THE VASCULAR FLORA OF BOILING SPRING LAKES PRESERVE, BRUNSWICK COUNTY, NORTH CAROLINA

J. Clay Morris

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TABLE OF CONTENTS

ABSTRACT
CHAPTER 1

The vascular plants of Boiling Spring Lakes Preserve (BSLP) in Brunswick County, North Carolina were collected and catalogued during the growing seasons of 2005 through 2007. The 2,400 ha tract is comprised of Coastal Fringe Sandhills, Wet Pine Flatwoods, Pine Savannas, Small Depression Ponds, and Pond Pine Woodlands. The variety of ecosystems and relatively low disturbance has resulted in the designation of BSLP as a nationally significant ecological site. Brunswick County has the highest concentration of rare plants in North Carolina, but few floristic surveys from the region have been published. This study is the first comprehensive floristic survey of BSLP. A total of 403 species from 88 families were found in the survey. Families with greatest representation of individual species were Asteraceae (61), Cyperaceae (46), Poaceae (44), Fabaceae (20), and Ericaceae (14). Two new state records, *Croton michauxii* and *Rubus discolor*, and 40 new county records were added to the state and county floras. Further conservation implications and management suggestions were suggested based on observations made in several powerline clearcuts that transect the site.

ABSTRACT
CHAPTER 2

Longleaf pine ecosystems are characterized by high groundcover species richness, but the intent of most commercial pine plantation management techniques is to reduce understory competition. In areas where pine plantations are the focus of longleaf pine restoration efforts, questions arise as to the negative impact of intensive management practices on the native groundcover. The objective of this study was to examine plant associations in a loblolly (*Pinus taeda*) pine plantation and determine some of the abiotic variables driving the associations. Such information provides insight into restoration techniques that will best address current problematic site issues (erosion, low soil organic material (SOM)) that hamper restoration efforts.

Thirty-one North Carolina Vegetation Survey (NCVS) plots were established in the summer of 2006 to classify the vegetation in a 57 ha loblolly pine plantation within the Boiling Spring Lakes Preserve in Brunswick County, North Carolina. Abiotic variables measured were soil organic carbon (SOC) in the A, E, and B horizons, elevation, and the depth to the B horizon (DBTH). Water availability is one of the main limiting resources in longleaf pine systems and is critical to the storage of SOC, therefore, SOC from the A, E, and B horizons were used as proxies for moisture content.

Non-metric multidimensional scaling (NMS) was used to classify and ordinate the herbaceous plots into two consistent groups, hydrophytic and xerophytic, based on a soil moisture gradient along the first axis. Canonical correspondence analysis (CCA) and Detrended correspondence analysis (DCA) grouped plots along gradients of the abiotic variables with xerophytic plots being positively correlated with elevation and DBTH. This is reasonable because increasing DBTH with increasing elevation results in decreased proximity to perched water tables, favoring the establishment of xeric adapted species. This study demonstrated that moisture availability structures plant associations and early restoration efforts should focus on increasing SOM as a means to maintain the water balance and reduce the effects of erosion, providing conducive conditions for restoration planting.

ACKNOWLEDGEMENTS

First and foremost, I would like to thank my advisor, Greg Chandler, for his tremendous support and mentorship. Being his first graduate student was a unique and rewarding experience, and I am grateful for his perspective on the whole graduate experience. I also want to thank Steven Brewer for his guidance, enthusiasm, and knowledge throughout this entire process. I am forever indebted to Alan Weakley for proposing an absolutely amazing site to conduct exactly the kind of graduate research that I have always wanted. To Larry Cahoon, I wish to express my thanks for the many helpful insights he offered throughout the course of my work. I am especially grateful to the hard work and joyous times from my field crew: Amy Cherry, Sondi and Dallas Hoffman, Amanda Grusz, Mike Dennis, Tom Nance, Blake Hocker, Erin Spruill, Caryn Dunayer, Tabitha Yarborough, Joseph Butschko, and Brookes Graves. I would like to thank Anne Stapleton, Fred Sharf, and Martin Posey for offering courses that edified and broadened my knowledge. To Ann Pabst, I offer my utmost respect and gratitude for being a wonderful friend and confidant. I wish to acknowledge the biology office staff for their support, amazing problem solving skills, and hard work in keeping the lives of so many professors and graduate students flowing in one harmonious direction. Lastly, I want to express my deep gratitude to Dan Bell, with the Nature Conservancy, for his continuous help and access to the research site.

DEDICATION

I dedicate this work to my wife, Susan Morris, my son Talon, and my daughter Emmalene. I will never be able to repay the understanding, hardwork, support, and joy that my family has given me throughout this process.

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1. THE VASCULAR FLORA OF THE BOILING SPRINGS LAKES PRESERVE, BRUNSWICK COUNTY, NORTH CAROLINA

INTRODUCTION

Boiling Spring Lakes Preserve (BSLP; Fig. 1) was created through a joint land purchase between the Nature Conservancy, the Plant Conservation Program of the North Carolina Department of Agriculture and Consumer Services, and the North Carolina Natural Heritage Trust Fund. Currently comprised of *ca*.2,400 ha, the BSLP design was been based on efforts to acquire and protect those ecosystems that are most characteristic, and most unique, to southeastern North Carolina. The variety of ecosystems, with relatively low disturbance within the Preserve, contributed to the designation of BSLP as a nationally significant ecological site (NC Natural Heritage Program 1995). Brunswick County has the highest concentration of rare plant species in North Carolina. However, the region has few published floristic surveys, and most of these are available only as government documents or theses (*e.g.*, Dumond 1981, Strickland 2000). The objective of this study was to provide the first comprehensive floristic survey of BSLP.

Floristic composition

Many rare plant species occur in the southeastern U.S., with local endemics and globally rare species reaching their highest levels in Alabama, Georgia, and South Carolina. A combination of landscape age and glaciation-induced range contractions have resulted in geographically restricted species (Collins et al. 2001). Habitat destruction and modification have further contributed to the rarity of certain plant species.

The location and geologic history of BSLP plays a significant role in shaping the floristic component of the site. Located on the Cape Fear Arch, formed from a series of minor uplifts of Cretaceous deposits probably during the middle Eocene (*ca*. 45 million yr BP), the Arch is the only area within the Atlantic and Gulf Coastal Province in which Cretaceous deposits occur within a few kilometers of the ocean (Walker and Coleman 1987). Distribution patterns of rare endemic taxa suggest the Arch has maintained refugia, corridors for migration, and isolated habitats that proved conducive to speciation during the last glaciation. Endemic plant taxa (22 species) or nearly endemic (22 species) to the Coastal Plain have a distributional pattern strongly associated with the Arch, concentrated in a region extending along the coast from Carteret County, North Carolina, to Georgetown, South Carolina, as well as northwesterly along the Cape Fear River terraces into the sand-hill regions of North Carolina (LeBlond 2001). Estrill and Cruzan (2001) determined that the border of North Carolina and South Carolina is a region of notable endemic species richness, reaching its highest point in Brunswick County.

Of the 44 coastal Carolina endemic species, the great numbers of species are associated with fire-maintained southern pine and evergreen shrub communities, including wet pine savannas and flatwoods, savanna/pocosin ecotones, dry pine/shrub oak sandhills, and pond pine/evergreen shrub pocossins (LeBlond 2001). All of which are well represented in BSLP.

The depression wetlands of BSLP include more than a third of the rare plant species in the southeastern Coastal Plain (Sutter and Kral 1994). The considerable loss of wetlands over the last 200 years has been one of the primary causes of increased plant rarity in the southeastern U.S., therefore, records of their occurrence, along with details of their habitat and biology will be crucial to the conservation, protection and management of the areas in which they occur (Edwards and Weakley 2001).

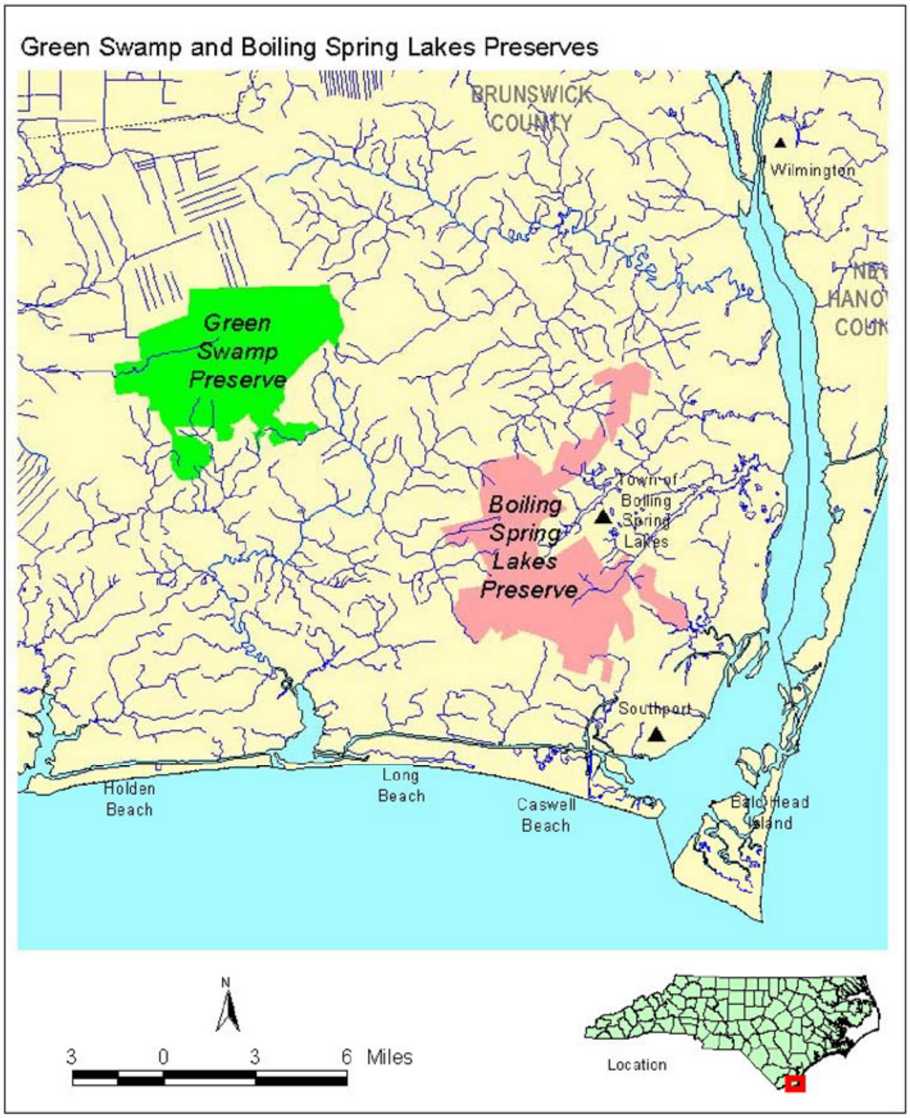

Fig. 1. Location of Boiling Spring Lakes Preserve, Brunswick County, North Carolina.

Ecosystems

BSLP has typical, as well as unique, Coastal Plain ecosystems. The sampling focus of this study was on terrestrial (Coastal Fringe Sandhills), palustrine (Wet Pine Flatwoods and Pine Savanna), depressional wetland (Small Depression Pond), and pocosin (Pond Pine Woodland) communities of the Coastal Plain (Schafale and Weakley 1990).

Coastal Fringe Sandhill

Formed from the reshaping of relict dune ridge and swale systems that were remnants of an ancient ocean shorelines (Late Pleistocene), coastal fringe sandhills occur on xeric, excessively drained, acidic mineral soils (Kureb, Mandarin, and Leon series) with a vegetational composition of open to sparse canopies of *Pinus palustris* and an understory of *Quercus geminata*, *Q. laevis*, and *Q. hemisphaerica* (Schafale and Weakley 1990). BSLP contains *ca*.320ha of this G3S1 (global rank- very rare, state rank-highly rare) community type, ~30% of its known distribution in North Carolina (LeBlond 1995).

Wet Savannas

The predominant communities of the Preserve are Wet Savannas of the Wet Pine Flatwoods and Pine Savanna type. Wet Pine Flatwoods occur in seasonally wet to persistently wet sites on flat to nearly flat Coastal Plain sediments. The vegetation is an open to closed canopy of *P. palustris* (and/or *P. taeda* [by planting only] and *P. serotina*), a low shrub layer of *Ilex glabra*, *Lyonia mariana*, and an herbaceous layer dominated by *Aristida stricta*, *Andropogon* spp., and *Xyris* spp. The Wet Pine Flatwoods *Leiophyllum* Variant (G3S4: global rank-very rare, state rank-apparently secure) has about 70% of its known distribution in the BSLP Complex, and has *Leiophyllum buxifolium* (now *Kalmia buxifolia fide* Weakley 2005) as a codominant in the shrub layer.

