by non-native lawn grass.

FLEWELLEN CREEK – VIEW SOUTH (PHASE-3)

SLIPPERY ELM

Flewellen Creek at Cross Creek Ranch Master-Planned Community has been transformed from a clay-based, highly eroded tributary of the Brazos River into a forested outdoor recreational space for the residents and visitors of the Fulshear area through large-scale native trees plantings (SWA reforestation project)

Exploration Green in Clear Lake City (Houston)

In Southeast Houston, dedicated groups of volunteers with the Clear Lake City Water Authority transformed a defunct golf course into an innovative stormwater detention center and green space, called *Exploration Green*. Now covered with forestation-style native tree species, the land now provides an integrated, natural solution for catastrophic seasonal flooding holding up to 500-million-gallons of stormwater while also serving as a nature preserve and recreation area. Located near NASA's Johnson Space Center, this 200-acre urban green space provides the community with countless opportunities to explore, offering 40 acres of both wetlands and permanent detention lakes, home to over 1,000 native species.To get more detailed information and photos on specific native tree species, these two resources provide comprehensive lists of all tree species:

- **Texas A&M Forest Service**: http://texastreeid.tamu.edu/content/listOfTrees/
- **Garden Club of Houston** (Summer 2012): Tough-Texas-Trees-by-Doris-Heard.pdf
- **Hermann Park** tree species tour: https://www.hermannpark.org/visit/park-guides/trees/

VERTICAL DIVERSITY: MULTI-STORIED FOREST STRUCTURE

Multi-storied forests are communities of plants dominated by trees in the canopy layer, with three additional layers below: the subcanopy, the understorey, the shrub layer and the forest floor, all of which are crucial to the ecological function and sustainability of the forest system. The subcanopy is comprised of slow-growing and shade tolerant trees that are poised to take the place of the canopy as it ages. The understorey is made up of small trees and shrubs. The forest floor is comprised of small plants such as grasses, ferns and wildflowers. This layer also includes soil, decomposing organic matter that supports and sustains the trees, shrubs, and grasses.
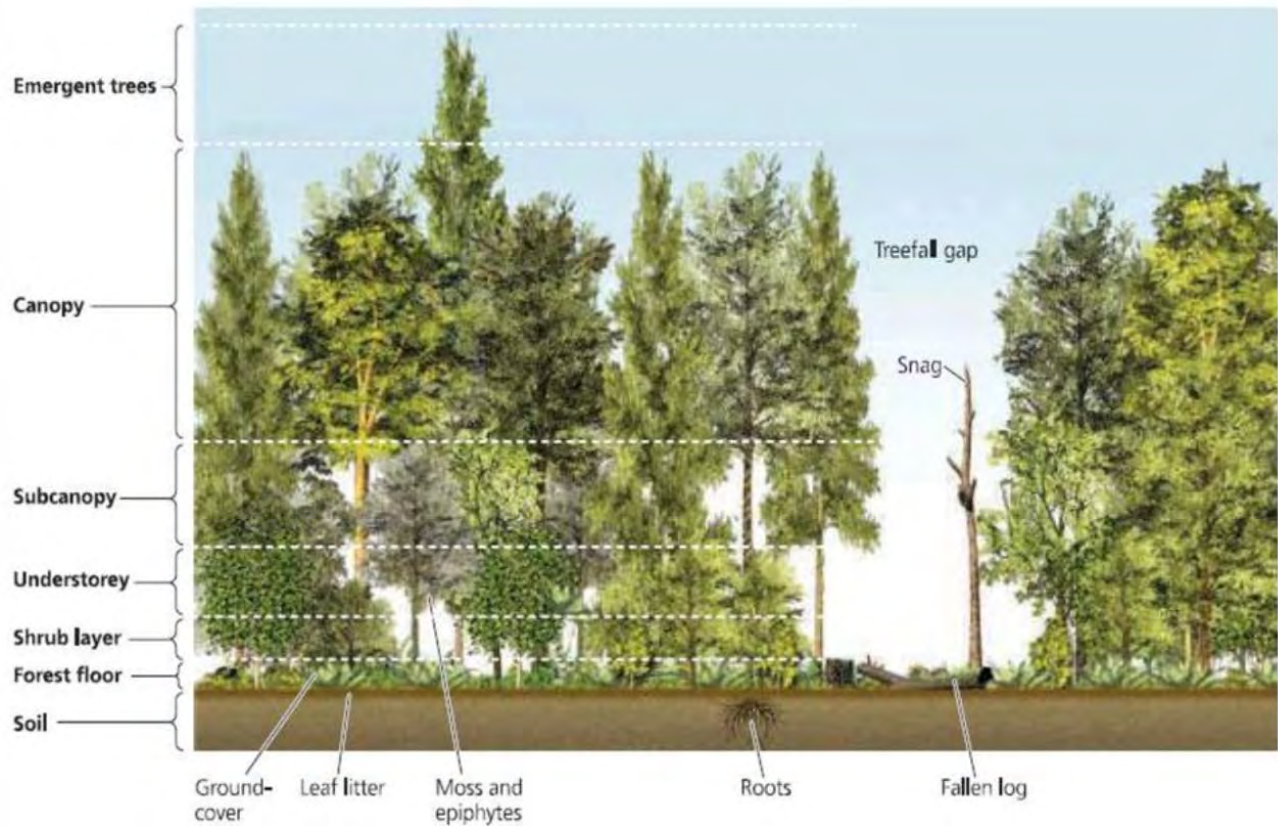
Figure 4.1: Vertical Forest Structure. Kory Beasley, Hug a tree they have less issues than people Presentation, 2018 (*https://slideplayer.com/slide/13767425/*). A tree can be roughly divided into 6 layers from top to bottom. The different layers of the forest are constantly interacting with various biotic and environmental elements. For example, the canopy acts as a windbreak and intercept rainfall, while the understorey can be a refuge for small animals from predators.

How to find native trees to purchase in Greater Houston: There are many native tree vendors in the Greater Houston area. To find one near you, search "Native Tree Nurseries." See also examples of native mulch, compost and tree species vendors in Appendix C.
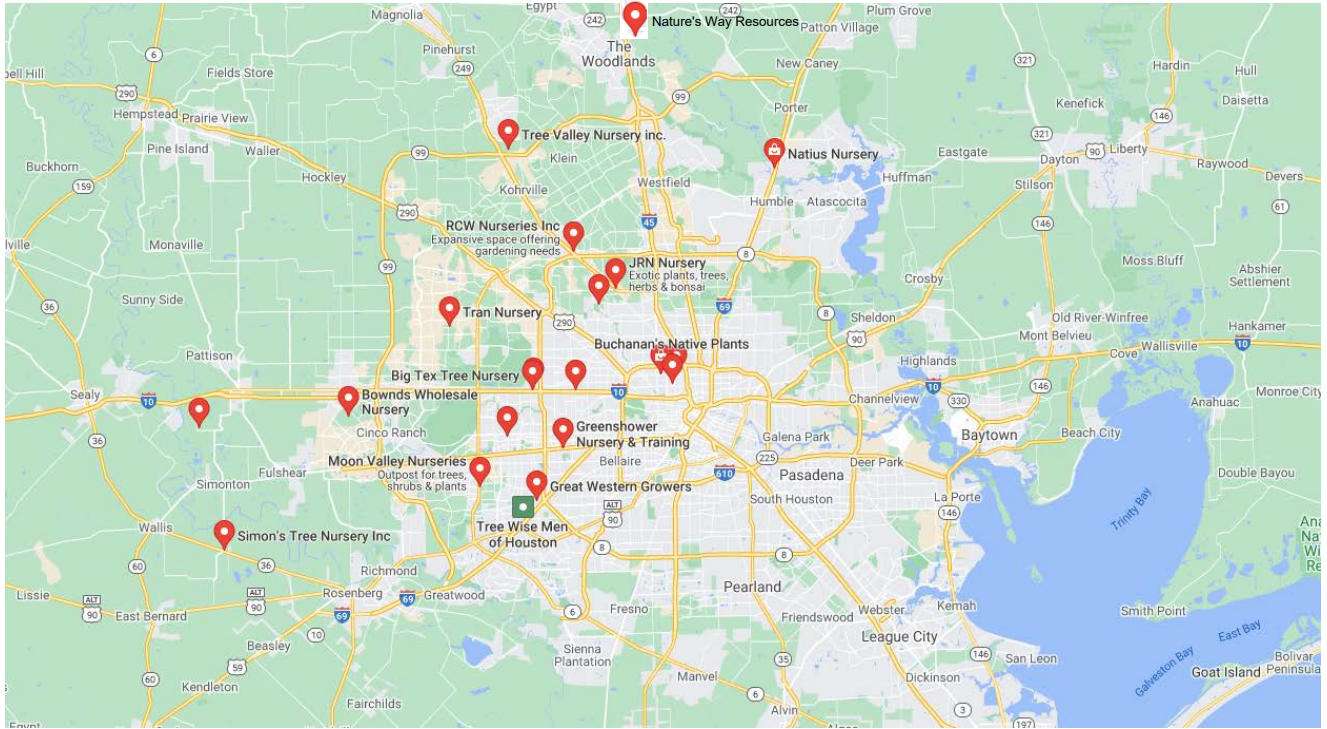
Search result of Native Tree Nurseries in Greater Houston

OUR REGION'S NATIVE TREES ARE ALL HIGH IN ECOSYSTEM SERVICES.

The 14 SUPER TREES below rank highest in all four of these beneficial categories:
- WATER QUALITY • GREENHOUSE GAS ABSORPTION
- CARBON SEQUESTRATION • FLOOD MITIGATION

LIVE OAK, BOXELDER, LAUREL OAK, RED MAPLE, WILLOW OAK, AMERICAN ELM, SWEETGUM

WATER OAK, SLIPPERY ELM, TULIP TREE, AMERICAN SYCAMORE, GREEN ASH, LOBLOLLY PINE, WHITE ASH

CHAPTER FIVE:
Locations for Forestation-Style Tree Plantings

TSIG Video Forum featuring major landscape architects' discussion on native tree plantings at various locations around the region - See Youtube link
https://www.youtube.com/watch?v=94YmI35bGro

Large-scale native tree plantings (reforestation) can occur on multiple acres of land or smaller land sizes, as well as riparian and roadway corridors - all land sizes can accommodate a certain number of diverse native tree species, creating a forestation-style planting.

In the Greater Gulf-Houston Region, many reforestation opportunities exist in natural/green space areas, residential areas and along riparian, rights-of-way and roadway corridors. Available space is one of the considerations most overlooked or misunderstood when deciding what and how many trees to plant. Before you plant, it is important to consider what the tree will look like as it nears maturity. Consider its height, canopy spread, and root space.
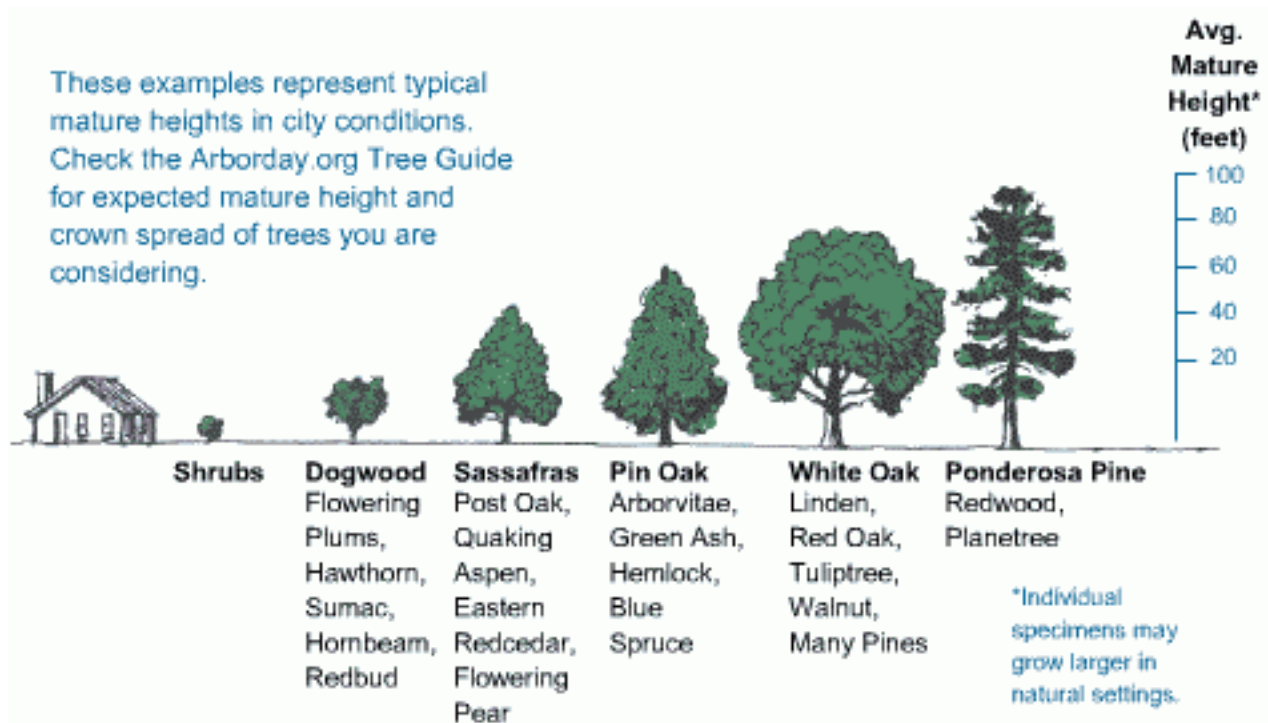
Figure 5.1: The Basic Spacing Guide From Various Distances and Various Tree Heights. Arbor Day Foundation, Right Tree in the Right Place (https://www.arborday.org/trees/righttreeandplace/size.cfm). As shown in the figure, different trees look very different when they are approaching maturity. For example, the crown shape of the pin oak is pyramidal, but that of white oak is layered.

