VEGETATION SURVEY ANALYSIS 2022

AN ECOLOGICAL STUDY AT THE HOUSTON ARBORETUM & NATURE CENTER

MARCH 2024

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Houston Arboretum & Nature Center

HOUSTON ARBORETUM & NATURE CENTER

PREFACE

The Houston Arboretum & Nature Center (HANC) is a non-profit organization whose mission is to provide education about the natural environment to people of all ages and to protect and enhance the Arboretum as a haven and as a sanctuary for native plants and animals. HANC seeks to be "nature connectors," stewards and providers of best-in-class nature-centered experiences and knowledge for a diverse Houston.

HOUSTON
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ACKNOWLEDGEMENTS

Many thanks to Adrian Scroggins, Kayla Zinsmeyer, and Nicholas Hacker for their persistent data collection and management efforts that made this possible.

Cover photograph: Data collection methodology looking south at Plot 69. All photos by HANC.

SUGGESTED CITATION

Benigno, S. 2024. Vegetation Survey Analysis 2022: An ecological study at the Houston Arboretum & Nature Center. Unpublished report for the Houston Arboretum & Nature Center. Houston, Texas.

EXECUTIVE SUMMARY

The Houston Arboretum & Nature Center (Arboretum) is a public nature sanctuary with a mission to protect and enhance its ecosystems for the benefit of native plants and animals. This vegetation survey analysis was produced to assess current biodiversity, monitor habitat, collect baseline vegetation data, and inform conservation and restoration activities to continue the Arboretum's mission.

Three previous surveys in 1991, 1998 and 2005 assessed vegetation but did not follow a consistent methodology or provide detectable monitoring locations to revisit. A simple, repeatable and consistent monitoring plan was necessary to allow staff to collect and analyze data for comparison over time.

The methodology in this report assesses overstory, midstory, understory, and ground cover types in the summer of 2022 following the completion of the Arboretum's Master Plan. Thirty monitoring plots were proportionally split by area between six plant associations (Ravine, Buffalo Bayou, Poorly-Drained and Well-Drained Savanna, and Poorly-Drained and Well-Drained Woodland) and vegetation metrics were recorded at each plot.

Species preferences by plant association were observed, dependent on sunlight availability and soil-water character. *Pinus taeda* was the dominant overstory species in 2022 but appear to be proportionally decreasing in favor of hardwood species such as elms (*Ulmus spp.*) when compared to data from previous surveys. Invasive species in the overstory and midstory cover types were very low (2.1%, <1%, respectively) but relatively higher in the understory (24%) and ground cover (18%). Chinese Privet (*Ligustrum sinense*) was the dominant invasive species in the understory (23%) and observed in relatively high percentage in the ground cover (6%). Native species such as Elms, Cherry Laurel (*Prunus caroliniana*), Yaupon (*Ilex vomitoria*), Dewberries (*Rubus spp.*) and Trumpet Creeper (*Campsis radicans*) were dominant in the midstory, understory and ground cover types.

This data indicates that a small number of both invasive and native species appear to be aggressively colonizing and forming a dense understory thicket that may reduce diversity in all canopy strata and cover types in the short and long term. This is most likely due to the absence of natural disturbances such as fire or herbivory that would improve overall vegetation diversity by managing the population numbers of these aggressive species.

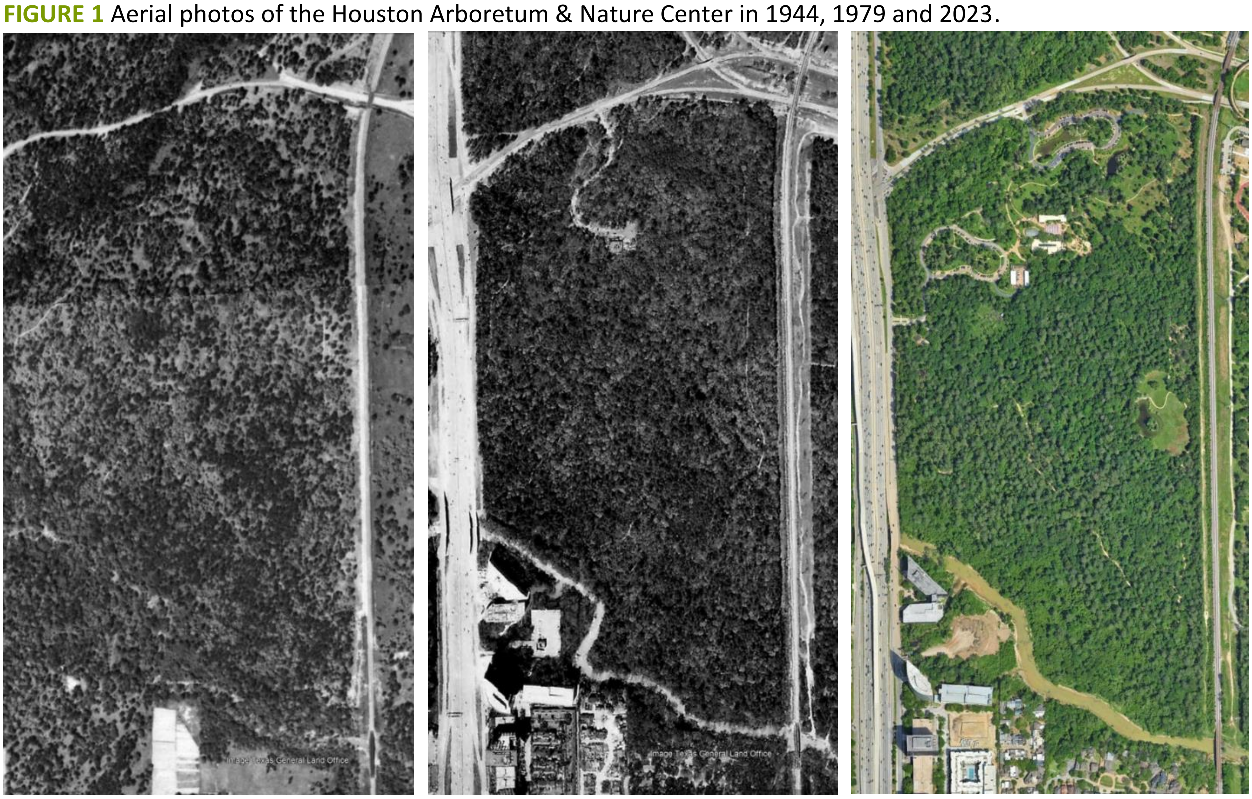
Restoring the Arboretum's natural areas to replicate a specific ecosystem or plant community may not be an attainable endeavor given the difficulty of locating a true reference ecosystem in the region. A more holistic approach should focus on enhancing overall vegetation diversity using a combination of management strategies that mimic natural disturbances, with the end goal of continual dynamic ecological succession with minimal human intervention.

INTRODUCTION

The Houston Arboretum & Nature Center (Arboretum) is a 155-acre nature sanctuary in the middle of the fourth largest city in the country. Its mission is to provide education about the natural environment to people of all ages and to protect and enhance the Arboretum as a haven and as a sanctuary for native plants and animals. The Arboretum is situated at the convergence of three Texas ecoregions: Gulf Coast Prairies and Marshes, Pineywoods, and Post Oak Savanna (Gould 1975), and its plant communities are unique in that they contain vegetation indicative of all three (Williams 1991). Prior to European settlement, the Arboretum landscape was less densely vegetated, with a prairie - savanna - open woodland habitat, evidenced by historic aerial photos (Fig 1).

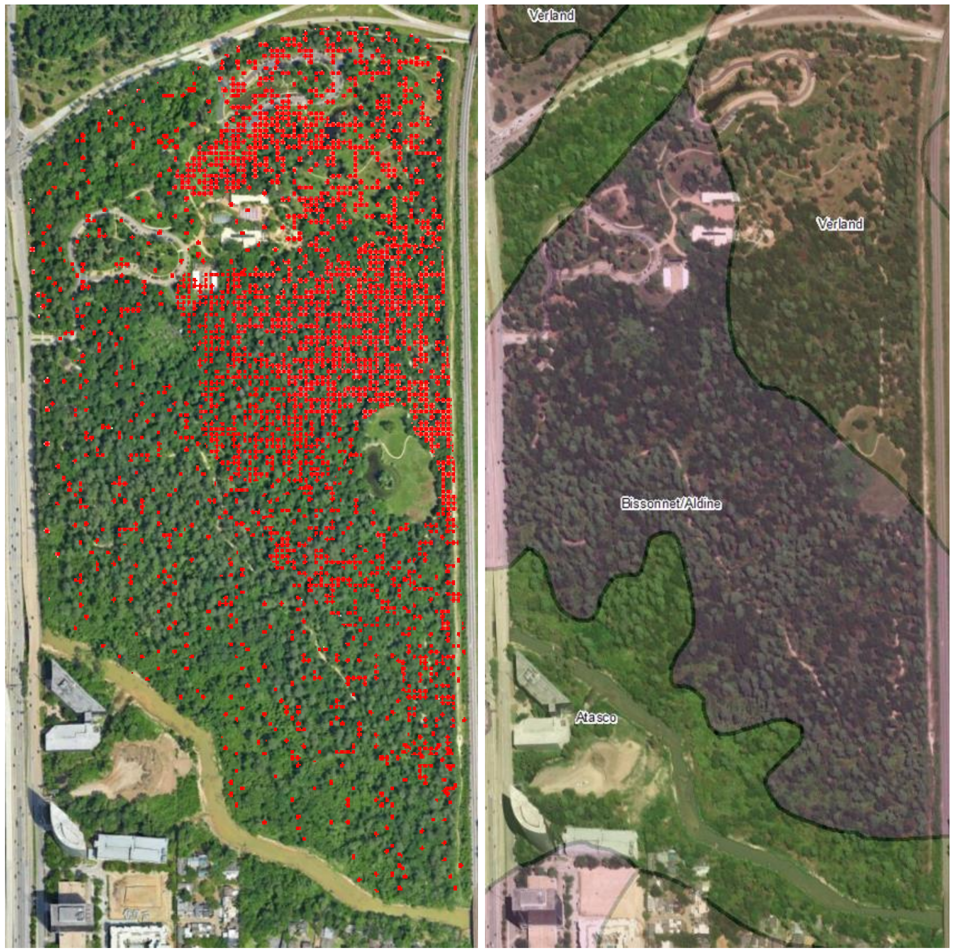
Historical accounts of travelers in 1831 described the vegetation south and west of Houston, suggesting that the dominant trees may have included bald cypress (*Taxodium distichum*) in the wettest areas, and red oaks (*Quercus falcata*), pines (likely *Pinus taeda*), pecan (*Carya illinoensis*), cherry laurel (*Prunus caroliniana*) and holly (*Ilex spp*.) would have been common in upland areas (Gray 1975). A bank survey by the county in the 1840's notes red oaks, pines, ash (*Fraxinus spp.*) and magnolias (likely *Magnolia grandiflora*) (Turner Collie & Braden 2001). However, a detailed vegetation description of the Arboretum prior to settlement does not exist, and the surrounding development has influenced the ecological community through the influx of species, both native and invasive.

FIGURE 1 Aerial photos of the Houston Arboretum & Nature Center in 1944, 1979 and 2023.



Human development has also excluded disturbances such grazing and fire, resulting in woody encroachment and a closed canopy landscape over time (Fig 1). The lack of disturbances, coupled with the antiquated, but prevalent and widely-accepted philosophy that conservation should be "hands-off" with little to no natural resource management, created vegetation communities that were not sustainable, particularly on specific soil types found in the Arboretum, evidenced and exacerbated by extreme climatic events in the early 21st century. Following Hurricane Ike in 2008 and an extreme drought in 2011, an estimated 50% tree mortality was observed and concentrated in soils with a relatively higher clay content that historically supported prairie and savanna ecosystems (Fig 2). In 2021, the Arboretum Master Plan was completed to create new public facilities and restore original landscapes, with a focus on restoring savanna habitat in areas that experienced high tree mortality.

FIGURE 2 Estimated tree mortality after extreme drought (red dots), and the main soil types of the Arboretum. Mortality was mainly concentrated on Verland soils that primarily support prairie vegetation but are prone to tree encroachment. Bissonnet soils are found on flat plains with mostly soft and hardwood trees and are poorly drained, while Atasco soils exist along sloping river valleys that support similar woodland species but are moderately well-drained.



While more resilient against extreme climatic events, these landscapes require ongoing management to prevent woody and invasive species encroachment or dense thickets and monocultures of aggressive native species. Informed management decisions require the collection of community assemblage data over time. Past vegetation inventories (Williams 1991, Bersche 1998, Siemann 2005) were conducted prior to extreme mortality caused by climatic events but did not follow a consistent methodology or provide detailed inventory locations for repeated data collection. This document serves as an updated vegetation monitoring plan to include the newly restored habitats following completion of the Master Plan, provide instructions for consistent and repeatable data collection, and allow data integration from previous inventories. This data can be analyzed over time to understand vegetation community dynamics and trajectories that will protect and enhance the Arboretum as a haven and as a sanctuary for native plants and animals in perpetuity.

METHODOLOGY

As part of the Master Plan, an annual vegetation survey was implemented in 2015 to track ecosystem succession, evaluate the effects of the restoration efforts and guide vegetation management. A stratified random sampling design established a total of 88 permanent vegetation monitoring plots across the Arboretum. A variable number of plots were sampled each year so that all 88 plots were sampled on a 5-year rotation (Fig 3). The survey methodology was initially a reasonable workload per year and sampled a large area across the entire Arboretum. However, the 5-year gap between sampling all 88 plots and staff turnover made managing and analyzing the data a difficult task.

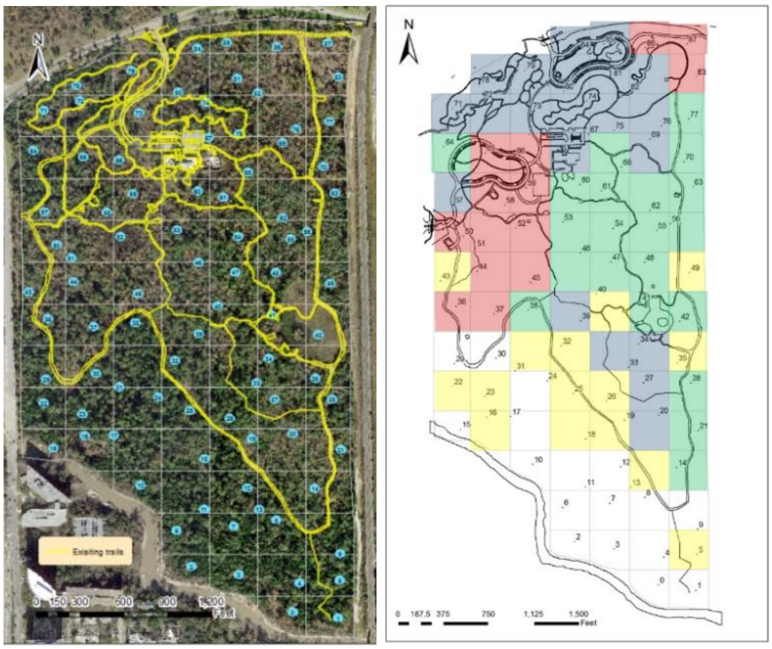


FIGURE 3 Original vegetation monitoring plots. In 2015, 88 permanent vegetation monitoring plots were established randomly within two-acre grids. Sampling of all 88 plots was staggered over five years, with annual groupings based on colors shown.

The methodology was reevaluated in 2022 and determined that re-surveying a smaller subset of the same plots annually would be more effective given the staff and resources available. The number of plots was randomly reduced from 88 to 30 and proportionally divided between major plant associations and restored Master Plan habitats: Ravine, Buffalo Bayou, Poorly-Drained and Well-Drained Savanna, and Poorly-Drained and Well-Drained Woodland (Fig 4, Appendix A). Plant associations were adapted from Williams 1991, the earliest available vegetation and soil survey of the Arboretum with a detailed methodology. The 1991 survey provided vegetation, soil and hydrologic descriptions, but preceded handheld GIS technology and sample points from the study were unable to be located for repeated measurements. While the revised methodology surveys fewer plots over time, every habitat type of the Arboretum is represented and comparisons may provide quicker feedback regarding management practices.

