A SYNTHESIS OF RIGHTS-OF-WAY NATIVE PLANT COMMUNITIES: IDENTIFYING THEIR RELEVANCE TO HISTORICAL AND CONTEMPORARY PIEDMONT SAVANNAS

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ABSTRACT

NICHOLAS S. ADAMS: A synthesis of rights-of-way native plant communities: identifying their relevance to historical and contemporary Piedmont savannas
(Under the direction of Robert K. Peet, John L. Randall, and Alan S. Weakley)

The presettlement Piedmont landscape supported an apparent abundance of fire-maintained landscapes, including Piedmont savannas. A loss of fire on the natural landscape led to a decline of fire-tolerant, sun-loving native herbaceous plants that had persisted for thousands of years. These plants are now restricted to few natural areas, and a suite of rights-of-way where frequent mowing has favored them. There is great interest within the conservation community in restoring these management-intensive savanna landscapes.

Thirty-one rural rights-of-way displaying savanna-like herbaceous vegetation in the North Carolina Piedmont were surveyed in order to build a reference for managers wishing to restore savannas. Four distinct vegetative groups and their environmental preferences were identified. This information was then used to determine which group(s) should be prescribed for a restoration site at Mason Farm Biological Reserve.

DEDICATION

To Margaret and Robbie for their naturalistic spirits, and to my father and mother for fostering my respect for and appreciation of nature.

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INTRODUCTION

The once widespread Piedmont savanna was prominent on the landscape due to natural and anthropogenic fires. The relatively recent loss of Piedmont savannas, and transition to a landscape dominated by closed-canopy forests where natural areas remain, can also be traced to human activity. Remnant savanna-like vegetation now persists on only a few sites, typically where humans have continued to manage for open-canopied landscapes or for woody plant control. Concurrently, conservation managers are preferentially using prescribed fire as a tool to maintain healthy, productive, and diverse plant communities on natural areas in the Piedmont. Savanna-like vegetation responds positively to these activities, and is gaining ground as a conservation target.

The Piedmont savanna was an important component of the historically widespread open conditions in the Piedmont region, encompassing a range of open-canopied plant communities. The current Piedmont landscape lacks the savanna vegetation that was described by early European explorers. They observed widespread or "ubiquitous" open conditions, including "prairies," "fields," "open wood[land]s," and "savannas" in this region (as cited in Barden 1997). The native vegetation that thrived in such open landscapes is now restricted to a limited number of rather uncommon natural community types, as well as certain maintained landscapes, including rural roadsides and utility rights-of-way (ROWs).

The character of the Piedmont savannas of the southeastern US is not widely discussed in the literature, nor is the success or failure of Piedmont savanna restoration.

The preponderance of temperate savanna studies have been performed in the upper Midwest, the Ozark Plateau, the Interior Low Plateau, and California's Central Valley (e.g., Nuzzo 1986; Haney and Apfelbaum 1995; Allen-Diaz et al. 1999; Abella et al. 2001). These regions harbor a substantial number of remnant savanna sites. Many studies were focused on community descriptions based on historical data and remnant sites (e.g., Curtis 1959; Nuzzo 1986; Leach and Givnish 1999). The restoration of these community types through the renewal of natural disturbance, such as fire, has also been investigated (e.g., Kettle et al. 2000; Prober et al. 2005; Peterson et al. 2007; Harrington and Kathol 2009). For example, Kettle et al. (2000) examined the long-term effects of management and initial site conditions on an oak-hickory prairie-forest ecotone and found that burning and mowing effectively prevent or reduce woody plant establishment while promoting herbaceous community persistence. Managers in the Piedmont have, within the past two decades, been mimicking these activities, but results are not well documented.

The decline in presence of open plant communities has prompted studies that explore historical documentation of such communities in the Piedmont, as well as studies on how to restore them (e.g., Waldrop et al. 1992; Barden 1997; Juras 1997; Frost 1998; McRae 1999; Davis et al. 2002; Taecker 2007; Yelton 2007). These studies only represent a portion of the historical variability of open Piedmont landscapes. More studies are needed to document remnant vegetation in a variety of open areas so as to provide more comprehensive reference species lists for the restoration of open plant communities in the Piedmont.

The vegetation of Piedmont savannas includes native, non-ruderal heliophytes that persist in habitats where an open canopy is maintained, either through anthropogenic processes such as fire or mowing, or non-anthropogenic processes such as lightning-caused fire, grazing, or extreme physical conditions. The loss of this type of maintenance or human influence in the adjacent woodlands contributed to the loss of savanna-like vegetation. Heliophilic herbs have persisted without anthropogenic influence on various documented natural communities including glades, barrens, and hardpan woodlands. These sites are physically extreme in that the character of the soil is not conducive to the establishment of roots due to high clay content, a shallow, rocky character, nutrient deficiency, or a combination of these. These sites are not abundant. Heliophilic herbs have also persisted in the Piedmont on many ROWs where trees have been prevented from colonization by mowing or, more recently, herbicide use. However, these patches are probably not perfect replicas of historical open community types. Rights-of-way do provide us with some useful information in understanding the habitat of heliophilic herbs, as they have persisted there for decades. In fact, ecologists and botanists have regularly sought and returned to roadsides for their display of heliophilic plants (e.g., Radford, et al. 1968 and Weakley 2011 refer to many species as often found on "road banks" and "roadsides").

Conservation biologists have expressed interest in describing and restoring the Piedmont savanna community type due to its noted former extent, its importance to the natural and cultural heritage of the Southeastern Piedmont, and its importance in harboring several rare or threatened species. Ecologists have recognized fire suppression and the loss of grazing as significant factors in the major shift of plant communities in the Piedmont toward closed canopy forests, nearly devoid of heliophilic herbs (Peet and Christensen 1980; Taverna et al. 2005; Schwartz 2007). The challenge remains to “reproduce” the Piedmont savanna without many local reference areas—there are few documented natural communities that support savanna-like vegetation, and many scattered occurrences of such species on rural rights-of-way (ROWs). Rights-of-way sites are, in some views, highly artificial. However, the rehabilitation of a Piedmont savanna might be especially reliant on roadsides with remnant savanna vegetation, especially in light of the lack of “ideal” remnant savannas. White and Walker (1997) emphasized the importance of utilizing all components of reference information in guiding restoration projects so that a more comprehensive picture of the restoration target can be captured.

This thesis contains three chapters. Chapter 1 is a qualitative review and description of the Piedmont savanna vegetative community. Chapter 2 is a quantitative investigation of remnant savanna vegetation found on rights-of-way within an approximate 50 km radius of the Mason Farm Biological Reserve in the North Carolina Piedmont. Chapter 3 uses the plant species and environmental data gathered in Chapter 2 to provide an approximate target for which species would fit best on a savanna restoration site at the Mason Farm Biological Reserve based on edaphic conditions.

CHAPTER 1: A REVIEW OF THE PIEDMONT SAVANNA

1.1 Introduction

There is very little discussion of the Piedmont savanna in the literature. Juras (1997) synthesized historical documentation of savanna-like landscapes in the Southeastern Piedmont, and drew on descriptions of other temperate savannas to project the character of Piedmont savannas. However, further corroboration of the character of Piedmont savannas is needed. Piedmont prairies, a similar community type, are better studied, but they represent only a portion of the variability of plant communities with an herb-rich ground layer and more open canopy. Generally speaking, today most natural communities in the Piedmont are characterized by forests with a high level of canopy cover and a ground layer populated sparsely by mostly shade-tolerant herbs. This characterization is in contrast to the widespread open landscapes that European explorers described in the 16th-19th centuries (**Table 1.1**). In this chapter, I characterize the Piedmont savanna and discuss its natural history and the anthropogenic factors that contributed to its persistence and subsequent demise.

1.2 Savanna characterization

Cole (1986) reported that Oveido y Valdes' (1535) original definition of savannas (grasslands devoid of trees) was broadened sometime in the 19th century to include a variable, yet light cover of trees. The dominant understanding of what defined savannas at the time of Cole's publication was that savanna distribution has been driven primarily by climate. She asserted that savannas occur between the tropics and mid-latitude deserts, and are composed of tropical grasses, which are physiologically distinct from temperate grasses. However, the definition now includes temperate communities that exhibit savanna (or at least savanna-like) characteristics—those with a varying open canopy and grass and forb-dominated understory. These temperate savannas in the US include Midwestern oak savannas ranging from Wisconsin to Arkansas (Curtis 1959; Nuzzo 1987; Guyette and Cutter 1991), lowland temperate savannas, for example, in Ohio and Kentucky (Apfelbaum and Haney 1990), pine-dominated savannas of the southeastern Coastal Plain (Platt 1999, Peet 2006) and Piedmont savannas (Juras 1997; Barden 1997). Although the historic extent of Piedmont savannas is unknown, the presence of savanna-like vegetation and landscapes was described by early European explorers, and likely maintained for thousands of years by fire and grazing. Here, I define a Piedmont savanna as a community with varying tree cover of 10-60%, and a diverse mixture of light-demanding or shade-intolerant perennial grasses and forbs ("heliophilic herbs") in the understory. This definition captures the few remaining examples of documented natural savanna communities, but is also meant to be useful for savanna restoration targets.

