MODELING SPECIES RICHNESS WITHIN THE EAST TEXAS LONGLEAF PINE ECOSYSTEM AND A STUDY OF THE INTERMEDIATE DISTURBANCE HYPOTHESIS

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by
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DEDICATION

Dedicated to Frank, Sharon, and Andy - the most influential people of my life.

ABSTRACT

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The longleaf pine ecosystem had an extensive range throughout the southeast continental United States. Since the arrival of the Europeans to the continent the ecosystem has been reduced to a fraction of its original extent, losing many endemic species. One of the key elements to maintenance of species richness within the longleaf pine ecosystem is the presence of a well-maintained fire regime. An ongoing fire regime within the longleaf pine ecosystem helps to promote the establishment and growth of one of the most rich and diverse ecosystems outside of the tropics.

I created a model to predict species richness within this fire-maintained ecosystem. I measured species richness within increasing nested plots at the community level to calculate C and z values to see if I could apply them to predict the species richness at the landscape level. The model was able to predict with some accuracy the species richness of several known floras within the longleaf pine ecosystem of east Texas. Future management within the longleaf pine ecosystem can use this model to predict what standards should be meet for the use of management practices

KEY WORDS: Longleaf pine, Species richness, Species area curves, Fire ecology

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CHAPTER I

Introduction

The original range of the longleaf pine ecosystem encompassed 412 counties in nine states totaling approximately 92 million acres of dominant and mixed species stands (Frost 1993). It covered most of the Atlantic and Gulf Coastal Plains, from southeastern Virginia to eastern Texas and south through the northern two-thirds of Florida, extending into the Piedmont and mountains of Alabama and northwest Georgia. By 1935 only about 20 million acres of longleaf pine forest were left. With continued poor management practices, the remaining forest declined to fewer than 5 million acres by 1975 (Landers *et al*. 1995). Today, there remains less than 0.7 percent of the original extent in good condition, having the proper understory component of native grasses and forbs along with the necessary fire regime. The largest remaining concentration of longleaf is in Okaloosa and Santa Rosa counties in the Florida panhandle and the adjacent Escambia County, Alabama (Frost 1993, Outcalt & Sheffield 1996). Over a hundred plant and animal species, such as the Louisiana pine snake (*Pituophis melanoleucus*), scarlet catchfly (*Silene subciliata*) and golden gladecress (*Leavenworthia aurea*), are endemic to the ecosystem (Rudolph & Burgdorf 1997, Walker 1993). Barnett (1999) states: “Longleaf ecosystems represent significant components of the Region’s cultural heritage, ecological diversity, timber resources, and present essential habitat for many animal and plant communities. This once extensive ecosystem has nearly vanished.”

Because longleaf pine was so economically valued in the south, it became one of the first forest species to be studied in detail by botanists and early professional foresters. Major studies included hundreds of locations of longleaf pine communities by means of maps, lumbering records, and calculations of acreage and board feet by state, allowing a reasonable estimation of the original range and abundance (Frost 1993).

First described in 1768 the longleaf pine has a life-span of 160 years with some individuals living to over 300 years (Coder 2017); however, forests dominated by longleaf pine are often exposed to catastrophic events such as blowdown or fire that may lead to changes in forest dynamic. Most of the longleaf pine ecosystem is within 150 miles of the Atlantic or Gulf coasts and these regions are subject to damaging tropical storms. Since longleaf pines are intolerant pioneer species, are poor seed producers, and because the seeds have a limited dispersal range coupled with the extreme habitat conditions, few of the pines reach maturity (Landers *et al*. 1995).

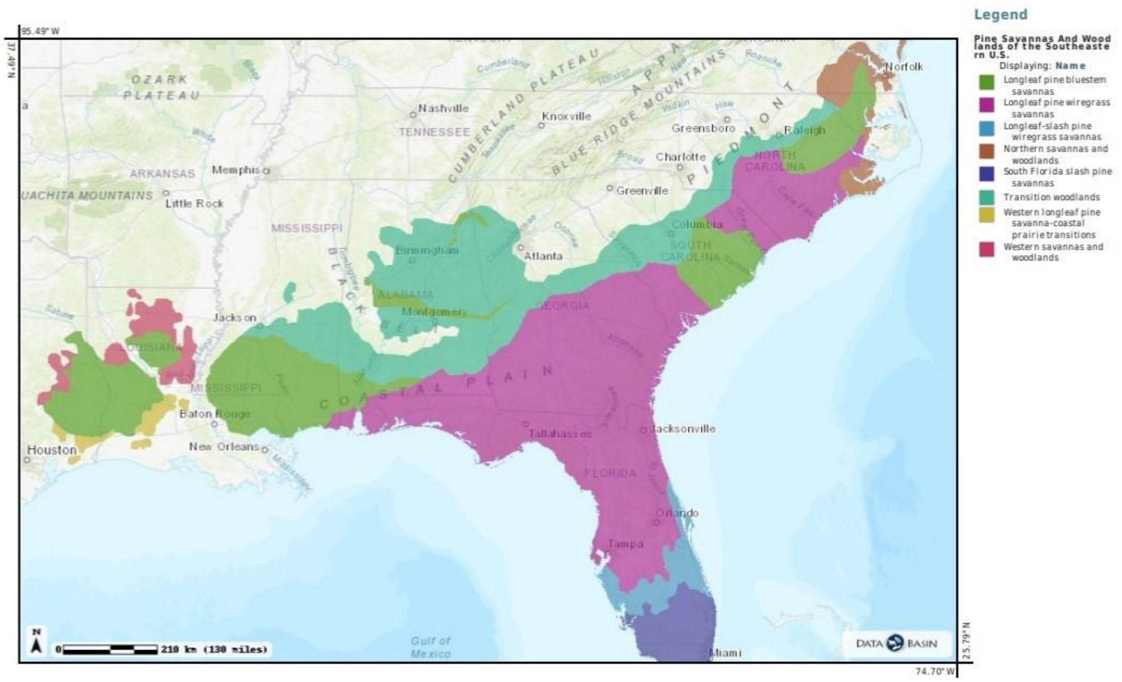


Figure 1. Range of Longleaf Pine Ecosystem. Map taken from the South Atlantic Landscape Conservation Cooperative Website (2018).

The longleaf pine has the longest needles and largest cones of any eastern pine species. The crown is open and irregular with few spreading branches on the older and more mature trees, adding 1 row of branches each year. Trees can reach heights of 30 meters with a trunk diameter of close to a meter. The needles occur 3 per fascicle and are evergreen with a maximum length of about 38 centimeters. The bark is orange-brown and furrowed into scaly plates. Twigs are typically dark brown, very stout, and terminated by large narrow buds. Cones are between 15-25centimeters long, narrowly conical, or cylindrical, and dull brown (Little 1980).

Longleaf pines occur in forest, woodlands, and savannas on sites that range from wet poorly drained flatwoods to mesic uplands, xeric sandhills, and rocky mountainous ridges (Figure 1). Other species associated with the longleaf pine are influenced by site quality; however, the longleaf pine itself is a species of general habitat selection (Brockway *et al.* 2006).