The thirty vegetation monitoring plots were physically marked at a center point and recorded with GPS coordinates (Appendix B). The type of physical marker was dependent on proximity to trails and potential for public visibility (Fig 5). Monitoring plot layouts were created by stretching one measuring tape 37ft north and 37ft south (74ft total) and another east to west from the center point to create a circular 0.10ac subplot (Fig 6). Ground cover, canopy cover, photo monitoring, and overstory cover data were then collected. The measuring tapes were then reduced to 26ft from the center point (52ft total) to create a circular 0.05ac subplot to collect midstory and understory cover data (Fig 6).

FIGURE 4 Revised vegetation monitoring plots. In 2022, thirty plots were randomly chosen and divided proportionally between major plant and soil associations present at the Arboretum. Plant associations adapted from Williams 1991.

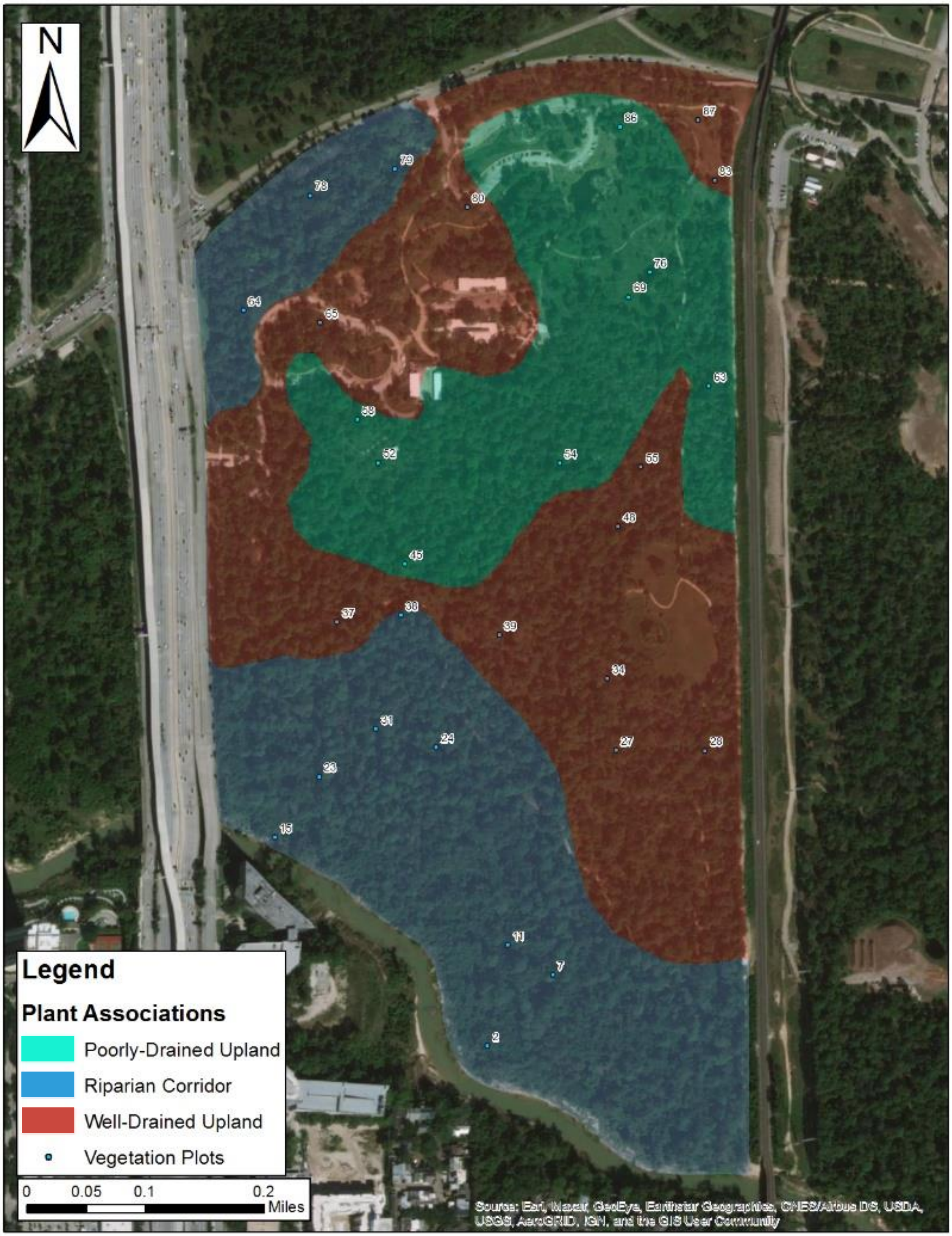


FIGURE 5 Types of physical markers at the center point of vegetation monitoring plots. a) PVC, rebar and pin flag, b) t-post with flagging tape c) t-post without flagging tape.

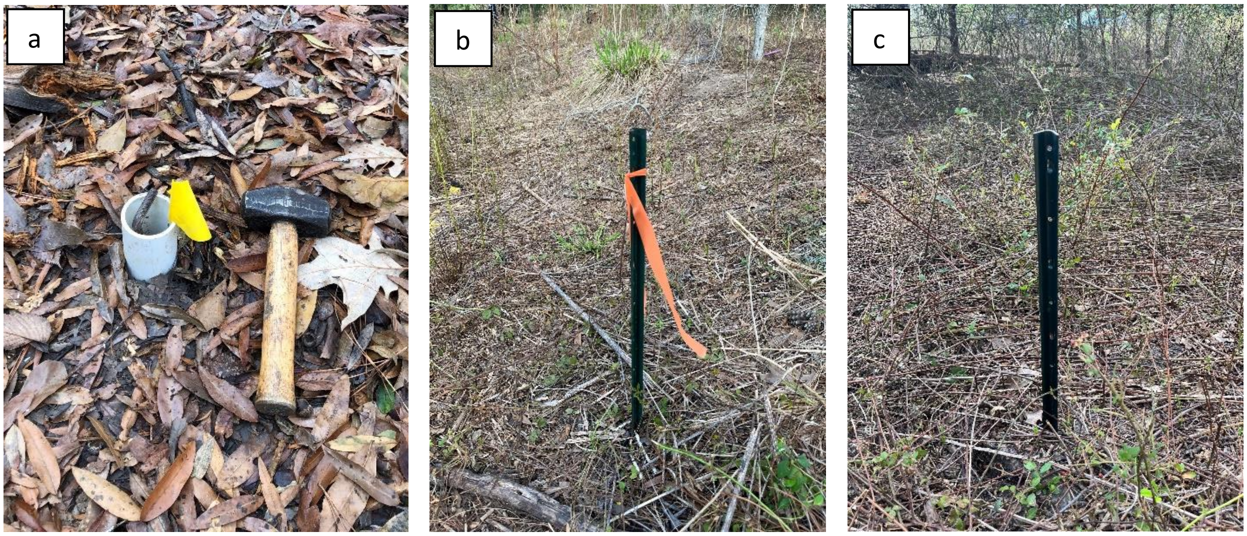
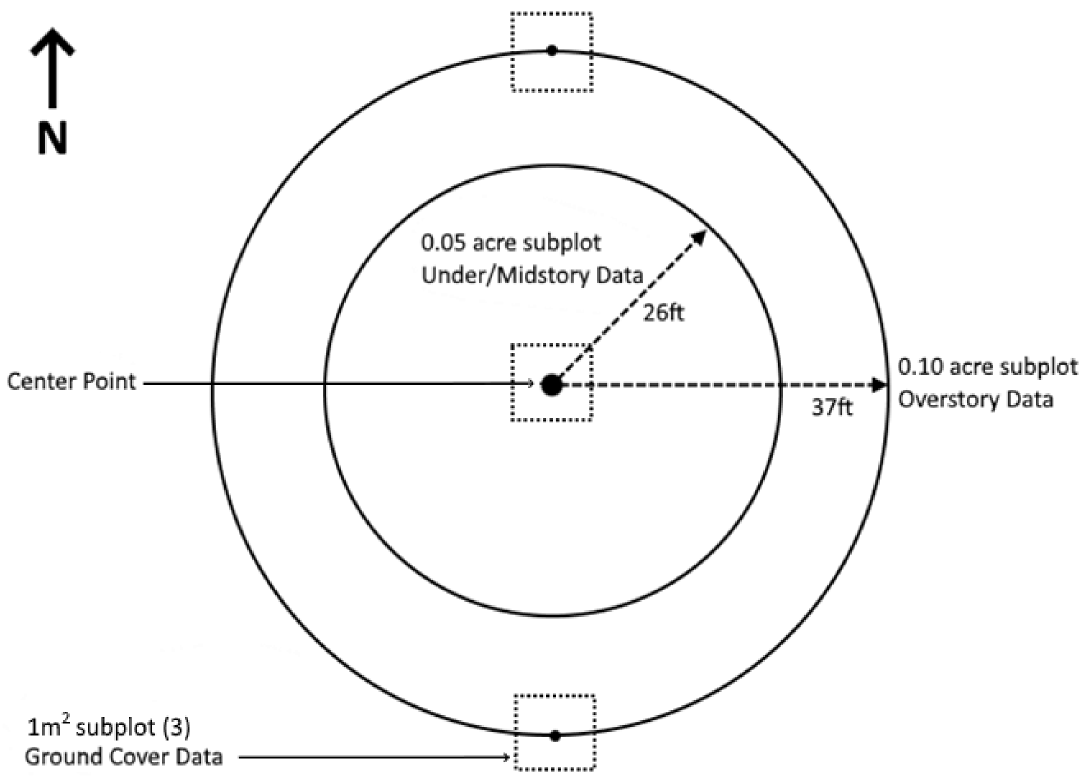


FIGURE 6 Monitoring plot layout



MATERIALS

- $1m^2$ PVC Frame
- Measuring Tape (x2)
- DBH Tape
- GPS
- Field Data Sheets
- Clipboard
- Pen or Pencil
- Spherical Convex Densiometer

COVER TYPE

Overstory Cover Type

Overstory cover type monitors trees greater than 6in Diameter at Breast Height (DBH) within a 37ft radius from the center point. Individual tree species, and shrub species that reach this size, and DBH should be recorded.

Midstory Cover Type

Midstory cover type monitors trees and shrubs with a DBH between 3in and 6in within a 26ft radius from the center point. Individual trees and shrubs of each species should be recorded along with their DBH.

Understory Cover Type

Understory cover type monitors trees and shrubs with trunks less than 3in diameter at breast height (DBH) and greater than 3ft height within a 26ft radius from the center point. Stem count (number of trunks less than 3in DBH) and estimated average height for each species should be recorded.

Ground Cover Type

Ground cover type monitors grasses, forbs, vines, and trees/shrubs less than 3ft height. The $1m^2$ subplots should be oriented north at three locations within the vegetation monitoring plot: 1) the center point, 2) 37ft north of the center point and 3) 37ft south of the center point. Species present and cover percentage within the subplots should be recorded along with bare ground and leaf litter.

VEGETATION METRICS

The metrics below can be calculated and analyzed as needed, and a study-specific excel spreadsheet was developed internally to analyze data consistently and repeatedly (Appendix E).

Diameter at Breast Height (DBH)

DBH is a forestry metric that records the trunk diameter at a standardized height of 4.5ft above ground. DBH data is essential for ecological research and conservation and management efforts to study the growth, dynamics, and health of forest ecosystems and assessing the growth of individual trees over time.

DBH measurements are collected using a diameter tape wrapped around the trunk of the tree at a height of 4.5ft. If the tree is growing on a slope, the measurement is taken from the uphill side. If a single trunk forks or splits into multiple stems below 4.5ft, measure the DBH of each stem at 4.5ft and add together. DBH should be recorded for Overstory and Midstory Cover Types.

Basal Area (Density)

Basal area, or density, is the common term that describes the average amount of an area occupied by tree stems. It is defined as the total cross-sectional area of all stems in a stand measured at breast height and expressed as per unit of land area, usually square feet per acre. Typically, basal area greater than 100 square feet per acre markedly decreases ground cover and wildlife value. Greater basal area may correlate to greater tree canopy cover; thus, as both metrics increase less sunlight reaches the ground. This lack of sunlight impedes growth of grasses, forbs, and shrubs that provide important food and cover for some species of wildlife. Also, high basal area may lead to a decrease in tree growth and vigor from the increased competition for crown space, nutrients, and moisture. Basal Area should be recorded for Overstory and Midstory Cover Types.

$$\text{Basal area (sqft)} = \pi \times ((DBH)^2/4) \times 144$$
$$= 0.005454 \times (DBH)^2$$

Stem Count

Stem count is conducted by visually identifying and enumerating individual plant stems that are <6" DBH within the plot. Data are used to establish baseline information, understand ecosystem structure, and investigate the effects of environmental factors on vegetation. It can be used to create species lists, calculate plant density, estimate population size, and analyze vegetation patterns and trends in specific ecosystems. Stem count should be recorded for the Understory Cover Type.

Average Estimated Height

Changes in the average height of vegetation can indicate shifts in ecological succession or the effects of disturbances, such as wildfires or land management practices. Observing these changes over time can help understand how ecosystems are evolving. Taller, denser vegetation may indicate an increase in the likelihood and intensity of wildfires. Average estimated height should be recorded for the Understory Cover Type.

Ground Cover Percentage

The diversity of plant species in an area can be assessed by quantifying ground cover. High ground cover percentages often indicate greater species diversity, as different plant species can occupy different niches. Ground cover percentages can track shifts in ecological succession, the impacts of disturbances, and undesirable species. Ground cover percentage should be recorded for each species in the Ground Cover Type and include Leaf Litter and Bare Ground cover percentage as well.

Species Richness

Species richness refers to the quantity of distinct species. It is a straightforward tally of species that does not consider the population size or distribution. Although species richness is often used interchangeably with species diversity, the formal measure of species diversity considers both species richness and the equitable distribution of species. Species richness should be calculated for all cover types and plant associations.

Species Evenness

Species evenness is a measure used in ecology to quantify the relative abundance of different species within a community. It complements species richness, which simply counts the number of species present. Evenness considers not just the number of species but also how evenly distributed individuals are among those species. Species evenness should be calculated for all cover types and plant associations.

Species Diversity

Shannon Weiner Diversity Index is a measure of biodiversity in a given ecosystem or community. It quantifies the uncertainty or entropy associated with the identity and abundance of species in a community, providing a single dimensionless numerical value that can be used to monitor changes in biodiversity spatially or temporally within the Arboretum. A Hutcheson t-test was used to determine statistical comparisons between Shannon Weiner Diversity Index of each plant association.

Canopy Cover

A spherical convex densiometer measures canopy cover using the procedure in Appendix C. Separate measurements should be collected facing north, south, east and west while standing at the center in each of the three $1m^2$ subplots used to collect Ground Cover, for a total of twelve measurements per plot. A Pearson's Correlation test was used to determine statistically significant linear relationships between canopy cover, basal area, vegetation cover, and species richness.

