

# Houston Parks Board, Woodland/Forest Restoration and Management Best Management Practices

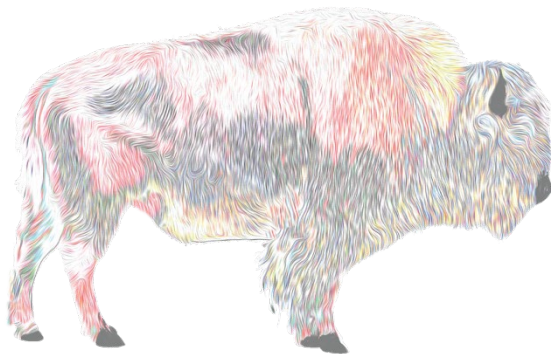
Blackland Collaborative, June 2023

## AUTHORS

Emily Manderson  
Principal / Senior Environmental Designer

Michelle Bertelsen  
Principal / Senior Ecologist

John Hart Asher II  
Principal / Senior Environmental Designer



BLACKLAND COLLABORATIVE

REVIVE | REWILD | RESTORE

This Woodland/Forest Restoration Best Management Practice is meant to provide a framework for restoration practices and principles. The habitat BMPs serve to provide a foundation to a growing program to promote continuity for all staff and ensure a cohesive approach. This serves as a land management document providing an initial restoration toolbox. The BMPs are broad recommendations and should be viewed as starting the process for restoration. Every site is unique and it will be up to the discretion of the conservation team to implement these BMPs in the most appropriate way given the conditions. This BMP is a living document that will be updated overtime as the HPB learns more through implementation and management.

## Table of Contents-

Section		Page
	LIST OF FIGURES	iii
	LIST OF TABLES	iv
I	BACKGROUND	1
	A. Document overview	1
	B. Ecological context and definitions	1
	C. Value and ecosystem services	4
	D. Sustainable development	4
	E. Project sequencing	5
	F. Restoring landscapes	6
II	SITE ASSESSMENT	8
	A. Field check	10
	B. Predesign ecological site assessment	10
	C. Maintenance Rapid Assessment	13
III	LONG TERM MONITORING	14
	A. Monitoring parameters	15
IV	DESIGN	20
	A. Placement and selection of elements	20
	B. Design for maintenance	20
	C. Community assembly	20
	D. Soil protection	20
V	INSTALLATION & MAINTENANCE	22
	A. Soil sampling	22
	B. Site preparation	26
	C. Vegetation and Soil protection	26
	D. Site Hygiene	26
	E. Invasive removal	27
	F. Soil preparation	36
	G. Soil amendments	39
	H. Seeding	40
	I. Live planting	48
	J Watering for establishment	57
	K. Monitoring for establishment	59
	L. Management and Maintenance	60
VI	REFERENCES	64
	Figures	
1	Forestland across the state of Texas.	2
2	East Texas forest region	3
3	Project Sequencing and Major Milestones	5
4	Houston area ecoregion map	8

5	Ecological function	11
6	Soil sample information form	23
7	Soil sample results and interpretation	25
8	Facilitators or Followers graph	29
9	Cone scale penetrometer image	37
10	Bulk Density to Standard Proctor Density graph	37
11	Image of soil particles	38
12	Image of Dew Drop Drill	45
13	Image of no till drill vs hand seeding Headwaters at the Comal	46
14	Image of seeding passes	46
15	Image of Eastern gamagrass	47
16	Indian Paintbrush seed	47
17	Image of weed wrench	61
18	Diagram of the Adaptive Management process	62
19	Example maintenance schedule for prairie habitat	63
	Tables	
1	Site assessment types	9
2	Common invasive species and treatment.	30
3	Starter Seed Mix Seed Mix Type 1: Upland/Savanna Mix	42
4	Starter Seed Mix Seed Mix Type 2: Shade/Riparian Shade Mix	43
5	Woodland/Forest tree species list	50
6	Planting Windows	56
7	Bare Patch Mix	60
VII	Appendices	68
	Appendix A. Data Sheets	
	1. Field Check	
	2. Rapid Assessment	
	Appendix B. Methods	
	1. Vegetation Monitoring	
	2. Pollinator Monitoring	

## I. Background

### A. Woodland BMP topic overview

- Ecological context and definitions
- Value and ecosystem services
- Sustainable development
- Site assessment
- Long-term monitoring
- Design
- Installation
- Establishment & Maintenance
- References

### B. Ecological context and definitions

Woodlands and Forests are important habitat types that provide an abundance of ecosystem services and add to the diversity of the Earth's overall ecosystem and vegetation types. The density of trees present in a certain area plays an important role in defining woodland types. In general, to define habitat types, the continuum of tree density plays a critical role. Starting with Prairie, where very little to no trees are present, then moving to Savanna where trees are present but the condition is still predominantly a grassland, to Woodlands which have more densely growing trees and also are able to sustain an herbaceous layer, then finally to Forest with the most dense trees present and have reduced herbaceous species due to an extensive canopy cover and limited light availability (Pakard and Mutel 2005).

#### Woodlands

Woodlands are terrestrial areas dominated by trees with a canopy that is more open than a forest (30 to 100 percent cover), with understory species, and a relatively dense groundcover. Fire is an important part of maintaining woodland habitats.<sup>1</sup>

#### Forests

Forest are terrestrial areas dominated by trees with closed or nearly closed canopies with understory species adapted to specific light conditions.

Woodlands and Forests compose a significant amount of Texas' habitat types. According to Texas A&M Forest Service, there are 63.2 million acres of forestland across the state of Texas (Figure 1). The definition based on Forest Inventory and Analysis (FIA) has a broader definition of forestland than this document where an acre area has at least 10 percent canopy cover by live trees of any size. While this paper will use a more restrictive definition for woodlands and forests, it is none the less important to understand the range of trees on the Texas landscape as illustrated in the map below.

---

<sup>1</sup> <https://mdc.mo.gov/discover-nature/habitats/forests-woodlands>

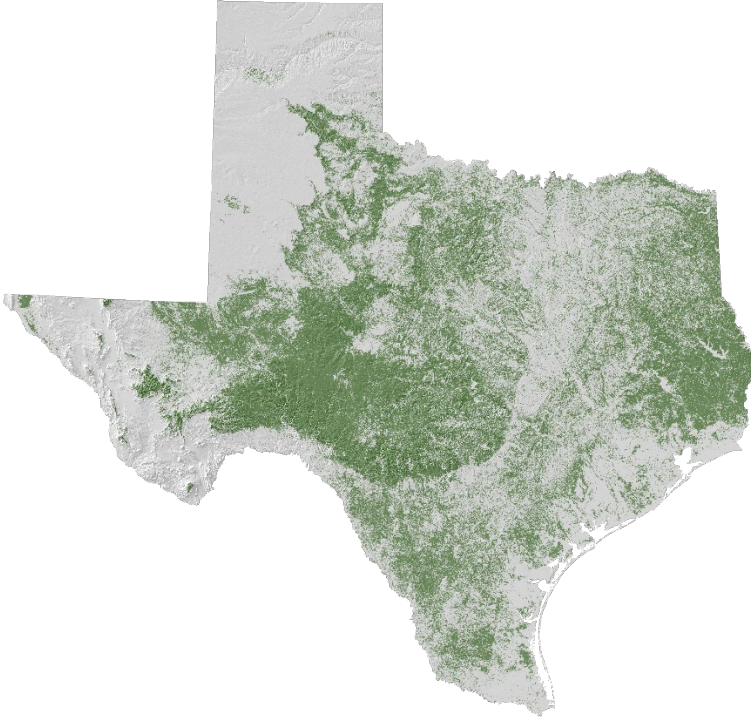


Figure 1. Forestland across the state of Texas. Texas A&M University

The highest percentage of woodlands and forests are in the eastern portions of Texas due to higher precipitation rates and other favorable conditions. The East Texas forest region, known as the Piney Woods, is approximately 23 million acres, an area larger than Indiana. The East Texas forest region was primarily composed of Longleaf Pine forest, Shortleaf Pine, Loblolly Pine, and Post Oak (Figure 2). The forest of Texas have shaped the state's history and have been a major resource environmentally and economically. Stephen F. Austin described the region in 1828:

“The country on the Sabine, Neches, Trinity, and San Jacinto is heavily timbered and wooded with thick groves of good pine, cypress, oak, ash, and other timber...The thickly wooded lands continue quire to the Red River north of the heads of the Sabine and the Neches, and pretty high on the Trinity.

The whole of this eastern and wooded region is very abundantly supplied with living streams of pure water, which afford many favorable sites for saw and other mills, either water or steam. The lumber business from this quarter will be very valuable so soon as mills are put in extensive operation.”

From 1880-1930 Texas forest were deeply impacted by “Bonanza” Lumbering leading to the removal of the longleaf pines and overall destruction of the pine forest. The process was laissez-fair and exploited the forest. The unregulated process included the removal of smaller trees through logging operations leaving stumps fields and ghost towns by the 1940s (Maxwell and Martin 1970). The forest were considered an impediment to farming.

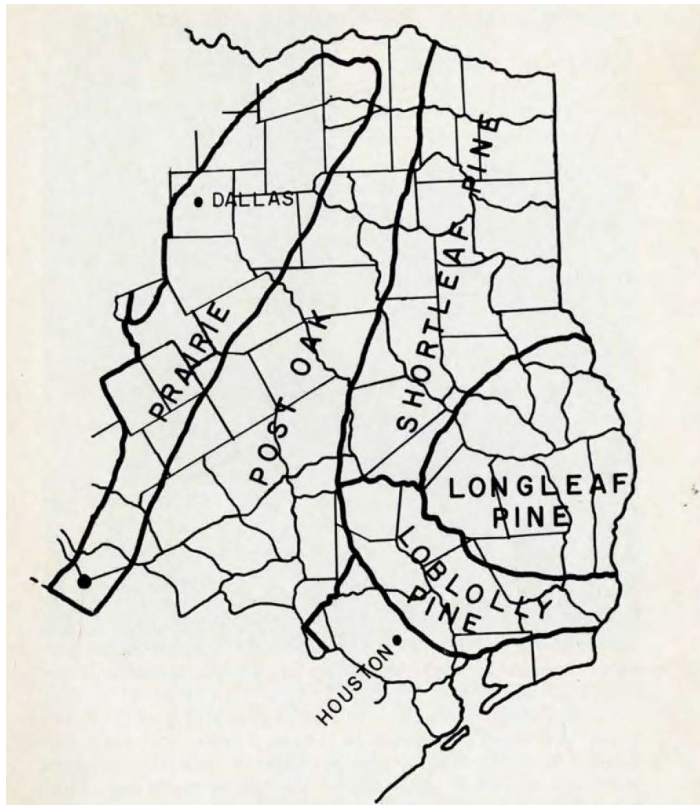


Figure 2. East Texas forest region Maxwell and Martin 1970.

Unfortunately, Texas had not learned from the east and west coast forest destruction and felt supply was inexhaustible. It was not until national conservation efforts led by Theodore Roosevelt and Gifford Pinchot helped in the awareness for preservation of existing pine forest. In Texas, W. Goodrich Jones' promotion of forest conservation practices and raising the alarm of complete denudation in the early 1900's was critical to the eventual formation of the Texas Forest Service. Conservation forestry practices began to be more widely implemented in the 1930's especially with the help of the Civilian Conservation Corps and more national support. The regenerative capacity of the loblolly pine and favorable growing conditions also played an important role in conserving and expanding existing pine stands (Maxwell and Martin 1970).

Currently, the northeastern and eastern portions of the Greater Houston area are classified as the Piney Woods region, and east of that is the diverse Big Thicket. Bottomland forests are also found along the Trinity, Colorado, San Bernard, and Brazos Rivers comprising the Columbia bottomlands. The primary historical woodlands located within HPB locations are mostly the Piney Woods ecoregion. Due to current development patterns, deforestation is happening at an accelerated rate, and many of the woodland habitats are suffering canopy loss, quality decline, and ultimately degradation of ecosystem functions.

## C. Value and Ecosystem services

### Ecosystem Services

Ecosystem services are services that nature provides for free that humans rely on to live such as cleaning air and water, providing food, regulating temperatures, and improving mental health and wellness.

Woodlands provide many important ecosystem services, including stormwater retention by intercepting rain through their canopies and infiltrating water to the ground through their root systems. Woodlands sequester carbon while trees remain living and aid in noise abatement. Most importantly for urban environments, trees provide shade, regulate temperatures, and improve air quality. Due to the positive impacts that trees offer, the City of Houston has identified a goal of planting 4.6 million native trees by 2030 as part of Resilient Houston initiatives.<sup>2</sup>

USDA's Houston's Urban Forest Report, 2015 analyzed the urban forest of Houston, Texas and found Houston at the time had 33.3 million live trees covering 18.4 percent of the city.<sup>3</sup> The most common trees in Houston are, Chinese tallowtree, Chinese privet, Japanese privet, and sugarberry. Sugarberry being the only native tree. In the analysis, ecosystem services trees provide were quantified specifically for Houston. A few of those are:

- Houston trees store about 2.0 million tons of carbon which has a value of \$272 million.
- About 140,000 tons of carbon per year and about 2,400 tons of air pollution per year are removed by Houston's trees.
- Houston's urban forest is estimated to reduce annual residential energy costs by \$53.9 million per year.
- Houston's trees reduce runoff at 173 million cubic feet per year valuing at an estimate of \$7.8 per year.

## D. Sustainable development

Sustainable development protects and enhances ecological function while integrating it with human use. The following process (Figure 3) illustrates sustainable development and ecological restoration principles as pertains to prairie restoration and integration into Houston Parks Board projects. Success requires a holistic approach. The timeline below outlines the general progression of activities for a project from consideration for acquisition through the initial stages of maintenance.

---

<sup>2</sup> <https://www.houstontx.gov/mayor/chief-resilience-officer.html>

<sup>3</sup> <https://www.fs.usda.gov/research/treesearch/54109#:~:text=An%20analysis%20of%20the%20urban,are%20located%20on%20private%20lands.>



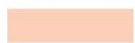
## E. Project Sequencing

Restoration as a practice is a trajectory, which lacks a defined end point, since the restoration process revolves around restoring ecosystem function and natural systems that have cycles of activity. It is always possible to lose a restoration no matter how long it has been established. Maintenance begins with site preparation and never ends as it evolves from establishment to an iterative process of adaptive management. Establishing the monitoring program as early as possible will also benefit the project flow and capacity to gather valuable information that will inform management decisions.

### Adaptive management

Adaptive management is a management approach that acknowledges uncertainty in ecological systems and reduces uncertainty by using a problem-solving management approach. The focus is on learning about the system and how to best change the system. The process for adaptive management is circular in nature starting with assessment, design, implementation, monitoring, evaluation, and adjusting. Adaptive management is a hybrid of management and research (Murray and Marmorek 2003).

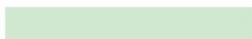
### FIELD CHECK



### LAND ACQUISITION



### PRE - DESIGN ECOLOGICAL ASSESSMENT



### LONG TERM MONITORING



### SITE PREPARATION



### DESIGN



### INSTALLATION / SITE HYGIENE



### MAINTENANCE



Figure 3 Project Sequencing and Major Milestones

## Major questions and actions for each phase:

### Pre-design

- What are the habitat and soil types and what condition is it in?
- What are the opportunities and performance goals?
- Are there special considerations for this site that would shape our planning?
- Identify nearby reference ecosystems that could be used for comparison.

### Metrics and Monitoring

- Set the program up early to get baseline data and have as long of data collection as possible.

### Design

- Where is the optimal placement and layout for optimal ecosystem function and maintenance success.

### Site Preparation and Installation

- **Scheduling enough time to prepare the site soils and gather plant materials.** Installing in an ideal sequence to vegetate as soon as possible.
- Maintain good site hygiene during installation.

### Maintenance and Management

- Maintenance, especially controlling invasive species, start once site preparation begins and continues through maintenance and adaptive management.
- Monitoring of performance will inform management activities which is part of the adaptive management process.

## F. Restoring landscapes

The restoration techniques mentioned in this BMP are designed to guide conservation staff in the process of repairing land or converting resource-intensive landscapes into areas that are both beautiful and best suited to perform ecosystem services. The species listed in this document evolved in disturbance-driven ecosystems that included wildfire and floods and are best adapted to contribute towards the recovery of ecosystem services. Houston Parks Board staff should note that the transition of a site from a degraded state dominated by invasive plant growth or severe erosion will be challenging and take a concerted effort that involves biotic and abiotic manipulation. Emphasis should be placed on the positive impacts from the restoration process rather than an end product. Minor disturbances in healthy, functioning ecosystems usually self-heal and return to a stable functioning state within a relatively small amount of time. However, such healthy systems are rare within or near urban and suburban areas because of significant alterations to natural processes, such as the water's movement through the landscape (hydrology), nutrient cycling (capture and utilization of soil nutrients), and soil health and organic matter production have resulted in an inability of the land to reset itself (Whisenant 2005).

During the restoration process, it is very likely that the best laid plans will face setbacks and that multiple efforts will be required to achieve success. Ecosystems are dynamic entities consisting of complicated networks of interconnected biotic and abiotic components. By slowing water and keeping it on site, incorporating native plantings in a system-based approach (not relegating plants to flower beds), and allowing tallgrass communities to thrive on parts of their property, conservation staff will make a major difference over time and help mitigate damage from future climatic events. This is not to say that restoration will completely prevent damage, but by embracing these measures, the residents of Houston will be able to enjoy a more diverse, healthy, and functional urban landscape and contribute towards an overall improvement of their urban habitats.

## II. Site Assessment

When evaluating the site to determine the appropriate ecosystem, it is important to look at the historical ecological condition of the greater Houston area as a reference. Understanding the ecological condition at a regional scale informs the restoration target at a project level. The Houston region is one of the most diverse urban areas in the United States. Houston is also one of two cities in the United States to be classified as a “Hotspot” city that evaluates biodiversity and urban growth<sup>4</sup>. According to Houston Wilderness ecological classifications in the Gulf-Houston Region are composed of ten ecoregions. Seven of the ecoregions are land-based and three are water-based (Figure 4). Houston Wilderness defines ecoregions as large areas of land or water that contain geographically distinct assemblages of species, natural communities, and environmental conditions<sup>5</sup>.