Generally speaking, the savanna community type is considered a transitional community between prairie and closed forests, and is dominated by grasses and forbs in the understory and with scattered trees in the overstory (Zedler 2007). Packard and Mutel (1997) asserted that the savanna is distinct because it harbors, in addition to species with prairie and forest affinities, plants, animals, and fungi that are adapted to conditions of filtered or strong but partial sunlight. Savanna communities are favored in climates that are both warm and dry. However, recent studies suggest that grazers and fire are the primary ecological drivers of savanna persistence (e.g., Bond et al. 2005; Sankaran et al. 2005; and Staver et al. 2009).

While there are few remaining Piedmont savannas, *approximations* of the character of this community have been utilized by some researchers for restoration thus far (e.g., **Figures 1.1** and **1.2**).

Figure 1.1 Piedmont savanna at Ft. Pickett, Virginia (courtesy of R.K. Peet).

Figure 1.2 Artist's concept of the historical Piedmont savanna. Reprinted with permission by the artist and author (Juras 1997).

A small number of remnant Piedmont savannas, or woodland communities that could be characterized as such, have been documented in Virginia, North Carolina, and South Carolina. These communities are referred to as "oak woodland" at times in the technical reports. Two of the few known remnant Piedmont savanna sites are located on military bases in Virginia and are subject to a high frequency of fire due to artillery impact (Fleming et al. 2001). Fleming et al. (2001) documented an oak-hickory savanna at Quantico Marine Corps Base, while mentioning a similar occurrence on Fort A.P. Hill, and Fleming and Van Alstine (1994) document oak-hickory savanna at Fort Pickett Maneuver Training Center. On the Uwharrie National Forest in North Carolina an area of less than 70 hectares of "oak woodlands" persists, in this case synonymous with savanna (Uwharrie National Forest 2011). Sites in South Carolina include a post oak savanna on Sumter National Forest land (NatureServe 2004). A table of contemporary documented natural communities of Piedmont savannas can be found in **Table 1.2**.

Not all researchers recognize historic widespread occurrence of Piedmont savannas. Anderson et al. (1999) suggest that in the Eastern US primarily the geographic and climatic conditions of the Midwest favor savannas, including large fire compartments and seasonal drought. The Piedmont is subject to seasonal drought, but fire compartments are not as large as those found on the southeastern Coastal Plain or in the Midwest (Frost 1998). Piedmont savannas, nevertheless, contain numerous fire-tolerant and somewhat fire-responsive prairie and forest species similar to those of the Midwestern oak savannas and somewhat similar to Coastal Plain savannas. Cowell (1998) provided historical evidence showing that woodland canopy composition has changed since pre-settlement times in the Georgia Piedmont where hardwood dominated uplands were generally more fire tolerant and contained species also commonly found on Midwestern savannas such as post oak (*Quercus stellata*), blackjack oak (*Quercus marilandica*), and shortleaf pine (*Pinus echinata*). These species occur on drier sites in the Piedmont, which have been associated with higher fire frequency and dependence (Schafale and Weakley 1990; Frost 1998).

Piedmont savannas differ from the longleaf pine savannas on the Coastal Plain in both floristic composition and topographic character. Examples of compositional differences between the two include pine versus oak canopy dominance (Coastal Plain vs. Piedmont, respectively) and floristic diversity (see Peet 2006 for discussion of longleaf pine savanna, Fleming et al. 2001 for Piedmont savanna (oak woodland/savanna), Sechrest and Cooper 1970 for an analysis of upland communities in the Piedmont and Coastal Plain). Additionally, fire-return intervals differ for physiographic regions. Fire compartment size in the Coastal Plain is much larger than in the Piedmont where there is greater and finer-scale topographic relief. Presettlement fire-return intervals for the Coastal Plain were typically 2-4 years, whereas they are estimated to have been at 4-7 years for the Piedmont (Frost 2000). Despite these distinctions, there remains a large degree of floristic overlap.

The Midwestern oak savannas vary greatly, but in most cases include an oak-dominated canopy, as well as many genera of herbs similar to those found on Piedmont prairies and savannas (Anderson et al. 1999; Packard and Mutel 1997). Overlap at the generic level of familiar Piedmont associates include, for example, *Andropogon*, *Schizachyrium*, *Silphium*, *Parthenium*, *Liatris*, *Sorghastrum, Helianthus,* and *Baptisia,* among many others. Presettlement fire return intervals of savannas and prairies in the Midwest varied, typically falling somewhere between 2 and 3 years. The range was dependent on historical human activity in the area and topographic context (Cutter and Guyette 1994; and McClain et al. 2010).

Although forbs and C4 grasses dominate Piedmont prairies, and thus the herbaceous layer of savannas, there is also a mixture of early and late C3 (cool-season) grasses that respond to spring and autumn climate, including *Danthonia*, *Elymus*, and some species of *Dichanthelium*. Remnant Piedmont prairies also tend to occur on clayey substrates, to which graminoids and forbs are well adapted. These clayey substrates can be physically harsh enough to slow ecological succession by deterring woody plant root growth (Davis et al. 2002; Schafale and Weakley 1990).

The Piedmont savanna is a largely historical community type that harbored heliophilic herbs and a varying and open canopy of trees. It occurred on Piedmont uplands, and was largely dependent on disturbance in the form of fire, grazing, or mowing. There are few extant examples of Piedmont savanna. Remnants of open-canopied, savanna-like communities that remain in the Piedmont are dependent on either chronic disturbance (such as fire, grazing, or mowing), or physically unusual sites (such as glades, barrens, or hardpan soils). These examples, along with other North American temperate savannas, inform our understanding of the possible range of variability of a Piedmont savanna. The distinction of Piedmont savannas from Piedmont prairies and woodlands in the definition here is defined by a canopy structure of 10-60% cover, falling between that of a prairie and woodland. Although there are few extant examples of Piedmont savannas, heliphilic herbs that respond positively to chronic disturbance also exist on roadsides and utility rights-of-way (ROWs) where disturbance from mowing has provided favorable conditions for these associates. These sites are not very abundant. This seemingly drastic loss of Piedmont savanna begs a discussion of the conditions in the Piedmont that were once favorable for this plant community.

1.3 Natural history of Piedmont savannas

Many European travelers encountered widespread open conditions along their travel routes in the Piedmont of the southeastern United States from the 16th through the 19th centuries (Rostlund 1957; Barden 1997). Barden (1997) collated accounts of pre-settlement European travelers who described the landscape they encountered in the Piedmont region of what is now North and South Carolina. There are several references to savannas ("savanae," prairies, old "Indian" fields, etc.) throughout the travelers' descriptions. The travelers (including Hernando de Soto, Juan Pardo, John Lederer, John Speed, John Lawson, Mark Catesby, John Adair, and William Bartram (see Barden 1997)) also noted the openness, and almost "park-like" appearance of southeastern woodlands (Rostlund 1957; Barden 1997). While much of this characterization of southeastern savannas is anecdotal, other remnant North American savannas have been described in qualitative, but more descriptive, terms (McPherson 1997; Taft 1997; Anderson et al. 1999; Fleming *et al*. 2001; Fleming and Van Alstine 1994). Detailed descriptive information, both qualitative and quantitative, is lacking for Piedmont savannas.

Pollen records indicate that even before the first humans arrived in the Southeast, there were many heliophilic herbs present on the landscape (Delcourt and Delcourt 1997). Unfortunately there is no quantitative evidence of the historical abundance of heliophilic herbs on the Piedmont owing to the mature topography and the consequent lack of a pollen record. However, the oak-pine forests described by Kuchler (1964), likely exhibited a more open character, similar to most of the oak-dominant woodlands in the Eastern US (Abrams 1992; Carroll et al. 2002). These dominant tree species, along with heliophilic herbs, have persisted here historically due to many contributing factors, though primarily grazers and lightning- and human-induced fires (Juras 1997; Stanturf, et al. 2002; Fowler and Konopik 2007).

The open, natural, savanna-like landscapes described by early European explorers were greatly reduced in extent over the course of European settlement of the Piedmont of the southeastern US. This occurred for four reasons: 1) The conversion of land to agriculture during European settlement (especially existing prairies/savannas); 2) the introduction of domestic animals; 3) extensive timber harvesting during the 19th century; and 4) fire suppression since at least the 1920s (Carroll et al. 2002).

Initiated by a push from the United States Department of Agriculture, fire suppression was placed in practice in 1924 on all federal lands in order to mitigate timber loss (Stanturf et al. 2002). Fire suppression led to the rapid succession of many open woodlands to closed-canopy forests. The result is that the native vegetation that thrived in once widespread, open landscapes now exists on a limited amount of natural area, including some rural roadsides and utility rights-of-way.

There are few remaining examples of Piedmont savannas. The present-day natural areas of the Piedmont are largely characterized by woodlands or forests with closed canopies that lack light-demanding forbs and grasses. However, we can infer that savannas, along with associated grasses and forbs (or heliophilic herbs), were much more prominent on the Piedmont landscape prior to the settlement of Europeans in the area. Ecological drivers that influenced the persistence of the Piedmont savanna are discussed below and include: 1) climate, 2) substrate, 3) large mammalian grazers, and 4) fire (Bond et al. 2005; Sankaran et al. 2005; and Staver et al. 2009). Of these four drivers, grazers and fire qualify as disturbances defined by Lomolino, Riddle, and Brown (2006): events that alter the successional process that would otherwise lead to closed-canopy forests. Anthropogenic use of fire, according to most researchers, gradually replaced non-anthropogenic fires as the most important disturbance feature in the Piedmont of the SE US for maintaining open habitat from the arrival of humans approximately 14,000 years ago (Fagan 2000, as cited in Stanturf et al. 2002) through the early part of European settlement (Harmon 1982; Van Lear and Waldrop 1989; Barden 1997; Frost 2000).

