Houston Parks Board, Prairie 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 Prairie 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-

I. Background

A. Prairie 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

Grassland is a grass dominated biome that provides a suite of critical ecosystem services including carbon storage, water capture and cleaning, food and forage as well as being home to an enormous number of plants and animals.

Grassland

Is a biome that covers 31-43 percent of the Earth's terrestrial habitats that is now critically endangered. Defining grassland is surprisingly difficult, with many proposed definitions. The International Forage Grazing Terminology Committee defines native or natural grassland as a natural ecosystem dominated by indigenous or naturally occurring grasses and other herbaceous species used mainly for grazing by livestock and wildlife (Gibson & Newman 2019).

The International Vegetation Classification (IVC) recognized 49 taxonomically and spatially distinct historic and current grasslands (Gibson & Newman 2019). This guidance document is concerned primarily with two - savanna and prairie, defined below.

Savanna

Savannas are grassland ecosystems with small trees or widely-spaced trees that do not create a canopy and retain a ground cover dominated by herbaceous plants. Across the Midwest a mosaic of forest, savanna, and prairie communities existed due to landscape and climatic conditions in addition to biotic interactions and fire history (Anderson 1983). Savannas represent the middle of the continuum from forest to prairie (Barbour et al. 1980).

Prairie

Prairie's are grasslands with a diverse plant community dominated by native grasses and forbs. Prairies that have survived the last few hundred years without being plowed for farming or had the majority of their species replaced through the processes of overgrazing, urban development or invasive species encroachment are called remnant prairies (Helzer 2007).

The North American Prairies historically covered over 170 million acres of North America (Figure 1). It was the continent's largest continuous ecosystem and one of the most diverse in the world, surpassed only by the rainforest of Brazil[1]. The prairies and savannas recognized today formed between 8000 and 10000 years ago. The disturbance-driven ecologies rely on periodic fire and grazing to maintain their diversity and their structure. Overgrazing, fire suppression, and tilling beginning in the mid-1800s in North America, and more recent urbanization, have made these once dominant ecosystems critically endangered. However, prairies and savannas are resilient and they, and the ecosystem services they provide, can be restored over time. This is not to diminish the importance of preserving remnant prairies and the efforts and expense that go into the reconstruction process of a prairie[2].

Figure 1. Historic grassland types of North America based on mapping data from NatureServe (Comer et al. 2018) and the International Vegetation Classification and Terrestrial Ecoregions of the World (Dixon et al. 2014). Map: Daniel Huffman[3]

[1] NPS.gov. A complex prairie ecosystem. https://www.nps.gov/tapr/learn/nature/a-complex-prairie-ecosystem.htm
[2] https://moprairie.org/2020/02/26/prairie-remnants-restorations-reconstructions/#:~:text=Restoration%3A%20enhancing%20a%20site%20that%20has%20been%20degraded,row-cropped%20and%20plowed%20site%2C%20with%20a%20seeded%20planting.
[3] https://www.audubon.org/conservation/working-lands/grasslands-report

Texas grasslands once covered over 128,000,000 acres, approximately over three quarters of the state. The key characteristic of Texas' grasslands was the lack of trees and dominance of graminoid species (grass and sedges) and diverse and species-rich forb component. The lack of woody species was due to the effects stemming from wildfires that historically occurred every 10-11 years in some areas and in

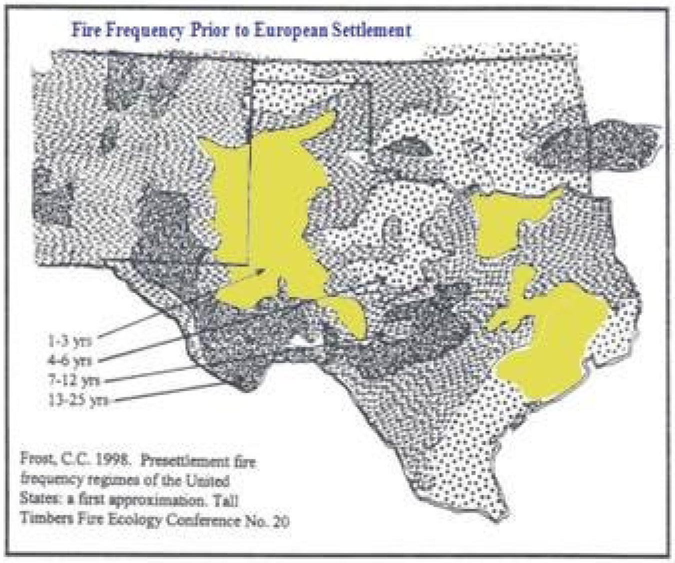


Figure 2. Historical Fire Frequency in Houston (Coastal Prairie Conservancy)

the Houston area as frequent as 1-3 years intervals (Figure 2.) covering over 14,000,000 acres of the state. In addition to wildfires fires influence, high intensity/low frequency grazing that occurred at random intervals during the movements of various megafauna ungulates that dominated North America such as the American bison and wild horses suppressed woody species. The makeup of grassland plant communities was largely driven by soil type, slope, and aspect and these characteristics influenced moisture regimes within the soil. Microtopographic variations in upland grasslands, though subtle, helped create a patchwork of distinct zones of influence and allowed dry and wet plant communities to exist immediately adjacent to one another over a landscape scale (Collins 1975). While mima mound formations are a classic example of such microtopography, even more minimal changes in grade from the shrink/swell properties of clay soils created gilgai formations that resulted in shallow depressions measuring a few feet across and less than 12" deep, creating vast areas of micro-relief across the landscape (Kishne 2009). This information is important because upland grasslands are often associated as consistent communities, but this could not be further from the truth. Incorporating minimal changes into soil elevations allows for a richer and diverse community that consists of gulf coast plain upland (UPL), facultative upland (FACU), facultative (FAC), and even facultative wetland (FACW) communities. Texas is divided into ten general ecoregions with most of them supporting grassland ecosystems: the Piney Woods, the Gulf Prairies and Marshes, the Post Oak Savanah, the Blackland Prairies, the Cross Timbers, the South Texas Plains, the Edwards Plateau, the Rolling Plains, the High Plains, and the Trans-Pecos (Figure 3).

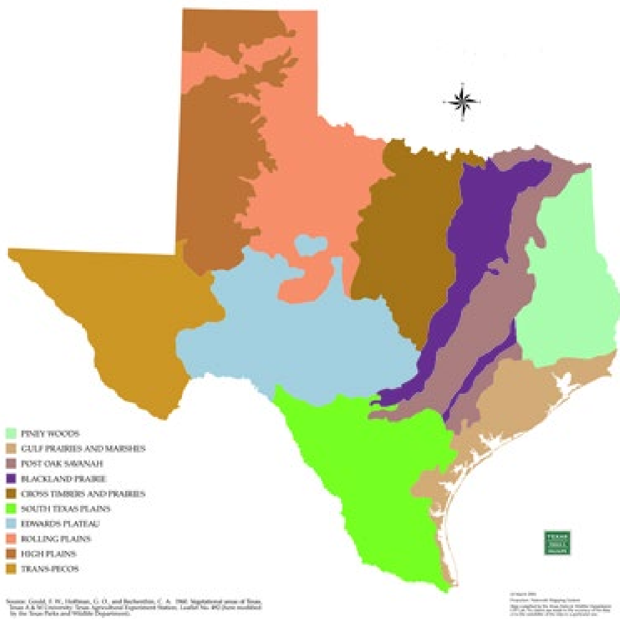


Figure 3. Texas Ecoregions (Texas Parks and Wildlife) [4]

The Gulf Coast Prairie is the primary ecosystem of the greater Houston region (Figure 4). Prairies are an iconic Texas landscape and once accounted for more than 70% of the greater Houston region[5]. The Gulf Coast Prairie is a flat and slow draining linear prairie system following the Gulf Coast. As a whole, less than 1% of the Gulf Coast Prairie ecosystem, in its highest quality, remains due to the removal of fire, grazing, and development patterns. This diverse ecosystem is now in critical decline in addition to the majority of grasslands in North America which are estimated to have only 5% left in the United States.