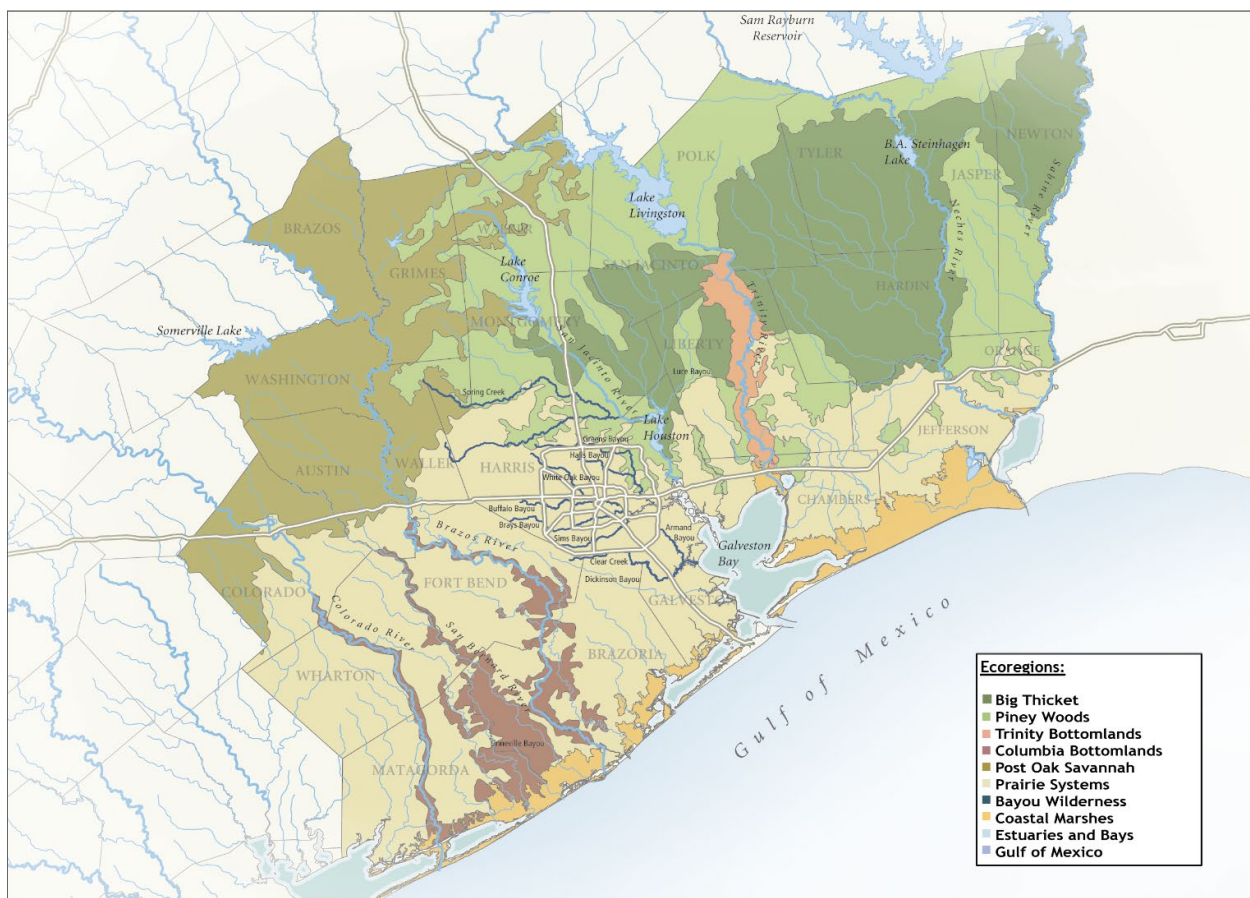


Figure 4. Houston area ecoregion map. Houston Wilderness

Based on the regional information, HPB conservation program is restoring and managing for 5 different habitat types that provide critical ecosystem services. *Ecosystem services are services that nature provides for free that we rely on to live such as cleaning air and water, providing food, regulating temperatures, and improving mental health and wellness.* These habitat types are

<sup>4</sup> <https://hotspotcitiesproject.com/cities/houston>

<sup>5</sup> <https://houstonwilderness.org/about-ecoregions>

prairie, woodland/forest, wetland, riparian, and native landscaping. Prairies were once the dominant ecosystem of the greater Houston region. Woodland and forest to the northeast, northwest, and along lower lying riparian areas is the second most significant ecosystem. Wetlands and riparian habitats (especially along the bayous) are dispersed throughout the landscape and play critical roles in mitigating flooding and water improving quality. Lastly native landscapes are planted areas that are more horticulturally based but use native and adapted plant communities to help provide needed ecosystem services.

Protecting, restoring and building ecological health requires a detailed understanding of the site’s condition, its processes and how it is changing over time. Several types of site assessment are needed for different phases in a project from acquisition through maintenance. Three types of site assessment are needed for basic operations (field check, predesign ecological assessment, maintenance assessments). These assessments inform operational and maintenance decisions and track project status. Additionally, a long-term monitoring program is needed to track how the program is reaching conservation and HPB goals. The long-term monitoring program can also provide practical information to inform future restoration efforts within HPB and efforts of other conservation organizations. Table 1 below summarizes the assessment types.

The field check, pre-design ecological assessment, and maintenance rapid assessment will be discussed in this Site Assessment section. The Monitoring Protocol will be discussed in its own section.

Table 1. Site assessment types

Type	Project Phase	Purpose	Data gathered
Field Check	Pre-acquisition	Gather preliminary data on habitat value to be considered during purchase decisions	Community type, basic structure, dominant species, presence/absence of ecological assets/liabilities
Pre-design ecological assessment	Pre-design	Evaluate current ecological condition and identify opportunities and issues to be considered during design	Ecological context, vegetation community structure and composition, soil condition, hydrologic condition.
Maintenance rapid assessment	Post installation, ongoing	Monitor project condition and identify maintenance needs	Plant health, invasive species presence/expansion, soil condition including erosional features
Monitoring protocol	Initiate prior to installation, repeat	Evaluate contribution to Ecological goals, provide data on restoration evolution	Species use as habitat, soil condition,

	periodically for life of project		community complexity, species diversity, connectivity, heat.
--	----------------------------------	--	--

**A. Field check**

The Field Check occurs during the acquisition process. This is a high-level check intended to be performed during initial consideration of a property, in coordination with Capital’s initial assessment. The goal is to obtain a high-level understanding of the site’s existing condition, possible value, and liabilities from an ecological perspective. In addition to doing desk top analysis of the site with LiDAR data, aerial maps, and other sources to determine the sites natural history, it is important to assess the site on the ground. This is a windshield survey identifying the following parameters:

- Community Structure: Woodland/Forest, Riparian, Prairie, Wetland, Urban condition (% canopy)
- Dominant species in each layer
- Approximate percentage of invasive species, native species
- Presence of rare or valuable species/communities
- Presence of factors that will complicate restoration/management efforts such as severe erosion, substantial presence of invasive species, problematic adjacent properties etc.
- Presence of factors that will assist restoration/management efforts
- Presence/extent/severity of soil erosion

An example data sheet for a rapid assessment and erosion assessment is found in Appendix A: Data Sheets.

**B. Pre-design ecological assessment**

The predesign ecological assessment evaluates the site’s current ecological condition and identifies opportunities for improving ecological health, sensitive features, and liabilities such as damaged soil and invasive species. It is important that this assessment occurs before design to ensure that planned restorations, as well as features such as paths and other amenities, are optimally placed within the landscape.

One of the main reasons for doing a Pre-Design Site Assessment is to assess the ecological condition of the site to determine challenges and opportunities. The diagram below illustrates how ecological function exists on a spectrum (Figure 5). To the left is a fully functional condition and to the right is a nonfunctional system such as a parking lot. Understanding where the project is on this spectrum during all phases of the project’s life is valuable to informing management decisions. The goal is to continually move the project up the spectrum towards the left. However, a variety of scenarios could impact the site’s function such as a delay in construction leaving areas unvegetated, an extreme weather event, or an insect infestation. Being able to assess where the project is on this spectrum pre-design through the life space of the project will help inform necessary steps for improving the site’s ecological function through adaptive management.

## ECOSYSTEM FUNCTION

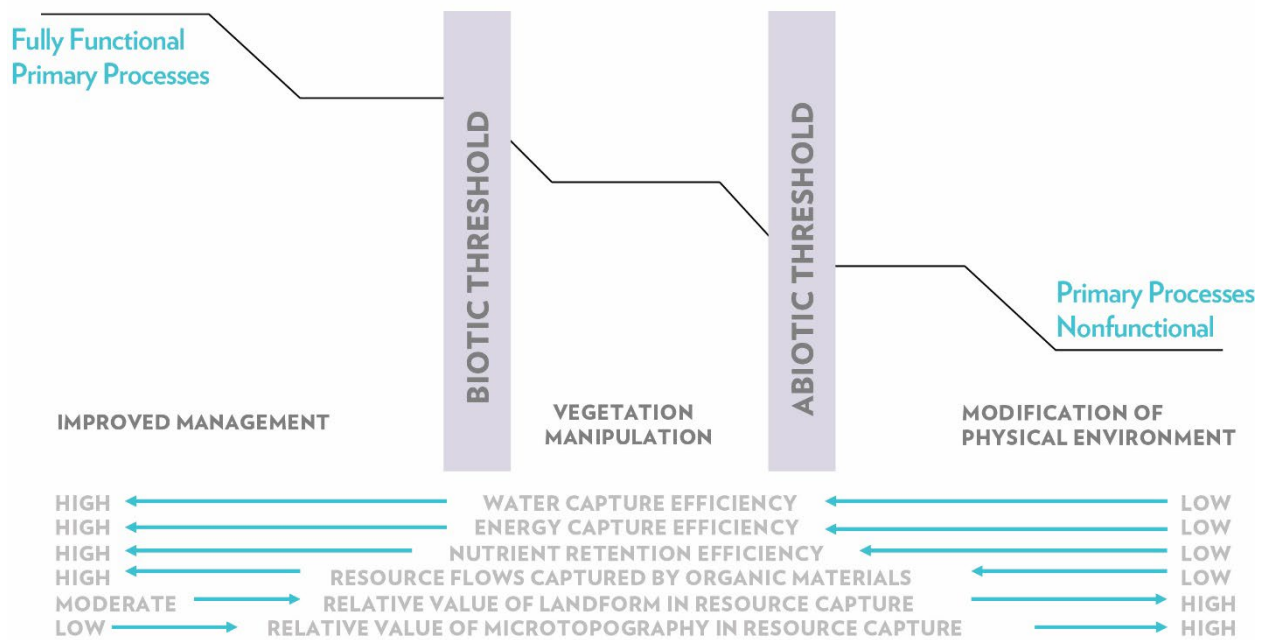


Figure 5. Ecological function. (Whisenant 2002)

Prior to the on-site portion of the assessment, the EPA Level III ecoregion, soils, ecological sites, flood plain, and stream network should be mapped. The Level III ecoregion provides an overview of the types of communities that would naturally occur for the area. Soils can be gathered from the USDA-NRCS soil survey. Soil information within the soil survey contains expected attributes for the soils on-site, which include texture, erodibility, and several classifications. One of the most important classifications from a restoration perspective is the Ecological Site. The ecological site description outlines the vegetative communities the site can support, including the historic or reference community, and provides a discussion of the ecological dynamics that shifts composition between these communities. It is one of the few nationally available resources that discusses ecological dynamics for a particular site. Soil survey information is available online at the Web Soil Survey<sup>6</sup>. More information on referencing the Ecological Site for restoration and long-term management can be found in the **HPB Habitat Maintenance and Management Guidelines** document. Once these elements have been mapped the on-site portion of the site assessment can begin. The on-site assessment can be divided into several parameters: Hydrology, Soils, Vegetation, and Site Context.

### Hydrology

- Map stream, wetland, shoreline, (Desktop exercise/field confirmation)
- Current overland flow direction (Desktop exercise/field confirmation)
- Existing and potential pollution sources & and health hazards, on site and adjacent sites

<sup>6</sup> USDA-NRCS Web Soil Survey. <https://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm>

## Soils

Reference regional soil maps and the USDA-NRCS soil survey and compare to existing conditions. Map healthy soils and disturbed soils to allow development of a soil management plan. An interpretation of soil sample findings is included below in the Installation section.

- Take composite soil samples within each soil type and vegetative community type. Obtain agricultural soil analysis of organic matter, texture, macronutrients, micronutrients. The Texas A&M Agrilife Extension Soil Lab can perform testing. Soil sampling methodology is found in Appendix A: Data sheets and linked here: <http://soiltesting.tamu.edu/files/websoilunified2021.pdf>
- Assess soil compaction through bulk density or soil cone penetrometer measurements. Penetrometer measurements are quick, but results will vary with soil moisture. Bulk density testing provide more robust measurements, but takes a bit more processing.
- Bulk Density sampling methodology found in Appendix A: Data sheets, and is available here: [https://www.nrcs.usda.gov/Internet/FSE\\_DOCUMENTS/nrcs143\\_019165.pdf](https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs143_019165.pdf)
- Penetrometers test the pressure required to penetrate soil, providing quick, in situ information on soil compaction. Penetrometers are particularly useful during and after construction to assess compaction.
- Test soil infiltration. Infiltration testing methodology from NRCS USDA is found in Appendix A; Data sheets and is available here: [https://www.nrcs.usda.gov/Internet/FSE\\_DOCUMENTS/nrcs142p2\\_052494.pdf](https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_052494.pdf)
- Assess % bare ground and compare to acceptable amount for Ecological Site in the Soil Survey
- Erosion: Assess extent, severity, and type. Erosion evaluation datasheet found in Appendix A.

## Vegetation

Map:

- Threatened or endangered species habitat<sup>7</sup>
- Zones of land cover/vegetation types. Note invasive species, native communities, special status plants and relative abundance classification (Abundant, common, frequent, occasional, rare<sup>8</sup>). Take diameter at breast height (DBH) for significant trees.
- Vegetative structure: % cover for overstory, mid-story, understory/herbaceous layer, litter cover, bare soil. Identify dominant species in each layer.
- Natural history and land management changes (historic aerial photos and LiDAR data)

## Site context

Take note of elements surrounding the site that will influence it. For example, a parking lot adjacent to the site that is channeling water into the site, or a dense stand of invasive species. These elements will need to be considered during design and maintenance planning.

---

<sup>7</sup> [https://tpwd.texas.gov/landwater/land/habitats/cross\\_timbers/endangered\\_species/](https://tpwd.texas.gov/landwater/land/habitats/cross_timbers/endangered_species/)

<sup>8</sup> [https://tpwd.texas.gov/huntwild/wild/wildlife\\_diversity/nongame/tcap/sgcn.phtml](https://tpwd.texas.gov/huntwild/wild/wildlife_diversity/nongame/tcap/sgcn.phtml)



The following equipment can facilitate the necessary data collection and determinations:

- Infiltrator or Amoozometer
- Slide-hammer or rings for bulk density
- Soil sampling bags/equipment (permanent marker, plastic bags, shovels)
- GPS
- Camera
- DBF tape
- Meter tape

### **C. Maintenance Rapid Assessment**

The Maintenance Rapid Assessment follows the protocols of the Existing Prairie and Wetland Habitat Assessment Protocol (updated Feb 2020), with the addition of these parameters: Bare patches, failing planted species, erosion, human or maintenance factors impacting the community (social trails, offroading etc).

HPB Maintenance Rapid Assessment is include in Appendix A: Data sheets

### III. Long-term Monitoring

For an ecological monitoring program to be successful over the long term, the benefits of the information must justify the cost. The most value will be provided by a monitoring program that allows HPB to track progress toward organizational goals, allows improvements to restoration and maintenance operations over time, and provides information to the larger conservation community to facilitate efforts across the greater Houston area. The largest single cost is data collection. However, the cost of data management, quality assurance, and analysis are equally important and are often neglected during monitoring program design (Caughlan & Oakley 2001). The ideal monitoring protocol is often cost prohibitive, and the quality and depth of data collected must be balanced with the time and effort required to collect it. In some cases, easily measured parameters can be used as surrogates for more costly parameters.

It is unrealistic to monitor everything of interest, so statistical sampling should be included as part of the design. The HPB properties should be seen as a system, and sampling points should be selected to represent the system, not necessarily individual sites. A stratified sampling design ensuring each habitat type has adequate coverage is recommended. Replication over time is equally important. The correct sampling interval will detect changes over time but avoid oversampling. The appropriate interval depends on the parameter being sampled. Long term changes in vegetation can be detected with yearly, or twice-yearly sampling soil changes occur more slowly and can be sampled every other year. Use of sites by target faunal species will be documented on a schedule timed to the life history of that species, or within an interval that will capture use by multiple species of interest. The framework for data collection is being created and established at this time. The earlier the framework is established the better the data will be overtime. **Gathering baseline data is highly recommended whenever possible to have a comparison and reference point for ecosystem improvement.**

In addition to formal observations and monitoring methods used by staff or partner organizations, less formal methods of citizen science data collection can be used to supplement these data.

- Photo monitoring points in which visitors take photos and link to a database, can provide ongoing monitoring as well as help tell the story of the site. An example of a photo-point protocol can be found in the USGS Tidal Marsh Monitoring Program<sup>9</sup>. Another protocol example is the Photo-Point Standard Operating Procedures developed by USGS<sup>10</sup>. The Conservation Team should look at these examples in addition to other to create a photo monitoring program that suites their specific needs. More detailed information regarding the USGS method is included in the HPB BMP Management and Maintenance document.

---

<sup>9</sup> [http://www.tidalmarshmonitoring.net/pdf/USGS\\_WERC\\_Photo-Point\\_SOP.pdf](http://www.tidalmarshmonitoring.net/pdf/USGS_WERC_Photo-Point_SOP.pdf)

<sup>10</sup> US Geological Survey. 2012.

- Creation of a project within an application like iNaturalist can provide an informal, but quite useful, index of species present. “Friends” groups of trained volunteers can assist in monitoring for invasive species and other maintenance concerns.

Turnover in personnel is a constraint to long-term monitoring that can be mediated by selection of techniques that are less sensitive to differences in observers, and that are easily communicated to new staff/volunteers. Training observers is an important mechanism to reduce variability in observation.

Two critical components of a monitoring program are scientific oversight by a qualified person, ideally attached to the program for the long-term, and quality assessment (QA). For an ecological monitoring program QA means that the data are of known quality and meet the program's needs. Quality controls (QCs) are an important part of QA and should be designed along with the monitoring protocol. This is especially true for HPB because multiple researchers, methodologies, and data types will be used. Using a QA plan can increase the cost effectiveness of the monitoring program.

Reporting of monitoring data is especially important. The audience for the HPB monitoring data is varied, including field staff making management decisions, managers reviewing budgets and making investment decisions, conservation organizations such as The Nature Conservancy looking to improve their own programs, as well as the general public. A basic reporting plan and budget should be developed during the creation of the monitoring program.

Possible models exist. One such model is the Waller Creek Biodiversity & Ecosystem Monitoring Project conducted by The Nature Conservancy (Belaire et al. 2018). This study demonstrates a straightforward way to monitor biodiversity and ecosystem services across a large area. The methods used could be modified to fit the needs of HPB.