Climate

During the latter part of the Pleistocene epoch (through approximately 12 ka), lower CO_2 levels led to an increase in C4 grasses in the Piedmont. This, along with a cooler and drier climate, yielded a dominance of boreal, "meadow" or prairie-like vegetation, mixed with northern hardwood species (Delcourt and Delcourt 1979 as cited in Carroll et al. 2002). Regional temperatures then began to steadily increase, in some zones as much as 5°C (Delcourt and Delcourt 1979). The warming trend during the beginning of the Holocene was coupled with an increase in annual precipitation (estimated to increase from approximately 50-75 cm/y to100-150 cm/y), which contributed to a change of plant community composition in the region. Specifically, oak-hickory woodlands have since dominated the southeastern Piedmont. However, the continued pressure from grazers and fire, as well as harsh substrates, ensured more widespread open canopies of these woodlands for thousands of years. The open canopies provided habitat for heliophilic grasses and herbs, which responded positively to these conditions.

Substrate

Some Piedmont substrates can limit where woody plants become established. Particularly noteworthy in the persistence of open areas is the presence of intrusive rock leading to thin soils, barrens, or hardpan soils (Schafale and Weakley 1990; Anderson et al. 1999). These geologic features provide physical barriers and occasionally create chemical conditions that affect the establishment and composition of woody plants. Intrusive rocks weather to shallow soil, and can physically impede the establishment of woody plants. Additionally, these uncommon soils on intrusive rock typically support a rich herb layer, including a handful of species (some of which are rare) that are adapted to these uncommon nutrient conditions or clay minerology (e.g., *Echinacea laevigata*, *Silphium terebinthinaceum,* and *Lithospermum canescens*). Barrens are areas where the substrate is often exposed, and soil layers are quite thin where not exposed. Woody plants are therefore greatly limited by these physical conditions. Hardpan soils are derived from a handful of Piedmont substrates owing to soils with a high magnesium to calcium ratio differentially weathering to montmorillonitic clays, which produce shrink-swell soils that are exceptionally hard when dry and saturated when wet, restricting root establishment, sometimes breaking the roots, and yielding distinctly open canopies (Schafale and Weakley 1990).

Large mammalian grazers

The historical development and persistence of grasslands in the SE Piedmont could also be attributed in part to the presence of large grazers paired with climatic conditions during the Pleistocene and early Holocene epochs. Around 16,000-18,000 years ago, during the Last Glacial Maximum (LGM) of the Pleistocene epoch, grazers, relatively drier conditions, and lower atmospheric carbon dioxide levels were important ecological agents in the creation of open, grassy landscapes in the Piedmont (Cowdrey, 1983; Delcourt and Delcourt, 1993; Silver, 1990; Skeen et al. 1993; Juras 1997). According to Bond and others (2005), the influence of grazers as a driving variable for grassland persistence is not clear and may be minimal, even in the seemingly most conspicuous grasslands on Earth, including the African and South American subtropical savannas. They applied a global simulation model to exclude fire from all ecosystem types and found that tree biomass appears to be controlled or reduced at a global scale only by fire. This study challenges the impact of the role of grazers in perpetuating open conditions. However, Martin and Klein (1986) asserted that the disappearance of important grazers, such as the mastodon, ground sloth, and giant bison certainly "altered regional patterns of vegetation."

1.4 Fire

Fire is a disturbance that has played an important role in the distribution and composition of vegetation in the Southeastern US landscape since well before humans arrived on the continent (Waldrop et al. 1992; Stanturf et al. 2002). Fires maintained open vegetation in the Piedmont region, including savannas. Before humans migrated into the SE US, lightning was certainly a recurrent driver of the fire regime (Frost 2000; Fowler and Konopik 2007). Although lightning-caused fires continued to play an important role in the persistence of open vegetative communities in all regions of the Southeast, fire frequency increased after the arrival of humans in the region (Stanturf et al. 2002; Fowler and Konopik 2007).

Humans, who had migrated into the area at the time of the climatic transition at the end of the Pleistocene initiated the use of fire on the landscape (Waldrop et al. 1992; Stanturf et al. 2002; Fowler and Konopik 2007). Native Americans used fire in the SE US to facilitate hunting and enhance gathering grounds, to drive game, to maintain travel routes, and to clear fields for agriculture (Day 1953, Komarek 1974; Harmon 1982; Waldrop et al. 1992; Abrams 1992; Delcourt and Delcourt 1997). Delcourt and Delcourt (1997) suggest that Native Americans greatly increased the frequency and extent of fire near the North Carolina Mountains approximately four to five thousand years ago, as their uses of fire diversified (Fowler and Konopik 2007). An additional increase in anthropogenic fire frequency in the southeastern US was somewhat concurrent with the spread of agriculture in the region during the Woodland period, starting approximately 1,000 years ago (Waldrop et al. 1992; Fowler and Konopik 2007).

Much evidence for active management of open landscapes by Native Americans in the Piedmont is necessarily anecdotal. Frost (1998; 2000) estimated a fire return interval of 4-6 years for the Piedmont, which he extrapolated based on fire scar data from the Coastal Plain and Mountains. Cowell (1998) provided evidence, based on witness tree descriptions that showed that woodland canopy composition had changed over a 200-year interval (late 18th century – late 20th century) in the Georgia Piedmont. He found that hardwood-dominated uplands were generally more fire tolerant and contained species also commonly found on some Midwestern savannas, including post oak and blackjack oak. Cowell's interpretation of his results was that human activities were the prevailing force in the shift of woodland composition in the Georgia Piedmont.

At the beginning of European settlement in the Piedmont (the 18th century), the Europeans used fire to clear agricultural fields (slash and burn) and allowed natural fires to burn (Van Lear and Waldrop 1989). The land was quickly exhausted from erosion coupled with intrinsically low fertility. Subsequently, active fire suppression was implemented on federal lands, via the Clarke-McNary act of 1924, as a means of procuring lumber for industry (Stanturf et al. 2002). Following major fires in the Southeast because of droughts in the 1930s and 1950s, the benefits of prescribed fire were realized and put into practice on federal lands (Stanturf et al. 2002). However, federal lands make up only a small percentage of total area in the Southeast and only 7.7% in North Carolina as of 2010 (Gorte et al. 2012). The compositional change in oak-dominated forests in the eastern US has been widely studied and discussed (e.g., Abrams

1992; McDonald et al. 2002; Taverna et al. 2005). These studies suggest that the loss of frequent ground fires has contributed to a decrease in oak regeneration and an increase in mesophytic species, including red maple (*Acer rubrum*) and beech (*Fagus grandifolia*). Other significant factors contributing to vegetative change in the Piedmont leading to a loss of habitat for heliophilic herbaceous plants include habitat fragmentation, exotic plant species invasions, and selective timber harvesting. These factors were described by Taverna et al. (2005) as contributing to changes in Piedmont forests, and they certainly apply as factors that hinder the persistence of heliophilic herbaceous plants that would thrive in a savanna setting.

The change in forest structure in the Eastern US, including the Piedmont, is direct evidence of the influence of humans on ecological processes. Natural fire and anthropogenic fire both greatly contributed to the persistence and expansion of the Piedmont savanna. Few contemporary land use and management practices have favored Piedmont savanna plants. Mowing on roadsides and utility rights-of-way has been somewhat of a surrogate for fire (by removing woody vegetation), and has thereby favored open conditions and provided refugia for shade-intolerant plants on narrow sites. Remnant savanna vegetation is now restricted to very few sites, in contrast to its more extensive and often dominant occurrence described by early European travelers.

1.5 Conclusion

The southeastern Piedmont savanna is a vegetation type that is underrepresented in the literature. Qualitative historical accounts convey that this type of open landscape was common (at least near the extensive travel routes) during the time of European exploration in the 16^{th} – 18^{th} centuries. Studies show that 1) few remnant Piedmont savanna sites still exist, 2) fire was prominently used by Native Americans in the Piedmont landscape, and 3) plant communities of more open, herb-dominant character may persist today due to many factors, but fire was likely the most important driver in the presettlement landscape. Forbs and graminoids that would thrive on a Piedmont savanna landscape are today restricted to an inconsistent collection of refugia, and are commonly located on rural roadsides or utility rights-of-way that are managed to control for woody vegetation. These artificial sites, although imperfect, are worth studying because they harbor heliophytes that we would expect to find on prairies, savannas, or woodlands with canopies open enough to support such plants. If we wish to conserve savanna vegetation, it is essential to document sites with remnant savanna vegetation and synthesize the descriptive information. As more data are accumulated, they can more effectively guide the recreation of savanna vegetation on candidate sites.

Table 1.1 Historical documentation of open conditions in the Piedmont.

Historical description	Canopy cover	Sites	Authors
"…More open forests…land of fruit-bearing trees" "[near the Catawba River] three or four savannas…"	Unknown-perhaps an interpretation of Olviedo y Valdes' (1535) **savanna** definition: "land which is without trees but with much grass, either tall or short" (as cited in Cole 1986)	North and South Carolina Piedmont	Hernando De Soto, 1540 (as cited in Barden 1997)
"…the country here, by industry of these Indians, is very open, and clear of wood…"; well-known map with "Savanae" in the Piedmont]	"	North Carolina Piedmont	John Lederer, 1670 (as cited in Barden 1997)
"…large savannas…the woods newly burnt in many places…traveled 40 km over pleasant savanna ground…"	"	North Carolina Piedmont	John Lawson, 1701 (as cited in Barden 1997)
"…many tracts of meadow-land…burdened with grass 6 ft. high…"	"	North Carolina Piedmont	Mark Catesby, 1720 (as cited in Barden 1997)

Table 1.2 Documented natural communities with more open canopies and an herb layer. CEGL = Community Elemental Global occurrences.