Closely allied to the Wet Pine Flatwoods is the Pine Savanna. Clearly defined differences between the two are not straightforward, though differing soil types may be relevant. This is especially evident at BSLP with Wet Pine Flatwoods occurring mainly on Murville soils while Pine Savannas are found on Leon soils. Species compositions are similar, although the structure of abundances among species may vary significantly. The boundary between the two may be based on fire history (though soil moisture capacity may be also significant). Variants of this ecosystem include the Pine Savanna Typical Variant, estimated at *ca*.440 ha, and occurring on the wet, mineral soils of Carolina bay rims and relict dune ridges. An open to sparse canopy of *P. palustris* and *P. serotina* dominate, and a diverse groundcover of grasses, sedges, and composites are typical of this ecosystem. The closely allied *Pleea* Variant, in which *Pleea tenuifolia* (Tofieldiaceae) is dominant in the herbaceous layer, is endemic to North Carolina (*ca*.140 ha) with 80 ha occurring in BSLP. This variant does not occur outside of North Carolina (LeBlond 1995).

Both Wet Pine Flatwoods and Pine Savanna can be described (by the primary dominants of the canopy and herb layer) as a *P. palustris* / *A. stricta* savanna (longleaf pine-wiregrass savanna). Before European settlement, these and other longleaf pine-wiregrass savannas dominated the southeastern Coastal Plain. Longleaf pine ecosystems covered an estimated 24 to 37 million ha (Wahlenberg 1946, Frost 1993, Outcalt and Sheffield 1996, Platt 1999), probably covering much of the southeastern Coastal Plain for over 5000 years (Watts 1975, Stout and Marion 1993). Logging, loblolly and slash pine plantations (Croker 1987, Lander et al. 1995), fire suppression, and the subsequent urbanization of the eastern seaboard has considerably reduced the extent of this ecosystem to less than 2% (1,000,000ha) of presettlement levels (Simberloff 1993, Noss et al. 1995, Outcalt and Sheffield 1996). This ecosystem occupies a diverse range of ecological conditions, from xeric sandhills and upland savannas to flooded coastal plain flatwoods (Bridges and Orzell 1989, Harcombe et al. 1993, Peet and Allard 1993).

Various studies have confirmed the ecological significance of this plant community type, particularly for species richness (Walker and Peet 1983, Clewell 1986, Noss 1988). For instance, Peet and Allard (1993) demonstrated that naturally regenerated longleaf pine ecosystems support a diverse collection of herbaceous species, often >40 species/m^2, resulting in some of the most species-rich communities at this scale outside of the tropics.

Pocosins

Within BSLP, pocosins occur on extensive peatlands that have developed in the basins of the large Carolina Bay complex in the western portion of the site (LeBlond 1995). The hydrology of pocosins is nonalluvial, fed by rainwater or highly oligotrophic groundwater, typically with strongly acidic soils, and a peat or mineral soil overlain with organic matter. Vegetation consists of dense shrubs, usually a suite of holly and heath species (*Ilex glabra*, *Cyrilla racemiflora*, *Lyonia lucida*) and a sparse to absent herbaceous layer (Weakley and Schafale 1991).

Pocosins can be classified into various types: Low, High, Pond Pine Woodland, Peatland Atlantic Cedar Forest, Bay forest, Streamhead, Streamhead Atlantic Cedar Forest, and Small Depression, with Pond Pine Woodlands common at BSLP. This particular type is distinguished by a substantial *Pinus serotina* canopy with a dense shrub layer of *Cyrilla racemiflora*, *Lyonia lucida*, and *Ilex glabra*. When this type borders Wet Pine Flatwoods or other upland communities, a distinct ecotonal zone occurs which is often too small to classify, but often resembles Pine Savanna and has a high diversity of herbaceous plants and is the primary habitat for a number of rare plant species (Weakley and Schafale 1991).

Depression wetlands

The southeast region of Brunswick County is noted for the occurrence of several unimpacted small depression ponds. These doline ponds are a feature of karst geology and form from the collapse of underlying limestone deposits. The subsidence and resultant depression create a pond with water provided primarily from underground sources. The sloping nature of the surrounding topography and the seasonally varying water levels can result in distinct, concentric zones of vegetation. Typically, the upper zones include upland pine woodlands, a forest of predominantly evergreen taxa (*Quercus virginiana* and *Taxodium ascendens* / *T. distichum*), and shrubs (*Ilex* and *Lyonia* ssp). The middle zone is often a sandy beach dominated by grasses and sedges, with species compositions driven by the varying water levels. The inner area is one of tall, herbaceous emergents, predominantly grasses and sedges (*Panicum hemitomon*, *Eleocharis* spp. and *Polygonum* spp.) combined with shallow water emergents and floating aquatics (*Nymphoides*, *Utricularia*, and *Eleocharis*)(Sutter and Kral 1994).

BSLP has several examples of the Small Depression Pond (G3S2: global rank-very rare, state rank-rare) type. The Hog Branch Ponds of BSLP are among the best examples in Brunswick County, and have supported documented populations of eight rare plant species including as *Eleocharis elongata*, *Rhynchospora harperi*, and *R. pleiantha*. The Pretty Pond Limesink complex has depression ponds, with previous records of over 15 rare plants, including *Platanthera nivea* and *Eupatorium leptophyllum* (LeBlond 1995). Small depression ponds throughout the state are under increasing threats, and those of the BSLP are no exception. The connection to the regional water source makes these systems especially prone to water level decreases resulting from increased residential growth (Sutter and Kral 1994).

Climate, Physiography, Geology, and Soils

In the winter average daily temperature is 8.3°C, and in summer average daily temperature is 25°C. Average annual precipitation is 139.2 cm with 81.3 cm (60%) falling between April and September, typical for a subtropical region(Barnhill 1986).

Elevation ranges from 0-23m a.s.l. in Brunswick County. Soils were formed from marine and alluvial sediment. The three soil series that dominate this soil association are Leon fine sand (Aeric Haplaquod), Murville mucky fine sand (Typic Haplaquod), and Mandarin fine sand (Typic Haplahumod), nearly level soils with poor drainage, slow runoff, rapid to moderate permeability, low water capacity, and low pH (3.6-5.5). Several soils of minor extent occur scattered throughout the site. Kureb fine sand (Spodic Quartzipsamment) on sand ridges is excessively drained soil with slow runoff, rapid permeability, and very low water capacity. Being strongly acidic to neutral (pH4.5-7.3), Kureb soils support sparse vegetation adapted to droughty conditions. Muckalee loam (Typic Fluvaquent) is a nearly level, poorly drained soil on flood plains of freshwater streams with slow runoff, moderate permeability and water capacity, and a pH of 5.1 to 7.3 (Barnhill 1986).

METHODS

Surveys were conducted bi-weekly during the growing season (March 1-Nov. 15) from 2005-2007. Areas surveyed were determined using site reconnaissance, soil maps, aerial photos, and increased familiarity with floristic "hotspots" (ecotones that proved to have higher species richness than others).

Collecting

Voucher specimens were collected when possible. Rare and sensitive species were documented with high quality photographs, but not collected. Identification followed Radford et al.(1968) and Weakley (2005) with nomenclature following Weakley (2005). Final determinations were confirmed by Dr. Alan Weakley (UNC Chapel Hill) and Dr. Gregory Chandler (UNC Wilmington). Additional determinations for problematic groups were made by Richard LeBlond (*Panicum*/*Dichanthelium* and *Solidago*) and Bruce Sorrie (*Carex* and *Rhynchospora*). Specimens were deposited in the herbaria of the Universities of North Carolina Wilmington (WNC) and Chapel Hill (NCU), as well as the Wilmington office of The Nature Conservancy.

Areas of survey

To facilitate dialogue with The Nature Conservancy, some area names follow those used by the Conservancy in their management activities.

Causeway Bay

Located in the southwestern most portion of BSLP, this 366 ha tract is predominantly Wet Pine Flatwood and Pine Savanna with a small area of Xeric Sandhill Scrub. Extensive Carolina bays are the principal geomorphic feature. Soils are mostly Murville in the basins with Leon intrusions on the bay rims (Barnhill 1986). The basins have become large peatlands supporting various types of pocosins, although Pond Pine Woodland pocosins are most abundant. It is within this tract that the Wet Pine Flatwood *Leiophyllum* Variant and Pine Savanna *Pleea* Variant reach their greatest extent. There is evidence of historical logging of much of the site, with certain wetter areas being considerably impacted by skids, resulting in altered hydrology.

Long Bay

Immediately north of Causeway Bay, this 207 ha tract is similar to Causeway Bay, having similar soils and plant associations, as well as evidence of previous logging. Prescribed fires are set every 4-5 years in an effort to maintain the vegetation. Due to the wetness of the area, fire effects have been moderate at best, leaving vast areas of *P. palustris, P. taeda,* and *P. serotina* woodlands and dense undercanopies of ericaceous shrubs, and very little herbaceous development. Certain ecotones, such as Murville-Leon interfaces (Barnhill 1986), pocosin edges, and open areas devoid of trees seem to host the highest species richness. Several principal drainages into Boiling Spring Lake flow through this area.

Reynolds Road Burn Unit

Bordered by one of the larger Boiling Spring Lake drainages, this 34 ha tract is predominantly Pine Savanna with a Xeric Oak Scrub association. This area is rather dynamic in that the Xeric Oak Scrub (dominated by *Quercus laevis* and with very little herbaceous cover) is immediately adjacent to the drainages, resulting in transitions in plant associations from Xeric Oak Scrub to Pond Pine Woodland. Varying moisture and soil nutrient regimes due to small variation in slope are readily evident in the vegetation composition.

Orion Burn Unit

This 100 ha tract is in the northernmost section of BSLP. Lying on large areas of Murville soil with Leon soil (Barnhill 1986) to a minor extent, this area is similar to both Causeway and Long Bay in vegetation composition. Logging or prescribed burning has resulted in a more mesic quality with pocosins being less extensive and open grasslands more readily apparent.

Wetland Mitigation Site

Immediately northeast and adjacent to the Orion Burn Unit, this area is currently being studied as a possible wetland mitigation site for various road projects in the county. Murville soils predominate, and the entire area is bordered by perennial drainages. Logging of the *P. palustris* forest has resulted in an open, wet meadow.

Camp Pretty Pond

Southeast of the Wetland Mitigation Site, this tract is differs considerably in physiognomy from the previous areas. The Coastal Fringe Sandhill community type is dominant with large areas of Kureb soils interspersed with Leon, and to a lesser extent Murville, soils in the drainages, and it is in this tract that the Hog Branch Pond Complex occurs. A rolling topography (from 2-16 m a.s.l.) has resulted in some of the most dramatic vegetation and community changes in the entire Preserve. Coastal Fringe Sandhills rapidly change to more mesic and hydric plant associations as one moves downslope toward the small streams and drainages that dissect the area. Large changes in drainage may explain why this area has the highest species richness, as well as highest incidence of rare species within the Preserve. Portions of this extensive long-leaf pine savanna have been selectively logged while *ca*. 60ha has been converted to loblolly pine plantation with extensive disturbance through bedding and understory clearing.

Beaver Dam

Located in the southeastern-most area of the Preserve, this area's most noticeable features are very low disturbance and a large impoundment at the edge of a small Coastal

Fringe Sandhill and Pine Savanna. Numerous, small doline ponds (average 0.2 ha) are scattered throughout some of the more intact examples of longleaf pine-wiregrass savanna to be found in the Preserve.

RESULTS AND DISCUSSION

A total of 403 species from 88 families were found during the survey. Families with greatest representation of individual species were Asteraceae (61), Cyperaceae (46) Poaceae (44), Fabaceae (20), and Ericaceae (14).

Two state records, *Croton michauxii* and *Rubus discolor*, have been added to the state flora. Forty county records were also added: *Acer drummondii*, *Agrostis capillaris*, *Andropogon tenuispatheus*, *Aristida dichotoma*, *Bidens frondosa*, *Buchnera floridana*, *Carex oblita*, *Chamaesyce prostrata*, *Cirsium muticum*, *Crataegus spathulata*, *Cuthbertia graminea*, *Cyperus iria*, *Digitaria ischaemum*, *Dulichium arundinaceum*, *Eragrostis curvula*, *Eragrostis elliottii*, *Euphorbia exserta*, *Gratiola viscidula*, *Hieracium caespitosum*, *Hypericum boreale* (NC Watch), *H. canadense*, *H. setosum*, *H. stragalum*, *Iris germanica*, *Kummerowia striata*, *Lespedeza angustifolia*, *L. bicolor*, *L. cuneata*, *Ludwigia hirtella*, *Minuartia caroliniana*, *Packera aurea*, *Panicum repens*, *Phragmites australis*, *Rubus enslenii*, *Sabatia quadrangula*, *Scleranthus annus*, *Solidago bicolor*, *Syngonanthus flavidus* (NC Watch), *Symphiotricum racemosum*, and *Xyris elliottii*.