The decline of the longleaf pine can be attributed to three historical factors: (1) the low rate of restocking after logging, (2) feral hogs feeding on the seedlings, and (3) fire suppression (Frost 1993). There is an interest in longleaf pine regeneration and management systems among land managers, ecologists, the forest products industry, and the general public in promoting a region wide recovery of longleaf pine forest for their ecological and economic benefits (Jose *et al*. 2006).

Before the arrival of Europeans, open canopied forest dominated by longleaf pine occurred in fire-frequented habitats throughout most of the South. Early travelers and scientists described these once extensive forests as essentially single species stands of scattered large trees intermixed with occasional oaks, dense clumps of small pines, and low ground cover of grasses, forbs, and shrubs (Platt *et al.* 1988a). With the arrival of European settlement, longleaf trees were cut for building homes and for agriculture. At the beginning of settlement, harvest was near waterways because it allowed for ease of movement. With the advent of railroad logging near the end of the 19th century, larger tracks of land were cleared until logging slowed to a halt with the Great Depression (Landers *et al.* 1995). Many longleaf pine stands never regenerated. Along the Atlantic Coastal Plain the more competitive loblolly pine (*Pinus taeda*) took over the areas that were logged. Further south, slash pine (*Pinus elliottii*) replaced longleaf pine, while hardwoods and shortleaf (*Pinus echinata*) became the dominant species on many of the upland areas of the interior range.

Logging was not the only threat to regeneration of the longleaf pine. Heavy feeding by feral hogs on seedlings of the longleaf pine were also a major contributor in the decline of the ecosystem. Unlike other pines, the longleaf pine has a non-resinous carbohydrate- rich meristem. As a seedling, it is vulnerable to grazing for five to seven years. Only through fencing was the destruction mitigated from the effects of browsing by feral hogs (Frost 1993, Outcalt 2000).

Fire could be the most important factors for maintaining the integrity of the longleaf pine ecosystem. The species and ecosystem have evolved so that fire occurs approximately every two years (Stambaugh *et al.* 2011). All stages of its life cycle are adapted to withstand and reproduce in a fire-maintained environment, thus giving it a competitive edge over other species of pine and hardwoods. This adaptation allows the species to dominate on the more upland xeric communities where fire has more frequent return intervals. The grass understory also helps to maintain a fire dependent community (Outcalt 2000).

The longleaf pine ecosystem is composed of numerous communities of rare habitats that include wetlands, hammocks, pocosins and wetland/upland ecotones. These habitats are threatened by conversion of land to agriculture, urbanization, tree plantations, and exclusion of fire, causing habitat fragmentation and loss of species, such as the Texas trailing phlox (*Phlox nivalis* spp. *texensis*), scarlet catchfly (*Silene subciliata*), gopher tortoise (*Gopherus polyphemus*). With the introduction of invasive species along with habitat loss, the ecosystem is in peril of being lost (Van Lear *et al.* 2005).

Species richness is the true number of species in a given area or given sample (Spellerberg & Fedor 2003). We can estimate species richness by quantifying observed species richness, the number of species that were observed during surveying of the given area. Species richness of small areas can be used to estimate species richness of larger areas. The use of this method can allow for better private and industry-based management practices within the east Texas longleaf pine ecoregion. With additional data collection and larger extrapolations, a region-wide method could potentially be produced throughout the entire longleaf pine range.

It is important to quantify species richness among sites so that a comparison can be made for practical management solutions (Gotelli & Colwell 2001). Species richness estimators can fall into four categories: (1) number of observed species, or those species counted within a defined area, (2) extrapolations of species-area curves by plotting the number of species sampled as a function of area (3) integration of the lognormal distribution by graphing the number of species as a function of the logarithm of abundance, and (4) nonparametric estimators (Palmer 1990). Whittaker and Mathews (2014) state: “It has been commented that the species-area relationship (SAR), whereby the number of species increases with area sampled is one of ecology’s few general laws.”

Each of the estimators listed above has its pros and cons when comparing species richness among sites. In the first method, observed species richness is typically determined by conducting plot surveys and sampling for species presence within a determined geographic area. While this method would provide an actual verifiable list of species with documented specimen vouchers, the efficiency of collecting is proportional to the size of the area, meaning the larger the area the more time expense to collect the data. Another issue is that species can be seasonal, so multiple trips to the same area may be necessary because of hibernation, migration, seasonal succession, or possible dormancy. Because habitats are disparate, a field biologist might not be satisfied they have collected all the specimens. At what point will they know they have found the maximum number of species for a given area?

A species-area curve expresses the relationship between areas of different sizes and the number of species found in those areas (Cain 1938). The use of this method requires no real taxonomic skills, rather simply the ability to distinguish one species from another without determining species. This method also allows the estimation of C and z values, those values representing constants as the theoretical slope (z) and intercept (C) that can give a threshold of the number of species or estimates the number of species in a given area. This method would give a predicted number of species, yet it does not tell what species are present within the area.

Integration of lognormal distributions, as proposed by method three, requires an extensive amount of data collection requiring more time and effort than previous extrapolations. While this data collection can be very time consuming, it better portrays the entire community by expressing several variables that can be expressed as indices, such as species diversity and abundance. Species diversity is an index calculated by species richness and evenness that is often used in ecological theory (Kirkman *et al*. 2004; Brockway *et al.* 1998; Brockway & Lewis 2003).

The final approach to estimating species richness, nonparametric estimators, is advantageous in that only presence-absence data needs to be collected. This lessens the time needed to count all individuals like the extrapolations of species-area curves and integration of the lognormal distribution methods. Another advantage is that this method makes no assumption about the within-quadrat species interactions, whereas abundance models, those models that describe quantities of species within a given area, typically require an assumption of independence among species. The disadvantage of this approach is that it often underestimates the true species richness (Smith & van Belle 1984).

In this study, I used the species area curve as an estimator for species richness within a given area. I chose this method because it can best be used to predict the species richness of larger areas by sampling smaller sites. Species area curves can be modeled in multiple ways (Gray *et al.* 2004). Curves are created by plotting the number of species as a function of a series of increasing sample sizes, that yield a monotonically increasing curve with a steep slope at first but gradually becomes nearly flat reaching an asymptote (He & Legendre 1996). These curves are used to estimate species richness by different methods, with each method based on a need for sample coverage and each method generating different results (Brose *et al.* 2003; Colwell *et al.* 2012). He and Legendre (1996) indicate the three most commonly used models to calculate the curve are:

1. Exponential curve

$$S = Z \ln (A) + C$$

2. Power curve

$$S = CA^{z}$$

3. Logistic curve

$$S = \frac{B}{C + A^{-z}}$$

Where S is the number of species, A is the area, and B, C, and Z are constants by conventional notation.

Keeley (2003) found by using the exponential curve a better fit model was represented for species-area relationships in a vascular plant survey in an Australian heathland. Williams and Lutterschmidt (2006) used the power curve to provide a quantifiable and objective approach for identifying large scale data gaps in species inventories and museum collections by comparing documented species richness to predict species richness within given area. Testing several models, Wei *et al.* (2010) found that in subtropical forest of southern China, the logistics curve outperformed various other models.

Having a theoretical basis for understanding the relationships between sample size and number of species accumulated is useful because, (1) it gives rigor to floristic work by allowing quantitative comparisons among species lists, (2) it provides a planning tool for collecting expeditions, and (3) it provides a predictive tool for conservation and biodiversity studies, if used to extrapolate the total number of species present in the area (Soberó & Llorente 1993). Problems arise when using estimators after sampling an area when rare species are not encountered or when crossing into ecotones (Kaeser & Kirkman 2009). Estimating species richness in the longleaf pine ecosystem presents difficulties because the fire regime must be taken into consideration (Kirkman *et al*. 2004).