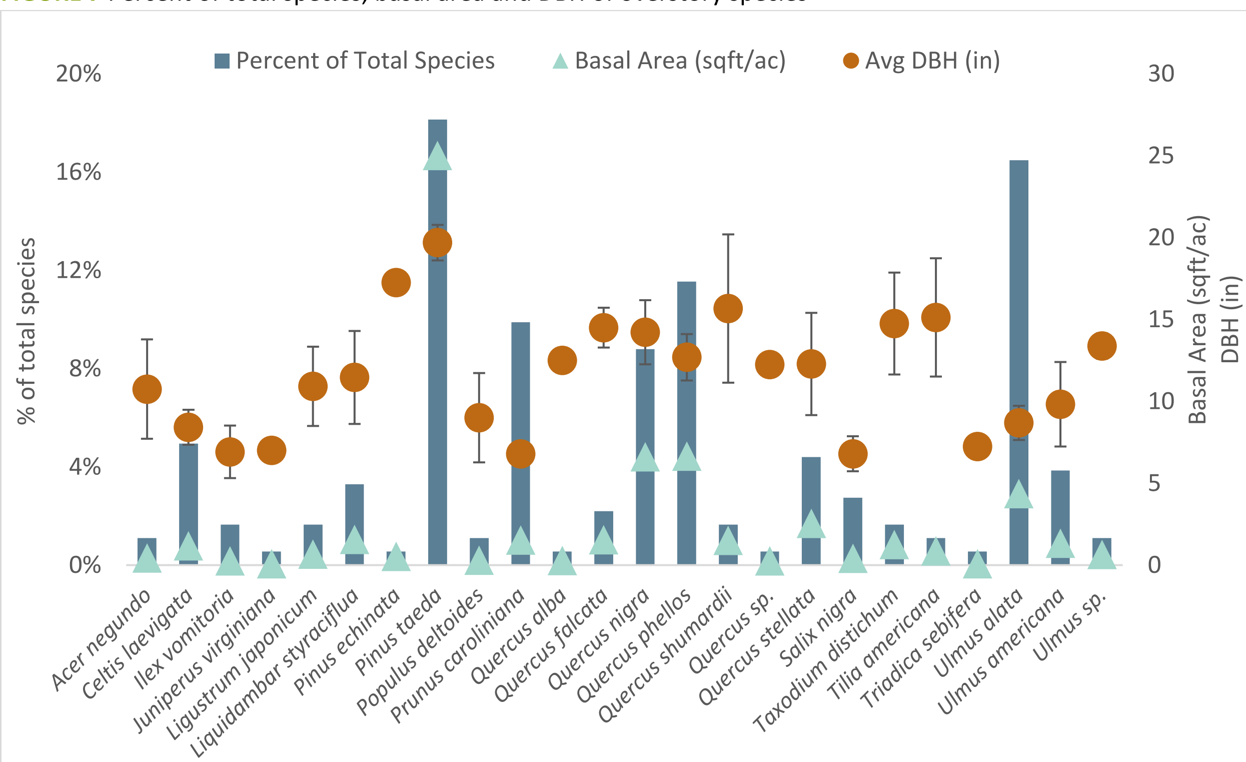
Photo Monitoring
Two photos should be collected for each vegetation monitoring plot, facing north and south from the center point. Image name should be recorded for post-processing and documentation (Appendix E).

RESULTS

The following data were collected in June and July 2022.

Overstory
Overstory species richness was 24 species, including two invasive species (*Triadica sebifera*, *Ligustrum japonicum*). Invasive species accounted for 2.1% of the total overstory species recorded (Fig 6). *Pinus taeda* recorded the largest average DBH, greatest basal area, and highest percentage of the total overstory tree species (Fig 7). Oaks (*Quercus spp.*) and Elms (*Ulmus spp.*) accounted for 29.7% and 21.4% respectively (Fig 7). Willow Oak (*Q. phellos*) and Water Oak (*Q. nigra*) were the most common oak species recorded, while Winged Elm (*U. alata*) was the most common elm species recorded (Fig 7). Cherry Laurel (*Prunus caroliniana*) accounted for almost 10% of overstory species recorded but possessed the smallest average DBH (Fig 7).

FIGURE 7 Percent of total species, basal area and DBH of overstory species



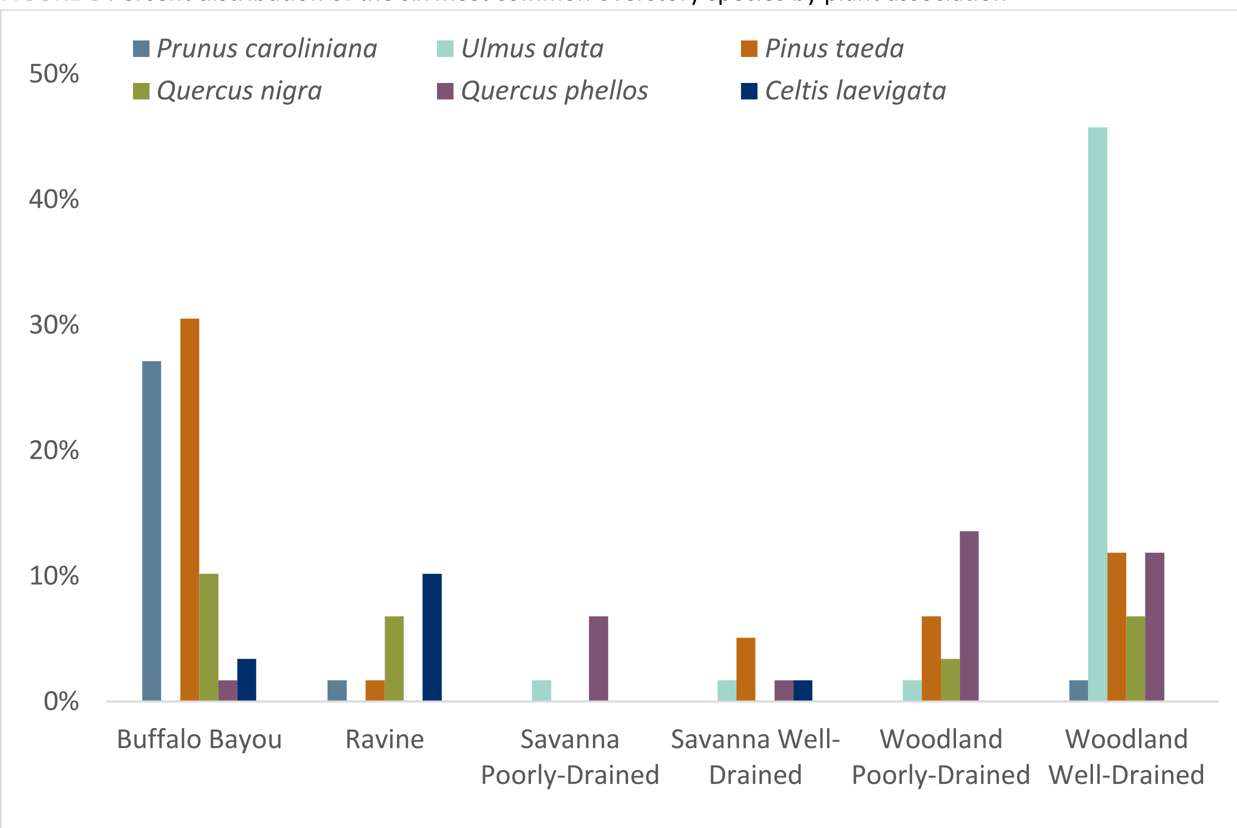
The lowest overstory species richness was observed in Savanna Poorly-Drained, with the highest in Buffalo Bayou (Table 1). The highest number of overstory species per acre were found in the Ravine and the lowest in Savanna Poorly-Drained (Table 1). Buffalo Bayou, Ravine, Woodland Well-Drained and Woodland Poorly-Drained had basal areas above 53 sqft/ac, with Savanna Well-Drained and Savanna Poorly-Drained had basal areas below 44 sqft/ac (Table 1). DBH between plant associations was relatively consistent (Table 1). Invasive overstory species were observed only in the Buffalo Bayou and Woodland Well-Drained plant associations (Table 1).

Plant association preferences of the six most common overstory species are shown in Figure 8. *P. caroliniana* appears to prefer Buffalo Bayou, while *U. alata* prefers Woodland Well-Drained. *P. taeda* was recorded in every plant association except Savanna Poorly-Drained, while *Q. nigra* and *Q. phellos* were relatively evenly distributed.

TABLE 1 Overstory cover by plant association

Plant Association	Richness	Avg DBH (in)	Basal Area (sqft/ac)	Native Species (No./ac)	Invasive Species (No./ac)
Buffalo Bayou	13	12.2	78	70	4
Ravine	8	11.8	69	80	0
Savanna Poorly-Drained	4	9.5	28	23	0
Savanna Well-Drained	7	14.1	44	30	0
Woodland Poorly-Drained	10	14.7	68	54	0
Woodland Well-Drained	11	11.1	53	69	1

FIGURE 8 Percent distribution of the six most common overstory species by plant association

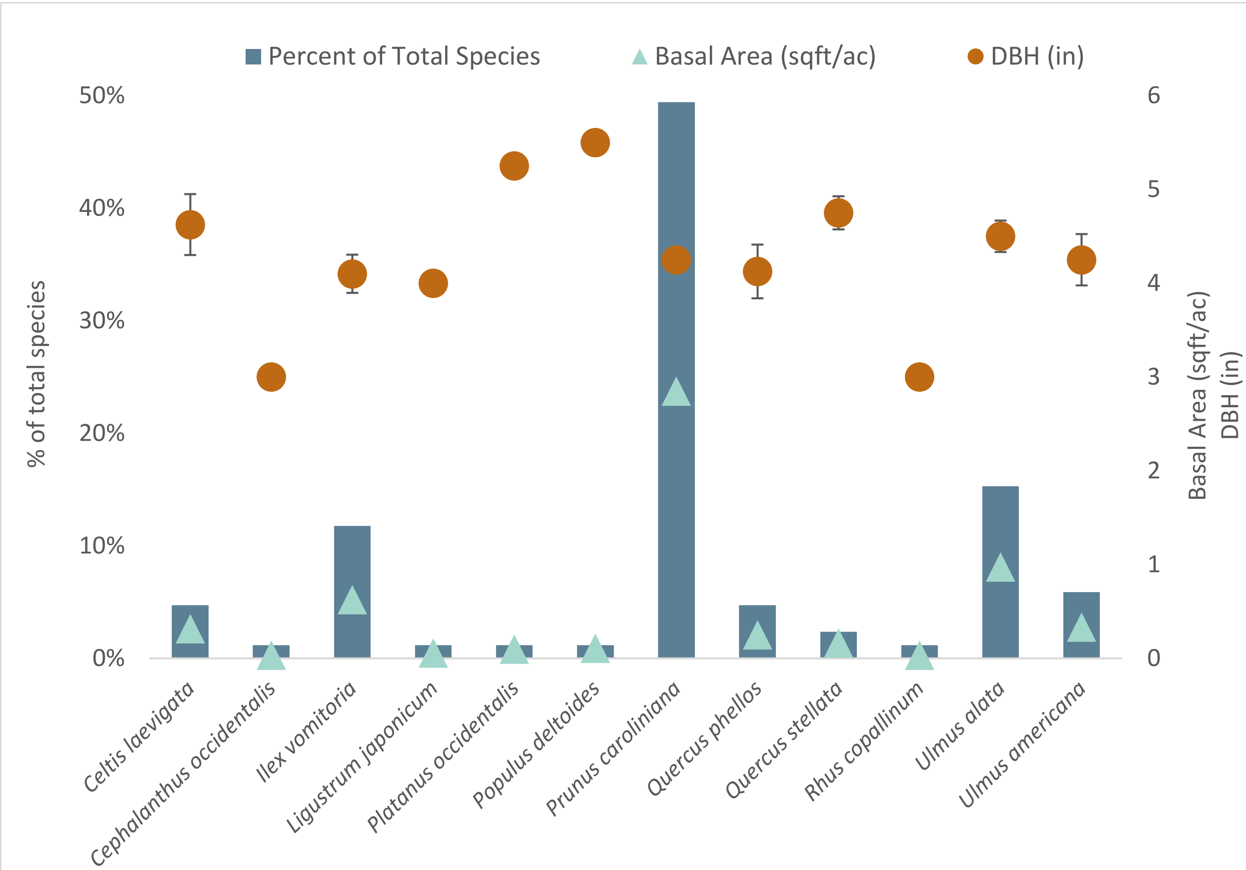


Midstory

Midstory species richness was 12 species, with *L. japonicum* as the only recorded invasive species at 1% of total (Fig 9). *P. caroliniana* dominated the total number of individuals (49%) and basal area, followed by *U. alata* and *Ilex vomitoria* (Fig 9). DBH and basal area did not fluctuate greatly between species given the data collection parameters (Fig 9).

The highest midstory species richness was observed in Woodland Well-Drained, and lowest midstory species richness and percent of total trees were observed in the Savanna plant associations (Table 2). Highest basal area, DBH and trees per acre was observed in Buffalo Bayou and Ravine plant associations. Invasive midstory species (*L. japonicum*) were observed only in Buffalo Bayou (Table 2).

FIGURE 9 Percent of total species, basal area and DBH of midstory species

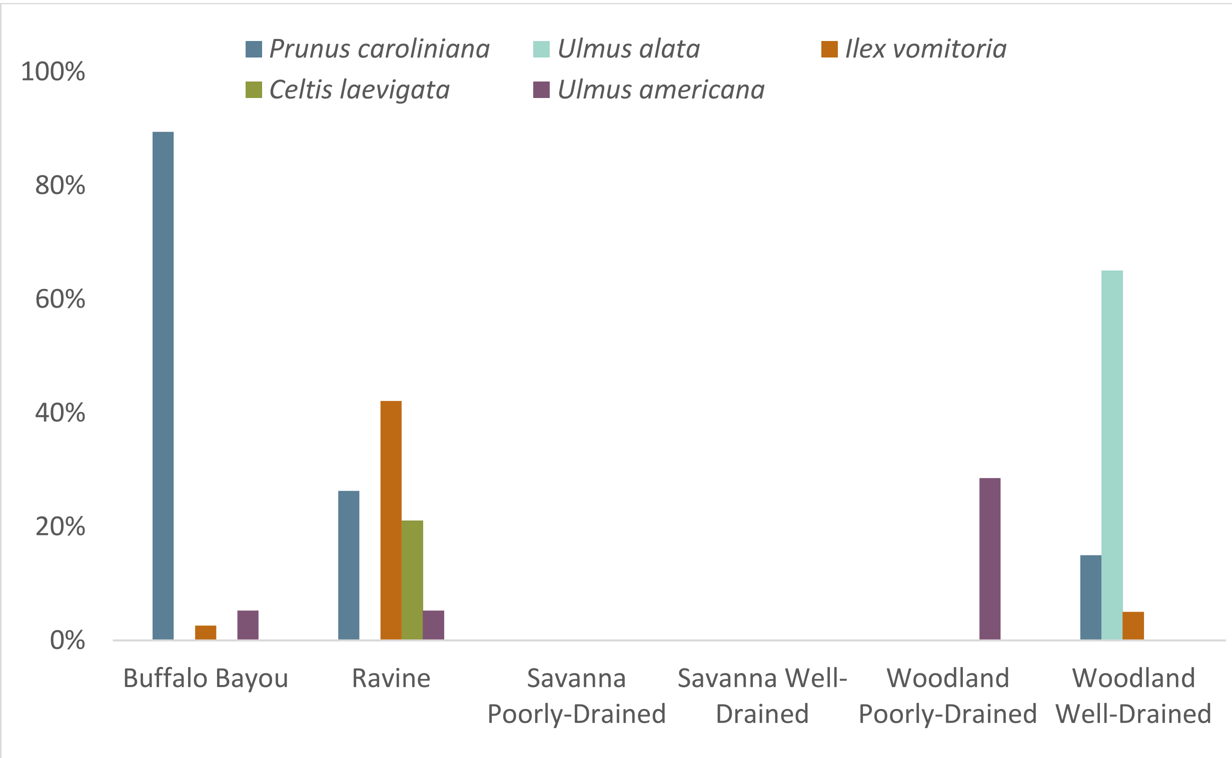


Plant association preferences of the five most common midstory species are shown in Figure 10. *P. caroliniana* appears to prefer Buffalo Bayou, and to a lesser extent Ravine and Woodland Well-Drained, while *U. alata* prefers Woodland Well-Drained and *U. americana* was observed mostly in Woodland Poorly-Drained with individuals in Buffalo Bayou and Ravine. *I. vomitoria* was observed mostly in Ravine, with individuals in Buffalo Bayou and Woodland Well-Drained. *Celtis laevigata* was represented only within the Ravine. *P. taeda* and *Quercus spp.* were not represented in high proportions in the midstory. Midstory species were not recorded within the Savanna plant associations.