One species, *Lysimachia asperulifolia*, is listed as US Endangered while three species are listed as US Species of Concern: *Oxypolis denticulata* (also NC Watch list), *Solidago pulchra* (NC Endangered), and *Dionaea muscipula* (NC Rare). One plant, *Amorpha georgiana* var. *confusa*, is on the North Carolina Threatened List. Twelve species are on the North Carolina Rare list: *Asclepias pedicellata*, *Eleocharis elongata*, *Lachnocaulon beyrichianum*, *Peltandra sagittifolia*, *Persicaria hirsuta*, *Pinguicula pumila*, *Rhexia cubensis*, *Rhynchospora alba*, *R. oligantha*, *Scleria reticularis*, *Spiranthes laciniata*, and *Xyris brevifolia.* Twenty one taxa are on the North Carolina Watch List: *Anthenanthia rufa*, *Asclepias longifolia*, *Bartonia verna*, *Carex elliottii*, *Cirsium lecontei*, *Dichanthelium erectifolium*, *Eleocharis equisetoides*, *E. melanocarpa*, *Eriophorum virginicum*, *Eupatorium recurvans*, *Habenaria repens*, *Hypericum boreale*, *Ilex cassine* var. *cassine*, *Oxypolis denticulata*, *Rhynchospora elliottii*, *R. inundata*, *R. nitens*, *Sabatia quadrangula*, *Syngonanthus flavidus*, *Utricularia cornuta*, and *Xyris baldwiniana.*

Twenty species are southeastern coastal plain endemics: *Arundinaria tecta*, *Balduina uniflora*, *Carphephorus bellidiformis*, *Carphephorus paniculatus*, *Carphephorus tomentosus*, *Chaptalia tomentosa*, *Ctenium aromaticum*, *Dionaea muscipula*, *Eupatorium recurvans*, *Gaura angustifolia*, *Gordonia lasianthus*, *Peltandra sagittifolia*, *Pleea tenuifolia*, *Prenanthes autumnalis*, *Quercus geminata*, *Q. hemispherica*, *Q. virginiana*, *Solidago pulchra*, *Rhynchospora latifolia*, and *Vaccinium crassifolium.*

Management implications

Prescribed burning is the main management tool for maintaining BSLP ecosystems. Fire serves multiple purposes in the maintenance of long-leaf pine savannas, pocosins, and other Coastal Plain ecosystems where much of the flora has evolved in response to low-frequency fire events (Myer 1990, Stout and Marion 1993). Fire enhances reproduction, reduces competition by woody plants, and promotes germination by removing thick layers of organic material, thereby enhancing diversity (Parrot 1967, Vogl 1973, Walker and Peet 1983, Christensen 1981, Folkerts 1982, Grubb 1977, Platt et al. 1988a, Provencher et al. 2001, Mulligan and Kirkman 2002). However, the proximity of the Preserve to the town of Boiling Spring Lakes presents managers with numerous constraints as to the extent, timing, and intensity of effective burns. Generally, the prescribed burn season ranges from late October to early March, although the natural burn season is in the summer when dry vegetation and lightening strikes create optimal conditions for removing woody vegetation. Summer fires are higher in their intensity, capable of reducing woody vegetation and promoting germination of fire-evolved species. Winter fires are often low intensity as moisture content is higher, resulting in lower reduction, and therefore tempering the effects of fire. In some instances, fire may even stimulate woody growth by encouraging "stump sprouting" (pers. observ.). The constraints imposed on prescribed burning may necessitate other management methods, such as those used in powerline right-of-ways, that might achieve the same goal. Progress Energy has two powerlines that pass though the Preserve. Periodic bush-hogging (every 4-5 years) reduces woody vegetation growth and simulates a natural fire event (~ every 5 years) for this region in both scale and effect. Furthermore, there is no use of fire or herbicide in their management methods. The powerlines may provide refugia for disturbance-dependent species that were historically a part of this ecosystem.

Of the 37 species found in this survey that are considered US endangered/ Concern, NC Endangered, NC Rare, or NC Watch, 20 were found in the two powerline clearcuts within BSLP, a significant number considering the small fraction (>3%) of the total Preserve that is within these rights-of-way. The powerline on the western edge of the Preserve that passes through Causeway and Long Bay Quads is level and savanna-like with several drainages, bisecting it with an open, meadow-like habitat dominated by grasses and composites. The powerline on the eastern edge of the Preserve passes through the Pretty Pond Quad and has a rolling topography characteristic of this Coastal Fringe Sandhill ecosystem with a topographic gradient ranging from 2-16 m a.s.l. Several streams pass through the lowest gradients supporting wetland vegetation typical of a Bottomland Hardwood Forest while the upper gradients are supporting Xeric Sandhill Scrub communities. Approximately 2 ha of this powerline was burned in the winter of 2007 to assess if there was any effect on vegetation composition. Initial findings are promising with the collection of *Lilium catesbaei*, an increase in *Platanthera blephariglottis* and *P. ciliaris* numbers and a marked reduction in much of the woody cover that was impacting the herbaceous layer.

Tables 1. Annotated list of vascular plants of the Boiling Spring Lakes Preserve, Brunswick County, North Carolina. Families, genera, and species are arranged alphabetically within major taxonomic groups. Specific nomenclature follows Weakley (2005), major angiosperm groups follow Angiosperm Phylogeny Group (2003). A single asterisk denotes non-native status. Species name and authority are followed by conservation status (i.e. NC Rare, NC Watch, etc.) and record status (new state or county record) Designations of abbreviations for specific areas within the Preserve in which each species was present: CW=Causeway Bay, LB= Long Bay, RR= Reynolds Road Burn Unit, OR= Orion Burn Unit, WM= Wetland Mitigation Site, PP= Camp Pretty Pond, BD= Beaver Dam. CP indicates Coastal Plain endemic.

Species	**Status**	**State record**	**County record**	**CW**	**LB**	**RR**	**OR**	**WM**	**PP**	**BD**
LYCOPODIOPHYTA										
LYCOPODIACEAE										
Lycopodiella alopecuroides (L.) Cranfill	CP			x	x		x	x	x	x
Lycopodiella appressa (Chapm.) Cranfill				x	x					
Pseudolycopodiella caroliniana (L.) Holub						x	x	x		
PTERIDOPHYTA										
ASPLENIACEAE										
Asplenium platyneuron (L.) Britton, Sterns, & Poggenb.				x	x				x	x
BLECHNACEAE										
Woodwardia areolata (L.) T. Moore				x	x		x	x	x	x
Woodwardia virginica (L.) Sm.				x	x	x	x	x	x	x
DENNSTAEDTIACEAE										
Pteridium aquilinum (L.) Kuhn var. *pseudocaudatum* (Clute) Heller				x	x	x	x	x	x	x

Species	**Status**	**State record**	**County record**	**CW**	**LB**	**RR**	**OR**	**WM**	**PP**	**BD**
OSMUNDACEAE										
Osmunda cinnamomea L. var. *cinnamomea*				x	x	x	x	x	x	x
Osmunda regalis L. var. *spectabilis* (Willd.) A. Gray					x			x	x	x
PINOPHYTA										
CUPRESSACEAE										
Juniperus virginiana L. var. *virginiana*						x				x
Taxodium distichum (L.) Rich									x	
PINACEAE										
Pinus palustris P. Miller	CP			x	x	x	x	x	x	x
Pinus serotina Michx.	CP			x	x	x	x			x
Pinus taeda L.				x	x	x			x	x
MAGNOLIOPHYTA										
Eudicots										
ADOXACEAE										
Viburnum nudum L.									x	
ALTINGIACEAE										
Liquidambar styraciflua L.				x	x	x	x	x	x	x
ANACARDIACEAE										
Rhus copallinum L. var. *copallinum*									x	
Toxicodendron radicans (L.) Kuntze var. *radicans*				x			x	x		
APIACEAE										
Centella erecta (L.) Fernald				x	x	x	x	x	x	x
Cicuta maculata (L.) var. *maculata*									x	x
Eryngium integrifolium Walter										

Species	Status	State record	County record	CW	LB	RR	OR	WM	PP	BD
Oxypolis denticulata (Baldwin) J.R. Edm.	US Concern/ NC Watch								x	
Oxypolis rigidor (L.) Raf.					x					
Ptilimnium capillaceum (Michx.) Raf.					x					
APOCYNACEAE										
Asclepias amplexicaulis Sm.					x					
Asclepias longifolia Michx.	NC Watch/ CP								x	
Asclepias pedicellata Walter	NC Rare/ CP			x	x					
Asclepias rubra L.									x	
AQUIFOLIACEAE										
Ilex cassine L. var. *cassine*	NC Watch/ CP								x	
Ilex coriacea (Pursh) Chapm.	CP			x	x	x	x	x	x	x
Ilex glabra (L.) A. Gray	CP			x	x	x	x	x	x	x
Ilex opaca Aiton *var. opaca*				x	x					
Ilex vomitoria Aiton	CP								x	
ARALIACEAE										
Hydrocotyle bonariensis Comm. ex Lam.				x	x	x			x	
ARISTOLOCHIACEAE										
Hexastylis arifolia (Michx.) Small var. *arifolia*						x				
ASTERACEAE										
Ambrosia artemisiifolia L.								x	x	
Baccharis halimifolia L.					x	x				
Balduina uniflora Nutt.	CP				x					
Bidens frondosa L.			x		x	x				
Bidens laevis (L.) Brittons, Stern, & Poggen.				x	x					
Bigelownia nudata (Michx.) DC. var. *nudata*				x	x	x		x		x

Species	**Status**	**State record**	**County record**	**CW**	**LB**	**RR**	**OR**	**WM**	**PP**	**BD**
Carphephorus bellidiformis (Michx.) Torr. & A. Gray	CP			x	x					
Carphephorus paniculatus (J.F. Gmel.) Herb.	CP							x	x	x
Carphephorus tomentosus (Michx.) Torr. & A. Gray	CP						x	x	x	
Chaptalia tomentosa Vent.	CP				x					
Chrysopsis gossypina (Michx.) Elliott	CP				x		x	x	x	
Cirsium lecontei Torr. & A. Gray	NC Watch/ CP								x	
Cirsium muticum Michx.			x						x	
Cirsium repandum Michx.	CP								x	
Conyza canadensis (L.) Cronquist	CP			x	x					
Coreopsis lanceolata L.				x	x				x	
Croptilon divaricatum(Nutt.) Raf.	CP					x				
Elephantopus nudatus A. Gray	CP				x					
Erechtites hieracifolia (L.)Raf. ex									x	
Erigeron quercifolius Lam.	CP					x	x			
Erigeron strigosus Muhl. ex Willd. var. *beyrichii* (Fisch. & C.A. Mey.) Torr. & A. Gray ex A. Gray				x	x					
Erigeron vernus (L.) Torr. & A. Gray	CP						x			x
Eupatorium capillifolium (Lam.) Small								x		x
Eupatorium compositifolium Walter	CP							x	x	x
Eupatorium leucolepis (DC.) Torr. & A. Gray	CP			x	x	x	x	x	x	x
Eupatorium mohrii Greene	CP								x	

Species	**Status**	**State record**	**County record**	**CW**	**LB**	**RR**	**OR**	**WM**	**PP**	**BD**
Eupatorium pilosum Walter						x			x	
Eupatorium recurvans Small	NC Watch/ CP							x	x	x
Eupatorium rotundifolium L.									x	
Eurybia paludosa (Aiton) Nesom	CP			x	x				x	
Euthamia tenuifolia (Pursh) Nutt.	CP				x				x	
* *Helenium amarum* (Raf.) H.Rock var. *amarumm*				x	x	x	x	x	x	
Helianthus angustifolius L.									x	
Heterotheca subaxillaris (Lam.) Britton & Rusby								x	x	
* *Hieracium caespitosum* Dumort						x				
Liatris pilosa (Aiton) Willd.				x	x	x	x		x	
Liatris spicata (L.) Willd. var. *resinosa* (Nutt.) Gaiser								x	x	x
Marshallia graminifolia (Walter) Small	CP			x	x				x	x
Mikania scandens (L.) Willd.									x	
Packera aurea (L.) A. & D. Löve			x			x			x	
Pityopsis aspera (Shuttlew. ex Small) Small var. *adenolepis* (Fernald) Semple & Bowers					x	x			x	
Pluchea foetida (L.) DC. var. *foetida*	CP								x	
Pluchea rosea Godfrey	CP									
Pseudognaphalium obtusifolium (L.) Hilliard & Burtt									x	x
Pterocaulon pycnostachyum (Michx.)Elliott							x	x		
Pyrrhopappus carolinianus (Walter) DC.				x	x					