Hypothesis I: Power curves generated by sampling at local communities predict landscape area species richness.

Disturbances have been shown to affect the succession and maintenance of species diversity in Texas forest and throughout the range of longleaf pine (Dale *et al.* 2002, Gilliam *et al*. 2006, Glitzenstein *et al.* 1986, Lemon 1949). Fire is an important component of the longleaf pine ecosystem for determining forest structure and species composition by ameliorating the encroachment of older successional stages (Brockway & Lewis 1997, Gilliam & Platt 1999, Glitzenstein *et al.* 1995, Liu *et al*. 1997, Odum 1966). However, it should be noted the lack of fire is not the only disturbance that may affect species composition (Brudvig & Damschen 2011). Variation in season and frequency of burns has been shown to affect species composition within the longleaf pine range (Glitzenstein *et al.* 2003, Platt *et al.* 1998b). Not only does fire increase the diversity of plants within the longleaf pine, but it has been shown to affectively increase the richness and diversity of the local fauna as well (Provencher *et al.* 2003).

Two working hypotheses explain resprouting response of shrubs after a burn, the ambient temperature hypothesis and the plant physiology hypothesis. The ambient temperature hypothesis suggests that trees and shrubs resprout less after a growing-season fire than after a dormant-season fire because the former tend to have higher and longer burning temperature thus making it more likely to damage or stress underground organs. The plant physiology hypothesis suggests that reduced resprouting will occur after a growing season fire because the carbohydrates need for growth are in the aboveground portions of the plant and thus killed by the fire (Drewa *et al.* 2002).

There are conflicting studies on whether fire affects species richness in longleaf pine (Glitzenstein *et al.* 2003 vs. Beckage & Stout 2000). Fire provides a means of eliminating or reducing the hardwood shrub and tree layer, decreasing competition for the herbaceous understory and thereby increasing species richness (Provencher *et al.* 2001). Fire also helps control the density of longleaf pine as well (Grace & Platt 1995) thereby opening the canopy for light to expose the forest floor and allow the herbaceous layer to flourish. In the alternative, if overstory and forest structure have not been properly maintained then fire would have no such effect on species richness because of the lack of suitable fuel loads to produce an adequate burn regime (Beckage & Stout 2000).

The theory of the intermediate disturbance hypothesis has been studied in a multitude of ecosystems (Beckage & Stout 2000, Flöder & Sommer 1999, Townsend *et al*. 1997). Simply put the theory predicts maximum species richness at intermediate levels of disturbance, or in some cases the lack thereof a necessary disturbance, brought on by competitive exclusion causing a balance by the destruction of the competing dominants.

Hypothesis II: Sites having an intermediate time since last burn will have greater species richness than those sites with low or high intervals of time since last burn.

CHAPTER II

Methods

Sites

The Big Thicket lies within the Gulf Coastal Plain region of Eastern Texas between the Trinity and Sabine River (Pessin 1933).

The origin of and meaning of the term "Big Thicket" are unclear, although it seems likely that early travelers would have been impressed by the dense scrub of many of the forests in comparison with the open coastal prairies to the south and the open longleaf pinelands and cross timbers to the north, east, and west. Regional treatments combine the Big Thicket and the Oak-Hickory-Pine Forest to the north and west into the "Pineywoods" region. To the south and southwest, forest of the Big Thicket abruptly give way to coastal prairie (Marks & Harcombe 1981).

Marks and Harcombe (1981) have divided the vegetation of the longleaf pine ecosystem of east Texas, or commonly called the "Big Thicket", into four broad types: uplands slopes, floodplains, and flatland, with each being further divided as follows:

Uplands

Sandhill Pine Forest, Upland Pine Forest, Wetland Pine Savanna

Slopes

Upper Slope Pine Oak, Mid Slope Oak Pine Forest, Lower Slope Hardwood Pine Forest

Floodplains

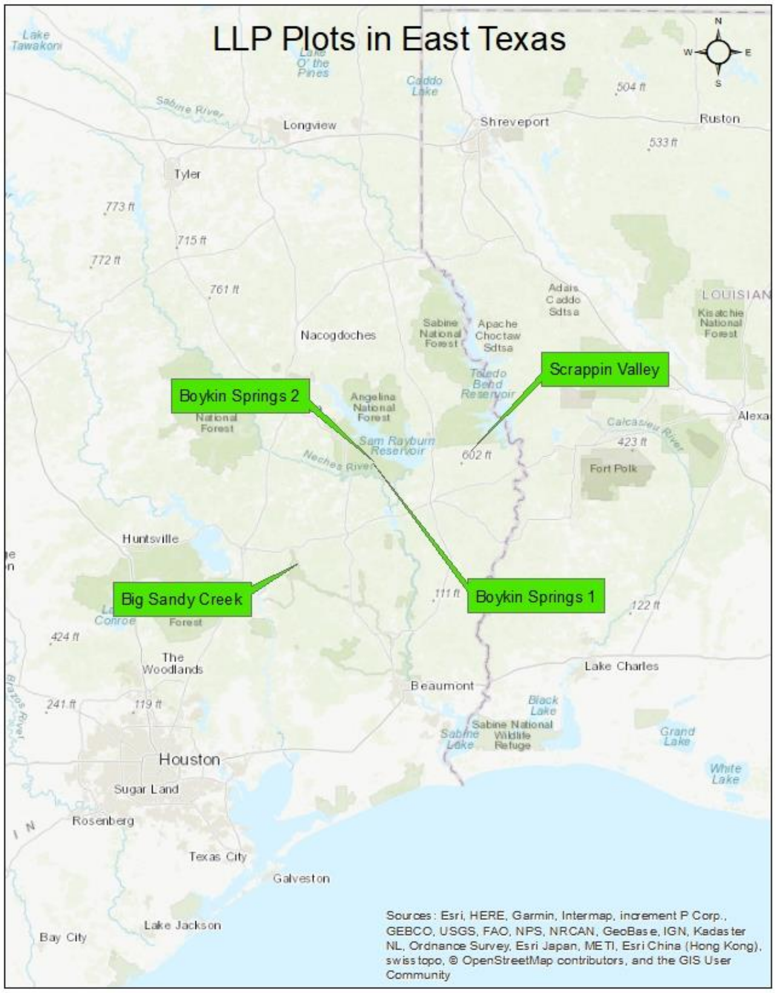
Floodplain Hardwood Pine Forest, Floodplain Hardwood Forest, Wetland Baygall (*Nyssa sylvatic*a, *Quercus laurifolia*, *Acer rubrum,* and *Magnolia virginiana*) Shrub Thicket, Swamp Cypress Tupelo (*Taxodium distichum-Nyssa aquatica*) Forest

Flatlands

Flatland Hardwood Forest

Sandhill pine forests occur on level, deep, sandy terraces associated with river bluffs. Upland pine (*Pinus palustris*) forests are found on level to gently rolling hilltops with sandy surface soils. Wetland pine savannas occur within the uplands of shallow, undrained depressions. Slopes that are within the region are mostly gentle and mantled with fine sands or fine sandy loams. Slope and uplands together comprise the majority of the landscape within the region. Floodplains include broad, flat terraces between the bluffs of the Neches River and along some of the major tributaries. Flatlands are level, low-elevation terraces associated with the ancient floodplains of the Trinity River system. Surface patterns within the flatlands are poorly developed because of flat topography and fine soil textures that create standing water in heavy rains.

