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Restoration of a wet longleaf pine (*Pinus palustris*) savanna in southeast Louisiana: Burning toward reference conditions

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Restoration of a wet longleaf pine (*Pinus palustris*) savanna in southeast Louisiana:
Burning toward reference conditions

A Thesis

Submitted to the Graduate Faculty of the
University of New Orleans
In partial fulfillment of the
Requirements for the degree of

Master of Science
In
Biological Sciences

By
Alex Entrup
B.A. University of St. Thomas 2002

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Table of Contents

List of Figures and Tables	iv
Abstract	v
Methods	5
Study Area and Reference Site	5
Restoration Treatments: Abita restoration sites	8
Data Analysis	11
Comparative Analysis of Abita Creek and Reference Site	11
Individual Species Measures	13
Results	15
Part 1: Logging effects	15
Initial vegetation responses to logging	15
Responses to logging over time	16
Part 2: Overall treatment effects	17
Treatment responses compared to reference site over time	17
Species richness response	20
Individual species response	20
Basal area response to restoration activities	22
Discussion	23
References	28
Appendix A. Prescribed fire weather and behavior	34
Appendix B. Relative species frequency chart	36
Appendix C. Pearson and Kendall correlations with major axes of NMS ordination (Figure1.)	44
Appendix D. Species codes	51
Vita	57

List of Figures and Tables

Figure 1. Project area map

Figure 2. Photos of Abita pre-treatment restoration site

Figure 3. Photos of Lake Ramsey reference site

Figure 4. Photos of post-logging conditions at Abita restoration site

Figure 5. NMS ordination of 10m² presence/absence species data for restoration site and reference site

Table 1. PerMANOVA table of comparisons of Abita logged, Abita unlogged and Lake Ramsey reference site for 1997, 1999, 2013

Table 2. PerMANOVA table of comparisons of Abita restoration site 1997, 2000, 2005, 2013 and Lake Ramsey reference site 2013

Table 3. Dispersion measures and comparisons of Abita restoration site 1997, 2000, 2005, 2013 and Lake Ramsey reference site 2013

Table 4. Species richness measures at Abita restoration site

Table 5. Indicator Species Analysis of Abita restoration site for years 1997, 2000, 2005 and 2013

Table 6. Basal area measures for logged and unlogged sites at Abita restoration site

Abstract

This study quantifies the changes in vegetation composition and structure of a fire-excluded *Pinus palustris* (longleaf pine) wetland savanna restoration site in southeastern in comparison to a proximate contemporary reference site. The restoration site was invaded by hardwood species and off-site pines, and never underwent extensive soil disturbance. The restoration treatments involved logging across portions of the site and the reintroduction of fire across the entire site. All species present in 10m² quadrats were recorded prior to treatment and throughout the 17 year study at reference and treatment sites. The community composition of both logged and unlogged sites converged over time, and became more similar to the reference site. We conclude that logging of off-site pine coupled with the reintroduction of frequent fires can be effective in restoring ground cover in remnant longleaf pine savannas with <20 years of fire-exclusion and no history of intensive soil disturbance.

Keywords: Prescribed fire; logging; species richness; species diversity; reference site; fire reintroduction

Introduction

Across the globe, most fire-dependent ecosystems are in a degraded state due to man made changes of native fire regimes (Shlisky 2007). Since the advent of modern land management practices and policies, the composition and structure of formally open fire maintained woodlands has changed dramatically, even in protected natural areas. Timber operations and fire-suppression promotes hardwood invasion and changes in dominant species (Clewett 2014). In fire-excluded woodland and savanna communities, groundcover production suffers as mid- and overstory trees and shrubs dominate competition for light and other resources (Oswald, et al. 2014). Restoration of natural woodland communities and native fire regimes becomes increasingly difficult with lengthening periods of fire suppression.

Longleaf pine (*Pinus palustris*) ecosystems are no exception to the trend of degraded fire-dependent systems. Once occupying approximately 37 million ha of the southeastern-United States coastal plain, they are now confined to only 2-5% of the former range (Frost 1993, Oswald 2012). Longleaf pine was the dominant overstory tree in ecosystems occupying a wide range of soil conditions including xeric to mesic and sandy to silty, in both upland and wetland sites (Peet 2006). Heavy logging from the 1870s-1920s followed by a remarkable lack of regeneration led to the decline of the longleaf pine landscapes of the Southeastern Coastal Plain. Most longleaf forests and savannas burned every 2-3 years during the pre-settlement era. The practice of burning pasture land by ranchers maintained the presence of fire in the landscape after European settlement, however as ranching declined between 1860s and 1950s, the role of fire diminished. Fire-suppression became common between 1920 and 1950, during which time former longleaf plant communities were largely replaced by slash pine (*Pinus elliottii*) and loblolly pine (*Pinus taeda*) plantations. The herbaceous plant communities associated with longleaf pine were subsequently overtaken by woody species. By the 2000s few tracts of intact longleaf remained, and numerous associated species were considered threatened or endangered (Van Lear, et al. 2005). In

recognition of their high ecological value, longleaf ecosystems have recently become a conservation and restoration target for many organizations and government agencies (Regional working group for America's longleaf 2009).

Use of the remaining high quality longleaf sites as reference sites can provide a context by which restoration success can be measured. Species composition is an integral component of monitoring the recovery of a degraded site (Legendre 2005, Irvine et al. 2011, Provencher 2001). If vegetation composition is to be measured, it is important to have a reference condition that represents the desired end state by which success can be gauged (White & Walker 1997, Walker & Silletti 2006). In the absence of a reference site, reliance on species richness alone can be problematic. Increases to the number of species may not necessarily indicate compositional changes toward a desired end-state.

The degree to which long-unburned sites can recover is largely unknown. Some plant species may persist in the seed-bank (Coffey & Kirkman 2006, Sharma 2012, Matlack & Good 1990, Cohen *et al* 2004), or as undetected dormant propagules (Varner *et al.* 2005) and emerge after the reintroduction of fire (Moore *et al.* 1982). Species that have dramatically reduced in abundance during fire-suppression, may not immediately recolonize following fire (Abrahamson & Abrahamson 1996). Some species may take many years to reappear, or return to previous levels of abundance. If species are extirpated from a site, they may or may not return without intervention. Not all seed dispersal mechanisms are capable of transporting seed from disconnected or distant sites (Kirkman *et al.* 2004, Hinman *et al.* 2008), and reintroduction may be required (Coffey & Kirkman 2006).

The methods of restoration to be used must be appropriate for a particular site. In some fire-deprived sites, the reintroduction of fire may be sufficient to move the structure and composition toward reference conditions (Lewis & Harshbarger 1976, Addington *et al.* 2015). Fire may stimulate ground cover growth and simultaneously reduce cover of the woody midstory. In some more severely

encroached sites, the immediate reintroduction of fire may not be appropriate or possible. A high density of woody stems in the mid- and overstory may prevent the penetration of fire by increasing moisture and decreasing the abundance and availability of fine fuels (Browckway & Lewis 1997). Conversely, long periods of fire exclusion can cause a buildup of fuels that can result in increased fire intensity that exceeds the levels of historic variability (Thaxton & Platt 2006). The first fires following long periods of fire exclusion have been documented to kill large numbers of mature longleaf pine trees (Varner *et al.* 2005). If low intensity ground fire cannot be applied to a restoration site, mid- and overstory reduction may be needed before reintroducing fire to the system (Kreye 2012, Kreye *et al.* 2013).

One problem facing land managers is how to reverse the encroachment of off-site trees and brush while minimizing undesirable impacts (Provencher *et al.* 2000, Addington *et al.* 2015). More severely impacted sites can require chemical or mechanical control of the shrub layer (Freeman & Jose 2009, Provencher 2001, Ranasinghe 2003). Those sites that have undergone extensive periods of fire suppression or severe soil disturbance may require re-seeding of the herbaceous layer (Kirkman *et al.* 2004, Polley *et al.* 2005). It is not well understood which interventions are necessary for a particular level of encroachment or time period under altered fire-regime in longleaf savannas. Higher levels of intervention are more expensive and have greater potential for undesirable unintended consequences (Greenberg *et al.* 1995, Provencher 2001), yet too little, or the wrong actions may cause the restoration to fall short of objectives (Platt *et al.* 2015). Learning what changes occur in the vegetation community and structure over the long-term under different restoration scenarios will help inform land managers initiating restoration projects.

Our study is focused on the restoration of a wet longleaf pine savanna in the southeastern United States near Abita Springs, Louisiana. Having been clear-cut sometime in the 1940s, at the beginning of the

restoration in 1997 the structure was typical of fire-suppressed, “abandoned” cut-over longleaf site (Oswald *et al.* 2014, Heyward 1939, Lewis & Harshbarger 1976 Cohen *et al.* 2004, Varner *et al.* 2005). Fire-regime was altered since at least the 1940s, and it had not experienced any fire for at least 20 years. The midstory was nearly a closed canopy of hardwood species with patchy areas of herbaceous cover, and the overstory was primarily slash pine (*Pinus elliottii*). Restoration consisted of logging in some portions of the site and reintroduction of fire across the whole site. We used a nearby, high-quality longleaf savanna as a contemporary reference site. There have been relatively few studies measuring vegetation community response to restoration in wetland longleaf savannas, and fewer that use a contemporary reference site for comparison.

The purpose of our study is to measure the vegetative community response to mechanical removal of undesirable overstory trees and the reintroduction of fire. Our first study objective was to compare the vegetation community response of two restoration treatments in relation to each other and to our reference site. We examined the differences in the vegetative community of the logged and unlogged areas for both short-term and long-term differences. Our second objective was to examine the vegetation response of the restoration, as a whole, in relation to our reference site. We examined the vegetation community changes at each sample period following the introduction of fire. We predicted that the logged and unlogged sites would respond similarly to the reintroduction of fire. We expected that logging would not cause an invasion of non-native or weedy plants, and changes to the vegetative community caused by logging would be transient. We also predicted that the vegetative community at the restoration site would become more similar to the reference site with the continued application of prescribed fire. We also expected species richness to increase over the course of the study.

Methods

Study Area and Reference Site

Our study sites are located in southeastern Louisiana within the Gulf Coastal Plain region of the U.S. on Pleistocene deposits of the Prairie and Citronelle terrace formations. Soils are predominantly poorly drained Stough and Myatt fine sandy loams (Fragiaquic Paleudults and Typic Ochraquults respectively; Trahan *et al.* 1990). Soils moisture conditions are volatile, with seasonal flooding in years with high precipitation, and complete drying during droughts (Trahan *et al.* 1990). Historical accounts of the area describe a landscape of longleaf pine dominated savannas and flatwoods, which were typically annually burned between the late 1700's to widescale logging in the 1930s (Mohr 1898, Penfound & Watkins 1937, Penfound 1944, Wahlenberg 1946). Canopy pines approaching 200-300 years old were interspersed with patches of younger pines and overtopped a continuous cover of herbaceous vegetation (Penfound & Watkins 1937, Penfound 1944). The pre-settlement concept of fire maintained pine woodlands with well-developed herbaceous groundcover informed our concept of reference site conditions for our ecological restoration goals.