#### **A. Monitoring parameters**

It is of utmost importance that each of the monitoring protocols outlined below support the Conservation Program’s vision as well as HPB’s conservation messaging and outreach. Also of significance, is that the monitoring below aligns with the work and messaging of HPB’s partners. Partners can also benefit from HPB’s monitoring data as well as contribute to HPB’s data collection. Ultimately, the monitoring must feed into habitat conservation practices and inform adaptive management decisions. The main performance criteria the Conservation Team would like to monitor have been identified over a series of meetings with Blackland Collaborative. These are:

- Stormwater capture
- Biodiversity
- Habitat Connectivity
- Habitat Quality
- Heat Island Mitigation

Below the areas of research are described for their purpose, a proposed method for measurement, as well as potential issues. The Conservation Team will then take these frameworks and further develop the methods into a research framework that works best for the needs of the Conservation Team. The Conservation Team should consider the time of the year, data collection frequency, and general achievability based on staff availability in addition to getting the needed data to be able to make valuable conclusions regarding their management strategies.

## **Stormwater capture**

### Summary and purpose

The stormwater capture metric is about monitoring the site's capacity to slow down, hold, and infiltrate water. Since the majority of the Bayou Greenway locations are adjacent to bayou systems, having a performance goal focused on water movement and quality is a benefit to improving bayou ecosystem function. Furthermore, locating and designing all HPB's restoration projects with a watershed approach that aims to slow and capture stormwater as much as possible could have a positive impact on the Houston region that has high rainfall, is prone to flooding, and continues to increase impervious cover. One of City of Houston's Resilient Houston goals is to complete 100 new green stormwater infrastructure projects by 2025, HPB projects are being recorded to help meet this goal. To be able to contribute performance data to the City of Houston, will help further inform future planning and initiatives to better improve ecosystem function in urban environments.

Measuring water quality most likely means following the City of Houston Code of Ordinances chapters 9 and 13<sup>11</sup> as well as Harris County's Low Impact Development and Green Infrastructure Design Criteria for Stormwater Management.

### How we measure

Estimate the combined capacity of restored communities, green infrastructure practices such as rain gardens and infiltration basins, and traditional parkland. Tools are available such as the National Stormwater Calculator and the calculations available within the Sustainable Sites Initiative<sup>12</sup> to assist with this effort. Reasonable estimations of capture capacity for each habitat type will need to be assembled from existing literature or new experimental results<sup>13</sup>.

### Potential issues with this metric

These calculations are normally done by an engineer and sometimes with special software.

## **Biodiversity**

### Summary and purpose

---

<sup>11</sup> <https://www.houstontx.gov/codes/>

<sup>12</sup> <https://sustainablesites.org/resources>

<sup>13</sup> <https://www.epa.gov/water-research/national-stormwater-calculator>

In general, a more diverse ecosystem is a healthier ecosystem. Species diversity means more robust ecosystem services are provided and offered, and there is more resilience in the face of disaster.

The purpose of measuring biodiversity is to evaluate and hopefully show that HPB restoration projects are increasing wildlife and vegetation biodiversity, therefore creating a healthier urban habitat.

Formally sampling vegetation over time (to represent flora) and pollinators (to represent fauna) should be the priority. Organized bird observations with volunteers and other groups such as Houston Audubon and Master Naturalist to tally species are also high priority though data collection will not be as formalized.

Other wildlife monitoring would be supplemental to vegetation, pollinators, and birds. Though important, it seems challenging to collect this data without partnerships or more staff. Wildlife cameras wherever possible would be extremely beneficial.

#### How we measure

*HPB conservation team is developing methods for assessing flora and fauna biodiversity and those methods should be referenced once fully developed. Below is a working methodology.*

- Vegetation- a suggested framework has been proposed
  - Use the 9 bayous and their watersheds to organize the data collection.
  - A bayou as a sample area. If a project is not right on the bayou it can be included in the sample area of the closest bayou.
  - 3 bayous per year on a 3-year rotation to capture all the bayous and associated greenspaces.
  - 6 points per habitat type (4) = 24 points per bayou= 108 collection points per year.
  - Data collection can be done at organized times throughout the year- i.e. fall and spring and with interns/volunteers.
  - If a site is big enough and distinct from the bayou system, use the same structure as above- The site itself becomes a sample area and then sampled by habitat type (six samples of 4 habitat types) within that area- i.e. Coolgreen.
  - As much as possible wildlife, vegetation, and pollinators data collection should be in the same area.
  - Establishing a control would be beneficial to the analysis of the data and for telling the performance story. An example control site could be sampling turf areas to compare performance.
  - Before beginning, reference maps and assign habitat types on them then establish sampling locations that you return to on a yearly basis.
  - Once the sample locations are established, put something physical in the ground to mark them such as orange forestry stake or metal marker such as rebar in addition to GPS points. It is recommended to locate the center of the sampling point in the middle of the habitat type- not randomly located.

- Assign a central point and follow the radial methods defined in Houston Arboretum vegetation methods (Appendix B) which is based on the US Forestry methods. To get more data for the herbaceous layer, it is recommended to add more quadrats, specifically either define 4 other quads based on that central point or do a random scatter of quads around the point each time.
- Birds and pollinators
  - Pollinator and wildlife data should be collected in the same locations if possible.
  - A pollinator method could be layered on the radial/quadrat method. Blackland can assist with developing a method.
  - Another option is following a pollinator-transect example titled Streamlined Bee Monitoring Protocol for Assessing Pollinator Habitat provided in (Appendix B). Other organizations in Houston are following this method. It is easy and fast. Since the method was established not in Texas, it is recommended to go out earlier in the day than what is specified.

#### Potential Issues with this Metric

Data on flora and fauna changes over time is useful information for storytelling and reaching out to the public about restoration improvements. The data collection can take time and needs to be replicated consistently.

### **Habitat Connectivity**

#### Summary and Purpose

Connectivity can be defined as the capacity of the landscape to facilitate movement of species, resources, seed etc. between larger habitat patches. Connectivity supports migration and allows some species to effectively increase their habitat area. To continue the example from above, most wild bees need a patch size of 48 to 198 acres to fully support a population. However, much smaller patches are valuable as long as they are close enough that the bees can move between them, stepping-stone style. This metric is focused more on connectivity within the different projects rather than project wide.

The purpose of habitat connectivity metric is to increase connectivity within each HPB conservation project so that the layout, design, and maintenance considers wildlife movement through the different ecosystems.

#### How we Measure

- Pollinators - A body of research exists outlining the distances and floristic richness needed between patches of habitat to elevate the value of an area for pollinators. Key species can be selected, and connectivity evaluated based on the requirements of those species.
- Other species such as bats, reptiles, and select bird species can be included over time if there is capacity

#### Potential Issues with this Metric

Selecting the appropriate scale can be challenging. This metric would most likely be program-wide, and a summary would be done every few years. Partnering with professors would be the ideal way to do this.

## **Habitat Quality**

### Summary and Purpose

Habitat Quality is an important part of assessing ecological function.

Creating a Habitat quality index for the greater Houston region as mentioned in HPB high level metrics, is a need for multiple professionals to evaluate habitat function. Gathering habitat quality data at the project level could help contribute to this data need. Collaboration with other like-minded organizations and stakeholders is recommended to coordinate the collection of highest priority data, and organization and distribution of the data. The Nature Conservancy Biodiversity and Ecosystem Monitoring program conducted in Austin (Belaire et al. 2017, provided in Appendix B: Resources) provides a possible model.

### How we measure

- Species diversity
- Community diversity
- % native
- Structural diversity, when appropriate
- Utilization by target species
- Soil quality

### Potential issues with this metric

Habitat quality is defined by species and settling on an overall metric is challenging.

## **Heat Island Mitigation**

### Summary and Purpose

Greenspaces help mitigate heat island effect by transpiration and reflecting more solar radiation than human made surfaces such as buildings and roads. Urban environments typically are warmer than surrounding rural areas. The number one weather related deaths are caused by heat.<sup>14</sup> Houston's temperatures on a whole are getting hotter and hotter as seen in the Houston Climate Impact assessment.<sup>15</sup>

### How we measure

- Temperature measurements adjacent to and within project boundaries
- Can follow Houston-Harris Heat Team's mapping process [Houston Heat Mapping | The Nature Conservancy](#)<sup>16</sup>

### Potential issues with this metric

Finding the time to organize staff and volunteers to get enough data points.

---

<sup>14</sup> <https://weather.com/safety/heat/news/2021-06-03-heat-america-fatalities>

<sup>15</sup> <https://www.houstontx.gov/mayor/Climate-Impact-Assessment-2020-August.pdf>

<sup>16</sup> <https://www.nature.org/en-us/newsroom/houston-heat-mapping/>

## IV. Design

Several elements during overall park design should be considered to increase the success of included conservation projects.

### A. Placement and selection of elements

The results of the ecological site assessment should be used to help place both conservation projects as well as other elements such as trails. Focus elements such as trails, ballfields and parking lots in areas identified as damaged, or in low ecological health, during the ecological site assessment. Restoration will be prioritized in more healthy areas, in areas in which the soils or existing vegetation would best support the planned restoration, and in areas damaged by construction. All elements should be coordinated to ensure optimum ecosystem services. For example, prairie restorations can be placed to help capture and clean water flowing from parking lots. Wetlands can be placed to help with flood mitigation and to reduce storm pulses to the bayou. Green infrastructure, native landscaping, and restoration areas can be placed in such a way that they create a series of refugia for pollinators making their way through the park, and all elements can be organized into a cohesive system for capturing and cleaning water.

### B. Design for maintenance

Maintenance capacity and logistics should be a design parameter. Elements like pathways can be used to simplify maintenance and delineation of different types of areas.

### C. Community assembly for restoration areas

Develop unified soil/plant communities that reflect historic or appropriate reference communities of the site, the site's current condition and its intended purpose. Community assembly conditions change depending on the stage and condition of the project.

- Early condition/very disturbed sites will require a larger complement of early successional and generalist species. This is true for tree plantings and for seed mixes that are spread underneath. However, even at the start of the project, late successional trees and grasses should be encouraged. Late successional grasses can be included in seed mixes, but live planting them is often worth the expense. **The mycorrhizal fungi they bring with their roots can help the soil progress more quickly toward a mature state.** The strategy of having fast establishing species in addition to slower maturing climax species provides more diversity as well as less void space for invasive species to establish.
- Consider multiple plant introductions over time as the soil matures. Later successional and diversity species can often be supported once the soil and plant community has matured for a few years but will not thrive under earlier conditions. Additionally, small sites will continue to lose species and individuals over time that will need to be replaced. Most urban sites are not large enough to be completely self-sufficient.

### D. Soil Protection

Vegetation and soil protection zones (VSPZs) should be delineated early in the design, based on the results of the ecological site assessment and the design requirements of the site. These zones should be protected in the final design as well as during the installation process.



Results of soil testing, observations of existing plant communities, and desired final condition should determine the final soil design for the restoration. It is generally preferential to repair existing soils rather than replacing them. However, if soils must be replaced, they should be closely matched to the native soils linked to the restoration vegetative community. This requires working with soil suppliers well in advance, because native prairie soils differ from standard mixes available from vendors. Similarly, compost should be sourced very early in the design/installation process because quality static-piled compost is difficult to find.

## V. Installation & Maintenance

### A. Soil Sampling

Before starting any work, it will be imperative to understand the basic conditions of the soils to see if they align with soil survey data or have been altered significantly as drastic changes might necessitate a plant mix that is not representative of the historical climax plant community.

Houston Parks Board will submit soil samples for each restoration site to the Texas A&M Agrilife Extension office. Samples should follow these steps as laid out by Texas A&M's T.L. Provin and J.L. Pratt in their document, [Testing Your Soil: How to Collect and Send Samples](#). The conservation department will utilize the *Urban Homeowner Soil Sample Information Form SU<sub>12</sub>* (this form also has sampling guidelines at the end of the document for guidance). Sample information is as follows:

- Sample ID (name of specific restoration site)
- Square footage
- Last time fertilized (not applicable)
- Previously used fertilizers/organics (not applicable)
- I am growing -> Enter J. Buffalograss (or other native species if this category changes)
- Choose test 12 – Routine (R) + Micro + B + Org. Matter + Detailed Sal. + Texture



would call “nutrient poor” conditions. If you treat restorations as crops and apply large, or even recommended, nutrients as per your soil sample recommendations, you will only succeed in encouraging a bumper weed/invasive crop. If you choose a non-native crop the recommended fertilization regime will be even higher and take you down the wrong path.

The main objective of carrying out these soil tests is to:

- Understand if soil web results align with actual soil conditions
- Understand current textural condition
- Understand if any macro (Nitrogen-N, Phosphorus-P, Potassium-K) levels are at 0
- Understand current organic matter (OM) level

Understanding these four factors will allow conservation staff to 1) design appropriate plant communities, 2) recognize if any specific macronutrients need to be added to adjust for complete absence, and 3) anticipate how much organic matter might need to be brought in for amendment to help improve soil condition and provide food source and environment for establishing/increasing soil food web.



## Soil Analysis Report

Soil, Water and Forage Testing Laboratory  
 Department of Soil and Crop Sciences  
 2478 TAMU  
 College Station, TX 77843-2478  
 979-845-4816 (phone)  
 979-845-5958 (FAX)  
 Visit our website: <http://soiltesting.tamu.edu>

Report generated for:

Sample received on: 1/4/2021  
 Printed on: 1/14/2021  
 Area Represented: 17800 acres  
 SWFTL recommends <40 acres/sample

Travis County  
 Laboratory Number:  
 Customer Sample ID: Middle West

Crop Grown: MINIMUM REQUIREMENT: WARM SEASON PERENNIAL GRASS

Analysis	Results	CL*	Units	ExLow	VLow	Low	Mod	High	VHigh	Excess.	
pH	7.5	(5.8)	-	Slightly Alkaline							
Conductivity	144	(-)	umho/cm	None							Fertilizer Recommended
Nitrate-N	14	(-)	ppm**								10 lbs N/acre
Phosphorus	17	(50)	ppm								35 lbs P2O5/acre
Potassium	100	(130)	ppm								5 lbs K2O/acre
Calcium	17,603	(180)	ppm								0 lbs Ca/acre
Magnesium	148	(50)	ppm								0 lbs Mg/acre
Sulfur	18	(13)	ppm								0 lbs S/acre
Sodium	8	(-)	ppm								
Iron	4.51	(4.25)	ppm								
Zinc	3.71	(0.27)	ppm								0 lbs Zn/acre
Manganese	8.63	(1.00)	ppm								0 lbs Mn/acre
Copper	0.19	(0.16)	ppm								0 lbs Cu/acre
Boron	0.43	(0.60)	ppm								0.5 lbs B/acre
Limestone Requirement											0.00 tons 100ECCE/acre
Limestone Requirement (Chemical Test)											0.0 tons 100ECCE/acre
Detailed Salinity Test (Saturated Paste Extract)											
pH	7.5										
Conductivity	0.53 mmhos/cm										
Sodium	18 ppm	0.786 meq/L									
Potassium	16 ppm	0.410 meq/L									
Calcium	124 ppm	6.200 meq/L									
Magnesium	8 ppm	0.636 meq/L									
SAR	0.43										
SSP	9.78										
Organic Matter	2.43	%									

\*CL=Critical level is the point which no additional nutrient (excluding nitrate-N, sodium and conductivity) is recommended. \*\*ppm=mg/kg

**pH** - Important to know what plant community you need to aim for. Houston will have acidic and alkaline communities.

**N/P/K (Macros)** - vital for plant growth. If applying fertilizer make sure you can reference "available" N,P,K as they are immediately available to plants. Regarding soil report, you are mainly determining if there is no available macro. Native plants **DO NOT NEED** excessive nutrients. Many evolved on soils that agronomists would consider nutrient poor soils. Adding excessive nutrients will result in invasive plant explosion.

**CL** - "Critical Level" is the amount that agronomists aim for, but is not as important for native plants. Again, you can add organic fertilizer if chlorosis becomes an issue, but the soil report should verify that there is no lack of any macro.

**Fertilizer Recommended** - these recommendations are from a crop perspective. No need to follow the recommendation. HPB staff just need to understand if there is a complete lack of a major nutrient.

**Conductivity** - Indicates the amount of salts present in the soil. (K,Ca, Mg, Na, CL, HCO<sub>3</sub>). Excessive salts will hinder or prevent plant growth and can affect infiltration. 1 mmhos/cm = 1 dS/m. Adverse impacts will start at .75 dS/m.

**Organic Matter** - prairie soil organic matter varied upon the specific soil type, but acceptable percentage range is 2-5% with 2-3% being common. Even if OM falls within acceptable ranges, compost should be added as a soil amendment to help address soil structure and inoculate with beneficial microorganisms.

Figure 7. Soil sample results and interpretation

## **B. Site Preparation**

Ecological restoration is a trajectory, not an intervention. The amount of time you place on site preparation will determine your rate of success. While it is true that conservation staff could take a minimalist approach in site prep and save money up front, it is very likely that species diversity and richness will never be achieved, and a massive amount of sweat equity will be involved trying to “right the ship” by dueling with invasive species within the interior space of the restoration plots over the life of the plot. It cannot be overstated how much work will be saved if the Houston Parks Board understands that each step of the process of identifying acquisitions, prepping chosen sites once acquired, and installing during the optimal installation windows must be given adequate time to ensure success. Trying to flip a portion of land in a limited amount of time will yield poor results.

The first part of this BMP reviews all the steps recommended for site selection and assessment. This portion will focus on ensuring a solid foundation, installing sites correctly, and establishing these plots:

- Invasive removal
- Soil preparation
- Compaction rates
- Soil Amendments
- Seeding
- Live planting
- Establishment
- Post installation monitoring first year

## **C. Vegetation and Soil Protection**

A vegetation and soil management plan is needed at this phase. The plan should identify areas of healthy vegetation and soils to protect with vegetation and soil protection zones (VSPZ). Healthy soils are identified through a combination of vegetation community assessment, agricultural soil testing, and comparison to reference soils either in the soil survey or from identified reference sites nearby. These areas should be clearly marked for contractors and communicated through maps and in the field to reduce damage and compaction. In addition, laydown areas and construction access and circulation should be identified. Limits of construction should be well defined to reduce site disturbance as much as possible. Though the site is a greenspace and seems like it has ample space for moving around it should be treated as an urban downtown project with tight constraints. Protecting healthy areas will reduce work in the future and increase project success.

## **D. Site Hygiene**

Once site activity begins, the site should be considered a construction zone and maintenance begins. Site hygiene should be a high priority as much as possible for HPB and its contractors. Maintaining site hygiene practices, means protecting the site from invasive species

encroachment or preventing damage such as soil loss or compaction. Site hygiene practices include:

- Washing equipment
- Properly stockpiling soils
- Managing invasive species during construction
- Stormwater protection measures such as silt fences and erosion control mats

Timing between site preparation and installation is critical to sequencing in the most effective and efficient manner. Communication between all involved parties should occur regularly so that the project is well coordinated, and adjustments do not significantly alter the forward process.