There are 10 key guiding principles when implementing a large-scale tree planting (reforestation) effort:

1. Select a suitable site or landscape, including the analysis and evaluation of current land uses and land tenure/ownership, and identify involved stakeholders (See Figure 8 below)
2. Analyse and evaluate the drivers of deforestation or forest degradation.
3. Engage stakeholders, discuss long-term goals of forest restoration considering the interests of all stakeholder groups, and draft a preliminary restoration/rehabilitation plan.
4. Develop a restoration management plan, including: preparing a topographic land-use map, including a designation of forest functions, assessment of road accessibility, existence of natural regeneration and needs for planting; agreeing on restoration/rehabilitation objectives selecting the restoration/rehabilitation method choosing the species to be used, and establishing a nursery and assessing possible positive and negative social and environmental impacts.
5. Collect seeds, produce seedlings in nurseries and prepare for planting.
6. Plant trees.
7. Assess capacity-building needs and plan for the necessary training.
8. Establish realistic time schedules and plan for financial requirements.
9. Monitor restored/rehabilitated areas, and conduct maintenance activities as required
10. Consider possible climate-change impacts.

Figure 5.2: Restoration Site Selection Process. New York City Department of Parks & Recreation, Guidelines for Urban Forest Restoration, 2014 (https://www.nycgovparks.org/pagefiles/84/guidelines-to-urban-forest-restoration.pdf).

For more detailed analysis of landscape planning ideas, The Wildflower Center, the United States Botanic Garden and the American Society of Landscape Architects Created The Sustainable SITES Initiative®, originally modeled after the U.S. Green Building Council's LEED® Green Building Rating System, SITES v2 provides a comprehensive set of guidelines and performance-based metrics for rewarding leadership in the design and development of high-performance landscapes. See more at
https://www.wildflower.org/project/sites-rating-system

There are many examples of diverse large-scale native tree plantings on different size acreage all around the Greater Gulf-Houston Region.

1) **Greens Bayou - Clark Condon LA reforestation project**

2) **Llewellyn Creek - SWA LA reforestation project - Cross Creek Ranch (in Fulshear)**

3) **TxDOT-Houston District - along Highway 69 in Greater Houston**
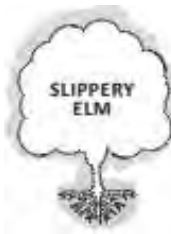
4) Corporate campus (Shell Woodcreek)

Corporate campus example: Smaller land acreage can also accommodate large-scale diverse native tree plantings, such as the Shell campus of I-10 in west Houston. This forestation effort was planted in 2015 and now allows for the walking trail to be covered in shade for a lovely walk in the park feeling for the campus employees.

5) Kelly Village Park - Asakura Robinson reforestation project (Houston)

A multi-famiy residential and senior living community

6) **Houston Parks and Recreation Department's Natural Resources Management Program** - building a network of riparian buffers in parks across the city. Called the HPARD *Riparian Restoration Initiative*, this large-scale tree planting program targets parks and green spaces along various bayous and creeks in the City, including as many as 70 City of Houston Parks and resulting in the planting of over 200,000 trees.

Houston Parks and Recreation Department
Riparian Restoration Initiative

● Riparian Project Site
☐ Park Boundary

0   2.5   5   10
                    Miles

N

HPARD
HOUSTON PARKS
AND RECREATION DEPARTMENT
A CAPRA Accredited Agency
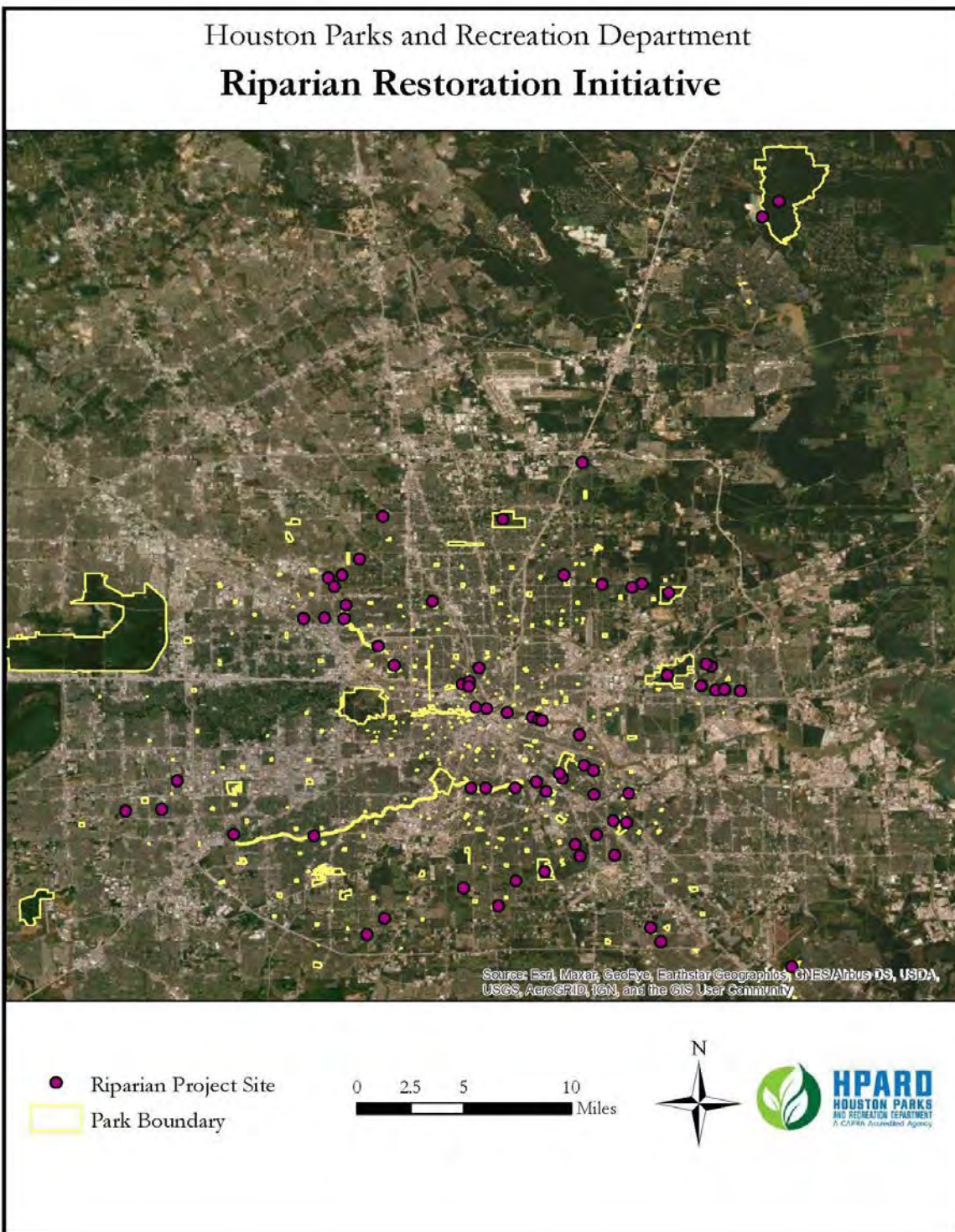
CHAPTER SIX:
Planting Forestation-Style Native Trees

TSIG Video Forum **featuring Harris County Flood Control District (HCFCD) native forestation-style tree plantings along riparian corridors and use of the 14 Super Trees with high ecosystem services - See Youtube link** https://youtu.be/_2xKDfW8WGc

As mentioned at the beginning of this Manual, the Tree Strategy Implementation Group (TSIG) came together in early 2020 to create a strategy to accomplish the Resilient Houston Plan's goal to plant *4.6 million new native trees by 2030*. Part of that strategy was to create an educational campaign to encourage residential involvement in large-scale native tree plantings (encouraging the equivalent of two new trees for every Houstonian), and provide data and tracking of the planting of millions of native trees through 2030, which will be provided via an online City of Houston tracking system. That process has now been created and is available to public involvement on the City of Houston's Office of Resilience webpage (see more in Appendix G).

The primary goal of large-scale native tree plantings, and reforestation, is to create and/or restore multi-species forests at various sizes in areas that were traditionally forested in the region in order to provide critical ecosystem services to residents and wildlife.

At each site(s), use your design to maximize ecological function and habitat value. The healthy forests you create will build soil, encourage the growth of planted native species, recruit additional native species, resist the invasion of non-native species, and enhance the experiences of green space/park users and neighbors. The restoration will result in improved resiliency, robustness and resistance to disturbance.

Practical and administrative considerations: Design a large-scale planting within the limitations posed by your budget and your available time frame. While there are a host of variably-priced techniques for removal of invasive growth, soil preparation, and plant

materials, as discussed in the chapters above, the process/technique of planting/installing the native trees in a forestation-style planting is relatively the same no matter the size or location of the site(s) to be planted.

Earlier chapters provide information on choosing which native trees species to plant based on respective ecosystem services and soil type. Other considerations on planting of tree species include:

A. <u>Identification of size of tree placed on various locations:</u>

1. Use of native tree seeds (gathered directly or bought from vendors)
2. Use of native bareroot/seedlings/liners/plugs

3.   Use of native 3-5 gallon size and containers

B. <u>Adding other grasses/forbs to a large-scale tree planting</u>

You can also introduce native wildflowers and grasses to a tree planting site(s) through native seeding or by planting grass/forb plugs. The decision to use seeds or plugs will be based on budget and site scale. Plugs ensure establishment of plants exactly where desired.

Herbaceous plugs   Bareroot tree seedlings   Contanerized tree   B&B tree
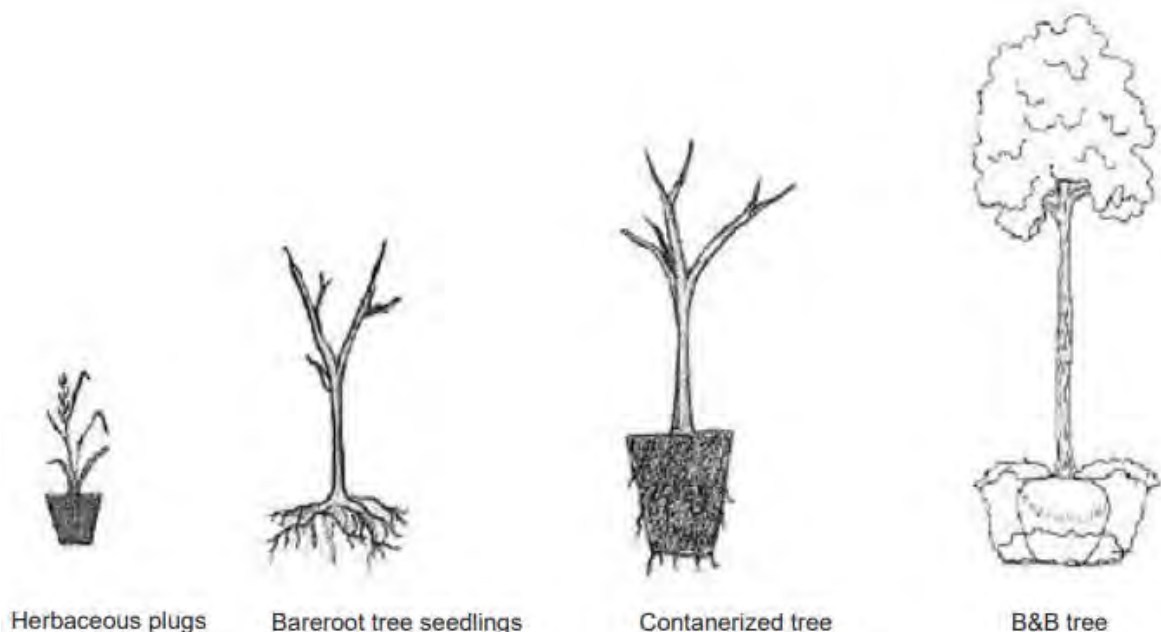
Figure 6.1: Size and Packaging Choices for Plant Material. New York City Department of Parks & Recreation, Guidelines for Urban Forest Restoration, 2014 (https://www.nycgovparks.org/pagefiles/84/guidelines-to-urban-forest-restoration.pdf).

C. <u>Native tree species that drop leaves (defoliation), fruit or nuts</u>

Some site locations may be more difficult to maintain if chosen native tree species loose leaves, or drop fruit or nuts on an annual basis. Consideration should be given to other native trees species in those instances.

Whether organizing a large-scale native tree planting (reforestation) effort with volunteers or under contract, the process to complete a native tree planting can be fairly straightforward, once initial planning on site(s), species, soil, and other materials are determined.

This TSIG Manual provides a step-by-step large-scale native tree planting guide in Appendix H. The Guide presents suggestions to help future large-scale tree plantings, based on prior regional projects that have been tested during multiple planting seasons and have shown to be successful in the Gulf-Houston region.

Also, as mentioned above in Chapter One, a major regional goal of the *Resilient Houston Plan* is to plant 4.6 million new native trees by 2030. Appendix G provides detailed information on how to become a participant in that 4.6 Million Trees by 2030 effort.

CHAPTER SEVEN:
Avoiding Deforestation of Native Trees

TSIG Video Forum featuring major landscape architects' discussion on large-scale native tree plantings and avoiding deforestation in new developments at various locations around the region - See Youtube link: https://www.youtube.com/watch?v=94YmI35bGro

Like many urban areas, Greater Houston experiences a large amount of deforestation as new developments are created in traditionally forested areas and mature native trees are bulldozed.

While some deforestation data is collected from public entities, there is not regular monitoring of canopy loss in the Greater Gulf-Houston Region. In 2021, Houston Wilderness provided some research in this regard based on deforestation that occurred in the Greater Houston area from 2013 to 2019. The research was collected, analyzed in a report called 16,487.25 acres.