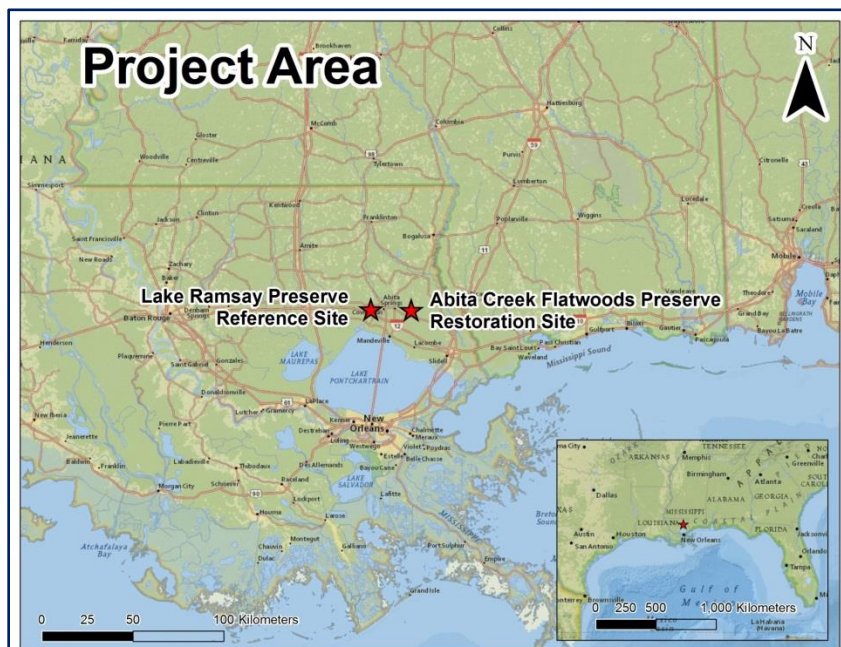
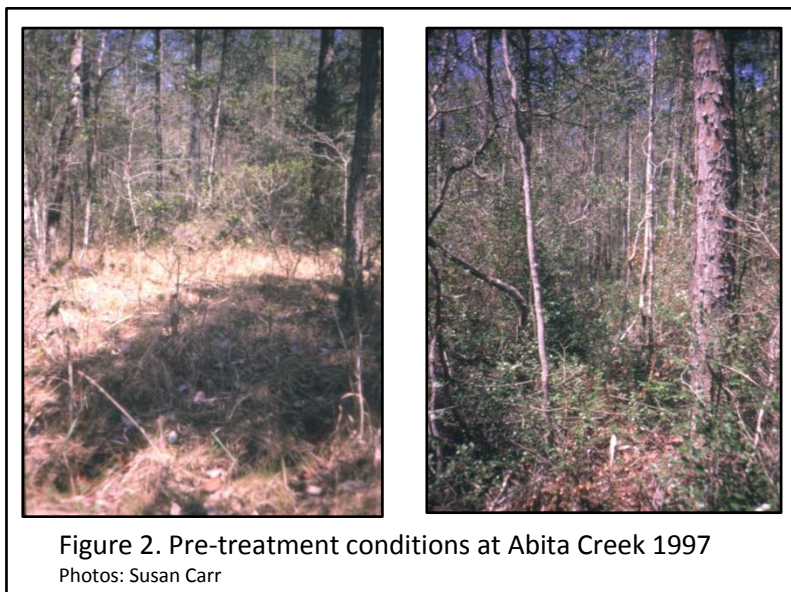


Figure 1. Project area for longleaf restoration and reference site

Imagery ESRI/National Geographic

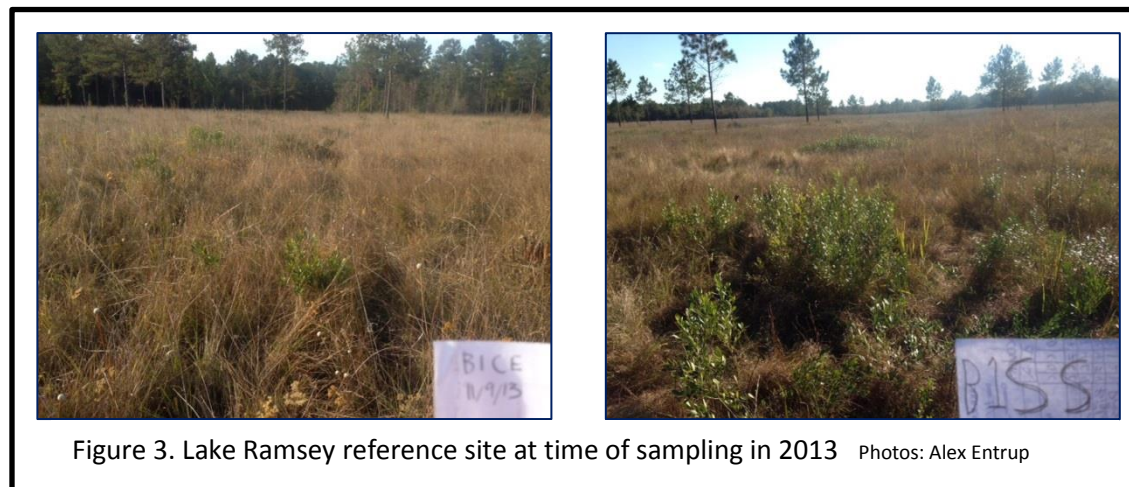
Our restoration site is the Abita Creek Flatwoods Preserve (Abita) located near Abita Springs, Louisiana (30° 31' N, 89° 58' W; The Nature Conservancy 2001) (Figure 1). The 318 hectare Abita preserve was acquired by the Louisiana Field Office of The Nature Conservancy (TNC) in 1996. At that time, conditions at Abita were typical of wet pine flatwoods following decades of fire suppression. *Pinus elliotii* (slash pine) was the dominant canopy species, mixed with a few scattered remnant *Pinus palustris* (longleaf pine; The Nature Conservancy 1997, Baton Rouge, LA, unpublished report). Initial basal area (for trees > 10 cm dbh) ranged from 1.0 to 39.3 m²/ha. Although few hardwoods were present in the pre-restoration canopy, dense swaths of evergreen trees and shrubs comprised much of the midstory and understory vegetation (heights ranging in height from 0.75-2 meters). These included *Cyrilla racemiflora* (swamp titi), *Magnolia virginiana* (sweetbay), *Ilex coriacea* (large leaf gallberry), *Nyssa biflora* (swamp blackgum), *Acer rubrum* (red maple), and *Ilex glabra* (gallberry). Herbaceous ground cover vegetation was sparse and patchily interspersed with thickets of woody vegetation (Figure 2).



Recent land management history of Abita preserve is typical of the regional rural landscape following the wide spread land clearing of the early 1900's. Following clearcutting of the original pinelands in the 1930s, the Abita preserve area remained essentially treeless throughout the 1940s, and was frequently burned (Smith 2013 unpublished). From the 1940s through the 1970s, the site was fire restricted, meaning that natural fire regimes were suppressed, and any prescribed burning was infrequent and applied during the dormant season. These fire regime alterations allow the colonization of slash pine (*Pinus elliottii*) in what was formerly *Pinus palustris* (longleaf pine) woodlands. Similarly, fire maintained slash pine-pond cypress wetland communities suffered hardwood encroachment under fire restriction. After circa 1980, fire was completely excluded in the Abita area until TNC initiated its prescribed fire program in 1998. In general, deviations from pre-settlement "reference site" conditions at Abita result from landscape fragmentation and fire suppression, rather than land use conversion to agricultural or timber cultivation. Our restoration site has not experienced intensive soil disturbance.

The Lake Ramsey Wildlife Management Area (hereafter "Lake Ramsey") serves as our contemporary reference site condition, which represents the target condition for our restoration treatment sites at Abita. As such, we assumed that contemporary conditions of Lake Ramsey generally resemble Abita pre-settlement and desired future conditions for Abita preserve (our restoration site). The second growth longleaf pine woodlands at Lake Ramsey are proximate to Abita preserve (located about 16 km west of Abita: 30° 31' N, 90° 10' W). Furthermore, Lake Ramsey pine woodlands resemble regional pre-settlement conditions. Lake Ramsey woodlands were frequently burned (8-10 fires) between 1993 and 2012 (Latimore Smith, The Nature Conservancy, Baton Rouge, LA, unpublished report). Before 1993, Lake Ramsey was burned less frequently, having experienced periods restricted fire activity. However, in contrast to Abita, Lake Ramsey was not fire excluded long enough to be substantially invaded by off-site species.

In this study, the reference and restoration sites are both proximate and environmentally similar. Lake Ramsey is located on Stough fine sandy loams and Abita and Guyton silt loams (Glossaquic Paleudalfs and Typic Glossaqualfs, respectively; Trahan *et al.* 1990). In general Lake Ramsey and Abita are edaphically similar although Lake Ramsey soils are siltier. Because of their close proximity, they experience the roughly same average annual rainfall (166 cm/year Abita, 162 cm/year Ramsey). Both sites have relatively flat topography (average slope <1%), and are poorly drained.



Restoration Treatments: Abita restoration sites

The study took place in conjunction with an ongoing program for ecological restoration of fire maintained pine woodlands at Abita preserve. Included in this program was the removal of offsite slash pine via commercial logging followed by longleaf pine seedling planting. Growing season fire was reintroduced to the site following the logging. These efforts targeted the restoration of composition of Abita canopy vegetation to resemble historical and contemporary stands of old-growth longleaf pine.

The first phase of this study involved the comparison of effects between two treatments intended to reduce slash pine and hardwood dominance and restore native stand structure. Specifically, two stand restoration treatments were installed at Abita preserve: 1) removal of slash pines using commercial logging followed by application of prescribed fire (hereafter “logged+fire”) and 2) the application of prescribed fire only (hereafter “fire-only”). The logged portions of Abita were harvested during the winter of 1997-1998. Merchantable trees were harvested during dry conditions using a feller-bunchers and skidders equipped with low-pressure tires to minimize soil disturbance and damage to residual trees. Prescribed fire was reintroduced at Abita preserve in 2000. All monitoring plots were burned six times over the duration of this study (Appendix A.)



Figure 4. Photos of post-logging conditions at Abita restoration site (1998) Photos: Susan Carr

Sampling sites for the two Abita treatments were selected to represent a range of starting conditions, in terms of initial pine basal area (BA). Five sample sites were installed for the logged+fire treatment and four plots were selected for the fire-only treatment. Initial BA for the former ranged from 1.0 to 38.0 m²/ha, and for the latter range from 0.5 to 46.3 m²/ha. At each treatment site, four 10m² plots were installed and all vascular plant species recorded during each sampling year. We identified plant taxa using the highest taxonomic resolution possible, which was species for the majority of identifications.

Lower resolution identifications (genus or family) were assigned to sterile or unidentifiable and were omitted from datasets used in compositional analyses. In addition, woody stems > 2 cm diameter breast height (dbh; 1.4 m height) were tallied by species and size class in a larger 100 m² sample area (2-5 cm, then 5 cm size classes up to 40 cm dbh) which included the smaller sample plots. Actual dbh was recorded for trees > 40 cm.

Our first Abita sample occurred in September-December of 1997, prior to logging in 1998. Subsequent samples were recorded during the same season in the following years: 1999 (post-logging), 2000 (after first burn), 2005 (after second burn), and 2013 (after sixth burn). All restoration sites were prescribed burned six times during the study period. The first prescribed burns occurred approximately two years following logging, in November 1999 and May 2000. The second set of prescribed burns occurred in April and June 2002, and March 2003. Each sample site was burned either two or three years following the first burn and every two to three years until all plots were burned for the sixth total time in June of 2012 (Appendix A). Standard fuel models (Anderson 1982) or fuel model combinations were estimated for each burn unit at the time of burning and weather data were obtained from the National Weather Service station in Slidell, Louisiana (25 km east of Abita Creek Preserve). Average and maximum flame lengths were estimated at each site using the computer program BEHAVE 5.0.5 (Andrews *et al.* 2008).

The second part of this study involved the quantitative comparison of restoration treatment effects to a reference site condition. In this manner, we were able to assess the quality and magnitude of restoration success for the two Abita treatments, relative to our restoration target represented by our Lake Ramsey site. The reference site data includes three years (1997, 1999, 2013) of vegetation data from Lake Ramsey. Field methods resembled those from Abita; all species in 10m² plots were recorded to the highest possible taxonomic resolution, and all woody stems were counted and the DBH measured.

For comparisons of the logged and unlogged areas, the species composition matrices were used for comparisons to the same year data from the Lake Ramsey reference site. We used same year sampling data for Abita and Lake Ramsey for the years 1997, 1999 and 2013, which corresponded to the pre-treatment, post-logging and after six prescribed fires. For analysis of fire effects (1997, 2000, 2005, 2013), we used reference data from one year of sampling (2013).

The specific reference data that we used in this study were collected by the Louisiana Department of Wildlife and Fisheries Natural Heritage Program (LNHP) in the years 1997, 1999 and 2000 as part of an ongoing monitoring project. Vegetation data were collected from fixed plots scattered throughout the management area (Faulkner *et al.* 2006 unpublished). We collected the 2013 reference data at all wetland plots using the LNHP protocols. Wetland areas of Lake Ramsey closely resemble the conditions of the savannas at the Abita restoration site.

Data Analysis

Comparative Analysis of Abita Creek and Reference Site

As a precursor to multivariate analyses, we assembled species composition matrices from species presence/absence data at the 10m² scale. Species with fewer than two occurrences in the 10m² data sets were omitted (McCune & Grace 2002). A species frequency occurrence table is included for Abita and Lake Ramsey 10m² is included for each sample year in Appendix B. Similarity matrices were calculated from square-root transformed species response matrices using the Bray-Curtis metric (McCune & Grace 2002).

Two data sets were used for analysis. In examination of logged+fire vs fire-only we used same year data from the reference site and the restoration site for the years 1997 (pre-logging), 1999 (post-logging) and 2013 (post-six prescribed fires). The use of same year data controlled for some year effects associated

with climate (White & Walker 1997). We did not have reference site data for sample years after 1999, so all analysis testing for overall treatment effects at the restoration site (1997, 2000, 2005, 2013) were compared to a single sample year at the reference site (2013).

Hypothesis testing on treatment types and reference site were conducted using permutation-based multivariate analysis of variance (PerMANOVA) (Anderson 2001). Because sample sizes were different between logged (n=20), unlogged (n=16) and the reference site (n=11), we used bootstrapping (1000 iterations) to balance the design (Peck 2010). Mean pseudo-F values and mean p-values are reported for comparison (Table 1, Table 2). Pseudo-f, as a measure of signal-to-noise ratio, is used to measure effect-size, (McCune, et al. 1997). We tested the following two null hypotheses in examination of logging effects: 1) there was no difference in species composition in pairwise comparisons of treatment types and the reference site for same-year comparisons for the years 1997, 1999 and 2013, 2) there was no difference in species composition between the restoration site as a whole and the reference site for same-year comparisons of the years 1997, 1999 and 2013. In examination of the changes of the whole restoration site over time, we tested the null hypothesis that there were no differences in species composition between the 2013 reference site and the restoration site for the years 1997, 2000, 2005 and 2013.