Species	**Status**	**State record**	**County record**	**CW**	**LB**	**RR**	**OR**	**WM**	**PP**	**BD**
Sericocarpus tortifolius (Michx.) Nees	CP								x	
Silphium compositum Michx. var. *compositum*									x	
Solidago bicolor L.			x						x	
Solidago elliottii Torr. & A. Gray					x					
Solidago fistulosa P. Mill.	CP				x					
Solidago latissimifolia P. Mill.	CP								x	
Solidago odora Aiton var. *odora*									x	
Solidago petiolaris Aiton var. *petiolaris*						x				
Solidago pulchra Small	US Concern/ NC Endangered/ CP		x	x	x			x	x	
Solidago rugosa P. Mill.							x			
Symphyotrichum dumosum (L.) Nesom var. *dumosum*									x	
Symphyotrichum elliottii (Torr. & A. Gray) Nesom	CP								x	
Symphyotrichum racemosum (Elliott) Nesom var. *racemosum*			x					x		
BIGNONIACEAE										
Campsis radicans (L.) Seem. ex Bureau									x	
CABOMBACEAE										
Brasenia schreberi J.F. Gmel.										x
CACTACEAE										
Opuntia humifusa (Raf.) Raf. var. *humifusa*									x	
CAMPANULACEAE										
Lobelia canbyi A. Gray	CP				x				x	
Lobelia glandulosa Walter	CP								x	

Species	Status	State record	County record	CW	LB	RR	OR	WM	PP	BD
CAPRIFOLIACEAE										
Lonicera sempervirens L. var. *sempervirens*									x	
CARYOPHYLLACEAE										
Minuartia caroliniana (Walter) Mattf.	CP		x						x	
* *Scleranthus annuus* L.			x						x	
Stipulicida setacea Michx. var. *setacea*	CP					x			x	
CLETHRACEAE										
Clethra alnifolia L.	CP					x			x	
CONVOLVULACEA										
Calystegia sepium (L.) R. Br.									x	
Cuscuta compacta Juss. ex Choisy var. *compacta*									x	
Stylisma patens (Desr.) Myint var. *angustifolia* (Nash) Myint	CP								x	
CORNACEAE										
Cornus florida L.				x						
CYRILLACEAE										
Cyrilla racemiflora L.				x	x	x	x	x	x	x
DIAPENSIACEAE										
Pyxidanthera barbulata Michx. var. *barbulata*	CP			x	x					
DROSERACEAE										
Dionaea muscipula Ellis	US Concern/ NC Rare/ CP			x	x				x	
Drosera brevifolia Pursh				x	x					
Drosera intermedia Hayne										x

Species	**Status**	**State record**	**County record**	**CW**	**LB**	**RR**	**OR**	**WM**	**PP**	**BD**
EBENACEAE										
Diospyros virginiana L.						x			x	x
ERICACEAE										
Chamaedaphne calyculata (L.) Moench				x	x					
Eubotrys racemosa (L.) Nutt.						x				
Gaylussacia dumosa (Andrews) Torr. & A. Gray var. *dumosa*				x	x	x	x	x	x	x
Kalmia buxifolia (P.J. Bergius) Gift, Kron, & Stevens				x	x	x				
Lyonia ligustrina (L.) DC. var. *foliosiflora* (Michx.) Fernald	CP				x	x				
Lyonia lucida (Lam.) K. Koch	CP			x	x	x	x	x	x	x
Lyonia mariana (L.) D. Don	CP			x	x	x	x		x	
Rhododendron atlanticum (Ashe) Rehder	CP									
Rhododendron viscosum (L.) Torr.					x				x	
Vaccinium arboreum Marshall				x						
Vaccinium crassifolium Andrews	CP			x	x	x	x	x	x	x
Vaccinium stamineum (L.)				x	x	x	x	x	x	x
Vaccinium tenellum Aiton	CP			x	x	x	x	x	x	x
Zenobia pulverulenta (Barton ex Willd.) Pollard				x	x	x				
EUPHORBIACEAE										
* *Chamaesyce prostrata* (Aiton) Small			x		x				x	
Cnidoscolus stimulosus (Michx.) Engelm. & A. Gray						x			x	
Croton michauxii Webster		x								x
Euphorbia exserta (Small) Coker	CP			x						

Species	**Status**	**State record**	**County record**	**CW**	**LB**	**RR**	**OR**	**WM**	**PP**	**BD**
Euphorbia ipecacuanhae L.	CP								x	x
Euphorbia pubentissima Michx.								x		
FABACEAE										
Amorpha georgiana Wilbur var. *confusa* Wilbur	NC Threatened/ CP								x	
Apios americana Medik.									x	
Baptisia cinerea (Raf.) Fernald & Schub.	CP				x					
Chamaecrista nictitans (L.) Moench var. *nictitans*				x	x	x	x			
Crotalaria purshii DC.	CP				x					
Galactia regularis (L.) Britton									x	
* *Kummerowia striata* (Thunb.) Schindl.			x				x			
Lespedeza angustifolia (Pursh) Elliott	CP		x							x
* *Lespedeza bicolor* Turcz.			x							x
Lespedeza capitata Michx.										x
* *Lespedeza cuneata* (D.-Cours) G. Don			x	x	x					
* *Melilotus albus* Medik.					x					
* *Senna obtusifolia* (L.) Irwin & Barneby				x	x	x				
*? *Sesbania herbacea* (P.Mill.) McVaugh							x			
Strophostyles helvola (L.) Elliott									x	
Stylosanthes biflora (L.) Britton									x	
Tephrosia hispidula (Michx.) Pers.	CP								x	
Wisteria frutescens (L.) Poir.	CP									x
* *Wisteria sinensis* (Sims) DC.										x
FAGACEAE										
Castanea pumila (L.) P. Mill.				x						

Species	**Status**	**State record**	**County record**	**CW**	**LB**	**RR**	**OR**	**WM**	**PP**	**BD**
Quercus geminata Small	CP			x		x			x	
Quercus hemisphaerica Bartram ex Willd.	CP								x	
Quercus incana Bartram	CP							x		
Quercus laevis Walter	CP			x	x	x	x	x	x	x
Quercus margarettae Ashe ex Small	CP								x	
Quercus nigra L.									x	
Quercus virginiana P. Mill.	CP							x	x	
GELSEMINACEAE										
Gelsemium sempervirens (L.) Aiton				x	x	x	x	x	x	x
GENTIANACEAE										
Bartonia verna (Michx.) Raf. ex Barton	NC Watch/ CP			x						
Bartonia virginica (L.) Britton, Sterns, & Poggenb.				x						
Gentiana autumnalis L.	CP				x				x	
Sabatia quadrangula Wilbur	NC Watch			x	x				x	x
HAMAMELIDACEA										
Fothergilla gardenii L.	CP				x					
HYPERICACEAE										
Hypericum boreale (Britton) Bicknell	NC Watch		x							x
Hypericum canadense L.			x							x
Hypericum cistifolium Lam.	CP						x			
Hypericum crux-andreae (L.) Crantz	CP			x			x			x
Hypericum drummondii (Grev. & Hook.) Torr. & A. Gray						x				
Hypericum hypericoides (L.) Crantz				x	x	x				
Hypericum mutilum L. var. *mutilum*					x	x	x			

Species	**Status**	**State record**	**County record**	**CW**	**LB**	**RR**	**OR**	**WM**	**PP**	**BD**
Hypericum setosum L.	CP		x	x					x	
Hypericum stragalum P. Adams & Robson			x					x		
Hypericum tenuifolium Pursh	CP			x	x	x	x	x		x
Triadenum virginicum (L.) Raf.									x	x
ITEACEAE										
Itea virginica L.						x				
LAMIACEAE										
Callicarpa americana L.					x					
Monarda punctata L. var. *punctata*					x					
Salvia lyrata L.					x					
Scutellaria incana Biehler			x	x	x					
Scutellaria integrifolia L.				x						
Trichostema dichotomum L.									x	x
LAURACEAE										
Persea palustris (Ref.) Sarg.	CP			x	x	x	x	x	x	x
Sassafras albidum (Nutt.) Nees						x			x	
LENTIBULARIACEAE										
Pinguicula caerulea Walter	CP				x					
Pinguicula pumila Michx.	NC Rare/ CP									x
Utricularia biflora Lam.	CP			x	x					
Utricularia cornuta Michx.	NC Watch				x					
Utricularia juncea M. Vahl				x	x					
Utricularia purpurea Walter					x				x	
Utricularia subulata L.										x
LOGANIACEAE										
Mitreola sessilifolia (J.F. Gmel.) G. Don	CP			x	x					

Species	**Status**	**State record**	**County record**	**CW**	**LB**	**RR**	**OR**	**WM**	**PP**	**BD**
LYTHRACEAE										
Decodon verticillatus (L.) Elliott									x	
MAGNOLIACEAE										
Magnolia virginiana L. var. *virginiana*	CP			x	x	x	x	x	x	x
MELASTOMATACEAE										
Rhexia alifanus Walter	CP			x	x		x		x	x
Rhexia cubensis Griseb.	NC Rare								x	
Rhexia lutea Walter	CP								x	
Rhexia nashii Small	CP								x	
Rhexia petiolata Walter	CP							x	x	x
MYRICACEAE										
Morella caroliniensis (P. Mill.) Small	CP			x	x	x				
Morella cerifera (L.) Small				x	x	x	x	x	x	x
MYRSINACEAE										
Lysimachia asperulifolia Poir.	US Endangered/ NC Endangered				x					
NYMPHAEACEAE										
Nuphar advena (Aiton) R. Br. ex Aiton f.					x					x
Nymphaea odorata W.T. Aiton var. *odorata*				x	x					x
NYSSACEAE										
Nyssa biflora Walter	CP							x		x
Nyssa sylvatica Marshall								x	x	
ONAGRACEAE										
Gaura angustifolia Michx.	CP									x
Ludwigia alternifolia L.									x	
Ludwigia hirtella Raf.	CP								x	

Species	**Status**	**State record**	**County record**	**CW**	**LB**	**RR**	**OR**	**WM**	**PP**	**BD**
Ludwigia leptocarpa (Nutt.) Hara										x
Ludwigia linearis Walter *var. linearis*	CP								x	
Ludwigia palustris (L.) Elliott										x
Ludwigia pilosa Walter	CP								x	
Ludwigia virgata Michx.									x	
Oenothera laciniata Hill									x	
OROBANCHACEAE										
Agalinis aphylla (Nutt.) Raf.	CP			x						
Agalinis fasciculata (Elliott) Raf.				x	x	x			x	x
Agalinis purpurea (L.) Pennell									x	
Buchnera floridana Gand.	CP		x	x	x					
PASSIFLORACEAE										
Passiflora incarnata L.				x	x					
PLANTAGINACEAE										
Gratiola viscidula Pennell			x			x			x	
Nuttallanthus canadensis (L.) *D.A. Sutton*	CP			x	x	x	x	x	x	x
* *Plantago lanceolata* L.				x	x	x	x	x	x	x
POLYGALACEAE										
Polygala brevifolia Nutt.	CP			x			x			
Polygala cymosa Walter	CP								x	
Polygala lutea L.	CP			x	x				x	
POLYGONACEAE										
Persicaria hirsuta (Walter) Small	NC Rare/ CP								x	
* *Persicaria maculosa* S.F. Gray									x	
Persicaria punctata (Elliott) Small									x	
Persicaria sagittata (L.) Gross ex Nakai									x	

Species	**Status**	**State record**	**County record**	**CW**	**LB**	**RR**	**OR**	**WM**	**PP**	**BD**
Polygonella polygama (Vent.) Engelm. & A. Gray	CP					x			x	
Rumex hastatulus Baldwin				x	x					
RHAMNACEAE										
Berchemia scandens (Hill) K. Koch					x					
ROSACEAE										
Aronia arbutifolia (L.) Pers.				x	x	x	x	x	x	x
Crataegus spathulata Michx.			x							x
Prunus caroliniana (P. Miller) Aiton	CP									x
Rubus argutus Link										x
* *Rubus discolor* Weihe & Nees		x								x
Rubus enslenii Trattinick			x							x
RUBIACEAE										
Galium obtusum Bigelow var. *obtusum*						x	x			
Galium tinctorium (L.) Scop.					x					
Oldenlandia uniflora L.								x	x	
SALICACEAE										
Populus heterophylla L.									x	
Salix caroliniana Michx.									x	x
SAPINDACEAE										
Acer drummondii Hook. & Arn. ex Nutt.			x		x					
Acer rubrum L. var. *trilobum* Torr. & A. Gray ex K. Koch				x						
SARRACENIACEAE										
Sarracenia flava L.	CP		x	x						