TABLE 2 Midstory cover by plant association

	Richness	Avg DBH (in)	Basal Area (sqft/ac)	Native Species (No./ac)	Invasive Species (No./ac)
Buffalo Bayou	4	4.1	10.2	93	3
Ravine	5	4.2	12.7	127	0
Savanna Poorly-Drained	1	1.8	1.0	7	0
Savanna Well-Drained	0	0.0	0.0	0	0
Woodland Poorly-Drained	4	2.4	2.6	28	0
Woodland Well-Drained	6	3.0	5.0	50	0

FIGURE 10 Percent distribution of the five most common midstory species by plant association



Understory

Understory species richness was 60 species, with six invasive species observed (Table 5). Invasive species accounted for 23.6% of total understory recorded (Table 5). *I. vomitoria*, *P. caroliniana,* and *L. sinense* comprised 63.2% of the total stem count (Table 5). Other notable high percentages were *Cephalanthus occidentalis* (11.3%) and *Rubus argutus* (8.7%) (Table 5).

A higher species richness, stem count, and proportion of invasive understory species were observed in the two Woodland plant associations compared to other plant associations (Table 6). *L. sinense* followed by *L. japonicum* comprised the majority of invasive species. Understory height averaged approximately 6ft between all plant associations (Table 6).

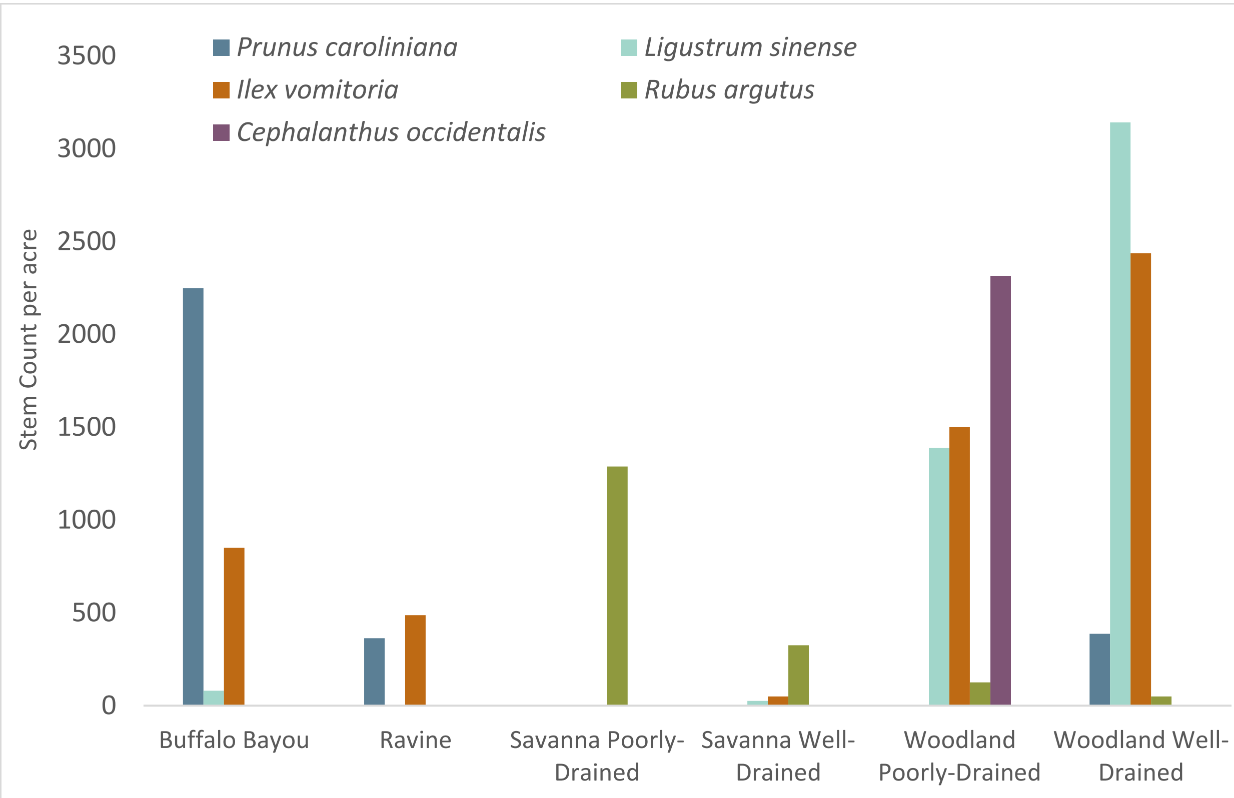
TABLE 5 Understory species with invasive species in bold font

Species	Total Stem Count	Avg Height (ft)	Percent of Total
Acer spp.	2	12.0	0.02%
Aralia spinosa	1	13.0	0.01%
Bacharis halimifolia	5	3.0	0.06%
Callicarpa americana	187	3.5	2.28%
Celtis laevigata	4	9.0	0.05%
Cephalanthus occidentalis	925	7.5	11.28%
Forestiera acuminata	65	4.8	0.79%
Fraxinus pennsylvanica	83	4.3	1.01%
Hibiscus laevis	400	5.0	4.88%
Hibiscus lasiocarpos	125	4.0	1.52%
Ilex decidua	51	8.9	0.62%
Ilex vomitoria	2,130	8.3	25.98%
Juniperus virginiana	2	3.5	0.02%
Ligustrum japonicum	**51**	**6.8**	**0.62%**
Ligustrum quihoui	**5**	**3.0**	**0.06%**
Ligustrum sinense	**1,854**	**5.1**	**22.61%**
Liquidambar styraciflua	2	4.0	0.02%
Malvaviscus arboreus var. drummondii	5	3.0	0.06%
Morus alba	**1**	**3.0**	**0.01%**
Pinus taeda	92	4.7	1.12%
Platanus occidentalis	3	11.0	0.04%
Populus deltoides	13	7.0	0.16%
Prunus caroliniana	1,200	8.1	14.64%
Quercus michauxii	1	8.0	0.01%
Quercus nigra	15	7.0	0.18%
Quercus phellos	75	7.8	0.91%
Quercus stellata	5	3.0	0.06%
Rubus argutus	715	4.8	8.72%
Salix nigra	8	8.0	0.10%
Sambucus nigra	10	6.0	0.12%
Solanum pseudocapsicum	**10**	**3.0**	**0.12%**
Triadica sebifera	**13**	**8.0**	**0.16%**
Ulmus alata	15	22.5	0.18%
Ulmus crassifolia	36	5.0	0.44%
Ulmus sp.	40	14.0	0.49%
Viburnum dentatum	50	6.7	0.61%

TABLE 6 Understory cover by plant association

	Richness	Avg Height (ft)	Stem Count/ac	% Invasive
Buffalo Bayou	5	7.3	3,243	3.6%
Ravine	7	6.7	2,713	0.2%
Savanna Poorly-Drained	6	5.4	3,560	0.2%
Savanna Well-Drained	10	4.6	1,340	10.9%
Woodland Poorly-Drained	18	7.6	11,184	20.0%
Woodland Well-Drained	23	6.6	7,410	44.0%

FIGURE 11 Average stem count per acre of the five most common understory species by plant association



Plant association preferences of four common understory species are shown in Figure 11. *P. caroliniana* appears to prefer Buffalo Bayou and to a lesser extent Ravine and Woodland Well-Drained, while *I. vomitoria* was represented well in all plant associations except the Savanna plant associations. *L. sinense* was observed mostly in the Woodland plant associations with low occurrences in Buffalo Bayou and Savanna Well-Drained, and *R. argutus* was observed primarily in the Savanna plant associations. *Cephalanthus occidentalis* was observed in high numbers within only one plot in the Woodland Poorly-Drained plant association (Plot 52). *Ulmus spp*. was not represented in high proportions within the understory (Table 5).

Ground Cover

Ground cover species richness was 76 species, with eleven invasive species observed (Table 7). Invasive species accounted for 17.7% of total ground cover recorded (Table 7). *L. sinense* was the only invasive species that comprised above 5% of total ground cover (Table 7). Notable high percentages for native species include *Campsis radicans* (11.9%), *I. vomitoria* (5.6%), *P. caroliniana* (6.9%), and *R. argutus* (11.5%) (Table 7). *Quercus spp.* (5.2%), *P. taeda* (0.4%) and *Ulmus spp.* (4.9%) seedlings were represented within ground cover (Table 7).

TABLE 7 Ground cover species with invasive species in bold font

Species	Avg Total Cover	Habit
Ageratina havanensis	1.1%	Forb
Ambrosia artemisiifolia	0.4%	Forb
Andropogon gerardii	0.9%	Grass
Callicarpa americana	1.0%	Shrub
Campsis radicans	11.9%	Vine
Celtis laevigata	0.1%	Tree
Chasmanthium latifolium	1.9%	Grass
Croton capitatus	0.6%	Forb
Cynodon dactylon	**1.0%**	**Grass**
Cyperus entrerianus	**2.7%**	**Graminoid**
Cyperus esculentus	**0.2%**	**Graminoid**
Diodia virginiana	1.0%	Grass
Eleocharis sp	0.1%	Graminoid
Elephantopus carolinianus	0.2%	Forb
Eupatorium capillifolium	1.5%	Forb
Eupatorium serotinum	0.4%	Forb
Euphorbia prostrata	0.1%	Forb
Euthamia leptocephala	0.6%	Forb
Evolvulus sericeus	0.1%	Forb
Fraxinus pennsylvanica	0.1%	Tree
Helianthus angustifolius	0.6%	Forb
Hibiscus lasiocarpos	0.1%	Shrub
Hibiscus sp.	0.1%	Forb
Hydrolea ovata	3.2%	Forb
Hygrophila latifolia	0.1%	Forb
Hypericum hypericoides	1.6%	Forb
Ilex vomitoria	5.6%	Shrub
Ipomoea cordatotriloba	0.1%	Vine
Juniperus virginiana	0.1%	Tree
Liatris pycnostachya	0.4%	Forb
Ligustrum japonicum	**2.7%**	**Shrub**
Ligustrum sinense	**6.0%**	**Shrub**
Lonicera japonicum	**0.2%**	**Vine**
Ludwigia alternifolia	0.1%	Forb
Lygodium japonicum	**0.5%**	**Vine**
Lythrum alatum lanceolatum	0.2%	Forb
Mecardonia acuminata	1.2%	Forb

TABLE 7 cont.

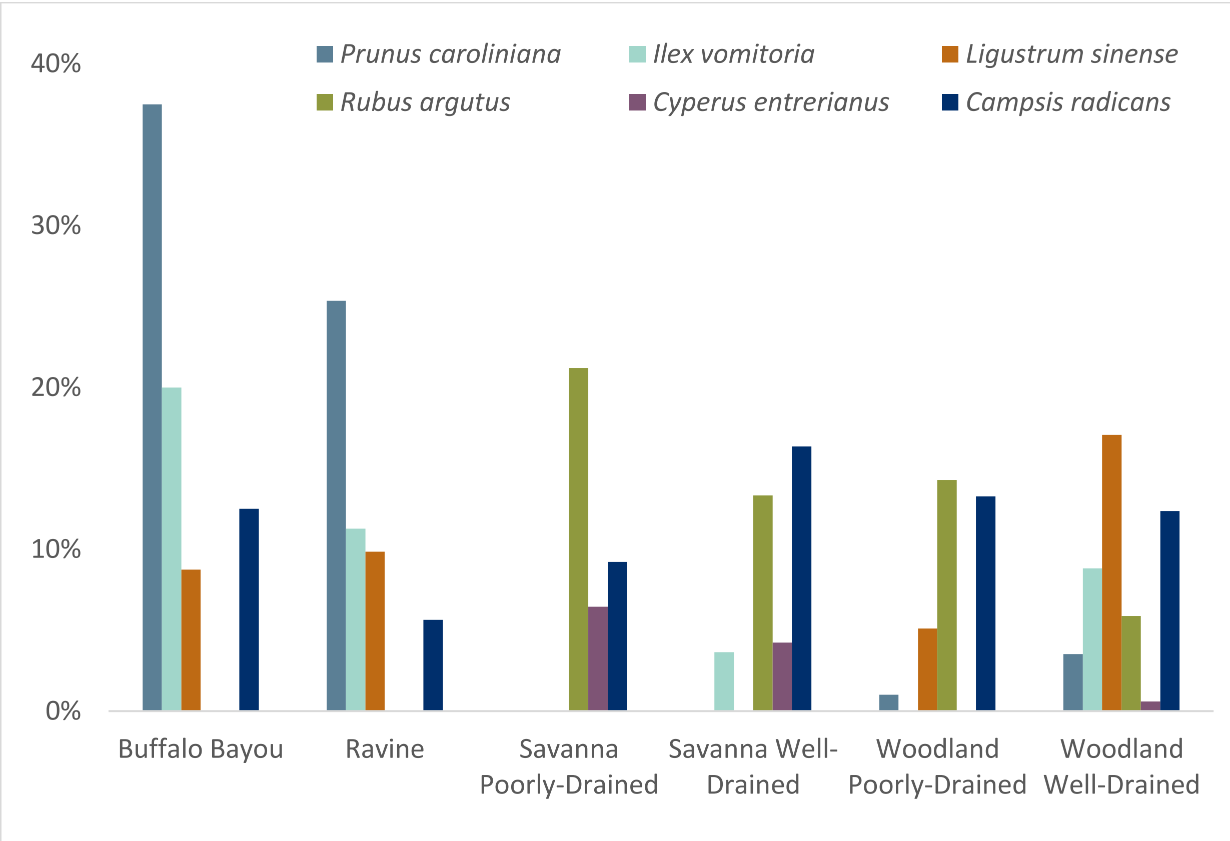
Species	Avg Total Cover	Habit
Mikania scandens	0.6%	Vine
Nekemias arborea	1.4%	Vine
Nothocalais sp.	0.1%	Forb
Oplismenus hirtellus	**0.2%**	**Grass**
Panicum repens	**0.4%**	**Grass**
Parthenocissus quinquefolia	0.1%	Vine
Passiflora incarnata	1.0%	Vine
Phyllanthus urinaria	**3.7%**	**Forb**
Pinus taeda	0.4%	Tree
Poaceae sp.	0.2%	Grass
Polygonum hydropiperoides	0.8%	Forb
Prunus caroliniana	6.9%	Tree
Quercus nigra	0.1%	Tree
Quercus phellos	4.2%	Tree
Quercus shumardii	0.2%	Tree
Quercus sp.	0.1%	Tree
Quercus stellata	0.6%	Tree
Rhynchospora sp.	0.1%	Graminoid
Rubus argutus	11.5%	Shrub
Rubus trivialis	2.1%	Shrub
Salix nigra	0.1%	Tree
Saururus cernuus	0.6%	Forb
Schizachyrium scoparium	0.6%	Grass
Scirpus cyperinus	0.4%	Graminoid
Smilax bona-nox	0.6%	Vine
Smilax glauca	1.9%	Vine
Smilax smallii	0.6%	Vine
Smilax sp.	0.5%	Vine
Solanum pseudocapsicum	**0.1%**	**Shrub**
Solidago altissima	2.9%	Forb
Taxodium distichum	0.1%	Tree
Tridens flavus	0.2%	Grass
Tripsacum dactyloides	1.6%	Grass
Ulmus alata	2.7%	Tree
Ulmus americana	0.9%	Tree
Ulmus crassifolia	0.7%	Tree
Ulmus sp.	0.6%	Tree
Vitis rotundifolia	0.2%	Vine

Species richness was greatest in the two Woodland plant associations (Table 8). Ravine and Woodland Well-Drained plant associations had invasive species percentages greater than 25%. Average ground cover was mostly leaf litter (83.8%) and was relatively consistent across plant associations (Table 8). Bare ground was greatest in the Savanna plant associations. Vegetation ground cover was comprised of percentages from multiple individual species and was highest in the Savanna plant associations (Table 8).

TABLE 8 Ground cover by plant association

	Richness	% Bare Ground	% Leaf Litter	% Vegetation	% Invasive
Buffalo Bayou	12	11%	89%	17%	9%
Ravine	12	12%	86%	39%	35%
Savanna Poorly-Drained	17	21%	79%	121%	14%
Savanna Well-Drained	8	21%	79%	92%	11%
Woodland Poorly-Drained	26	9%	81%	33%	5%
Woodland Well-Drained	28	9%	89%	35%	33%

FIGURE 12 Percent distribution of six common ground cover species by plant association.