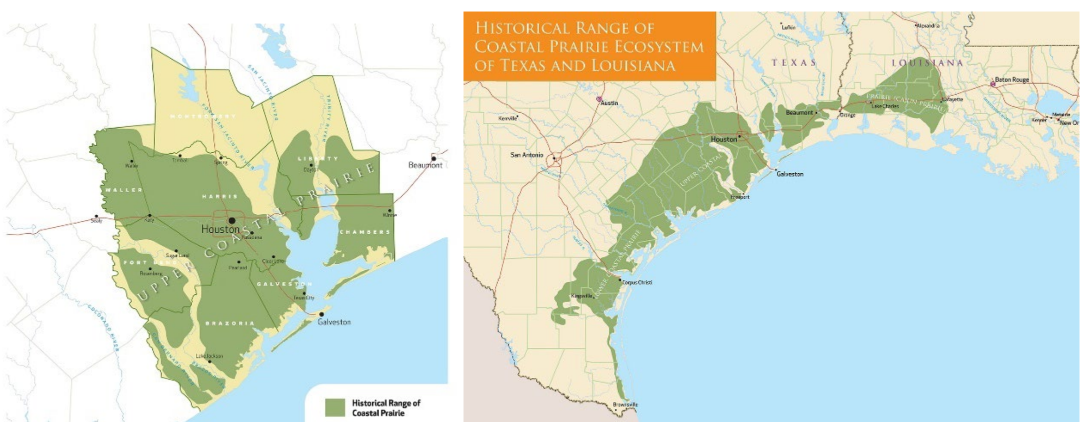


Figure 4. Coastal Prairie in Houston Figure and Historical range of Coastal Prairie (Coastal Prairie Conservancy)[6]

---

[4] https://tpwd.texas.gov/education/hunter-education/online-course/wildlife-conservation/texas-ecoregions

[5] Coastal Prairies — HERE in Houston

[6] https://www.katyprairie.org/prairies

The Gulf Coast Prairie provides a significant amount of ecosystem services but is especially valuable when considering water function. Prairies slow, store, and soak water into their system. The grasses that grow in the irregular prairie surface cause the landscape to perform as a green sponge. Prairie grasses have deep, dense root systems that absorb water and increase the soil porosity. The small depressions in the landscape can hold water for long periods of time reducing runoff. This capture impacts flooding by reducing water velocities and volume through detention and retention as well as infiltration, while additionally improving water quality with sediment and pollutant removal. For more on the benefits of Gulf Coast Prairie and flooding please refer to the Coastal Prairie Conservancy's document on Natural Solutions to Flooding[7].

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.

Grasslands provide many important goods and services such as food, forage, recreation, wildlife habitat and ecosystem services such as: stormwater management, soil conservation, soil carbon storage, aquifer recharge, soil water conservation during drought, improved soil and chemical properties (Gibson & Newman 2019). Additionally, all green spaces reduce the heat island effect, improve air quality, and provide recreational and cultural value (Bellaire 2019).

Grasslands particularly shine in their ability to provide services in densely developed urban environments. Very small prairies can provide refugia for pollinators and grassland birds moving through the city. Grasslands are a significant soil carbon sink compared to other ecosystems, with up to 90 percent of biomass below ground (estimated at 650-810 gigatons of carbon worldwide (White et al. 200 *in* Gibson & Newman 2019). Grassland communities and the soils they build are particularly good at infiltrating and filtering water over a short distance (Barrett et all 2006). The management BMPs outlined in this manual are designed to protect, enhance, or rebuild the ability of grassland communities to provide these and other services.

D. Sustainable development

Sustainable development protects and enhances ecological function while integrating it with human use. The following process (Figure 5) 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.

[7] Natural Solutions to Flooding

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).

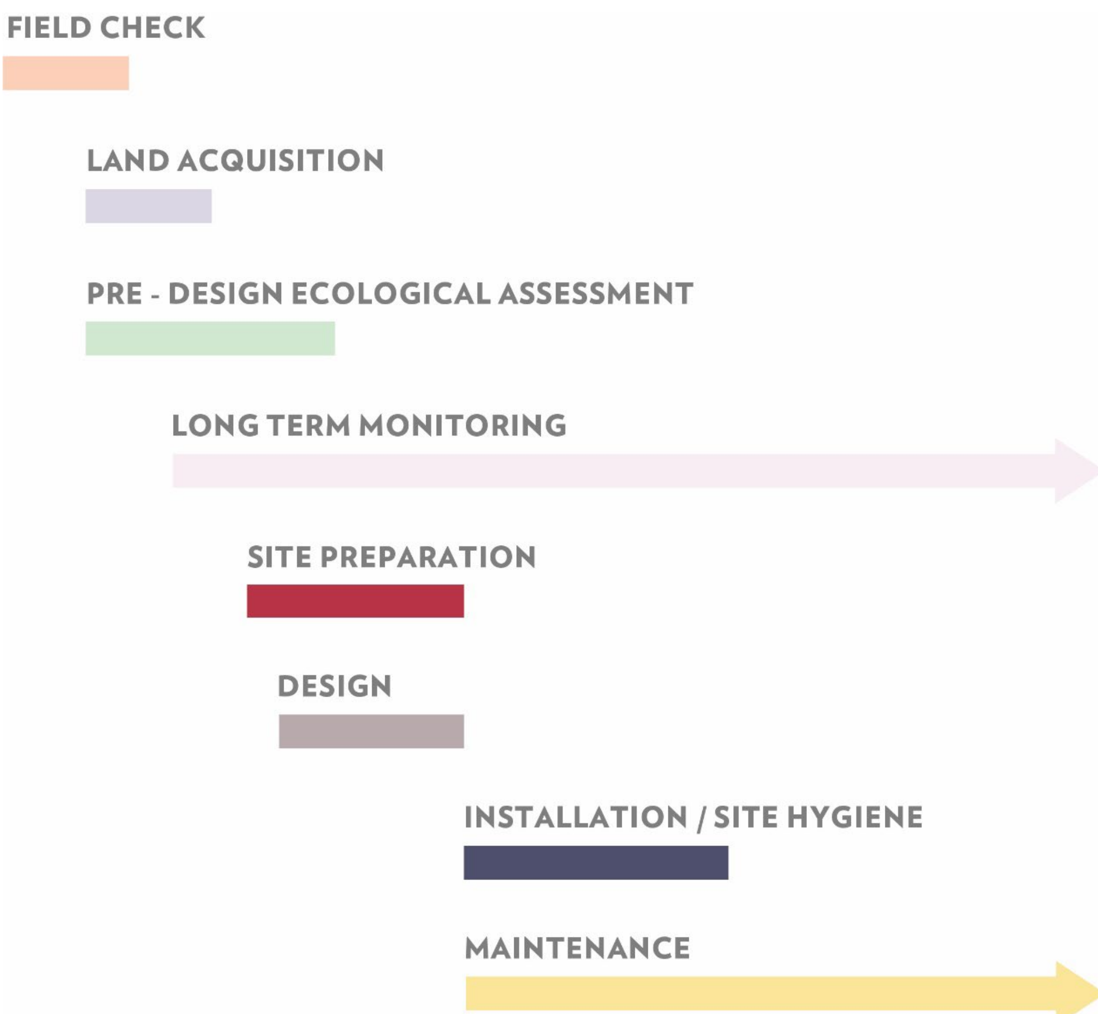


Figure 5. Project Sequencing and Major Milestones

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[8]. 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 6). Houston Wilderness defines ecoregions as large areas of land or water that contain geographically distinct assemblages of species, natural communities, and environmental conditions[9].

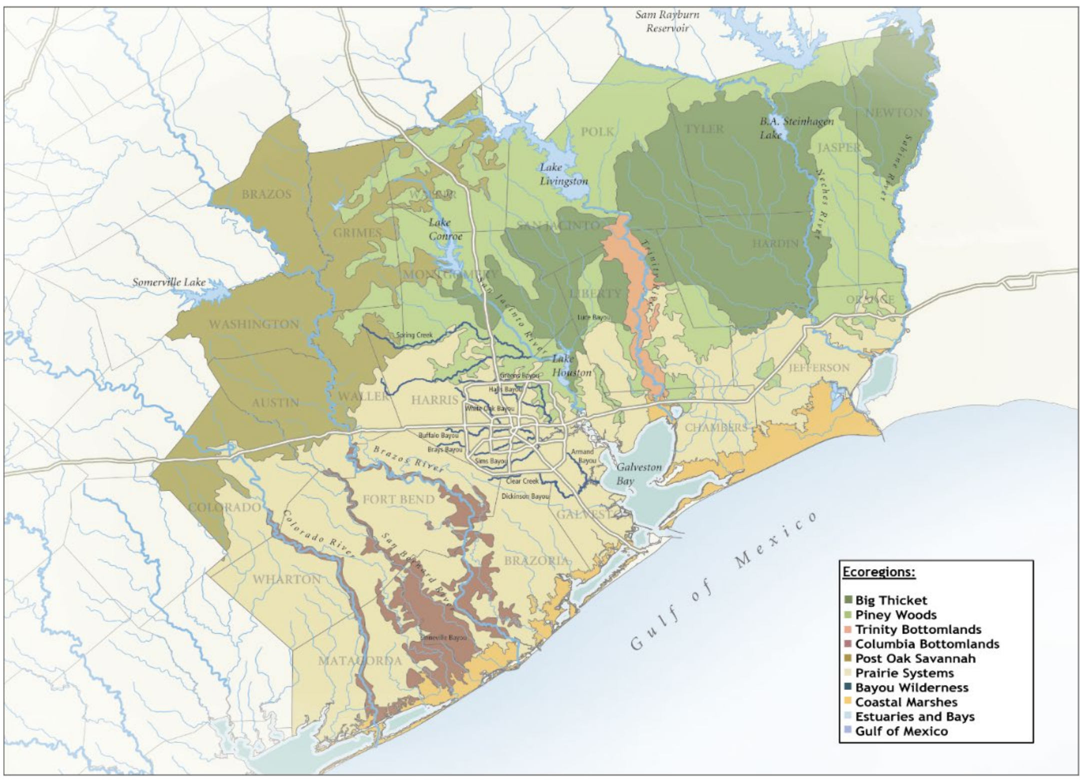


Figure 6. Houston area ecoregion map.