Generally findings in the *Greater Houston Deforestation Report: 2013 to 2019 (GHD)* were that the **average annual deforestation rate** from 2013 to 2019 in the Greater Houston area was 4,127 acres per year (based on dividing Greater Houston/Harris County into 15 equal transects, as Figure 10 illustrated below). The highest deforestation rate occurred at Transect 15 at 16,487.25 acres per year, and the lowest deforestation rate occurred in Transect 9 at 540 acres per year. According to the GHD Report, areas with high rates of deforestation are mostly used to develop homes, farms and retail establishments. For more information, see Appendix I for the full GHD Report.

Figure 7.1: 15 equal transects in the Greater Gulf-Houston Region. Houston Wilderness, Greater Houston Deforestation Report: 2013 to 2019 (GHD), 2021.
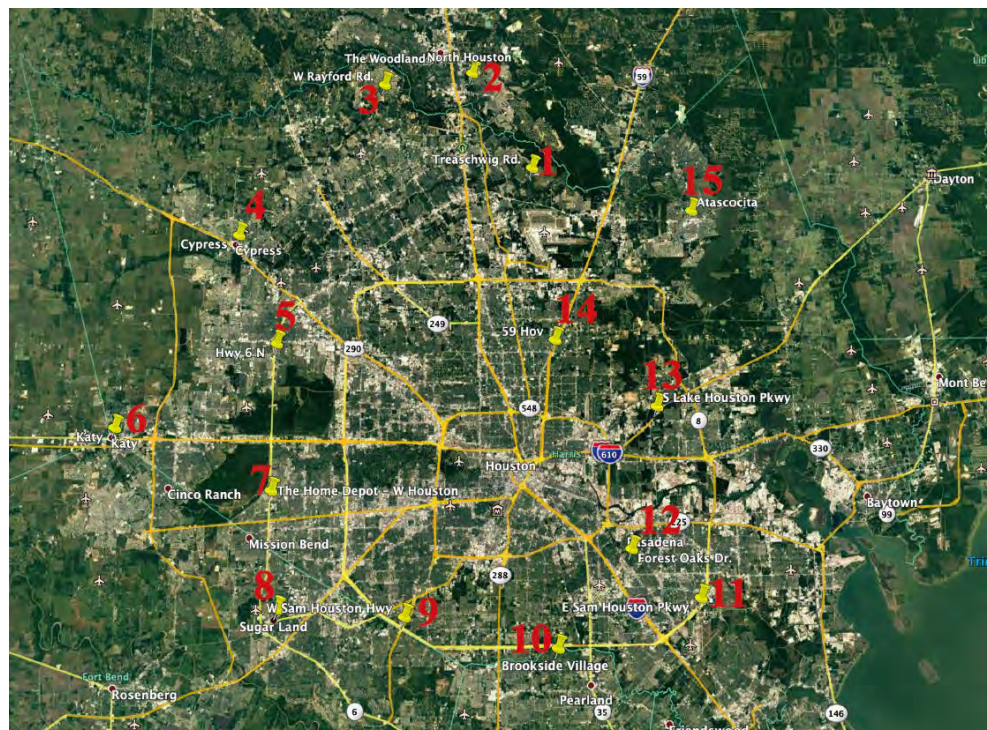
Transect 15 - Example of Deforestation Rate: Atascocita, Harris County (NE)

Figure 7.2: Atascocita Satellite image as of May 1, 2013 (Right) (35 dark green grids, 173,116 acre)
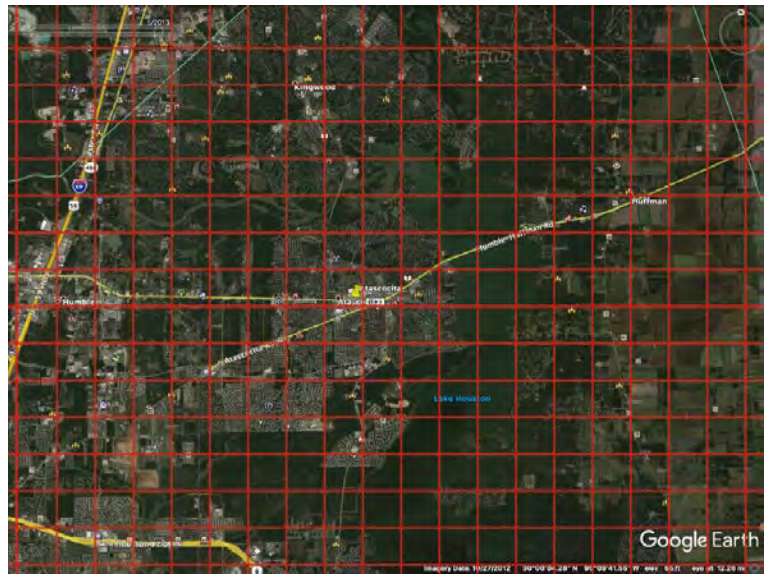
Figure 7.3: Atascocita Satellite image as of April 1, 2016 (Below) The image as of May 2016 was not selected because it was covered by clouds, and it was impossible to accurately distinguish the location of the forest (18 dark green grids, 89,031 acre)
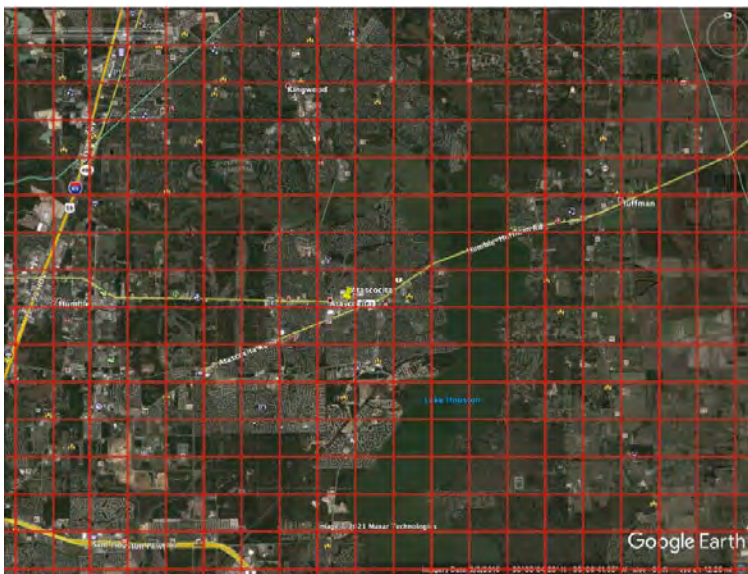
Figure 7.4: Atascocita Satellite image as of May 1, 2019 (Below) (15 dark green grids, 74,193 acre)
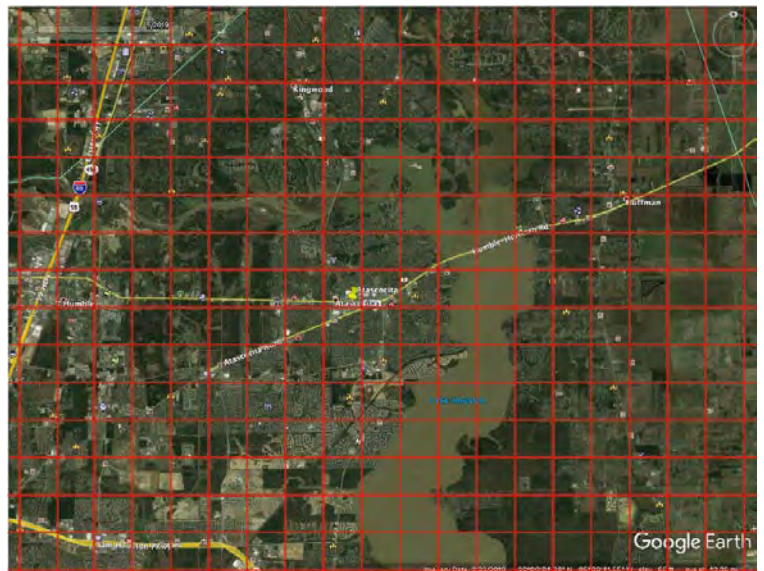
The acreage with the greatest decrease is Transect 15, the Atascocita, Harris County area. The deforestation rate in this location is 16,487.25 acres per year on average. As illustrated in the three satellite images below - for years 2013, 2016 and 2019, the annual average forest cover reduction rate clearly shows a significant amount of deforestation taking place between those years. Based on this high deforestation rate, it shows that large-scale tree removal in the north side of Greater Houston is faster than that in the south.

An important observation noted in this report is that there is no direct relationship between the proportion of deforestation area and the velocity of deforestation in the Greater Houston area. In other words, a larger deforestation area does not necessarily mean a faster deforestation rate. The forest area observed in the west and south was small, and although the deforestation area proportion was large, the rate was slow. Near Brookside Village region (transect 10), for example, forest cover of approximately 10,864 acres was observed in 2013 and decreased to 4,074 acres in 2016, with a deforestation proportion of 62.5%. By 2019, the forest area had decreased to 2,715 acres, with 75% of the deforestation proportion. But for an average of six years, the rate of deforestation in transect 10 was only 1,357 acres per year.

As large-scale native tree plantings continue to scale up to meet the Resilient Houston Plan's 4.6 million trees by 2030 goal, a substantial education campaign needs to be established to encourage residential and commercial developers to avoid deforestation going forward. Examples of similar campaigns in other cities who have also adopted large-scale tree planting goals include (Virsilas et al., 2019):

1) Baltimore, MD
2) Detroit, Michigan
3) Eugene, OR
4) Honolulu, Hawaii
5) King County, WA
6) Little Rock, AR
7) New York, NY
8) Oakland, CA
9) Philadelphia, PA
10) Raleigh, NC
11) San Francisco, CA
12) Seattle, WA
13) Washington, DC

CHAPTER EIGHT:
Maintenance of Native Trees

TSIG Video Forum featuring Harris County Flood Control District (HCFCD) native forestation-style tree plantings along riparian corridors and maintenance of forested areas - See Youtube link https://youtu.be/_2xKDfW8WGc

The success of restoration depends heavily on management after planting but mainly during the first two years of a newly-planted trees' life, whether a seedling, 5 gallon or 15 gallon trees.

Once a native tree is established in a good location, the tree(s) should be watched and watered for 2 years and then the tree(s) should be established enough to not require much more maintenance. Methods of watering, continued invasive control, and litter removal are the main components of a 2-year management plan. If the large-scale native tree planting is over one-half acre, a site management plan may be helpful - that locates the closest water source, and designates responsibility for maintenance activities during the 2-year period. The plan should also include descriptions of potential future problems and strategies for their resolution, as well as a clear description of the projected future state of the site. These recommendations could include prescribing planting, tree species changes in future planting years based on the observed success of the originally selected species.

For more information on maintenance of native trees, see these two comprehensive sources:
- **Texas A&M Forest Service**: http://texastreeid.tamu.edu/content/listOfTrees/
- **Garden Club of Houston** (Summer 2012): Tough-Texas-Trees-by-Doris-Heard.pdf

CHAPTER NINE:
Removing Invasive Trees and Diseases

TSIG Video Forum featuring the A&M Texas Forest Service on common invasive species and tree diseases - See Youtube link https://www.youtube.com/watch?v=3Ex3RdHv4ro

Many times newly arrived plants, whether they arrived years ago or recently can become invasive: they thrive and expand rapidly in the absence of natural controls, such as competing plants, predators, or diseases. This situation has occurred throughout the Greater Gulf-Houston Region over many years.

HEALTHY FORESTS VS. STRESSED FORESTS (Bounds et al., 2014)

Healthy forests are characterized by:

• Complex and varied ecosystems adapted to the region, with a range of layers of vegetation, including canopy and understory trees, shrubs, wildflowers, grasses, ferns, and vines.
• Well-structured soils in which invertebrate and decomposition activity is considerable, and nutrient levels are supportive of native plants.
• Water regimes in which rainfall and run-off is effectively filtered, and stored in soil and plant roots.
• A resistance to disturbances, from disease, storms, and invasion by exotic species.
• Reproduction of native species.

Figure 9.1: Example of Healthy forest   Figure 9.2: Example of Stressed forest
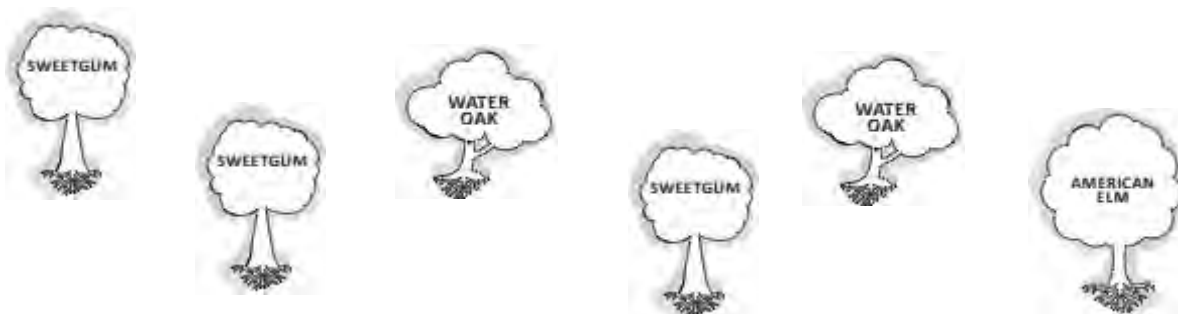
Stressed Forests are Characterized by:

• Compacted or eroded soils that have a decreased capacity to absorb or retain rainwater, resulting in a simplified forest structure manifested by a lack of understory and groundcover plants.

• Soil contaminated by pollutants and characterized by reduced nitrogen cycles, drier conditions, extremes of pH, and altered decomposition rates.