Community Common name	Community element global code	Sites	References
Piedmont Diabase White Oak Woodland	CEGL003721	Ft. Pickett, VA	Fleming et al. 2001
Piedmont Granitic White Oak-Black Oak Savanna	CEGL003722	Ft. Pickett, VA, Quantico MCB, VA, Cowpens National Battlefield, SC	Fleming et al. 2001
Piedmont Basic Hardpan Woodland	CEGL003558	Granville County, NC and York County, SC	Carolina Vegetation Survey (CVS) data, unpublished
Rich Granitic Lower Piedmont Deciduous Woodland	CEGL008489	Oconee National Forest, GA, and Aiken and York Counties, SC	CVS data

Piedmont Granitic Dome Woodland (Basic type)	CEGL003684	Alexander and Wilkes Counties, NC, Pickens County, SC, and Jones County, GA	CVS data, Schafale (2012)
Granitic Flatrock Border Woodland	CEGL003993	GA, NC, and SC	Schafale (2012)
Ultramafic Outcrop Barren (Piedmont Subtype)	CEGL007045	unknown	Schafale (2012)
Piedmont Acidic Glade	CEGL004910	unknown	Schafale (2012)
Diabase Glade	CEGL004276	Alexander County, NC	CVS data
Xeric Piedmont Slope Woodland	CEGL004446	Durham and Montgomery Counties, NC	CVS data
Southern Piedmont Basic Rocky Woodland	CEGL004443	Anson, Montgomery, Person, Stanly, and Wake Counties, NC and Lancaster and York Counties, SC	Schafale (2012), CVS data
Piedmont Chestnut Oak-Blackjack Oak Woodland	CEGL003708	Gaston County, NC	CVS data

CHAPTER 2: AN INVESTIGATION AND SYNTHESIS OF SAVANNA-LIKE VEGETATION ON RIGHTS-OF-WAY

2.1 Introduction

A diverse suite of heliophilic native plants occurs on narrow roadsides and rights-of-way in the Piedmont region of the southeastern US. These sites are generally thought of as marginal, and are certainly not documented as natural community types. Many of the plants that now occur almost exclusively on these sites are thought to have at one time occurred in open natural communities such as prairies, savannas, and open woodlands, but have now largely vanished from these habitats owing to loss of fire from the landscape. Consequently, what we know of the botanical assemblages and environmental contexts within which heliophilic, savanna-like vegetation occurred could be greatly augmented by investigating old roadsides and rights-of-way (ROWs) where this vegetation occurs either as preserved remnants, or perhaps as relatively newer, dispersal-driven, refugial communities. In doing so, we might capture a more accurate picture of variation in savanna-like vegetation with variation in environmental conditions. Ultimately, this information could contribute to a more comprehensive guide for restoration of Piedmont savannas by conservation managers.

There are a variety of natural community types in which heliophilic plants occur in the southeastern Piedmont (see **Table 1.2** in **Chapter 1**). These sites are often either environmentally extreme (e.g., characterized by hardpan soils), or regularly managed habitats (e.g., characterized by high fire frequency). As a result, the sites retain a more open-canopied structure that allows for substantial sunlight to reach the understory.

Roadsides and utility ROWs are also managed to prevent establishment of woody vegetation. Where otherwise undisturbed these sites tend to remain open and dominated by native grasses and forbs. However, these sites are highly susceptible to exotic plant invasion due to their "edge" and travel corridor setting, as well as general degradation due to increasing herbicide use and disruptive ROW management (John Randall, pers. communication). This presents a threat to native plant populations found on these sites. Therefore, it is urgent that the plants in such environmental contexts be documented where both the quality and quantity of native plants remain high.

Open plant communities are thought to have been widespread in the southeastern U.S. prior to European settlement (see Chapter 1; Rostlund 1957; Barden 1997). The evidence for the historical distribution of savanna-like plant communities is mostly qualitative and often anecdotal (e.g., Barden 1997). Following the last glacial maximum, heliophilic plants that had migrated into the region persisted owing to lightning-induced fire and perhaps megafaunal grazers (Cowdrey 1983; Barden 1997). During the warm and dry Hypsithermal Period, heliophilic prairie and savanna plants are thought to have expanded their ranges due to the extreme climatic conditions (Delcourt and Delcourt 1993). Approximately 5,000 YBP, the climate became more cool and wet, settling into weather patterns similar to those of today. Our picture of the contemporary natural communities of the Piedmont is that of a complex mixture of forested communities, with very few examples of "open" communities (Schafale 2012). However, it is widely asserted that the open, grass-dominated plant communities persisted in the Piedmont region through much of the post-Hypsothermal period due to use of fire by indigenous cultures (Waldrop et al. 1992; Delcourt and Delcourt 1997; Frost 1998; Stanturf et al.

2002). The aboriginal use of fire continued several centuries beyond the first European explorers, and its use helped to create and maintain a complex of open plant communities ranging from prairie to savanna (e.g., Barden 1997; Juras 1997).

The Piedmont savanna, as defined in Chapter 1, refers to an open plant community with an understory dominated by grasses and herbs and with an overstory of tree cover varying from 10-60%. The extant documented natural communities with this open canopy structure are scattered about the southeastern Piedmont. However, the varying structure and composition of the historical Piedmont savanna is still largely unknown. In this chapter, I first present a synopsis of the botanical and environmental characteristics of 31 ROWs exhibiting high-quality savanna-like forbs and graminoids (e.g., *Baptisia*, *Desmodium*, *Hypericum*, *Parthenium, Silphium, Sorghastrum*, *Andropogon* and *Dichanthelium*) in a localized portion of the southeastern Piedmont. I then categorize these plots into groups that have similar species assemblages. I also examine the environmental characteristics of these plot groups to better understand if theyhave strong environmental preferences. Finally, I attempt to relate these plot groups to documented natural communities.

2.2 Methods

Study area

The field study was conducted on utility rights-of-way in Chatham, Durham, and Orange Counties in the North Carolina Piedmont during the summer of 2008 (**Figure 2.1**). Many ROWs in this area are mown every two to 10 years, depending on which utility company is managing it (Duke Energy and Piedmont Electric Membership Corporation, personal communications). This area is characterized by a warm temperate climate, with an average temperature of 14° C, and an average rainfall of 122 cm (NOAA Online Weather Data 2009).

A remnant ROW site is one that harbors native plants that we would expect to find in open-canopied natural communities in the Piedmont. Consideration of a true "remnant"—that is, an area that is essentially a much smaller representation of a plant community that once stood at a much larger extent on that site—was of less concern in this scenario than capturing an appropriate set of plant species occurrences. The focus lay in finding ROW sites that, regardless of origin, still held a significant diversity and dominance of native grasses, legumes, and Asteraceous plants. Sites were found by exploring the rural roads of the study area and looking for assemblages of these kinds of plants. Local ecologists and botanists also suggested a handful of sites to survey.

Quantitative data were collected on 31 sites determined as quality sites harboring native heliophilic herbaceous species. These sites occurred on rural roadsides in Orange, Durham, and Chatham Counties. Five criteria were used to choose sites:

1) Dominance of regionally native forbs and graminoids,

2) Presence of indicators suggested by botanists as "high quality"(e.g., *Sorghastrum*, *Schizachyrium*, *Parthenium*, *Silphium*, *Eupatorium*, and *Baptisia*)

3) Extent of the site (sufficient to include a 5 x 20m or 10 x 10m plot),

4) Occurrence within a 50 km radius of Chapel Hill, North Carolina, and

5) Access and landowner permission.