Species	**Status**	**State record**	**County record**	**CW**	**LB**	**RR**	**OR**	**WM**	**PP**	**BD**
Sarracenia purpurea L. var. *venosa* (Raf.) Fern.	CP		x	x						
THEACEAE										
Gordonia lasianthus (L.) Ellis	CP		x	x	x	x	x	x	x	x
VERBENACEAE										
Verbena brasiliensis Vell.									x	x
Verbena scabra Vahl										x
VIOLACEAE										
Viola lanceolata L. var. *vittata* (Greene) Weath. & Griscom			x							
Viola primulifolia L.				x						
VISCACEAE										
Phoradendron serotinum (Raf.) M.C. Johnson *ssp. serotinum*					x					
VITACEAE										
Parthenocissus quinquefolia (L.) Planch.			x	x			x	x		x
Vitis rotundifolia Michx. var. *rotundifolia*			x	x	x			x		x
Monocots										
AGAVACEAE										
Yucca filamentosa L.									x	
ALISMATACEAE									x	
Sagtittaria lancifolia L. var. *media*										
ARACEAE										
Peltandra sagittifolia (Michx.) Morong	NC Rare/ CP			x					x	
BROMELIACEAE										
Tillandsia usneoides (L.) L.			x	x			x	x		

Species	**Status**	**State record**	**County record**	**CW**	**LB**	**RR**	**OR**	**WM**	**PP**	**BD**
BURMANNIACEAE										
Burmannia capitata (J.F. Gmel.) von Mart.					x	x				
COMMELINACEAE										
Cuthbertia graminea Small			x						x	
CYPERACEAE										
Bulbostylis ciliatifolia (Elliott) Fernald	CP						x	x		
Bulbostylis stenophylla (Elliott) C.B. Clarke	CP									
Carex atlantica Bailey									x	
Carex elliottii Schwein. & Torr.	NC Watch/ CP								x	
Carex glaucescens Elliott	CP								x	
Carex lonchocarpa Willd.	CP								x	
Carex oblita Steud.			x							x
Carex stipata Muhl. ex Willd.										x
Carex striata Michx.	CP								x	x
Carex tribuloides Wahlenb.									x	x
* *Cyperus iria* L.			x							x
Cyperus odoratus L.					x					
Dulichium arundinaceum (L.) Britton var. *arundinaceum*				x	x					
Eleocharis baldwinii (Torr.) Chapm.	CP					x	x			
Eleocharis elongata Chapm.	NC Rare								x	
Eleocharis equisetoides (Elliott) Torr.	NC Watch									x
Eleocharis melanocarpa Torr.	NC Watch/ CP					x	x		x	
Eleocharis obtusa (Willd.) Schult.				x						
Eleocharis tortilis (Link) Schult.	CP				x					

Species	**Status**	**State record**	**County record**	**CW**	**LB**	**RR**	**OR**	**WM**	**PP**	**BD**
Eleocharis tuberculosa (Michx.) Roem. & Schult.				x	x			x		
Eriophorum virginicum L.	NC Watch				x					
Fimbristylis autumnalis (L.) Roem. & Schult.				x				x		
Fimbristylis puberula (Michx.) Vahl var. *puberula*						x				
Fuirena breviseta (Coville) Coville in Harper	CP								x	
Fuirena pumila (Torr.) Spreng.	CP								x	
Rhynchospora alba (L.) Vahl	NC Rare								x	
Rhynchospora chalarocephala Fernald & Gale	CP		x	x					x	
Rhynchospora chapmanii M.A. Curtis	CP				x					
Rhynchospora ciliaris (Michx.) C. Mohr	CP				x	x				
Rhynchospora elliottii A. Dietr.	NC Watch							x	x	
Rhynchospora fascicularis (Michx.) Vahl var. *distans* (Michx.) Chapm.	CP		x	x	x	x	x	x	x	x
Rhynchospora filifolia A. Gray	CP			x						
Rhynchospora inexpansa (Michx.) Vahl	CP			x						
Rhynchospora inundata (Oakes) Fernald	NC Watch/ CP		x	x						
Rhynchospora latifolia (Baldwin ex Elliott) Thomas	CP		x	x						
Rhynchospora megalocarpa A. Gray	CP				x		x		x	
Rhynchospora microcephala (Britton) Britton ex Small	CP					x	x	x		
Rhynchospora nitens (Vahl) A. Gray	NC Watch									x
Rhynchospora oligantha A. Gray	NC Rare								x	
Rhynchospora perplexa Britton				x						

Species	**Status**	**State record**	**County record**	**CW**	**LB**	**RR**	**OR**	**WM**	**PP**	**BD**
Rhynchospora plumosa Elliott							x			
Scirpus cyperinus (L.) Kunth									x	
Scleria ciliata Michx. var. *glabra*	CP								x	
Scleria muehlenbergii Steud.									x	
Scleria reticularis Michx.	CP								x	
Scleria triglomerata Michx.									x	
ERIOCAULACEAE										
Eriocaulon compressum Lam.	CP				x				x	
Eriocaulon decangulare L. var. *decangulare*	CP			x	x					
Lachnocaulon anceps (Walter) Morong	CP			x	x		x		x	x
Lachnocaulon beyrichianum Sporl. ex Körnick	NC Rare/ CP			x	x				x	
Lachnocaulon compressum Lam.				x	x		x	x		x
Syngonanthus flavidus (Michx.) Ruhland	CP			x	x			x		
HAEMODORACEAE										
Lachnanthes caroliniana (Lam.) Dandy	CP			x	x	x	x	x	x	x
HALOGORACEAE										
Proserpinaca pectinata Lam.									x	
HYPOXIDACEAE										
Hypoxis hirsuta (L.) Coville					x					
IRIDACEAE										
* *Iris germanica* L.			x		x					
Iris verna L. var. *verna*	CP				x					
Iris virginica L. var. *virginica*					x					
JUNCACEAE										
Juncus abortivus Chapm.							x	x		
Juncus acuminatus Michx.							x			

Species	**Status**	**State record**	**County record**	**CW**	**LB**	**RR**	**OR**	**WM**	**PP**	**BD**
Juncus biflorus Elliott						x				
Juncus coriaceus Mack.					x	x				
Juncus debilis A. Gray								x	x	
Juncus dichotomus Elliott				x			x			
Juncus polycephalus Michx.	CP			x				x		
Juncus repens Michx.									x	x
LILIACEAE										
Lilium catesbaei Walter	CP								x	
MELANTHIACEAE										
Stenanthium densum (Desr.) Zomlefer & Judd	CP								x	
Zigadenus glaberrimus Michx.	CP								x	x
NARTHECIACEAE										
Aletris farinosa L.										x
ORCHIDACEAE										
Calopogon tuberosus (L.) Britton, Sterns & Poggenb.	CP			x	x					x
Cleistes divaricata (L.) Ames	CP								x	
Habenaria repens Nutt.										x
Platanthera blephariglottis (Willd.) Lindl.	CP								x	
Platanthera ciliaris (L.) Lindl.									x	
Platanthera cristata (Michx.) Lindl.									x	
Pogonia ophioglossoides (Linnaeus) Ker-Gawler				x	x				x	x
Spiranthes laciniata (Small) Ames	NC Rare/ CP				x					
Spiranthes vernalis Engelm. & A. Gray					x					

Species	**Status**	**State record**	**County record**	**CW**	**LB**	**RR**	**OR**	**WM**	**PP**	**BD**
POACEAE										
* *Agrostis capillaris* L.			x		x					
Agrostis scabra Willd.						x				
Amphicarpum amphicarpon (Pursh) Nash	CP								x	
Andropogon gerardii Vitman									x	
Andropogon glaucopsis Elliott	CP							x	x	
Andropogon glomeratus (Walter) Britton, Sterns,& Poggenb. var. *glomeratus*					x	x				
Andropogon glomeratus (Walter) Britton, Sterns,& Poggenb. var. *hirsutior* (Hack.) C. Mohr				x						
Andropogon tenuispatheus (Nash) Nash			x	x						
Andropogon ternarius Michx. var. *ternarius*				x						
Andropogon virginicus L. var. *decipiens* C.S. Campb.	CP			x	x				x	x
Andropogon virginicus L. var. *virginicus*				x	x	x	x	x	x	x
Anthenanthia rufa (Nutt.) J.A. Shultes	NC Watch/ CP								x	x
Aristida dichotoma Michx.			x		x					
Aristida longespica Poiret var. *geniculata* (Raf.) Fernald							x			
Aristida stricta Michx.	CP			x	x	x	x	x	x	x
Aristida virgata Trin.	CP								x	
Arundinaria tecta Walter	CP			x	x	x	x	x	x	x
Chasmanthium laxum (L.) Yates						x			x	x
Ctenium aromaticum (Walter) Wood	CP				x					
Danthonia sericea Nutt.								x	x	

Species	**Status**	**State record**	**County record**	**CW**	**LB**	**RR**	**OR**	**WM**	**PP**	**BD**
Dichanthelium chamaelonche (Trin.) Freckmann & Lelong	CP			x						
Dichanthelium dichotomum (L.) Gould var. *nitidum* (Lam.) LeBlond				x	x	x	x	x	x	x
Dichanthelium erectifolium (Nash) Gould & Clark	CP						x			x
Dichanthelium mattamusketense (Ashe) Mohlenbr.	CP							x		
Dichanthelium portoricense (Desv. ex Ham.) B.F. Hansen & Wunderlin *ssp. patulum*	CP									x
Dichanthelium scabriusculum (Elliott) Gould & Clark	CP							x		
Dichanthelium scoparium (Lam.) Gould					x					
Digitaria ciliaris (Retz.) Köler				x						
Digitaria cognata (J.A. Shultes) Pilg.					x					
* *Digitaria ischaemum* (Schreb.) Muhl.			x				x			
Eragrostis elliottii S. Watson			x	x						
Muhlenbergia capillaris (Lam.) Trin.					x					
Panicum longifolium Torr. var. *longifolium*	CP			x						
Panicum hemitomon J.A. Shultes	CP								x	
Panicum repens L.			x						x	
Panicum verrucosum Muhl.								x		
Panicum virgatum L. var. *virgatum*								x	x	x
Paspalum laeve Michx. var. *laeve*						x	x			
Paspalum setaceum Michx. var. *setaceum*					x					
* *Paspalum urvillei* Steud.								x		

Species	Status	State record	County record	CW	LB	RR	OR	WM	PP	BD
* *Phragmites australis* (Cav.) Trin. ex Steud. var. *australis*			x						x	
Sacciolepis striata (L.) Nash									x	
* *Schedonorus arundinaceus* (Schreb.) Dumort.				x	x					
Schizachyrium scoparium (Michx.) Nash var. *scoparium*	CP			x	x	x	x	x	x	x
Tridens flavus (L.) A.S. Hitchc.				x			x		x	
Triplasis americana P. Beauv.	CP				x			x		
PONTEDERIACEAE										
Pontederia cordata L. var. *cordata*									x	
SMILACACEAE										
Smilax bona-nox L.									x	
Smilax laurifolia L.				x	x	x	x	x	x	x
Smilax rotundifolia L.					x	x				
Smilax walteri Pursh	CP			x						
TOFIELDIACEAE										
Pleea tenuifolia Michx.	CP			x	x	x				x
Triantha racemosa (Walter) Small	CP								x	
TYPHACEAE										
Sparganium americanum Nutt.										x
Typha domingensis Pers.									x	x
XYRIDACEAE										
Xyris ambigua Beyr. ex Kunth				x						
Xyris baldwiniana J. A. Shultes	NC Watch					x				
Xyris brevifolia Michx.	NC Rare								x	
Xyris caroliniana Walter	CP							x	x	
Xyris elliottii Chapm.			x				x			x
Xyris fimbriata Elliott	CP				x					
Xyris platylepis Chapm.	CP									x

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CHAPTER 2. SOIL ORGANIC CARBON AND ELEVATIONAL GRADIENT ON THE STRUCTURING OF PLANT ASSOCIATIONS IN A LOBLOLLY PINE PLANTATION

INTRODUCTION

Effective ecosystem restoration requires a clear understanding of site characteristics and vegetation associations in determining which management methods are best suited to that particular ecosystem. The restoration of longleaf pine savanna is currently receiving considerable attention in an effort to mitigate the substantial losses (>98%) of this ecosystem. Before European settlement, longleaf pine ecosystems covered an estimated 24 to 37 million ha, covering most of the southeastern Coastal Plain for over 5000 years before European settlement. Logging, a preference for loblolly and slash pine plantations, fire suppression, and the subsequent urbanization of the eastern seaboard has reduced this ecosystem to less than 2% of pre-settlement levels (Wahlenberg 1946, Frost 1993, Simberloff 1993, Outcalt and Sheffield 1996, Croker 1987, Lander *et al*. 1995, Platt 1999, Watts 1975, Stout and Marion 1993). The ecological significance, particularly in supporting high species richness, of this plant community has been demonstrated across many ecosystem types from xeric sandhills and upland savannas to flooded coastal plain flatwoods (Walker and Peet 1983, Clewell 1985, Noss 1988, Christensen 1989, Bridges and Orzell 1989, Harcombe *et al*. 1993, Peet and Allard 1993). Peet and Allard (1993) found that naturally regenerated longleaf pine ecosystems support a high diversity of herbaceous taxa, often with >40 species/ m^2, and some of the most species-rich communities at this scale outside of the tropics.