• Soils lacking essential fungi and bacteria.

• Decreased fitness and resilience of native plants and animals.

• Increased presence of invasive plants and animals.

• Litter and dumping, as well as damage by fire and other types of vandalism.

SPECIAL NOTE ON ECOLOGICAL THREAT OF CHINESE TALLOW

Chinese tallow trees are able to withstand periods of drought because of a deep taproot. Native plant species are out-competed for resources once the Chinese tallow becomes established in an area. With an ability to utilize minimal water sources from deep taproots and an affinity for growing in crowded places, native plant species are quickly eradicated from areas with Chinese tallow. Leaves and fruit of Chinese tallow is toxic to humans and cattle. If ingested by humans, severe nausea and vomiting occurs.

MANAGEMENT OF CHINESE TALLOW

Preventative measures are the most important for managing Chinese tallow. If Chinese tallow is found on your property, do not move the plant. It is important to remove plants and seeds in effort to completely eradicate the plant. Seedlings can be removed manually prior to maturity to prevent reestablishment of Chinese tallow. Mature trees can be removed using a chainsaw by cutting the tree as close to the soil as possible. Burning or mowing can be used for mature Chinese tallow and seedlings. Chemical treatment can be effective in the form of foliar treatments in the Fall prior to seed release. To prevent re-growth on cut stumps a 20% solution of triclopyr has been proven effective. Texas Invasive Species Institute - http://www.tsusinvasives.org/home/database/triadica-sebifera

Background on how Invasive Species Occur in an area

A wide variety of non-native plants have been introduced to North America - and they will continue to arrive - both intentionally, through horticulture, and unintentionally, through ship ballast and packing materials. In some cases, newly arrived species do not spread: they do not migrate vegetatively into surrounding areas; they do not produce viable fruit, due to a lack of appropriate pollinators or other factors; or they do not out-compete native vegetation. A climate similar to that of their original habitat coupled with adaptations to the light and disturbance levels common in cities can allow non-native invasive species to smother, crowd and strangle existing vegetation. These plants tend to decrease overall biodiversity and available habitat and water, disrupt natural disturbance regimes, and alter soil conditions in ways that prevent the germination and/or establishment of native plant species. The presence of these aggressive newcomers threatens the structure and function of our native forests.

Select removal methods based on the most aggressive and/or dominant of the invasive plant species present, and adapt them throughout the site preparation process in response to changes in the composition and vigor of the remaining invasive vegetation to be managed. The size of the area and maturity of the invasive plants will also influence your technique selection and the duration of treatment required.

CHAPTER TEN:
Large-scale Land Mitigation/Restoration Planning and Warmer Temperatures

TSIG Video Forum featuring mitigation bank company, RES, highlighting reforestation on large landscapes and impacts from extreme weather events - see youtube link
https://youtu.be/LY0_u6MV7m4

During the initial meetings of the TSIG members, they recognized a series of basic principles in creating the TSIG *4.6 million native trees by 2030* Strategy:

● As illustrated in the Greater Houston Ecoregion Map above, this region is ecologically diverse with multi-species forests in three main areas: 1) along over 500 miles of waterways (creeks, bayous, rivers and streams) in the 8-county region, 2) in the Piney Woods, and 3) in the Big Thicket parts of the region. As a result, large-scale forestation is a major ecological asset and critical to this region's ecosystem services, habitat protection and human sustainability and resilience.

● Forest landowners, public and private entities, are plentiful in this region, serving an important role in Texas agriculture and as the stewards of forests around the region. Many of these entities work closely with their local landscape architects, arborists, Soil and Water Conservation Districts and the Texas A&M Forest Service district office to implement conservation practices that promote the health and sustainability of forests and forest ecosystems. These public- and private-owned forests contribute significantly to the Texas economy and provide numerous environmental and social benefits.

● To truly have healthy forests, reforestation, proper management and conservation is needed. Many forest landowners in Texas are implementing beneficial conservation practices such as strategic large-scale tree plantings, prescribed burning, brush management to remove diseased trees and invasive species, native grass management, wildlife management, and even bee propagation to stimulate pollination. In certain instances, livestock can be included as part of a prescribed grazing plan to strategically manage the leaf litter, soil, and underbrush in a forested area, which can ultimately assist in preventing wildfires. Without these sustainable management practices, problems such as soil erosion, insect and disease outbreaks, invasive species encroachment, declines in biodiversity, and even catastrophic wildfires can occur.

● Trees provide a large number of ecosystem services, including filtering and reducing air pollution, holding and absorbing water, reducing point source and nonpoint source water pollution, reducing ambient temperatures (lowering the Urban Heat Island effect), absorbing carbon dioxide, and producing oxygen. They also help conserve energy by casting summer shade and blocking winter winds. Tree roots hold the soil in place and fight erosion. Trees absorb and store rainwater, reducing runoff and sediments after storms, which also helps recharge groundwater supply and prevent flooding. Research in the region provides a quantifiable list of the ecosystem services (ES) of

each native tree species, allowing the region to quantify the ES benefits as different tree species as planted. Essential products made from trees include paper products and lumber. Trees also offer habitat and food to birds, insects, lichen, fungi, mammals, and reptiles. Finally, trees increase our quality of life through a relaxing effect, reducing stress.

● Land Architects need opportunities to recommend forestation-style trees that provide more than just the "DBH replacement" requirements (avoiding the driving up of cost) under the current CoH tree ordinance

● A large-scale native tree planting education campaign is needed to bring more awareness and support to native tree species, the planting of millions of native trees, and the need for voluntary land stewardship

Due to warming trends in the Greater Gulf-Houston Region, the 14 native Super Trees, and other tree species, are good choices due to their high levels of ecosystem services and weather hardiness.

Excerpts from *[Climate Impact Assessment for the City of Houston](#)* (Stoner et al., 2020)

Houston's climate is already changing and many of the observed changes are projected to continue and even accelerate over the rest of this century. Since 1950, the City of Houston has experienced significant increases in annual average temperature, in the number of hot days with temperature above 100°F, in the number of warm nights with temperature above 80°F, and in cooling degree-days, a measure of air conditioning needs.

Over the rest of this century, projected future changes for Houston include:

● Increases in the average temperature of all seasons
● Lengthening of summer, with summer beginning earlier and ending later
● Increases in energy demand for cooling buildings for the spring, summer, and fall seasons
● Increases in the number of hot days per year (defined here as maximum temperature above 100°F) and the number of warm nights per year (defined here as minimum temperature above 80°F)
● Increases in the temperature of the hottest days experienced each year
● Longer multi-day heatwaves
● Little change in total annual precipitation but a decrease in summer precipitation and increase in fall precipitation
● Greater variability in day-to-day precipitation that includes both slight increases in number of dry days and increasing risk of drought due to soil moisture decreases resulting from higher temperatures, as well as increases in the precipitation falling during extreme precipitation events such as the wettest three-day period each year.

More climate and extreme weather impacts can be found here: Fourth U.S. National Climate Assessment (NCA4) [Volume 1](#) and [Volume 2](#).

Due to this region's southern location in the U.S., our native trees will generally survive warmer temperatures for many years to come.

Many plant species exist over a wide geographic range, and have distinct populations with localized adaptations within those ranges. As temperature and moisture patterns change, it is likely that some, maybe even most, plant species will stay in place and adapt to new conditions or may already have the genes in their population for hotter and or drier conditions, obviating the importance of maintaining intact local populations in the face of climate change. This speaks to the importance of regional, landscape-scale diversity of native tree species to ensure that corridors of plant migration exist to allow for migration.

Adaptive Management - A type of natural resource management in which decisions are made as part of an ongoing process. Adaptive management combines planning, implementing, monitoring, research, evaluating, and incorporating new knowledge into management approaches based on scientific findings and the needs of society. Results are used to modify future management methods and policy.

Biodiversity - The variety of life forms and processes including complexity of species, communities, gene pools, and ecological functions.

Carbon Sequestration - Generally refers to the process, activity and mechanism of removing carbon dioxide from the air. It mainly refers to the amount of carbon dioxide absorbed and stored by forests, or the ability of forests to absorb and store carbon dioxide. Simply put, it means donating money for afforestation, so that the forest cultivated by oneself can eliminate the carbon dioxide emitted by work and life.

Community Protection - Actions or programs undertaken for the purpose of protecting human lives, property, and infrastructure.

Ecosystem - A spatially explicit, relatively homogeneous unit of the earth that includes all interacting organisms and components of any part of the natural environment within its boundaries. An ecosystem can be of any size. (Society of American Foresters, 1998.)

Ecosystem Function - Ecosystem functions are the biological, geochemical and physical processes that are constantly occurring within ecosystems. These can also be thought of as components, processes, and actions that must occur within an ecosystem to maintain a healthy balance. Put another way, ecosystem functions are the capacity of natural processes and components to provide goods and services that satisfy human needs, directly or indirectly (de Groot et al., 2002).

Ecosystem/Ecological Integrity - The completeness of an ecosystem that at multiple geographic and temporal scales maintains its characteristic diversity of biological and physical components, spatial patterns, structure, and functional processes within its approximate range of historic variability. Ecosystems with integrity are resilient and sustainable**.**

Ecosystem Process - The actions or events that link organisms and their environment, such as predation, mutualism, successional development, nutrient cycling, carbon sequestration, primary productivity, and decay. Natural disturbance processes often occur with some periodicity

Ecosystem Resilience - The ability of a system to respond to disturbances. Resiliency is one of the properties that enable the system to persist in many different states or successional stages.

Forest Ecosystem Health - A condition where the parts and functions of an ecosystem are sustained over time and where the system's capacity for self-repair is maintained, allowing goals for uses, values, and services of the ecosystem to be met.

Invasive - Any non-native species of plant which is detrimental or destructive and difficult to control or eradicate

Landscape - An area composed of interacting and inter-connected patterns of habitats (ecosystems) that are repeated because of the geology, landform, soils, climate, biota, and human influences throughout the area**.**

Sustainable (Sustainability) - Meeting the needs of the current generation without compromising the ability of future generations to meet their needs. Ecological sustainability entails maintaining the composition, structure and processes of a system, as well as species diversity and ecological productivity

Appendix B
TxDOT Soil Preparation Bid Sheet
Texas Department of Transportation, 2014

The first sheet is an engineering bid sheet table titled "TYPE OF WORK" and "ITEMS AND REQUIREMENTS FOR EACH TYPE OF WORK."

192-6063 PLANT BED PREP (TYPE I) SY	192-6064 PLANT BED PREP (TYPE II) SY	192-6065 PLANT BED PREP (TYPE III) SY	192-6066 PLANT BED PREP (TYPE IV) SY		Reference Item 161, 192 of the Texas Standard Specifications for Construction and Maintenance of Highways, Streets and Bridges 2014 for specifications, dimensions, volumes and measurements that are not shown. Reference Special Specification Item 1006.	
✓	✓	✓		161-6012 GENERAL USE COMPOST CY	APPLICATION RATE	
✓	✓	✓	✓	1006-6001 LANDSCAPE SOIL AMENDMENT (TYPE I) SY	APPLICATION RATE	
✓	✓	✓	✓	1006-6002 LANDSCAPE SOIL AMENDMENT (TYPE II) SY	APPLICATION RATE	
	✓	✓	✓	1006-6003 LANDSCAPE SOIL AMENDMENT (TYPE III) SY	See PLANTING AND ESTABLISHMENT SHEET 5 of 8 For Requirements	
				1006-6004 LANDSCAPE SOIL AMENDMENT (TYPE IV) SY	See PLANTING AND ESTABLISHMENT SHEET 5 of 8 For Requirements	
✓	✓	✓	✓	1006-6005 LANDSCAPE SOIL AMENDMENT (TYPE V) SY	APPLICATION RATE	
✓				RIPPING/TRENCHING Incidental to Item 192 Plant Bed Preparation.	RIP/TRENCH DEPTH	
✓	✓	✓		ROTOR TILLING Incidental to Item 192 Plant Bed Preparation.	ROTOR TILL DEPTH	
		✓	✓	HERBICIDE and MOWING Incidental to Item 192 Plant Bed Preparation.	APPLICATION RATE	

PLANTING BED PREPARATION SECTION

Texas Department of Transportation — HOUSTON DISTRICT — PLANTING AND ESTABLISHMENT — SHEET 4 of 8 — BED PREPARATION — STD K-4

USE COMPOST TEA OR EXTRACT AS SHOWN ON THIS SHEET

COMPOST EXTRACT
ITEM 1006-6003 LANDSCAPE SOIL AMENDMENT (TYPE III) and
ITEM 1006-6004 LANDSCAPE SOIL AMENDMENT (TYPE IV) requirements.

MATERIALS REQUIREMENTS

EQUIPMENT REQUIREMENTS

TRANSPORT, STORAGE AND APPLICATION REQUIREMENTS

CONSTRUCTION METHODS AND APPLICATION RATES

COMPOST TEA
ITEM 1006-6003 LANDSCAPE SOIL AMENDMENT (TYPE III) and
ITEM 1006-6004 LANDSCAPE SOIL AMENDMENT (TYPE IV) requirements.