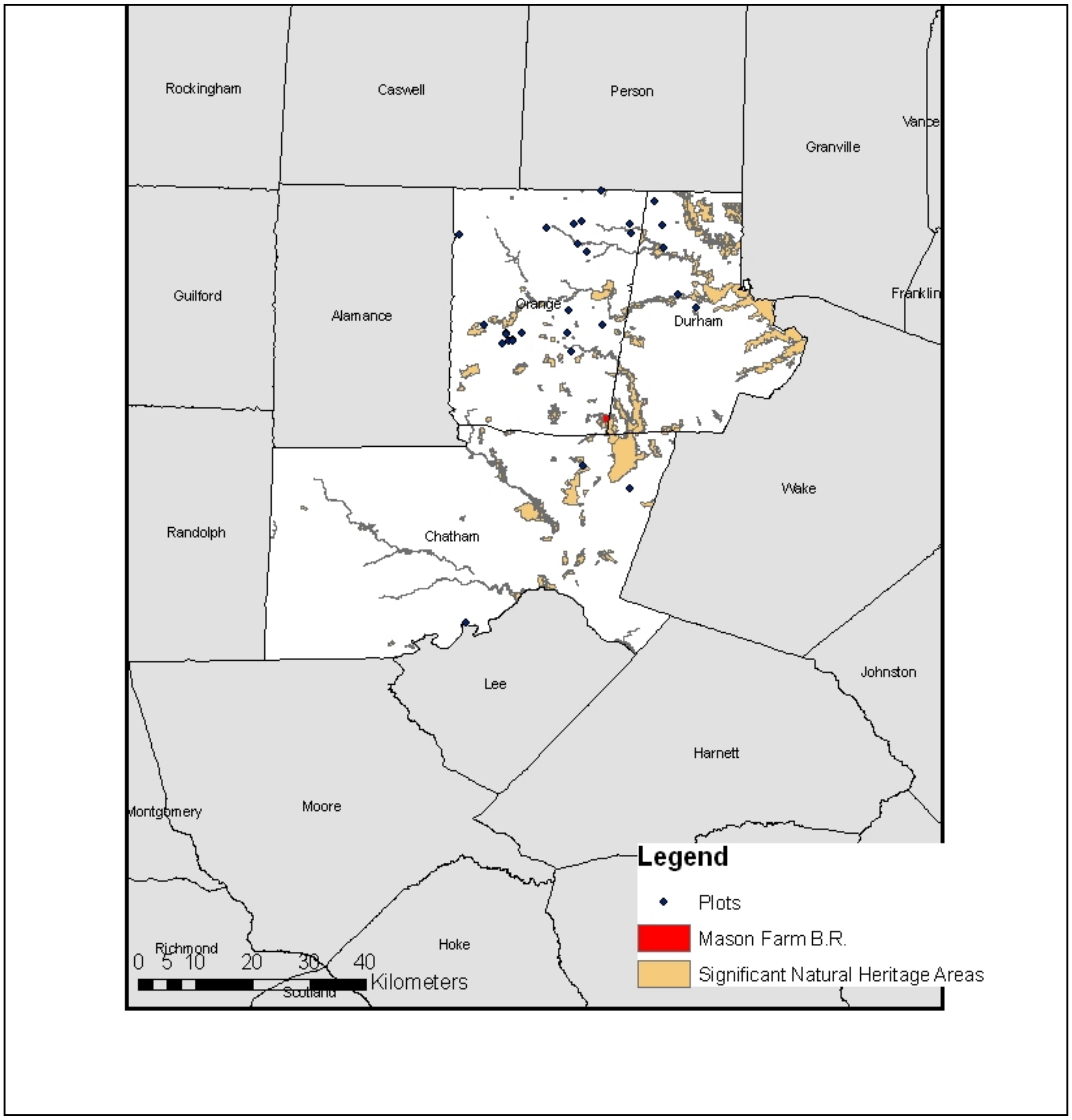

Figure 2.1 Plot locations in the local 3-county area are denoted by dark blue points. Significant Natural Heritage Areas are also featured on the map for reference.

Field methods

The Carolina Vegetation Survey (CVS) protocol was applied as the vegetation sampling method (Peet, Wentworth, and White 1998). In addition to recording species presence and cover, abiotic conditions were also documented. Botanical nomenclature follows Weakley (2011).

Twenty-nine 5m x 20m plots, and two 10m x 10m plots, were sampled, each scenario using the CVS single-module protocol. Species cover and nested presence values were recorded. Twenty-one environmental variables were measured at each plot. Soil samples collected from the upper mineral horizons were sent to Brookside Laboratories, Inc., New Knoxville, OH, for nutrient and texture analysis. Total cation exchange capacity (TEC; milliequivalents /100g), pH, percent organic matter (OrgMa), estimated nitrogen release (ENitR; lbs./acre), exchangeable cations (Ca, Mg, K, Na parts per million), extractable micro-nutrients (B, Fe, Mn, Cu, Zn, Al ppm), soluble sulfur (ppm), and extractable P (ppm) were all measured. Extractions were made using the Mehlich III method (Mehlich 1984). Texture analysis was carried out using the hydrometer method. In addition to measuring species abundance and edaphic conditions, aspect, slope, and canopy openness were measured. Aspect and slope were extracted from North Carolina Department of Transportation data resources with accuracy to 25 cm (NCDOT 2007). To determine canopy openness, hemispheric photos were taken of the canopy at each plot. The program Gap Light Analyzer (version 2.0; Frazer et al. 1999), was used to extract the percentage of canopy openness from digital canopy photos.

Figure 2.2 Some examples of ROW plots (Summer 2008).

Species data

Plants were identified to species when possible. However, if there was a lack of critical floral parts, taxa were either lumped into lower resolution complexes of the same genus (e.g., *Solidago* spp.) or treated as a distinct taxonomic unit identified to genus (e.g., *Allium* sp.). There were cases where multiple taxonomic units shared the same genus, but were determined as distinct (e.g., *Eupatorium* sp. #1 and *Eupatorium* sp. #2). These complexes served as the operational taxonomic units for the analysis.

The open-sourced platform for statistical computing, R (Version 2.10.1) was used to perform all statistical analyses on the 31 roadside plots. To identify groups of roadside plots, cluster analysis was performed with distance values generated from average species cover class values found on those plots. A cluster analysis was also performed on species presence-absence data to determine if plot groups might relate differently using presence-absence data only. Results of the presence-absence cluster analysis were found not to be different than those of the average species cover class cluster. Results were displayed with a dendrogram (see Figure 2.3). The flexible beta method was used for clustering (Lance and Williams 1966); McCune and Grace (2002) consider this method the most compatible with community data. The flexible beta method generalizes multiple agglomerative clustering algorithms into one, and the user can manipulate beta to view how groups may shift with different criteria (Borcard et al. 2011). The beta values chosen were $\beta = -0.1$, $\beta = -0.25$, $\beta = -0.45$, $\beta = -0.65$, and $\beta = -0.85$. A stopping rule was applied subsequent to examining two different grouping scenarios for each of the cluster results (10 total) and the results from an indicator species analysis (Dufrene and Legendre 1997) on those grouping scenarios. The indicator value for each species was calculated by combining the relative abundance and relative frequency of each species in each plot group. The statistical significance for indicator values (p) was calculated using a Monte Carlo test with 100,000 iterations. The best grouping scenario was chosen where the number of indicators and strongest significance was obtained.

Species and environmental data

Ordination was used to display complex relationships among the roadside plots by placing those objects along as few axes as possible to simplify relationships among objects (McCune and Grace 2002). Nonmetric multidimensional scaling (NMDS) was used on the species data, as it is an ordination method well suited to data that are nonnormal or arbitrary scales (McCune and Grace 2002). This method is widely known as appropriate for viewing species community data (Okansen 2011). Additionally, a principal components analysis (PCA) was additionally performed on the environmental data (Legendre and Legendre 1998). Biplots were produced for both ordinations to assess the relationship of the environmental variables to the ordination axes. The environmental data was transformed and standardized prior to the ordinations. For soil texture variables (silt and sand), a log-ratio transformation was used (Lark and Bishop 2007) in which the pair wise ratio of the percent composition was log-transfomed (silt.sand, clay.sand). For aspect, a sine transformation was used. Each nutrient variable was log-scaled, except aluminum (ppm) and iron (ppm), which displayed normal distributions and were scaled to unit variance (Borcard et al. 2011). Clustered groups of plots are displayed as hulls in the ordinations and are distinguishable by color.

2.3 Results

I recognized 236 taxonomic units on 31 sites. A complete table of species with their group designation and indicator value is included in **Appendix 2.1**. Although there were woody species recorded, they did not reach breast height. Otherwise, grasses and forbs dominated the sites. Included in the grand total of taxa were 13 exotic species (or "introduced," as designated by the USDA Plants Database). There were five operational taxa whose native status remains unknown due to failure to identify to species level. Species summaries are represented by the cluster analysis, indicator species analysis, and non-metric multidimensional scaling. An environmental variable table of roadside plots is presented in **Appendix 2.2**.

Cluster analysis

Although many plots retained their position on the dendrogram when beta was varied, the shifting division of groups was more variable. A beta value of -0.25 with plots split into four groups resulted in the best combination of indicator species number and values. The dendrogram of this cluster scenario is displayed as **Figure 2.3**, with plot numbers colored according to their associated group. An additional cluster analysis of presence-absence data revealed nearly identical results.