Four upland sites were chosen within the range of the original Big Thicket longleaf pine ecosystem of eastern Texas (Figure 2). All sites had a component of longleaf pine as part of the overstory. Three of the sites, Big Sandy Creek in the Big Thicket National Preserve (BITH) and the two Boykin Springs sites, are federally owned and operated by the U.S. National Parks Service or U.S. Forest Service. Scappin Valley is privately owned by Rufus Duncan and has historically been used for hunting.


LLP Plots in East Texas

Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Figure 2. Plot Locations.

The climate in the region is warm and humid most of the year. The average annual temperature is 19.5°C with an average low of 10.6°C in January and average high of 27.6°C during the month of August. There is an average of 210 to 240 frost-free days per year. Precipitation averages 132 cm annually and is evenly distributed through the year. Because of the proximity to the Gulf of Mexico, the Big Thicket experiences a high frequency of tropical storms and hurricanes (Marks & Harcomb 1981).

Study Sites

Big Sandy Creek Unit in the Big Thicket National Preserve

The Big Sand Creek Unit (Figure 3) is located in the Big Thicket National Preserve in Polk County, Texas (N 30°38.815’ and W 094°40.277) consisting of an area of 14,347 acres. Dominant vegetation of the site consists of upper slope pine oak forest, mid slope oak pine forest, floodplain hardwood pine forest, bay gall, cypress-tupelo swamp, and sandhill pine forest (Brown et al. 2006a). The Big Sandy Creek Unit lays on the Willis Formation (coastward belt). Soils have a thickness of ± 100 feet and are composed of clay, silt, sand, and siliceous gravel of granule to pebble size, including some petrified wood. The underlying geological formation is deeply weathered and lateritic being indurated by clay and cemented by iron oxide locally with numerous concretions of iron oxide and non-calcareous soil. The formation was created by fluviatile means. The formation was created during the Quaternary Period and the Pleistocene Epoch (USGS 2018). The last burn was recorded in 2008 (personal communication with DW Ivans 2017) as shown on

GIS data layers provided by the U.S. National Parks Service.

Figure 3. Big Sandy Creek Unit at Big Thicket National Preserve. Taken 23 May 2018 at plot location viewed southeast.

Boykin Springs Recreation Area

Boykin Springs Recreation Area (Figure 4 and 5) is located in the Angelina National Forest with the majority of forest in Angelina County, Texas (Site 1: N 31°04.851' and W 094°17.290'; Site 2: N 31°05.349' and W 094°17.345'). The area is 350 acres in size (Orzell 1990). The plots lay on the Whitsett Formation. Soils are characterized as quartz sand, fine to medium grained, and light gray with a thickness of 60 feet. The formation was created during the Tertiary Period and the Oligocene Epoch (USGS 2018). Orzell (1990) states: "Boykin Spring Longleaf is the finest quality remnant of fire-maintained, old-growth, species-rich dry upland longleaf pine savanna in the West Gulf Coastal Plain." Site 1 was last burned in 2017 as shown in maps provided by the U.S. Forest Service. Site 2 was last burned in the spring of 2018 as shown in maps provided by the U.S. Forest Service (personal communication with Dale Snyder 2017).

Figure 4. Boykin Springs Site 1 at Angelina National Forest. Taken 8 May 2018 at plot location viewed northeast.

Figure 5. Boykin Springs Site 2 at Angelina National Forest. Taken 23 May 2018 at plot location viewed southwest.

Scrappin Valley

Scrappin Valley (Figure 6) is privately owned land in Newton County, Texas (N 31°08.442’ and W 093°47.674’). The property is situated on approximately 11,213 acres (“Scrappin’ Valley Expansive” 2013). Scrappin Valley lays on the Catahoula Formation. Soils are composed of mudstone and sand. The upper 300-500 feet is mudstone, tuffaceous sandy and weathered dark gray with fossil wood abundant. The formation often creates cuesta and was created during the Tertiary Period and the Oligocene Epoch (USGS 2018). The area was burned in February of 2017 (personal communication with Paul Stone 2018).

Figure 6. Scrappin Valley. Taken 9 May 2018 at plot location viewed northwest.

Field Sampling

Data was collected during the spring and summer season of 2018. Sites were originally chosen based on date since last burn; however, this changed for Boykin Spring Site 2 prior to field sampling. Points were chosen on level ground to avoid crossing ecotones. Random points were chosen to set the corner plot and recorded with a Garmin eTrex 10 GPS unit. For each corner point a tape measure was run in two 90-degree directions that would maximize the area covered. Flags were placed at 1, 2, 5, 10, 15, 25, 50 and 100 meters to create nested quadrants, except in Boykin Springs site 2. Boykin Springs site 2 would have moved out of longleaf pine savanna and into wetter areas thereby adding additional communities not captured from other sites. Boykins Spring site 2 had plots established up to the 50x50 plot and included an additional 75x75 plot not established in any other site.

Plots were sampled starting at the 1x1 and continued until the last nested plot. All rooted plant species within the plots were recorded. Specimens that were not identified to the species level were identified at the lowest possible taxonomic rank. Several plants were not identified to any rank and were therefore listed as unknown. Appendix B is the list of species and their locations.

Data Analysis

To determine if the model could be used to predict landscape species richness using community level data, log of the area and species richness values were plotted to obtain a regression line. The values of C and z were taken from the regression line as C was the point of intercept representing the species richness at 1-meter square and z as the slope of the line representing the rate of species richness increase as area increases.

Various published flora throughout the Big Thicket region were reviewed to obtain species richness and area. Invasive and subspecific taxa were not included in analyses because doing so would have skewed the numbers of the natural ecosystem. The area of each study site was used in the power curve equation for predictions. Using the C and z values obtained from the regression line, we inputted them into the power curve and took the known area of each referenced flora and calculated a predicted species richness. These values were then run through the independent t-test, Wilcoxon Test, using the VassarStats program (VassarStats 2019) to determine if there was a statistical significance between predicted and observed species richness.

To test the intermediate disturbance hypothesis, the sites were chosen based on time since the last burn. Originally the sites were chosen with burn times of one, five, and ten years since the last burn; however, upon arrival to Boykins Spring Site 3, the site had recently been burned within a week of data collection. Total species richness for each plot was used to test the intermediate disturbance hypothesis would hold true. The data was plotted on an excel bar graph.

CHAPTER III

Results

Power Curve Hypothesis

The species richness values for the 64 plots are presented in Table 1 and Figure 7. The regression analysis comparing species richness (y-axis) of the 64 plots to area (x-axis) calculated an intercept (*C* value) of 2.3285 and a slope (z value) of 0.2765. The predicted species richness values calculated from the *C* and z values determined from the plot data for the various management units within the Big Thicket National Preserve are presented in Table 2 and Figure 8.