Plant association preferences of six common understory species are shown in Figure 12. *P. caroliniana* appears to prefer Buffalo Bayou and Ravine, while *I. vomitoria* was represented in all plant associations except Woodland Poorly-Drained and Savanna Poorly-Drained. *L. sinense* was observed in all plant associations except Savanna, while *C. entrerianus* was represented mainly in Savanna. *R. argutus* was observed in every plant association except Buffalo Bayou and Ravine, and *C. radicans* was ubiquitous as a ground cover in every plant association.

Species Richness and Diversity

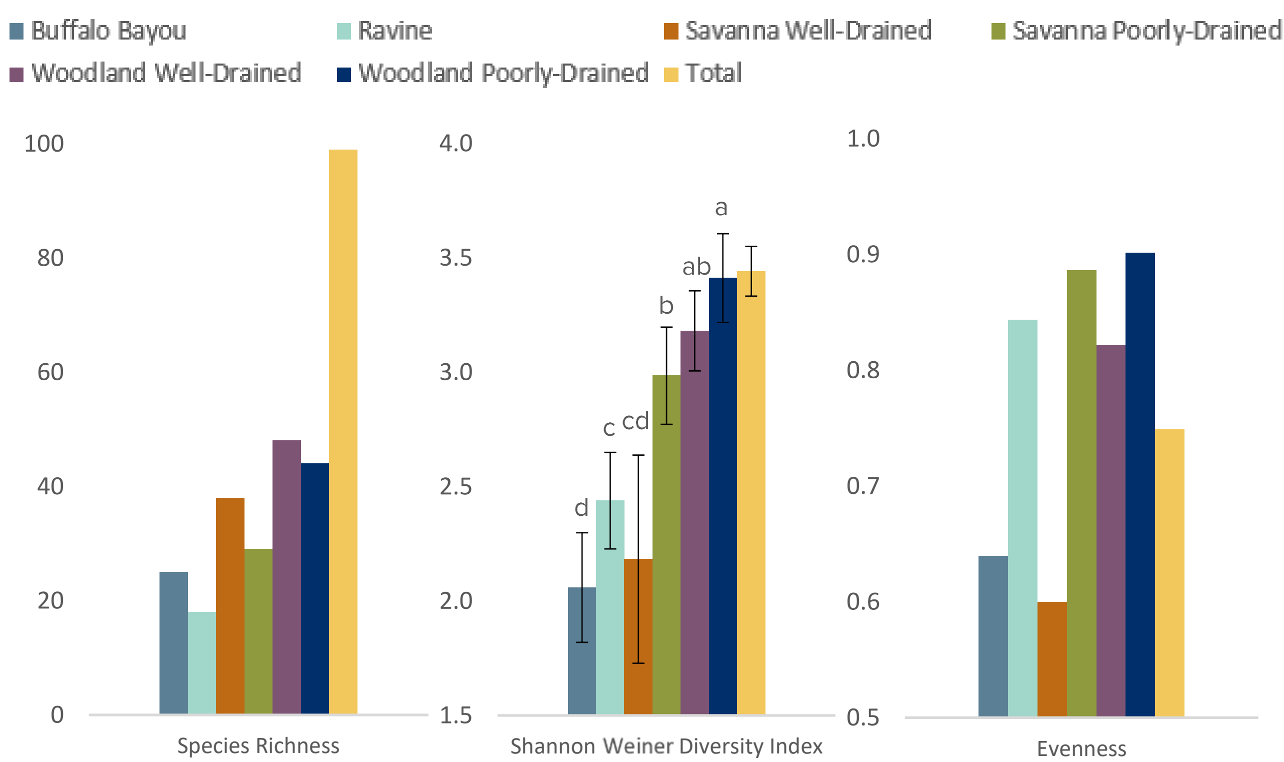
Total species richness recorded was 99 species, with the greatest in Woodland Well-Drained (48) and the lowest in the Ravine (18) (Fig 13). Trees represented the highest species richness for growth form, followed by forbs, while grasses and graminoids were the lowest (Table 9). Tree and shrub species richness was lowest in the midstory compared to all other canopy strata (Table 9).

TABLE 9 Species richness by growth form and canopy strata and entire Arboretum.

Growth Form	Overstory	Midstory	Understory	Groundcover	Total
Grass	-	-	-	9	9
Graminoid	-	-	-	5	5
Forb	-	-	-	25	25
Vine	-	-	-	13	13
Shrub	2	3	16	8	17
Tree	22	9	20	16	30

Shannon Weiner Diversity Index was 3.44 for all plots surveyed (Fig 13). Diversity was statistically highest in Woodland Poorly-Drained and Woodland Well-Drained, followed by Savanna Poorly-Drained. Savanna Well-Drained, Ravine and Buffalo Bayou had the lowest diversity. While species richness was lowest in the Ravine, higher evenness contributed to its statistically greater diversity compared to Buffalo Bayou (Fig 13).

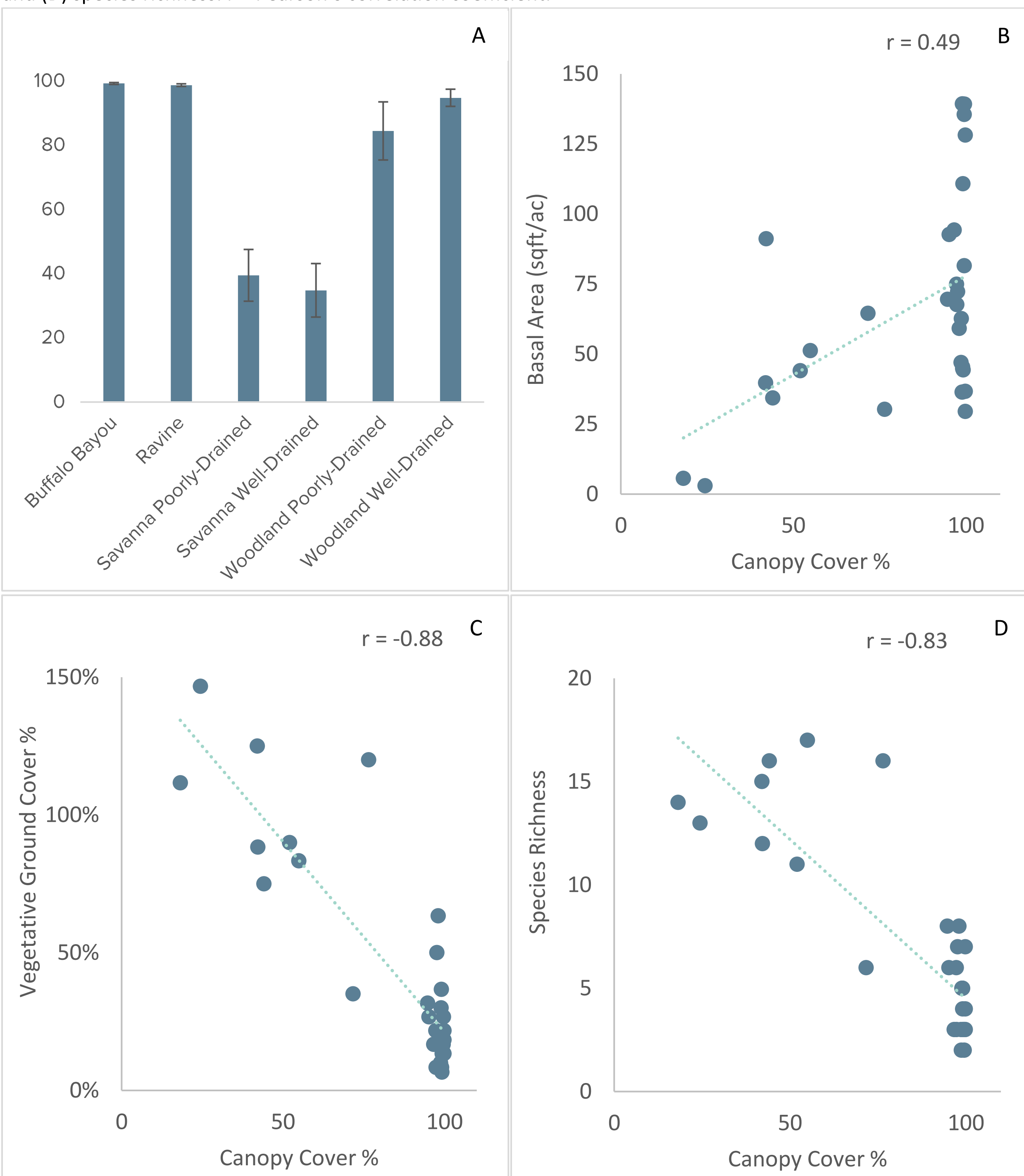
FIGURE 13 Species richness, Shannon Weiner diversity index and evenness by plant association and the entire Arboretum. Letters denote statistical differences in diversity index between plant associations, $p<0.05$.



Canopy Cover

Canopy cover was highest in Buffalo Bayou and Ravine, followed by Woodland, then Savanna plant associations, and assessed using Pearson's correlation (Fig 14). Canopy cover was significantly and positively correlated with basal area while both vegetative ground cover and species richness were significantly and negatively correlated with greater canopy cover ($p \leq 0.05$).

FIGURE 14 (A) Canopy cover by plant association, and canopy cover vs (B) basal area, (C) vegetative ground cover, and (D) species richness. r = Pearson's correlation coefficient.

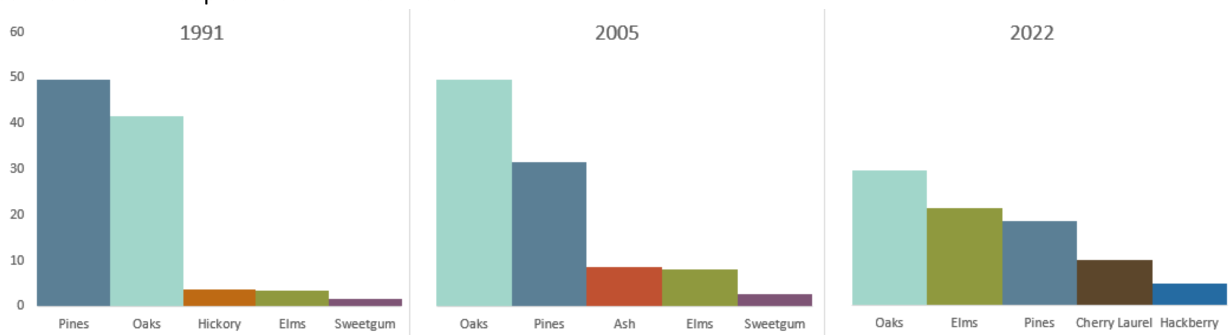


DISCUSSION

Canopy Strata Descriptions by Species

The overstory canopy of the Arboretum primarily consists of Pine-Oak-Elm with a diverse assemblage of secondary species, while the midstory is dominated primarily by Cherry Laurel-Elm-Yaupon. The understory consists mainly of Yaupon-Privet-Cherry Laurel with a diversity of shrubs and tree saplings, and the ground cover consists of a diverse assemblage of shrubs, vines, tree saplings and herbaceous species. *P. taeda* was the dominant overstory species in both number of individuals and size, as it was thirty years prior (Williams 1991). Compared to previous studies, a lower percentage of *Quercus spp.* and *Pinus spp.* in the midstory and understory canopies was observed in 2022 and may represent a transition toward an overstory canopy community dominated by *Ulmus spp.* and *P. caroliniana* (Fig 15). This assertion is supported from data in Williams 1991 and Siemann 2005 indicating a decrease in the proportion of pines and oaks and an increase in *Ulmus spp.*, *P. caroliniana* and *C. laevigata* (Fig 15). This trend may be a response to the high tree mortality associated with Hurricane Ike (2008) and the extreme drought of 2011, allowing *Ulmus spp*. and *P. caroliniana* to establish a competitive advantage driven by functional attributes such as high seed production, high germination rate, and relatively low-light tolerance indicative of these species (Fig 16, Fig 17), along with a lack of disturbances such as grazing or fire. Additionally, *P. taeda* has been shown to experience high seedling mortality rates in closed-canopy forests (Bormann 1956), making natural regeneration difficult for this species in an established woodland.

FIGURE 15 Percent of the five dominant overstory tree canopy species from Williams 1991, Siemann 2005 and 2022 collected data. Adapted from Watson 2013.



A limitation from previous studies is that only the relative frequency of species is known, and not the total number of individuals per unit area for comparison to the current data. It is possible that while the percentage of oaks and pines is lower in 2022 versus 1991 and 2005, their actual number may be constant, and only that the numbers of *Ulmus spp.* or *P. caroliniana* have increased. In 2022, the high proportion of *Ulmus spp.* and *P. caroliniana*, and their relatively lower basal areas could indicate that these species are of a younger age class compared to more mature pines and oaks. Without active management, greater proportions of these species can be expected but future consistent monitoring is needed to confirm this.

Canopy Strata Descriptions by Plant Associations

Buffalo Bayou and Ravine are both riparian ecosystems and exhibited relatively similar numbers of overstory trees per acre and basal area (Table 1). Coincidentally, both Poorly-Drained Woodland and Savanna contained 23% fewer overstory trees per acre than their Well-Drained counterparts (Table 1), possibly a result of the high mortality observed following droughts in these lower-lying areas. Given its recent tree removal, Savanna plant associations intentionally have the fewest trees and shrubs per acre in all canopy strata.

FIGURE 16 High germination rate and resprouting capability of *P. caroliniana*

FIGURE 17 High seed production and germination of *Ulmus spp.*

Basal areas in the Woodland and Savanna plant associations are consistent with their respective habitat values (Vander Yacht et al. 2020). While basal areas above 100 sqft/ac can markedly decrease ground cover, no plant association exceeded this value (Vander Yacht et al. 2020). The Savanna plant associations have an average basal area below 50 sqft/ac and canopy cover percentage of less than 45%, indicating that sufficient light can reach the ground to allow growth of herbaceous species. As canopy cover decreases, both vegetative ground cover and species richness increase (Fig 14). However, this should not be an indication to remove overstory trees within plant associations other than the Savanna, and other methods to improve ground cover and diversity should be implemented in these areas without impacting canopy cover, such as introducing shade tolerant native species.

Species diversity, as measured by the Shannon Weiner Index, appears to be heavily influenced by species evenness. High occurrences of *P. caroliniana* in Buffalo Bayou and the Ravine, and low overall species distribution in Savanna Well-Drained reduce their overall diversity. The remaining plant associations exhibit a statistically greater diversity index than the former three. It was expected that the Savanna plant associations would have the highest diversity, as an open canopy improves conditions for a diverse herbaceous ground cover. Given its relatively young age, the Savanna may require more time and management to establish a greater diversity of herbaceous species compared to habitats with a closed canopy and historically less ground cover diversity. Within ground cover, the overall number of herbaceous species (grasses, graminoids and forbs) is similar to woody species (vines, shrubs and trees).

Invasive and Undesirable Species

Invasive species were present in all canopy strata but were not represented in high proportions within the overstory and midstory. Currently only *T. sebifera* and *L. japonicum* appear to be growing and maturing to these strata. However, the observation of these two species in the understory and ground cover indicates that a seedbank and multi-age classes exist in addition to mature individuals. *L. sinense* is represented in high proportions in both the understory (22.6%) and ground cover (6%), continuing observations from Williams 1991, where *L. sinense* comprised 41% of total stem count of all small shrubs. This species was the most prevalent invasive species and larger individuals were mostly observed within the Well-Drained Woodland plant association. Their preference for low light and well-drained soils was also noted by Bersche 1998, although individuals were also recorded in Poorly-Drained Woodland areas in 2022. *Cynodon dactylon* and *Cyperus entrerianus* are two of the most common herbaceous invasive ground cover species but appear to be confined mostly to the Savanna plant associations with its lower canopy cover and higher light conditions, taking advantage of recent canopy clearing that exposed large areas of bare ground during savanna restoration activities of the Master Plan.