Previous management studies have focused on the effects of intensive management on the understory vegetation of longleaf pine forests. Conclusions about the ultimate effects of such management methods had been equivocal (Noss 1989, Moore *et al*. 1982, Conde *et al*. 1983, Swindel *et al*. 1984, Lewis *et al*. 1988). Further work is necessary to assess the effects of intensive management on the long-term ecological responses that develop through the successional processes (Glitzenstein 1993). This study used ecological ordination methods to ascertain some of the plant associations and abiotic variable present in a longleaf pine restoration project. These analyses provided insight into how previous intensive management techniques have altered the site (decreased soil organic matter (SOM), erosion, decreased water budget), and recommendations are made to mitigate for these losses.

The objectives of this study were to determine the plant associations present in a loblolly pine plantation undergoing restoration, and to examine some potential mechanisms driving these associations. Soil organic carbon (SOC) is a major component of the soil organic fraction, and variation in quantity and location of SOC causes clear soil structural modifications and influences soil chemical and physical properties that control nutrient cycling, having major effects on forest productivity (Switzer and Nelson 1972, Johnson and Curtis 2001). Studies in southeastern pine stands have found soil C concentrations 20% lower after 12 to 18 years of intensive understory management (Echeverria *et al*. 2004). This management often includes the use of herbicide treatments to reduce under-story vegetation competition which decreases soil organic matter (SOM), the principal source of SOC, which, in turn, reduces SOC levels (Aust and Lea 1991, Polglase *et al*. 1992, Carlyle 1993, Munson *et al*. 1993, Busse *et al*. 1996). Water availability is one of the main limiting resources in longleaf pine-wiregrass systems and has been shown to be critical in the storage of SOC, therefore, in this study, SOC from the A, E, and B soil horizons was used as proxies for moisture content. It was anticipated that in this system with rapid drainage, vegetation would respond to the moisture retentive capacity of the soil horizons and distance of the available water by the presence of species adapted to xeric or hydric conditions. Such knowledge may offer valuable insights into those management methods that best address the conditions of the site.

METHODS

Site description: history, physiography, geology and soils

The study site is located on the Camp Pretty Pond Quad of Boiling Spring Lakes Preserve, Brunswick County, North Carolina. Before its transfer to the Plant Conservation Program of the North Carolina Department of Agriculture and Consumer Services (PCP), the area was actively managed by International Paper as a loblolly pine plantation. Based on aerial photos, the site was converted to an intensively managed loblolly plantation in the early 1970's. Trees were planted in bedded rows, and herbicides and prescribed burns were utilized to control unwanted understory growth. In the winter of 2006, the PCP began the initial steps in restoring the site to longleaf pine savanna. At the inception of this study, there were 57 ha of loblolly pines (planted in 1999) at a stand density of approximately 1000 trees/ ha.

The geomorphology of the site is dominated by a dune ridge and swale system. These ancient dunes have been reshaped by intermittent drainages passing through the rolling topography (2-16 m a.s.l.) The formation of these drainages typically occurs along gentle elevational gradients. Changes in vegetation associations along these gradients have been described in many southeastern long-leaf pine savannas (Bridges and Orzell 1989, Clewell 1986, Harcombe *et. al*. 1993, Peet and Allard 1993).

Soils were formed from alluvial and marine sediments. The major soil association occurring within the study site is Leon-Murville-Mandarin. Leon fine sand (Aeric Haplaquod), Murville mucky fine sand (Typic Haplaquod), and Mandarin fine sand (Typic Haplahumod) are nearly level soils with poor drainage, slow runoff, rapid to moderate permeability, low water capacity, and low pH (3.6-5.5). Several soils of minor extent occur throughout the site. Kureb fine sand (Spodic Quartzipsamment) on the sand ridges is excessively drained soil with slow runoff, rapid permeability, very low water capacity and low pH (4.5-7.3)(Barnhill 1986).

Soil texture of the A horizon is 98% sand, 1.5 % loam, 0.5% clay. The E horizon (99% sand, 0.5% loam, 0.5% clay) is a zone of leaching in which C passes through with very little accumulation until it reaches the B horizon. The B horizon (98% sand, 0% loam, 2% clay) is the zone of accumulation as the movement of carbon is reduced as it reaches the hardpan formed by clay particles in the soil matrix and reacts with the increased moisture. Stratification of the soil results in changes in water movement. The change in texture from that of the overlying material results in conductivity differences which prevent rapid downward movement of water as it reaches the hardpan (Brady 1974).

Sampling methods

This study adopted the North Carolina Vegetation Survey Protocol (Peet *et al*. 1997) to characterize the vegetation associations The choice of this protocol was made because (1) it has been demonstrated to be appropriate for a wide range of applications, (2) is scale transgressive [to address issues of dependence of species richness observations on the scale of observation (Whittaker 1977, Whittaker *et al*. 1979, Shmida and Whittaker 1981)], (3) is data-compatible with commonly used methods of vegetation characterization, (4) is flexible in terms of use and time required, and (5) has a sufficiently open architecture so that it may be adapted to different applications.

The NCVS standard plot is 50 m x 20 m with nested subplots. Thirty one plots were established between June 27 and August 11, 2006. Plots were placed to represent the distinct vegetational assemblages and topographic variation in the study area. Data recorded included estimates of total percent cover for each species found in each plot. Each species was assigned at wetland indicator value (Tables 2 and 3) of upland (UPL), facultative upland (FACU), facultative (FAC), facultative wetland (FACW), or obligate (OBL) (Reed 1988). Numbers of FACW-OBL, FAC, and FACU-UPL species were calculated for each plot. FACs were excluded in the delineation process due to the broad moisture ranges that they can occupy. If a plot had a higher number of OBL-FACW than FACU-UPL then it was considered a hydrophytic plot. If there were more FACU-UPL than OBL-FACW, then plot was considered a xerophytic plot. .From the 31 plots, a subset of 17 plots was chosen for soil sampling for abiotic variables. Plot selection was based on having adequate representation of vegetation associations, location on an elevational gradient, and soil series. Abiotic variables included SOC in the A, E, and B horizons (hereafter, C-A, C-E, and C-B respectively), depth to the B horizon (DTBH), and elevation. Soil cores were drawn from the center of each plot. Depth of soil horizons (A, E, and B) was measured, and individual soil samples were collected from each horizon. Each soil sample was thoroughly dried in a dessicator before being processed for soil organic carbon estimation procedure.

Loss-on-ignition (LOI) was employed to estimate the amount of SOC in the soil samples (Lowther *et al*. 1990, Konen *et al*. 2002). Approximately 10g of soil was weighed to the nearest mg, heated to 440°C for 12 hrs (Barnstead Thermolyne Type 48000, model F48015 Furnace), then weighed again after heating. DTBH was determined by measuring the length of the soil core to the point at which soil colors demonstrated a sharp contrast between the E and B horizon, or where soil colors approached those as defined by the soil survey (Barnhill 1986).

Data analyses

Plant associations were determined through the use of non-metric multidimensional scaling (NMS) and cluster analyses using PC-ORD software (McCune and Mefford 1999). An indirect gradient analysis, NMS has been shown to work well with data that may be non-normal or in which scale may be questionable. There are no assumptions of linear relationships among variables, ranked distances tend to linearize relationships between distances in species space and environmental space, and is flexible in its use of distance measures (McCune and Grace 2002). NMS ordinations were performed using the compliment of Jaccard's index of similarity (1-J) and chord Euclidean distance (CHD) as the distance measures. Jaccard's index is based upon species presence/ absence, and CHD is a measure of distance based on proportional abundances of species.

Canonical correspondence analysis (CCA) was performed using CANOCO (ter Braak 2002) to test the influence of abiotic variable on the structuring of the various plant associations. Ordination axes of CCA are constrained to be linear combinations of environmental variables. Detrendend Correspondence Analysis (DCA) was used as a complementary approach to NMS and CCA to determine relationships among the environmental variable and the plant associations. Økland (1990) provides a discussion as to the various advantages and disadvantages of DCA and concludes that despite its shortcomings, it has proven to be a useful ordination method in many vegetation science applications (e.g., Moral 1983, van der Maarel *et.al*. 1985).

RESULTS

Eighty-five species were recorded in the 31 plots (Table 3). Of these 85 species, 3% were observed in all plots, 10% were found in 75% of the plots, 14% existed in 50% of the plots, 21% were seen in 25% of the plots, and 31% found in <25% of the plots. Eighteen percent were present in only one plot. Thirty species were FACW-OBL, 34 were FAC, and 21 were FACU-UPL.

Ordination

Three axes captured the most information in the distance matrices for both of the NMS ordinations based on presence-absence data (stress= 11.48, p=0.032) (Fig.2) and relative cover (stress= 11.68, p=0.032) (Fig 3.). The sample plots were separated into two groups, hydrophytic and xerophytic, based on the three ordination analyses, suggesting two general vegetation associations defined by a moisture gradient.

For the CCA (Fig. 4) and DCA (Fig. 5) ordinations, the two axes may be broadly interpreted as soil moisture gradient (Axis 1) and % Carbon (Axis 2). The first axis accounted for 23.4% of the variation in the first axis and 9.6% in the second. The xerophytic plots grouped together around the DTBH vector; correlation coefficients of the variables are given in Table 4. This is logical because as DTBH increases, so does the distance to the available water table. The hydrophytic plots were spread amongst the C vectors. C-A was negatively correlated with DTBH (r= -0.418) and elevation (r= -0.459). C-E was positively correlated with C-B (r= 0.467) and negatively correlated with DTBH (r= -0.549). C-B was negatively correlated with DTBH (r= -0.532). The DCA ordination further supported the CCA results by tightly grouping the xerophytic plots around the DTBH vector, and hydrophytic plots where spread among the C-A, C-E, and C-B vectors.

Table 2 . Wetland indicator values of plant species that occur in wetlands under natural conditions (Tiner 1999).

Wetland indicator category	Estimated probability of wetland occurrence	Estimated probability of non-wetland occurrence
Obligate wetland (OBL)	>99%	<1%
Facultative wetland (FACW)	67-99%	1-33%
Facultative (FAC)	34-66%	34-66%
Facultative upland (FACU)	1-33%	67-99%
Upland	<1%	>99%

Table 3. Vascular plant and lichen species found in 31 North Carolina Vegetation Survey plots from June 27 through August 11, 2006 with wetland indicator category.