The variance between the predicted and the observed species richness values for the various management units ranged from 6 to 148. Comparison of the observed versus predicted species richness values of the management units tested indicated that nine of the ten units had predicted species richness values that fell below or close to the observed species richness. One of the units had a predicted species richness value of greater than 75 species higher than the observed.

Table 1

Species Richness within Nested Plots

Area (sq. meters)	Big Sandy Creek Unit (spring)	Big Sandy Creek Unit (summer)	Boykin Springs 1 (spring)	Boykin Springs 1 (summer)	Boykin Springs 2 (spring)	Boykin Springs 2 (summer)	Scrappin Valley (spring)	Scrappin Valley (summer)
1	2	3	6	8	1	2	13	9
4	3	4	12	13	3	4	22	13
25	7	5	22	26	6	7	27	18

Area (sq. meters)	Big Sandy Creek Unit (spring)	Big Sandy Creek Unit (summer)	Boykin Springs 1 (spring)	Boykin Springs 1 (summer)	Boykin Springs 2 (spring)	Boykin Springs 2 (summer)	Scrappin Valley (spring)	Scrappin Valley (summer)
100	13	8	28	35	9	13	37	27
225	20	15	34	40	10	14	42	33
624	21	20	45	51	15	21	51	42
2500	26	28	53	60	20	30	65	59
5628	X	X	X	X	28	38	X	X
10000	37	33	60	70	X	X	87	80

Area (sq. meters)	Big Sandy Creek Unit (spring)	Big Sandy Creek Unit (summer)	Boykin Springs 1 (spring)	Boykin Springs 1 (summer)	Boykin Springs 2 (spring)	Boykin Springs 2 (summer)	Scrappin Valley (spring)	Scrappin Valley (summer)

Note. X indicates that species richness was not taken at that magnitude

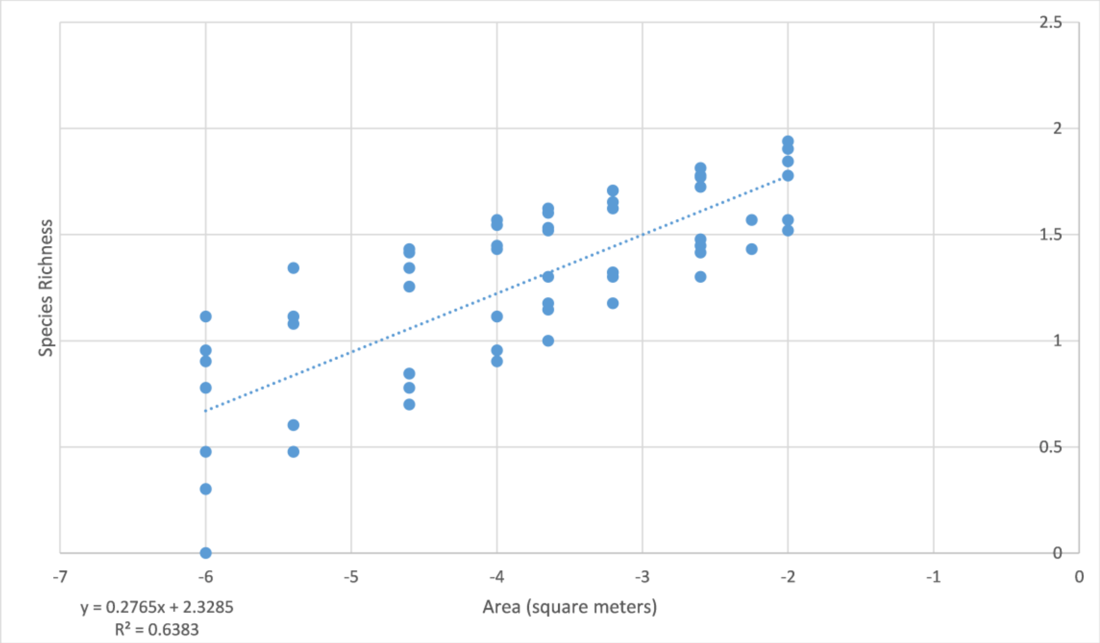


Figure 7. Logarithmic Regression Line. Log line of species richness as a function of the area for the data collected in the field. Note the values at that lower left corner representing the C and z values.

Table 2

Observed and Predicted Species Richness for Various Locations

Location	Predicted Species Richness	Observed Species Richness*	Area (Square Kilometers)	Citations
Loblolly Unit	266	267	2.22	Brown *et al.*, 2008

Location	Predicted Species Richness	Observed Species Richness*	Area (Square Kilometers)	Citations
Hickory Creek Unit	284	355	2.84	MacRoberts *et al.*, 2002
Menard Creek Corridor	454	611	15.37	Brown *et al.*, 2009
Beech Creek Unit	492	414	20.59	Brown *et al.*, 2008
Turkey Creek Unit	553	635	31.5	Brown *et al.*, 2005
Jack Gore Baygall and Neches Bottoms Unit	641	643	53.79	MacRoberts *et al.*, 2010
Lance Rosier	763	615	101	Brown *et al.*, 2006a
Roy E Larsen Sandylands	389	512	8.81	Matos & Rudolph, 1985
Big Sandy Creek Unit	655	632	58.06	Brown *et al.*, 2006b
Canyonlands Unit	349	343	5.97	Haile & Hatch, 2013

*Note. * Invasive and intra specific taxa removed*

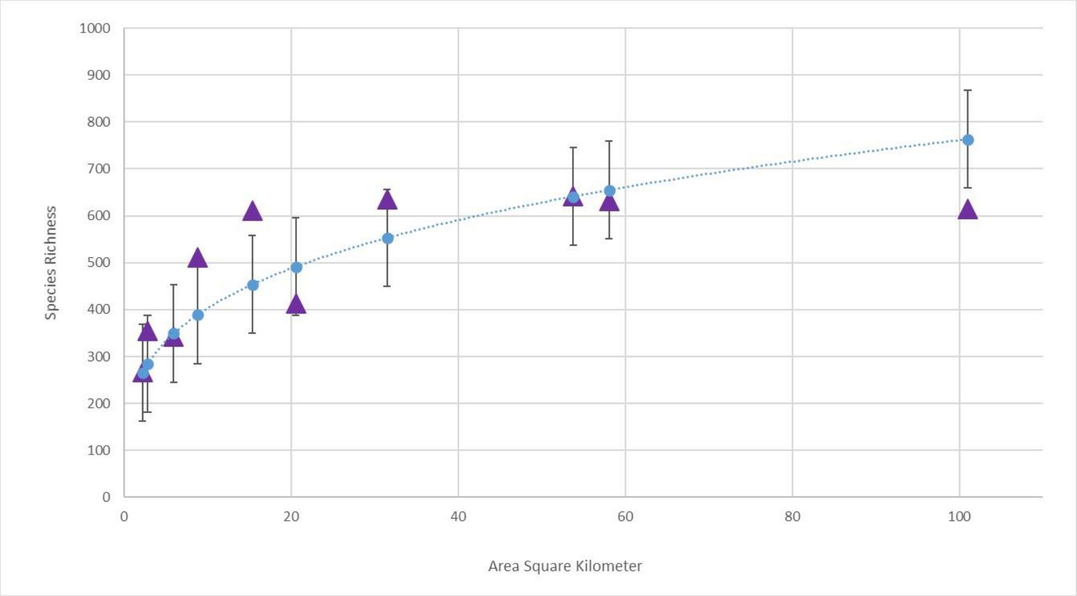


Figure 8. Species Area Curve. Species area curve for the predicted and observed values of various flora. Blue dots represent the predicted values and purple triangles represent the predicted values. Confidence intervals are set at 95%.