MATERIALS REQUIREMENTS

EQUIPMENT REQUIREMENTS

TRANSPORT, STORAGE AND APPLICATION REQUIREMENTS

CONSTRUCTION METHODS AND APPLICATION RATES

Texas Department of Transportation — HOUSTON DISTRICT — PLANTING AND ESTABLISHMENT — SHEET 5 of 8 — COMPOST TEA/EXTRACT — STD K-4

Appendix C
List of Native Tree, Organic Mulch and Compost producers/vendors in Gulf-Houston Region

https://thegroundup.com/retail

GREATER HOUSTON

FARM DIRT
6231 Carson Rd, Houston, TX 77048
Danny Wilson: (713) 494-1148
http://farmdirtcompost.com/index.html

THE LETCO GROUP LLC - Living Earth Cutten Road (N Houston)
12200 Cutten Road, Houston, TX 77066
281-537-2377
https://livingearth.net/texas/locations-houston/living-earth-cutten-road-n-houston/

THE LETCO GROUP LLC - Living Earth West Katy
27733 Katy Freeway, Katy, TX 77494
281-392-0300
https://livingearth.net/texas/locations-houston/living-earth-west-katy/

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14110 Katy Fwy, Houston, TX 77079
281-579-1472
https://livingearth.net/texas/locations-houston/living-earth-katy-tx/

THE LETCO GROUP LLC - Living Earth Crawford Road (NW Houston)
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713-466-7360
https://livingearth.net/texas/locations-houston/living-earth-crawford-road-nw-houston/

THE LETCO GROUP LLC - Living Earth McCarty (E Houston)
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713-670-0810

https://livingearth.net/texas/locations-houston/living-earth-mccarty-e-houston/

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713.862.2323

www.qualityfeedco.com

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www.wabashfeed.com

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(936) 273-1200 Conroe

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Website

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936. 449-9057

www.jdh-crushed-concrete-materials.business.site/

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409.386.0204

www.southernlawntexas.com

HOUSTON BLACK
Texas State Soil

SOIL SCIENCE SOCIETY OF AMERICA

Introduction

Many states have a designated state bird, flower, fish, tree, rock, etc. And, many states also have a state soil – one that has significance or is important to the state. Let's explore how the Houston Black is important to Texas.

History

The Houston Black soil series (**Figure 1**) is found only in Texas, and was first described in 1902, the third year of the National Soil Survey program, in Brazoria County. The Professional Soil Scientists Association of Texas chose Houston Black as the state soil of Texas. While the Houston Black has not been officially declared the state soil of Texas, it is considered a soil of state-wide importance, and thus is the unofficial state soil.

What is Houston Black Soil?

The first thing you'll notice about this soil is its dark color and how sticky and moldable it is when wet. Because of these qualities, it's often called "black gumbo."

The Houston Black soil developed from calcareous clays and *marls* that were deposited during the Cretaceous Age (145 to 66 million years ago) from the receding and advancing shorelines of ancient seas. Prairie vegetation contributed to the *organic matter* and dark color in the surface of these soils.

The climate contributed its extreme wetting and drying cycles to the soils shrink-swell nature.

Houston Black soils occur on level to moderately sloping landscapes (0-8% slopes). This soil series is usually more than 200 cm (80 inches) deep. Water will drain through the profile moderately well; however, *permeability* of water is very slow due to the high clay content (46-60%) in this soil. Every soil can be separated into three separate size fractions called sand, silt, and clay, which make up the *soil texture*. They are present in all soils in different proportions and say a lot about the character of the soil. In Houston Black soils, the texture for this series is most commonly clay or silty clay.

The *topsoil* (A horizon) will crack when dry. Cracks can be more than 10 cm (4 inches) wide and 30 cm (12 inches) deep, and remain open for 90 to 150 days in most years. In the top 20 cm (8 inches), these soils typically have a few small shell fragments.

Houston Black is known around the world as a classic example of a *Vertisol*, a soil order which is a soil high in a particular type of clay called *smectite*. These clays swell during wetting cycles and shrink during drying cycles and cause the soil to crack when dry (**Figure 2**). In addition to the cracks, the repeated physical movement of the soil commonly results in formation of surface mounds and depressions that are called gilgai. Gilgai is an Australian aborigine term meaning "little water hole" (**Figure 3**).

Photo: Chip Clark/Smithsonian Institution

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Fig. 1 Soil Profile of Houston Black Soil Series.Credit: USDA NRCS

Fig. 2 Cracks up to 2.5 cm (1 inch) wide in Houston Black soil after several days with no rain. Credit: Julie Howe

Fig. 3 Gilgai features on Texas Vertisol. Depressions that are filled with water after a rain reflect the aboriginal origins of the word meaning "little water hole." Credit: Cristine Morgan

Fig. 4 *Slickensides* are polished, grooved surfaces caused by the surfaces sliding against each other during shrinking and swelling of the soil. Credit: Soil Science Society of America

Fig. 5 Location of the Houston Black soil in Texas. Credit: *Smithsonian Institution's Forces of Change.*

A common feature of this soil order is the presence of *slickensides* (Figure 4) in the *subsoil* (B horizon) below depths of 30-60 cm (12-24 inches).

The *smectite* clays are known for their ability to hold on to nutrients tightly enough to prevent them from being lost through water movement, but weakly enough that plants can use them. These nutrients include calcium, magnesium, and potassium.

The soils are generally gray to black due to *organic matter* left from decomposition of the prairie grasses. Because the soil formed from calcareous materials, the soil is slightly alkaline and will fizz when it contacts acid.

Houston Black is a Hall of Fame Series due to its long history of use in the National Cooperative Soil Survey. It is also a Benchmark Soil Series, which indicates that it has a special significance to farming, engineering, urban development and other uses.

Where to dig a Houston Black

Yes, you can dig a soil. It is called a soil pit and it shows you the soil profile. The different horizontal layers are called *soil horizons*. If you want to dig a Houston Black soil pit, you will have to travel to the Blackland Prairie of Texas, which extends from the Texas border north of Dallas to just south of San Antonio, along the route of Interstate 35 (Figure 2). It is here that you'll find the Houston Black. This soil can only be found in Texas, where it covers about 0.6 million hectares (1.5 million acres) of land in 33 counties (Figure 5). This does not mean that other types of soil

Fig. 6 Cotton and sorghum are common crops grown on Houston Black soils. Credit: NRCS, istock.

are not found in that portion of the state, just that Houston Black is very common.

There are more than 1300 named soils (series) in Texas.

Importance

What makes the Houston Black soil so important is that it is unique to Texas. Before settlers arrived, the region was a tallgrass prairie. Less than 1% of the native prairie exists today. So, this soil reflects the special climate and vegetation conditions of our past. Native vegetation in the Blackland Prairie consists of tall and mid-sized grasses such as little bluestem, big bluestem, indiangrass, switchgrass, and sideoats grama. Now, the land is devoted to producing crops and animals, and to urban, recreational, and industrial uses.

Uses

Generally, soils everywhere can be used for agriculture (growing food for humans and animals); engineering (roads, buildings, tunnels); ecology (wetlands), recreation (ball fields, playground, camp areas), and more. Most Houston Black soil is found on farms, with the majority growing cotton, sorghum, and corn, but hay and pastureland are also common (Figure 6). It is one of the highest agricultural producing soils in Texas, generating between $300 to $500 million in annual revenue. Houston Black occurs in the area where millions of people live and work, including three of the largest metropolitan areas in Texas.

Limitations

When a soil cannot be used for one or more of the described functions, it is referred to as a limitation.

Soil experts, called *Soil Scientists*, studied Houston Black soil and determined that it has moderate to severe limitations that affect the choice of plants that can be grown.

While the soil and the landscape make the Blackland prairie very fertile agriculturally; the high clay content causes the soil to be very hard when dry and very sticky when wet, and it tends to shrink when dry and swell when wet. These properties pose limitations to how the land is worked for farming and construction. There are special management issues associated with the soil due to these properties.

Fig. 7 Contour terraces draining into a grassed waterway. Credit: http://passel.unl.edu/Image/siteImages/Terintogrsdwtrwy-LG.jpg

Fig. 8 Cracked foundation on home due to the shrinking and swelling of Houston Black clay it was built upon. Credit: Clay Robinson

Management

Houston Black soil is well known for its management problems. Erosion and water problems are the primary concerns.

Houston Black soil is very clayey, especially in the lower horizons, below 30 to 60 cm (12 to 24 inches). The great amount of clay hinders the movement of water and air. This affects growth of plant roots. Dry soils are cracked, but when it rains, they close and water enters slowly. If rainfall is intense, water may run off before it can infiltrate into the soil. Available water for plants is very high when the soil is wet and erosion hazards are generally moderate. Often *terraces, contour tillage,* and *grassed waterways* are used to keep water from running off the land before it has time to infiltrate (Figure 7). Construction on this soil is often plagued by cracking from the shrinking and swelling movements (Figure 8). Hydrated lime often is added to stabilize the clays, and also layers of crushed rock and gravel are added to stabilize roads and large buildings. Foundations of buildings also need to be reinforced with steel rods.

Houston Black Soil Formation

Before there was soil there were rocks and in between, ClORPT. Without ClORPT, there will be no soil. So, what is ClORPT? It is the five major factors that are responsible for forming a soil like the Houston Black series. These are Climate, Organisms, Relief, Parent material and Time. ClORPT is responsible for the development of the soil profiles and chemical properties that differentiate soils. So, the characteristics of Houston Black soil (and all other soils) are determined by the influence of ClORPT. Weathering takes place when environmental processes such as rainfall, freezing, and thawing act on rocks causing them to fracture and break into pieces. ClORPT then acts on rock pieces, sediments and vegetative materials to form soils.

Climate – Temperature and precipitation affect the chemical, physical and biological relationships in the soil, and influence the rate at which parent materials weather and dead plants and animals decompose. The Houston Black soil developed in a warm climate with hot summers and cool winters. Rainfall ranges from 700-1000 millimeters (28-40 inches) during an average year. This climate was ideal for prairie grass formation, and the low rainfall prevented high weathering processes that would eventually dissolve and remove much of the calcium carbonate materials.

Organisms – Organisms are the plant and animal life. In the soil, plant roots spread, animals burrow in, and bacteria and fungi break down plant and animal tissue. These and other soil organisms speed up the breakdown of large particles into smaller ones. Plants and animals also influence the formation and differentiation of soil horizons. Plants determine the kinds and amounts of *organic matter* that is added to a soil under normal conditions. Animals break down complex compounds into smaller ones, and in doing so add *organic matter* to soil.

Houston Black soil is strongly influenced by the tall prairie grasses that grew on them (**Figure 9**). Tall grasses provided plant litter that protected the surface, and as they decomposed they added organic residues to the soil. These residues help provide the characteristic dark color to the soil and provide good growing conditions for the plants. In addition, roots eventually decayed and provided food for earthworms and other soil organisms. Channels formed by roots and soil organisms improved water and air flow through the soil, both of which further improve the soil for plant growth.

Relief – Landform position or relief describes the shape of the land (hills and valleys), and the direction the slopes face which makes a difference in how much sunlight the soil gets and how much water it keeps. Deeper soils form at the bottom of the hill than at the top because gravity and water move soil particles downhill.

The Houston Black soil developed in a relatively flat to gently sloping landscape (0 to 8%) that was formed by ancient shorelines.

Fig. 9 Native tallgrass plant community in the Blackland Prairie of Texas contributed to the dark color of the soils. Dominant grasses include Little Bluestem, Indiangrass, and Big Bluestem. Credit:http://texasprairie.org/images/gallery/nelson_wieting_prairie/Winecup_and_Little_Bluestem.JPG

Parent material – Just like people inherit characteristics from their parents, every soil inherits some traits from the material from which it forms. Some parent materials are transported and deposited by glaciers, wind, water or gravity while others form in place from weathered bedrock. Houston Black soils developed from weathered marine sediments, primarily calcareous clays and *marls*, as well as some shales, sandstones, and chalk.

Marl and chalk are sedimentary rocks that form from the weathering of other rocks and marine deposits, accompanied by erosion and deposition. During deposition, the weathered materials pile up and eventually become compacted and cemented into a new rock. The compaction occurred when they were under water. The parent materials of Houston Black soil developed when the ocean extended into what is now the state of Texas.

Time – All the factors act together over a very long time to produce soils. As a result, soils vary in age. The length of time that soil material has been exposed to the soil-forming processes makes older soils different from younger soils. Generally, older soils have better defined horizons than younger soils. Less time is needed for a soil profile to develop in a humid and warm area with dense vegetative cover than in a cold or dry area with sparse plant cover.

The three main processes involved in the formation of horizons in Blackland soils are (1) accumulation of *organic matter* at the surface, (2) leaching of calcium carbonates and bases, and (3) weathering of parent rock into *smectitic clays*. All these processes influenced the development of Houston Black soil. The shrink-swell nature of the clays in the Houston Black creates mixing that limits the development of well-defined *horizons*, and so the Houston Black appears younger than nearby soils on the same landscape with less clay content.

Natural Regions of Texas

Fig. 10 Ecoregions of Texas include High Plains (orange), Trans Pecos (grey), Rolling Plains (brownish-green), Llano Uplift (yellow), Edwards Plateau (dark beige), Blackland Prairie (light beige), Oakwoods and Prairies (darkest green), Piney Woods (medium green), South Texas Brush Country (light green), Coastal Sand Plain (maroon), and Gulf Coast Prairies and Marshes (blue). Credit: Artwork courtesy Texas Parks and wildlife Department © 2004.

Ecoregions and Soils of Texas

Texas is a huge, diverse state that has mountains, valleys, hills, rolling plains, mesas, and coasts. These features occur on landscapes of different ages (Figure 10).

Climate, parent materials, and organisms, combine to create diverse biomes in Texas, with several natural regions, or ecosystems, ranging from deserts to prairies to savannas to forests. Notice how the dominant soil orders of Texas can be related to the natural regions of Texas (Figures 10 and 11).

Remember ClORPT? All these factors contribute to the many different types of soil that can be found in Texas. These individual soils are classified into groups based on similarities in their profiles and other characteristics. Soil, like plants and animals, has a classification system. It's called Soil Taxonomy. It has six levels: Order, Suborder, Great Group, Subgroup, Family, and Series. Nine of the 12 orders can be found in Texas (Figure 13). Houston Black is in the *Vertisol* Order. Notice how the dominant soil orders of Texas resemble the natural regions of Texas (Figures 9 and 10).Most soils around the state are used to support plant or animal agriculture. Cattle, sheep, goats, and wildlife graze on the prairies. Cotton, corn, wheat, sorghum, vegetables, citrus fruit, and pecans are some of the most important crops. Total receipts from all Texas crops totaled $6.9 billion in 2011.