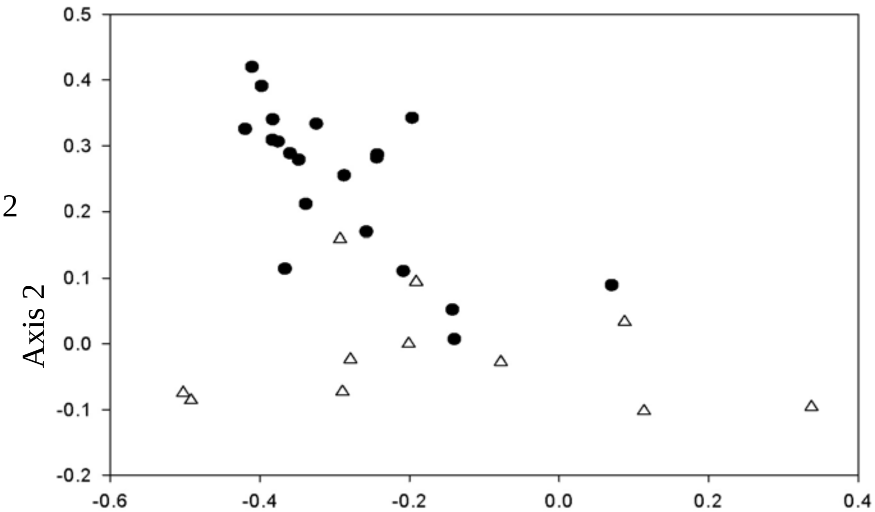
Species	Indicator	Species	Indicator
Acer rubrum L.	FAC	*Lyonia mariana* (L.) D. Don	FAC
Agalinis purpurea (L.) Pennell	FACW	*Magnolia virginiana* L.	FACW+
Ambrosia artemisiifolia L.	FACU	*Morella cerifera* (L.) Small	FAC+
Amorpha herbacea Walter	FAC	*Opuntia humifusa* (Raf.) Raf.	UPL
Andropogon virginicus L.	FACU	*Osmunda cinnamomea* L.	FACW+
Aristida stricta Michx.	FAC-	*Osmunda regalis* L.	OBL
Aronia arbutifolia (L.) Pers.	FAC	*Panicum hemitomon* J.A. Shultes	OBL
Arundinaria gigantea Walter	FACW	*Panicum virgatum* L.	FAC+
Asclepia pedicillata Walter	FACW+	*Parthenocissus quinquefolia* (L.) Planch	FAC
Baptisia cinerea (Raf.) Fernald & Schub.	FAC	*Persea palustris* (Ref.) Sarg.	FACW
Carphephorus tomentosus (Michx.) Torr. & A. Gray	FAC	*Pinus palustris* P. Miller	FACU+
Chamaecrista fasciculata (Michx.) Greene	FACU	*Pityopsis aspera* (Shuttlew. ex Small) Small	FACU
Chamaecrista nictitans (L.) Moench	FACU	*Polygala lutea* L.	FACW+
Cladonia sp.	FACU	*Polygonella polygama* (Vent.) Engelm. & A. Gray	FACU
Clethra alnifolia (L.)	FACW	*Pteridium aquilinum* (L.) Kuhn	FACU
Cnidoscolus stimulosus (Michx.) Engelm. & A. Gray	UPL	*Pyxidanthera barbulata* Michx.	FAC
Cyrilla racimiflora L.	FACW	*Quercus geminata* Small	FAC
Dichanthelium dichotomum (L.) Gould	FAC	*Quercus incana* Bartram	FAC
Diospyros virginiana L.	FAC	*Quercus laevis* Walter	FAC
Eupatorium leucolepis (DC) Torr. & A. Gray	FAC	*Quercus nigra* L.	FAC
Euphorbia ipecacuanhae L.	UPL	*Rhexia alifanus* Walter	FACW
Galactia regularis (L.) Britton	FACU	*Rhexia lutea* Walter	FACW+
Gaylussacia dumosa (Andrews) Torr. & A. Gray	FAC	*Rhexia petiolata* Walter	FACW+
Gelsemium semperivens (L.) Aiton	FAC	*Rhododendron viscosum* (L.) Torr	FACW+
Gordonia lisianthus (L.) Ellis	FACW	*Rhus copallinum* L.	FAC
Hydrocotyle bonariensis Comm. ex Lam.	FACW	*Rhynchospora megalocarpa* A. Gray	FAC

Hypericum crux-andreae (L.) Crantz.	FAC	*Rubus argutus* Link	FACU+
Hypericum tenuifolium Pursh	FACU	*Sassafras albidum* (Nutt.) Nees	FACU
Ilex cassine L.	FACW	*Schizachyrium scoparium* (Michx.) Nash	FACU
Ilex coriacea (Pursh) Chapman	FACW	*Scleria ciliata* Michx.	FAC
Ilex glabra (L.) A. Gray	FACW	*Smilax laurifolia* L.	FACW+
Ilex opaca Aiton	FAC-	*Stipulicida setacea* Michx.	UPL
Juncus polycephalus Michx.	OBL	*Stylisma patens* (Desr.) Myint	FAC
Kalmia buxifolia (P.J. Bergius) Gift, Kron, & Stevens	FAC	*Tephrosia hispidula* (Michx.) Pers.	FAC
Lachnanthes caroliniana (Lam.) Dandy	OBL	*Toxicodendron radicans* (L.) Kuntze	FAC
Lachnocaulon anceps (Walter) Morong	OBL	*Vaccinium arboreum* Marshall	FACU
Lachnocaulon compressum Lam.	FACW	*Vaccinium crassifolium* Andrews	FAC+
Lespedeza angustifolia (Pursh) Elliott	FACU+	*Vaccinium tenellum* Aiton	FACU-
Liatris pilosa (Aiton) Willd	FAC	*Vitis rotundifolia* Michx	FAC
Liquidambar styraciflua L.	FAC+	*Woodwardia virginiana* (L.) Sm	OBL
Lobelia canbyi A. Gray	OBL	*Xyris caroliniana* Walter	FACW+
Ludwigia virgata Michx	OBL		
Lycopodiella alopecuroides (L.) Cranfill	FACW		
Lyonia lucida (Lam.) K. Koch	FACW		

Table 4. Weighted Pearson correlations among environmental variables used in the Canonical Correspondence Analysis. DTBH= depth to B horizon , C-A= % carbon in the A horizon, C-B= % carbon in the B horizon, C-E= % carbon in the E horizon

	C-A	C-E	C-B	DTBH	Elevation
C-A	1.000	0.188	0.305	-0.418	-0.459
C-E	0.188	1.000	0.467	-0.549	0.092
C-B	0.305	0.467	1.000	-0.532	-0.321
DTBH	-0.418	-0.549	-0.532	1.000	0.204
Elevation	-0.459	0.092	-0.321	0.204	1.000

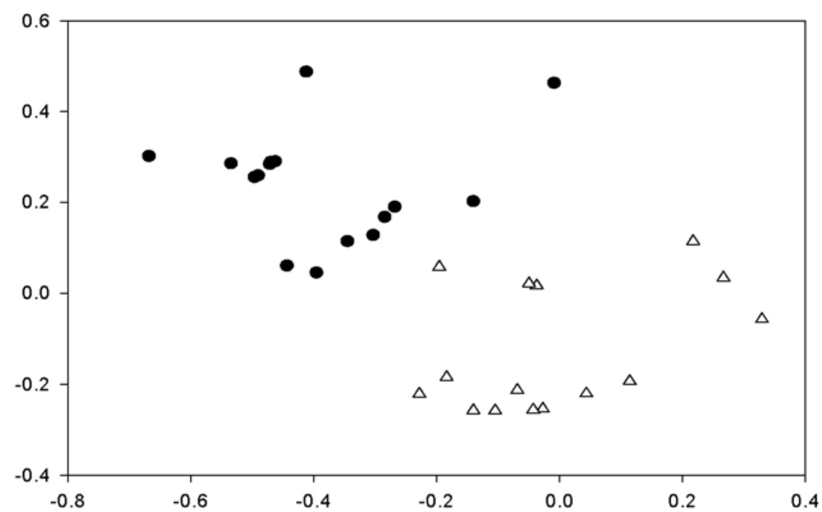
Axis 2



Axis 1

Figure 2. NMS of 31 plots based on species presence-absence. Symbols indicate plots dominated by hydrophytic (△) and xerophytic (●) species.

Axis 2



Axis 1

Figure 3. NMS of 31 plots based on proportional abundance of species. Symbols indicate plots dominated by hydrophytic (△) and xerophytic (●) species.

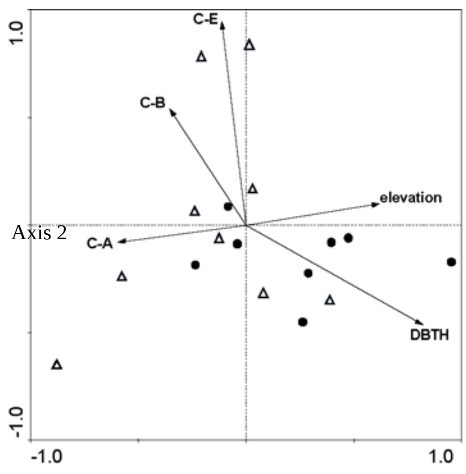


Figure 4. Canonical correspondence analysis (CCA) of 17 plots based on proportional abundance of species (as chord Euclidean distance). Environmental variables are shown to scale as vectors. Symbols indicate plots dominated by hydrophytic (△) and xerophytic (●) species. (DTBH= depth to B horizon , C-A= % carbon in the A horizon, C-B= % carbon in the B horizon, C-E= % carbon in the E horizon)

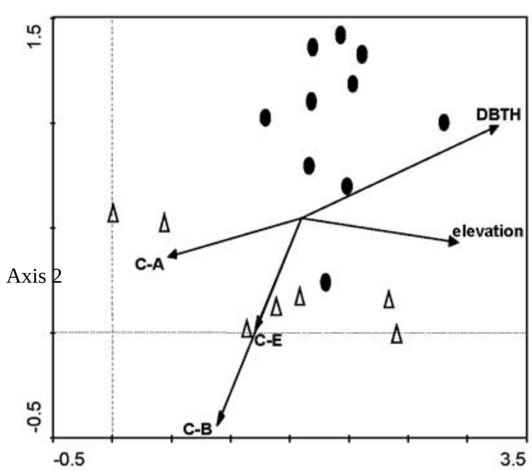


Figure 5. Detrended correspondence analysis (CCA) of 17 plots based on proportional abundance of species (as chord Euclidean distance). Environmental variables overlain as vectors Symbols indicate plots dominated by hydrophytic (△) and xerophytic (●) species. (DTBH= depth to B horizon , C-A= % carbon in the A horizon, C-B= % carbon in the B horizon, C-E= % carbon in the E horizon)

DISCUSSION

Ordinations of the plots support the hypothesis that moisture is a significant factor in structuring the vegetation in this particular site. Both NMS ordinations of xerophytic and hydrophytic plant associations suggest a moisture gradient along Axis 1 (Figs. 2 & 3).

The CCA and DCA ordinations (Figs. 4 & 5) also group plots apparently along gradients of abiotic variables that serve as proxies for moisture availability. This is most readily evident in the xerophtyic plots which are positively correlated with the elevation and DTBH vectors. The positive correlation (r= 0.204) of elevation and DTBH is a reasonable expectation; increasing DTBH with increasing elevation results in decreased proximity to the soil layer of highest moisture, therefore favoring the establishment of xeric-adapted taxa. Elevational gradient is one of the most important factors in structuring vegetation in savannas because, as rainwater percolates rapidly through the highly weathered, porous, upslope soils, water perches at the impermeable layer of clay at the B horizon(Martin and Smith 1991). This water seeps laterally out of the hillside as this clay layer nears the surface (Olson and Platt 1995). Soil characteristics, such as the ones investigated in this study, are influenced by this perched water table as it nears the surface along the elevational gradient (Rome 1988, Roberts and Oosting 1958, Christensen 1977). As soil moisture increases, savannas give way to pocosins. The gradient from the middle of the savanna to the pocosin margin is predominantly one of increasing soil moisture, but Brady (1974) suggests the amount of water is generally influenced by texture, soil structure and SOM. These factors, along with elevational gradient, cause changes seen in soil water retention and height of the water table (Roberts and Oosting 1958), and as is evident in the ordinations, results in plant association responses to the available moisture.

The negative correlation between DTBH and C-B (r= -0.532) suggests that there is less SOM, the principle source of SOC, at ground-level and the A horizon, resulting in low accumulation of SOC in the B horizon. In general, SOC declines with intensive management systems (Sparrow *et al*. 1999) and tends to decrease with increasing soil depth due to reduced biological activity including root growth. Reasons for this decrease include increased decomposition due to elevated soil surface temperatures and drying of the soil (Aust and Lea 1991, Munson *et al*. 1993, Hofstede *et al*. 2002, Hofstede 1995), reduced organic litter inputs from above- and below-ground litter (Busse *et al*. 1996) and changes in SOM quality from organic matter inputs. Wind and water movement across the tops of ridges and upslope areas of the site have resulted in erosion of SOM. Redistribution of soil results in redistribution of SOC (Eynard *et al*. 2005) causing a positive feedback whereby as SOM declines, soils are less water retentive, and as a result, decomposition increases with further declines in SOM and SOC (Paitek and Allen 2001).

Positive associations of the hydrophytic plots with the C-A, C-E, and C-B vectors suggest interactions between moisture and SOC accumulations. The negative correlation between elevation and C-B and C-A is expected because, through erosion and rapid oxidation, low amounts of SOM accumulate on these steeply sloping, well-aerated soils (Kleiss 1970, Maol *et al*. 1974, Schimel *et al*. 1985), and these soils usually exhibit differing morphologies along the elevational gradient because of changes in microclimate, vegetation, and moisture status (Birkeland 1974). Moisture controls SOC storage by lowering redox potential and decreasing decomposition of SOM (Shuur *et al*. 2001). The DCA ordination supports the CCA ordination (Fig. 5).

Management implications

This study has demonstrated that plant associations in this site are correlated with a moisture gradient. Since it was known that moisture is one of the primary limiting resources in this system type, management goals should address means of mitigating for loss of moisture, providing a conducive growing environment prior to restoration planting.

Generally, the first steps in restoring this type of ecosystem are to either burn or remove the existing pine plantation trees. This practice may not be prudent as it either eliminates or volatilizes a readily available source of organic material. Initial steps should be taken to increase SOM in the soil surface through the incorporation of plant litter, either through roller-chopping or chipping and discing. Plant litter can play an important role in structuring plant communities in unproductive or arid environments by directly and indirectly affecting individuals and populations (Sydes and Grime 1981, Carson and Peterson 1990, Facelli and Pickett 1991) such as mediating stressful environmental conditions (*e.g*., low moisture levels; Fowler 1986) and reducing soil erosion.