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 prairie, woodland/forest, wetland, riparian, and native landscaping. Prairies were once the

[8] https://hotspotcitiesproject.com/cities/houston
[9] https://houstonwilderness.org/about-ecoregions

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 periodically for life of project	Evaluate contribution to Ecological goals, provide data on restoration evolution	Species use as habitat, soil condition, 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 Field check 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 7). 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.

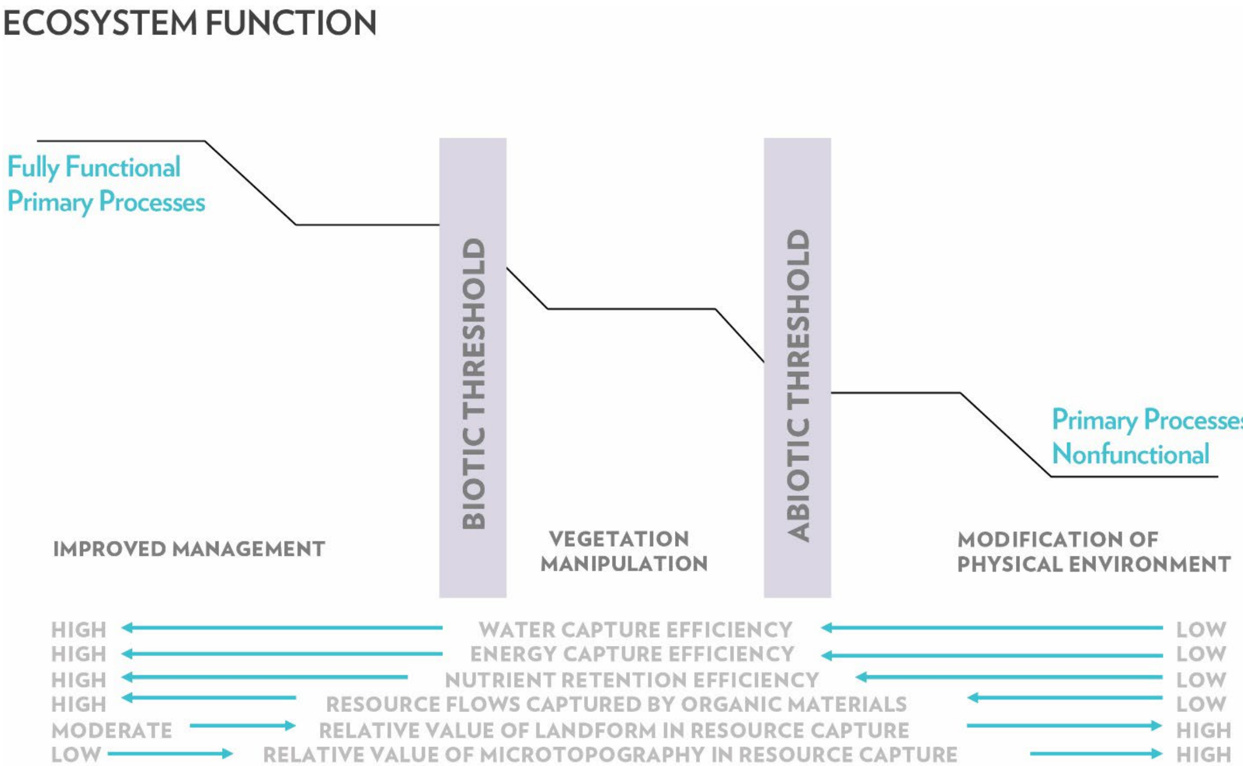


Figure 7. Ecological function. (Whisenant 2002)

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[10]. 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. 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)

[10] USDA-NRCS Web Soil Survey. https://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm

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

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
- 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
- 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[11]
- Zones of land cover/vegetation types. Note invasive species, native communities, special status plants and relative abundance classification (Abundant, common, frequent, occasional, rare[12]). 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)

---

[11] https://tpwd.texas.gov/landwater/land/habitats/cross_timbers/endangered_species/

[12] https://tpwd.texas.gov/huntwild/wild/wildlife_diversity/nongame/tcap/sgcn.phtml

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.

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

- Infiltrometor or Amoozemeter
- 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, before construction begins, 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 is the USGS Tidal Marsh Monitoring Program[13]. Another protocol example is the Photo-Point Standard Operating Procedures developed by USGS[14]. 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.

[13] http://www.tidalmarshmonitoring.net/pdf/USGS_WERC_Photo-Point_SOP.pdf

[14] 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 HBP 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. As identified as one of City of Houston's Resilient Houston goals 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[15] 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[16] 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[17].

Potential issues with this metric

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

[15] https://www.houstontx.gov/codes/
[16] https://sustainablesites.org/resources
[17] https://www.epa.gov/water-research/national-stormwater-calculator

Biodiversity

Summary and purpose

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.

<u>Potential Issues with this Metric</u>

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

<u>Summary and Purpose</u>

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.

<u>How we Measure</u>

- 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.[18] Houston's temperatures on a whole are getting hotter and hotter as seen in the Houston Climate Impact assessment.[19]

[18] https://weather.com/safety/heat/news/2021-06-03-heat-america-fatalities

[19] https://www.houstontx.gov/mayor/Climate-Impact-Assessment-2020-August.pdf

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 [20]

Potential issues with this metric

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

[20] 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, particularly in seed mixes. However, even at the start of the project, late successional grasses should be encouraged. They can be included in seed mixes, but live planting them is often worth the expense. **The mycorrhyzal fungi they bring with their roots can help the soil progress more quickly toward a mature state**.
- 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 the 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.

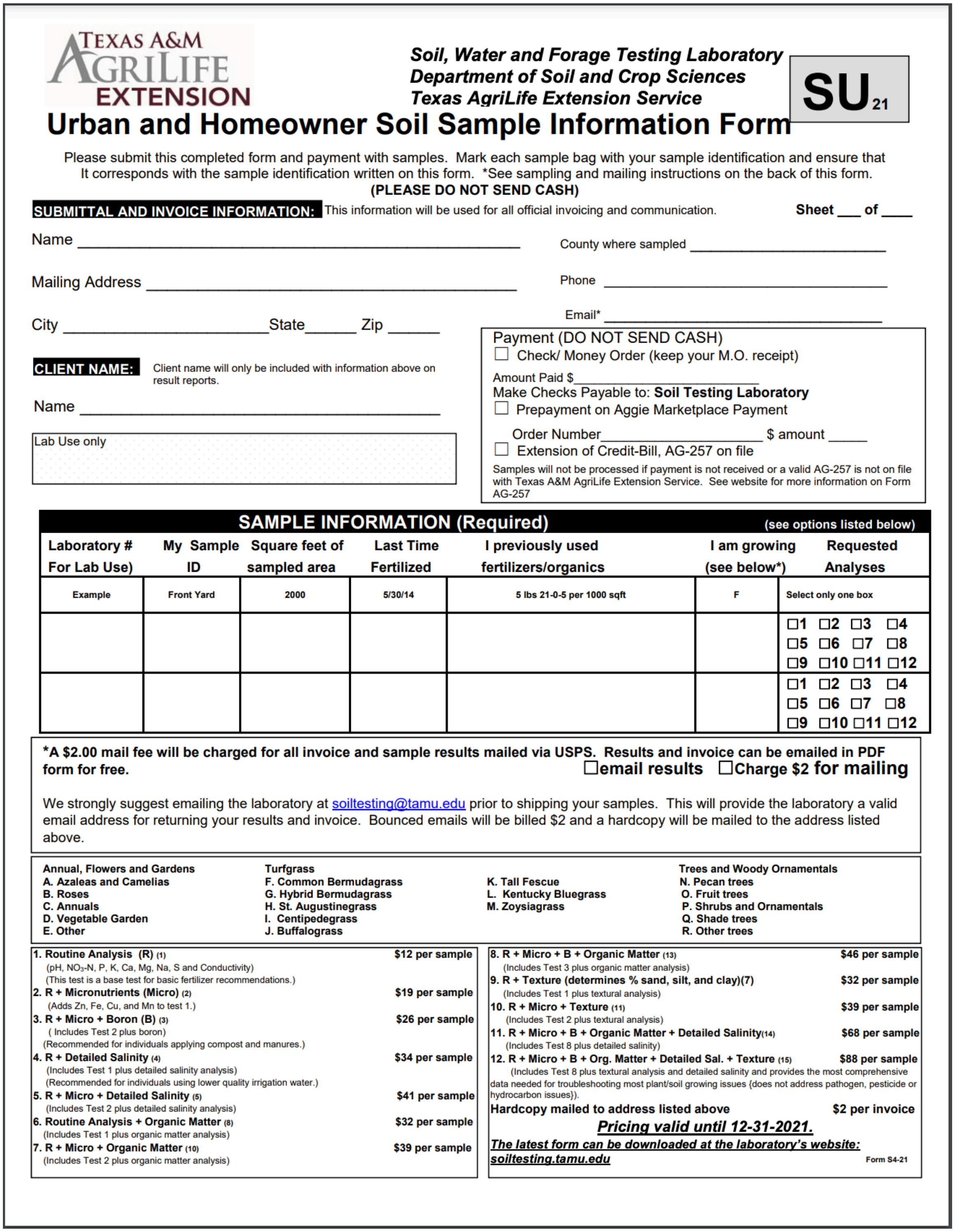
V. Installation & Maintenance

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_{12}* (Figure 8) 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