The Wilcoxon Test for variance between observed and predicted species richness for the 10 management units analyzed resulted in a p-value of 0.28774, indicating no statistical difference between the observed versus predicted species richness values. Seven of the ten observed values fell within our 95% confidence intervals of the predicted value.

Intermediate Disturbance Hypothesis

For the intermediate disturbance hypothesis, Boykin Springs site 2 during the spring and Big Sandy Creek during the spring had the lowest richness at 37 species. Scrappin Valley during the spring had the highest richness at 87 species. Variance between the lowest and highest species richness is 50. Table 3 shows the total species richness for each plot with the time since last burn.

Table 3

Species Richness and Time Since Last Burn

Site	Time Since Last Burn (Years)	Number of Species
Boykin Springs Site 2 (Spring)	0	28
Boykin Springs Site 2 (Summer)	0	38
Boykin Springs Site 1 (Spring)	1	60
Boykin Springs Site 2 (Summer)	1	70
Scrappin Valley (Spring)	1	87
Scrappin Valley (Summer)	1	80
Big Sandy Creek (Spring)	10	37
Big Sandy Creek (Summer)	10	33

Note. 0 time of Boykin Springs Site 2 was burned the year of sampling

Because of the lack of data from an intermediate site of five years, it is difficult to determine if the intermediate disturbance hypothesis was supported. The sites burned within the past one to two years had the highest species richness and those sites that were either recently burned or not been burned within the past ten years had the lowest species richness.

CHAPTER IV

Discussion

This study demonstrates that species richness on a landscape scale can be predicted using *C* and z values obtained from data collected at the community level. The advantage to this approach is that management time required to determine the species richness for a large-scale management area can be reduced substantially.

By gradually increasing the sampling area up to 10,000 square meters and using the power curve, a rough estimate of the landscape species richness can be reasonably predicted within the Big Thicket region of the longleaf pine ecosystem. These estimates must take into account that invasive species and taxa below the rank of species were not used in the estimates of the C and z values. One study shows that non-native species invade local habitat and can reduce the overall species richness of the native plant community (Brewer 2008). The p-value of 0.28774 indicates that our sampling methodology can be used for predictive purposes.

Difficulty arises when trying to predict species richness when various ecological disturbances and other factors are present (Kirkman *et al.* 2004). The study was done in plots that ranged from 0-10 years of fire regime yet was still able to present a working model that could predict with some accuracy the species richness of the landscape. It should be noted that of the ten samples, six were underestimated and four were overestimated. For units that are under-estimated one can feel satisfied that the area has been reasonably surveyed to completion, and for those units that were over-estimated one may be inclined to continue surveying as all the species may not have been identified. The model depicts a scaled invariant graph as opposed to an exponential. Although the asymptote was never reached, the model was able to predict, with some accuracy, the richness of areas much larger than the survey areas.

Interestingly, the time of year at which sites were surveyed did not matter. Exactly half of the plots showed higher richness in the spring and half showed higher richness in the late summer. Rare species can be found throughout all seasons with a quarter flowering in the spring, half during the spring and summer, and the last quarter flowering during the summer and fall or fall (Walker 1993). We encountered the Louisiana catchfly (*Silene subciliata*) at the Scrappin Valley site, which happened to also have the highest species richness within our sites.

By using the methods presented in this study, land managers working in the east Texas area now have a suitable way to estimate and evaluate species richness within the longleaf pine ecosystem. The tool can function for best practice land management to identify areas of conservation concern and can also be used to extrapolate a desired richness for the landscape. Along with the advantage of having best management practices, these methods indicate whether a checklist may have exceeded the expected values or if an area still needs to have additional surveying. Units such as Lance Rosier, Big Sandy Creek, and Canyonlands whose observed values are less than those of predicted values suggest that additional surveying may be needed to find additional species not previously reported.

Disturbances change the structure and function of forest ecosystems. Natural disturbance regimes vary by type, severity, frequency, spatial patterns, and seasonality. Variation in components of disturbance may result ecosystem biodiversity (Palik *et al.* 2002).

Various opinions have been presented as to what constitutes diversity success when restoring longleaf pine habitat and how success should be measured (Hobbs & Harris 2001). The literature varies on what is the appropriate amount of time to wait between burning to maximize richness from one to two years. Several authors also dispute weather growing or dormant seasons lead to greater diversity and richness (Beckage & Stout 2000, Brockway & Lewis 1997, Glitzenstein *et al*. 2003, Kirkman *et al.* 2004). A personal interview was conducted with Geyata Ajilvsgi (2018) where she suggested an approach to maximize rare species by having burn intervals once every 5 years and differs from the more conventional burn time between one and two years.

Because the five-year plot was burned just prior to data collection there is no evidence to support the intermediate disturbance hypothesis. However, the plots that were burned the same year data were collected and the plots that were burned ten years prior to data collection showed the least amount of species richness.

Through progressive science we are finding that fire is an important component to manage the dwindling longleaf pine ecosystem. Chemical application and mechanical means along with a proper fire regime has been shown to increase species richness (Brockway & Outcalt 2000). Continued research on the best management practices to increase species richness and diversity is paramount if we are to save this once extensive ecosystem from becoming lost.

The study has both theoretical and practical applications in the field of ecology. Through this study we can make predictions for current and future management issues within the east Texas LLP ecosystem by setting goals for species richness. From a theoretical standpoint we believe areas such as the Lance Rosier and Hickory Creek Unit may need additional surveying because they fall well below the curve. The authors of the Lance Rosier Unit Flora state they believe that additional taxa may be present in the unit and could increase the richness to as much 705 species adding additional support to our analysis. It also gives us a foundation as to future-prospects and questions for the Longleaf pine. We did additional data collecting in Alabama, South Carolina, Virginia, and Florida. We also found other floras outside of the state of Texas. Future studies could help to increase the range the Power curve can predict species richness within the LLP ecoregion.

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APPENDIX A

Methods to extrapolate predicted species richness by way of species area curve.

1. Identify at least four suitable local areas to collect field data. Areas should best represent the entire landscape level and not cross over into any outside ecotones. Randomly select a point to position corner of quadrats within the local area. Increase quadrates from 1x1, 2x2, 5x5, 10x10, 15x15, 25x25, 50x50, and 100x100 meters while sampling species richness within each quadrat by adding only new species observed. Data should be collected at multiple times of the year to allow for species that are only seasonally present.
2. Using the data collected in the field, calculate a regression line using Microsoft Excel software with the log of area and species richness. The regression line will calculate C and z values necessary to determine the species area curve, where C is the value of species richness at the 1 square meter plot and z is the rate of increase for species richness.
3. Using the power curve, predicted species richness can be calculated with the formula:

   $S = CA^z$ where C and z values are as stated in the above step and A is the area to be predicted and S is the predicted value of the species richness.

The above procedure can be used in management practices throughout the East Texas longleaf pine range. These values will provide data on whether restoration sites have met the desired number of species within a given area.