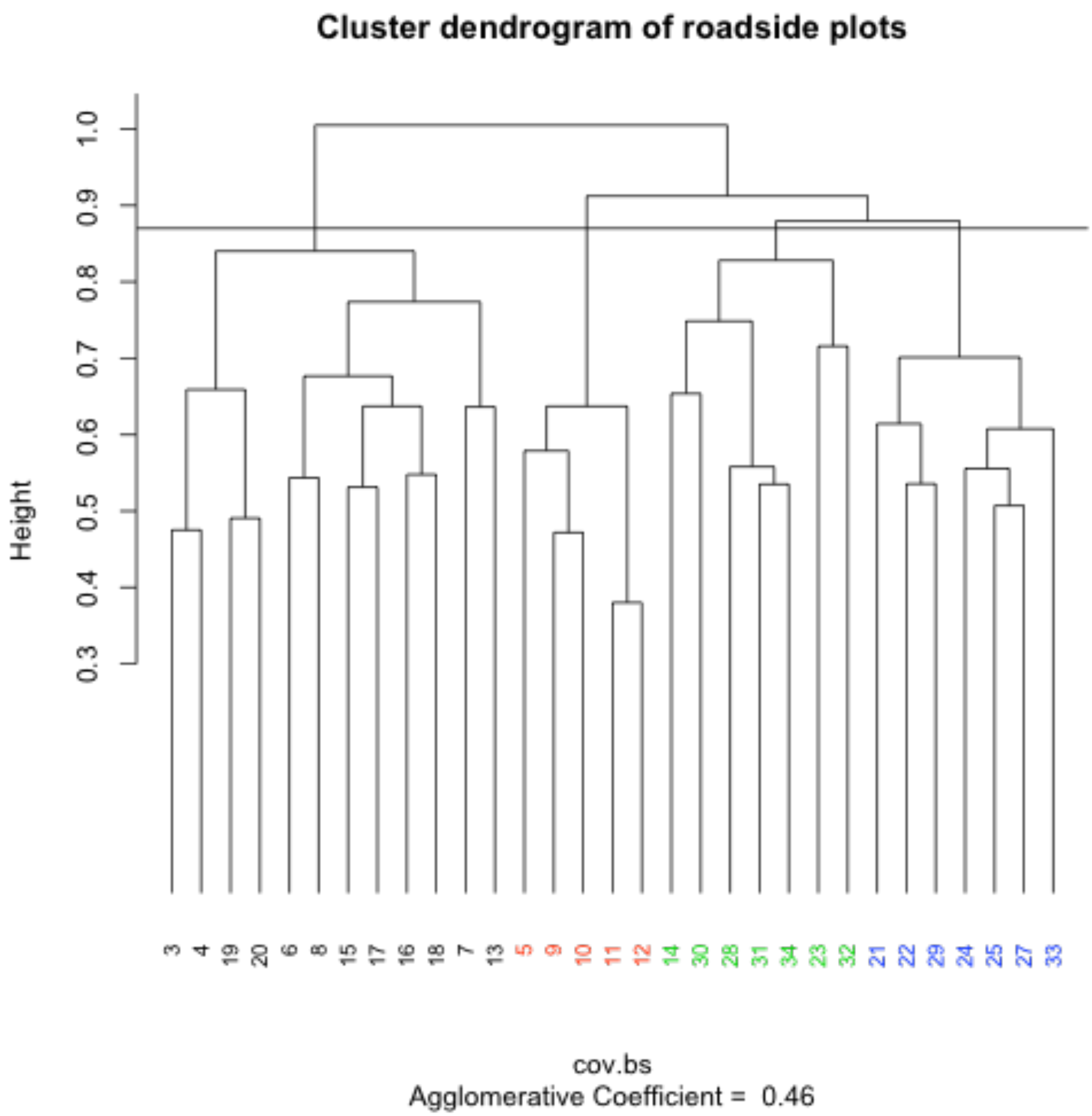

Figure 2.3 Cluster dendrogram of species data from ROW plots. Plots are grouped by species cover data using flexible beta agglomerative clustering. A horizontal line represents the length at which group divisions were designated (n = 0.87).

Indicator species analysis

Indicator species analysis identified a total of 36 species as significant indicators. Two of these indicators are exotics (5.5 %), and seven are woody species (19.4 %). The tables below list indicator species by their associated plot groups from the cluster analysis. The Monte Carlo test of significance was run with 100,000 iterations to determine p-values and indicator values. There were 8 indicator species identified in Group 1 with one of these indicators being a woody, exotic species. There were twelve indicators identified in Group 2, two of which are exotics, and four of which are woody. There were 13 indicators identified in Group 3, six of which are woody species. In Group 4 there were three indicators identified.

Table 2.1 List of indicator species for ROW group 1 determined by species cover. Constancy, Indicator Value, and Monte Carlo significance (p-value), are represented for each taxon. Woody species are denoted with a "^", and exotic species are denoted with a "*".

Group 1 Taxa	Constancy	Indicator Value	p-value
Chamaecrista nictitans	58 %	0.36	0.05
Chrysopsis mariana	75 %	0.47	0.01
Gymnopogon brevifolius	50 %	0.50	0.00
*Lespedeza cuneata**^	75 %	0.49	0.01
Muhlenbergia capillaris	75 %	0.65	0.00
Solidago rugosa	66 %	0.39	0.05
Solidago spp.	91 %	0.43	0.02
Symphyotrichum pilosum	75 %	0.52	0.00

Table 2.2 List of indicator species for ROW group 2 determined by species cover. Constancy, Indicator Value, and Monte Carlo significance (p-value), are represented for each taxon. Woody species are denoted with a "^", and exotic species are denoted with a "*".

Group 2 Taxa	Constancy	Indicator Value	p-value
Aletris farinosa	60 %	0.51	0.01
Apocynum cannibinum	80 %	0.47	0.02
Asclepias variegata	60 %	0.60	0.00
Coreopsis auriculata	40 %	0.40	0.02
Desmodium strictum	80 %	0.40	0.03
*Festuca spp.**	100 %	0.70	0.00
*Fraxinus americana^*	100 %	0.58	0.00
*Liquidambar styraciflua^*	100%	0.38	0.01
Lonicera japonica^*	100 %	0.39	0.05
Oenothera fruticosa	80 %	0.40	0.04
Potentilla canadensis	100 %	0.41	0.00
*Vaccinium pallidum^*	100 %	0.64	0.00

Table 2.3 List of indicator species for ROW group 3 determined by species cover. Constancy, Indicator Value, and Monte Carlo significance (p-value), are represented for each taxon. Woody species are denoted with a "^", and exotic species are denoted with a "*".

Group 3 Taxa	Constancy	Indicator Value	p-value
Anemone virginiana	42 %	0.43	0.02
Aureolaria virginica	42 %	0.37	0.02
*Cercis canadensis^*	71 %	0.57	0.00
*Cornus florida^*	71 %	0.39	0.04
*Corylus americana^*	42 %	0.43	0.02
Elymus spp.	71 %	0.58	0.00
*Euonymous americanus^*	42 %	0.36	0.03

Galium circaezans	71 %	0.39	0.04
Hypericum punctatum	57 %	0.57	0.00
*Hypericum stragalum^*	71 %	0.46	0.02
*Liriodendron tulipifera^*	85 %	0.67	0.00
Prenanthes altissima	42 %	0.37	0.03
Verbesina occidentalis	42 %	0.43	0.02

Table 2.4 List of indicator species for ROW group 4 determined by species cover. Constancy, Indicator Value, and Monte Carlo significance (p-value), are represented for each taxon. Woody species are denoted with a "^", and exotic species are denoted with a "*".

Group 4 Taxa	Constancy	Indicator Value	p-value
Tephrosia virginiana	85 %	0.75	0.00031
Baptisia tinctoria	71 %	0.50	0.01
Silphium compositum	85 %	0.49	0.01

Nonmetric multidimensional scaling

The non-metric multidimensional scaling ordination reveals that the four groups that were defined with the cluster analysis display some overlap (**Figure 2.4**). A 3-dimensional scenario was chosen, and a view of the remaining two views of the ordination reveals a similar level of overlap. **Figures 2.4-2.6** are biplots of each view of the 3-dimensional ordination. Groups can be interpreted as sub-types of mostly native vegetative communities found along roadsides.

Ordination-environment biplot

The biplot in **Figure 2.4** displays environmental variables that may be driving the roadside plot groups. It appears that, in this graphical scenario, pH (r^2 = 0.52), Cappm (r^2 = 0.40), BDen (r^2 = 0.37), OrgMa (r^2 = 0.35), Mnppm (r^2 = 0.34), and TEC (r^2 = 0.30) are the most significant drivers of the ordination. Group 1 is likely driven by soil texture (BDen and low silt/sand), whereas Groups 2 and 4 appear to be distinguished mostly by pH and nutrients (e.g., Cappm and Mnppm), and perhaps canopy openness (CPYOPN). Group 3, on the other hand, looks to be driven by a combination of the texture and nutrient variables, as well as estimated nitrogen release (ENitR), organic matter (OrgMa), and slope. **Table 2.5** displays the mean values of each pre-transformed variable for each plot group.

Table 2.5 Mean value of each environmental variable for each ROW plot group, prior to data transformation.

Variable	**Group 1**	**Group 2**	**Group 3**	**Group 4**
TEC	6.9	6.5	7.4	4.5
pH	5.0	5.1	5.1	4.6
OrgMa (%)	2.6	3.4	3.7	2.7
ENitR(meq/100g)	70.8	82.6	79.7	71.1
Sppm	16.8	18.6	19.1	22.7
Pppm	5.6	5.8	5.4	5.7
Cappm	412.8	494.6	544.7	207
Mgppm	122.9	83.8	150.3	55.6
Kppm	44.2	49.0	51.3	35.0
Nappm	51.5	48.0	54.9	47.7
Bppm	0.2	0.4	0.9	0.5
Feppm	175.3	160.4	117.3	181.9
Mnppm	62.1	145.8	106.4	40.9
Cuppm	2.4	3.5	1.9	1.1
Znppm	1.8	1.3	1.9	1.5
Alppm	801.3	839.4	892.7	864.4
BDen	1.1	1.1	1.0	1.1
Silt (%)	44.6	52.6	47.0	48.5
Sand (%)	37.1	27.1	28.5	29.4
Clay (%)	18.3	20.3	24.5	22.1
CPYOPN (%)	47.7	36.1	42.5	38.0
Aspect	156.9	169.6	237.9	216.8
Slope	5.0	3.7	4.4	3.7