We used R Vegan package, function Betadisp to calculate the multivariate homogeneity of group dispersions. Betadisp is analogue function to the PERMDISP2 analysis as described by Marti Anderson (2006). ANOVA was performed to test the null hypothesis that the dispersion of one or more sample years is not different from the others. The average distance to the centroid and p-values for pairwise comparisons of differences in average distance to median were reported for the 1997, 2000, 2005 and 2013 sample years at the restoration site.

Nonmetric multidimensional scaling (NMS), a technique of nonparametric indirect ordination (Kenkel and Orloci 1986) (Minchin 1987) was used to display Abita compositional changes in relation to the reference site. Similar to earlier analyses, we applied Bray-Curtis similarity metrics to the presence-absence species response matrices (McCune & Grace 2002). Abita data from the years 1999, 2000, 2005, and 2013 along with Lake Ramsey 2013 data were used for the ordination. We displayed centroids and convex hulls for each sample year at the restoration site and the reference site along with each individual plot. We also displayed joint plot lines to represent the relationship of the two variables, basal area (BA) and species richness (numsp), to the ordination scores. The lines radiate from the centroid of all the ordination scores. The angle and length of each line indicates the direction and strength of the relationship. The R^2 value for each line is reported. Species correlations with major axes, as measured by R , R^2 and Tau, are reported in Appendix C. The two-dimensional ordination was constructed for 175 species and 155 plots over four sample years at Abita and one year at Lake Ramsey. The 2-dimensional solution explained 85.8% of the variation in the distance matrix, and had a final stress of 17.2 with a p-value of 0.004 using randomized test (Monte Carlo 250 iterations).

Individual Species Measures

We used Indicator Species Analyses to examine individual species responses to the restoration treatments (McCune & Grace 2002). Diagnostic indicator species were those which were significantly higher in constancy and fidelity over a certain sample year. We applied Indicator Species Analysis of Dufrene and Legendre (1997) and Monte Carlo randomization tests as implemented in PC-ORD (McCune & Mefford 2011). Indicator Value (IV) quantifies a species' relative frequency between factor levels tested; high IVs indicate better diagnostic species. We selected species with type I error < 0.01 from Monte Carlo tests, and present lists of indicator species for significant comparisons between sample years. Presence absence data at the 10m^2 scale were used for these analyses.

When testing for individual species responses to the logging, we tested by year for both treatment types, and by treatment across years. We used indicator species analysis to uncover species “responders” and “decreasers” related to treatment type and sample year. We tested logged vs. unlogged in one test for each year 1997 (pre-logging), 1999 (post-logging) and 2013 (after six fires). We also tested for species differences pairwise by year for both treatment types. Species that were indicative of site for pre-treatment were ascribed to site differences, and were not used as indicators for later years. Species that responded in both logged and unlogged for the same year were ascribed to year effect. Only species that were significant responders in the logged sites by year and treatment are reported as “responders” or “decreases” related to logging effects.

Indicator species analysis was also used to examine individual species responses across the restoration site for individual years. The years 1997 (pre-treatment), 2000 (after one fire), 2005 (after two fires) and 2013 (after six fires) at Abita were included in one analysis to identify species which were significantly more abundant and frequent in one sample year when compared to the others. Species reported from this analysis are indicators of a certain phase of the restoration (Table 5).

Results

Part 1: Logging effects

Initial vegetation responses to logging

The abundance of overstory pines predictably decreased dramatically in the Abita logged sites, following the logging in 1997-98. Furthermore there was a concurrent reduction in midstory hardwood abundance in the logged treatment sites, as a direct result of the logging activity. Mean basal (BA) area (woody stems > 10 cm dbh) in the logged+fire plots was drastically reduced in the year following logging. Over the same period, the mean basal area of the fire-only plots increased slightly (Table 6). Basal area was calculated using midpoint values per size class plus actual measurements.

In the year following the Abita logging treatment, there were pronounced compositional shifts in groundcover vegetation compared to the Abita unlogged sites. However, logged site composition did not shift toward reference site conditions in the first post-logging year. The logged sites began less similar in species composition to the reference sites than the unlogged sites to the reference sites (1997 logged vs. 1997 Lake Ramsey $F=8.54$ $P\text{-value}<0.001$, 1997 unlogged vs. 1997 Lake Ramsey $F=6.60$ $P\text{-value}<0.001$) as measured by pseudo- F (signal to noise ratio as measure of effect size) (McCune, et al. 1997) (Table 1). Immediately following the logging, the logged sites became less similar to the reference site (1999 logged vs. 1999 Lake Ramsey $F=9.98$ $p\text{-value} < 0.001$). Following logging, the logged and unlogged sites also became less similar to each other (1997 logged vs. unlogged $F=2.87$ $p=0.017$, 1999 logged vs. unlogged $F=3.51$, $p=0.004$).

Compositional responses to logging at Abita were largely attributable to decreases in certain woody plants and increases in certain grasses and sedges. Following the logging in 1997, there was a measureable increase of certain graminoids detected in the 1999 sampling. Indicator species analysis showed the biggest increasers to be grasses (family *Poaceae*). The perennial grass *Dichanthelium*

scabriusculum (IV 56.4 p-value=0.046), and the annual grass *Panicum verrucosum* (IV 53.5 p-value=0.043) were the only species that reached a significance level of $p < 0.05$ in the immediate post-logging environment of 1999 when compared to the pre-logging environment of 1997.

Table 1. Effect size (pseudo-f) and p-value for pairwise comparisons for similarity of species composition in 10m² presence/absence plots in logged, unlogged and reference site for years 1997, 1999, 2013 at Abita Creek restoration site and Lake Ramsey reference site in Louisiana.

Number of plots per treatment: logged N=20, unlogged N=16, reference N=11

Pairwise comparisons by treatment		Mean pseudo-F	mean p-value ^a
logged vs. unlogged	1997	2.87	0.017
	1999	3.51	0.004
	2013	2.03	0.048
logged vs. reference	1997	8.54	<0.001
	1999	9.98	<0.001
	2013	5.88	<0.001
unlogged vs. reference	1997	6.60	<0.001
	1999	7.21	<0.001
	2013	5.49	<0.001

^a Mean pseudo-F values and p-values calculated from bootstrapped PerMANOVA tests (1000 iterations) using Bray-Curtis distance measure (Anderson 2001, Peck 2010).

Responses to logging over time

By the end of the study, initial differences in ground cover and midstory composition between Abita restoration treatments attenuated following six prescribed fires. Logged and unlogged sites became increasingly similar (1997 logged vs. unlogged $F=2.87$ P-value=0.017, 2013 logged vs. unlogged $F=2.03$ P-value=0.048). Meanwhile, the composition in both treatment sites became more similar to the reference site (Table 1). All species that were indicative of the post-logging environment when compared to the unlogged sites were no longer significant indicators by the end of the study. The annual grass *Panicum verrucosum* was the greatest “responder” to logging in the short-term, but

between 1999 and 2013 was the greatest “decreaser” (IV 62.8 p-value<0.01). By 2013, only 30% of plots contained *P. verrucosum* compared to 80% immediately post logging and it was no longer significantly indicative of logging.

Part 2: Overall treatment effects

Treatment responses compared to reference site over time

Importantly, the ground cover composition of Abita treatment sites became increasingly similar to the Lake Ramsey reference site. Immediately following the first prescribed fire, the restoration site became slightly less similar in species composition to the reference site, as is indicated by the increase in the pseudo-F value. Although PerMANOVA tests show the reference site and restoration site remained significantly different in species composition (P-value<0.001), the restoration site composition became more similar to the reference site over the course of the study, as is indicated by a diminishing pseudo-F values following the reintroduction of fire in 2000 (Table 2). The rate of change, as measured by pseudo-F, was virtually the same from 2000 to 2005 and from 2005 to 2013 at an average rate of 0.24 per year. The trend of Abita composition converging with that of Ramsey is evident in the NMS ordination diagram (Figure 5).

Table 2. Effect size (pseudo-f) for pairwise comparisons for similarity of species composition in 10m² presence/absence plots for Abita (restoration site) and Ramsay (reference site) for year effect 1997 (pre-treatment), 2000 (after first prescribed fire), 2005 (after second prescribed fire), 2013 (after sixth prescribed fire). All p-values are <0.001.

Abita N=36 plots Ramsay N=11 plots

Sample	Years	Mean pseudo-f ^a
97 Abita vs 13 Ramsay		7.775205
00 Abita vs 13 Ramsay		8.073298
05 Abita vs 13 Ramsay		6.878328
13 Abita vs 13 Ramsay		4.950712

^a Mean pseudo-f values and p-values calculated from bootstrapped PerMANOVA tests (1000 iterations) using Bray-Curtis distance measure (Anderson, 2001; Peck, 2010).

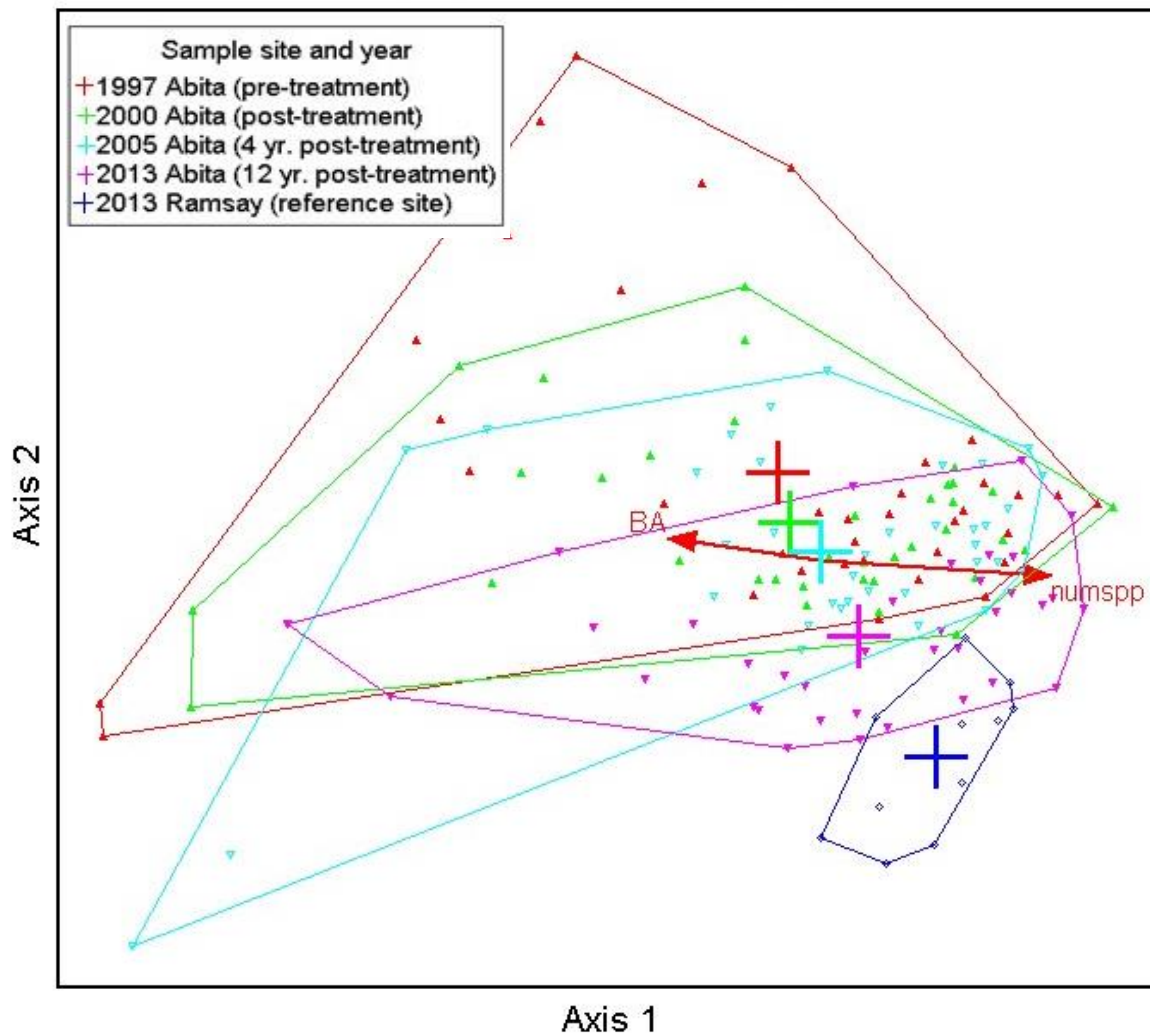


Figure 5. NMS ordination of 10m² plot presence/absence data collected at Abita Creek Flatwoods Preserve restoration site in four sample years, and one year at Lake Ramsay Preserve reference site. Individual plots, are represented by small triangles, centroids for each sample year are represented by crosses, and convex hulls are displayed for each sample year. Joint plot lines represent the relationship of basal area (BA) and species richness (numsp) to the ordination scores. The R^2 values for basal area are 0.301 axis 1 and 0.043 axis 2, and R^2 values for richness are 0.456 axis 1 and 0.032 axis 2. The Abita restoration site becomes increasingly similar to the reference site over time.