Texas A&M AgriLife Extension

Soil, Water and Forage Testing Laboratory
Department of Soil and Crop Sciences
Texas AgriLife Extension Service

SU21

Urban and Homeowner Soil Sample Information Form

Please submit this completed form and payment with samples. Mark each sample bag with your sample identification and ensure that It corresponds with the sample identification written on this form. *See sampling and mailing instructions on the back of this form.

(PLEASE DO NOT SEND CASH)

SUBMITTAL AND INVOICE INFORMATION: This information will be used for all official invoicing and communication. **Sheet ___ of ____**

Name ______________________ County where sampled ______________

Mailing Address ______________________ Phone ______________

City ____________ State______ Zip ______ Email* ______________

CLIENT NAME: Client name will only be included with information above on result reports.

Name ______________________

Lab Use only

Payment (DO NOT SEND CASH)
☐ Check/ Money Order (keep your M.O. receipt)
Amount Paid $____________
Make Checks Payable to: **Soil Testing Laboratory**
☐ Prepayment on Aggie Marketplace Payment
Order Number____________ $ amount _____
☐ Extension of Credit-Bill, AG-257 on file
Samples will not be processed if payment is not received or a valid AG-257 is not on file with Texas A&M AgriLife Extension Service. See website for more information on Form AG-257

SAMPLE INFORMATION (Required) (see options listed below)

Laboratory # For Lab Use)	My Sample ID	Square feet of sampled area	Last Time Fertilized	I previously used fertilizers/organics	I am growing (see below*)	Requested Analyses
Example	Front Yard	2000	5/30/14	5 lbs 21-0-5 per 1000 sqft	F	Select only one box
						☐1 ☐2 ☐3 ☐4 ☐5 ☐6 ☐7 ☐8 ☐9 ☐10 ☐11 ☐12
						☐1 ☐2 ☐3 ☐4 ☐5 ☐6 ☐7 ☐8 ☐9 ☐10 ☐11 ☐12

***A $2.00 mail fee will be charged for all invoice and sample results mailed via USPS. Results and invoice can be emailed in PDF form for free.** ☐**email results** ☐**Charge $2 for mailing**

We strongly suggest emailing the laboratory at soiltesting@tamu.edu prior to shipping your samples. This will provide the laboratory a valid email address for returning your results and invoice. Bounced emails will be billed $2 and a hardcopy will be mailed to the address listed above.

Annual, Flowers and Gardens
A. Azaleas and Camelias
B. Roses
C. Annuals
D. Vegetable Garden
E. Other

Turfgrass
F. Common Bermudagrass
G. Hybrid Bermudagrass
H. St. Augustinegrass
I. Centipedegrass
J. Buffalograss
K. Tall Fescue
L. Kentucky Bluegrass
M. Zoysiagrass

Trees and Woody Ornamentals
N. Pecan trees
O. Fruit trees
P. Shrubs and Ornamentals
Q. Shade trees
R. Other trees

1. Routine Analysis (R) (1) — **$12 per sample**
(pH, NO_3-N, P, K, Ca, Mg, Na, S and Conductivity)
(This test is a base test for basic fertilizer recommendations.)

2. R + Micronutrients (Micro) (2) — **$19 per sample**
(Adds Zn, Fe, Cu, and Mn to test 1.)

3. R + Micro + Boron (B) (3) — **$26 per sample**
(Includes Test 2 plus boron)
(Recommended for individuals applying compost and manures.)

4. R + Detailed Salinity (4) — **$34 per sample**
(Includes Test 1 plus detailed salinity analysis)
(Recommended for individuals using lower quality irrigation water.)

5. R + Micro + Detailed Salinity (5) — **$41 per sample**
(Includes Test 2 plus detailed salinity analysis)

6. Routine Analysis + Organic Matter (8) — **$32 per sample**
(Includes Test 1 plus organic matter analysis)

7. R + Micro + Organic Matter (10) — **$39 per sample**
(Includes Test 2 plus organic matter analysis)

8. R + Micro + B + Organic Matter (13) — **$46 per sample**
(Includes Test 3 plus organic matter analysis)

9. R + Texture (determines % sand, silt, and clay)(7) — **$32 per sample**
(Includes Test 1 plus textural analysis)

10. R + Micro + Texture (11) — **$39 per sample**
(Includes Test 2 plus textural analysis)

11. R + Micro + B + Organic Matter + Detailed Salinity(14) — **$68 per sample**
(Includes Test 8 plus detailed salinity)

12. R + Micro + B + Org. Matter + Detailed Sal. + Texture (15) — **$88 per sample**
(Includes Test 8 plus textural analysis and detailed salinity and provides the most comprehensive data needed for troubleshooting most plant/soil growing issues {does not address pathogen, pesticide or hydrocarbon issues}).

Hardcopy mailed to address listed above — **$2 per invoice**

Pricing valid until 12-31-2021.

The latest form can be downloaded at the laboratory's website: soiltesting.tamu.edu

Form S4-21

Figure 8. Soil sample information form

The key to understanding this test is that the lab is using the soil sample results to provide macro level amendments for a crop. Prairie restoration does not require a robust fertilization regime. This is mainly because many prairie/grassland species evolved in what agronomists would call “nutrient poor” conditions. If you treat prairie 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 (Figure 9).

TEXAS A&M AGRILIFE EXTENSION

Report generated for:

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

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.	Fertilizer Recommended
pH	7.5	(5.8)	-	Slightly Alkaline	
Conductivity	144	(-)	umho/cm	None	
Nitrate-N	14	(-)	ppm**		10 lbs N/acre
Phosphorus	17	(50)	ppm		35 lbs P2O5/acre
Potassium	100	(130)	ppm		5 lbs K20/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

Organic Matter	2.43	%

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	

*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 availabe 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, HCO3). 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 9. 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:

- Bermudagrass (*Cynodon dactylon*)
- Johnsongrass (*Sorghum halepense*)
- Brome (*Bromus* spp.*)*
- Old World Bluestems
- Bahiagrass (*Paspalum notatum*)
- Malta star thistle (*Centaurea melitensis*)
- Burr clover (*Medicago polymorpha*)
- Yellow sweet clover (*Melilotus officinalis*)
- Bastard cabbage (*Rapistrum rugosum*)
- Spreading hedgeparsley (*Torilis arvensis*)
- Cheeseweed (*Malva neglecta*)
- Curly dock (*Rumex crispus*)
- Field bindweed (*Convolvulus arvensis*)

These invasives and 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.

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[21], increasing data demonstrates that they also cultivate specific microbes through root exudates[22] and prevent development of the soil food web, excluding important drivers of later successional growth such as mycorrhizae. See Figure 10. For a graph of normal vegetation trajectory, fungal:bacterial ratio, and microbial biomass in soil.

[21] "Leachates from johnsongrass inhibited vegetative and sexual growth of the dominant Texas prairie grass in the United States." (Rout et al., 2013a)

[22] "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).