Some native species have colonized aggressively, and their high proportions may be undesirable when a diverse ecosystem is an objective. *I. vomitoria* dominates the understory of the Arboretum, with almost a quarter of the individuals sampled attributed to this species. It has a similar habitat preference to *L. sinense*, able to grow in low light conditions and preferring well-draining soils. The emergence of *P. caroliniana* throughout the landscape appears to be a relatively recent occurrence, as a 1938 inventory of the nearby area listed this species as "scattered" only along the banks of Buffalo Bayou and did not record a meaningful occurrence of this species in upland areas (Fitzgerald 1938). A more recent analysis observed a decrease in total *P. caroliniana* basal area from 4.4 sqft/ac to 2.9 sqft/ac between 1991-1998 (Siemann 2005), but this has since rebounded back to 4.4 sqft/ac in 2022. This species has a clear preference for the well-drained, low-light conditions along Buffalo Bayou, with instances in the Ravine and Woodland Well-Drained where it was able to advance to the overstory and midstory canopies.

I. vomitoria, *L. sinense* and *P. caroliniana* account for 63% of understory stem count and are all ubiquitous as a ground cover, indicating a dependable regeneration for these species. The high stem count of the Woodland plant associations is mostly associated with *I. vomitoria* and *L. sinense*, while *I. vomitoria* and *P. caroliniana* prefer Buffalo Bayou, and to a lesser extent the Ravine. *Cephalanthus occidentalis* stem count in the understory was observed at 11%, but observations of this species are isolated to a single plot located in a low-lying and poorly-drained area, referred to as the Swamp. *Rubus argutus* is another notable aggressive understory and ground cover species that was only observed in Savanna and Woodland plant associations. *Campsis radicans* is prevalent in every plant association in relatively high amounts. Both it and *R. argutus* propagate by seed and rhizome and grow in a range of environmental conditions. These aggressive native and invasive species contribute to the "thicketization" found in lower canopy strata by creating high stem counts and ground covers that are no longer managed by natural disturbances such as grazers and periodic fires.

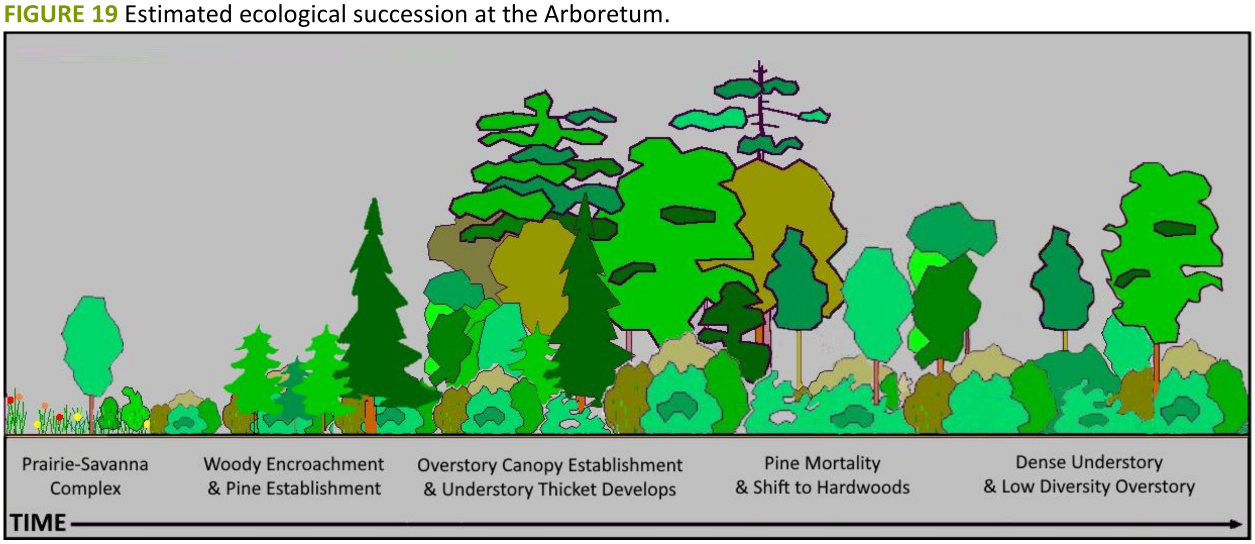
Future patterns

Historic aerial photos indicate that the Arboretum was originally a mosaic of savanna and coastal prairie habitat, and the relatively fast-growing *P. taeda* were likely the early woody colonizers to take advantage of disturbance-free conditions, followed by the slower growing oaks, elms and other hardwood species that likely migrated from the bayou corridors or surrounding upland areas. These original pine colonizers may be coming to the end of their lifespan, and a new overstory canopy community may develop in its place. Whether or not these trends continue is to be determined, but all previous studies predicted a shift toward a hardwood climax forest (Bersche 1999, Williams 1991). It is also worth reiterating that the upland areas of the Arboretum were originally a savanna-coastal prairie mosaic, and attempting to maintain a closed canopy woodland dominated by a preferred overstory species is not a return to its true historical state.

A point of greater importance may not be related to one specific species, but of overall tree diversity between canopy strata that indicates a bottleneck between the understory and overstory. The overstory, understory and groundcover each exhibited a greater diversity of tree species than the midstory (Table 9), and within the midstory, 82.4% of all individuals surveyed were *I. vomitoria*, *P. caroliniana*, or *Ulmus spp.* (Fig 8) with relatively low percentages of pine and oak species. Given the broad diversity of tree seedling and sapling species in the ground cover and understory (Table 5, Table 7), seeds appear able to germinate but are unable to reach maturity. The density and ability of *I. vomitoria*, *P. caroliniana*, and *L. sinense* to thrive in the understory and midstory may be preventing tree diversity found in the groundcover and understory strata from advancing into the overstory canopy strata (Table 7). These three species exhibit high stem counts within the current understory and also quickly colonize canopy gaps left by dead or fallen trees (Fig 18) (Bersche 1998). Based upon size and the estimated age of current overstory trees, it is possible that these individuals were the original woody colonizers and established at a time when there was more open canopy and little to no competition. As these mature trees die off, there is a future risk of an overstory with low tree diversity hindered by a dense understory thicket. Whether this trend continues may not become apparent for decades as the mature overstory dies off and the current low-diversity midstory becomes the dominant canopy stratum (Fig 19).

FIGURE 18 Dense understory of yaupon, and yaupon and privet colonizing a canopy gap left by a dead tree.

FIGURE 19 Estimated ecological succession at the Arboretum.



CONCLUSIONS

Siemann 2005 noted that there is currently little quantitative data on vegetation at the Arboretum and recommended that consideration should be given to its collection. This monitoring study creates a simple, documented, and consistent baseline inventory that should be repeated every 5-10 years. Although conclusions can be made from the current data set, more meaningful conclusions will occur from comparisons to previous monitoring events.

From the three previous monitoring studies, it appears that a gradual shift in the overstory canopy is occurring, following a successional path from loblolly pine dominance to that of oak and elm. While pine mortality appears to be occurring at an observable rate, this may be a natural cycle of ecological succession. There is not a clear reference ecosystem for its stable state, and cycles of droughts and hurricanes experienced in this region could create a dynamic path of ecological succession that may never allow for stabilization.

A true reference ecosystem is difficult to identify given much of the surrounding region has been developed for urban or rural use, and the plant associations in Table 10 may currently be the optimal reference for future targets and goals. The location within a major metropolitan city has resulted in ecosystems that have been extremely fragmented for decades and heavily influenced by anthropomorphic factors, both indirectly and directly. Therefore, its plant associations do not necessarily adhere to ecosystems that have been previously described but appear to be a unique combination of many (Table 10) (NatureServe 2024).

The prevalence of invasive and aggressive native species (*I. vomitoria*, *L. sinense*, *P. caroliniana*) in the understory, and the resulting thicketization, may be suppressing a more diverse and healthy woodland ecosystem. This thicketization process began once the Arboretum became surrounded by urban development, removing grazing and historic periodic fire that would have suppressed these species (Fig 22). The prevalence of these aggressive understory species was also noted in previous surveys and impacts from a prolonged lack of sufficient management may now be quantifiable. A diversity of woody seedlings in the lower canopy strata indicate successful initial recruitment, but these seedlings are unable to reach maturity due to competition from the dense understory of aggressive species free of any constraints. Impacts will become more evident over time as the mature overstory canopy dies, resulting in a loss of overall vegetation diversity.

Suppression of invasive species, especially *L. sinense*, should be a high priority to enhance woodland succession. Anecdotally and from Bersche 1998, both *L. sinense* and *T. sebifera* quickly colonize open areas with more sunlight, such as trail edges and canopy gaps from downed overstory trees. Responding to and managing these select locations may prevent colonization by these invasives while allowing desirable species to establish.

From the current data set, enough evidence also exists to support the controlled management of aggressive native species such as *P. caroliniana*, *Ulmus spp*., *I. vomitoria* and *C. occidentalis* in select areas, as well as *C. radicans* and *R. argutus*, to favor more diversity, especially in the absence of natural control methods of fire and grazers. A targeted management approach to suppress select species that are increasing in dominance (*Ulmus spp., P. caroliniana, C. laevigata*) to curate a woodland comprised of "traditionally dominant" species (*P. taeda, Quercus spp., Carya spp*.), may be a difficult, resource-intensive, and biased endeavor. A more holistic approach should focus on enacting management strategies that enhance diversity in all canopy strata and plant associations. A combination of prescribed fire, importing grazing animals such as goats (Benigno 2022), along with mechanical and chemical removal and the reintroduction of native species may be the most effective management strategy implemented on a scale large enough to sustain a diverse assemblage of ecosystems with the ability to continue down a path of dynamic ecological succession with minimal human intervention.

It is recommended that a natural resource management plan be developed for separate ecosystems or specific areas of the Arboretum. The results in this report and future monitoring studies should be referenced as a guide when developing and adapting these plans.

TABLE 10 Ecosystem classifications relevant but not conclusive to those found at the Arboretum.

Macrogroup	Group	Alliances	Associations
Coastal Plain Basin Swamp & Flatwoods	Hardwood - Loblolly Pine Nonriverine Wet Flatwoods	*P. taeda – Q. laurifolia – Q. phellos* West Gulf Coastal Plain Wet Flatwoods Forest	*Q. stellata – P. taeda* Flatwoods Wet Forest
			P. taeda - Liquidambar styraciflua – Q. (nigra, phellos) / Crataegus marshallii Floodplain Forest
		P. echinata – P.taeda – Q. stellata Forest	*P. echinata – P. taeda – Q. stellata - Carya texana / Vaccinium arboreum* Woodland
			P. taeda – Q. stellata / Crataegus spp. Woodland
South-Central Oak - Pine Forest & Woodland	Texas Post Oak Savanna & Woodland	*Q. stellata – Q. virginiana / I. vomitoria* Woodland	*Q. stellata – U. crassifolia / Ilex decidua / Carex cherokeensis - Schizachyrium scoparium* Woodland
		Q. virginiana / I. vomitoria Woodland	*Q. virginiana – Q.stellata / Schizachyrium scoparium - Paspalum plicatulum* Woodland
Southeastern North American Ruderal Forest	Southeastern Native Ruderal Forest	*Liquidambar styraciflua – C. laevigata – Q. nigra* Ruderal Forest	*C. laevigata* Coastal Plain Ruderal Forest
Southern Great Plains Forest & Woodland	Cross Timbers Woodland	*Q. stellata – Q. marilandica* Forest & Woodland	*Q.s stellata - Ulmus alata* Forest
		Q. stellata – U. crassifolia Forest & Woodland	*Q. stellata - (U. crassifolia) / Callicarpa americana / Verbesina virginica* Woodland
			Q. stellata – U. crassifolia / Ilex decidua / Carex cherokeensis - Schizachyrium scoparium Woodland
			Q. stellata - (U. crassifolia) / Sideroxylon lanuginosum / Nassella leucotricha Paluxy Sands Woodland
Southern Coastal Plain Floodplain Forest	Oak - Sweetgum Floodplain Forest	*Q. phellos – Q. virginiana – Q. nigra* West Gulf Floodplain Forest	*Q. nigra / I. vomitoria / Chasmanthium sessiliflorum* Ruderal Floodplain Forest
			Q. nigra – Q. phellos - (P. taeda) / Crataegus marshallii / Smilax smallii Floodplain Forest
			Q. nigra – U. alata / Ostrya virginiana Floodplain Forest
			Q. virginiana / I. vomitoria - Sabal minor / Carex cherokeensis - Malvaviscus arboreus var. drummondii Forest
			Q. virginiana - Quercus nigra / Chasmanthium latifolium Forest
		Q. laurifolia – Q. phellos – P. taeda Coastal Plain Riparian Forest	*P. taeda* Riparian Forest

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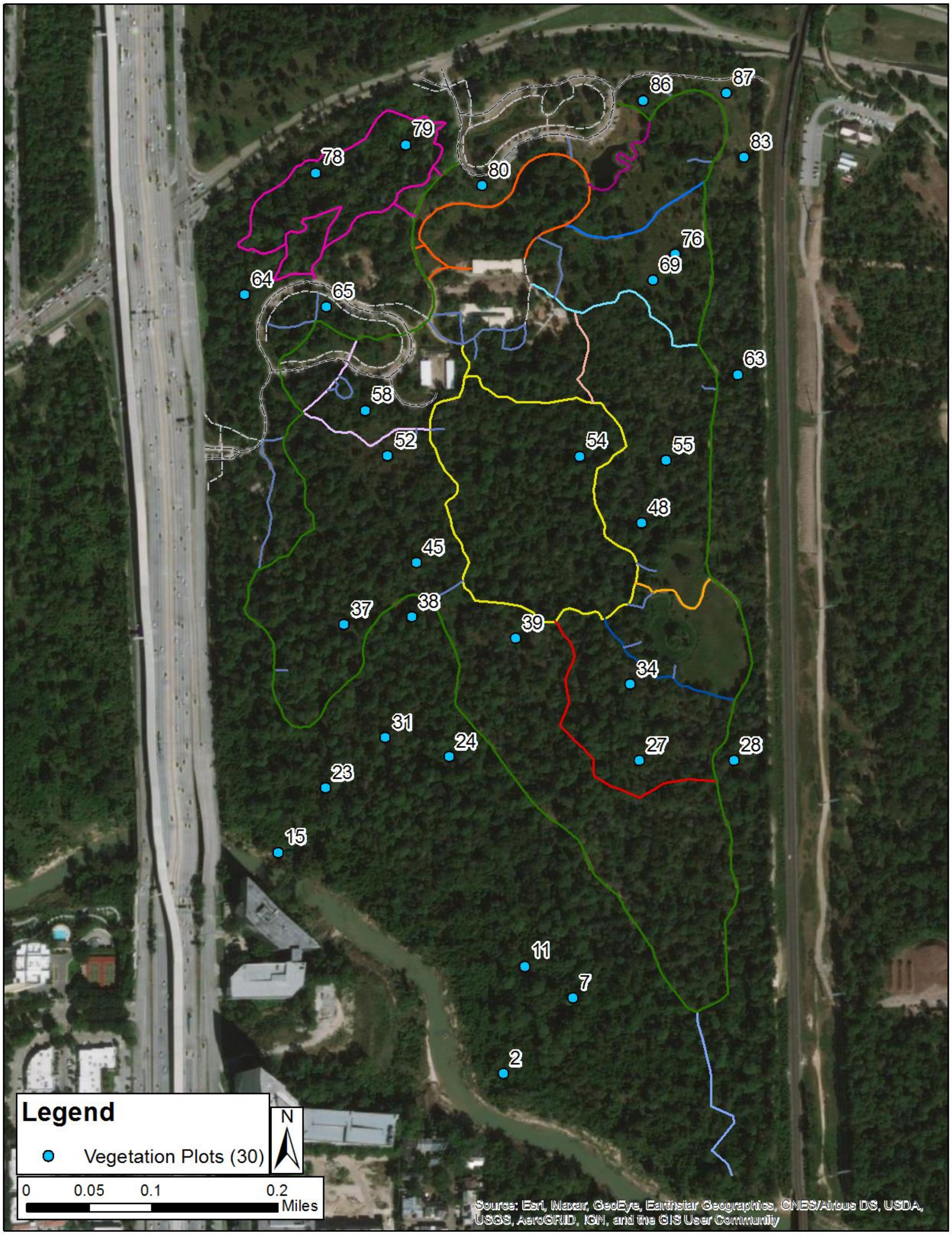
APPENDIX A Vegetation Monitoring Plot Location Map