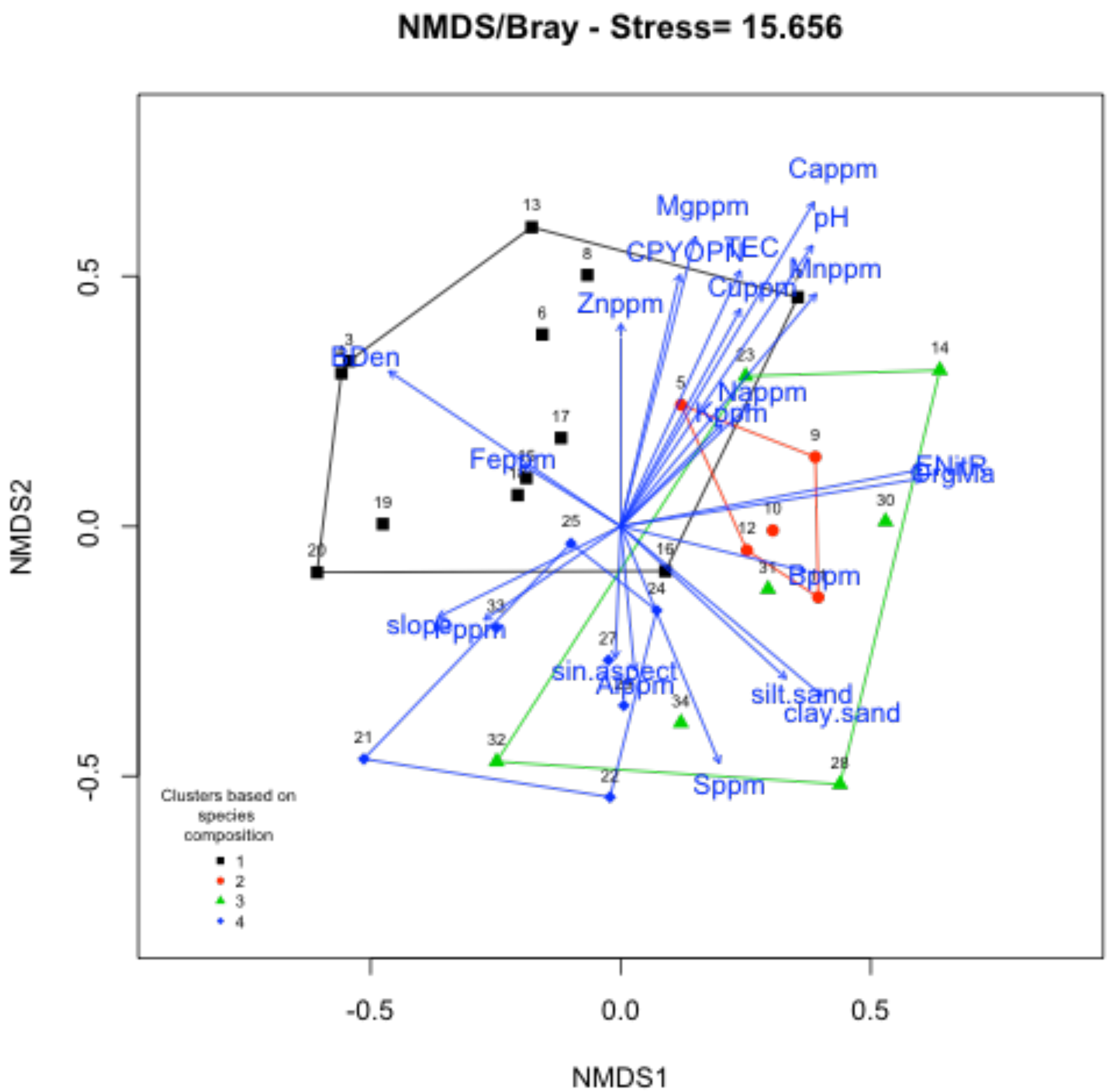

Figure 2.4 NMDS biplot of ROW plot groups, displaying axes 1 and 2. Vectors represent environmental data.

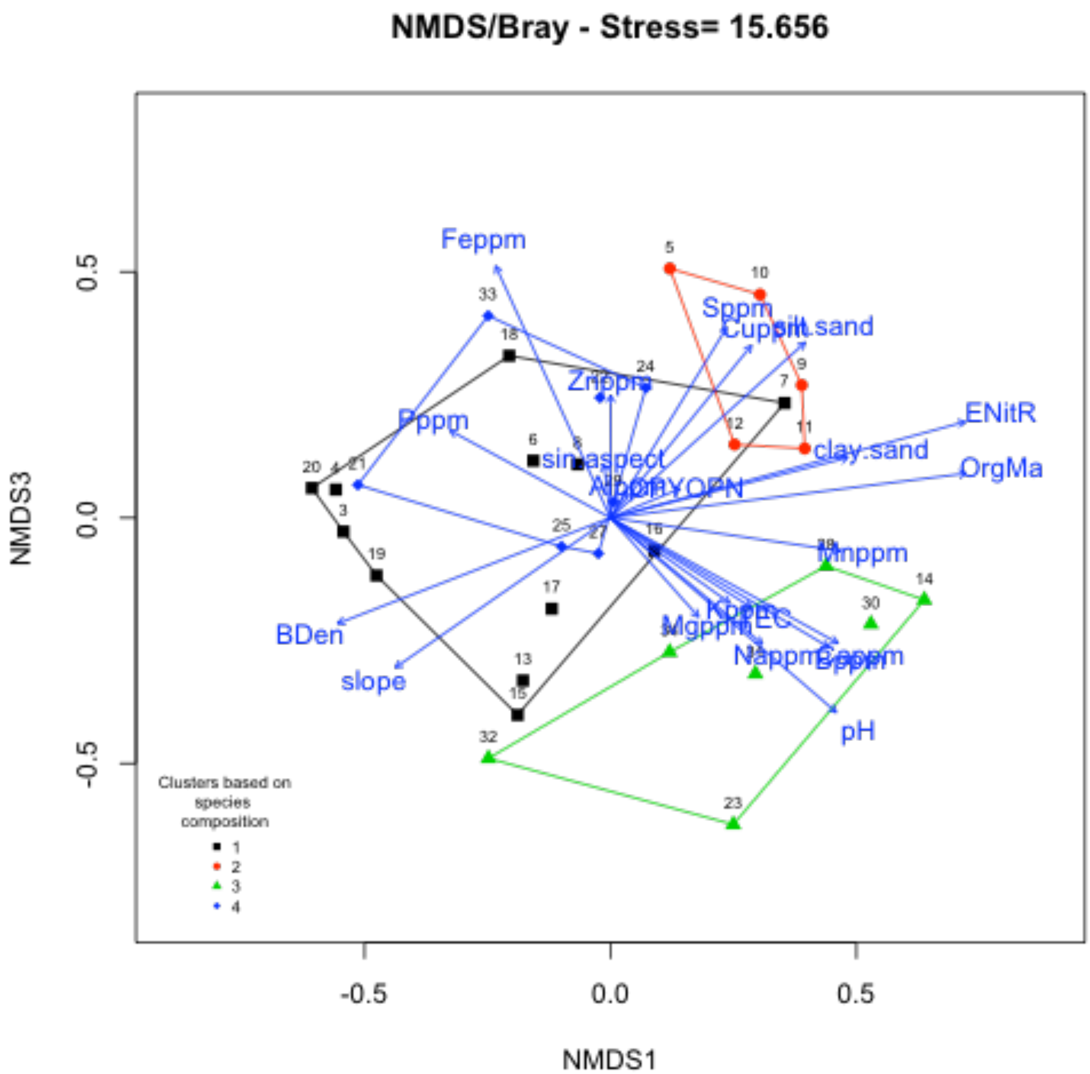

Figure 2.5 NMDS biplot of ROW plot groups displaying axes 1 and 3.