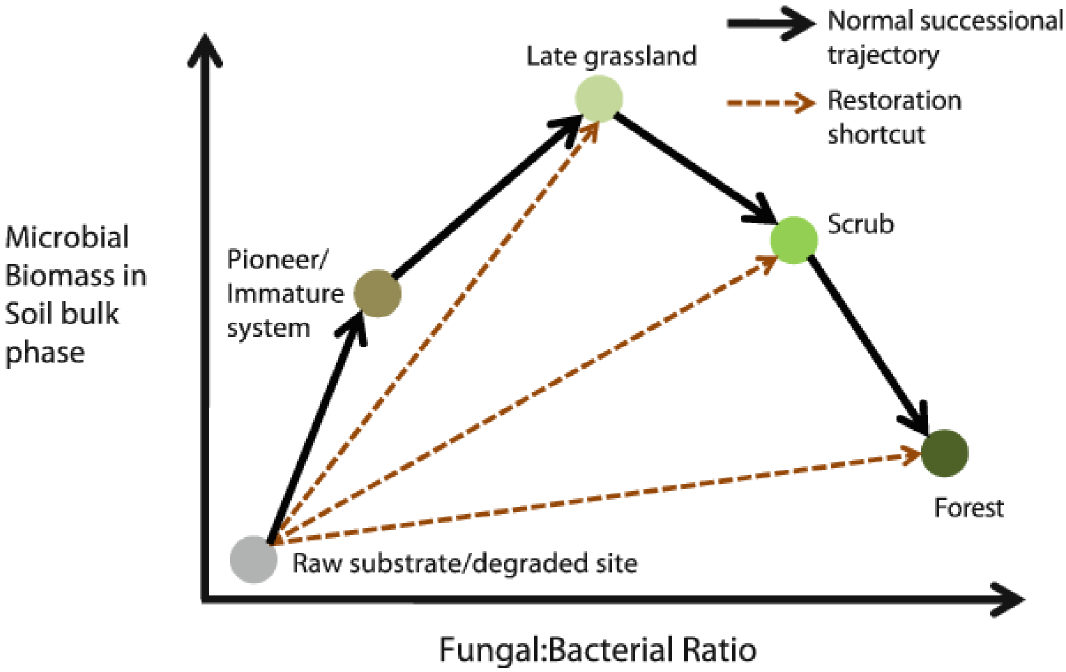


Figure 10. Facilitators or Followers graph.
Relationship between ecosystem successional state and microbial community size and composition. Copyright: JA Harris. From (Harris 2009)

<u>It is recommended that the conservation team should develop an Integrated Pest Management (IPM) plan specifically for the Conservation Program's invasive species needs.</u> 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.

For more information regarding IPM management please refer to the *HPB BMP Maintenance and Management Manual*.

Table 2. Common invasive species and treatment. Sources are a compilation of resources and practitioner experience. Be sure to read labels and follow HPB established 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 (*Cynodon dactylon*) - Similar to site clearing due to invasive potential	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 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.

Bahia grass (*Paspalum notatum*)	HPB method- 7 put 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 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
Johnsongrass (*Sorghum halepense*)	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 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 criticalto 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

	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
Old World Bluestems - Similar to site clearing due to invasive potential	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 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.
Brome (*Bromus spp.*)	23.6% Ammonium Salt of Imazapic (Plateau) - 4 to 8 oz per acre. Pre-emergent weed control in crop converted stands. Post-emergent weed control of brome species, Johnsongrass, crabgrass, cocklebur in established stands. Label will indicate tolerant NWSG & forbs. Mix with Methylated Seed Oil if forbs not in seed mix. Use silicone-based surfactant if forbs present in seed mix.

Perennial Rye (*Lolium perenne*)	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 (*Rubus trivialis*) 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 specfic 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
McCartney Rose (Rosa bracteate) 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
Chinese Privet (Ligustrum sinense)5 out of 10	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.
	Preferred control method is mechanical removal and herbicide applied in the spring/summer.

Yaupon (Ilex vomitoria). 4 out of 10	2, 4-D Amine, Triclopyr 4, and MSO* recipe came from TPWD and mixed in large batches. Cutting the stump is the application method.
Chinese Tallow (Triadica sebifera)6 out of 10	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.
McCartney Rose (Rosa bracteate) 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
Deep Rooted Sedge (Cyperus enterianus) 9 out of 10	Preferred control method is herbicide applied in the spring/summer. Halosulfuron-methyl 5% 1 packet covers 1000 sq. ft.
Guinea Grass (Megathyrsus maximus) 5 out of 10	Preferred control method is herbicide applied in the spring/summer with young vegetative growth and actively growing. 1.5% glyphosate can be used to kill individual plants with perfect coverage. Use 2% of a 41% solution + surfactant formulation if you don't think you will have perfect coverage. If you have good funding or resources, 3% gives a quicker kill, but not a more thorough kill.
Itchgrass. (Rottboellia chochinchinensis) 5 out of 10	Preferred control method is herbicide applied in the spring/summer with young vegetative growth and actively growing. Fluazifop applied at 6 to 12 oz/A to achieve mortality. This will affect othre grasses as well.
	Preferred control method is hand removal for individual plants or small infestations. Be sure to wear gloves as this species is poisonous.

Castor Bean (Ricinus communis) 5 out of 10	For larger infestations, apply foliar spot treatment of triclopyr 1% v/v solution (Garlon3A) or for cut stump treatement use 100% v/v solution (Garlon 3A).

F. Soil preparation

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 11) 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 12). 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 11. Cone scale penetrometer image

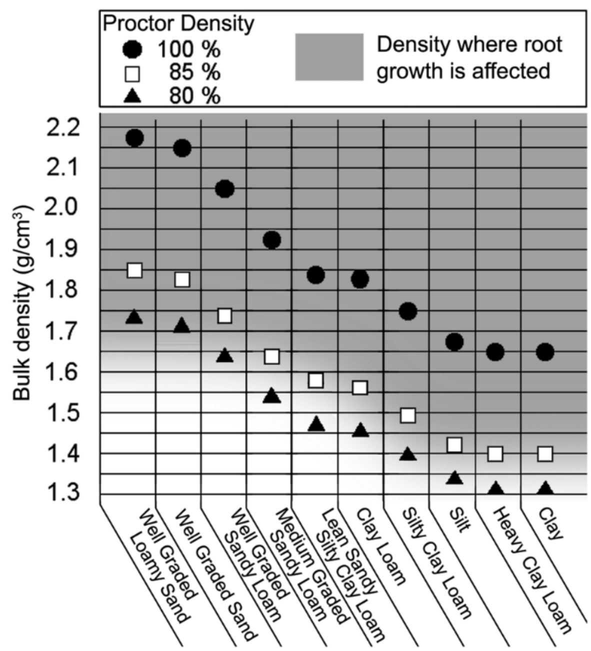


Figure 12. Bulk Density to Standard Proctor Density graph. James Urban, Up By Roots, Healthy Soils and Trees in the Built Environment.

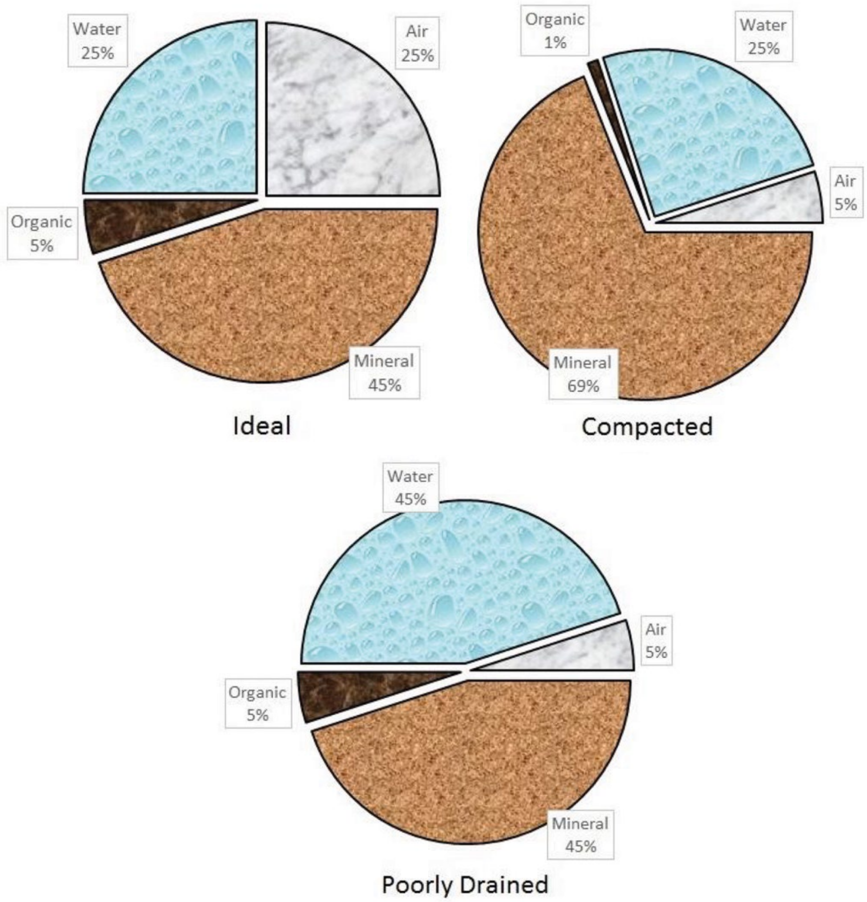


Figure 13. Image of soil particles. Luke Gatiboni, Extension Soil Fertility Specialist and Assistant Professor, NC State Department of Crop & Soil Sciences, North Carolina State University Extension.