APPENDIX B Vegetation Monitoring Plot Descriptions

Plot	Vegetation Association	Physical Marker	X	Y	GPS Name
2	Buffalo Bayou	t-post & flagging tape	-95.4518	29.75763	Veg 2
7	Buffalo Bayou	t-post & flagging tape	-95.4511	29.75839	Veg 7
11	Buffalo Bayou	t-post & flagging tape	-95.4516	29.75871	Veg 11
15	Buffalo Bayou	t-post & flagging tape	-95.4544	29.75985	Veg 15
23	Buffalo Bayou	t-post & flagging tape	-95.4539	29.76049	Veg 23
24	Buffalo Bayou	t-post & flagging tape	-95.4525	29.76081	Veg 24
27	Woodland Well-Drained	t-post & flagging tape	-95.4503	29.76077	Veg 27
28	Woodland Well-Drained	t-post & flagging tape	-95.4492	29.76077	Veg 28
31	Buffalo Bayou	t-post & flagging tape	-95.4532	29.7610	Veg 31
34	Woodland Well-Drained	t-post, no flagging	-95.4504	29.76153	Veg 34
37	Woodland Well-Drained	t-post & flagging tape	-95.4537	29.76213	Veg 37
38	Buffalo Bayou	t-post & flagging tape	-95.4529	29.7622	Veg 38
39	Woodland Well-Drained	t-post & flagging tape	-95.4517	29.76199	Veg 39
45	Woodland Poorly-Drained	t-post & flagging tape	-95.4529	29.76275	Veg 45
48	Woodland Well-Drained	t-post & flagging tape	-95.4503	29.76315	Veg 48
52	Woodland Poorly-Drained	t-post, no flagging	-95.4532	29.76382	Veg 52
54	Woodland Poorly-Drained	t-post & flagging tape	-95.451	29.76382	Veg 54
55	Woodland Well-Drained	t-post & flagging tape	-95.45	29.76378	Veg 55
58	Woodland Poorly-Drained	t-post & flagging tape	-95.4534	29.76428	Veg 58
63	Woodland Poorly-Drained	t-post & flagging tape	-95.4492	29.76464	Veg 63
64	Ravine	t-post & flagging tape	-95.4548	29.76544	Veg 64
65	Woodland Well-Drained	PVC, rebar, pin flag	-95.4539	29.76531	Veg 65
69	Savanna Poorly-Drained	PVC, rebar, pin flag	-95.4501	29.76558	Veg 69
76	Savanna Poorly-Drained	PVC, rebar, pin flag	-95.4499	29.76584	Veg 76
78	Ravine	t-post, no flagging	-95.454	29.76666	Veg 78
79	Ravine	t-post, no flagging	-95.453	29.76694	Veg 79
80	Savanna Well-Drained	PVC, rebar, pin flag	-95.4521	29.76653	Veg 80
83	Savanna Well-Drained	PVC, rebar, pin flag	-95.4491	29.76682	Veg 83
86	Savanna Poorly-Drained	PVC, rebar, pin flag	-95.4502	29.76739	Veg 86
87	Savanna Well-Drained	PVC, rebar, pin flag	-95.4493	29.76746	Veg 87

APPENDIX C Spherical Densiometer Instructions

Using Forest Densiometers

Originally developed and published by Dr. Paul E. Lemmon, the Spherical Densiometer is designed for rugged field use while remaining compact and lightweight for ease of transport. This instrument has been extensively tested by numerous foresters and forestry technicians on stands of ponderosa pine, lodgepole pine and Douglas fir.

History

The pioneering work was done mainly in the Pacific Northwest; however, subsequently the instrument has been used for measuring overstory density throughout the U.S. and internationally. The original methodology was developed to characterize and quantify canopy density for representative forest sites where numerous parameters such as tree size (height, girth, age and growth rates), tree spacing, soil type, slope and slope orientation, elevation and others were determined.

Reading Canopy Areas

The spherical densiometer consists of either a concave or a convex mirror with twenty-four ¼″ squares engraved on the surface. The design is such that the operator views the same degree of arc overhead regardless if the user is in a low lying canopy area or a mature stand of high canopy timber.

Each square of the grid is then equally sub-divided mentally into 4 smaller squares (⅛″ x ⅛″) and represented by an imaginary dot in the center of each of the smaller squares. Thus a total of 96 dots representing smaller square areas can then be counted within the grid. Once the representative forest site has been selected for measurement, the user holds the instrument level and far enough away from his/her body such that the operator's head is just outside the grid. The operator can then count the number of dots, representing the smaller (⅛″ x ⅛″) square areas of canopy openings, up to a total of 96. The number determined is then multiplied by 1.04 to obtain the percent of overhead area *not* occupied by canopy. The difference between this percentage and 100% is the estimated overstory density in percent.

Four readings are taken about a reference tree in each site area and averaged. The operator should be positioned with his/her back toward the reference tree, and moving about the reference tree facing North, East, South and West.

"The reference tree in each site represents a typical dominant or co-dominant species in the stand. The points selected around each reference tree should be far enough away (from the reference tree) so that the crown of the reference tree is just outside the overstory area being estimated" (Lemmon, 1956).

The statistical accuracy and repeatability of the instrument is based on taking four readings, using up to 96 dots representing the smaller (⅛″ x ⅛″) squares for up to a total of 384 smaller squares per site (96 x 4), and then averaging all four readings at the different orientations about the reference tree. Obviously, in a forest environment, you will be counting considerably less than 9 dots representing the smaller squares, so the exercise is a lot less laborious than it might first appear. The denser the overstory canopy, the fewer dots you will have to count since you are counting the ⅛″ x ⅛″ areas in which you can see sky in the major portion of each of the smaller squares. With a little practice, you will find that the data can be gathered quickly and with repeatability using the same or different operators.

In open forest where more than half of the canopy area is open to the sky, you can reverse the process and count just the smaller square areas (⅛″ x ⅛″) that are covered by the canopy and multiply by 1.04 to obtain the estimated overstory density percentage.

Reference: Lemmon, Paul E., 1956, A Spherical Densiometer for Estimating Forest Overstory Density; Forest Science 2(4)314-320.
Lemmon, Paul E., 1957, A New Instrument for Measuring Forest Overstory Density; Journal of Forestry 55(9)667-668. 236501.LET

APPENDIX D Sample Data Sheet

HANC Vegetation Monitoring

Plot: ______________ Date: ______ Observers: ______________

Cover Type: Ground Cover - Grasses, forbs, vines, trees/shrubs < 3' height 1m^2 square plot

Center SubPlot

No.	Species	% Cover	No.	Species	Cover %
1			10		
2			11		
3			12		
4			13		
5			14		
6			15		
7			16		
8			17	Bare Ground	
9			18	Leaf Litter	

North SubPlot

No.	Species	% Cover	No.	Species	Cover %
1			10		
2			11		
3			12		
4			13		
5			14		
6			15		
7			16		
8			17	Bare Ground	
9			18	Leaf Litter	

South SubPlot

No.	Species	% Cover	No.	Species	Cover %
1			10		
2			11		
3			12		
4			13		
5			14		
6			15		
7			16		
8			17	Bare Ground	
9			18	Leaf Litter	

Photograph image names

North: South:

Canopy Cover:	N	S	E	W
Center Subplot:				
North Subplot:				
South Subplot:				

APPENDIX D Sample Data Sheet (cont.)

HANC Vegetation Monitoring

Cover Type: Overstory - Trees > 6" DBH — 1/10th acre plot - 37' radius

No.	Species	DBH (in)	No.	Species	DBH (in)
1			8		
2			9		
3			10		
4			11		
5			12		
6			13		
7			14		

Cover Type: Midstory - Tree/shrub trunks 3" < DBH < 6" — 1/20th acre plot - 26' radius

No.	Species	DBH (in)	No.	Species	DBH (in)
1			16		
2			17		
3			18		
4			19		
5			20		
6			21		
7			22		
8			23		
9			24		
10			25		
11			26		
12			27		
13			28		
14			29		
15			30		

Cover Type: Understory - Tree/shrub trunks < 3" DBH and > 3' height — 1/20th acre plot - 26' radius

No.	Species	Stem Count	Est. Average Height (ft)
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			

APPENDIX E Data Analysis Spreadsheet & HANC Internal File Path Locations

DATA ANALYSIS

An excel spreadsheet was developed to analyze data consistently and repeatedly and can be found on the HANC Internal Server at the file path location shown below. This spreadsheet also contains a tab with a printable version of the Field Data Sheet (Appendix D).

Vegetation Metrics
Vegetation metrics recorded on field data sheets should be manually entered as instructed on the 'Data Entry' tab in the corresponding columns in the Data Analysis Spreadsheet. Once input, data should be filtered by vegetation cover type, copied, and pasted on the corresponding 'Overstory', 'Midstory', 'Overstory+Midstory', 'Understory', and 'Ground Cover' tabs. On these tabs, instructions are provided to further analyze the data. Data should be assessed for quality and will be graphed automatically on each tab.

Cover Type, Plot, Species Code
Cover type, plot number and species code should be manually entered into the 'Data Entry' tab. Species code is a consistent method of abbreviating species names and is typically the first two letters of the genus and first two letters of the species (ex. *Prunus caroliniana* = PRCA).

Plant Association, Growth Form, Native or Invasive
The titled categories above are automatically populated in the 'Data Entry' tab once cover type, plot and species code are input. These cells extract species information from the 'Code Reference' tab. If a new, unreferenced species is added, corresponding information will need to be manually input into the 'Code Reference' tab to compensate.

Photo monitoring
Images should be placed in the file folder below according to year taken, and then renamed with the specific vegetation plot number and cardinal direction. For example: photos collected at Vegetation Monitoring Plot Number 2 and taken in the north direction would be renamed '2N'.

HANC INTERNAL FILE PATH LOCATIONS

Field Data Sheet and Data Analysis Spreadsheet file
OneDrive - Houston Arboretum & Nature Center\Documents\CONSERVATION\Monitoring\Vegetation Monitoring Plots\Vegetation Monitoring Data Record & Analysis Sheet.xlsx

Photo Monitoring Folder
OneDrive - Houston Arboretum & Nature Center\Documents\CONSERVATION\Monitoring\Vegetation Monitoring Plots\Photomonitoring

APPENDIX F Supplemental Data

Overstory by plot and plant association

Plot	Plant Association	Native	Invasive	Total	% Invasive	Richness	Avg DBH (in)	Sum Basal Area (sqft)
2	Buffalo Bayou	5	1	6	17%	3	8.0	2.2
7	Buffalo Bayou	7	0	7	0%	4	8.9	3.7
10	Buffalo Bayou	10	0	10	0%	5	10.4	7.0
11	Buffalo Bayou	4	0	4	0%	3	11.9	4.3
23	Buffalo Bayou	2	2	4	50%	3	14.1	6.1
24	Buffalo Bayou	9	0	9	0%	4	15.1	13.5
31	Buffalo Bayou	8	0	8	0%	4	15.0	12.0
38	Buffalo Bayou	11	0	11	0%	5	14.0	13.4
64	Ravine	5	0	5	0%	2	9.9	3.0
78	Ravine	4	0	4	0%	3	14.3	5.2
79	Ravine	15	0	15	0%	5	11.4	12.4
69	Savanna Poorly-Drained	0	0	0	0%	0	0.0	0.0
76	Savanna Poorly-Drained	4	0	4	0%	1	13.6	4.4
86	Savanna Poorly-Drained	3	0	3	0%	3	15.0	4.0
80	Savanna Well-Drained	5	0	5	0%	3	18.1	9.1
83	Savanna Well-Drained	3	0	3	0%	3	13.9	3.4
87	Savanna Well-Drained	1	0	1	0%	1	10.3	0.6
45	Woodland Poorly-Drained	5	0	5	0%	5	15.2	6.5
52	Woodland Poorly-Drained	8	0	8	0%	2	9.8	5.0
54	Woodland Poorly-Drained	6	0	6	0%	2	15.8	9.4
58	Woodland Poorly-Drained	6	0	6	0%	4	17.0	10.1
63	Woodland Poorly-Drained	2	0	2	0%	2	15.6	2.7
27	Woodland Well-Drained	5	0	5	0%	1	8.0	1.8
28	Woodland Well-Drained	4	0	4	0%	2	13.3	4.4
34	Woodland Well-Drained	13	0	13	0%	3	9.1	6.2
37	Woodland Well-Drained	5	0	5	0%	3	16.6	9.3
39	Woodland Well-Drained	10	0	10	0%	3	10.0	6.9
48	Woodland Well-Drained	7	1	8	13%	4	11.3	6.8
55	Woodland Well-Drained	7	0	7	0%	4	10.0	4.1
65	Woodland Well-Drained	4	0	4	0%	4	10.8	2.7
-	Buffalo Bayou	56	3	59	5%	13	12.2	62.2
-	Ravine	24	0	24	0%	8	11.8	20.6
-	Savanna Poorly-Drained	7	0	7	0%	4	9.5	8.4
-	Savanna Well-Drained	9	0	9	0%	7	14.1	13.1
-	Woodland Poorly-Drained	27	0	27	0%	10	14.7	33.8
-	Woodland Well-Drained	55	1	56	2%	11	11.1	42.1

APPENDIX F Supplemental Data cont.

Overstory species

Species	Avg DBH (in)	Std Error Avg DBH	Sum Basal Area (sqft)	Basal Area (sqft/ac)	Count	Percent of Total Species
Acer negundo	10.8	3.0	1.3	0.4	2	1.1%
Celtis laevigata	8.4	1.1	3.5	1.2	9	4.9%
Ilex vomitoria	6.9	1.6	0.8	0.3	3	1.6%
Juniperus virginiana	7.0	0.0	0.3	0.1	1	0.5%
Ligustrum japonicum	10.9	2.4	2.0	0.7	3	1.6%
Liquidambar styraciflua	11.5	2.8	4.7	1.6	6	3.3%
Pinus echinata	17.3	0.0	1.6	0.5	1	0.5%
Pinus taeda	19.7	1.1	75.1	25.0	33	18.1%
Populus deltoides	9.0	2.7	0.9	0.3	2	1.1%
Prunus caroliniana	6.8	0.7	4.6	1.5	18	9.9%
Quercus alba	12.5	0.0	0.9	0.3	1	0.5%
Quercus falcata	14.5	1.2	4.6	1.5	4	2.2%
Quercus nigra	14.2	2.0	19.9	6.6	16	8.8%
Quercus phellos	12.7	1.4	20.0	6.7	21	11.5%
Quercus shumardii	15.7	4.5	4.5	1.5	3	1.6%
Quercus sp.	12.3	0.0	0.8	0.3	1	0.5%
Quercus stellata	12.3	3.1	7.7	2.6	8	4.4%
Salix nigra	6.8	1.1	1.3	0.4	5	2.7%
Taxodium distichum	14.8	3.1	3.8	1.3	3	1.6%
Tilia americana	15.1	3.6	2.6	0.9	2	1.1%
Triadica sebifera	7.3	0.0	0.3	0.1	1	0.5%
Ulmus alata	8.7	1.0	13.1	4.4	30	16.5%
Ulmus americana	9.8	2.6	4.0	1.3	7	3.8%
Ulmus sp.	13.4	0.8	2.0	0.7	2	1.1%

APPENDIX F Supplemental Data cont.