## **E. Invasive removal**

It is highly likely that most urban sites will be dominated by undesirable invasive vegetation. Each site should be evaluated during the site assessment to determine appropriate restoration activities. While the focus of long-term pest management should focus on least toxic means, often the best option when starting on invasive dominated sites is to completely start over with the goal of eliminating all vegetative growth. Site preparation should include herbicides, tillage, adequate depth mulching, and, depending upon timeline/approval, prescribed fire. Sites with pre-existing stands of competitive or dominant invasive plants such as Chinese Privet *Ligustrum sinense*, Japanese privet *Ligustrum japonicum*, Chinese Tallow Tree *Triadica sebifera*, Golden rain tree *Koelreuteria paniculata*, or many others, will require multiple treatments with herbicide to knock back vigorous stands. Houston Parks Board staff should **wear personal protective equipment and follow manufacturer's directions as posted on labels and materials safety and data sheet sets**. It is recommended that the Conservation Team develop an Integrated Pest Management Plan (IPM) that is specific to HPB projects, defines priorities, and outlines procedures for each invasive species. This will provide application uniformity and provide more safety for the staff. More on this is mentioned below.

### Woody invasive removal

For woodland planting locations that will also be seeded with an understory savanna seed mix, it is recommended to “start over” as described below however majority of woodland locations will focus primarily on removing woody invasive species or preparing the tree plantings in locations with turf grass and not a larger scale preparation. Woody invasive trees and shrubs should be cut and then spot treated immediately if possible. If not, it should be as soon after cutting as possible. Herbicide should be applied at least two-three times. Sequencing of cutting and herbicide applications should be considered. Due to multiple projects, planning for the clearing process is recommended to help ensure that the team has the capacity to return to the invasive species and not let the invasives overtake the site again. Also considering the time of the year for the herbicide to be most effective and so that the site preparation works well with the optimal planting window.

### Invasive grass removal

Multiple treatments of herbicide help deplete carbohydrate reserves in rhizomes and minimize regrowth potential in these invasives. However, these species have likely been present for years

and have established seedbanks that can remain viable in the soil for over a decade. Another complicating factor is there will be a mix of warm and cool season invasive species, so if sites are not prepared over a minimum of a year, Houston Parks Board conservation staff might only knock back one type of invasive growth and not address the other. For example, multiple treatments of Bermudagrass over a growing season could result in the elimination of this explosive invasive, but over the winter and into early spring, perennial/annual rye grass, brome, or bastard cabbage could thrive and outcompete forbs during the early spring and even persist into late spring and reduce native grass cover. **Therefore, if possible, initial herbicide treatments to “start over” should be paired with tillage to a depth no deeper than 5”, that is then followed by the application of no less than 5” of mulch over the entire site that is left for a minimum of one year.** This will help repress growth and then allow conservation staff to focus on spot treatments instead of repeated sitewide herbicide applications. There are several conservation organizations that advocate for two years of treatment before planning. Application timing is crucial. All efforts should be made to eliminate invasive species before they flower. Conservation staff must realize that the invasive seed bank will never be completely exhausted. Subsequent seeding post site preparation will bring up invasive seed from lower soil horizons no matter how clean the field may seem after site has been treated, even after multiple attempts.

Invasive presence does not prevent native growth through vegetative competition alone. Many of the common invasive species hijack the soil and alter the biogeochemical conditions preventing certain native species from establishing. While allelopathy is a well-known mechanism by which invasive species control or eliminate competition from other plants<sup>17</sup>, increasing data demonstrates that they also cultivate specific microbes through root exudates<sup>18</sup> and prevent development of the soil food web, excluding important drivers of later successional growth such as mycorrhizae.

---

<sup>17</sup> “Leachates from johnsongrass inhibited vegetative and sexual growth of the dominant Texas prairie grass in the United States.” (Rout et al., 2013a)

<sup>18</sup> “Endophytic bacteria were transmitted horizontally along [johnsongrass] rhizomes and vertically into seeds. When bacteria were suppressed with tetracycline, plant growth slowed, supporting the importance of these bacteria to plant growth.” (Rout et al., 2013b).



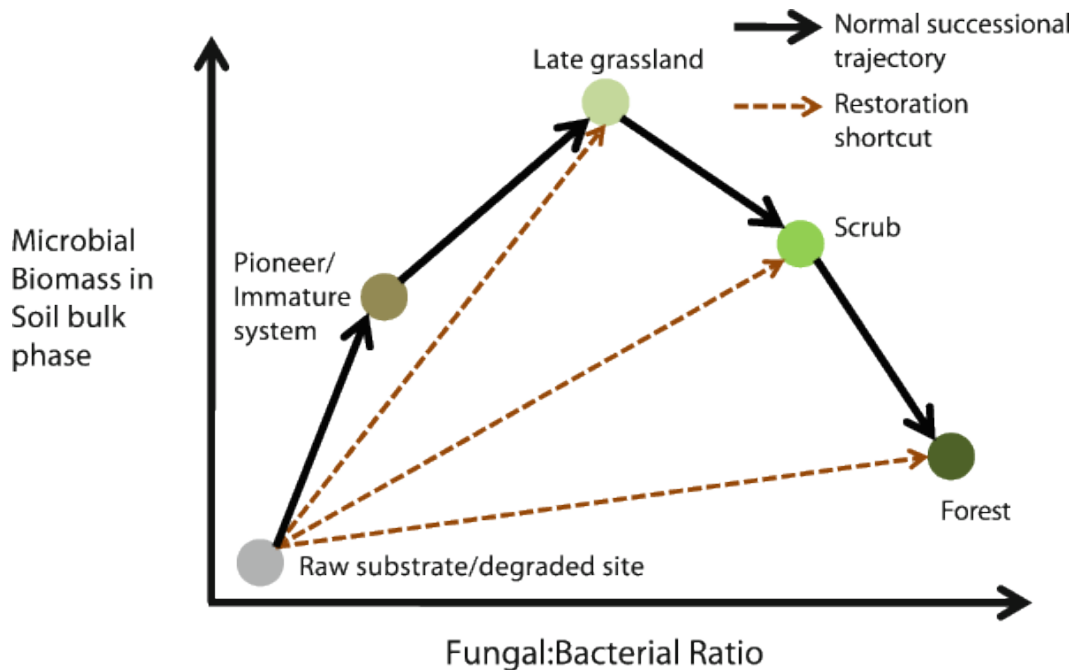


Figure 8. Facilitators or Followers graph.

Relationship between ecosystem successional state and microbial community size and composition. Copyright: JA Harris. From (Harris 2009)

It is recommended that the conservation team should develop an Integrated Pest Management (IPM) plan specifically for the Conservation Program's invasive species needs. Best Management Practices for control of problematic vegetation are based on IPM principles that will maintain the desired site conditions using a combination of available methods (cultural, manual, mechanical, chemical), while minimizing risk to people, property, and the environment. Employing the least toxic, yet effective, treatment is desired. Managers use current information on pest life cycles and control methods to select the least toxic control method that is effective and economical. IPM principles identify current infestations, set action thresholds for treatment, and prescribe control and prevention methods.

All pesticide applicators must follow all label requirements and read the material safety data sheets (MSDS), including dilution, application and disposal of containers. Equipment must be maintained to ensure cost effectiveness and safety. Do not apply herbicide when rain is expected within 48 hours. Use directed or individual plant treatment, rather than broadcast, application methods.

Table 2. Common invasive species and treatment. Be sure to read labels and follow HPB established IPM guidelines.

Target Species	Herbicides, Rates, and Notes
Broad spectrum complete site clearing - Both forbs and grasses	48% glyphosate – 3.0-3.3 quarts per acre of chemical mixed with water carrier. Comes in 2.5 gallon jugs, 2 jugs per box = gallons 1 box sprayed at 3 quarts per acre treats 6.67 acres Plan no less than 4 applications for the summer. One early and then one at least 4 weeks before first frost date. Will not control weeds such as crabgrass. Not recommended for aquatic areas.
Bermudagrass ( <i>Cynodon dactylon</i> ) - Similar to site clearing due to invasive potential	<p>HPB method- 9 out of 10 problematic. Use both mowing and herbicide. Mow in the winter and spray in the spring/summer.            Use 2oz/gal of Glyphosate (Ranger Pro) and 1oz/gal Triclopyr (Triclopyr 3).            Application method is Foliar spray</p> <p>Other recommendations: 48% glyphosate - 1.5-2 quarts per acre (heavier rates for heavier infestation and more mature plants) 1, 5 gallon box will treat 10 acres if sprayed at 2 quart per acre rate Plan multiple applications for the growing season (no less than 4-5). Spray no later than 4 weeks before first frost date or when night time temperatures routinely drop below 50 degrees Plan at least 2 applications for the summer. One early and then one at least 4 weeks before first frost date. Follow up in early spring with application of Fluazifop-P-butyl (Fusilade II) and non ionic surfactant at rate recommended by manufacturer and within temperature range approved by manufacturer. Fusilade II will kill grasses without affecting forbs. Once spring seeding occurs, Fusilade II will not be an option due to inclusion of native grasses in mix. If Bermudagrass is still present before seeding, team may need to discuss omitting grasses in this mix to continue Fusilade II treatments to eliminate Bermudagrass. Glyphosate will not control weeds such as crabgrass. Not recommended for aquatic areas.</p>

<p>Bahia grass (<i>Paspalum notatum</i>)</p>	<p>HPB method- 7 out of 10 problematic. Uses mowing and herbicide as a control method. Mow in the winter and spray in spring/summer          Use 2oz/gal of Glyphosate (Ranger Pro) and 1oz/gal of Triclopyr (Triclopyr 3)          Application method is Foliar spray</p> <p>Other recommendations: 60% metsulfuron methyl (Escort XP) 0.4 ounces mixed with water carrier. Comes in 8 or 16 oz container. 8 oz container treats 20 acres, 16 oz container treats 40 acres. Best applied when bahia grass seed heads begin to rise but before the Y-shaped seed head emerges and matures. Soil active for up to 4 months after application</p>
<p>Johnsongrass (<i>Sorghum halepense</i>)</p>	<p>HPB method: 10 out of 10 problematic. Uses both mowing and herbicide for control. Mow in winter and spray in the spring/summer          Use 2oz/gal of Glyphosate (Ranger Pro) and 1oz/gal of Triclopyr (Triclopyr 3)          Application method is Foliar spray</p> <p>Other recommendations: 0.75 to 2 ounces/acre of sulfosulfuron (Outrider 75DF) for Johnsongrass control. Herbicides should be applied with a nonionic surfactant at 0.25% volume/volume. Applications three weeks after a mowing or prior to plants reaching the seedhead stage can be critical to optimize efficacy for control. Herbicide will take two to three weeks after treatments to provide this chemical sufficient time for movement in the Johnsongrass, thus maximizing control. Fall applications of herbicides are generally more effective than spring treatments for long-term Johnsongrass control. Johnsongrass begins allocating carbohydrates from leaves to rhizomes in fall, which enhances the movement of herbicides in this source-to-sink pattern. Conversely, spring treatments of postemergence herbicides can provide temporary control of Johnsongrass leaves, but rapid regrowth from rhizomes often occurs. While spring treatments can help release desirable species from competition, restricted herbicide translocation to rhizomes may result in erratic control as Johnsongrass allocates energy to shoot growth. For long-term</p>

	<p>Johnsongrass control, glyphosate (Roundup, others) is another systemic herbicide that works more effectively when applied in the fall compared to spring treatments. Glyphosate is nonselective and should be limited to spot treatments at rates required to control Johnsongrass.* *University of Georgia Extension, Bulletin 1513</p>
<p>Old World Bluestems - Similar to site clearing due to invasive potential</p>	<p>HPB method: 10 out of 10 problematic. Uses both mowing and herbicide for control. Mow in winter and spray in the spring/summer Use 2oz/gal of Glyphosate (Ranger Pro) and 1oz/gal of Triclopyr (Triclopyr 3) Application method is Foliar spray</p> <p>Other recommendations: 48% glyphosate – 3.0 - 3.3 quarts per acre Plan multiple applications, 1 application by itself will actually encourage greater seed production of surviving plants. You MUST conduct a minimum of 4 sprayings in a single growing season if hoping to reduce its abundance over the longer term. It will still be there when done, but you can increase diversity and reduce its abundance drastically. 2 growing seasons of control is desired, but often not practical. It is also very expensive.</p>
<p>Brome (<i>Bromus spp.</i>)</p>	<p>23.6% Ammonium Salt of Imazapic (Plateau) - 4 to 8 oz per acre. Pre-emergent weed control in cropconverted stands. Post-emergent weed control of brome species, Johnsongrass, crabgrass, cocklebur in established stands. Label will indicate tolerant NWSG &amp; forbs. Mix with Methylated Seed Oil if forbs not in seed mix. Use silicone-based surfactant if forbs present in seed mix.</p>

Perennial Rye ( <i>Lolium perenne</i> )	23.6% Ammonium Salt of Imazapic (Plateau) - 2 to 3 oz per acre. Post emergence control for perennial ryegrass. In some areas of the US ryegrasses have developed a resistance to glyphosate and other classes of herbicides. This species can be difficult to eliminate and had demonstrated allelopathic abilities. Native forb seed germination has been reduced by up to 1/3 in some studies, it is not clear if this is due to allelopathy or vegetative competition.
Broadleaf invasive/weeds within native grass matrix	1.5% triclopyr (Remedy Ultra) - 1.5 pints per acre with the addition of 0.5% aminopyralid (Milestone) 3 -7 ounces per acre. This mix will knock back most broadleaf invasive species and younger woody material. It is not recommended to try and hand pull species such as dewberry ( <i>Rubus trivialis</i> ) due to the persistent rhizomatous root growth habit.
Grassland near riparian and wetland habitat (broad spectrum control)	1.5% Isopropylamine salt of Imazapyr (Habitat) - 1.9 oz to 6 pints mixed with appropriate corresponding gallons of water and non ionic surfactant. Habitat has very specific conditions where it can be applied in regards to irrigation canals/ditches, quiescent or slow moving waters, or moving water in close proximity to active irrigation water intake.

Other species HPB is treating are listed below with treatments:

Target Species	Herbicides, Rates, and Notes
<b>McCartney Rose</b> <i>(Rosa bracteata)</i> 4 out of 10	Preferred control method is herbicide applied in the spring/summer. Use 2oz/gal Glyphosate (Ranger Pro) and 1 oz/gal Triclopyr (Triclopyr 3). Foliar spray is preferred but it varies from location to location

<p><b>Chinese Privet</b>  <i>(Ligustrum sinense)</i>  5 out of 10</p>	<p>Preferred control method is mechanical removal and herbicide in the spring/summer.  2, 4-D Amine, Triclopyr 4, and MSO* recipe came from TPWD and mixed in large batches.  Cutting the stump is the application method.</p>
<p><b>Yaupon</b>  <i>(Ilex vomitoria)</i>  4 out of 10</p>	<p>Preferred control method is mechanical removal and herbicide applied in the spring/summer.  2, 4-D Amine, Triclopyr 4, and MSO* recipe came from TPWD and mixed in large batches.  Cutting the stump is the application method.</p>

<p><b>Chinese Tallow</b> <i>(Triadica sebifera)</i> 6 out of 10</p>	<p>Preferred control method is mechanical removal and herbicide applied in the summer. 2, 4-D Amine, Triclopyr 4, and MSO* recipe came from TPWD and mixed in large batches. Cutting the stump is the application method.</p>
---	---

## F. Soil preparation

For woodland restoration, soil preparation will primarily focus on areas where individual trees will be planted rather than swaths or larger landscape patches. Tree planting and the associated soil amendments will be addressed below in Section I. If seeding or understory planting is going to be done in addition to tree planting, then it is recommended to prepare as much of the restoration area as possible and then additionally prepare tree holes for planting.

After herbicide treatments, mulching, and follow up spot treatments, the site's soil will be ready to be worked in preparation to receive seed and live planting. Sites that have been treated and mulched will be devoid of vegetation, but the soil will need to be made loose and friable to ensure good seed/soil contact and to eliminate compaction that exceeds ranges that allow root penetration into lower soil horizons. This is especially important to ensure plant resilience to drought conditions, allow infiltration of stormwater down into the soil horizon rather than promoting surface sheet flow off the site, and replicating hydrographic conditions that would have existed prior to impacts from site development or overuse.

Conservation staff will need to use a cone scale penetrometer (Figure 9) to gauge the level of compaction to assess how much manipulation will be required to address compaction conditions. A general guide to acceptable compaction ranges for multiple soil types comes from James Urban's *Up By Roots: Healthy Soils and Trees in the Built Environment*. Soil scientists and ecologists tend to describe soil compaction by using bulk density, while engineers utilize Standard Proctor Density. There was no good translation correlating these two metrics until Urban's text. His table below shows that regardless of soil type (albeit with some variation) **Standard Proctor Density should not exceed 80 – 85%** to ensure deep root penetration (Figure 10). This language will allow conservation staff to communicate with HPB Capital projects on desired finished compaction levels once projects are handed over to conservation. Conservation should know that these levels are well below the typical compaction levels specified by engineers because they use compaction as a means to prevent erosion. However, this strategy is problematic because vegetation is the most effective means of erosion control and if soils are compacted beyond optimal ranges, vegetation will be limited to taproot plants and annuals that are able to take hold under extreme compaction. Often, these over-compacted sites will require erosion matting that remains until invasive plants can get a hold and start to spread over several years. This approach is fundamentally opposed to restoration work goals of vegetation quality, focusing instead on total coverage with no assessment of species or growth type (e.g., annual, tap root, invasive). Monitoring compaction on construction sites also inhibits contractors' abilities to drive heavy equipment all over the site. This restriction might not be a factor for work occurring in existing greenways but will need to be considered for HPB Capital projects where major grading and construction occurs.





Figure 9. Cone scale penetrometer image

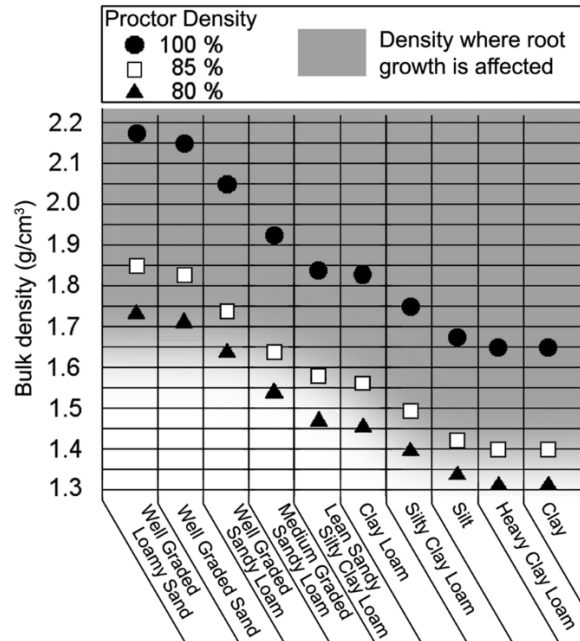


Figure 10. Bulk Density to Standard Proctor Density graph. James Urban, Up By Roots, Healthy Soils and Trees in the Built Environment.