Increasing SOM will also increase the moisture and SOC budget available to colonizing plant taxa. SOM is one of the factors that contribute to high water retention capacity by promoting the formation of stable soil aggregates capable of holding capillary and hygroscopic water (Nanzyo *et al*. 1993), however, stablishment of pine plantations through site preparation and intensive management methods alters inputs of SOM in both quality and location(Jackson *et al*. 2000, Guo and Gifford 2002). Pines contribute litter to the soil surface which decomposes more slowly and is not readily incorporated into the subsurface, but in systems where soil moisture is important in retarding decomposition and retaining SOC, the loss of water retention after afforestation may be the dominant cause of C loss. The change from herbaceous to woody vegetation can cause rapid changes in ecosystem water balance (Jackson *et al*. 2000, Duncan 1995, Fahey and Watson 1991).

Initial planting and restoration efforts should focus on increasing herbaceous components, especially wiregrass (*Aristida stricta*). Inclusion and expansion of grass in management systems has shown to be the best means of maintaining SOC in the soil and minimizing losses and redistribution of C from wind, water, and tillage erosion. Grasslands and savannas form extensive underground root systems thought to be the major source of below-ground SOM (Scott et al. 1999; Guo and Gifford 2002). Wiregrass is also important because of its high pyrogenicity (Clewell 1989; Outcalt 1992; Outcalt et al. 1999) and structural dominance of ground cover (Noss 1989; Glitzenstein et al. 1995).

Prescribed burn regimes should also be scheduled to optimize the effect on the vegetation. Timing (season) and frequency of prescribed burns can greatly influence successful, naturally recruited wiregrass seedling establishment. Optimal burn regimes for wiregrass expansion include variation in timing and frequency of fire to permit greater opportunities for successful natural recruitment and establishment. In particular, a growing season burn for seed protection followed by 1-2 years without another growing season will likely increase natural wiregrass recruits (Mulligan and Kirkman 2002). Mortality of first and second-year summer burns suggests that season of burn may be more important to wiregrass seedling survival than age at this early stage of development.

The elimination of seedlings with growing season fire could be the result of high ambient temperature (Robbins and Myers 1992, Glitzenstein *et al*. 1995, van Eerden 1997), however, increased SOM many mitigate the effects of fire and low moisture availability.

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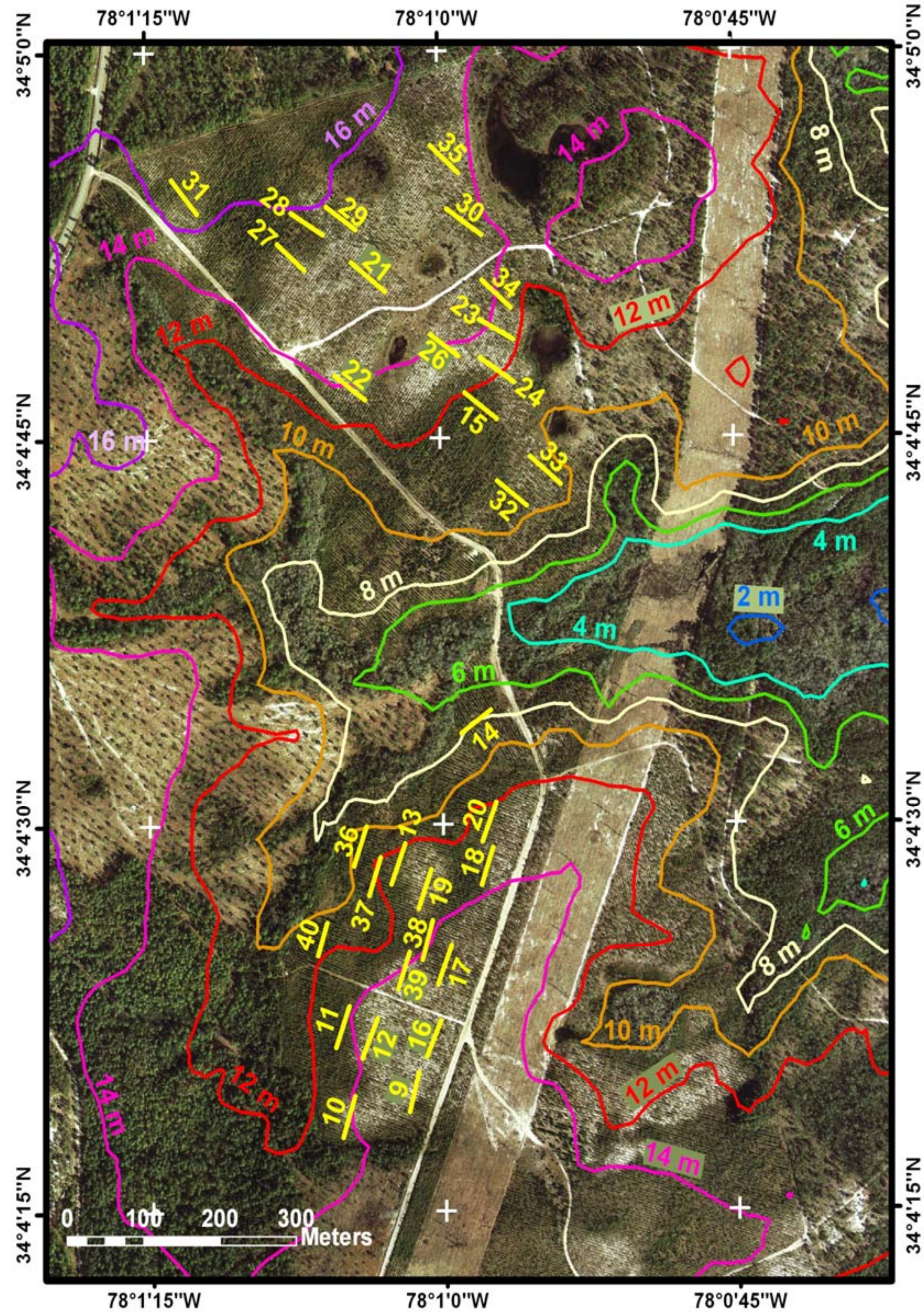
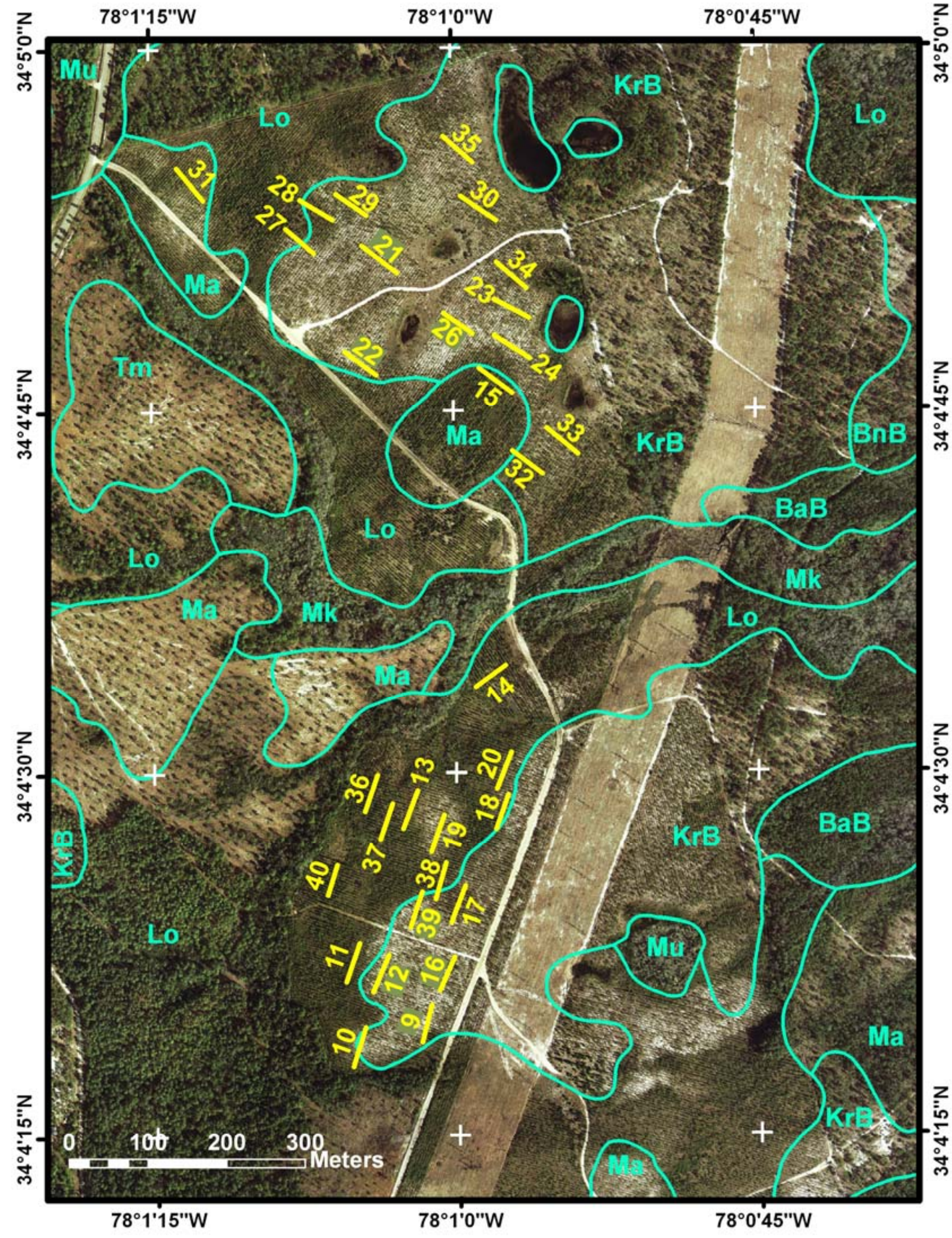
Appendix A. Location of plots 9-40 on topographic map of longleaf pine restoration site.



Appendix B. Location of plots 9-40 on soil survey map of longleaf pine restoration site.



Appendix C. GPS coordinates for NCVS plots in longleaf pine restoration site

GPS coordinates for plots in BSL

Plot # (Tag #)	0 meter n	0 meter w	50 meter n	50 meter w	info.
9	34 04.346	78 01.019	34 04.313	78 01.030	
10	34 04.324	78 01.077	34 04.299	78 01.069	
11	34 04.383	78 01.081	34 04.357	78 01.090	
12	34 04.374	78 01.058	34 04.374	78 01.069	
13	34 04.479	78 01.030	34 04.462	78 01.040	
14	34 04.574	78 00.958	34 04.563	78 00.981	
16 (929)	34 04.372	78 01.008	34 04.356	78 01.018	
17 (928)	34 04.423	78 00.993	34 04.394	78 01.003	
18 (925)	34 04.483	78 00.958	34 04.456	78 00.970	
19 (926)	34 04.476	78 01.006	34 04.446	78 01.024	
20 (924)	34 04.517	78 00.959	34 04.490	78 00.964	
36 (980)	34 04.488	78 01.077	34 04.473	78 01.078	
37******	34 04.480	78 01.052	34 04.455	78 01.062	
38 (927)	34 04.437	78 01.010	34 04.415	78 01.021	
39 (930)	34 04395	78 01.039	34 04.419	78 01.029	
40 (931)	34 04.412	78 01.111	34 04.435	78 01.098	
(989)	34 04.903	78 01.201	34 04.920	78 01.226	
(995)	34 04.859	78 01.114	34 04.879	78 01.137	
(996)	34 04.881	78 01.089	34 04.897	78 01.125	
(997)	34 04.883	78 01.067	34 04.891	78 01.100	
(985)	34 04.921	78 00.983	34 04.936	78 01.006	
(1000)	34 04.874	78 00.953	34 04.900	78 00.986	
(994)	34 04.847	78 01.046	34 04.862	78 01.072	
(987)	34 04.854	78 00.968	34 04.837	78 00.939	
(981)	34 04.826	78 00.963	34 04.812	78 00.936	
(983)	34 04.801	78 00.964	34 04.788	78 00.936	
(984)	34 04.818	78 01.006	34 04.802	78 00.981	
15	34 04.787	78 00.974	34 04.778	78 00.957	
(991)	34 04.741	78 00.923	34 04.721	78 00.896	
(999)	34 04.722	78 00.949	34 04.704	78 00.925	
(990)	34 04.790	78 01.084	34 04.769	78 01.053	
42	34 04.167	78 01.041	34 04.157	78 01.011	
45	34 04.211	78 01.023	34 04.185	78 01.037	
44	34 04.226	78 01.003	34 04.194	78 00.997	
47	34 04.284	78 00.988	34 04.274	78 00.959	
48	34 04.314	78 00.980	34 04.290	78 00.965	
46	34 04.373	78 00.952	34 04.364	78 00.927	