In addition to directionality of compositional shifts of treatment sites toward that of the reference site, compositional variance of treatment sites decreased over time, as an indication of compositional convergence toward the reference site condition. Dispersion was tested with pairwise comparisons of year using the Vegan function Betadisper in R. Differences in dispersion were not significant ($p < 0.05$) for any of the pairwise comparisons between Abita sampling years (Table 3). This indicates that changes in pseudo-F are primarily the result of changes in composition, not dispersion. Although the differences in dispersion between Abita sampling years did not reach significant levels, it followed a consistent trend of decreasing over the course of the study. For pre-treatment (1997) to first year post-fire (2000), and each subsequent sample period (2005, 2013), the dispersion, as measured by average distance to the median, diminished each year. Dispersion was significantly lower ($p < 0.05$) for Lake Ramsey 2013 data than each Abita sample year.

Table 3. Dispersion measures by treatment year for comparisons for similarity of species composition in 10m² presence/absence plots. 1997 data are pre-treatment conditions, 2000 are first year post-fire, 2005 are after two fires, 2013 are after six fires. Average distance to the median decreased each sample year at the restoration site, but remained greater than the reference site. Pairwise comparisons of p-value below, show that there were no significant differences ($p < 0.05$) in dispersion detected between sample years at the restoration site. All restoration sample years were significantly different ($p < 0.05$) from the reference site (Ram '13).

Sample Year	1997	2000	2005	2013	Ram '13
Avg. Dist. to median ^a	0.4587	0.4283	0.4138	0.4130	0.3045
	1997	2000	2005	2013	Ram '13
1997		0.434	0.247	0.215	0.006
2000	0.420		0.702	0.669	0.008
2005	0.242	0.682		0.983	0.030
2013	0.192	0.630	0.980		0.006
Ram '13	0.005	0.010	0.026	0.007	

^a Average distance to median is reported for each sample year using R Vegan function Betadisper, to test for homogeneity of variance.

Species richness response

Despite the dramatic change in species composition at the restoration site, there was little overall change in species richness detected. Mean species richness at the 10m² scale varied from the lowest in 1999 at 27.2 species per 10m², to the highest in 2005 at 34.9 species per m² (Table. 4). There were, however, nearly the same average number of species per 10m² in the pre-treatment sampling (32.4 species in 1997) as the most recent (32.2 species in 2013). Overall, there was no detectable trend.

Table 4. Average species richness and standard deviation per 10m² at Abita restoration site. 1997 data are pre-treatment conditions, 2000 are first year post-fire, 2005 are after two fires, 2013 are after six fires.

Year	Avg. no. ssp/10m ²
1997	32.4 +/- 15.9
1998	34.1 +/- 14.5
1999	27.2 +/- 13.3
2000	32.8 +/- 12.4
2005	34.9 +/- 11.6
2013	32.2 +/- 11.2

Changes in the variance of species number in sample plots indicated that the average number of species present per 10m² converged over the course of the study. The variance of species richness, as measured by the standard deviation of the mean number of species per 10m² plot, decreased following the logging and introduction of fire. Between 1997 and 2013, fifteen plots had fewer species, nineteen had more species and two plots had the same number. The standard deviation of mean richness at the restoration site reduced greatly during that time period, down each sample year, from +/-15.9 ssp/10m² in 1997 to +/-11.2 ssp/10m² in 2013.

Individual species response

Throughout the restoration, certain species were indicative of different phases of the restoration (Table 5). When comparing the Abita sample years 1997, 2000, 2005 and 2013 in one test, four species were significantly indicative (p-value <0.01) of the 1997 pre-treatment environment, *Pinus elliottii* (IV 38.2), *Acer rubrum* (IV 22.3), *Eleocharis tuberculosa* (IV 17.4), *Hypericum brachyphyllum* (IV 16.3). The following two species are significantly indicative of the 2000 post-fire sampling, *Panicum verrucosum* (IV 30.9) and *Euthamia leptoccephala* (IV 15.1). Two species were indicative of 2005, *Andropogon virginicus* (IV 23.1) and *Rhynchospora cephalantha* (IV 29.3). The following eight species were of significant indicator value for the 2013 sampling, *Drosera sp.* (IV 60.5), *Polygala ramosa* (IV 52.6), *Rhynchospora compressa* (IV 50.1), *Symphyotrichum dumosum var. dumosum* (IV 28.4), *Helianthus angustifolius* (IV 25.0), *Balduwiana uniflora* (IV 20.3), *Xyris caroliniana* (IV 19.4) and *Scleria hirtella* (IV 13.9).

Table 5.

Indicator species values (IV) associated with sample years at restoration site. 1997 data are pre-treatment conditions, 2000 are first year post-fire, 2005 are after two fires, 2013 are after six fires.

Species	Year	Max IV ^a	P-value ^b
<i>Pinus elliottii</i>	1997	38.2	0.0002
<i>Acer rubrum</i>	1997	22.3	0.0084
<i>Eleocharis tuberculosa</i>	1997	17.4	0.0036
<i>Hypericum brachyphyllum</i>	1997	16.3	0.007
<i>Panicum verrucosum</i>	2000	30.9	0.0006
<i>Euthamia leptoccephala</i>	2000	15.1	0.0044
<i>Rhynchospora cephalantha</i>	2005	29.3	0.001
<i>Andropogon virginicus</i>	2005	23.1	0.0018
<i>Drosera sp.</i>	2013	60.5	0.0002
<i>Polygala ramosa</i>	2013	52.6	0.0002
<i>Rhynchospora compressa</i>	2013	50.1	0.0002
<i>Symphyotrichum dumosum</i>	2013	28.4	0.0076
<i>Helianthus angustifolius</i>	2013	25.0	0.0062
<i>Balduwiana uniflora</i>	2013	20.3	0.0036
<i>Xyris caroliniana</i>	2013	19.4	0.0002
<i>Scleria hirtella</i>	2013	13.9	0.0036

^a Indicator Value (IV) for maximum year is displayed in bold (see Dufrene and Legendre (1997) for details of calculation). Species are displayed by year and IV from highest to lowest.

^b Significant (p-value <0.01) indicator values obtained for four years of sampling at the Abita restoration site with presence/absence data on the 10m² scale. P-values obtained from Monte Carlo test of significance of observed maximum indicator value (4999 permutations).

Basal area response to restoration activities

Predictably, following logging, the basal area in the logged sites was dramatically reduced (Table 6). The basal area dropped from $20.8 \pm 2.3 \text{ m}^2/\text{ha}$ to 2.4 ± 0.8 . The BA in the logged sites decreased with each repeated fire application, however the changes were not statistically significant ($p < 0.05$) for any years post-logging. The unlogged areas maintained a steady BA over time. Following the first fire, the BA dropped in the unlogged areas from $11.1 \pm 3.5 \text{ m}^2/\text{ha}$ (1999) to $7.5 \pm 2.5 \text{ m}^2/\text{ha}$, although the difference was not statistically significant. The BA then rebounded to $9.4 \pm 2.8 \text{ m}^2/\text{ha}$ in 2005 and an almost identical $9.4 \pm 2.4 \text{ m}^2/\text{ha}$ in 2013. In the unlogged areas, fire alone did not significantly ($p < 0.05$) change the BA. The logged sites began with a significantly higher average basal area ($20.8 \pm 2.3 \text{ m}^2/\text{ha}$ logged, $9.4 \pm 3.3 \text{ m}^2/\text{ha}$ unlogged, two-tailed t-test $p\text{-value}=0.02$), and ended with a significantly lower BA ($0.7 \pm 0.5 \text{ m}^2/\text{ha}$ logged, $9.4 \pm 2.4 \text{ m}^2/\text{ha}$ unlogged, two-tailed t-test $p\text{-value}=0.003$).

Table 6. Basal area measured in m^2 per ha for stems over 10 cm dbh shown with standard error. Logging was conducted in 1998, the first fire was implemented in 2000 before sampling and second fire before 2005 sampling. Six total fires were conducted between the beginning of the study and 2013.

Unlogged $N=16 \times 100\text{m}^2$ plots, logged $N=20 \times 100\text{m}^2$ plots

Year	Logged	Unlogged	p-value ^a
1997	20.8 ± 2.3	9.4 ± 3.3	0.012
1999	2.4 ± 0.8	11.1 ± 3.5	0.025
2000	1.7 ± 0.9	7.5 ± 2.5	0.039
2005	0.8 ± 0.7	9.4 ± 2.8	0.010
2013	0.7 ± 0.5	9.4 ± 2.4	0.003

^a P-values are reported for two-tailed student's t-test comparing logged and unlogged for the same years.

Discussion

This study demonstrates the capacity to affect recovery of native ground cover vegetation in a fire-excluded wet pine savanna community through restoration of forest structure and reintroduction of native fire regime. It is possible to restore the plant community using prescribed fire and logging, where needed, in areas that have not experienced extensive soil disturbance. It also suggests that many herbaceous species of southern pine flatwoods can endure periods of fire exclusion of 20 or more years, and rebound with the reintroduction of fire into the system.

The use of Lake Ramsey as a contemporary reference site provided a target community by which to measure progress and success of the Abita restoration. A contemporary reference site provides a desired end-state that accounts for current environmental conditions. So long as a contemporary reference site is near in proximity, shares similar underlying site characteristics, and is sampled at roughly the same time, it can account for many unknown environmental factors such as climate and historic effects (White & Walker 1997). Many restoration studies measure only changes to the restoration site, and fail to compare them to a proximate reference site. Lake Ramsey and Abita are close in proximity and are climatically, edaphically, and topographically similar, thus fulfilling the requirements of a contemporary reference site. The use of a reference site provided a context for the study of the Abita restoration project.

During the course of the restoration study, fire was the primary driving force behind the changes in the plant community. Logging caused some initial changes in the vegetative community, but over time, logging effects were overwhelmed by the fire effects. Others studies of longleaf restoration have similarly found fire to be the dominant factor for increasing herbaceous groundcover densities when using both overstory reduction and fire (Provencher 2001). The disturbance of the logging and the initial fire caused changes in the vegetative community, but the initial changes did not immediately bring the

restoration site to more closely resemble the composition of the reference site. Other studies have also found that the initial prescribed fire into long-unburned pine forests did not immediately impact the diversity of the herbaceous layer (Elliott & Vose 2005, Abrahamson & Abrahamson 1996). It was only after subsequent fires at our restoration site that it made significant strides toward the reference condition.

The effects of the logging, while secondary to the effects of the fire, appear to have accelerated restoration. Logged sites began less similar to the reference site than the unlogged, but ended up approximately equal in similarity to the reference site. Species richness began lower in logged areas than unlogged, but ended higher. The inverse relationship between overstory cover and herbaceous productivity has been documented in other studies (Jameson 1967, Grelen & Enghardt 1973). Increasing the amount of light that reaches the ground and reducing the amount of woody biomass can accelerate the restoration of groundcover (Harrington & Edwards 1999). Reduction of the overstory increases light availability, reduces needle cast, and stimulates the groundcover, thus improving understory performance (Harrington 2003, McGuire 2001). Logging not only reduced the overstory cover, but also greatly reduced the woody midstory. As the logging skidders drove through the logging zones, they cut whatever brush was in their paths. This mid-story reduction further contributed to the availability of light to the emergent groundcover (Simmons 2007). Logging expedited the process of restoring structure and light availability, but the introduction of fire moved both logged and unlogged areas closer to the composition of the reference site.

Concerns at the outset of the project that logging would produce a novel succession of weedy or invasive species, proved unfounded. Soil disturbance has been known in some cases to be precursor to non-native invasion (Mattingly 2013). In other studies, restoration of pinelands via mechanical methods prompted an initial insurgence of native ruderal species (Greenberg *et al.* 1995, Harrington & Edwards

1999), although the short duration of these studies precluded detection of eventual declines. In our study, some ruderal species, such as *Panicum verrucosum*, flushed-out post logging, but greatly diminished following subsequent prescribed fires. Invasive, non-native species, for the most part, did not appear during the study period. The species that were significantly more abundant the final sampling year were primarily a mix of annual and perennial forbs and perennial graminoids. However, following several fires, the restoration treatments favored recovery of native plant species characteristic of Coastal Plain pine savannas (Smith 1996, unpublished report).

The introduction of fire initiated a succession of species that tended toward herbaceous forbs and perennial grasses. Many grass (plant family *Poaceae*) and sedge (family *Cyperaceae*) species increased in abundance and frequency. Species responses, however, varied among those that increased in the years following the introduction of fire. Some, such as *Andropogon virginicus* and *Rhynchospora cephalantha* peaked and then later declined. Others, such as the annual forbs *Drosera sp.* and *Polygala ramosa* were sparsely present in the first five years after the introduction of fire, but exploded in population by the final sampling year. This may indicate that recovery is ongoing, as there are many species still present at very low levels when compared to the reference site.