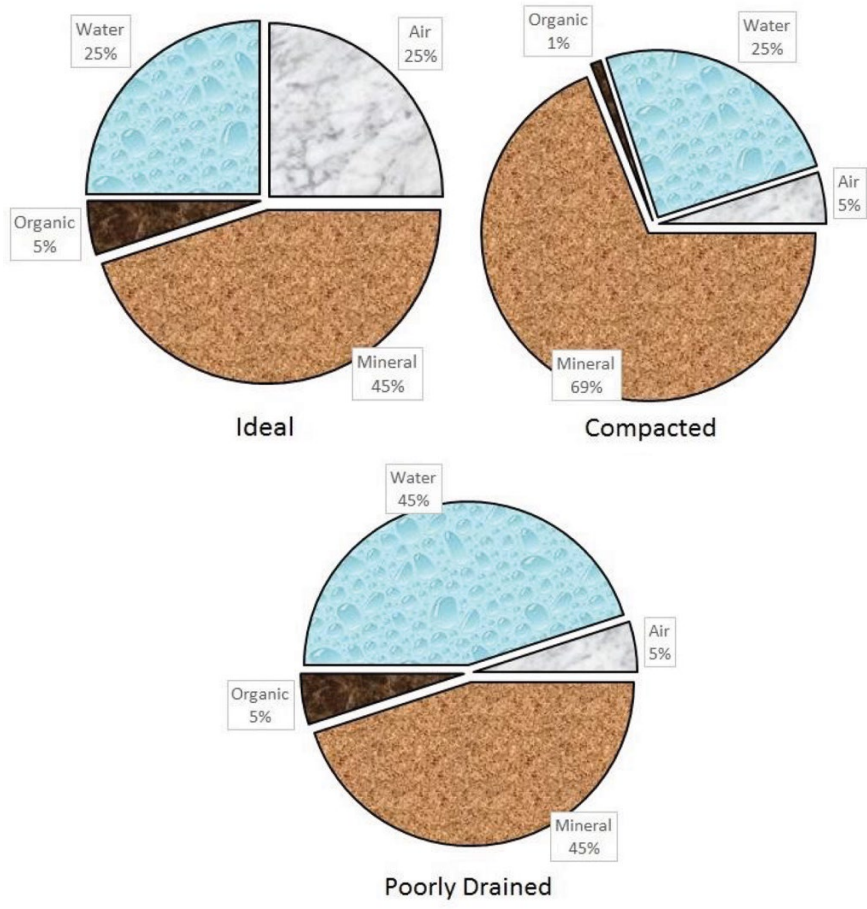


Figure 11. Image of soil particles, Luke Gatiboni, Extension Soil Fertility Specialist and Assistant Professor, NC State Department of Crop & Soil Sciences, North Carolina State University Extension.

The cone scale penetrometer will not provide hyper accurate data though it will provide conservation staff with an immediate answer as to whether the soil compaction rates are suitable, bordering compacted, or beyond acceptable compaction ranges. It is a very useful tool when dealing with contractors and helps provide instant feedback so that unsatisfactory work can be controlled and corrected.

Only utilize deep tilling to loosen soil if it is absolutely necessary based on compaction test results (e.g., cone scale penetrometer, bulk density testing) and if the site has no trees. As mentioned before, deep tilling or cultivation will pull up dormant invasive seed bank.

To address soil compaction, it is recommended to rototill or airspade on a low level if near tree root systems and finances allow. Rototilling at least 2' in depth and integrating 2" of high quality compost. Natures Way Resources has the best product available. Then a 1' layer of compost should be added on top. Enforcement of VSPZ will help reduce unnecessary compaction. Once a soil is compacted it is generally not going to perform as well as an undisturbed area for quite some time even if amended.

## **G. Soil amendments**

Besides being excessively compacted, urban soils lack important components that drive soil food web development. Grassland soils possessed organic matter (OM) built up over millennia and featured charcoal from reoccurring wildfires that occurred quite frequently based on historical fire return interval data. OM helps provide food for beneficial microbes (i.e., bacteria, fungi, protozoa, and nematodes), contributes towards optimal soil structure, promotes moisture retention, provides nutrients (macro and micro), drives pH levels to optimum ranges, promotes greater soil biodiversity over time (many microbes cannot be grown in labs), helps prevent runoff (a 5% increase in soil OM can quadruple soil water holding capacity), and reduces plant pathogens.

Houston Parks Board should look to acquire or self-produce static piled compost as this method is low tech and results in OM that is well balanced with all of the aforementioned key soil food web species. Most compost is now produced via the windrow method that involves long rows of parent material that is repeatedly turned via machinery. This method allows compost manufacturers to make a product that meets all of the U.S. Composting Council and TXDOT definitions of compost (e.g., does not resemble parent material, meets weak maturity and stability standards, contains no heavy metals and no E. coli or similar pathogens) within a short time span, but also results in a bacteria dominant microbe profile with minimal protozoa and no mycorrhizae. Additionally, various manufacturers use different types of feedstocks that can produce dramatic ranges of macro and micronutrients, meaning that when applying windrow compost conservation staff would not be sure if they are dousing new plots with high levels of nitrogen, phosphorous, potassium (N,P,K) which can result in explosive weed growth.

Many Texas native species evolved in nutrient poor conditions and do not require the fertilization regime that crops or non-native transplants need. Furthermore, in Texas, compost providers cannot provide nutrient information regarding their product or they will get regulated as a fertilizer manufacturer. Houston Parks Board conservation staff will have to request tests per certain batch amounts (e.g., every 1000 cubic yards) if they want to know more information, and such testing adds cost and coordination. Nature's Way Resources makes the best compost product in the Houston area and Houston Parks Board staff could be sure that they are using compost that provides all of the aforementioned benefits, but their product costs more than typical compost, and demand is high. Because HPB has a good relationship with Nature Way Resources it is recommended to make this the priority compost source. Conservation staff should incorporate 1-3" of compost into the soil.

Though the benefits of charcoal, or biochar, are still being analyzed, there is evidence that this component was a part of historical grassland soils given the role of wildfire. There is an increasing understanding of the importance of adequate carbon-nitrogen (C:N) ratios in soil, though there is no definitive prescription for replicating conditions that best promotes grassland restoration, nor is there a definitive list of what specific C:N ratios existed for the soil orders where grasslands dominated (e.g. Alfisols, Vertisols, Mollisols). However, an important insight into the benefits provided by soil charcoal is demonstrated by archaeological research into the prehistorical and

historical amendment of tropical sandy and loamy soils with charcoal, or *Terra Preta*. These amended agricultural soils have maintained fertility and other desirable performance traits for over 2000 years, and researchers found that charcoal makes it possible to “convert infertile soils’ insufficient physical and hydrological properties to sustainable, fertile soils with good physical and hydrological properties.”<sup>19</sup> Further examination of the amended soils provided a definitive correlation between improved soil function with charcoal particle size stating, “The reduction of particle size causes an increase in water retention and total porosity and a decrease in available water content and bulk hydrological and chemical properties of soil.”<sup>20</sup> Smaller particles were demonstrated to be the most effective. To be clear, de Jesus Duarte et. al. 2019 did focus on tropical sandy and loamy soils, but the purpose of the inclusion of this study is to provide an accurate, non-industry assessment of the potential beneficial effects of charcoal when integrated into soil horizons.

Given the documented presence of charcoal with soil matrices in fire ecologies, Houston Parks Board conservation should endeavor to not only recreate above ground conditions, but also mimic below ground components when practical and economically feasible. When looking to restore ecosystems it will be important to must embrace systems-based design, a strategy that acknowledges the drivers, components, complex relationships, and functional processes of ecosystems rather than static reactionary responses. Blackland Collaborative currently uses a product out of Washington State by Biochar Supreme called Black Owl™ Premium Organic BIOCHAR and integrates ½” – 1” into the soil. Shipping costs are expensive for this product, but if Houston Parks Board conservation staff purchases bulk amounts, they could potentially negotiate product cost to negate some of the shipping fees.

In addition to compost and charcoal, Houston Parks Board conservation staff can further improve soil conditions by adding amendments that contain low level N|P|K, organic fertilizer, humic acid, horticultural molasses, beneficial microbe inoculant, and micronutrients. Organic fertilizer feeds the soil life as well as boosting vegetative growth. Humic acid serves as food for mycorrhizae while horticultural molasses serves as food for beneficial bacteria. There are products that can be applied to the soil before seeding and planting as well as after the native growth has started. Products with organic fertilizer should aim for low levels such as 2,3,2. The object is to feed the soil more so than the plants. Organic fertilizer should only be applied 2-3 per season or more frequently if in response to chlorosis, but increased frequency should be driven by **soil sample nutrient data** if chlorosis does occur.

## H. Seeding

In a woodland restoration, trees do not provide instant canopy and it takes time for trees to grow into a mature woodland condition. Seeding an herbaceous seed mix that will eventually adapt to shade conditions is recommended when possible. This adds vertical and species diversity to the restoration and will also provide other benefits such as soil stabilization and wildlife habitat.

---

<sup>19</sup> “Effect of Biochar Particle Size on Physical, Hydrological and Chemical Properties of Loamy and Sandy Tropical Soils.” (de Jesus Duarte et al. 2019).

<sup>20</sup> Ibid., (de Jesus Duarte et al. 2019).

Using the upland Savanna seed mix and the riparian shade seed mix can be used depending upon the light and soil moisture conditions of tree plantings.

Seeding is the most cost-effective means of achieving diversity and richness for establishing an herbaceous understory. The key to seeding successfully is ensuring that seeding is done with appropriate species and rates, with correct method, and within appropriate seasonal windows. Below are starter seed mixes to reference depending upon sun and shade conditions (Table 3 and Table 4). It is strongly encouraged that recommended seed rates are doubled or tripled. This will provide the projects with an instant native seed bank and help combat competition.

In addition to commercially purchased seed, wild collected seed from remnant prairies and other local conservation groups should be incorporated into the seed mix or spread separately on projects. This is important for genetic diversity and to have the most local sources available. Commercially purchased seed should be well researched and the origin of the seed should be discussed with the supplier. Seasonal seed collection outings should be part of the conservation team's regular duties for yearly supplemental diversity seedings.

Table 3. Starter Seed Mix Type 1

<b>SEED MIX TYPE 1: UPLAND/SAVANNA MIX</b>			
<b>Habit</b>	<b>Scientific Name</b>	<b>Common Name</b>	<b>Ideal lbs Per Acre Needed</b>
grass	<i>Andropogon gerardii</i>	Big bluestem	3
grass	<i>Andropogon glomeratus</i>	Bushy bluestem	1
grass	<i>Bouteloua curtipendula</i>	Sideoats grama	3
grass	<i>Chasmanthium latifolium</i>	Inland Sea Oats	3
grass	<i>Elymus canadensis</i>	Prairie Wildrye	1
grass	<i>Paspalum floridanum</i>	Florida paspalum	2
grass	<i>Leptochloa dubia</i>	Green sprangletop	1.5
grass	<i>Schizachyrium scoparium</i>	Little bluestem (Gulf)	4
grass	<i>Sorghastrum nutans</i>	Indiangrass	3
grass	<i>Tridens flavus</i>	Purpletop tridens	1
grass	<i>Tripsacum dactyloides</i>	Eastern gamagrass	2
forb	<i>Coreopsis lanceolata</i>	Lanceleaf coreopsis	2.5
forb	<i>Coreopsis tinctoria</i>	Plains coreopsis	1.5
forb	<i>Dracopis amplexicaulis</i>	Clasping coneflower	1.5
forb	<i>Echinacea purpurea</i>	Purple coneflower	5
forb	<i>Gaillardia pulchella</i>	Indian Blanket	4
forb	<i>Ipomopsis rubra</i>	Standing Cypress	3
forb	<i>Lobelia cardinalis</i>	Cardinal flower	(pkt 50 ct)
forb	<i>Monarda citriodora</i>	Lemon beebalm	2
forb	<i>Phlox drummondii</i>	Drummond Phlox	2
forb	<i>Rudbeckia hirta</i>	Black-eyed Susan	2
forb mix	<i>Asclepias incarnata, Asclepias syriaca, Asclepias tuberosa</i>	Roundstone Seed Southern Monarch Milkweed Seed Mix	1
		<b>Total</b>	<b>45</b>

Table 4. Starter Seed Mix Type 2

<b>SEED MIX TYPE 2: SHADE RIPARIAN SHADE MIX</b>			
<b>Habit</b>	<b>Scientific Name</b>	<b>Common Name</b>	<b>Ideal lbs Per Acre Needed</b>
grass	<i>Andropogon gerardii</i>	Big bluestem	3
grass	<i>Andropogon glomeratus</i>	Bushy bluestem	1
grass	<i>Bouteloua curtipendula</i>	Sideoats grama	3
grass	<i>Elymus canadensis</i>	Prairie Wildrye	1
grass	<i>Paspalum floridanum</i>	Florida paspalum	2
grass	<i>Leptochloa dubia</i>	Green sprangletop	1.5
grass	<i>Schizachyrium scoparium</i>	Little bluestem (Gulf)	4
grass	<i>Sorghastrum nutans</i>	Indiangrass	3
grass	<i>Tridens flavus</i>	Purpletop tridens	1
grass	<i>Tripsacum dactyloides</i>	Eastern gamagrass	2
grass	<i>Chasmanthium latifolium</i>	Inland sea oats	3
forb	<i>Coreopsis lanceolata</i>	Lanceleaf coreopsis	2.5
forb	<i>Coreopsis tinctoria</i>	Plains coreopsis	1.5
forb	<i>Dracopis amplexicaulis</i>	Clasping coneflower	1.5
forb	<i>Echinacea purpurea</i>	Purple coneflower	5
forb	<i>Gaillardia pulchella</i>	Indian Blanket	4
forb	<i>Lobelia cardinalis</i>	Cardinal flower	(pkt 50 ct)
forb	<i>Phlox drummondii</i>	Drummond Phlox	2
forb	<i>Rudbeckia hirta</i>	Black-eyed Susan	2
<b>Total</b>			<b>43</b>

Seeding method will have a big impact on project success. No-till drill is by far the best means of incorporating seed into the soil at the proper depth without causing problems arising from deep cultivation. The [Dew Drop Drill](#) is a great piece of equipment that will allow you to seed areas ¼ acre and above with ease and can be pulled by an ATV (Figure 12). Like most no till drills, it has a bin with auger for fluffy seed and another bin? for dense seed. the benefit of this piece of equipment can not be overstated, and Houston Parks Board conservation staff should look to acquire one when able. When no till drilling, best results are achieved by making a first pass along the entire plot and then following up with a second pass that runs perpendicular to the path of initial coverage.

Hand seeding or broadcast seeding is acceptable for smaller plots, but this method can skew success and favor certain species over others (Figures 13-16). If this is the only option, follow the same strategy as with no till drilling where staff seeds in one direction to cover entire plot, and then finish out seeding by making a second pass perpendicular to the first pass. After seeding is complete, staff will need to brush the seed in with a rake or branch from a tree. The idea is to ensure good seed/soil contact without burying the seed too deeply. This can be very tricky as the seed mix will incorporate many types of seed of varying size. The rule of thumb guides that seed should not be buried deeper than twice its width. Burying seed deeper than this depth will eliminate the potential of germination. This method is not recommended for large scale seeding.

A third option for Houston Parks Board staff where slope is an issue is hydraulically applying seed mixed with the product similar to Proganics Biotic Soil Media (BSM). Staff or contractor should follow manufacturer's installation instructions and recommendations. Proganics is mixed at a rate of 75 to 100 pounds per 100 gallons of water. Proganics should be applied at 3,500 to 5,000 lbs/A. Contractor should be able to mix custom seed mix as required, but staff will need to coordinate with contractor to ensure that equipment can handle the required amounts. Proganics is an expensive product with many benefits and HPB will need to determine if this is justified on a per project basis

A cheaper option for hydroseeding would be to use the typical cellulose/tackifier/seed mix. This method typically consists of applying a mixture of wood fiber, seed, and stabilizing emulsion with hydro-mulch equipment, which temporarily protects exposed soils from erosion by water and wind. The practice may also be called hydro mulching, hydraulic planting, hydraulic mulch seeding, hydraseeding.

Hydroseeding isn't as preferred as no till drill seeding and Blackland Collaborative has had mixed results with this method. Other researchers have also documented skewed species results (legumes tend to be favored) and restoration companies also report that hydroseeding is generally not recommended. Having said that, if this option is needed for steep slopes or other access issues the following steps should be followed:

### Materials

- Seed
- Wood Mulch
- A guar based tackifier (organic plant based thickening and binding agent) can be used, though the BC has had issues with germination rates with the application of tackifier. It is recommended that HPB omit the tackifier if the hydroseeding is not being used for slopes or to reduce soil erosion.

### Seed Mix:

Utilize appropriate mix of choice




Wood mulch:

1850 lbs per acre (about 45 lbs. per 1,000 square feet), HPB should not exceed that number as wood (brown) material will begin to break down and impede germination due to loss of macronutrients

Guar tackifier:

30 lbs./acre prepared in mechanically agitated hydro-seeder slurry

### Construction Guidelines

1. Prior to application, roughen embankment and work so soil surface is even, but friable and  ready to receive seed

2. Hydroseeding can be accomplished using a multiple-step or one-step process:

- The multiple-step process ensures maximum direct contact of the seeds to soil
- When the one-step process is used to apply the mixture of seed, fiber, etc., the seed rate shall be doubled to compensate for all seeds not having direct contact with the soil
- Follow-up applications shall be made as needed to cover weak spots
- The time allowed between placement of seed in the hydraulic mulcher and the emptying of the hydraulic mulcher tank should not exceed 30 minutes
- Application of the slurry should proceed until a uniform cover is achieved. The applicator should not be directed at one location for too long a period of time or the applied water will cause erosion

**\*It is extremely important that Houston Parks Board staff ensures contractors have washed out all tanks meticulously before application. Failure to do so could result in a dirty tank contaminated with invasive seed such as bermudagrass.**



Figure 12. Image of Dew Drop Drill



Figure 13. Image of No till Drill vs hand seeding Headwaters at the Comal



Figure 14. Image of seeding passes



Figure 15. Image of Eastern gamagrass



## Indian Paintbrush, *Castilleja coccinea*

Figure 16. Indian Paintbrush seed

Seeding windows are extremely important to ensure success. There are two seasons for installing seed, fall and spring. Forbs and cool season grasses have the best success if planted in the fall while warm season grasses and annual forbs prefer going in during the spring. Often projects can only have one seeding so conservation staff will have to decide if they want to seed a plot only once or if they can incorporate two seasons of seeding to provide warm and cool season grasses and forbs the best chance to become established. Possessing a no till drill makes the two-season approach very easy and only requires that the site is prepped by removing thatch and growth by prescribed fire or mowing and hand removal. The seed can then be drilled into the “cleared” area. If conservation staff only seeds once, you will need to be very patient with the evolution of the prairie to see if there is reduced presence of any species that were planted outside their optimal installation window. The planting window times can contract and expand depending upon El Niño Southern Oscillation (ENSO) trends and weather patterns. For the Houston area, the fall window could likely be October – December and spring March – June. Conservation staff will need to ascertain the best windows based on climate data and weather forecasts. While water is an extremely important factor, the main concern is excessive heat. If the temps are above 80°F or below 60° F the seed will not grow very well and there is the chance that if there are any excessive swings within the first 6 weeks of growth, seedlings will be lost.