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 prairie 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."[23] 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."[24] 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

Seeding is the most cost-effective means of achieving diversity and richness within a grassland restoration. The key to seeding successfully is ensuring that seeding is done with appropriate species and rates, with correct method, and within appropriate seasonal windows. Blackland Collaborative has provided Houston Parks Board conservation staff with a starter seed mix to

[23] "Effect of Biochar Particle Size on Physical, Hydrological and Chemical Properties of Loamy and Sandy Tropical Soils." (de Jesus Duarte et al. 2019).
[24] Ibid., (de Jesus Duarte et al. 2019).

reference that they can incorporate (Table 3). It is strongly recommended that recommended seed rates are doubled or tripled. This will provide the projects with an instant native seed bank and help combat competition and has proven successful in a number of Blackland Collaborative projects.

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 teams regular duties for yearly supplemental diversity seedings.

Table 3. Starter Seed Mix

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

Table 4. Diversity Seed Mix

SEED MIX TYPE 2: DIVERSITY MIX			
Habit	**Scientific Name**	**Common Name**	**Apply**
grass	*Andropogon virginicus*	Broomsedge bluestem	Spring
grass	*Carex cherokeensis*	Cherokee Sedge	Spring
grass	*Dichanthelium acuminatum var. fasciculatum*	Western Panicgrass	Spring
grass	*Dichanthelium clandestinum*	Deertongue	Spring
grass	*Dichanthelium dichotomum*	Cypress Panicgrass	Spring
grass	*Eragrostis spectabilis*	Purple Lovegrass	Spring
grass	*Paspalum denticulatum*	Longtom	Spring
grass	*Paspalum plicatulum*	Brownseed Paspalum	Spring
forb	*Arnoglossum ovatum*	Ovateleaf Cacalia	Fall
forb	*Arnoglossum plantagineum*	Prairie Plantain	Fall
forb	*Asclepias linearis*	Slim Milkweed	Fall
forb	*Asclepias oenotheroides*	Zizotes Milkweed	Fall
forb	*Asclepias verticillata*	Whorled Milkweed	Fall
forb	*Asclepias viridis*	Green Milkweed	Fall
forb	*Baptisia alba*	White Wild Indigo	Fall
forb	*Baptisia australis*	Blue Wild Indigo	Fall
forb	*Baptisia sphaerocarpa*	Yellow Wild Indigo	Fall
forb	*Callirhoe involucrate*	Winecup	Fall
forb	*Desmanthus illinoensis*	Illinois Bundleflower	Fall
forb	*Eryngium yuccifolium L.*	Rattlesnake Master	Fall
forb	*Euthamia leptocephali*	Bushy Goldentop	Fall
forb	*Helianthus angustifolius*	Swamp Sunflower	Fall
forb	*Helianthus maximiliani*	Maximilian Sunflower	Fall
forb	*Lobelia puberula*	Downy Lobelia	Fall
forb	*Polytaenia nuttallii*	Prairie Parsley	Fall
forb	*Rudbeckia texana*	Texas Coneflower	Fall
forb	*Silphium gracile*	Slender Rosinweed	Fall
forb	*Sisyrinchium angustifolium*	Narrowleaf Blue-eyed Grass	Fall
forb	*Solidago sempervirens*	Seaside Goldenrod	Fall
forb	*Vernonia missurica*	Missouri Ironweed	Fall
	*Harvest Seed When Possible or Transplant		

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 14). 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 15-16). 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 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 seeing 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 the HPB omit the tackifer 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 14. Image of Dew Drop Drill


Figure 15. Image of No till Drill vs hand seeding Headwaters at the Comal

Figure 16. Image of seeding passes

Figure 17. Image of Eastern gamagrass

Figure 18. 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 Sothern 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

Live planting is a great way to boost the seeding effort and shortcut the grassland's evolution by incorporating later successional species such as little bluestem (*Schizachyrium scoparium*) or compassplant (*Silphium laciniatum*). Currently, conservation staff is utilizing live plantings as a buffer on the outer edges of the prairies to help prevent infiltration of invasive species from the exterior. This is a great strategy, but conservation staff should also incorporate swaths of later successional species and diversity plantings within the interior (Figure 19). 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 prairie, the conservation team will inoculate the interior component of the restoration areas.

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.

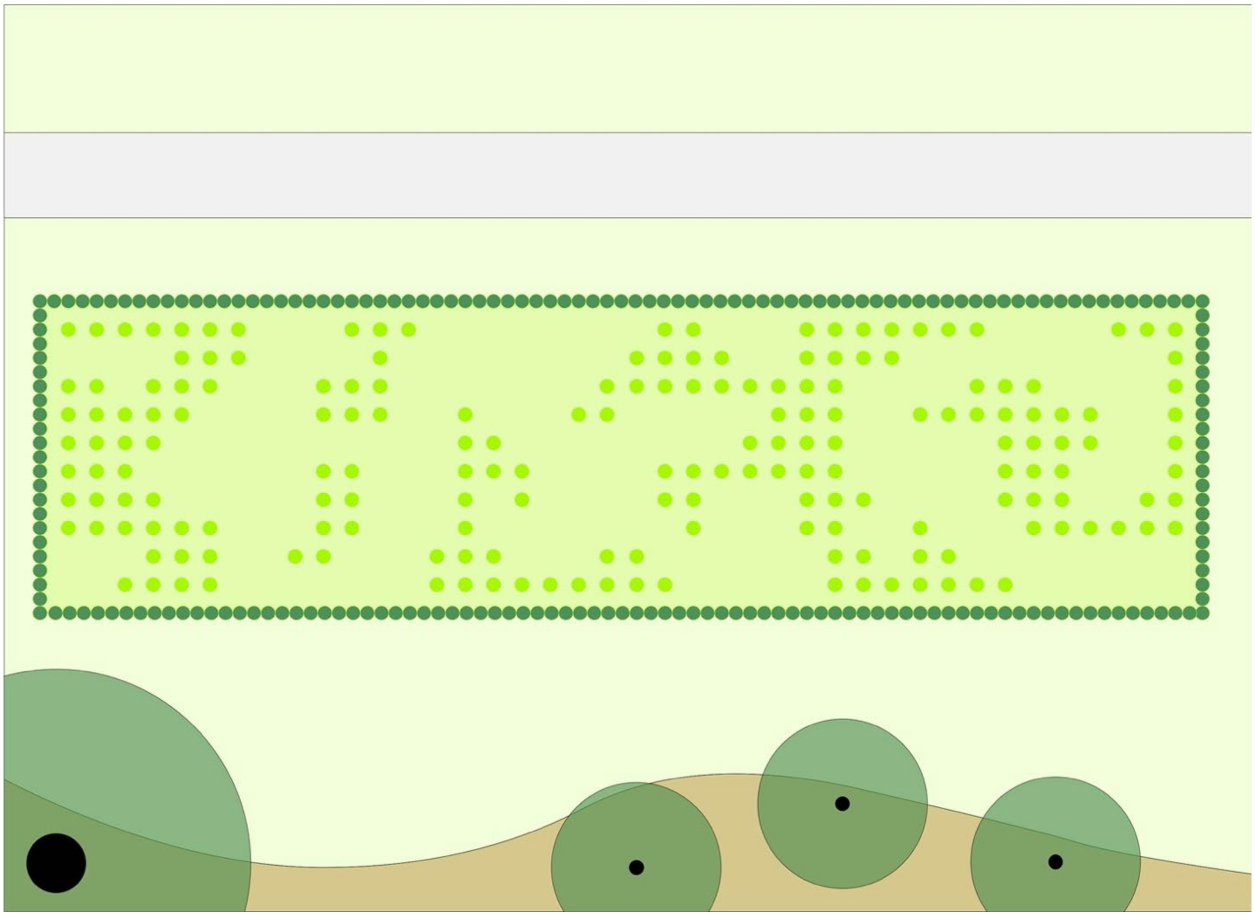


Figure 19–Planting strategy diagram. Dark green circles are exterior edge of diversified native plantings that HPB currently uses, interior space would be seeded and drifts of latter successional species, such as little bluestem, are plugged to help inoculate soils and introduce older growth.

Planting Windows

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

Table 5. 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	Ovtober - 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

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. Watering should not occur after a sufficient rain event or when otherwise unnecessary.

K. Monitoring for 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 6). 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 6. Bare Patch Mix

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

Undesired woody growth should be removed as it presents with a weed wrench (Figure 20). Woody species are a threat to grasslands because they will overcrowd the grasses and eventually shade out the prairie, morphing into a woodland ecotype. Nature prevented sapling establishment with wildfire and high intensity grazing. The absence of these disturbance events means that conservation staff will have to take up that function and serve as bison surrogates where appropriate.