The variety of responses may indicate different natural history strategies in response to long periods of fire-suppression. Given the lack of past soil disturbance at these sites, it is likely that plant populations persisted at the restoration site during the decades of fire exclusion, either in the seed bank or in dormant vegetative states. These dormant life forms may not have been detected in our pre-treatment sampling, and the initial flush of sedges and grasses suggests rapid growth in response to increased light, resource availability and space. Some plants, however, may have been extirpated from portions of the study area and took multiple generations to recolonize. A large number of forbs, especially some annual forbs, recovered later than many other species. Numerous species typical of longleaf forests are

known have seeds presence in the seed bank (Sharma 2012), but some tend to be absent in fire-deprived or disturbed sites (Cohen *et al.* 2004). Frequent ground-fires facilitate the recovery of many of the plant species of the longleaf flatwoods by removing competition, but also stimulating flowering (Platt *et al.* 1988). Our study supports the view that, for the most part, the plants typical to the longleaf savanna have adopted strategies to overcome extended periods of fire-exclusion.

Despite a dramatic shift in species composition, average species richness remained relatively constant over the years in the restoration and reference sites. The repeated application of fire had a homogenizing effect on the richness of the plant communities. The plots that began with the highest species richness decreased over time, while the plots with the lowest richness gained species. Woody species declined and herbaceous species expanded, with the overall effect on richness being negligible. In some cases, species richness has been used as an indication of restoration success or as a measure of response to management actions (Gilliam 1986, Bremer & Farley 2010, Proulx & Mazumder 1998). In this study, however, richness was not a reliable measure of restoration success. Species composition shifted dramatically in the direction of the reference site, but the richness remained generally unchanged. It is possible that richness may have changed at larger or smaller scales, but at the 10m² scale richness was largely unchanged. This study demonstrates the importance of measuring species composition and relating it to a reference site when evaluating a restoration project.

The ground cover at Abita ultimately became quite similar to the Lake Ramsey reference site. By the end of the study, numerous plots were compositionally indistinguishable from Lake Ramsey. Other portions of the Abita restoration site remained quite different from the reference condition, however even the plots that were least similar to the reference site became more similar over the course of the study. Without annual sampling, it is not possible to say with certainty whether the rate of change has been steady or fluctuating. The average annual rate of change, however, has been remarkably constant

between the three sampling periods after the first prescribed fire. This seems to indicate that the recovery of groundcover at Abita is still underway thirteen years after the reintroduction of fire. There remained a gap between the composition at Abita and Lake Ramsey at the end of the study. While it is possible that a gap could persist between the two sites, our study suggests that the Abita groundcover will likely continue to become more similar to the reference site.

In conclusion, this study indicates that restoration of the longleaf pine savanna plant community is possible in sites that have undergone 2-3 decades of fire suppression and have not undergone extensive soil disturbances. This study corroborates others that have shown groundcover recovery is possible following woody biomass reduction via mechanical means and fire. The process of recovery does not necessarily affect species richness at all scales, as it is primarily succession driven. Species that are suppressed during fire excluded periods continue to repopulate and establish for many years after the reintroduction of fire. The results of this restoration suggest that fire-deprived southeastern pine flatwoods can be restored without extensive intervention.

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Appendix A. Prescribed fire weather and behavior

T = ambient temperature, RH = relative humidity, WS = average wind speed, maximum sustained wind speed in parentheses, L+B = logged+burned treatment, B = burned only treatment, FM = fuel model, FL = average flame length of heading fires, maximum flame length in parentheses. Basal area levels were combined because their fuel models and average flame lengths did not differ.

Burn Date	Max T (C)	Min RH	WS (kph)	Treatment	# Plots	FM	1 hr. % moist.	FL (m)
11/15/1999	23	37	3.7 (12.7)	L+B	1	11/2	7	1.5 (4.0)
				B	2	7	9	1.0 (2.0)
05/02/2000	26	52	5.3 (11.7)	L+B	2	11/2	7	1.5 (4.0)
				B	2	7	10	1.0 (2.0)
05/03/2000	27	60	7.3 (12.7)	L+B	2	11/2	8	2.5 (4.0)
04/23/2002	16	31	3.8 (10.4)	L+B	2	11/2	6	1.5 (3.5)
06/02/2002	33	45	4.0 (10.4)	L+B	2	11/2	7	1.5 (3.5)
				B	2	7/2	10	1.5 (2.5)
03/11/2003	22	48	2.3 (8.4)	L+B	1	11/2	8	1.0 (2.5)
				B	2	7/2	10	1.0 (2.5)
3/7/2004	26	31	5 (16)	L+B	1	3	8	2.8 (5.5)
				B	2	3	8	2.8 (5.5)
5/22/2004	30	53	5 (19)	L+B	2	3	7	2.9 (5.4)
4/27/2005	26	31	3 (14)	L+B	2	3	8	2.1 (6.1)
				B	2	3	8	2.1 (6.1)

5/2/2007	29	47	5 (19)	L+B	3	3	7	2.9 (6.4)
				B	2	3	7	2.9 (6.4)
6/6/2007	32	51	3 (26)	L+B	2	3	7	2.2 (7.7)
				B	2	3	7	2.2 (7.7)
4/7/2009	17	25	8 (21)	L+B	3	3	7	3.9 (6.8)
				B	4	3	7	3.9 (6.8)
4/9/2009	24	57	13 (37)	L+B	2	3	9	4.7 (8.8)
6/19/2012	31	53	8 (23)	L+B	5	3	7	3.9 (7.1)
				B	4	3	7	3.9 (7.1)

Appendix B. Relative species frequency chart

Table of relative frequency in group, for each species for all sample years.

The percentage of plots in a given group where given species is present is reported in the table.

	Species code	Avg value	Max value	Grp ID:	11	12	13	14	15	16	1	2	3	4	5	6
					Site/Year											
					No. Plots											
			Max Grp													
ACERU	31	58	1	36	18	0	27	0	36	58	50	53	39	36	19	
AGASP	13	82	16	9	0	27	27	0	82	0	0	0	0	6	0	
AGRPE	10	31	4	0	0	0	0	0	0	22	25	17	31	17	8	
ALESP	11	27	14	18	9	9	27	9	9	11	11	3	8	14	6	
ANDCA	30	45	13	0	36	45	45	36	18	17	25	25	39	36	31	
ANDGL	5	17	5	0	0	0	0	0	0	8	6	6	14	17	6	
ANDGY	8	27	12	0	27	18	18	27	0	3	0	0	0	0	0	
ANDMO	59	73	14	55	45	55	73	55	64	69	53	53	53	67	72	
ANDPE	39	100	13	27	27	100	82	82	36	11	14	19	28	31	6	
ANDVI	41	82	11	82	73	55	55	27	73	8	17	6	17	50	33	
ANTRU	65	82	11	82	82	82	82	82	64	47	67	53	64	56	19	
ARIPA	24	47	5	9	0	9	27	9	9	42	39	39	28	47	28	
ARIVI	55	100	11	100	36	73	82	73	82	31	19	31	36	56	42	
ASCLO	6	27	11	27	27	0	9	0	0	0	0	0	0	0	3	

ASTAD	14	36	11	36	9	27	27	27	36	0	0	0	0	3	6
ASTDU	70	91	16	73	64	82	73	73	91	53	58	47	58	78	89
BALUN	12	44	6	0	0	0	0	0	9	25	28	14	6	22	44
BARPA	10	27	14	18	18	18	27	0	9	14	0	0	0	6	6
BIDMI	22	50	1	9	9	9	9	9	0	50	39	44	28	33	28
BIGCA	2	11	2	0	0	0	0	0	0	6	11	3	3	0	3
BIGNU	43	91	16	64	73	64	64	64	91	8	8	6	22	28	31
BOLSP	6	27	11	27	27	9	9	0	0	0	0	0	0	0	0
BURSP	9	55	16	18	27	0	0	0	55	0	3	0	0	0	11
CACOV	13	33	1	0	0	0	0	9	27	33	22	19	14	22	3
CALAM	0	3	4	0	0	0	0	0	0	0	0	0	3	3	0
CARGL	32	78	4	0	0	0	0	0	9	58	72	53	78	61	53
CARPS	29	55	11	55	45	45	27	55	36	6	28	6	25	11	8
CENER	37	61	1	36	18	36	36	27	27	61	58	47	36	33	31
CHALA	0	3	1	0	0	0	0	0	0	3	3	0	0	0	0
CHAOR	2	11	1	0	0	0	0	0	0	11	6	3	0	3	0
CHATO	35	64	12	36	64	55	64	64	64	14	11	6	11	11	22
CHIVI	2	6	6	0	0	0	0	0	0	3	3	3	3	3	6
CIRLE	5	18	11	18	18	9	9	9	0	0	0	0	0	0	0
CLEAL	1	3	1	0	0	0	0	0	0	3	3	3	3	0	0
COERU	13	36	4	0	9	9	9	9	9	17	14	6	36	19	14
COETE	8	25	4	0	0	0	0	18	9	6	19	6	25	11	6
CORLI	58	73	11	73	64	55	73	64	64	36	47	44	50	58	69
CRASP	0	3	4	0	0	0	0	0	0	0	0	0	3	3	0
CTEAR	75	100	11	100	100	100	100	100	100	44	53	47	56	44	61
CYRRA	33	69	2	9	9	9	9	9	9	61	69	53	53	53	53
DESLI	2	9	12	0	9	9	0	0	9	0	0	0	0	0	0
DESSP	2	9	11	9	0	0	9	0	0	0	0	0	0	0	0
DICLA	15	27	11	27	27	18	18	27	18	3	6	3	8	8	11
DIOTE	4	11	4	0	0	0	9	0	0	0	0	0	11	11	11
DIOVI	13	19	4	18	9	18	9	18	18	8	6	8	19	11	11
DROBR	41	100	16	64	73	73	45	0	100	17	17	19	6	0	78

ELESP	2	9	13	0	0	9	9	0	0	0	0	0	0	0	0
ELETU	12	28	1	9	18	18	18	0	0	28	25	14	11	3	3
ERARE	26	55	12	27	55	45	18	18	36	22	17	11	25	22	11
ERICO	1	3	1	0	0	0	0	0	0	3	0	3	0	3	0
ERIDE	46	73	16	36	45	45	45	45	73	31	50	25	47	61	50
ERIGI	4	11	1	0	0	0	0	0	0	11	8	3	11	11	6
ERIVE	11	28	2	9	9	0	9	0	9	3	28	6	28	28	0
ERYIN	2	9	11	9	0	0	0	0	0	3	0	3	0	3	3
ERYYU	3	9	11	9	9	9	9	0	0	0	0	0	0	0	0
EUPLE	74	100	11	100	82	91	91	100	91	58	61	33	47	67	67
EUPRO	8	27	16	9	9	9	18	18	27	3	0	0	0	0	3
EUPSE	3	14	6	0	0	0	0	0	9	0	0	3	6	8	14
EUTLE	2	19	4	0	0	0	0	0	0	3	0	0	19	0	3
EUTTE	18	36	5	9	18	0	0	0	27	19	22	19	22	36	36
FUIBR	26	45	13	36	36	45	45	36	18	33	14	8	6	17	19
GAYMO	18	27	16	18	18	9	9	9	27	25	22	19	22	19	22
GELRA	25	61	1	0	0	0	0	0	0	61	50	47	50	50	44
GRAPI	7	18	16	0	0	0	9	0	18	11	3	8	11	8	14
GYMBR	18	55	12	36	55	36	45	27	0	6	3	0	0	0	8
HELAN	42	67	6	45	45	36	45	45	45	36	33	25	36	39	67
HELHE	49	82	12	73	82	73	55	55	45	31	44	33	42	47	6
HELRA	5	9	11	9	9	9	9	9	9	0	0	0	0	0	0
HIBAC	3	8	2	0	0	0	0	0	0	3	8	3	8	8	8
HYPBR	8	28	1	0	0	0	0	0	0	28	25	22	3	14	3
HYPCL	2	8	1	0	0	0	0	0	0	8	6	3	3	3	3
HYPHI	5	18	12	0	18	9	9	0	0	8	8	0	3	0	0
HYPHY	4	14	2	0	0	0	0	9	0	8	14	8	0	3	0
HYPSP	2	9	12	0	9	0	9	0	0	0	0	0	0	0	0
HYPST	27	55	16	27	18	27	18	9	55	44	22	22	19	36	28
ILECO	14	33	1	0	0	0	0	0	0	33	31	31	25	28	19
ILEGL	53	82	16	73	73	73	73	64	82	36	42	19	31	42	28
ILEMY	2	6	1	0	0	0	0	0	0	6	6	0	3	6	3