### **I. Live planting- Tree plantings**

#### Tree size

Planting trees is the primary restoration action of woodland restoration. When planting for restoration purposes, planting generally smaller trees rather than larger is recommended.

Majority of the trees that will be planted for HPB projects will be 3-5 gallon trees. These are the most ideal sizes for planting trees in an urban woodland restoration. The benefits of planting smaller sized trees are that they are easier to plant, more affordable, and will typically fill out faster than a larger tree. A larger tree when planted is essentially transplanted and shocked. It will need to spend more time establishing roots before it starts to grow in size. Often a 3-5 gallon tree will out grow 30+ gallon trees in a few years. Smaller trees and saplings can also be used however they have a lower survival rate, and more saplings should be planted with the anticipation that many will not survive.

### Tree diversity

In general, trees that are planted for woodland restoration should be a mixture of early successional species and later successional species. It is important to have trees that will grow quickly to efficiently create a woodland condition such as Hackberry *Celtis occidentalis* and Elm *Ulmus americana*

while also planting and allowing enough space for later successional trees such as Post Oak *Quercus stellata* and White Oaks *Quercus alba* (typically also slower growing trees) to eventually establish and fill out and as the ecosystem matures.

It is also important to have structural diversity in addition to species diversity. Woodland planting efforts tend to focus on overstory trees however incorporating more mid and understory trees is also recommended to increase vertical and species diversity. Additionally, it is important to have a variety of ages in trees. Having trees that are all the same age make the ecosystem more vulnerable to disturbances. Tree plantings should be organized so that supplemental plantings will successfully occur in the future. This requires evaluating ideal planting locations for current plantings such as planting new trees underneath a larger older existing tree as well as considering locations for future trees to have enough space to grow in a healthy manner. In general, most of the plantings should be spaced at least 7'-12' apart for mowing and reduce competition. These plantings also take into account that it is expected for some trees to die off.

In some cases, tree plantings may occur within already wooded conditions. If this planting is for species diversity of overstory canopy, some initial clearing of less desirable or invasive trees might be needed to have enough light for the tree to thrive. Clearing may not be needed for understory trees. Understory trees require less light to establish however they are more edge condition species so light conditions should be evaluated and some clearing might be warranted if it's too shady.

Lastly, establishing a diverse herbaceous and/or shrub layer adds to vertical and species diversity. This makes the ecosystem even more robust and resilient to disturbances. For example, this was observed during the flooding in Blanco County in 2014. Areas along the riparian bank of the Blanco River where there were both trees and an herbaceous understory performed significantly better at holding the stream bank than areas with solely Bald Cypress *Taxodium distichum*. Even though Bald Cypress *Taxodium distichum* have such an extensive root system and are significant in size, the grasses really were the plants that held the bank in that situation. The herbaceous

layer additionally adds other important ecosystem services such as improved wildlife habitat, soil health, and many more.

Other in-depth resources on best management practices for planting trees in urban environments are: James Urban’s *Up By Roots: Healthy Soils and Trees in the Built Environment* and the International Society of Arboriculture’s *Best Management Practices – Tree Planting, Second Edition*.

A recommended tree species list is below in Table 5. This is a working list and should be updated as needed.

Table 5. Woodland/Forest tree species list

<i>Trees/canopy</i>		<i>Base trees</i>	<i>Diversity plantings</i>	<i>Stability rating</i>	<i>Grow easily on their own</i>	<i>14 Super</i>	<i>10 Highest leaf area 2015 Houston Urban Forest</i>
Box Elder	<i>Acer negundo</i>			7	x	x	
Drummonds Red Maple	<i>Acer rubrum var. drummondii</i>		x				
Red Maple	<i>Acer rubrum</i>	x		6		x	
River Birch	<i>Betula nigra</i>		x	6		x	
American Hornbeam	<i>Carpinus caroliniana</i>		x				
Water Hickory	<i>Carya aquatica</i>	x		7			
Pignut hickory	<i>Carya glabra</i>			6			
Bitternut Hickory	<i>Carya cordiformis</i>		x				
Pecan	<i>Carya illinoensis</i>	x		6			x
Mockernut Hickory	<i>Carya tomentosa</i>		x				
Southern Catalpa	<i>Catalpa bignonioides</i>		x				
Sugar hackberry	<i>Celtis laevigata</i>	x		6	x		x
White ash	<i>Fraxinus americana</i>					x	
Green ash	<i>Fraxinus pennsylvanica</i>	x		6		x	x
Water locust	<i>Gleditsia aquatica</i>		x				
Honey locust	<i>Gleditsia triacanthos</i>		x	6			
American Holly	<i>Ilex opaca</i>		x				
Little walnut	<i>Juglans microcarpa</i>		x				
Black walnut	<i>Juglans nigra</i>		x	6			
Eastern redcedar	<i>Juniperus virginiana</i>		x	6			
Sweetgum	<i>Liquidambar styraciflua</i>	x		6		x	x
Tuliptree	<i>Liriodendron tulipifera</i>		x			x	

Southern Magnolia	<i>Magnolia grandiflora</i>			6				
Red Mulberry	<i>Morus rubra</i>		x	6				
Water tupelo	<i>Nyssa aquatica</i>		x	7				
Blackgum	<i>Nyssa sylvatica</i>		x					
Loblolly Pine	<i>Pinus taeda</i>	x			x	x	x	
American Sycamore	<i>Platanus occidentalis</i>	x		6		x		
Eastern cottonwood	<i>Populus deltoides</i>	x		6	x			
Black Cherry	<i>Prunus serotina</i>		x					
White Oak	<i>Quercus alba</i>	x						
Southern red oak	<i>Quercus falcata</i>		x					
Laurel Oak	<i>Quercus laurifolia</i>		x	6		x		
Overcup oak	<i>Quercus lyrata</i>	x		7				
Burr Oak	<i>Quercus macrocarpa</i>	x						
Swamp Chestnut oak	<i>Quercus michauxii</i>	x		6				
Water Oak	<i>Quercus nigra</i>	x		6	x	x	x	
Cherrybark Oak	<i>Quercus pagoda</i>	x		6				
Willow Oak	<i>Quercus phellos</i>	x		6	x			
Shumard Oak	<i>Quercus shumardii</i>			6				
Post Oak	<i>Quercus stellata</i>		x					
Nuttal Oak	<i>Quercus texana (nuttalli)</i>							
Live Oak	<i>Quercus virginiana</i>			6			x	
Black locust	<i>Robinia pseudoacacia var. umbraculifera</i>		x					
Sandbar willow	<i>Salix exigua</i>							
Black willow	<i>Salix nigra</i>	x			x			
Bald cypress	<i>Taxodium distichum</i>		x	9				
Basswood	<i>Tilia americana</i>		x					
Carolina Basswood	<i>Tilia americana var. canadensis</i>		x					
Winged elm	<i>Ulmus alata</i>		x	6				
American elm	<i>Ulmus americana</i>	x		6	x	x	x	
Cedar elm	<i>Ulmus crassifolia</i>	x		6	x			
Slippery elm	<i>Ulmus rubra</i>			6		x		
<b>Trees/understory</b>			<b>Base trees</b>	<b>Diversity plantings</b>	<b>Stability rating</b>	<b>Grow easily on their own</b>	<b>14 Super</b>	<b>10 Highest leaf area 2015 Houston</b>

							Urban Forest
Red Buckeye	<i>Aesculus pavia</i>	x				x	
Devil's walkingstick	<i>Aralia spinosa</i>						
Eastern Redbud	<i>Cercis canadensis var. canadensis</i>	x					
White Fringetree	<i>Chionanthus virginicus</i>	x					
Roughleaf dogwood	<i>Cornus drummondii</i>	x		6	x		
Flowering Dogwood	<i>Cornus florida</i>		x	4			
Parsley Hawthorn	<i>Crataegus marshallii</i>	x	x	6			
Littlehip Hawthorn	<i>Crataegus spathulata</i>		x	6			
Green Hawthorn	<i>Crataegus viridis</i>			6			
Mayhaw	<i>Crataegus opaca</i>		x	7			
Titi	<i>Cyrilla racemiflora</i>		x				
Texas Persimmon	<i>Diospyros texana</i>						
Common Persimmon	<i>Diospyros virginiana</i>			6	x		
Anacua	<i>Ehretia anacua</i>						
Carolina Buckthorn	<i>Frangula carolinia</i>						
Eastern swampprivet	<i>Forestiera acuminata</i>			7			
Water locust	<i>Gleditsia aquatica</i>			7			
Two-wing silverbell	<i>Halesia diptera</i>	x					
American Witchhazel	<i>Hamamelis virginiana</i>		x				
Dahoon Holly	<i>Ilex cassine</i>						
Possumhaw	<i>Ilex decidua</i>			6	x		
Greenleaf Holly	<i>Ilex opaca</i>						
Yaupon	<i>Ilex vomitoria</i>			6	x		x
Osage Orange	<i>Maclura pomifera</i>			6			
Sweetbay Magnolia	<i>Magnolia virginiana</i>	x		6			
Southern crabapple	<i>Malus angustifolia</i>						
Wax Myrtle	<i>Morella cerifera</i>	x		6			



American Hornbeam (Ironwood)	<i>Ostrya virginiana</i>		x	6				
Retama	<i>Parkinsonia aculeata</i>							
Redbay	<i>Persea borbonia</i>							
Planertree	<i>Planera aquatica</i>	x		7				
Honey Mesquite	<i>Prosopis glandulosa</i> <i>var. glandulosa</i>							
Chickasaw Plum	<i>Prunus angustifolia</i>	x						
Carolina Laurelcherry	<i>Prunus caroliniana</i>							
Cherry Laurel	<i>Prunus laurocerasus</i>			6	x			
Mexican Plum	<i>Prunus mexicana</i>	x						
Hog Plum	<i>Prunus umbellata</i>		x					
Common Hoptree	<i>Ptelea trifoliata</i>		x	6				
Winged Sumac	<i>Rhus copallinum</i>		x		x			
Flame-leaf sumac	<i>Rhus lanceolata</i>	x			x			
Black Willow	<i>Salix nigra</i>	x		7	x			
Black Elderberry	<i>Sambucus nigra</i>			6	x			
Western Soapberry	<i>Sapindus Saponaria</i> <i>var. drummondii</i>			6	x			
Sassafras	<i>Sassafras albidum</i>		x	6				
Gum Bumelia	<i>Sideroxylon</i> <i>lanuginosum</i>			6	x			
Mexican Buckeye	<i>Ungnadia speciosa</i>							
Farkleberry	<i>Vaccinium arboreum</i>		x					
Sweet Acacia	<i>Vachellia farnesiana</i>							
Rusty Blackhaw	<i>Viburnum rufidulum</i>			6				
Hercules' Club	<i>Zanthoxylum clava-</i> <i>herculis</i>		x					
<b>Shrubs</b>			<b>Base trees</b>	<b>Diversity plantings</b>	<b>Stability rating</b>	<b>Grow easily on their own</b>	<b>14 Super</b>	<b>10 Highest leaf area 2015 Houston Urban Forest</b>
Indigo bush	<i>Amorpha fruticosa</i>		x	8				
Eastern baccharis	<i>Baccharis halimifolia</i>			6	x			
Baccharis	<i>Baccharis neglecta</i>			6	x			
American beautyberry	<i>Callicarpa americana</i>	x		4				

Bottonbush	<i>Cephalanthus occidentialis</i>	x		8	x		
Coral bean	<i>Erythrina herbacea</i>	x		5			
Strawberry bush	<i>Euonymus americanus</i>		x				
Oak leaf hydrangea	<i>Hydrangea quercifolia</i>						
Virginia Sweetspire	<i>Itea virginica</i>	x					
Texas Lantana	<i>Lantana urticoides</i>	x			x		
Spicebush	<i>Lindera benzoin</i>	x					
Turk's cap	<i>Malvaviscus arboreus v. drummondii</i>	x					
Sabal Palm	<i>Sabal palmetto</i>	x		8			
Coralberry	<i>Symphoricarpos orbiculatus</i>	x		6			
Arrowwood	<i>Viburnum dentatum</i>	x			x		

### Planting recommendations

#### **Container grown trees:**

##### Prep and Storage

Before beginning any planting, it is very important to remove any extra growth or invasive species from the pots. This should be done before plants arrive to the restoration site, but it is important to always double check before planting. If trees are being stored before planting, make sure to keep the plants in the shade and water frequently depending upon the weather conditions to keep the soil moist in the pots as they will dry out frequently.

##### Tree hole and placement

Container grown trees should ideally be planted in a hole three times the diameter of the container. Majority of the HPB holes will be excavated using a tree auger. Shovels are also options for larger volunteer/staff plantings. Try to not overly compact the soil on the side of the holes. If the sides look too slick, you can scuff the sides with your hands. This will allow for easier root penetration.

##### Tree height

It is important to not plant a tree too low. The hole should be shallow enough to allow the top of the root ball or root flare to sit just above ground (or even a bit higher as nursery soil is lighter than native soil and will compact causing the tree to sink over time). If a tree is planted too low, it is susceptible to rot. This is a common error in tree planting. It is preferable to err on planting a tree too high rather than too low. If the tree is planted a bit too high this can be accounted for with mulch.

##### Root assessment

When removing the tree from the pot, the roots should be inspected for root binding and the soil should be lightly loosened from compaction. It is recommended to “tickle the roots” to get them ready for growth. It is not necessary to be more aggressive with decompaction of the roots. If roots are girdling or root bound there may be a need to cut some roots to help them grow in a straighter direction for the health of the tree.

### Backfilling

Before placing the tree in a hole, root hormone should be placed in the hole. When backfilling the soil, with native soil don't compress too much, add soil in stages, and make sure there are no air pockets. Break up the large clumps and heavily water the soil between rounds. Watering requirements depends on the soil and weather conditions. Generally, generous watering is recommended unless the conditions are very wet. It is not ideal to plant in too wet conditions as the soil will become compacted and will be hard for the tree to establish its roots. Filling the hole with water can be done if planting is occurring in dry conditions. Tree planting should be done in the tree planting windows. These are outlined below in this document. Planting outside of the ideal planting windows greatly increases tree mortality chances. Only fill the hole up to just below the root flare.

### Mulching

Adding a high-quality mulch to the top of the plantings is recommended with 50/50 compost from Natural Resources. Again, be careful to not place the mulch up against the tree trunk. This is a common mistake when planting trees and can also cause rot and disease. Mulch in a radius of 2 to 3 feet from the trunk. Spread about 3 to 4 inches deep of mulch. Leave a space of at least 3” between the mulch and the trunk itself. **Do not pile mulch up against the tree.** Tree rings around the outside edge of the planting area are recommended to keep moisture concentrated in the new tree planting zone. If the weather is wet for an extended period, then rings are most likely not necessary.

### Herbaceous and Shrub plantings

Starting with a seed mix is recommended when establishing the herbaceous layer if it is a young woodland restoration and there is limited canopy. Live plantings can also be used if there is a diversity of species and budget allows. Seeding recommendations are found in the seeding section in this document. Seeding in these areas will most likely be by hand rather than by no till drill as to not disturb the trees. If the area beyond the tree plantings is large enough for the equipment and will not cause damage to the planted tree zone, then no till drill seeding can occur. As the woodland system matures and more shade is produced by the canopy, the need for supplemental live plantings most likely will increase. Seed establishment in shady areas can be less successful and more shade tolerant plants might be needed. It is recommended to seed the newly planted woodland restoration areas with the savanna or riparian seed mix (Table 3 or 4) depending upon moisture and light. As the system matures, supplement with live plantings as needed. Additionally, as practiced in grassland restoration, live plantings can also be done to booster the seeding effort and shortcut the grassland's evolution by incorporating later successional species such as little bluestem (*Schizachyrium scoparium*) or compassplant (*Silphium laciniatum*).

When installed there is no formula for scale, but depending upon project size, staff should incorporate drifts of plants spaced 1' - 2' on center in grid. The number of plants incorporated per site should vary according to the site's scale, but for example a 16' x 16' space could incorporate 81 1-gallon plants at 2' on center grid spacing. Live planting in this manner allows conservation staff densely pack desired species into a small area. It is important to remember that later successional species can only grow and thrive if they have established a symbiotic relationship with certain microbes, so by planting these desired live plants into the understory, the conservation team will inoculate the interior component of the restoration areas. Planting densely is recommended in areas that are not well established to reduce voids that will allow invasive species to establish and flourish.

When installing live plants, the hole should be similar to the size of the planting (e.g., 4", 1 gallon, 3, gallon, etc.). The hole should not be too deep so that the base of the plant is lower than the surrounding ground level. The excavated soil should then be used to fill any air spaces, but the soil should not be over-compacted.

Live plantings are also beneficial for shady and/or wet areas where seed has difficulty establishing. Also, species that are difficult to purchase by seed such as sedges, diversity plants, and other cool season species should be planted as plugs or gallon material.

Rescuing valuable plant material from projects pre-construction is an excellent way to then replant the site with conserved material. The conservation team needs to have the capacity to pot and maintain the plants until they are ready to be planted. Salvaging plants from other sites beyond HPB in areas that will be disturbed due to construction or other impacts is another best management practice to preserve plant material and provide benefits to the soil biology. Plant salvage events should also be a regular practice.

### **TIMING/WHEN TO PLANT**

Depending upon current climatic conditions, ideal planting/sowing windows for each type of plant are listed below.

Table 6. Planting Windows

Plants	Season
Spring forbs and grass mixes	March - May
Warm season grasses	October - May*
Cool season grasses	October - mid November
Perennial forbs	October - May**

Annual Forbs	March - April
Shrubs	October - Early November and March - June
Trees	November - February***

\*Best results when planted in spring.

\*\*Best results when planted in fall.

\*\*\*Best to plant trees when they are dormant during the winter to avoid transplant shock. However, they can also be planted, depending on climatic conditions, in late fall and early spring if necessary. These trees will require more attention.

## J. Watering for Establishment

### Watering trees

Trees should be watered the day they are planted. Then they should be watered weekly depending upon the weather for two years. Watering needs will typically decrease in the winter and increase in the summer months. After the two-year establishment period the trees should be watered as needed. It will be important to regularly inspect for stress, especially during the summer months.

Drench all trees and shrubs with water twice, during the first 24 hours after installation. This will ensure the root zone is well saturated. Maintenance of soil moisture at or greater than 6" below grade during early (3-6) months is critical for tree establishment. Young saplings should be watered twice a week (saturating the critical root zone) for 2-3 months. At each watering, thoroughly saturate the soil around each tree and ensure proper soil moisture at least 6" below grade. Over the next four months, the root depth should not be allowed to dry out, watering every other week or as necessary depending on local weather conditions. After this initial establishment period, stormwater runoff should provide sufficient irrigation needs. However, if there is a long drought period or no significant precipitation for any 4-6 week period over the first two growing seasons, the trees will need supplemental watering. Trees should be maintained for two years and inspected at least once a month during this two-year establishment period.