Figure 20. Image of weed wrench

L. Restoration task summaries

Restoration Plot Task List

Is area covered with more than 30% invasive vegetation?

YEAR 1

Mow area and allow growth to reach height as required by herbicide manufacturer. Treat area a minimum of 4 times with herbicide.

Cover area with no less than 5-8" of mulch (can be single grind) and leave covered for a year. Spot treat emerging vegeation with herbicide.

After 1 year, remove mulch and test for compaction levels with cone penetrometer. If areas exceed acceptable levels till to depth of 5". If levels are within acceptable range, till 3" depth.

FALL OR SPRING

Incorporate 1-3" of static piled compost into loosened soil. Add 1/2-1" of biochar and other amendments if desired.

Apply seed at 2-3 times the recommended rate during the appropriate seasonal windows. Seed large sites with no-till drill. Be sure to follow manufacturers directions regarding calibration of machine. Smaller sites can be hand seeded. If possible, live plant immediately after seeding. This will help integrate seed into the soil. If live planting is delayed, lightly rake or brush hand seeded plots to ensure good seed/soil contact. Drilled sites do not require raking.

If possible, apply establishment irrigation, this will dramatically increase seedling success:

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

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

1 YEAR POST SEEDING

Monitor every two weeks for invasive species or establishment issues.

Invasive Grass Only Plot Task List

Is area covered with invasive grasses only?

Mow area and allow growth to reach height as required by herbicide manufacturer. Treat area a minimum of 4 times with grass specific herbicide. Spot treat emerging vegeation with herbicide. After 1 active growing season, test compaction levels with cone penetrometer. If areas exceed acceptable levels till to depth of 5". If levels are within acceptable range, till 3" depth.	SPRING AND SUMMER
Incorporate 1-3" of static piled compost into loosened soil. Add 1/2-1" of biochar and other amendments if desired. Apply forb only seed at 2-3 times the recommended rate during the appropriate seasonal windows. Seed large sites with no-till drill. Be sure to follow manufacturers directions regarding calibration of machine. Smaller sites can be hand seeded. If possible, live plant immediately after seeding. This will help integrate seed into the soil. If live planting is delayed, lightly rake or brush hand seeded plots to ensure good seed/soil contact. Drilled sites do not require raking. If possible, apply establishment irrigation, this will dramatically increase seedling success: • First 10 days seed is not allowed to dry out – irrigation event replicating 1" rain event every day • Next 3 weeks – irrigation event replicating 1" event every other day • Next 2 weeks - irrigation event replicating 1" event twice a week *This schedule can be adjusted and days skipped if rainfall occurs	FALL
Monitor every two weeks for invasive species or establishment issues. Continue to treat plots with grass specific herbicide to ensure elimination.	1 YEAR POST SEEDING
Mow or burn and then seed with native grasses and plug live grasses.	2 - 3 YEARS

M. 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.

Below is a general mowing and weeding schedule that indicates activities and the ideal timeframe (Figure 22). 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.

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 (Murrary and Marmorek 2003).

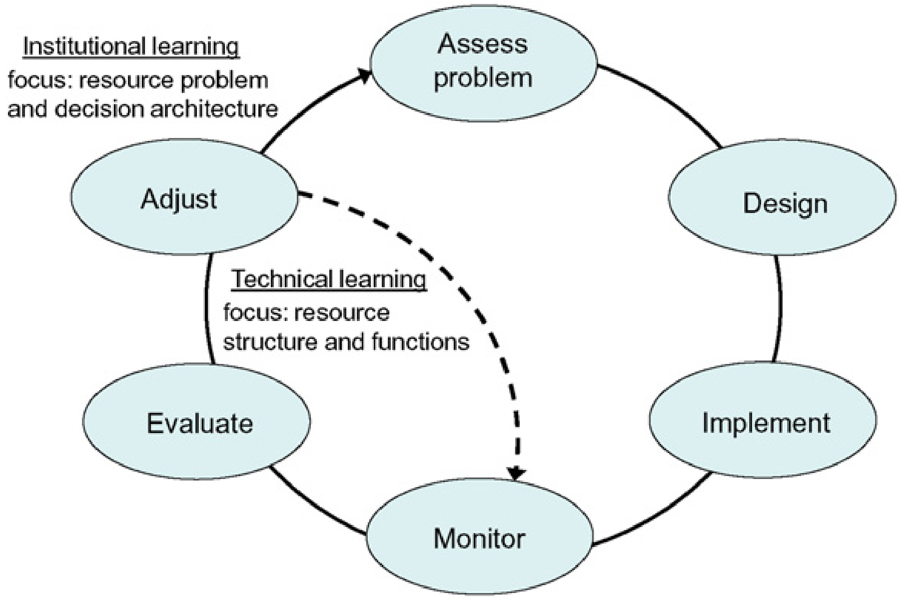


Figure 21. Diagram of the Adaptive Management process. (Williams and Brown 2016).

Figure 21 provides a diagram of adaptive managements 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.*

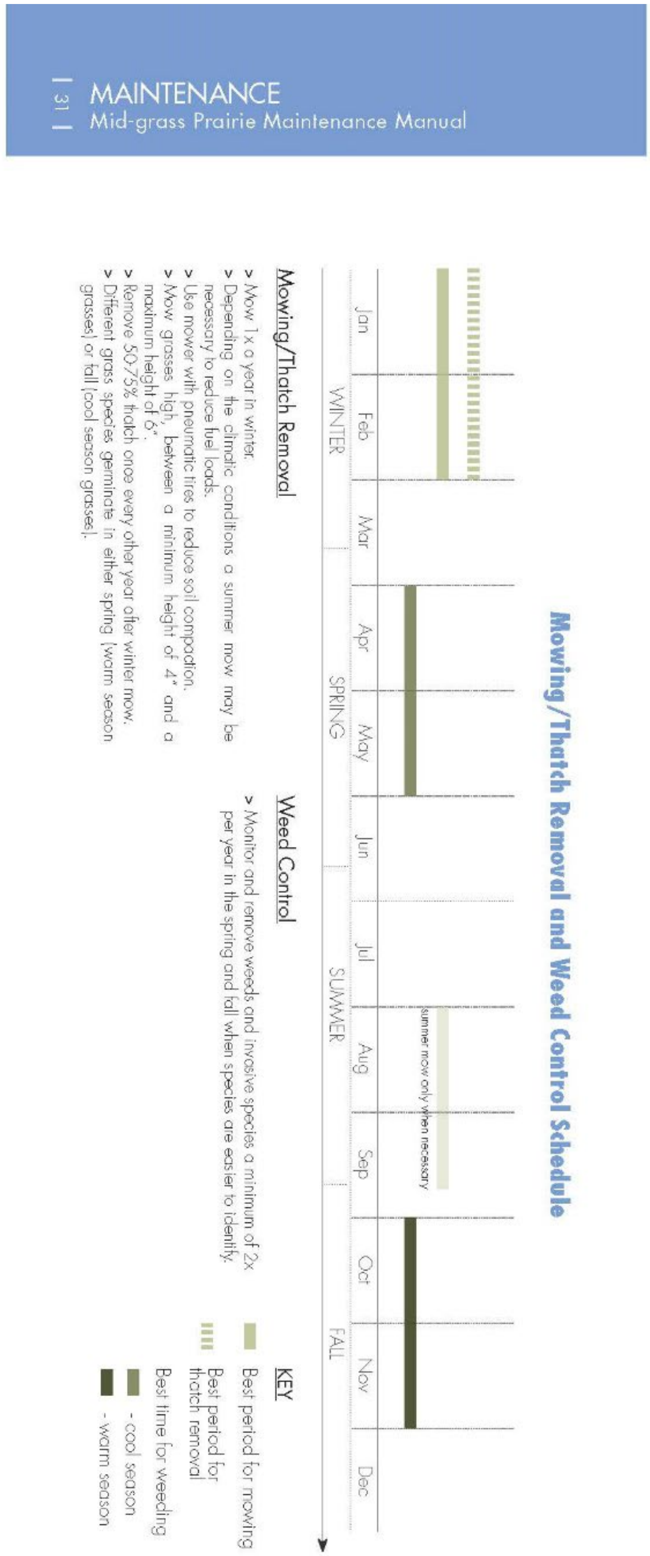


Figure 22. Example maintenance schedule for prairie habitat.

VI. References

Anderson, H.E. 1983. Predicting Wind-Driven Wild Land Fire Size and Shape. United States Department of Agriculture. Forest Service Research Paper INT-305.

Army Corps of Engineers. 2005. Army Corps of Engineers - Regulatory guidance letters - ordinary high water mark identification [Internet]. 07/2005.

Barbour, M. G., J.H. Burk, and W.D. Pitts. 1980. Terrestrial Plant Ecology.