Dominant Soil Orders Texas

- Alfisols
- Aridisols
- Entisols
- Inceptisols
- Mollisols
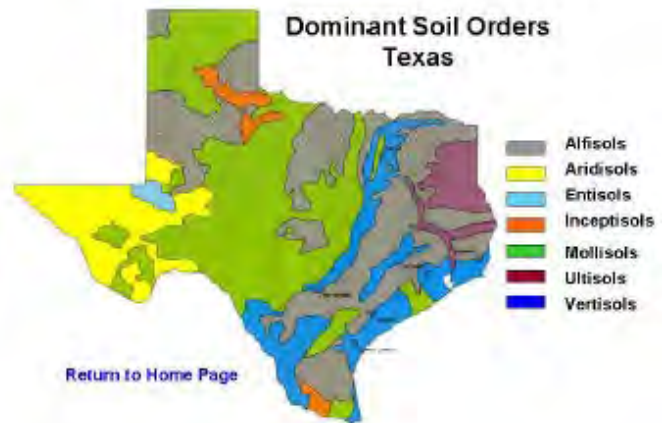- Ultisols
- Vertisols

Return to Home Page

Fig. 11 Dominant soil orders of Texas include Alfisols (grey), Aridisols (yellow), Entisols (light blue), Inceptisols (orange), Mollisols (green), Ultisols (purple), and Vertisols (blue). Credit: USDA-NRCS

Glossary

Contour: Strips of equal elevation on a landscape that run parallel to the slope. Very often they appear wavy across the farmland.

Contour tillage: Plowing and planting along contour lines (see *Contour* above).

Grassed waterway: Shallow long ditches which catch runoff water and slowly transport it off the field. The ditches have grass to slow water movement and trap sediment.

Marl: A type of sedimentary rock that forms from the weathering of other rocks and a mixture of soft calcium carbonate, clays and marine deposits, accompanied by erosion and deposition.

Organic matter: Material derived from the decay of plants and animals. Always contains compounds of carbon and hydrogen.

Permeability: Ability of air and water to pass through a soil.

Slickensides: A smoothly polished-looking surface on the surface of a soil crack caused by frictional movement.

Smectite: A type of clay that will shrink and swell due to their water content.

Soil Horizon: A layer of soil with properties that differ from the layers above or below it.

Soil Scientist: A soil scientist studies the upper few meters of the Earth's crust in terms of its physical and chemical properties; distribution, genesis and morphology; and biological components.

Subsoil: (B horizon) The soil horizon rich in minerals that eluviated, or leached down, from the horizons above it. Not present in all soils.

Terrace: Earthen structures build along contours on sloping farmlands to catch precipitation and reduce runoff.

Topsoil: (A horizon) – Mostly weathered minerals from parent material with a little organic matter added. The horizon that formed at the land surface.

Vertisol: One of 12 soil orders. They are characterized by *smectites* clays that swell when wet and shrink when dry causing cracks that may be deep and/or wide.

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Additional Resources

Lindbo, D. et al. 2008. Soil! Get the Inside Scoop. Soil Science Society of America, Madison, WI.

Lindbo, D. L., D. A. Kozlowski, and C. Robinson (ed.) 2012. Know Soil, Know Life. Soil Science Society of America, Madison, WI.

Web Links for More Information

Soils for Kids, http://www.soils4kids.org/

Resources for Teachers, www.soils4teachers.org

Have Questions? Ask a Soil Scientist,https://www.soils.org/ask

Soil Science Society of America, https://www.soils.org/

Natural Resources Conservation Service, Texas Soils Homepage http://www.nrcs.usda.gov/wps/portal/nrcs/main/tx/soils/

Texas A&M Soil Characterization Laboratory, http://soildata.tamu.edu/

Texas State Soil and Water Conservation Board, https://www.tsswcb.texas.gov/

Web Soil Survey, http://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm

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The Paleontology Portal. http://www.paleoportal.org/index.php?globalnav=time_space&sectionnav=state&state_id=42&period_id=18

Natural Resources Conservation Service, USDA. Official Soil Series Descriptions. http://soils.usda.gov/technical/classification/osd/

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Appendix E
City of Houston Native Tree Species List

https://static1.squarespace.com/static/52387981e4b0a2c53f25a411/t/5ee95b3c6d7f63060405fbc5/1592351548748/CoH+Master+List_Protected+Native+Trees+for+Houston+Area+%28updated+2020%29.pdf

Master List:
ROW- Right of Way Trees (Street Trees)
PL- Parking Lot Trees
Park- Park Trees
NA- Natural Area Trees

Species		Protected	Planting Eligibility	Usage
Scientific Name	**Common Name**			
Acer barbatum	Southern or Texas Sugar Maple	Y	None	Large Tree
Acer negundo	Box Elder	Y	NA	Large Tree
Acer rubrum	Red Maple	Y	ROW, Park, NA	Large Tree
Betula nigra	River Birch	Y	PL, Park, NA	Large Tree
Carpinus caroliniana	American Hornbeam	Y	PL, Park, NA	Large Tree
Carya aquatica	Water Hickory	Y	Park, NA	Large Tree
Carya cordiformis	Bitternut Hickory	Y	ROW, PL, Park, NA	Large Tree
Carya illinoinensis	Pecan	Y	ROW, Park, NA	Large Tree
Carya texana	Black Hickory	Y	ROW, Park, NA	Large Tree
Carya tomentosa	Mockernut Hickory	Y	ROW, PL, Park, NA	Large Tree
Catalpa bignonioides	Southern Catalpa	Y	PL, Park, NA	Large Tree
Celtis laevigata	Sugarberry	Y	NA	Large Tree
Diospyros virginiana	Common Persimmon	Y	ROW, PL, Park, NA	Large Tree
Fraxinus americana	White Ash	Y	ROW, Park, NA	Large Tree
Fraxinus pennsylvanica	Green Ash	Y	ROW, PL, Park, NA	Large Tree
Ginkgo biloba	Ginkgo	Y	None	Large Tree
Ilex opaca	American Holly	Y	ROW, Park, NA	Large Tree
Juglans nigra	Eastern Black Walnut	Y	ROW, Park, NA	Large Tree
Juniperus virginiana	Eastern Redcedar	Y	ROW, PL, Park, NA	Large Tree
Liquidambar styraciflua	Sweetgum	Y	ROW, Park, NA	Large Tree
Liriodendron tulipifera	Tulip tree or Yellow Poplar	Y	None	Large Tree
Magnolia grandiflora	Southern Magnolia	Y	ROW, Park, NA	Large Tree

Species		Protected	Planting Eligibility	Usage
Scientific Name	**Common Name**			
Magnolia virginiana	Sweet Bay Magnolia	Y	Park, NA	Large Tree
Metasequoia glyptostroboides	Dawn Redwood	Y	None	Large Tree
Morus rubra	Red Mulberry	Y	NA	Large Tree
Nyssa aquatica	Water Tupelo	Y	ROW, PL, Park, NA	Large Tree
Nyssa sylvatica	Blackgum	Y	ROW, Park, NA	Large Tree
Nyssa biflora	Swamp Tupelo	Y	ROW, PL, Park, NA	Large Tree
Pinus echinata	Shortleaf Pine	Y	Park, NA	Large Tree
Pinus glabra	Spruce Pine	Y	None	Large Tree
Pinus palustris	Longleaf Pine	Y	ROW, PL, Park, NA	Large Tree
Pinus taeda	Loblolly Pine	Y	ROW, Park, NA	Large Tree
Planera aquatica	Planertree or Water Elm	Y	Park, NA	Large Tree
Platanus mexicana	Mexican Sycamore	Y	None	Large Tree
Platanus occidentalis	American Sycamore	Y	ROW, Park, NA	Large Tree
Populus deltoides	Eastern Cottonwood	Y	NA	Large Tree
Prunus serotina	Black Cherry	Y	ROW, Park, NA	Large Tree
Quercus acutissima	Sawtooth Oak	Y	None	Large Tree
Quercus alba	White Oak	Y	ROW, Park, NA	Large Tree
Quercus canbii	Canby Oak	Y	None	Large Tree
Quercus falcata	Southern Red Oak	Y	ROW, Park, NA	Large Tree
Quercus laurifolia	Laurel Oak	Y	ROW, Park, NA	Large Tree
Quercus lyrata	Overcup Oak	Y	ROW, Park, NA	Large Tree
Quercus macrocarpa	Bur Oak	Y	ROW, Park, NA	Large Tree
Quercus michauxii	Swamp Chestnut Oak	Y	ROW, Park, NA	Large Tree

Species				
Scientific Name	**Common Name**	**Protected**	**Planting Eligibility**	**Usage**
Quercus muehlenbergii	Chinkapin Oak	Y	None	Large Tree
Quercus nigra	Water Oak	Y	Park, NA	Large Tree
Quercus pagoda	Cherrybark Oak	Y	Park, NA	Large Tree
Quercus palustris	Pin Oak	Y	None	Large Tree
Quercus phellos	Willow Oak	Y	Park, NA	Large Tree
Quercus polymorpha	Monterrey Oak	Y	None	Large Tree
Quercus rizophyllia	Loquat Leaf Oak	Y	None	Large Tree
Quercus shumardii	Shumard Oak	Y	ROW, Park, NA	Large Tree
Quercus stellata	Post Oak	Y	ROW, Park, NA	Large Tree
Quercus texana	Nuttall Oak	Y	ROW, Park, NA	Large Tree
Quercus virginiana	Southern Live Oak	Y	ROW, Park, NA	Large Tree
Sassafras albidum	Sassafras	Y	ROW, Park, NA	Large Tree
Sideroxylon lanuginosum	Gum Bully/Gum Bumelia	Y	ROW, Park, NA	Large Tree
Taxodium distichum	Bald Cypress	Y	ROW, Park, NA	Large Tree
Taxodium ascendens	Pond Cypress	Y	None	Large Tree
Taxodium mucronatum	Montezuma Bald cypress	Y	None	Large Tree
Tilia americana	Basswood	Y	ROW, Park, NA	Large Tree
Ulmus alata	Winged Elm	Y	ROW, Park, NA	Large Tree
Ulmus americana	American Elm	Y	ROW, PL, Park, NA	Large Tree
Ulmus crassifolia	Cedar Elm	Y	ROW, Park, NA	Large Tree
Ulmus parvifolia	Chinese Elm	Y	None	Large Tree
Zelkova serrata	Japanese Zelkova	Y	None	Large Tree
Acacia wrightii	Wright Acacia	Y	None	Small Tree

Species		Protected	Planting Eligibility	Usage
Scientific Name	**Common Name**			
Acer leucoderme	Chalk Maple	Y	None	Small Tree
Aesculus glabra	Ohio Buckeye	Y	None	Small Tree
Aesculus pavia	Red Buckeye	Y	ROW, Park, NA	Small Tree
Aralia spinosa	Devil's Walkingstick	Y	NA	Small Tree
Bauhinia congesta	Anacacho Orchid Tree	Y	None	Small Tree
Cercis canadensis	Eastern Redbud	Y	ROW, PL, Park, NA	Small Tree
Chionanthus retusus	Chinese Fringetree	Y	None	Small Tree
Chionanthus virginicus	White Fringetree	Y	NA	Small Tree
Cornus drummondii	Roughleaf Dogwood	Y	ROW, PL, Park, NA	Small Tree
Cornus florida	Flowering Dogwood	Y	Park, NA	Small Tree
Cotinus obovatus	American Smoke Tree	Y	None	Small Tree
Crataegus marshallii	Parsley Hawthorn	Y	ROW, PL, Park, NA	Small Tree
Crataegus mollis	Downy Hawthorn	Y	None	Small Tree
Crataegus spathulata	Littlehip Hawthorn	Y	ROW, PL, Park, NA	Small Tree
Crataegus viridis	Green Hawhtorn	Y	ROW, Park, NA	Small Tree
Crataegus opaca	Western Mayhaw	Y	ROW, PL, Park, NA	Small Tree
Crataegus reverchonii	Reverchon Hawthorn	Y	None	Small Tree
Cyrilla racemiflora	Titi	Y	ROW, Park, NA	Small Tree
Dermatophyllum secundiflorum	Texas Mountain Laurel	Y	None	Small Tree
Diospyros texana	Texas Persimmon	Y	ROW, PL, Park, NA	Small Tree
Ehretia anacua	Anacua	Y	Park, NA	Small Tree
Frangula caroliniana	Carolina Buckthorn	Y	ROW, Park, NA	Small Tree

Species				
Scientific Name	Common Name	Protected	Planting Eligibility	Usage
Halesia diptera	Two-Wing Silverbell	Y	ROW, PL, Park, NA	Small Tree
Hamamelis virginiana	American Witchhazel	Y	NA	Small Tree
Ilex cassine	Dahoon Holly	Y	ROW, PL, Park, NA	Small Tree
Ilex decidua	Possumhaw	Y	ROW, PL, Park, NA	Small Tree
Ilex vomitoria	Yaupon	Y	ROW, PL, Park, NA	Small Tree
Maclura pomifera	Osage Orange	Y	NA	Small Tree
Malus angustifolia	Southern Crabapple	Y	ROW, PL, Park, NA	Small Tree
Morella cerifera	Wax Myrtle	Y	Park, NA	Small Tree
Ostrya virginiana	American Hophornbeam	Y	ROW, PL, Park, NA	Small Tree
Parkinsonia aculeata	Retama	Y	PL, Park, NA	Small Tree
Persea borbonia	Redbay	Y	Park, NA	Small Tree
Pistacia chinensis	Chinese Pistache	Y	None	Small Tree
Pistacia texana	Texas Pistache	Y	None	Small Tree
Prosopis glandulosa	Honey Mesquite	Y	ROW, PL, Park, NA	Small Tree
Prunus angustifolia	Chickasaw Plum	Y	ROW, Park, NA	Small Tree
Prunus caroliniana	Carolina Laurelcherry	Y	PL, NA	Small Tree
Prunus mexicana	Mexican Plum	Y	ROW, PL, Park, NA	Small Tree
Prunus umbellata	Hog Plum	Y	ROW, Park, NA	Small Tree
Ptelea trifoliata	Common Hoptree (Wafer ash)	Y	Park, NA	Small Tree
Rhus copallinum	Winged Sumac	Y	ROW, Park, NA	Small Tree
Salix nigra	Black Willow	Y	NA	Small Tree
Sambucus nigra	Black Elderberry	Y	Park, NA	Small Tree

Species		Protected	Planting Eligibility	Usage
Scientific Name	Common Name			
Sapindus saponaria	Western Soapberry	Y	PL, Park, NA	Small Tree
Styphnolobium affine	Eve's Necklace	Y	None	Small Tree
Ungnadia speciosa	Mexican Buckeye	Y	PL, Park, NA	Small Tree
Vaccinium arboreum	Farkleberry	Y	Park, NA	Small Tree
Vachellia farnesiana	Sweet Acacia	Y	NA	Small Tree
Viburnum rufidulum	Rusty Blackhaw	Y	Park, NA	Small Tree
Zanthoxylum clava-herculis	Hercules' Club	Y	Park, NA	Small Tree

Houston Wilderness 14 Native *Super Trees* With High Ecosystem Services

https://static1.squarespace.com/static/52387981e4b0a2c53f25a411/t/600b337ebd1341636a54e058/1611346815707/The+14+Super+Trees+in+Greater+Houston+Region+-+Winter+2021.pdf

The 14 Super Trees of the Houston Region

A Super Tree is one that has a high rate of carbon absorption, flood mitigation, and greenhouse gas absorption ability.