### Tree Establishment Watering Schedule

- Trees generally will require anywhere between 5-10 gallons of water per inch of diameter. The lower value of this range is for trees planted in optimal conditions, with the latter needed by trees planted in stressed conditions (urban street trees, trees planted under turf or competing with other herbaceous components, trees surrounded by compacted soils). Ideally, the root zone will remain moist, but not soggy to a depth of 12 to 18 inches.

- For the first 18 months trees must receive water in addition to any water supplied via other sources (e.g. rain, lawn sprinkler, adjacent irrigation zones) if not permanently irrigated.
- Minimum watering:  
*January, February, March, November, and December once per week*  
*April, May, and October 3 days per week*  
*June, July, August, and September every other day*

Caliper	Requirement
Inches	Gallons Per Week
0-5	1-5
6-10	10-20
11-15	30-45
16-20	60-80
21-25	100-125
26-30	150-180
31-35	210-245
36-40	280-320
41-45	360-345
46+	450+

### Watering seeds

Houston Park Board might not be able to provide water for establishment for every project, but the presence of available moisture is vital for seed and newly planted species. Currently, all new sites enter a 1-year minimum contract with the contractor to water the projects for regular weekly or biweekly watering. It is critical for the site to be watered for the first 6 weeks after seeding- especially for large-scale projects. While Houston receives an average of 49" per year, staff should anticipate swings in precipitation stemming from climate change. Having the ability to water as needed will ensure that projects will not need to be reworked should dramatic dry spells occur. Houston Parks Board should also consider possibly establishing irrigation for "showpiece prairies" that might be located in important areas if financially feasible.

### Establishment Watering Schedule

- First 10 days seed is not allowed to dry out – watering event replicating 1” rain event every day
- Next 3 weeks – watering event replicating 1” event every other day
- Next 2 weeks - watering event replicating 1” event twice a week

\*This schedule can be adjusted, and days skipped if rainfall occurs

Ideally watering should occur during times when water loss from evaporation is lowest (dawn and/or dusk) but without potentially creating a disease-prone environment. Irrigation should not occur after a sufficient rain event or when otherwise unnecessary.

## **K. Monitoring for establishment**

### Tree establishment

When monitoring for woodland establishment it will be important to identify tree stress and adjust watering as needed or supplement with additional compost. Another common issue is that vines will often grow up on young trees and cover them completely. Regular inspection and removal of vines or other tall and competing vegetation should be removed. Additionally, removing invasive species, especially invasive woody species from the planted area will be needed to continue to give the newly planted tree an advantage at establishing itself.

### Seed establishment

The mantra of ecological restoration is “first year it sleeps, second year it creeps, third year it leaps”. Each project will establish differently over time, but if done right conservation staff should see verdant seedling growth within the first three weeks. Staff will need to become familiar with each native species seedling and seedlings of invasive plants. They will also need to know each of these plants as they advance in their life cycle. Each project should have regular establishment monitoring for the first two years with the first year having a minimum of a site visit every two weeks.

Spot treatment of invasive species should occur if rhizomatous or stoloniferous species such as bermudagrass or johnsongrass are present. Hand removal can occur, and regular sweeps should be made during inspections to make sure undesired plants are not allowed to go to seed. Any plants that are setting seed should be treated or pulled, seedheads or plants bagged, and then bags discarded. If invasive spot treatment occurs and results in dead patches, conservation staff should remove dead material and then reseed with bare patch mix (Table V.3). This will involve lightly roughening the soil and hand seeding into the site. While the seed can be ordered as needed, most practitioners find it helpful to have some seed on-hand so they can seed as soon as needed. It is imperative to not leave the void unattended because urban areas are vectors for invasive species and could potentially fill the space if native seed or live plugs are not planted as soon as possible.

Table 7. Bare Patch Mix

<b>SEED MIX TYPE 2: BARE PATCH MIX</b>			
Habit	Scientific Name	Common Name	1 Acre coverage
grass	<i>Bouteloua curtipendula</i>	Sideoats grama	1
grass	<i>Leptochloa dubia</i>	Green sprangletop	1
grass	<i>Sorghastrum nutans</i>	Indiangrass	0.5
grass	<i>Tridens flavus</i>	Purpletop tridens	1
grass	<i>Tripsacum dactyloides</i>	Eastern gamagrass	1
forb	<i>Gaillardia pulchella</i>	Indian Blanket	1
forb	<i>Monarda citriodora</i>	Lemon beebalm	1
forb	<i>Rudbeckia hirta</i>	Black-eyed Susan	1
<b>Total</b>			<b>7.5</b>

#### L. Management and Maintenance

The goal of restoration is to restore ecosystem process, not simply to replace components. Ecosystem processes allow natural systems to repair themselves and to remain relatively stable. The restoration principles help make connections between site context and site-specific information and help relate to future restoration projects and maintenance. Developing a restoration and maintenance plan that incorporates a well-supported interpretive plan reinforces a successful implementation, maintenance and education impact.

Maintaining and managing a woodland/forest restoration requires monitoring the site every two weeks or once a month at a minimum. If saplings are overgrown this is a trigger point and should be recorded on the maintenance list to inform the maintenance team to schedule time to go out and remove vines. The vines should be removed in a 2' radius around the tree. In the beginning trees should be monitored every couple of months and then reduce to every six months as the tree establishes and vine growth is controlled.

An important aspect of reducing woodland/forest management needs is appropriately sizing clearing areas based on the team's capacity. If the area is too large or there are too many areas are cleared at the same time, it might be that the conservation team is unable to get back to the clearing areas and encroachment or rethickening of an area will have occurred. This would mean that the conservation team would need to repeat the clearing process and essentially start over. It is important to sequence the woodland preparation so that the conservation team will be able to maintain without repeating efforts. The ideal size will tend to shift based on team capacity and other conditions so it will need to be evaluated on a regular basis.



Below is a general mowing and weeding schedule that indicates activities and the ideal timeframe for maintenance of a grassland ecosystem (Figure 19). The restoration invasive species toolbox is composed primarily of prescribe fire, mowing, physical removal, and chemical treatments. Often it is not one tool or another, it is a combined use of these tools and practices. Mowing will most likely be the main disturbance tool for HPB's prairies and savannas.

Mowing can be substituted for other treatments, such as fire, though the effects are not equivalent. Mowing leaves a thatch on the ground that will, over time, begin to choke prairie species (grasses and forbs). Raking thatch after mowing is recommended. However, mowing will retard woody invasion. Combining select spot treatment of herbicide on woody species will reduce the need for frequent mowing. During the first year of establishment, it would be beneficial to mow 1-3 times at 8" to let in sunlight and allow germination. This is especially recommended in areas where native aggressive plants might be present such as sumpweed (*Iva annua*) or aggressive plants that could quickly dominate a restoration. However, grasses can tolerate annual mowing in winter if desired, while most grasses are dormant. Mowing at other times of the year may result in loss of that year's seed and competitively favor undesired species. Mowing may be undertaken any time after grass seeds have ripened (December), or alternatively may be delayed until very early spring (February) just before the plants begin to green up. Bunch grasses grow from the crown, so mowing height should be at least 4 to 6 inches. Mowing in the Houston area may require mowing more than once a year due to invasive species pressure. If invasive species are an issue, mowing in mid-June to mid-July can help maintain plant diversity.

For woodlands, management of undesirable woody species will be a primary maintenance need. Removing woody species that have grown in can be done with a weed wrench (Figure 17). If there is a significant stand of woody species, then selective herbicide applications will be required and the stumps will need to be removed.



Figure 17. Image of weed wrench

Management of new habitat types requires frequent monitoring and recording of management activities and performance results. Adaptive management practices should be applied following an adaptive management framework. (Williams and Brown 2016).

### **Adaptive management**

Adaptive management is a management approach that acknowledges uncertainty in ecological systems and reduces uncertainty by using a problem-solving management approach. The focus is on learning about the system and how to best change the system. The process for adaptive management is circular in nature starting with assessment, design, implementation, monitoring, evaluation, and adjusting. Adaptive management is a hybrid of management and research (Murray and Marmorek 2003).

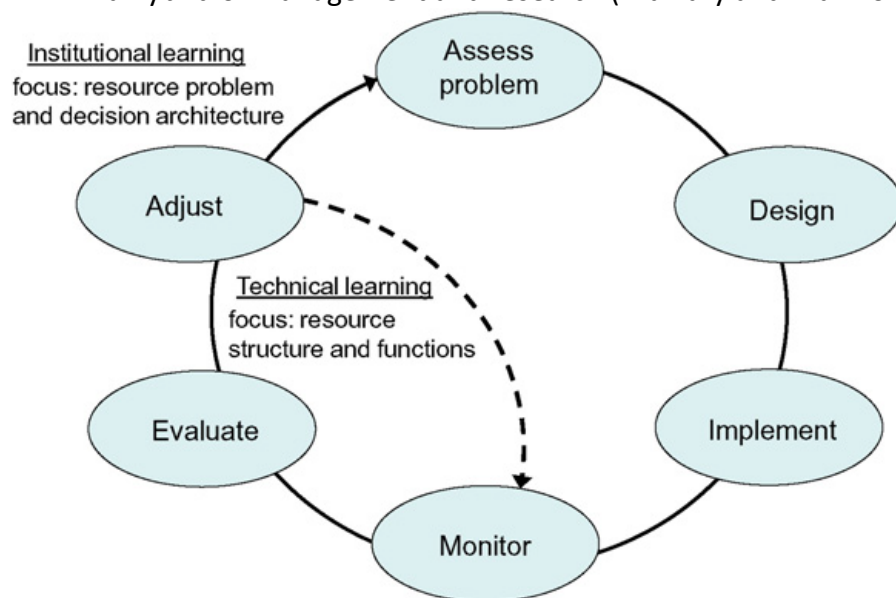


Figure 18. Diagram of the Adaptive Management process. (Williams and Brown 2016).

Figure 18 provides a diagram of adaptive management’s circular process starting with assessing the problem and then moving from there to design, implement, monitor, evaluate, and adjust. The diagram also highlights that there is a smaller circle within the larger framework where learning regarding the methods can be adjusted while maintaining the larger process. Managing complex living systems in urban environments with relatively new science requires flexibility, adaptability, as well as a method and process. More information regarding adaptive management and maintenance recommendations are included in the associated *HPB BMP Management and Maintenance Guidelines*.

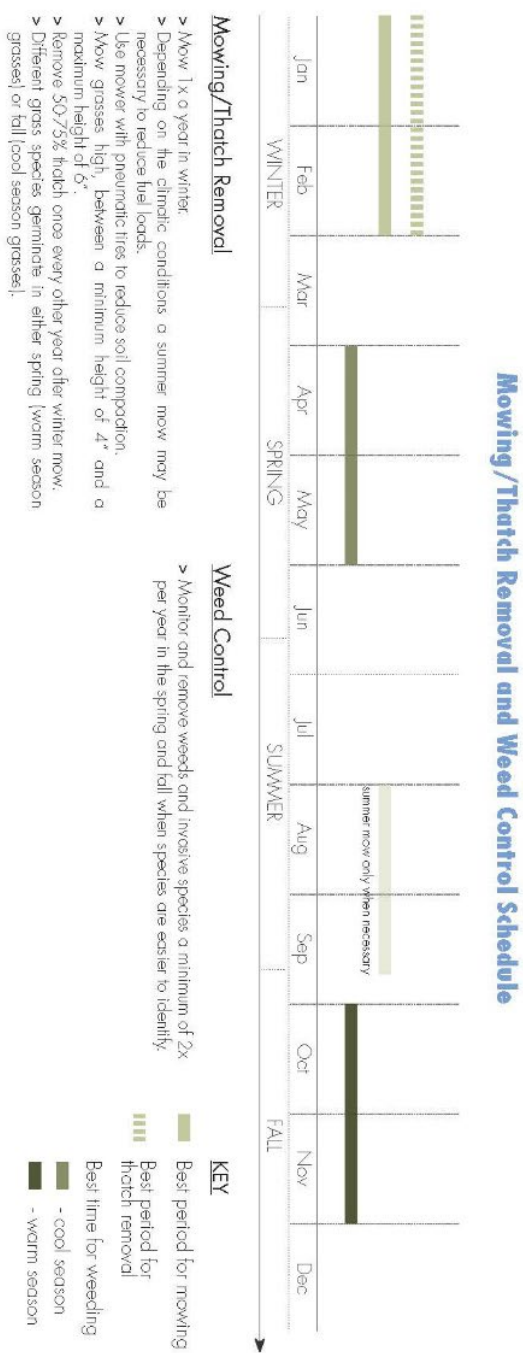


Figure 19. Example management schedule

## VI. References

- Army Corps of Engineers. Army Corps of Engineers - Regulatory guidance letters - ordinary high water mark identification [Internet]. 07/2005. Army Corps of Engineers.
- Burk, J. D., G. A. Hurst, D. R. Smith, B. D. Leopold, and J. G. Dickson. 1990. Wild turkey use of streamside management zones in loblolly pine plantations. *Proceedings of the National Wild Turkey Symposium* 6:84-89.
- Bellaire A, Higgins C, Fowler N, Keitt T, Jha S. 2019. Waller Creek Biodiversity & Ecosystem Monitoring Project. Technical Report. The Nature Conservancy, Texas.
- Caughlan L, Oakley KL. 2001. Cost considerations for long-term ecological monitoring. *Ecological Indicators* 1:123-134. [https://doi.org/10.1016/S1470-160X\(01\)00015-2](https://doi.org/10.1016/S1470-160X(01)00015-2)
- Cardinale, B. J., J. E. Duffy, A. Gonzalez, D. U. Hooper, C. Perrings, P. Venail, A. Narwani, G. M. Mace, et al. 2012. Biodiversity loss and its impact on humanity. *Nature*: 486:59–67. doi: 10.1038/nature11148.
- de Jesus Duarte S, Glaser B, Pellegrino Cerri CE. 2019. Effect of biochar particle size on physical, hydrological and chemical properties of loamy and sandy tropical soils. *Agronomy* 9(4):165. <https://doi.org/10.3390/agronomy9040165>.
- Dickson, J. G. 1989. Streamside zones and wildlife in southern U.S. forests. Pages131-133 in Greswell, R. E., and B. Kershner, eds. *Practical approaches to riparian resource management: an educational workshop*. U.S. Bureau of Land Management, Billings, Montana.
- Dickson, J. G., and J. C. Huntley. 1987. Riparian zones and wildlife in southern forest: the problem and squirrel relationships. Pages 37-39 in J. G. Dickson and O. E. Maughan, eds. *Managing southern forests for wildlife and fish*. U.S. Forest Service. Gen. Tech. Rep. SO-65.
- Eckbo, Garrett. 2002. *Landscape for living*. University of Massachusetts Press, Amherst, Massachusetts.
- Fleenor, S. B., and S. W. Taber. 2009. *Plants of Central Texas wetlands*. Texas Tech. University Press, Lubbock, TX.
- Gibson DJ & Newman JA, editors. 2017. *Grasslands and climate change*. United Kingdom: Cambridge University Press. 347 p. [www.cambridge.org/979110795264](http://www.cambridge.org/979110795264). DOI: 10.1017/9781108163941
- Grayson, J. E., M. G. Chapman, and A. J. Underwood. 1998. The assessment of restoration of habitat in urban wetlands. Centre for Research on Ecological Impacts of Coastal Cities, Marine Ecology, University of Sydney, Sydney, Australia.

- Gregory, S. V., F. J. Swanson, W. A. McKee and K. W. Cummins. 1991. An ecosystem perspective of riparian zones. *Bioscience* 41:540-551.
- Griffith, G. E., et al. 2004. *Ecoregions of Texas*. Environmental Protection Agency, Western Ecology Division.
- Halls, L. K. 1973. Managing deer habitat in loblolly-shortleaf pine forest. *Journal of Forestry* 71:752-757.
- Helzer C. 2010. *The ecology and management of prairies in the central United States*. Iowa City: University of Iowa Press. 173 p.
- Henley, W. F., M. A. Patterson, R. J. Neves, and A. D. Lemly. 2000. Effects of sedimentation and turbidity on lotic food webs: a concise review for natural resource managers. *Reviews in Fisheries Science* 8 (2):125-139.
- Holcomb, S. S. 2004. *An examination of the riparian bottomland forest in North Central Texas through ecology, history, field study, and computer simulation (Master's thesis)*. University of North Texas, Denton, TX.
- Jones-Lewey, M. E. S. (2015) *Your remarkable riparian: a field guide to riparian plants within the Nueces River Basin of Texas*, Nueces River Authority. Uvalde, TX.
- Kutac, E. A., and S. C. Caran. 1994. *Birds and other wildlife of South Central Texas: a handbook*. The University of Texas, Austin, TX.
- Leopold, Aldo. 1933. *Game management*. Charles Scribner's Sons, N.Y. Reprinted in 1986 by University of Wisconsin Press, Madison, WI.
- Lowrance, R. T., J. Fail, Jr., O. Hendrickson, Jr., R. Leonard, and L. Asmussen. 1984. Riparian forest as nutrient filters in agricultural watersheds. *Bioscience* 34:374-377.
- Maser, C., and J. Sedell. 1994. *From the forest to the sea: the ecology of wood in streams, rivers, estuaries, and oceans*. St. Lucie Press: Delray Beach, FL.
- Maxwell, Robert S. and Martin, James W., "Forestry Bulletin No. 20: A Short History of Forest Conservation in Texas, 1880-1940" (1970). *Forestry Bulletins* No. 1-25, 1957-1972. Book 16. <http://scholarworks.sfasu.edu/forestrybulletins/16>
- Mayer, P., S. Reynolds and T. Canfield. United States Environmental Protection Agency Office of Research and Development. 2005. *Riparian buffer width, vegetative cover, and nitrogen removal effectiveness: a review of current science and regulations*. <http://www.epa.gov/nrmrl/pubs/600R05118/600R05118.pdf>

Maywald, P. D., and D. L. Doan-Crider. Restoration manual for native habitats of South Texas. Caesar Kleberg Wildlife Research Institute. Texas A&M University, Kingsville, TX.

Messina, M. G., and W. H. Conner, eds. 1998. Southern forested wetlands: ecology and management. Lewis Publishers, Boca Raton, FL.

Murray, C., and D. Marmorek. 2003. Adaptive Management and Ecological Restoration. Ecological Restoration of Southwestern Ponderosa Pine Forests. The Science and Practice of Ecological Restoration Series. Washington: Island Press. 417-428.

Native Prairie Association of Texas. Tallgrass restoration manual.  
([http://texasprairie.org/index.php/manage/restoration\\_entry/tallgrass\\_restoration\\_manual/](http://texasprairie.org/index.php/manage/restoration_entry/tallgrass_restoration_manual/))

Nelle, S. 2009. Common plants of riparian areas--Central--Southwest Texas with wetland Indicator (WI) and proposed stability rating (SR). Natural Resources Conservation Service, San Angelo, TX. Contact: [steve.nelle@tx.usda.gov](mailto:steve.nelle@tx.usda.gov).