APPENDIX B

Species	BITH	BS I	BS II	SV	Family
Acer rubrum L.			X		ACERACEAE
Acer sp. L.			X		ACERACEAE
Yucca sp. L.	X			X	AGAVACEAE
Rhus copallinum L.	X	X			ANACARDIACEAE
Toxicodendron radicans (L.) Kuntze	X	X		X	ANACARDIACEAE
Ruellia sp. L.				X	ANCANTHACEAE
Asimina triloba (L.) Dunal	X	X		X	ANNONACEAE
Trachelospermum jasminoides (Lindl.) Lem.	X				APOCYNACEAE
Ilex decidua Walter		X	X		AQUIFOLIACEAE
Ilex opaca Aiton	X		X		AQUIFOLIACEAE
Ilex vomitoria Aiton	X	X	X	X	AQUIFOLIACEAE
Aristolochia sp. L.	X				ARISTOLOCHIACEAE
Asclepias sp. L.		X		X	ASCLEPIADACEAE
Asclepias tuberosa L.				X	ASCLEPIADACEAE
Ambrosia psilostachya DC.		X			ASTERACEAE
Ambrosia sp. L.				X	ASTERACEAE
Anaphalis margaritacea (L.) Benth.				X	ASTERACEAE
Artemisia sp. L.				X	ASTERACEAE
Asteraceae	1	5	1	7	ASTERACEAE
Coreopsis sp. L.				X	ASTERACEAE
Echinacea sp. Moench				X	ASTERACEAE
Elephantopus carolinianus Raeusch		X	X	X	ASTERACEAE
Erigeron sp. L.		X			ASTERACEAE
Eupatorium capillifolium (Lam.) Small				X	ASTERACEAE
Eupatorium perfoliatum L.				X	ASTERACEAE
Eupatorium serotinum Michx.			X	X	ASTERACEAE
Eupatorium sp. L.		X			ASTERACEAE
Helianthus sp. L.				X	ASTERACEAE
Hieracium sp. L.		X			ASTERACEAE

Liatris sp. Gaertn. ex Schreb.		X			ASTERACEAE
Pityopsis sp. Nutt.		X			ASTERACEAE
Rudbeckia sp. L.				X	ASTERACEAE
Solidago odora Aiton		X		X	ASTERACEAE
Solidago sp. L.				X	ASTERACEAE
Symphyotrichm sp. Nees				X	ASTERACEAE
Lithospermum sp. L.				X	BORAGINACEAE
Brassicaceae		X			BRASSICACEAE
Lobelia sp. L.				X	CAMPANULACEAE
Viburnum sp. L.	X	X			CAPRIFOLIACEAE
Silene subciliata B.L. Rob.				X	CARYOPHYLLACEAE
Hypericum sp. (L.)				X	CLUSIACEAE
Cornus drummondii C.A. Mey.	X		X		CORNACEAE
Nyssa aquatica L.			X		CORNACEAE
Nyssa sylvatica L.			X		CORNACEAE
Juniperus virginiana L.	X				CUPRESSACEAE
Cyperaceae	X	X		X	CYPERACEAE
Cyperus sp. L.	X	X		2	CYPERACEAE
Eleocharis sp. R. Br.				X	CYPERACEAE
Rhynchospora sp. Vahl.		X		X	CYPERACEAE
Scleria sp. P.J. Bergius		X			CYPERACEAE
Pteridium aquilinum (L.) Kuhn		X	X	X	DENNSTAEDTIACEAE
Drosera breviolia Pursh				X	DROSERACEAE
Diospyros virginiana L.				X	EBENACEAE
Lyonia lucida (Lam.) K. Koch		X			ERICACEAE
Vaccinium sp. L.	X	2	X		ERICACEAE
Vaccinium tenellum Aiton				X	ERICACEAE
Croton sp. L.				X	EUPHORBIACEAE
Euphorbia sp. L.		X			EUPHORBIACEAE
Euphorbiaceae			X		EUPHORBIACEAE
Stillingia sylvatica L.		X			EUPHORBIACEAE
Baptisia sp. (Vent)		X			FABACEAE

Chamaecrista fasciculata (Michx.)				X	FABACEAE
Clitoria mariana (L.)				X	FABACEAE
Crotalaria sagittalis L.				X	FABACEAE
Desmodium sp. Desv.				X	FABACEAE
Fabaceae	2	2		2	FABACEAE
Galactia sp. P. Br.		X			FABACEAE
Lespedeza sp. Michx.		X		X	FABACEAE
Mimosa sp. L.		X		X	FABACEAE
Stylosanthes biflora (L.) Britton, Sterns & Poggenb.				X	FABACEAE
Tephrosia onobrychoides Nutt.				X	FABACEAE
Tephrosia sp. Pers.				X	FABACEAE
Trifolium repens L.		X			FABACEAE
Quercus alba L.				X	FAGACEAE
Quercus falcata Michx.	X		X	X	FAGACEAE
Quercus incana W. Bartram	X	X		X	FAGACEAE
Quercus marilandica Münchh.		X	X	X	FAGACEAE
Quercus phellos L.	X	X	X		FAGACEAE
Quercus rubra L.	X	X	X		FAGACEAE
Quercus sp. L.	X	X	X	X	FAGACEAE
Quercus stellate Wangenh.	X	X	X	X	FAGACEAE
Quercus velutina Lam.	X			X	FAGACEAE
Liquidambar styraciflua L.	X	X	X	X	HAMAMELIDACEAE
Iris sp. L.				X	IRIDACEAE
Isoetes sp. L.				X	ISOETACEAE
Carya sp. Nutt.	X	2	X	2	JULANDACEAE
Juncus sp. L.				2	JUNCACEAE
Lamiaceae		X			LAMIACEAE
Pycnanthemum sp. Michx.				X	LAMIACEAE
Scutellaria lateriflora L.		X			LAMIACEAE
Scutellaria sp. L.				X	LAMIACEAE
Persea borbonia (L.) Spreng.	X	X	X		LAURACEAE

Sassafras albidum (Nutt.) Nees		X	X	X	LAURACEAE
Pinguicula pumila Michx.				X	LENTIBULARIACEAE
Utricularia sp. L.				X	LENTIBULARIACEAE
Allium sp. L.				X	LIACEAE
Linum sp. L.				X	LIACEAE
Nothoscordum bivalve (L.) Britton				X	LIACEAE
Gelsemium sempervires (L.) W.T. Aiton				X	LOGANIACEAE
Lycopodium sp. L.				X	LYCOPODIACEAE
Magnolia sp. L.			X		MAGNOLIACEAE
Magnolia virginiana L.		X			MAGNOLIACEAE
Rhexia sp. L.				X	MELASTOMATACEAE
Morella cerifera (L.) Small	X	X	X	X	MYRICACEAE
Botrychium sp. Sw.	X				OPHIOGLOSSACEAE
Spiranthes praecox (Walter) S. Watson				X	ORCHIDACEAE
Oxalis sp. L.				X	OXALIDACEAE
Pinus echinate Mill.	X	X			PINACEAE
Pinus palustris Mill.	X	X	X	X	PINACEAE
Pinus sp. L.				X	PINACEAE
Pinus taeda L.	X	X	X	X	PINACEAE
Andropogon gerardii Vitman				X	POACEAE
Andropogon virginicus L.		X	X	X	POACEAE
Chasmanthium laxum (L.) Yates	X		X		POACEAE
Dichanthelium sp. (Hitchc. & Chase) Gould	X	X	X	X	POACEAE
Panicum sp. L.	X	4		2	POACEAE
Paspalum sp. L.		X		X	POACEAE
Poaceae	4	6	3	3	POACEAE
Sporobolus sp. R. Br.				X	POACEAE
Tripsacum dactyloides (l.) L.		X			POACEAE
Polygala polygama Walter				X	POLYGALACEAE
Polygala sp. L.		2		X	POLYGALACEAE