ILEVO	15	31	1	0	0	9	0	9	0	31	31	31	25	31	11
ITEVI	0	3	1	0	0	0	0	0	0	3	3	0	0	0	0
LACCA	1	9	15	0	0	0	0	9	0	3	0	0	3	0	3
LECPU	3	9	13	0	0	9	9	9	9	0	0	0	0	0	0
LIAPY	21	73	12	64	73	45	18	36	18	0	0	0	0	0	0
LIASP	21	58	2	0	0	0	0	0	27	44	58	33	53	25	11
LINME	26	45	16	18	18	27	27	36	45	17	25	8	14	39	39
LIQST	0	3	5	0	0	0	0	0	0	0	0	0	0	3	3
LOBBR	56	91	16	45	82	64	82	64	91	50	22	19	47	50	53
LOBFL	4	11	1	0	0	0	0	0	0	11	11	3	11	3	8
LOPAU	3	9	14	0	0	0	9	0	0	3	3	3	3	6	6
LUDHI	12	27	11	27	9	9	9	0	18	17	14	8	6	17	8
LYCAL	26	47	4	0	0	9	9	18	27	39	42	39	47	44	36
LYCVI	6	19	1	0	0	0	0	0	0	19	14	17	14	11	0
LYGJA	0	3	2	0	0	0	0	0	0	0	3	0	3	0	0
LYOLU	5	14	1	0	0	0	0	0	0	14	6	11	6	11	8
MAGVI	14	33	2	0	0	0	0	0	0	31	33	22	28	28	22
MECAC	1	9	13	0	0	9	0	0	0	0	0	0	0	0	0
MITSE	4	45	16	0	0	0	0	0	45	0	0	0	0	0	6
MUHEX	60	91	12	82	91	91	82	91	82	25	36	31	42	39	31
MYRCE	53	82	11	82	64	82	73	64	55	47	50	28	39	36	19
MYRHE	2	8	6	0	0	0	0	0	0	3	6	6	0	3	8
NYSBI	22	39	1	18	18	0	18	9	9	39	39	22	33	33	25
OXYFI	13	27	16	9	0	18	0	0	27	17	25	14	8	22	19
PANAC	1	9	14	0	0	0	9	0	0	0	0	0	0	0	0
PANAN	29	73	12	64	73	55	55	45	55	3	0	0	0	6	0
PANCO	21	44	4	0	0	9	0	0	27	31	31	28	44	44	42
PANEN	31	73	11	73	27	55	55	64	36	0	0	6	22	6	28
PANET	5	45	12	0	45	0	0	0	0	0	0	0	3	8	3
PANLE	71	100	13	36	18	100	91	73	64	67	72	72	81	81	94
PANLO	6	27	14	9	0	9	27	18	0	0	0	0	0	0	6
PANRI	62	86	5	27	64	64	55	55	45	67	81	78	72	86	47

PANSC	49	89	2	0	9	27	27	27	18	72	89	86	89	83	56
PANSO	0	6	2	0	0	0	0	0	0	0	6	0	0	0	0
PANSP	4	36	11	36	0	0	9	0	0	3	0	0	0	0	6
PANST	5	9	11	9	9	9	9	9	0	3	3	3	0	6	3
PANTE	6	18	16	0	0	0	0	0	18	3	14	6	14	8	8
PANVE	35	83	4	9	18	18	18	9	9	39	58	58	83	69	33
PANVI	53	73	14	36	36	55	73	55	73	56	56	47	56	50	47
PASFL	12	27	11	27	27	27	9	9	0	6	11	6	11	8	0
PASPR	36	55	15	27	45	45	27	55	27	22	39	33	39	47	25
PASSE	2	9	13	0	0	9	0	9	0	0	0	0	0	3	0
PERBO	13	33	1	0	0	0	0	0	0	33	25	19	28	33	22
PINEL	19	75	1	0	0	0	0	0	0	75	44	36	22	39	11
PINPA	1	9	16	0	0	0	0	0	9	0	0	0	0	0	8
PINTA	4	18	12	9	18	9	9	0	0	0	0	0	0	0	0
PITGR	18	45	15	18	27	36	27	45	45	6	3	0	3	3	0
PLURO	3	17	5	0	0	0	0	0	0	0	6	3	3	17	8
POLCR	3	27	12	0	27	0	0	0	0	0	0	0	0	0	3
POLHO	2	18	16	0	0	0	0	0	18	0	0	0	0	0	0
POLLU	0	6	6	0	0	0	0	0	0	0	0	0	0	0	6
POLRA	24	82	16	18	18	27	45	0	82	6	3	0	0	17	69
PROPE	4	17	2	0	0	0	0	0	0	11	17	8	3	11	3
PRUSE	1	3	2	0	0	0	0	0	0	0	3	3	0	0	3
PTEAQ	1	3	1	0	0	0	0	0	0	3	3	0	3	3	3
PYRAR	14	28	4	9	9	0	0	0	9	17	25	22	28	25	28
QUEFA	1	3	1	0	0	0	0	0	0	3	0	3	3	3	3
QUELA	4	11	2	0	0	0	0	0	0	8	11	8	8	8	0
QUENI	4	14	6	0	0	0	0	0	0	6	8	6	8	3	14
RHEAL	71	100	11	100	82	100	100	100	82	58	53	39	47	50	44
RHELU	17	45	16	36	36	18	36	18	45	0	3	0	3	3	0
RHEPE	17	39	6	36	0	0	0	0	36	22	17	11	14	25	39
RHUCO	2	9	16	0	0	0	0	0	9	0	0	0	6	6	3
RHUVÉ	1	6	4	0	0	0	0	0	0	3	3	0	6	6	0

RHYBR	0	6	6	0	0	0	0	0	0	0	0	0	0	0	6
RHYCA	0	3	5	0	0	0	0	0	0	0	0	0	0	3	3
RHYCE	26	75	5	0	0	0	0	0	0	47	61	58	42	75	28
RHYCH	17	45	16	0	0	18	18	9	45	6	31	14	17	14	31
RHYCN	4	11	1	0	0	0	0	0	0	11	11	3	6	8	6
RHYCO	16	53	6	27	0	27	45	0	36	3	0	0	0	0	53
RHYDE	5	27	14	9	18	0	27	9	0	0	0	0	0	0	0
RHYEL	47	73	15	55	64	45	27	73	55	33	33	50	42	44	42
RHYFI	7	17	2	0	9	9	9	9	0	8	17	8	11	0	3
RHYGL	3	9	11	9	0	0	9	0	0	8	0	3	0	3	0
RHYGR	68	89	5	45	55	64	55	55	82	64	78	67	75	89	89
RHYIN	12	27	16	9	9	18	9	9	27	8	14	11	6	6	14
RHYOL	21	36	16	18	18	18	18	18	36	25	17	19	19	14	33
RHYPL	48	100	11	100	64	91	91	64	73	11	14	14	14	25	19
RHYPU	16	55	14	0	36	45	55	45	0	0	3	3	6	3	0
RHYRA	16	64	13	9	18	64	36	45	0	3	8	6	6	0	3
RHYSP	11	36	12	18	36	9	9	36	0	6	6	3	3	8	3
RUBUS	30	58	4	9	9	18	9	9	9	56	56	44	58	50	36
RUENO	19	55	11	55	45	27	18	18	9	14	14	3	8	3	8
SABSP	9	27	14	9	9	9	27	18	18	0	3	6	3	3	3
SAPSI	2	18	12	0	18	0	9	0	0	0	0	0	0	0	0
SARAL	42	53	2	36	36	36	36	36	36	44	53	44	53	53	42
SARPS	5	9	11	9	9	9	9	9	9	0	0	0	0	0	0
SCHSC	77	100	13	73	73	100	91	100	82	58	64	56	67	81	81
SCHTE	25	73	16	45	36	45	45	55	73	0	0	0	0	0	6
SCLCI	7	73	11	73	0	0	9	0	0	0	0	0	0	0	3
SCLGE	1	3	2	0	0	0	0	0	0	0	3	3	0	3	0
SCLHI	15	45	15	36	27	9	36	45	9	0	0	0	0	0	14
SCLMU	64	82	12	73	82	73	73	64	73	50	47	44	67	53	67
SCLPA	12	28	4	0	0	9	0	0	0	25	25	17	28	19	25
SCLPP	36	91	16	27	73	82	82	73	91	0	3	0	0	0	3
SCLTR	4	9	16	0	0	0	0	0	9	8	6	6	3	6	6

SCUIN	15	39	6	0	0	9	9	0	18	22	31	17	17	19	39
SISAL	1	3	4	0	0	0	0	0	0	0	0	0	3	3	3
SMIGL	16	39	4	0	0	0	0	0	18	31	36	36	39	28	0
SMILA	38	75	2	9	9	9	9	9	9	69	75	67	69	58	67
SMIRO	1	6	3	0	0	0	0	0	0	3	3	6	6	0	0
SOLOD	3	9	11	9	0	0	9	9	9	0	0	0	0	0	0
SPHAG	12	36	12	27	36	0	0	0	0	19	17	28	3	8	3
STOLA	3	9	16	0	0	0	0	0	9	6	6	6	8	6	0
STYAM	8	22	4	0	0	0	0	0	0	17	19	11	22	14	8
SYMTI	1	6	2	0	0	0	0	0	0	3	6	3	3	0	3
TEPON	9	27	11	27	18	9	18	27	9	3	0	0	0	0	0
TOFRA	2	8	5	0	0	0	0	0	0	6	0	0	3	8	8
TOXRA	10	31	2	0	0	0	0	0	0	28	31	28	28	8	3
TRADI	1	6	1	0	0	0	0	0	0	6	6	3	0	0	0
TRIAM	36	82	12	73	82	64	45	36	64	11	14	6	17	19	0
UTRIC	3	18	12	0	18	9	9	0	0	0	0	0	0	0	0
VACAR	0	3	4	0	0	0	0	0	0	0	0	0	3	0	3
VACEL	4	9	11	9	9	9	9	0	9	0	0	0	0	0	0
VIBDE	1	3	1	0	0	0	0	0	0	3	3	0	3	0	3
VIBNU	1	3	1	0	0	0	0	0	0	3	3	0	3	0	0
VIOPR	9	22	4	0	0	0	0	0	0	17	19	19	22	17	11
VITRO	3	8	2	0	0	0	0	0	0	3	8	6	6	8	6
WOOAR	1	3	1	0	0	0	0	0	0	3	0	3	0	3	3
XYRAM	24	64	13	45	55	64	45	36	18	3	3	0	3	8	8
XYRBA	1	6	2	0	0	0	0	0	0	3	6	0	0	0	0
XYRCA	24	64	16	45	45	45	36	27	64	0	0	0	0	0	19
XYRDI	1	3	2	0	0	0	0	0	0	0	3	3	3	3	0
XYRLO	22	64	16	0	18	18	18	27	64	25	14	6	28	25	22
XYRSP	11	45	11	45	18	18	27	18	0	3	0	0	0	0	3
XYRST	2	27	12	0	27	0	0	0	0	0	0	0	0	0	0
ZIGSP	0	6	5	0	0	0	0	0	0	0	0	0	0	6	0

	Averages	17	37	18	18	19	19	16	20	16	16	13	16	17	16
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Appendix C. Pearson and Kendall correlations with major axes of NMS ordination (Figure1.)

R² values over 0.2 are displayed in bold.