Packard, S and C. Mutel. 1997. The Tallgrass Restoration Handbook: For prairies, savannas, and woodlands. Society for ecological restoration international. Island Press.

Rout ME and Chrzanowski TH. 2009. The invasive Sorghum halepense harbors endophytic N<sub>2</sub>-fixing bacteria and alters soil biogeochemistry. Plant and Soil 315(1-2):163-172.

Rout ME, Chrzanowski TH, Smith WK, and Gough L. 2013a. Ecological impacts of the invasive grass Sorghum halepense on native tallgrass prairie. Biological Invasions 15(2):327-339.

Rout ME, Chrzanowski TH, Westlie TK, DeLuca TH, Callaway RM, and Holben WE. 2013b. Bacterial endophytes enhance competition by invasive plants. American Journal of Botany 100(9):1726-1737.

Rudolph, D. C., and J. G. Dickson. 1990. Streamside zone width and amphibians and reptiles abundance. Southwestern Naturalist 35:472-476.

Sala, O. E, F. S. Chapin, J. J. Armesto, E. Berlow, J. Bloomfield, R. Dirzo, E. Huber-Sanwald, L. F. Huenneke, et al. 2000. Global biodiversity scenarios for the year 2100. Science 287:1770–1774. doi: 10.1126/science.287.5459.1770.

Shirley, S. 1994. Restoring the tallgrass prairie. University of Iowa Press, Iowa City, IA. Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. 1974. Hays County Texas soil survey.

Strayer, D. L., R. E. Beighley, L. C. Thompson, S. Brooks, C. Nilsson, et al. 2003. Effects of land cover on stream ecosystems: roles of empirical models and scaling issues.

Ecosystems 6:407–23.

Sustainable Site Initiative. 2014. SITES V2 Reference Guide for sustainable land design and development. The Lady Bird Johnson Wildflower Center at The University of Texas.

Urban, J. 2008. Up by roots: healthy soils and trees in the built environment. International Society of Arboriculture. Champaign, IL.

U.S. Botanical Garden and Lady Bird Johnson Wildflower Center. 2014. Landscape for Life – based on the principals of the Sustainable Site initiative.

Wagner, M. 2003. Managing riparian habitats for wildlife. Texas Parks and Wildlife Department. PWD BR W7000-306.

Ward RJ, Griffiths RA, Wilkinson JW, Cornish N. 2017. Optimizing monitoring efforts for secretive snakes: a comparison of occupancy and N-mixture models for assessment of population status. *Scientific Reports* 7:18074 | DOI:10.1038/s41598-017-18343-5 1. [www.nature.com/scientificreports](http://www.nature.com/scientificreports)

Wanielista, M. P., N-B. Chang, M. Chopra, Z. Xuan, K. Islam, and Z. Marimon. 2012. Floating wetland systems for nutrient removal in stormwater ponds. Stormwater Management Academy Civil, Environmental, and Construction Engineering Department, University of Central Florida, Orlando, FL.

Whisenant, S. 2005. Repairing damaged wildlands: a process orientated, landscape-scale approach. Cambridge University Press: New York, NY.

White R, Murray S, Rohweder M. 2000. Pilot analysis of global ecosystems: grassland ecosystems technical report. Washington DC: World Resources Institute

Williams, B., and E. Brown, 2016. Technical challenges in the application of adaptive management. *Biological Conservation*. 195: 255-263.

Williams, J. E., C. A. Wood, and M. P. Dombeck, eds. 1997. Watershed restoration: principles and practices. American Fisheries Society, Bethesda, MD.

Woodson, D. 2013. Irrigation efficiency. Lecture conducted at the Texas AgriLife Research and Extension, Dallas, TX.

## VII. Appendix

### Appendix A. Data Sheets (also provided as an excel document)

#### 1. Field Check

Date: \_\_\_\_\_ Surveyor: \_\_\_\_\_ Rapid assessment-vegetation

Point/ location	Dominant communities	Soil surface condition overall (1-5)	Erosion class (1- 5)	Erosion extent (% cover)	Invasive (% cover)	Valuable species (% cover)	Invasives - other	High value - other
					total	total		
<b>Overall diversity</b>	<b>Woody age diversity</b>	<b>Dominants overstory</b>	<b>Dominants midstory</b>	<b>Dominants Herb</b>	Dominant spp.	heritage tree (>60.96 cm)		
					Ligustrum sp.	protected tree (>48.26 cm)		
					bermudagrass	Reference community spp.		
<b>Riparian buffer (width-ft)</b>	<b>Connection to floodplain (high/med/low)</b>	<b>Bottomland/ riparian diversity (high/med/low)</b>			<b>Challenges</b>	<b>Assets</b>	<b>Additional challenge/ asset</b>	<b>Boundary/ adjacent property</b>
<b>Comments</b>					Social trails	Reference species		
					Damaged soil	Healthy soil		
					Boundary influences	Microtopography		
					Poor access	Water availability		
					Invasive dominance	Existing work		
<b>Cover classes</b>		<b>Soil surface condition</b>			<b>Erosion classes</b>			
Class 1: None Class 2: trace Class 3: 1-25% Class 4: 26-50% Class 5: 51-75% Class 6: 75-100%		Class 5- <b>High</b> : developed organic layer, good structure, low/no disturbance  <b>Class 3: Medium</b>  Class 1- <b>Low</b> : thin, damaged, rocky, construction debris present			<b>Class 1: severe</b> , subsoil exposed, most rocks/plants pedestaled and roots exposed  <b>Class 3: moderate</b> movement of soil, surface rock/ or litter, pedestalling in flow patterns  <b>Class 5: no visual evidence of soil movement</b>			



## 2. Pre-design assessment

Date: \_\_\_\_\_ Surveyor: \_\_\_\_\_ Rapid assessment-vegetation

Point/ location	Ecological site / Community name	Overstory (% cover / diversity (1-5))	Midstory (% cover / diversity (1-5))	Ground (% cover / diversity (1-5))	Invasive (% cover)	Valuable species (% cover)	Invasives - other	High value - other
		% cover	% cover	% cover	total	total		
		Diversity	Diversity	Diversity	Dominant spp.	heritage tree (>60.96 cm)		
		Dominants	Dominants	Dominants	ligustrum sp.	protected tree (>48.26 cm)		
Overall diversity	Woody age diversity				bermudagrass	Reference community spp.		
Soil surface condition	Erosion severity	Erosion extent	Connection to floodplain (high/med/low)	Bottomland/ riparian diversity (high/med/low)	Challenges	Assets	Additional challenge/ asset	Boundary/ adjacent property
Comments					Social trails	Reference species		
					Damaged soil	Healthy soil		
					Boundary influences	Microtopography		
					Poor access	Water availability		
					Invasive dominance	Existing work		
<b>Cover classes</b>	<b>Soil surface condition</b>				<b>Erosion classes</b>			
Class 1: None Class 2: trace Class 3: 1-25% Class 4: 26-50% Class 5: 51-75% Class 6: 75-100%	Class 5- <b>High</b> : developed organic layer, good structure, low/no disturbance  Class 3: <b>Medium</b>  Class 1- <b>Low</b> : thin, damaged, rocky, construction debris present				Class 1: <b>severe</b> , subsoil exposed, most rocks/plants pedestaled and roots exposed  Class 3: <b>moderate</b> movement of soil, surface rock/ or litter, pedestalling in flow patterns  Class 5: no visual evidence of soil movement			

3. Soil condition classes

Characteristic	Class 1	Class 2	Class 3	Class 4	Class 5
<b>Soil movement</b>	Subsoil exposed on much of the area; may have embryonic dunes an/or wind scoured depressions	Soil and debris deposited against minor obstructions	Moderate movement of soil particles has occurred	Some movement of soil particles has occurred	No visual evidence of soil movement
<b>Surface rock and/or litter</b>	Very little remaining; if present, surface rock or fragments exhibit some movement and accumulation of smaller fragments behind obstacles	Extreme movement; many large deposits against obstacles; surface rocks exhibit movement; smaller fragments accumulate behind obstacles	Moderate movement; fragments deposited against obstacles, fragments have a poorly developed distribution pattern	May show slight movement; if present, coarse fragments have truncated appearance or spotty distribution caused by wind or water	Accumulation in place; if present, the distribution of fragments shows no movement caused by wind or water
<b>Pedestaling</b>	Most rocks and plants pedestaled and roots are exposed	Many rocks and plants pedestaled and roots are exposed	Rocks and plants pedestaled in flow patterns	Slight pedestaling in flow patterns	No visual evidence of pedestaling
<b>Flow patterns</b>	Flow patterns numerous, readily noticeable; may have large barren fan deposits	Flow patterns contain silt, sand deposits and alluvial fans	Well defined, small and few with intermittent deposits	Deposition of particles may be in evidence	No visual evidence of flow patterns
<b>Rills and gullies</b>	May be present at depths of 8-15 cm and at intervals of less than 13 cm; sharply incised gullies cover most of the area, with 50% actively eroding	Rills 1-15 cm deep at 150 cm intervals; gullies numerous and well developed; active erosion on 10-50% of their lengths or a few well-developed gullies with active erosion along more than 50% of their length	Rills 1-15 cm deep in exposed places at about 300 cm intervals; gullies well developed, with active erosion along less than 10% of their length with vegetation present	Few infrequent rills in evidence at distances of over 300 cm; evidence of gullies with little bed or slope erosion; some vegetation is present on slopes	No visual evidence of rills; may be present in stable condition, but with vegetation on channel bed and side slopes

## Appendix B. Methods

### 1. Vegetation Monitoring

#### **Houston Arboretum & Nature Center's Vegetation Monitoring Plots**

**Chris Garza**

#### **Introduction**

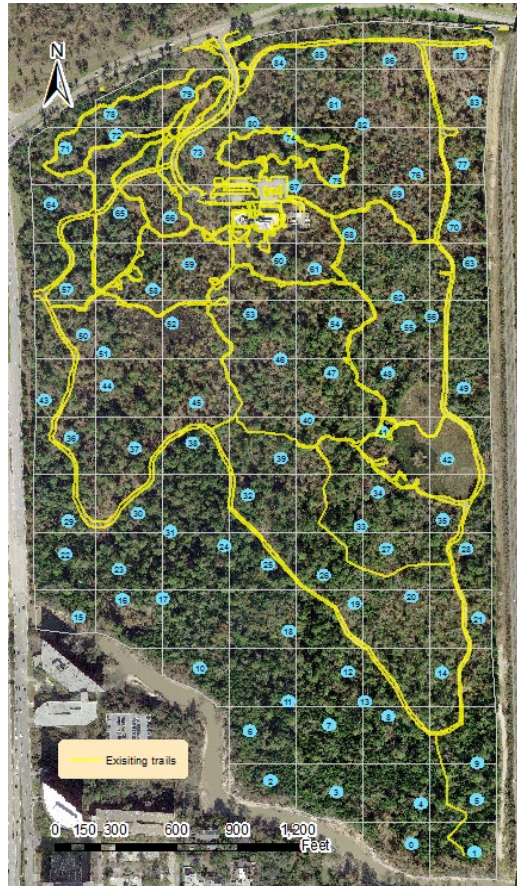
In 2015, a total of 88 permanent vegetation monitoring plots were created across the property of the Houston Arboretum & Nature Center. ArcMap software was used to generate these plots by placing a two acre grid across the site and randomly placing a plot center within each cell (Figure 1). When located with a Garmin GPS (each plot center is entered in the GPS as "RP##" with #'s denoting the plot number), each plot center is permanently established in the field with a stake. Vegetation monitoring consists of assessing trees, shrubs, and herbaceous plants (Figure 2). All trees with a diameter at breast height (dbh) greater than 6 inches within a circular 0.1 acre plot around the plot center have their dbh measured and the species are recorded. All trees and shrubs with a dbh between 3 and 6 inches are recorded the same way within a 0.05 acre subplot. All trees and shrubs with a dbh less than 3 inches are counted by species within the same 0.05 acre subplot. Grasses, forbs, vines, and tree/shrub seedlings are measured within a square meter quadrat around the plot center. Percent cover is recorded for each species. The percent cover of bare soil and leaf litter is also noted. Each year, a variable number of plots are sampled so that all 88 plots are sampled within 5 years. Plots can then be resampled and compared 5 years from when they were previously sampled. Refer to Figure 3 to see the plots when plots are to be sampled.

#### **Methods**

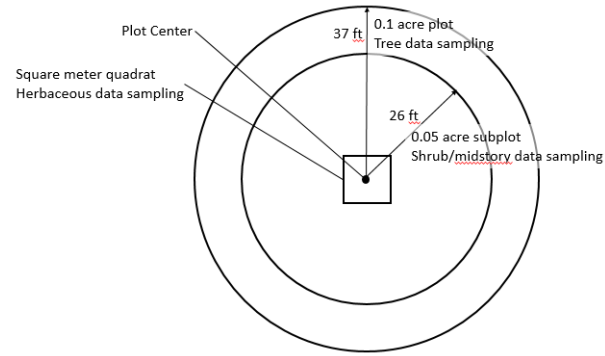
Materials used included a ½ meter by ½ meter square pipe, a compass, a GPS, eight pin flags, a DBH tape measure, and the data sheets. The location of each vegetation plot was determined with a GPS and a compass. An orange stake was placed in the ground at the center of the plot. Starting from the orange stake, two pin flags were placed in each cardinal direction, one 26 feet away and one 37 feet away from the orange stake. A DBH tape was used to measure the distance from the orange stake to the 26 and 37 feet marks in each direction. This effectively makes a big circle with a radius of 37 feet, and a smaller circle with a radius of 26 feet, both with the orange stake serving as the central point. One person stood at the orange stake holding the end of the tape measure while the other person measured and placed the pin flags. Once all of the pin flags were set up, a 1 meter vegetation sampling with the orange stake as the center point was completed. A compass was utilized to determine the northwest direction, and the ½ meter by ½ meter square pipe was placed in the northwest quadrant. Percentage of leaf litter and bare ground were recorded, as well as the species of any plant growing in the quadrant. This was repeated for the northeast, southeast, and southwest directions, effectively making a 1 meter square plot with the orange stake in the middle.

After the 1 meter square plot survey, trees were measured and counted. The DBH and species of any trees with a DBH over 6 inches and located within the bigger circle (radius of

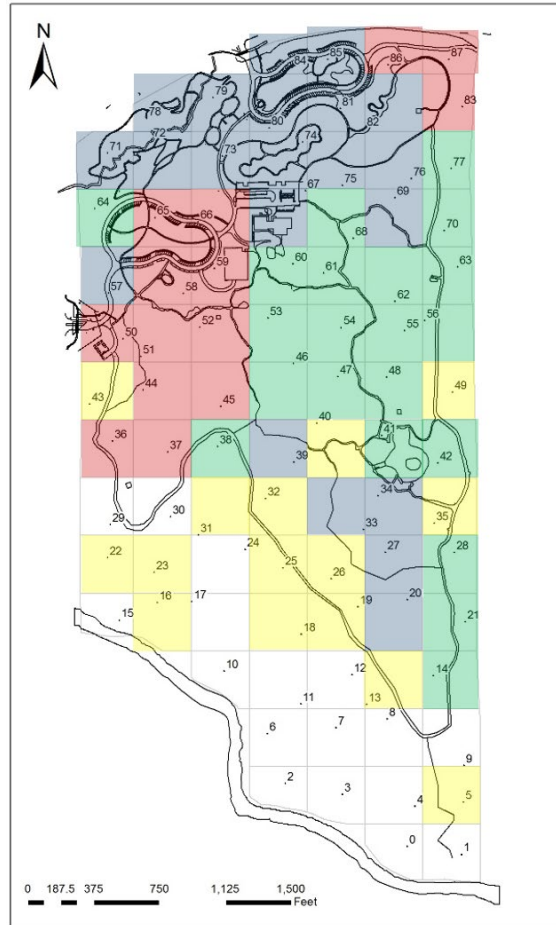
37 inches) were recorded. Any trees with a DBH between 3 and 6 inches and located only within the smaller circle (radius of 26 inches) were measured. The DBH and species were recorded. After that, any trees with a DBH below 3 inches and taller than hip height (around 3 feet) in the smaller circle were simply counted. The species and number of individuals of each tree were recorded.



**Figure 1:** In 2015, the 88 permanent vegetation monitoring plots were placed randomly within a two acre grid. Trees, shrubs, and herbaceous plants are monitored in these plots.



**Figure 2:** The vegetation monitoring plots were designed to sample trees, shrubs, and herbaceous plants.



**Figure 3:** The staggered plot sampling system over five years. Red plots (14 total) were sampled in 2015 and will be resampled in 2020. Yellow plots (15 total) were sampled in 2016 and will be resampled in 2021. Blue plots (21 total) were sampled in 2018 and will be resampled in 2023. Green plots (21 total) are to be sampled in 2019 and will be resampled in 2024. Note that no plots were sampled in 2017. The uncolored plots (17 total) can be sampled for the first time in 2022.



## 2. Pollinator Monitoring

### **Houston Arboretum Pollinator Methods- Chris Garza**

In 2015, 88 vegetation monitoring sites were chosen across the 155-acre HANC using ArcMap software, located with GPS coordinates, and permanently marked with a stake. 30 of these sites were randomly selected for pollinator community monitoring in addition to vegetation surveys to record changes in pollinator diversity with vegetation changes as the site undergoes continued restoration and development.

Materials used included a ½ meter by ½ meter square pipe, a compass, a GPS, a pin flag, a DBH tape measure, and the data sheets. A GPS device and compass were used to locate the pollinator plot locations marked with an orange stake. Once at the orange stake, the cardinal directions were determined with a compass. Then, one person stood over the orange stake holding one end of the tape measure while the other person walked with the tape measure in one cardinal direction until a distance of 26 feet was reached. A pin flag was placed in the ground at the 26 feet mark, and vegetation sampling around the flag was completed. With the pin flag serving as the center of a 1 meter square plot, the square pipe was placed in the northwest direction first, which was determined with a compass. The percentage of bare ground versus percentage of ground covered in leaf litter was recorded on the data sheets. Then any vegetation found within the square pipe was classified and its species and percent cover were recorded. The square pipe was then moved to the northeast quadrant of the 1 meter square plot and the percent cover and species present were again recorded. This was repeated for the southeast and southwest quadrants. If any flowers were present in or directly above the 1 meter square plot, the flowers were observed for 15 minutes and any pollinator activity was recorded along with the species of the pollinator. Then, the pin flag was taken back to the orange stake, the center of the big plot. Once a second cardinal direction was determined, one person held the end of the tape measure and the other walked 26 feet in the cardinal direction. As before, the pin flag was placed at the 26 feet mark and a 1 square meter vegetation survey was performed around the pin flag. This whole process was repeated for the two remaining cardinal directions. The relative humidity, temperature, and wind speed were determined with an iPhone and recorded on the data sheets as well.