Barrett, M. E., M. H. Li, P. Rammohan, F. Olivera, and H. C. Landphair. 2008. Documenting Stormwater Quality on Texas Highways and Adjacent Vegetated Roadsides. Journal of Environmental Engineering: 134 (1).

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 Biodiveristy & Ecosystem Monitoring Project. Technical Report. The Nature Conservancy, Texas.

Caughlan L., Oakley K.L. 2001. Cost considerations for long-term ecological monitoring. Ecological Indicators 1:123-134. 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.

Collins, B. 1975. Range Vegetation and Mima Mounds in North Texas. Journal of Range Management: 28(3): 209-211.

Costanza, R. et al. 1997. The value of the world's ecosystem services and natural capital. Nature 387: 253-260.

Costanza, R et all. 2017. Twenty years of ecosystem services: How far have we come and how far do we still need to go? Ecosystem Services. 28 (A):1-16.

de Jesus Duarte S., Glaser B., Pellegrino Cerri C.E. 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 D.J. & Newman J.A., editors. 2017. Grasslands and climate change. United Kingdom: Cambridge University Press. 347 p. 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.

Kishne, A., and C. L. S. Morgan, W. L. Miller 2009. Vertisol Crack Extend Associated with Gilgai and Soil Moisture in the Texas Gulf Coast Prairie. Soil Science Society of American Journal. 73 (4): 1221-1230.

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.

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/)

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.

Rout ME and Chrzanowski TH. 2009. The invasive Sorghum halepense harbors endophytic N2-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

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		
					Dominant spp.	heritage tree (>60.96 cm)		
					Ligustrum sp.	protected tree (>48.26 cm)		
Overall diversity	**Woody age** diversity	**Dominants** overstory	**Dominants** midstory	**Dominants** Herb	bermudagrass	Reference community spp.		
Riparian buffer (width-ft)	**Connection to floodplain (high/med/low)**	**Bottomland/ riparian diversity (high/med/low)**			**Challenges**	**Assets**	**Additioaal 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		

Cover classes	Soil surface condition	Erosion classes
Class 1: None Class 2: trace Class 3: 1-25% Class 4: 26-50% Class 5: 51-75% Class 6: 75-100%	Class 5-**High**: developed organic layer, good structure, low/no disturbance **Class 3: Medium** Class 1-**Low**: thin, damaged, rocky, construction debirs present	**Class 1: severe**, subsoil exposed, most rocks/plants pedestaled and roots exposed **Class 3: moderate** movement of soil, surface rock/ or litter, pedestalling in flow patterns **Class 5**: no visual evidence of soil movement

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**	**Additioaal 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		

Cover classes	Soil surface condition	Erosion classes
Class 1: None Class 2: trace Class 3: 1-25% Class 4: 26-50% Class 5: 51-75% Class 6: 75-100%	Class 5-**High**: developed organic layer, good structure, low/no disturbance **Class 3: Medium** Class 1-**Low**: thin, damaged, rocky, construction debirs present	**Class 1: severe**, subsoil exposed, most rocks/plants pedestaled and roots exposed **Class 3: moderate** 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
Soil movement	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
Surface rock and/or litter	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
Pedestaling	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 pedestalling in flow patterns	No visual evidence of pedestaling
Flow patterns	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
Rills and gullies	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.

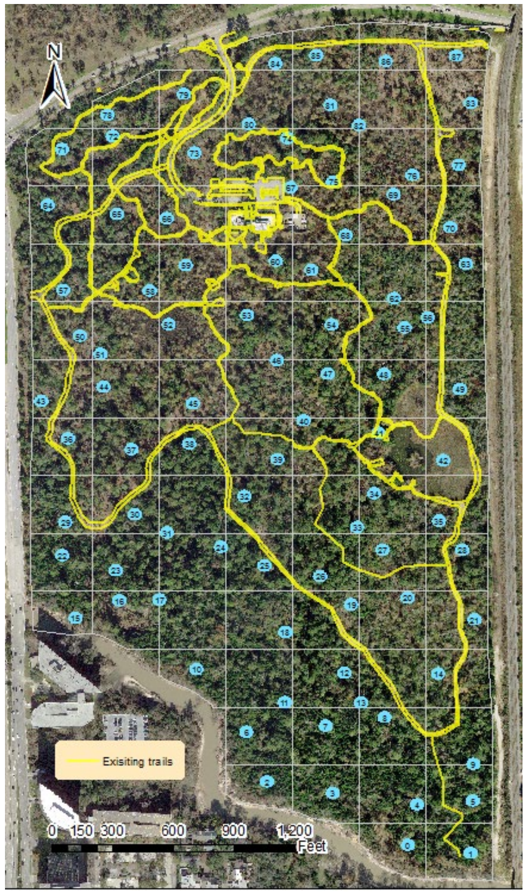


Figure 1: In 2015, the 88 permanent vegetation monitoring plots were placed randomly within a two acre grid. Trees, shrubs, and herbaceous plants are monitored in these plots.

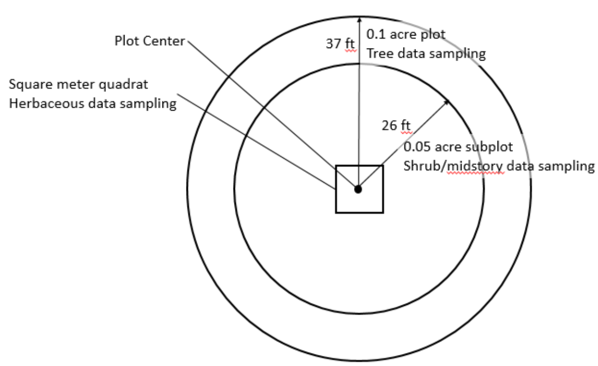


Figure 2: The vegetation monitoring plots were designed to sample trees, shrubs, and herbaceous plants.

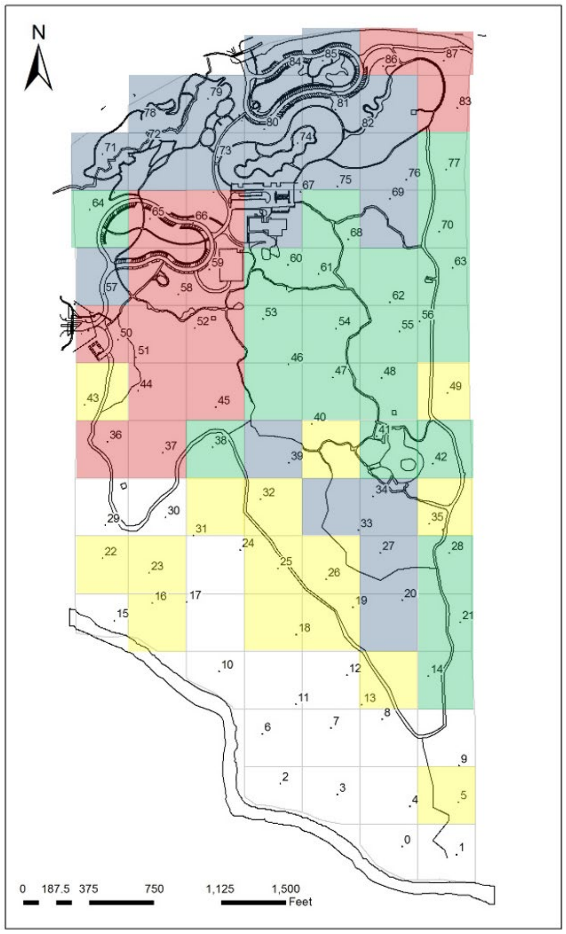


Figure 3: The staggered plot sampling system over five years. Red plots (14 total) were sampled in 2015 and will be resampled in 2020. Yellow plots (15 total) were sampled in 2016 and will be resampled in 2021. Blue plots (21 total) were sampled in 2018 and will be resampled in 2023. Green plots (21 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.

Plot #		Date		%Canopy cover	

Overstory trees with dbh > 6" within 1/10th acre plot (37' radius)

Species	*Dbh*	*Height*	*Notes*

Midstory trees with 3-6" dbh within 1/20th acre plot (26' radius)

Species	*Dbh*	*Height*	*Notes*

Understory trees with dbh < 3" within 1/20th acre plot (26' radius)

Species	*Count*	*Notes*

Herbaceous - NW

Species	*% Cov*	*Notes*	*Species*	*% Cov*	*Notes*
Bare					
Litter					

Herbaceous - NE

Species	*% Cov*	*Notes*	*Species*	*% Cov*	*Notes*
Bare					
Litter					

Herbaceous - SE

Species	*% Cov*	*Notes*	*Species*	*% Cov*	*Notes*
Bare					
Litter					

Herbaceous - SW

Species	*% Cov*	*Notes*	*Species*	*% Cov*	*Notes*
Bare					
Litter					

Figure 4: The template of the data sheets to be used in the field

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.