Phemeranthus sp. Raf.				X	PORTULACACEAE
Rhamnus sp. L.	X				RHAMNACEAE
Rubus sp. L.		X	X	X	ROSACEAE
Mitchella repens L.			X		RUBIACEAE
Agalinis fasciculata (Elliot) Raf.				X	SCROPHULARIACEAE
Penstemon laxiflorus Pennell				X	SCROPHULARIACEAE
Smilax bona-nox L.	X	X	X	X	SMILACACEAE
Smilax sp. L.	2		X	X	SMILACACEAE
Sphagnum sp. L.				X	SPHAGNACEAE
Ulmus Americana L.		X			ULMACEAE
Callicarpa Americana L.	X	X	X	X	VERBENACEAE
Verbena sp. L.		X			VERBENACEAE
Parthenocissus quinquefolia (L.) Planch.				X	VITACEAE
Vitis sp. L.	X		X		VITACEAE
Unknown	6	16	8	29	

VITA

DAVID HAGYARI

EDUCATION

- 2016-Present: Master of Science Candidate, Biology (Sam Houston State University)
- 2000-2003: Bachelor of Science, Botany (Oklahoma State University)

SKILLS

- Plant Taxonomy/Identification
- GPS, GIS, and Google Earth
- Basic SAS Programming
- Time, data, and budget management
- Writing of reports, permits, grants, and proposals
- Microsoft Word, Excel, and Power Point

PROFESSIONAL EXPERIENCE

- 2018- Present: Senior Ecologist (Horizon ESI)

  Environmental consulting for various projects to include wetland delineations, Phase I, threatened and endangered species habitat assessments, and urban wildlife studies. T&E and migratory birds habitat assessments. Presence absence surveys were conducted on the Golden Cheek Warbler while supervised with a permitted biologist. American burying beetle surveys.

- 2018: Teaching Assistant (Sam Houston State University)

  Zoology- Preparation of lab, administering quizzes, demonstration of dissections for various taxa, grading
  Environmental Science - Preparation of lab, administering quizzes, development of students in environmental issues, grading assignments and quizzes.
  Plant Taxonomy- Aid in collecting and identifying flora of the East Texas Region, development of students in taxonomic issues.
  Botany - Preparation of lab, administering quizzes, development of students in basic lab techniques, grading assignments and quizzes.

- 2017-2018: Student Researcher (Sam Houston State University Natural History Museum)

  Assist in the writing and research of a management plan for the longleaf pine ecosystem in Big Thicket National Preserve. Collection of plant specimens to be processed and added to the herbarium. Development of data collection to ascertain ideal circumstances for the restoration of longleaf pine. Worked alongside a PhD in entomology to secure contracts for American Burying Beetle surveys.

- 2005-2015: Environmental Consultant (Contractor)

  Assisted in over 1000 liner miles and 15000 acres of wetland delineations. Projects included the Keystone Pipeline, Bear Run Coal Mine, and Rover Pipeline, among others. Sites were in multiple states within the Midwest, Gulf Coastal Plains, and Eastern Mountain Range. Performed multiple surveys for the endangered American Burying Beetle. Monitored restored wetlands. Biological habitat assessments for the endangered Indiana Bat. Used GIS to upload data from various GPS units to create working maps of various projects. Lead on various teams.

- 2005: Biological Technician II (Apex Solutions)

  Seasonal position aiding in research for the US Geological Survey performing detailed wetland delineations inside Everglades National Park. Traveled to remote sites via helicopter to collect vegetation data. Performed soil analysis in the lab using loss of ignition method.

STUDENT INTERNSHIPS/WORK

- 2018: Student Researcher (Sam Houston State University)

  Aid in the sampling of marine estuaries fish study. Identification of fish, collection of tissue samples, and gut content analysis. Study of the ecological behavior during mating of crayfish.

- 2004: Botany Intern (Chicago Botanical Gardens)

  Seasonal position aiding in botanical surveys with the Bureau of Land Management. Collected seeds to be sent to the Kew Gardens for storage in seed bank. Surveyed for a particular species of plant to be considered as a new species and for consideration of listing as federally endangered.

- 2003: Student Intern (Oklahoma Aquarium)

Aided in the development of exhibits. Care of organisms. Identification of aquatic flora.

- 2003: Student Research Assistant (Oklahoma State University)

  Aided in the assistance of aquatic toxicology research. Care of species. Collection of species in their natural habitat to be used in lab research.

- 2001-2003: Student Researcher (Oklahoma State University Stars Biology Program)

  Research and development of experiments to be conducted by various primary grades.

PUBLICATIONS/AUTHORSHIPS

- Bauer, A.M., Beach-Mehrotra, M., Bermudez, Y., Clark, G.E., Daza J.D., Glynne, E., Hagyari, D., Harnden, J.M., Holovacs, N., Kanasiro, A., Lofthus, A.J., Pierce, Z.W., Aaliyah, R., Syed, S.., Vallejo-Pareja, M.C., & Walker, B.A. 2018. The tiny skull of the Peruvian gecko *Pseudogonatodes barbourin* (Gekkota: Sphaerodactylidae) obtained via a divide-and-conquer approach to morphological data acquisition. *South American Journal of Herpetology* **13**: 102-116.

- Montaña, C.G., Schalk, C.M., Schriever, T., Silva, S., Hagyari, D., Wager, J., Tiegs, L., Sadeghian, C. Revisiting 'What do tadpoles really eat?': A ten-year perspective (Target Journal: Freshwater Biology).

- Ross, M.S., Sah, J.P., Ruiz, P.L., Jones, H.C., Travieso, R., Tobias, F., Snyder, J.R., & Hagyari, D. 2006. Effects of hydrological restoration on the habitat of the cape sable seaside sparrow, annual report of 2004-2005. *SERC Research Reports*. Paper 85.

- Williams, J.K., Alford, J., Lutterschmidt, W., Godwin, W., & Hagyari, D. 2019. Modeling agriculture timber risks and southern pine beetle aggregation. *Poster Presentation, Conservation Biology Posters*.

PROFESSIONAL LICENSE/PERMITS/TRAINING

- American Burying Beetle Federal Permit TE3045B-0
- Basic Wildland Firefighting Training S-130/190; 2005
- PADI SCUBA Diver Number 17120D0930; 2017

- Wetlands Certificate – Texas Research Institute for Environmental Studies; 2018

GRANTS

- Longleaf Pine Restoration Management Plan with Justin Williams, PhD and William Godwin, Ph.D.; $40,000; Big Thicket National Preserve, U.S. National Parks Service; 2017
- Joey Harris Grant; $550; Sam Houston State University; 2018

AWARDS/HONORS

- Eagle Scout (Boy Scouts of America)
- Finished my undergraduate degree on the Dean’s Honor Roll