Midstory by plot and plant association

Plot	Plant Association	Native	Invasive	Total	% Invasive	Richness	Avg DBH (in)	Sum Basal Area (sqft)
2	Buffalo Bayou	4	1	5	20%	2	5.2	0.7
7	Buffalo Bayou	4	0	4	0%	1	4.0	0.4
10	Buffalo Bayou	3	0	3	0%	1	4.0	0.3
11	Buffalo Bayou	8	0	8	0%	2	4.8	1.0
23	Buffalo Bayou	9	0	9	0%	1	4.6	1.0
24	Buffalo Bayou	3	0	3	0%	1	3.5	0.2
31	Buffalo Bayou	5	0	5	0%	2	3.9	0.4
38	Buffalo Bayou	1	0	1	0%	1	3.3	0.1
64	Ravine	7	0	7	0%	1	4.5	0.8
78	Ravine	5	0	5	0%	1	3.6	0.4
79	Ravine	7	0	7	0%	4	4.4	0.8
69	Savanna Poorly-Drained	1	0	1	0%	1	5.3	0.2
76	Savanna Poorly-Drained	0	0	0	-	0	-	0.0
86	Savanna Poorly-Drained	0	0	0	-	0	-	0.0
80	Savanna Well-Drained	0	0	0	-	0	-	0.0
83	Savanna Well-Drained	0	0	0	-	0	-	0.0
87	Savanna Well-Drained	0	0	0	-	0	-	0.0
45	Woodland Poorly-Drained	0	0	0	-	0	-	0.0
52	Woodland Poorly-Drained	1	0	1	0%	1	3.0	0.0
54	Woodland Poorly-Drained	0	0	0	-	0	-	0.0
58	Woodland Poorly-Drained	5	0	5	0%	2	4.1	0.5
63	Woodland Poorly-Drained	1	0	1	0%	1	5.0	0.1
27	Woodland Well-Drained	9	0	9	0%	2	4.4	0.9
28	Woodland Well-Drained	1	0	1	0%	1	3.3	0.1
34	Woodland Well-Drained	3	0	3	0%	1	4.6	0.4
37	Woodland Well-Drained	0	0	0	-	0	-	0.0
39	Woodland Well-Drained	2	0	2	0%	1	3.9	0.2
48	Woodland Well-Drained	0	0	0	-	0	-	0.0
55	Woodland Well-Drained	3	0	3	0%	2	4.3	0.3
65	Woodland Well-Drained	2	0	2	0%	2	3.8	0.2
-	Buffalo Bayou	37	1	38	3%	4	4.1	4.1
-	Ravine	19	0	19	0%	5	4.2	1.9
-	Savanna Poorly-Drained	1	0	1	0%	1	5.3	0.2
-	Savanna Well-Drained	0	0	0	-	0	-	0.0
-	Woodland Poorly-Drained	7	0	7	0%	4	4.0	0.7
-	Woodland Well-Drained	20	0	20	0%	6	4.0	2.0

APPENDIX F Supplemental Data cont.

Midstory species

Species	Avg DBH (in)	Std Error Avg DBH	Sum Basal Area (sqft)	Basal Area (sqft/ac)	Count	Percent of Total Species
Celtis laevigata	4.6	0.3	0.48	0.3	4	4.7%
Cephalanthus occidentalis	3.0	0.0	0.05	0.0	1	1.2%
Ilex vomitoria	4.1	0.2	0.94	0.6	10	11.8%
Ligustrum japonicum	4.0	0.0	0.09	0.1	1	1.2%
Platanus occidentalis	5.3	0.0	0.15	0.1	1	1.2%
Populus deltoides	5.5	0.0	0.16	0.1	1	1.2%
Prunus caroliniana	4.3	0.1	4.27	2.8	42	49.4%
Quercus phellos	4.1	0.3	0.38	0.3	4	4.7%
Quercus stellata	4.8	0.2	0.25	0.2	2	2.4%
Rhus copallinum	3.0	0.0	0.05	0.0	1	1.2%
Ulmus alata	4.5	0.2	1.46	1.0	13	15.3%
Ulmus americana	4.3	0.3	0.50	0.3	5	5.9%

APPENDIX F Supplemental Data cont.

Understory by plot and plant association

Plot	Plant Association	Native	Invasive	% Invasive	Richness	Stem Count Native	Stem Count Invasive	Total Stem Count	Stem Count / ac	Avg Height (ft)
2	Buffalo Bayou	2	0	0%	2	100	0	100	2,000	9.5
7	Buffalo Bayou	2	1	33%	3	60	2	62	1,240	4.5
10	Buffalo Bayou	2	0	0%	2	35	0	35	700	9.0
11	Buffalo Bayou	2	0	0%	2	100	0	100	2,000	4.5
23	Buffalo Bayou	2	0	0%	2	210	0	210	4,200	4.0
24	Buffalo Bayou	2	2	50%	4	150	40	190	3,800	6.0
31	Buffalo Bayou	2	1	33%	3	225	5	230	4,600	10.7
38	Buffalo Bayou	2	0	0%	2	370	0	370	7,400	11.0
64	Ravine	4	0	0%	4	175	0	175	3,500	7.0
78	Ravine	4	1	20%	5	121	1	122	2,440	6.8
79	Ravine	4	0	0%	4	110	0	110	2,200	6.1
69	Savanna Poorly-Drained	4	0	0%	4	28	0	28	560	6.4
76	Savanna Poorly-Drained	0	0	0	0	0.0	0	0	0	0
86	Savanna Poorly-Drained	2	1	33%	3	505	1	506	10,120	4.2
80	Savanna Well-Drained	3	2	40%	5	12	20	32	640	3.2
83	Savanna Well-Drained	4	1	20%	5	135	2	137	2,740	4.0
87	Savanna Well-Drained	2	0	0%	2	32	0	32	640	9.8
45	Woodland Poorly-Drained	8	2	20%	10	128	105	233	4,660	6.5
52	Woodland Poorly-Drained	3	0	0%	3	1,450	0	1,450	29,000	5.5
54	Woodland Poorly-Drained	4	1	20%	5	166	50	216	4,320	7.0
58	Woodland Poorly-Drained	3	1	25%	4	80	5	85	1,700	10.3
63	Woodland Poorly-Drained	4	1	20%	5	412	400	812	16,240	9.6
27	Woodland Well-Drained	6	2	25%	8	151	85	236	4,720	5.4
28	Woodland Well-Drained	3	0	0%	3	360	0	360	7,200	12.0
34	Woodland Well-Drained	5	2	29%	7	65	85	150	3,000	7.9
37	Woodland Well-Drained	7	2	22%	9	460	510	970	19,400	5.2
39	Woodland Well-Drained	5	3	38%	8	285	406	691	13,820	5.8
48	Woodland Well-Drained	3	2	40%	5	121	60	181	3,620	7.8
55	Woodland Well-Drained	4	1	20%	5	121	150	271	5,420	5.7
65	Woodland Well-Drained	8	1	11%	9	98	7	105	2,100	7.1
-	Buffalo Bayou	16	4	20%	5	1,250	47	1,297	3,243	7.3
-	Ravine	12	1	8%	7	406	1	407	2,713	6.7
-	Savanna Poorly-Drained	6	1	14%	6	533	1	534	3,560	5.4
-	Savanna Well-Drained	9	3	25%	10	179	22	201	1,340	4.6
-	Woodland Poorly-Drained	22	5	19%	18	2,236	560	2,796	11,184	7.6
-	Woodland Well-Drained	41	13	24%	23	1,661	1303	2,964	7,410	6.6

APPENDIX F Supplemental Data cont.

Groundcover by plot and plant association

Plot	Plant Association	Native	Invasive	% Invasive	Richness	% Bare Ground Cover	% Leaf Litter Cover	% Vegetation Cover	% Native Vegetation Cover	% Native Ground cover	% Invasive Vegetation Cover	% Invasive Ground cover
2	Buffalo Bayou	7	0	0%	4	25%	75%	13%	13%	100%	0%	0%
7	Buffalo Bayou	5	0	0%	3	5%	95%	13%	13%	100%	0%	0%
10	Buffalo Bayou	7	1	13%	6	10%	90%	22%	18%	85%	3%	15%
11	Buffalo Bayou	2	0	0%	2	25%	75%	10%	10%	100%	0%	0%
23	Buffalo Bayou	4	0	0%	2	13%	87%	13%	13%	100%	0%	0%
24	Buffalo Bayou	5	1	17%	3	3%	97%	27%	18%	69%	8%	31%
31	Buffalo Bayou	5	0	0%	3	10%	90%	18%	18%	100%	0%	0%
38	Buffalo Bayou	5	0	0%	3	0%	100%	17%	17%	100%	0%	0%
64	Ravine	7	0	0%	5	7%	93%	18%	18%	100%	0%	0%
78	Ravine	10	3	23%	8	10%	83%	63%	25%	39%	38%	61%
79	Ravine	7	1	13%	5	20%	80%	37%	33%	91%	3%	9%
69	Savanna Poorly-Drained	18	6	25%	13	7%	93%	147%	115%	78%	32%	22%
76	Savanna Poorly-Drained	18	4	18%	11	17%	83%	90%	78%	87%	12%	13%
86	Savanna Poorly-Drained	18	2	10%	15	38%	62%	125%	117%	93%	8%	7%
80	Savanna Well-Drained	17	3	15%	12	8%	92%	88%	80%	91%	8%	9%
83	Savanna Well-Drained	18	2	10%	16	37%	63%	75%	67%	89%	8%	11%
87	Savanna Well-Drained	22	3	12%	14	18%	82%	112%	98%	88%	13%	12%
45	Woodland Poorly-Drained	9	0	0%	6	2%	98%	35%	35%	100%	0%	0%
52	Woodland Poorly-Drained	23	0	0%	17	25%	28%	83%	83%	100%	0%	0%
54	Woodland Poorly-Drained	5	0	0%	3	7%	93%	17%	17%	100%	0%	0%
58	Woodland Poorly-Drained	2	1	33%	3	3%	97%	7%	5%	75%	2%	25%
63	Woodland Poorly-Drained	6	2	25%	7	10%	90%	22%	15%	69%	7%	31%
27	Woodland Well-Drained	5	2	29%	5	8%	92%	30%	18%	61%	12%	39%
28	Woodland Well-Drained	5	0	0%	4	10%	90%	8%	8%	100%	0%	0%
34	Woodland Well-Drained	5	5	50%	8	17%	83%	32%	10%	32%	22%	68%
37	Woodland Well-Drained	6	2	25%	6	3%	97%	27%	20%	75%	7%	25%
39	Woodland Well-Drained	6	4	40%	7	2%	98%	50%	28%	57%	22%	43%
48	Woodland Well-Drained	3	1	25%	3	2%	98%	8%	7%	80%	2%	20%
55	Woodland Well-Drained	2	1	33%	3	3%	97%	8%	3%	40%	5%	60%
65	Woodland Well-Drained	20	2	9%	16	25%	58%	120%	95%	79%	25%	21%
-	Buffalo Bayou	40	2	5%	12	11.5%	88.5%	17%	15%	91%	1%	9%
-	Ravine	24	4	14%	12	12.2%	85.6%	39%	26%	65%	14%	35%
-	Savanna Poorly-Drained	54	12	18%	17	20.6%	79.4%	121%	103%	86%	17%	14%
-	Savanna Well-Drained	57	8	12%	8	21.1%	78.9%	92%	82%	89%	10%	11%
-	Woodland Poorly-Drained	45	3	6%	26	9.3%	81.3%	33%	31%	95%	2%	5%
-	Woodland Well-Drained	52	17	25%	28	8.8%	89.2%	35%	24%	67%	12%	33%

APPENDIX F Supplemental Data cont.

Shannon Weiner Diversity, richness and evenness by plant association of the entire Arboretum

Diversity Index	Species Richness	Evenness
3.44	99	0.75

Shannon Weiner Diversity, richness and evenness by plant association. Shannon Weiner Diversity Index p-values determined using Hutcheson t-test. p-values <0.05 denote statistical differences between plant associations.

Diversity Indices	Buffalo Bayou	Ravine	Savanna Well-Drained	Savanna Poorly-Drained	Woodland Well-Drained	Woodland Poorly-Drained
Total Occurrences	159	84	86	81	199	109
Species Richness	25	18	38	29	48	44
H (Shannon Wiener)	2.06	2.44	2.18	2.99	3.18	3.41
Hmax (Evenness)	0.64	0.84	0.60	0.89	0.82	0.90
S^2_H (SW Variance)	0.01	0.01	0.05	0.01	0.01	0.01
Confidence Interval	0.24	0.21	0.45	0.21	0.18	0.19
Plant Association Comparison	**Buffalo Bayou vs Ravine**	**Ravine vs Sav Well-Drained**	**Ravine vs Sav Poorly-Drained**	**Ravine vs Wood Well-Drained**	**Sav Well-Drained vs Sav Poorly Drained**	**Sav Poorly-Drained vs Wood Well-Drained**
Hutcheson t-value	2.38	1.02	3.65	5.41	3.19	1.42
Degrees freedom	234.3	121.3	164.9	199.5	112.3	179.7
Critical Value	1.97	1.98	1.97	1.97	1.98	1.97
p-value	0.0181	0.3097	0.0004	0.0000	0.0018	0.1562
Plant Association Comparison	**Buffalo Bayou vs Sav Well-Drained**	**Buffalo Bayou vs Sav Poorly-Drained**	**Buffalo Bayou vs Wood Well-Drained**	**Sav Poorly-Drained vs Wood Well-Drained**	**Sav Well-Drained vs Wood Well-Drained**	**Sav Poorly-Drained vs Wood Poor-Drained**
Hutcheson t-value	0.48	5.78	7.56	1.42	4.09	2.96
Degrees freedom	134.7	229.2	304.7	192.2	112.3	179.7
Critical Value	1.98	1.97	1.97	1.97	1.98	1.97
p-value	0.63	0.00	0.00	0.16	0.00	0.00
Plant Association Comparison	**Buffalo Bayou vs Wood Poorly-Drained**	**Ravine vs Wood Poorly-Drained**	**Sav Well-Drained vs Wood Poorly-Drained**	**Wood Well-Drained vs Wood Poorly-Drained**		
Hutcheson t-value	8.77	6.78	4.97	1.76		
Degrees freedom	267.9	184.5	117.1	263.1		
Critical Value	1.97	1.97	1.98	1.97		
p-value	0.00	0.00	0.00	0.08		

APPENDIX F Supplemental Data cont.

Canopy cover by plot and plant association

Plot	Plant Association	Avg Canopy Cover %	Std Error
2	Buffalo Bayou	99.8	0.1
7	Buffalo Bayou	99.3	0.5
10	Buffalo Bayou	97.3	2.2
11	Buffalo Bayou	98.8	0.6
23	Buffalo Bayou	99.6	0.2
24	Buffalo Bayou	99.7	0.3
31	Buffalo Bayou	99.8	0.1
38	Buffalo Bayou	99.6	0.3
64	Ravine	99.1	0.4
78	Ravine	98.1	0.8
79	Ravine	99.0	0.4
69	Savanna Poorly-Drained	24.4	7.4
76	Savanna Poorly-Drained	52.0	11.6
86	Savanna Poorly-Drained	42.0	10.2
80	Savanna Well-Drained	42.2	9.0
83	Savanna Well-Drained	44.1	12.3
87	Savanna Well-Drained	18.2	4.9
45	Woodland Poorly-Drained	71.7	11.8
52	Woodland Poorly-Drained	54.9	9.1
54	Woodland Poorly-Drained	96.7	1.8
58	Woodland Poorly-Drained	99.2	0.4
63	Woodland Poorly-Drained	99.8	0.1
27	Woodland Well-Drained	98.9	0.9
28	Woodland Well-Drained	99.1	0.4
34	Woodland Well-Drained	94.8	1.9
37	Woodland Well-Drained	95.2	2.0
39	Woodland Well-Drained	97.7	1.1
48	Woodland Well-Drained	97.4	1.2
55	Woodland Well-Drained	98.7	0.7
65	Woodland Well-Drained	76.5	5.6
-	Buffalo Bayou	99.2	0.3
-	Ravine	98.7	0.4
-	Savanna Poorly-Drained	39.5	8.1
-	Savanna Well-Drained	34.8	8.3
-	Woodland Poorly-Drained	84.5	9.1
-	Woodland Well-Drained	94.8	2.7

Canopy cover vs vegetation variables using Pearson's Correlation test. A coefficient closer to 1 or -1 indicates a positive or negative relationship between two variables. A coefficient closer to 0 indicates no linear relationship. A statistically significant relationship exists if the Test Statistic is greater than the Critical Value.

Variables	Pearson Correlation Coefficient	Test Statistic	Critical Value	Significant (Y/N)
Canopy Cover vs Basal Area	0.49	2.99	1.70	Y
Canopy Cover vs Vegetative Cover	-0.88	9.64	1.70	Y
Canopy Cover vs Richness	-0.83	8.01	1.70	Y