Sp. Code	Axis 1			Axis 2		
	R	R ²	Tau	R	R ²	Tau
ACERU	0.005	0	-0.052	0.188	0.035	0.206
AGASP	0.116	0.013	0.094	-0.287	0.082	-0.217
AGRPE	0.279	0.078	0.248	0.095	0.009	0.151
ALESP	0.113	0.013	0.052	-0.156	0.024	-0.174
ANDCA	0.293	0.086	0.231	-0.012	0	0.039
ANDGL	-0.029	0.001	-0.113	0.102	0.01	0.125
ANDMO	0.699	0.489	0.592	-0.109	0.012	-0.047
ANDPE	0.168	0.028	0.092	-0.067	0.004	-0.055
ANDVI	-0.059	0.004	-0.167	-0.214	0.046	-0.174
ANTRU	0.405	0.164	0.296	0.099	0.01	0.16
ARIPA	0.488	0.238	0.483	0.117	0.014	0.179
ARIVI	0.153	0.023	-0.018	-0.253	0.064	-0.216
ASTAD	0.077	0.006	0.032	-0.323	0.104	-0.242
ASTDU	0.556	0.309	0.359	-0.379	0.143	-0.291
BALUN	0.245	0.06	0.173	-0.108	0.012	-0.083
BARPA	0.144	0.021	0.128	-0.03	0.001	-0.036
BIDMI	0.361	0.131	0.323	0.157	0.025	0.241
BIGCA	-0.086	0.007	-0.093	0.087	0.008	0.073
BIGNU	0.287	0.082	0.218	-0.329	0.108	-0.302
BURSP	0.161	0.026	0.15	-0.201	0.04	-0.187

CACOV	0.261	0.068	0.223	-0.002	0	0.076
CALAM	-0.045	0.002	-0.089	0.172	0.03	0.139
CARGL	0.232	0.054	0.072	0.271	0.073	0.27
CARPS	0.15	0.023	0.078	-0.214	0.046	-0.204
CENER	0.454	0.206	0.395	0.054	0.003	0.125
CHAOR	-0.168	0.028	-0.134	0.178	0.032	0.182
CHATO	0.227	0.051	0.201	-0.222	0.049	-0.183
CHIVI	-0.168	0.028	-0.17	0.094	0.009	0.052
CLEAL	0.065	0.004	0.049	0.083	0.007	0.111
COERU	0.278	0.077	0.248	0.108	0.012	0.135
COETE	0.171	0.029	0.139	0.059	0.004	0.086
CORLI	0.649	0.422	0.591	-0.143	0.02	-0.084
CRASP	-0.193	0.037	-0.136	0.085	0.007	0.111
CTEAR	0.497	0.247	0.372	-0.335	0.112	-0.312
CYRRA	-0.186	0.035	-0.312	0.301	0.091	0.201
DICLA	0.243	0.059	0.263	0.022	0	0.049
DIOTE	-0.169	0.029	-0.218	0.036	0.001	0.063
DIOVI	-0.354	0.126	-0.3	0.039	0.002	0.032
DROBR	0.324	0.105	0.261	-0.447	0.199	-0.402
ELETU	0.148	0.022	0.1	0.213	0.046	0.257
ERARE	0.31	0.096	0.278	-0.135	0.018	-0.109
ERICO	0.062	0.004	0.043	0.084	0.007	0.112
ERIDE	0.586	0.343	0.542	-0.11	0.012	-0.045
ERIGI	0.033	0.001	0.037	0.16	0.026	0.183
ERIVE	0.192	0.037	0.146	0.008	0	0.026
ERYIN	0.045	0.002	0.014	-0.031	0.001	-0.04

EUPLE	0.468	0.219	0.305	-0.23	0.053	-0.182
EUPRO	-0.071	0.005	-0.086	-0.211	0.045	-0.142
EUPSE	-0.073	0.005	-0.116	-0.044	0.002	-0.038
EUTLE	0.037	0.001	-0.009	0.079	0.006	0.068
EUTTE	0.013	0	-0.165	-0.229	0.053	-0.235
FUIBR	0.315	0.099	0.308	0.088	0.008	0.108
GAYMO	-0.197	0.039	-0.308	-0.138	0.019	-0.094
GELRA	0.526	0.276	0.489	0.214	0.046	0.267
GRAPI	0.081	0.007	0.009	-0.035	0.001	-0.033
GYMBR	-0.076	0.006	-0.114	-0.057	0.003	-0.041
HELAN	0.296	0.087	0.167	-0.296	0.088	-0.285
HELHE	0.261	0.068	0.151	-0.127	0.016	-0.086
HIBAC	-0.145	0.021	-0.211	0.003	0	0.019
HYPBR	0.219	0.048	0.204	0.064	0.004	0.084
HYPCL	0.084	0.007	0.072	0.01	0	0.031
HYPHI	0.071	0.005	0.047	0.042	0.002	0.065
HYPHY	-0.081	0.006	-0.086	0.15	0.022	0.141
HYPST	0.117	0.014	-0.035	-0.175	0.031	-0.161
ILECO	-0.378	0.143	-0.281	-0.171	0.029	-0.125
ILEGL	-0.06	0.004	-0.175	-0.206	0.042	-0.159
ILEMY	0.118	0.014	0.109	-0.045	0.002	-0.057
ILEVO	-0.169	0.028	-0.301	0.129	0.017	0.071
LACCA	0.024	0.001	-0.012	0.147	0.022	0.147
LIAPY	0.099	0.01	0.119	-0.122	0.015	-0.12
LIASP	0.36	0.13	0.296	-0.025	0.001	-0.008
LINME	0.327	0.107	0.285	-0.22	0.048	-0.212

LIQST	-0.183	0.034	-0.133	0.052	0.003	0.072
LOBBR	0.484	0.234	0.373	-0.202	0.041	-0.129
LOBFL	0.241	0.058	0.264	0.097	0.009	0.144
LOPAU	0.16	0.026	0.18	0.008	0	0.017
LUDHI	0.126	0.016	0.079	0.103	0.011	0.153
LYCAL	0.426	0.181	0.356	0.069	0.005	0.101
LYCVI	0.151	0.023	0.103	0.115	0.013	0.127
LYOLU	-0.172	0.03	-0.248	0.237	0.056	0.118
MAGVI	-0.022	0	-0.1	0.135	0.018	0.12
MITSE	0.065	0.004	0.036	-0.263	0.069	-0.24
MUHEX	0.316	0.1	0.211	-0.341	0.116	-0.323
MYRCE	0.093	0.009	-0.016	-0.067	0.004	-0.055
MYRHE	0.032	0.001	-0.011	-0.102	0.01	-0.119
NYSBI	0.093	0.009	0.044	0.338	0.115	0.307
OXYFI	0.332	0.11	0.343	0.095	0.009	0.144
PANAN	0.101	0.01	0.056	-0.311	0.097	-0.219
PANCO	-0.03	0.001	-0.251	-0.163	0.027	-0.175
PANEN	-0.043	0.002	-0.126	-0.348	0.121	-0.326
PANET	-0.112	0.012	-0.139	0.046	0.002	0.054
PANLE	0.63	0.397	0.413	-0.153	0.023	-0.087
PANLO	-0.118	0.014	-0.116	-0.047	0.002	-0.041
PANRI	0.564	0.318	0.414	0.161	0.026	0.2
PANSC	0.494	0.244	0.329	0.229	0.053	0.274
PANSP	0.041	0.002	0.049	-0.075	0.006	-0.07
PANST	-0.041	0.002	-0.104	-0.073	0.005	-0.089
PANTE	0.235	0.055	0.26	-0.047	0.002	-0.024

PANVE	-0.265	0.07	-0.377	0.056	0.003	0.08
PANVI	0.487	0.237	0.404	-0.073	0.005	-0.022
PASFL	0.103	0.011	0.07	0.027	0.001	0.043
PASPR	0.348	0.121	0.294	0.016	0	0.056
PERBO	0.074	0.006	-0.077	0.101	0.01	0.051
PINEL	0.221	0.049	0.181	0.364	0.132	0.307
PINPA	0.047	0.002	0.013	-0.175	0.03	-0.154
PITGR	0.06	0.004	-0.004	-0.218	0.047	-0.147
PLURO	-0.132	0.017	-0.158	0.139	0.019	0.153
POLHO	0.089	0.008	0.098	-0.123	0.015	-0.122
POLLU	-0.006	0	-0.043	-0.103	0.011	-0.11
POLRA	0.211	0.044	0.123	-0.408	0.167	-0.394
PROPE	0.207	0.043	0.209	0.134	0.018	0.183
PTEAQ	-0.181	0.033	-0.168	0.162	0.026	0.11
PYRAR	-0.17	0.029	-0.243	0.013	0	0.029
QUEFA	-0.092	0.008	-0.139	-0.026	0.001	-0.025
QUELA	-0.387	0.15	-0.272	0.161	0.026	0.162
QUENI	-0.254	0.064	-0.233	-0.071	0.005	-0.075
RHEAL	0.264	0.07	0.114	-0.3	0.09	-0.277
RHELU	0.164	0.027	0.177	-0.12	0.014	-0.11
RHEPE	-0.009	0	-0.169	-0.273	0.075	-0.255
RHUCO	-0.038	0.001	-0.1	0.154	0.024	0.144
RHUVÉ	0.086	0.007	0.061	0.071	0.005	0.104
RHYBR	0.033	0.001	0.023	-0.043	0.002	-0.044
RHYCA	0.078	0.006	0.08	-0.043	0.002	-0.061
RHYCE	0.405	0.164	0.301	0.16	0.026	0.205

RHYCH	0.06	0.004	-0.065	-0.333	0.111	-0.314
RHYCN	0.169	0.029	0.186	0.151	0.023	0.19
RHYCO	0.106	0.011	0.045	-0.329	0.109	-0.34
RHYEL	0.374	0.14	0.28	-0.16	0.026	-0.15
RHYFI	0.15	0.023	0.142	0.034	0.001	0.066
RHYGL	0.057	0.003	0.048	0.073	0.005	0.107
RHYGR	0.714	0.509	0.477	-0.203	0.041	-0.118
RHYIN	-0.062	0.004	-0.132	-0.076	0.006	-0.053
RHYOL	0.332	0.11	0.334	-0.047	0.002	-0.034
RHYPL	0.166	0.028	0.078	-0.347	0.121	-0.359
RHYPU	0.019	0	-0.009	0.073	0.005	0.037
RHYRA	0.034	0.001	-0.011	0.089	0.008	0.067
RHYSP	-0.241	0.058	-0.193	0.131	0.017	0.171
RUBUS	-0.264	0.07	-0.389	0.211	0.045	0.19
RUENO	0.134	0.018	0.125	0.042	0.002	0.106
SABSP	0.092	0.008	0.074	0.004	0	0.01
SARAL	0.552	0.305	0.497	-0.061	0.004	-0.025
SCHSC	0.519	0.27	0.261	-0.255	0.065	-0.192
SCHTE	0.105	0.011	0.062	-0.417	0.174	-0.325
SCLHI	0.01	0	-0.008	-0.135	0.018	-0.162
SCLMU	0.486	0.237	0.382	-0.1	0.01	-0.02
SCLPA	-0.032	0.001	-0.133	-0.043	0.002	-0.056
SCLPP	0.128	0.016	0.102	-0.423	0.179	-0.336
SCLTR	-0.32	0.102	-0.228	0.106	0.011	0.126
SCUIN	0.332	0.11	0.301	-0.05	0.003	0.004
SISAL	0.001	0	-0.048	-0.102	0.01	-0.117

SMIGL	-0.507	0.257	-0.45	0.146	0.021	0.151
SMILA	-0.161	0.026	-0.294	0.245	0.06	0.201
SMIRO	-0.169	0.028	-0.148	0.216	0.047	0.168
SPHAG	0.206	0.043	0.209	0.152	0.023	0.209
STOLA	0.151	0.023	0.151	0.024	0.001	0.05
STYAM	-0.161	0.026	-0.161	0.248	0.061	0.208
SYMTI	-0.418	0.174	-0.189	-0.137	0.019	-0.141
TEPON	-0.01	0	-0.052	-0.117	0.014	-0.067
TOFRA	0.128	0.016	0.103	-0.094	0.009	-0.112
TOXRA	-0.017	0	-0.1	0.224	0.05	0.192
TRADI	0.055	0.003	0.042	-0.004	0	-0.004
TRIAM	0.199	0.04	0.151	-0.24	0.057	-0.209
VACAR	-0.122	0.015	-0.117	0.027	0.001	0.017
VIBDE	-0.202	0.041	-0.158	0.066	0.004	0.093
VIBNU	-0.027	0.001	-0.071	-0.005	0	0
VIOPR	-0.034	0.001	-0.099	0.123	0.015	0.165
VITRO	-0.256	0.065	-0.228	0.077	0.006	0.075
WOOAR	0.027	0.001	-0.015	0.117	0.014	0.128
XYRAM	0.154	0.024	0.147	-0.018	0	-0.001
XYRCA	0.142	0.02	0.136	-0.32	0.102	-0.278
XYRDI	-0.019	0	-0.063	0.177	0.031	0.142
XYRLO	0.313	0.098	0.259	-0.071	0.005	-0.031
XYRSP	-0.007	0	-0.025	0.023	0.001	0.032
ZIGSP	0.03	0.001	0.009	0.018	0	0.036

Appendix D. Species codes

Code	Species
ACERU	<i>Acer rubrum</i>
AGAOB	<i>Agalinus obtusifolia</i>
AGASP	<i>Agalinus</i> sp.
AGRPE	<i>Agrostis perennans</i>
ALESP	<i>Aletris</i> sp.
AMBAR	<i>Ambrosia artemisiifolia</i>
AMOSP	<i>Amorpha</i> sp.
ANDCA	<i>Andropogon capillipes</i>
ANDGL	<i>Andropogon glomeratus</i>
ANDGY	<i>Andropogon gyrans</i> var. <i>gyrans</i>
ANDMO	<i>Andropogon mohrii</i>
ANDPE	<i>Andropogon perangustatus</i>
ANDSP	<i>Andropogon</i> sp.
ANDVI	<i>Andropogon virginicus</i>
ANTRU	<i>Anthaenantia rufa</i>
ANTVI	<i>Anthaenantia villosa</i>
ARIPA	<i>Aristida palustris</i>
ARIVI	<i>Aristida virgata</i>
ARUTE	<i>Arundinaria gigantea</i> ssp. <i>tecta</i>
ASCLO	<i>Asclepias</i> sp.
ASCLO	<i>Asclepias longifolia</i>
ASTAD	<i>Symphytotrichum adnatum</i>
ASTDU	<i>Symphytotrichum dumosum</i> var. <i>dumosum</i>
AXOFI	<i>Axonopus fissifolius</i>
BACHA	<i>Baccharis halimifolia</i>
BALUN	<i>Balduwiana uniflora</i>
BARPA	<i>Bartonia paniculata</i>
BIDMI	<i>Bidens mitis</i>
BIGCA	<i>Bignonia capreolata</i>
BIGNU	<i>Bigelowia nudata</i>
BOLSP	<i>Boltonia</i> sp.
BURSP	<i>Burmannia</i> sp.
CACOV	<i>Cacalia ovata</i>
CALAM	<i>Callicarpa americana</i>
CARGL	<i>Carex glaucescens</i>
CARPS	<i>Carphephorus pseudoliatris</i>
CENER	<i>Centella erecta</i>
CEPOC	<i>Cephalanthus occidentalis</i>
CHALA	<i>Chasmanthium laxum</i>
CHAOR	<i>Chasmanthium ornithorhynchum</i>
CHATO	<i>Chaptalia tomentosa</i>
CHIVI	<i>Chionanthus virginicus</i>
CLEAL	<i>Clethra alnifolia</i>
CLEDI	<i>Cleistes divaricata</i>
COERU	<i>Coelorachis rugosa</i>