When ranking Houston-Region native trees in each of these categories, the first 10 species fall in the top 26 for all three categories (data recorded for 10 year old trees). (*) Indicates tree species that do well in wet areas

HOUSTON WILDERNESS *It's Our Nature*

TREES FOR HOUSTON

1) Live Oak

- CO2 Sequestered per year (lbs.): 268 (annual); 1,023 (10 yr)
- Water Absorption per year (gals.): 2,656
- GHG Absorption per year (lbs.): 1.9
- Flower: N/A
- Height at Maturity: 60-80 ft
- Canopy Width: 60-120 ft
- Soil Tolerance: Acidic, Alkaline, Clay
- Light: Full-Partial Sun

2) Boxelder

- CO2 Sequestered per year (lbs.): 159 (annual); 899 (10 yr)
- Water Absorption per year (gals.): 2051
- GHG Absorption per year (lbs.): 1.3
- Flower: Yellowish Green to Reddish Orange
- Height at Maturity: 30-50 ft
- Canopy Width: 30-50 ft
- Soil Tolerance: Alkaline, Clay, Acidic
- Light: Full-Partial Sun

3) *Laurel Oak

- CO2 Sequestered per year (lbs.): 194 (annual); 875 (10 yr)
- Water Absorption per year (gals.): 2,518
- GHG Absorption per year (lbs.): 1.3
- Flower: White
- Height at Maturity: 60-70 ft
- Canopy Width: 35-45 ft
- Soil Tolerance: Acidic, (slightly) Alkaline, Clay
- Light: Full-Partial Sun

4) Red Maple

- CO2 Sequestered per year (lbs.): 139 (annual); 859 (10 yr)
- Water Absorption per year (gals.): 2,592
- GHG Absorption per year (lbs.): 1.6
- Flower: Red
- Height at Maturity: 40-60 ft
- Canopy Width: 35-45 ft
- Soil Tolerance: Acidic (prefers), Alkaline, Clay
- Light: Full-Partial Sun

5) *River Birch

- CO2 Sequestered per year (lbs.): 215 (annual); 925 (10 yr)
- Water Absorption per year (gals.): 2646
- GHG Absorption per year (lbs.): 1.3
- Flower: Reddish green
- Height at Maturity: 40-70 ft
- Canopy Width: 40-60 ft
- Soil Tolerance: Acidic, Loamy
- Light: Full - Partial Sun

6) American Elm

- CO2 Sequestered per year (lbs.): 114 (annual); 669 (10 yr)
- water Absorption per year (gals.): 2364
- GHG Absorption per year (lbs.): 1.4
- Flower: Reddish Green
- Height at Maturity: 70-90 ft
- Canopy Width: 50-70 ft
- Soil Tolerance: Alkaline, Clay
- Light: Full Sun

Visit Houston Wilderness: http://houstonwilderness.org/

Tree Species Characteristic Sources: http://mortonarb.org - http://arborday.org - http://hort.ufl.edu

Ecosystems Services Data Sources: Air quality: https://www.fs.fed.us/nrs/pubs/jml/2014/nrs_2014_nowak_001.pdf Carbon: https://www.epa.gov/sites/production/files/2016-12/documents/sc_co2_tsd_august_2016.pdf https://www.fs.usda.gov/ccrc/tools/tree-carbon-calculator-ctcc VOC: https://www.nrs.fs.fed.us/units/urban/local-resources/downloads/vocrates.pdf Stormwater: http://www.itreetools.org/eco/resources/iTree_Eco_Precipitation_Interception_Model_Descriptions.pdf

7) Slippery Elm

CO2 Sequestered per year (lbs.): 197 (annual); 669 (10 yr)	
Water Absorption per year (gals.): 2,199	
GHG Absorption per year (lbs.): 1.5	
Flower: Reddish Orange	
Height at Maturity: 40-60 ft	
Canopy Width: 30-50 ft	
Soil Tolerance: Alkaline, Acidic, Clay	
Light: Full-Partial Sun	

8) Tuliptree

CO2 Sequestered per year (lbs.): 81 (annual); 659 (10 yr)	
Water Absorption per year (gals.): 3,006	
GHG Absorption per year (lbs.): 1.9	
Flower: Yellow-orange	
Height at Maturity: 70-90 ft	
Canopy Width: 40 ft	
Soil Tolerance: Acidic, Clay	
Light: Full Sun	

9) American Sycamore

CO2 Sequestered per year (lbs.): 111 (annual); 652 (10 yr)	
Water Absorption per year (gals.): 2,747	
GHG Absorption per year (lbs.): 1.9	
Flower: Green to Greenish Red	
Height at Maturity: 75-100 ft	
Canopy Width: 50-70 ft	
Soil Tolerance: Alkaline (prefers), Acidic, Clay	
Light: Full-Partial Sun	

10) Green Ash

CO2 Sequestered per year (lbs.): 200 (annual); 624 (10 yr)	
Water Absorption per year (gals.): 1,977	
GHG Absorption per year (lbs.): 1.3	
Flower: Greenish yellow	
Height at Maturity: 50-60 ft	
Canopy Width: 25-40 ft	
Soil Tolerance: Alkaline, Clay, Acidic	
Light: Full Sun	

A **Super Carbon Tree** is one that has a high carbon absorption ability (ranked in the top 20), but ranks below the top 20 in flood mitigation and greenhouse gas absorption ability.
Two that are native to the Houston Region are listed below.

11) Loblolly Pine

CO2 Sequesteres per year (lbs.): 106 (annual); 479 (10 yr)	
Water Absorption per year (gals.): 1,480	
GHG Absorption per year (lbs.): 1.1	
Flower: Yellowish Green	
Height at Maturity: 60-90 ft	
Canopy Width: 25-35 ft	
Soil Tolerance: Acidic, Clay	
Light: Full Sun	

12) White Ash

CO2 Sequesteres per year (lbs.): 118 (annual); 447 (10 yr)	
Water Absorption per year (gals.): 1,839	
GHG Absorption per year (lbs.): 1.3	
Flower: White	
Height at Maturity: 50-80 ft	
Canopy Width: 40-50 ft	
Soil Tolerance: Acidic, Alkaline	
Light: Full-Partial Sun	

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13) *Water Oak	14) Sweetgum
CO2 Sequestered per year (lbs.): 173 (annual); 869 (10 yr)	CO2 Sequestered per year (lbs.): 150 (annual); 719 (10 yr)
Water Absorption per year (gals.): 2,879	Water Absorption per year (gals.): 2,395
GHG Absorption per year (lbs.): 1.4	GHG Absorption per year (lbs.): 1.5
Flower: Yellowish to Green	Flower: Green-Yellow
Height at Maturity: 60-100 ft	Height at Maturity: 60-75 ft
Canopy Width: 50-80 ft	Canopy Width: 40-75 ft
Soil Tolerance: Acidic, Loamy, Clay	Soil Tolerance: Acidic (prefers), Clay
Light: Full-Partial Sun	Light: Full Sun

https://mailchi.mp/houstontx/city-of-houston-celebrates-arbor-day-by-planting-600-trees?e=b64a6035fa

MAYOR'S OFFICE PRESS RELEASE

Houston Celebrates Texas Arbor Day by Planting 600 Trees at Buffalo Bend Nature Center

Coalition launched to help reach Resilient Houston and Houston Climate Action Plan target of planting 4.6 million native trees by 2030

November 6, 2020 --The City of Houston planted 600 native trees today to kick off its new tree planting goal established by the City's Resilient Houston strategy and Houston Climate Action Plan. The effort centered on communities with the highest rate of health conditions that can be worsened by pollution and climate change.

"Our goal of planting 4.6 million new native trees is the equivalent of two new trees for every Houstonian," said Councilmember David Robinson. "As a resilient and sustainable city, we need to plant the seeds today for future generations to fully reap the benefits."

Representatives from the City of Houston, the newly formed Tree Strategy Implementation Group (TSIG), led by Houston Wilderness, Buffalo Bayou Partnership and approximately 100 volunteer tree-planters from Bank of Texas, Shell Oil, Dow Chemical, ALJ Lindsey and interested Houstonians participated in the event commemorating Texas Arbor Day at Buffalo Bend Nature Park.

"Trees improve our ability to combat many of the health, equity, climate, and built environment challenges that we face," said Marissa Aho, Chief Resilience Officer. "These include helping to cool and shade in the face of urban and extreme heat, improving air quality and capturing carbon, supporting rich biodiversity, improving health and wellbeing, and enhancing the built environment."

Houston's Climate Action Plan focused on how the City's tree planting goal will help restore, protect and enhance our natural ability to capture and store carbon to help mitigate climate change.

The area selected for the first 600 trees includes communities that experience twice the rate of cardiac arrest and six times the amount to asthma attacks compared to the rest of the city.

"This planting of native trees with the highest capacity to reap environmental benefits provides the opportunity to proactively address both climate change and its implications for health", said Dr. Loren Hopkins, Chief Environmental Science Officer for the Houston Health Department. "Air pollutants absorbed by trees include nitrogen dioxide, ozone and particulate matter, all pollutants associated with increased risk of cardiac arrest and asthma attacks in Houston."

Planting 4.6 million new native trees in 10 years will need every Houstonian to play a role, but some local leaders have volunteered to begin coordinating implementation of this ambitious target with public and private partners.

"The Tree Strategy Implementation Group, comprised of all the major large-scale native tree planters in the region, came together in early 2020 to create a strategy to accomplish the planting of 4.6 million native trees by 2030," said Deborah January-Bevers, President of Houston Wilderness. "Based on data analyzed by TSIG members to be most beneficial to the region, 40% of the native 4.6 million trees are targeted for Urban Heat Islandareas with tree species with large leaf canopies, and 60% of the native trees are targeted for native 'Super Trees' species, such as the Live Oak, American Elm and Sycamore, Tuliptree, Maple and Ash trees and Loblolly Pine, that provide high levels of air pollution reduction, water absorption, erosion control and carbon sequestration."

Resilient Houston also sets a target to conserve 24% of undeveloped regional land as natural spaces by 2040.

"We look forward to continuing to facilitate progress on the three key goals under the eight-county Gulf-Houston Regional Conservation Plan, which mirrors goals under the Resilient Houston Plan," said Graciela Gilardoni, Houston Wilderness Board Member. "The City of Houston, Harris County and other regional partners recognize that the urban forest is a critical part of the resilience goals to benefit residents now and in generations to come."

The Arbor Day tree planting was hosted by the Buffalo Bayou Partnership at their Buffalo Bend Nature Park.
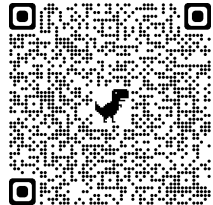
"Buffalo Bayou Partnership worked with Harris County Precinct Two and other governmental agencies to acquire and develop this abandoned industrial property," said Anne Olson, President of Buffalo Bayou Partnership, "And the 600 native Super Trees planted on November 6th are part of the transformation taking place on this riparian green space in Houston's East End."

Appendix H
Large-Scale Tree Planting Guide

This guide presents suggestions to help future large-scale tree plantings. Suggestions have been tested during multiple planting seasons and have shown to be successful in the Texas region.

Suggested Materials

·   **Shovels:** Shovels can be used to plant any size tree and quicken the process (versus using trowels).

·   **Trees:** Native tree species are recommended for their environmental and wildlife benefits. Native *Super Trees* species encouraged for ecosystem services. See *Super Trees* species on QR code:

·   **Microbial Fungi:** Microbial fungi naturally stimulate growth and increase the chance of survival. See Appendix for more information.

·   **Soil amendments:** Materials such as topsoil, compost, and/or mulch can be added to the soil to improve its nature.

·   **Water/Tree Diapers:** If planting in a dry or hot location, water may be needed. Water can be provided through gallon jugs, irrigation or helpful watering aids, such as tree diapers. These "diapers" are placed around the base of the tree and covered with soil. Tree diapers are good for hydrate trees over time. See more information, see TreeDiaper.com.