COETE	<i>Coelorachis tessellata</i>
CORLI	<i>Coreopsis linifolia</i>
CRASP	<i>Crataegus</i> sp.
CROTO	<i>Croton</i> sp.
CTEAR	<i>Ctenium aromaticum</i>
CYPSP	<i>Cyperus compressus</i>
CYRRA	<i>Cyrilla racemiflora</i>
DICDI	<i>Dichanthelium dichotomum</i>
DICLA	<i>Rhynchospora latifolia</i>
DIOTE	<i>Diodia virginiana</i>
DIOTE	<i>Diodia teres</i>
DIOVI	<i>Diospyros virginiana</i>
DROBR	<i>Drosera</i> sp.
ELEMI	<i>Eleocharis minima</i>
ELETU	<i>Eleocharis tuberculosa</i>
ERARE	<i>Eragrostis refracta</i>
ERARE	<i>Eragrostis elliotii</i>
EREHI	<i>Erechtites hieraciifolia</i>
ERICO	<i>Eriocaulon compressum</i>
ERIDE	<i>Eriocaulon decangulare</i>
ERIGI	<i>Saccharum giganteum</i>
ERIST	<i>Saccharum strictus</i>
ERIVE	<i>Erigeron vernus</i>
ERYIN	<i>Eryngium integrifolium</i>
EUPCA	<i>Eupatorium capillifolium</i>
EUPLE	<i>Eupatorium leucolepis</i>
EUPRO	<i>Eupatorium rotundifolium</i>
EUPSE	<i>Eupatorium semiserratum</i>
EUTLE	<i>Euthamia leptoccephala</i>
EUTTE	<i>Euthamia tenuifolia</i> var. <i>tenuifolia</i>
FRAPE	<i>Fraxinus caroliniana</i>
FUIBR	<i>Fuirena breviseta</i>
FUISP	<i>Fuirena</i> sp.
GALMO	<i>Gaylussacia mosieri</i>
GAYMO	<i>Gaylussacia dumosa</i>
GELRA	<i>Gelsemium rankinii</i>
GENSA	<i>Gentiana saponaria</i>
GRAPI	<i>Gratiola pilosa</i>
GRAPI	<i>Gratiola brevifolia</i>
GRASP	<i>Gratiola</i> sp.
GYMBR	<i>Gymnopogon brevifolius</i>
HELAN	<i>Helianthus angustifolius</i>
HELHE	<i>Helianthus heterophyllus</i>
HELVE	<i>Helenium vernale</i>
HIBAC	<i>Hibiscus asculenta</i>
HYPAL	<i>Hyptis alata</i>
HYPBR	<i>Hypericum brachyphyllum</i>
HYPCL	<i>Hypericum cistifolium</i>

HYPHI	<i>Hypoxis</i> sp.
HYPHY	<i>Hypericum hypericoides</i>
HYPMU	<i>Hypericum multilum</i>
HYPSE	<i>Hypericum setosum</i>
HYPST	<i>Hypericum crux-andreae</i>
HYPWA	<i>Triadenum virginicum</i>
ILECO	<i>Ilex coriacea</i>
ILEDE	<i>Ilex decidua</i>
ILEGL	<i>Ilex glabra</i>
ILEMY	<i>Ilex myrtifolia</i>
ILEOP	<i>Ilex opaca</i>
ILEVO	<i>Ilex vomitoria</i>
IRIVI	<i>Iris virginica</i>
ITEVI	<i>Itea virginica</i>
JUNMA	<i>Juncus marginatus</i>
JUNTR	<i>Juncus trigonocarpus</i>
LACCA	<i>Lachnanthes caroliana</i>
LECSP	<i>Lechea</i> sp.
LIASP	<i>Liatris spicata</i>
LIGSI	<i>Ligustrum sinense</i>
LINME	<i>Linum medium</i>
LINME	<i>Linum floridanum</i>
LIQST	<i>Liquidambar styraciflua</i>
LIRTU	<i>Liriodendron tulipifera</i>
LOBBR	<i>Lobelia brevifolia</i>
LOBFL	<i>Lobelia floridana</i>
LOBPU	<i>Lobelia puberula</i>
LOPAU	<i>Lophiola aurea</i>
LUDGL	<i>Ludwigia glandulosa</i>
LUDHI	<i>Ludwigia pilosa</i>
LUDHI	<i>Ludwigia hirtella</i>
LUDLI	<i>Ludwigia linearis</i>
LUDSP	<i>Ludwigia</i> sp.
LUDVI	<i>Ludwigia virgata</i>
LYCAL	<i>Lycopodiella</i> sp.
LYCVI	<i>Lycopus virginicus</i>
LYCVI	<i>Lycopus rubellus</i> var. <i>angustifolius</i>
LYGJA	<i>Lygodium japonicum</i>
LYOLU	<i>Lyonia lucida</i>
MAGGR	<i>Magnolia grandiflora</i>
MAGVI	<i>Magnolia virginiana</i>
MALAN	<i>Malus angustifolia</i>
MECAC	<i>Mecardonia acuminata</i>
MITSE	<i>Mitreola sessilifolia</i>
MUHEX	<i>Muhlenbergia cappilaris</i> var. <i>tricapodes</i>
MYRCE	<i>Morella cerifera</i>
MYRHE	<i>Morella heterophylla</i>
NYSBI	<i>Nyssa biflora</i>

OSMAM	<i>Osmanthus americanus</i>
OSMCI	<i>Osmunda cinnamomea</i>
OSMRE	<i>Osmunda regalis</i>
OXYFI	<i>Oxypolis filiformis</i>
PANAC	<i>Dichanthelium acuminatum</i>
PANAN	<i>Panicum anceps</i>
PANAN	<i>Panicum hians</i>
PANCO	<i>Dichanthelium consanguineum</i>
PANEN	<i>Dichanthelium ensifolium</i>
PANER	<i>Dichanthelium erectifolium</i>
PANET	<i>Dichanthelium ensifolium</i> var. <i>tenue</i>
PANLE	<i>Dichanthelium leucothrix</i>
PANLO	<i>Dichanthelium longiligulatum</i>
PANRI	<i>Panicum rigidulum</i>
PANSC	<i>Dichanthelium scabriusculum</i>
PANSO	<i>Dichanthelium scoparium</i>
PANSP	<i>Dichanthelium</i> sp.
PANST	<i>Dichanthelium strigosum</i>
PANTE	<i>Panicum tenerum</i>
PANVE	<i>Panicum verrucosum</i>
PANVI	<i>Panicum virgatum</i>
PARQU	<i>Parthenocissus quinquefolia</i>
PASFL	<i>Paspalum floridanum</i>
PASPR	<i>Paspalum praecox</i>
PASSE	<i>Paspalum setaceum</i>
PENSP	<i>Penstemon</i> sp.
PERBO	<i>Persea borbonia</i>
PINEL	<i>Pinus elliottii</i>
PINPA	<i>Pinus palustris</i>
PINTA	<i>Pinus taeda</i>
PITGR	<i>Pityopsis graminifolia</i>
PLURO	<i>Pluchea rosea</i>
PLURO	<i>Pluchea foetida</i>
POLLU	<i>Polygala lutea</i>
POLRA	<i>Polygala ramosa</i>
PROPE	<i>Proserpinaca pectinata</i>
PRUSE	<i>Prunus serotina</i>
PTEAQ	<i>Pteridium aquilinum</i>
PYRAR	<i>Photinia pyrifolia</i>
QUEFA	<i>Quercus falcata</i>
QUELA	<i>Quercus laurifolia</i>
QUENI	<i>Quercus nigra</i>
QUENI	<i>Quercus laurifolia</i>
QUEVI	<i>Quercus virginiana</i>
RHEAL	<i>Rhexia alifanus</i>
RHELU	<i>Rhexia lutea</i>
RHEMA	<i>Rhexia mariana</i> var. <i>mariana</i>
RHEPE	<i>Rhexia petiolata</i>

RHESP	Rhexia sp.
RHEVI	Rhexia virginiana
RHOSP	Rhododendron sp.
RHUCO	Rhus copallinum
RHUVI	Toxicodendron vernix
RHYCA	Rhynchospora chalarocephala
RHYCE	Rhynchospora cephalantha
RHYCH	Rhynchospora chapmanii
RHYCN	Rhynchospora corniculata
RHYCO	Rhynchospora compressa
RHYDE	Rhynchospora debilis
RHYEL	Rhynchospora elliottii
RHYFI	Rhynchospora filifolia
RHYGB	Rhynchospora globularis
RHYGL	Rhynchospora glomerata
RHYGR	Rhynchospora gracilentia
RHYIN	Rhynchospora inexpansa
RHYOL	Rhynchospora oligantha
RHYPL	Rhynchospora plumosa
RHYPU	Rhynchospora pusilla
RHYRA	Rhynchospora rariflora
RHYSP	Rhynchospora sp.
RUBUS	Rubus sp.
RUENO	Ruellia noctiflora
SABSP	Sabatia sp.
SABSP	Sabatia difformis
SABSP	Sabatia campanulata
SAGLA	Sagittaria lanceolata
SALAZ	Salvia azurea
SAPSI	Sapium sebiferum
SARAL	Sarracenia alata
SARPS	Sarracenia psittacina
SCHSC	Schizachyrium scoparium
SCHTE	Schizachyrium tenerum
SCLCI	Scleria ciliata var. ciliata
SCLGE	Scleria georgiana
SCLHI	Scleria hirtella
SCLMU	Scleria muhlenbergia
SCLPA	Scleria pauciflora var. caroliniana
SCLPP	Scleria pauciflora var. pauciflora
SCLTR	Scleria triglomerata
SCUIN	Scutellaria integrifolia
SETSP	Setaria sp.
SISAL	Sisyrinchium atlanticum
SMIBO	Smilax bona-nox
SMIGL	Smilax glauca
SMILA	Smilax laurifolia
SMIRO	Smilax rotundifolia

SMISM	<i>Smilax smallii</i>
SOLOD	<i>Solidago odora</i>
SOLRU	<i>Solidago rugosa</i>
SPHAG	<i>Sphagnum</i>
STOLA	<i>Stokesia laevis</i>
STYAM	<i>Styrax americanus</i>
SYMTI	<i>Symplocos tinctoria</i>
TEPON	<i>Tephrosia onobrachyoides</i>
TILUS	<i>Tillandsia usneoides</i>
TOFRA	<i>Tofieldia racemosa</i>
TOXRA	<i>Toxicodendron radicans</i>
TRADI	<i>Trachelospermum difforme</i>
TRIAM	<i>Tridens ambiguus</i>
TRIVI	<i>Triadenum virginicum</i>
UNKMO	<i>Poaceae</i> sp.
UNKSP	Dicot sp.
UTRIC	<i>Utricularia juncea</i>
VACAR	<i>Vaccinium arboreum</i>
VACEL	<i>Vaccinium elliottii</i>
VIBDE	<i>Viburnum dentatum</i>
VIBNU	<i>Viburnum nudum</i>
VIOLA	<i>Viola lanceolata</i>
VIOPR	<i>Viola primulifolia</i>
VITRO	<i>Vitis rotundifolia</i>
WOOAR	<i>Woodwardia areolata</i>
XYRAM	<i>Xyris ambigua</i>
XYRBA	<i>Xyris baldwiniana</i>
XYRCA	<i>Xyris caroliniana</i>
XYRDI	<i>Xyris difformis</i>
XYRIR	<i>Xyris</i> sp.
XYRLO	<i>Xyris louisianica</i>
XYRSM	<i>Xyris smalliana</i>
XYRSP	<i>Xyris</i> sp.
XYRST	<i>Xyris iridifolia</i>
XYRST	<i>Xyris sticta</i>
ZIGSP	<i>Zigadenus</i> sp.

Vita

The author was born in Quincy, Illinois. He obtained his Bachelor's degree in Environmental Studies from the University of St. Thomas in St. Paul, Minnesota in 2002. He has worked for The Nature Conservancy since 2007, and is currently a lead fire and stewardship technician at the North Shore Field Office in Abita Springs, LA.