Planting Tips

Volunteers: Use volunteers to help large-scale planting. Planting can be labor intensive and time consuming. Volunteers are a solution to these barriers while engaging the community in environmental efforts. Tree multiple planting events can be held during the planting season. Events can be open for the general public or be held for specific groups, such as corporations or and Boy Scouts, to participate in.

Assembly Line: When multiple people are present using an "assembly line" style to plant trees is recommended. Split everyone up into groups and assign each group with a specific task- mulching, placing trees by holes, planting trees, and mulching. Instead of working individually, approaching planting this way can significantly speed up the process and allow more trees to be planted in half the time.

Planting Process

Double Up: Planting large-scale can be challenging due to factors such as limited time, space, and people. To overcome these we have found success, in our region's clay based soil, doubling the seedlings per hole. Not only does this speed up the planting process but it also increases carbon sequestration and storage, and root connectivity strength in the area. The planting process remains the same but with wider holes and additional fungi, topsoil, mulch and/or compost to account for two seedlings.

Location: Trees must be spaced apart so their roots have the needed room to grow. Seedlings can be planted 12-18 inches apart while larger trees will need more room. If reforestation is the goal, planting in a forestation style is recommended. Trees are planted in a random manner (avoiding rows), while diversifying the species being planted next to one another.

Digging: Holes vary depending on the size of tree being planted and its root mass. To start, use shovels to scrape away any vegetation that may exist where the hole will be. Holes need to be wider than the root mass and deep enough so the top of the root mass is even with the ground.

Planting: Place a tree standing straight up in hole. If using fungi, sprinkle the content onto the trees' root mass (or as directed) and replace dirt into the hole making sure roots are covered. To avoid air pockets tightly pack the dirt into the hole. If using a tree diaper, place it around the base of the tree. Finally, place topsoil, mulch, or compost on top of the tree diaper or ground firmly pressing down. Water can be poured on top if desired.
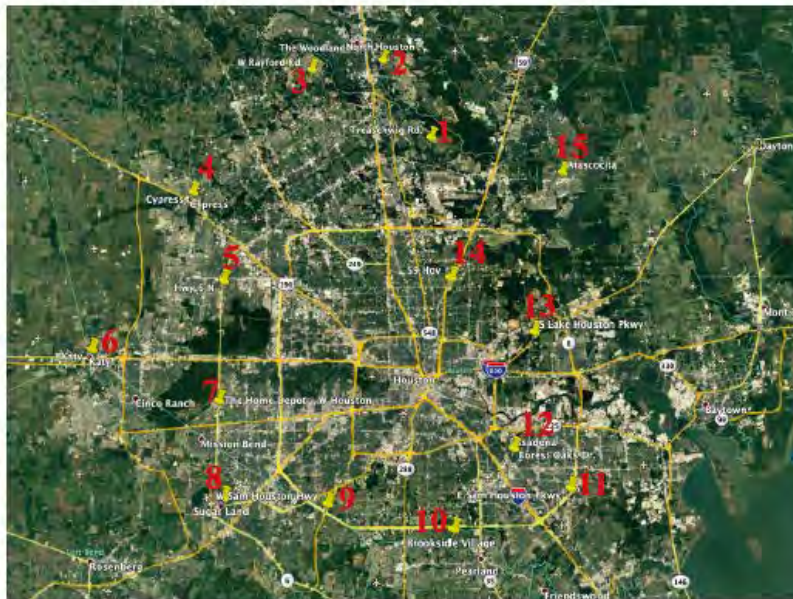
Greater Houston Deforestation Report: 2013 to 2019 (GHD)

Use for Houston Wilderness
Port of Houston Trees & Riparian Enhancement of Ecosystem Services (PoH TREES Program)

Updated by 4/2021

Spreadsheet:

	Latitude	Longitude	2013 (unit: acre)	2016 (unit: acre)	Percentage decrease of forest cover in 2016 compared with 2013	2019 (unit: acre)	Percentage decrease of forest cover in 2019 compared with 2013	Deforestation Rate in 6 years(acre/year)
Transect 1	30° 2'23.19"N	95°21'21.61"W	257112.704	229316.736	10.8108%	201520.768	21.6216%	9265.322667
Transect 2	30° 8'6.28"N	95°25'37.03"W	267536.192	236265.728	11.6883%	211944.256	20.7792%	9265.322667
Transect 3	30° 7'21.65"N	95°31'46.26"W	23568.66361	18173.42736	22.8916%	12494.23131	46.9880%	1845.738717
Transect 4	29°58'16.06"N	95°41'36.69"W	29568	25401.6	14.0909%	11289.6	61.8182%	3046.4
Transect 5	29°51'58.68"N	95°38'43.79"W	197486.464	115915.968	41.3043%	167434.176	15.2174%	5008.714667
Transect 6	29°47'6.76"N	95°49'28.63"W	32741.376	21827.584	33.3333%	16370.688	50.0000%	2728.448
Transect 7	29°43'41.15"N	95°38'45.49"W	9680	4840	50.0000%	4840	50.0000%	806.6666667
Transect 8	29°37'11.83"N	95°38'5.95"W	20070.4	12544	37.5000%	7526.4	62.5000%	2090.666667
Transect 9	29°36'50.28"N	95°29'39.81"W	10816	8652.8	20.0000%	7571.2	30.0000%	540.8
Transect 10	29°35'13.72"N	95°19'31.56"W	10863.616	4073.856	62.5000%	2715.904	75.0000%	1357.952
Transect 11	29°37'58.49"N	95°10'4.78"W	48108.096	29399.392	38.8889%	18708.704	61.1111%	4899.898667
Transect 12	29°40'37.27"N	95°14'38.05"W	518.1928489	1036.385698	-100.0000%	777.2892734	-50.0000%	-43.18273741
Transect 13	29°48'33.03"N	95°12'51.47"W	41223.2	33207.57778	19.4444%	33207.57778	19.4444%	1335.937037
Transect 14	29°52'18.18"N	95°19'44.95"W	60273.92	57260.224	5.0000%	40684.896	32.5000%	3264.837333
Transect 15	29°59'53.02"N	95°10'19.09"W	173116.16	89031.168	48.5714%	74192.64	57.1429%	16487.25333

Regional Native Tree Species – Targeted Ecosystem Services Rankings

HOUSTON WILDERNESS — It's Our Nature

Tree species	Total CO₂ Stored (lbs.) DBH = 10 years	Tree species	CO₂ sequestrated (lbs./tree/year) DBH ≈ 10 years	Tree species	Water absorption (gal./year) DBH = 10 years	Tree Species	Total air pollutant w PM2.5 (lbs./year) DBH = 10 years	Tree species	Total VOC Emission Potential (µg of C/g of leaf dry weight/hr)
Live Oak	1023	Live Oak	268	Tulip Tree	3006	American Sycamore	1.9	Southern Crabapple	0.0
Black Cherry	971	River Birch	215	Water Oak	2879	Live Oak	1.9	American Basswood	0.0
River Birch	925	Green Ash	200	American Sycamore	2747	Tulip Tree	1.9	Slippery Elm	0.2
Boxelder	898	Slippery Elm	197	Live Oak	2656	Black Walnut	1.9	American Elm	0.2
Laurel Oak	875	Laurel Oak	194	River Birch	2646	Red Maple	1.6	Black Cherry	0.2
Water Oak	869	Winged Elm	179	Red Maple	2592	Slippery Elm	1.5	Green Ash	0.2
Red Maple	859	Eastern Cottonwood	176	Black Walnut	2528	Sweetgum	1.5	White Ash	0.2
Willow Oak	739	Water Oak	173	Laurel Oak	2518	Water Oak	1.4	Elm	0.2
Sweetgum	719	Black Willow	169	Sweetgum	2395	American Elm	1.4	Plum	0.2
Slippery Elm	669	Boxelder	159	American Elm	2364	Laurel Oak	1.3	Winged Elm	0.2
American Elm	667	Elm	151	Willow Oak	2316	Boxelder	1.3	Common Persimmon	0.2
Tulip Tree	659	Sweetgum	150	Slippery Elm	2199	River Birch	1.3	Washington Hawthorn	0.2
American Sycamore	652	Baldcypress	146	Black Cherry	2095	Green Ash	1.3	Carolina cherry Laurel	0.2
Green Ash	624	Willow Oak	142	Boxelder	2051	White Ash	1.3	Eastern Redbud	0.2
Eastern Cottonwood	591	Red Maple	139	Green Ash	1977	Southern Magnolia	1.3	Tulip Tree	0.3
Black Willow	590	Plum	139	Hickory	1907	Black Tupelo	1.2	River Birch	0.3
Loblolly Pine	479	Southern red Oak	121	Red Mulberry	1876	Black Cherry	1.1	Red Mulberry	0.3
Washington Hawthorn	448	White Ash	118	Black Tupelo	1858	Willow Oak	1.1	Sugarberry/Hackberry	0.3
White Ash	447	American Elm	114	Southern red Oak	1858	Eastern Cottonwood	1.1	Holly	0.3
Southern Crabapple	445	Swamp chestnut Oak	114	White Ash	1839	Red Mulberry	1.0	Savannah Holly	0.3
Plum	445	American Sycamore	111	Eastern Cottonwood	1791	Hickory	1.0	American Holly	0.3
Baldcypress	443	Loblolly Pine	106	Oak	1740	Redbay	1.0	Redbay	0.7
Longleaf Pine	425	Black Cherry	101	Swamp chestnut Oak	1729	Flowering Dogwood	0.9	Red Maple	1.7
Southern red Oak	416	Oak	94	Flowering Dogwood	1639	Black Willow	0.9	Boxelder	1.7
Shumard Oak	413	Shortleaf Pine	91	Plum	1493	Sugarberry/Hackberry	0.9	Flowering Dogwood	1.7
Swamp chestnut Oak	412	Shumard Oak	90	Shumard Oak	1492	Shumard Oak	0.9	American Hornbeam	1.7
Oak	407	Longleaf Pine	85	Loblolly Pine	1480	Elm	0.9	Hickory	1.7
Black Walnut	386	Tulip Tree	81	Black Willow	1466	Southern red Oak	0.9	Sugar Maple	1.7
Shortleaf Pine	374	Willow	79	Southern Magnolia	1458	Oak	0.9	Bitternut Hickory	1.7
Hickory	355	Black Walnut	76	Redbay	1368	Shortleaf Pine	0.9	Mockernu Hickory	1.7
Black Tupelo	354	American Basswood	76	Southern Crabapple	1359	Carolina cherry Laurel	0.9	Pecan	1.7
Flowering Dogwood	338	Hickory	75	Shortleaf Pine	1332	Southern Crabapple	0.8	Eastern red Cedar	1.7
Holly	337	Sugar Maple	71	Elm	1323	Swamp chestnut Oak	0.8	Black Walnut	3.1
Winged Elm	327	Washington Hawthorn	68	Carolina cherry Laurel	1312	Plum	0.8	Southern Magnolia	3.1
Elm	326	Redbay	64	Pecan	1283	American Basswood	0.8	Longleaf Pine	3.1
Southern Magnolia	322	Savannah Holly	63	Winged Elm	1267	Eastern Redbud	0.8	Shortleaf Pine	3.1
Redbay	322	Holly	59	Eastern Redbud	1238	Winged Elm	0.7	Loblolly Pine	3.1
Willow	281	Sugarberry/Hackberry	58	American Basswood	1199	Sugar Maple	0.7	Baldcypress	3.1
American Basswood	261	Southern Magnolia	55	Sugarberry/Hackberry	1157	Mockernu Hickory	0.7	American Sycamore	70.1
Carolina cherry Laurel	232	Post Oak	55	Mockernu Hickory	1145	Longleaf Pine	0.7	Black Willow	70.1
Red Mulberry	219	Bitternut Hickory	54	Willow	1114	American Hornbeam	0.6	Eastern Cottonwood	70.1
Savannah Holly	192	White Oak	54	Bitternut Hickory	1098	Common Persimmon	0.6	Willow	70.1
Sugar Maple	191	Flowering Dogwood	46	Longleaf Pine	1094	Willow	0.6	Water Oak	70.2
Common Persimmon	164	Black Tupelo	46	Common Persimmon	1093	Baldcypress	0.6	Live Oak	70.2
Mockernu Hickory	140	Red Mulberry	44	Baldcypress	1078	Holly	0.6	Laurel Oak	70.2
Post Oak	139	Mockernu Hickory	44	American Hornbeam	1037	Savannah Holly	0.6	Willow Oak	70.2
Bitternut Hickory	138	Pecan	44	White Oak	907	Bitternut Hickory	0.5	Shumard Oak	70.2
White Oak	136	Common Persimmon	38	Sugar Maple	891	Pecan	0.5	Swamp chestnut Oak	70.2
Pecan	135	American Holly	33	Washington Hawthorn	790	White Oak	0.5	Southern red Oak	70.2
American Hornbeam	133	American Hornbeam	31	Post Oak	691	American Holly	0.3	Oak	70.2
American Holly	127	Southern Crabapple	27	Holly	665	Post Oak	0.3	White Oak	70.2
Sugarberry/Hackberry	111	Eastern Redbud	19	Savannah Holly	629	Washington Hawthorn	0.2	Post Oak	70.2
Eastern Redbud	72	Eastern red Cedar	17	American Holly	525	Eastern red Cedar	0.2	Black Tupelo	70.6
Eastern red Cedar	45	Carolina cherry Laurel	2	Eastern red Cedar	324			Sweetgum	73.0

Chapter 2
- Map of current and previous urban heat island campaigns conducted by NOAA, 2021, https://www.cnn.com/2021/06/02/weather/urban-heat-island-inequality-campaign/index.html
- "Houston & Harris County Heat Watch Report", by CAPA Strategies, LLC, https://www.h3at.org/

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