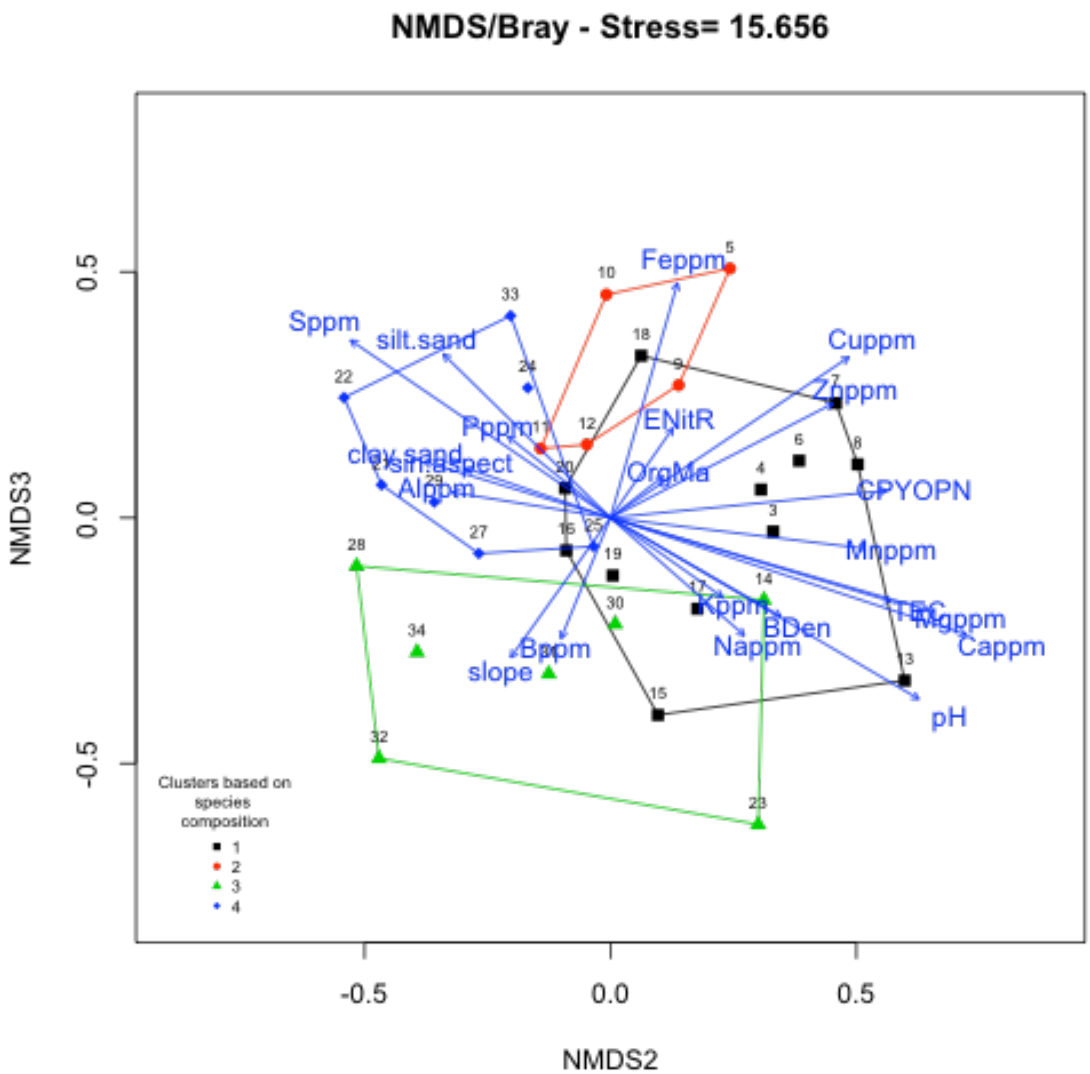

Figure 2.6 NMDS biplot of ROW plot groups displaying axes 2 and 3.

Principal components analysis

The PCA (**Figure 2.7**) shows the roadside plots ordinated by their environmental variables. The color-coded hulls represent the groups that were determined by the cluster analysis. The distinctions between the cluster groups are weaker than that shown on the NMDS ordination. Principal axis 2 appears to be most driven by texture (BDen, silt.sand and clay.sand), whereas axis 1 is most driven by a small suite of nutrients (Ca and Mg) and perhaps slightly by pH. Group overlap is fairly substantial and is also evident in the environmental summary table (**Appendix 2.2**).

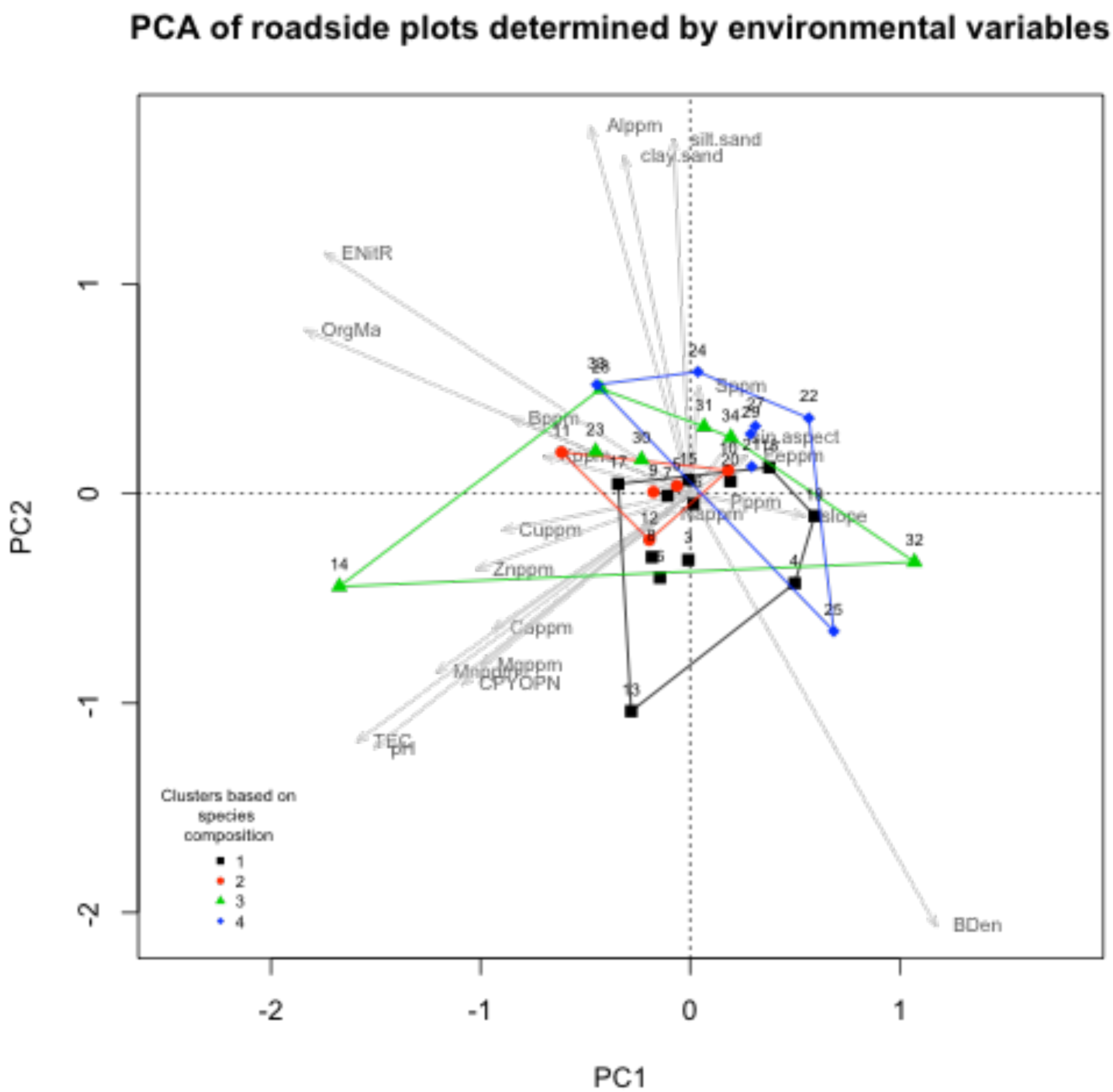

Figure 2.7 Principal components analysis, with biplot vectors and roadside plot position from environmental data. The color scheme originates from the cluster groups designated by species cover data.

2.4 Discussion

The data presented in this study reveal that species composition of the roadside and rights-of-way plots is driven mostly by edaphic factors. Soil texture is also a driving factor, as well as pH, calcium, and magnesium. The results from the NMDS and PCA biplot were generally consistent in this regard. Group divisions appear less distinct in the PCA, as plots tend to fall more gradually along an environmental gradient.

The ROW community sub-types or “Groups” do not strongly adhere to the documented open plant communities of the southeastern Piedmont (**Table 1.2**). I evaluated this by looking for matches of the dominant species of these natural communities with the dominant species (indicators) from the ROW groups. There are certainly floristic similarities amongst ROW groups, but the ROW group vegetation is assembled in patterns not quite equivalent to those of the documented natural communities. Group 1, which included the most open plots on average (% CPYOPN), consists of herbaceous vegetation also important in a few documented communities from **Table 1.2**. These include Piedmont Granitic White Oak-Black Oak Savanna (CEGL003722) and Piedmont Chestnut Oak-Blackjack Oak Woodland (CEGL003708). Examples of taxa overlap among Group 1 and the natural communities include *Desmodium ciliare*, *Gelsemium sempervirens*, and *Solidago rugosa*.

Group 2 consists of somewhat high-moisture plots, and important indicators include *Aletris farinosa*, *Oenothera fruticosa*, and *Potentilla canadensis*. In terms of similarities to natural community types, Group 2 consists of components present in several of the documented communities, including some with both acidic and circumneutral affinities.

Group 3 is the most nutrient-rich. However, this is not greatly apparent given the indicators of the group. For example, *Anemone virginiana*, *Hypericum stragalum*, and *Verbesina occidentalis* are high-valued indicators of this group. There are other, less significant botanical components in Group 3 present in the Piedmont Diabase White Oak Woodland (CEGL003721), Southern Piedmont Basic Rocky Woodland (CEGL004443), and Diabase Glade (CEGL004276) types. A few examples include *Clematis ochroleuca* and *Sorghastrum nutans*, and *Echinacea laevigata*.

Group 4 can be characterized as plots that were on acidic, nutrient-poor sites. This group exhibits the least variability in environmental measurements. The taxa on these sites are also found commonly on the Piedmont Acidic Glades (CEGL004910) and Piedmont Chestnut Oak-Blackjack Oak Woodland (CEGL003708) types. Among these species are *Danthonia spicata*, *Tephrosia virginiana*, and *Silphium compositum*.

These data suggest that these roadside "communities" are their own collection of ecological entities. One feature of these communities that may help explain their apparent uniqueness is that they serve as natural and somewhat compressed corridors for species dispersal in an increasingly fragmented landscape. Rights of way, where not already altered due to exotic species dominance, support opportunistic species that continue to thrive in a variety of environmental contexts.

The corridor concept of metapopulations is described in detail by Ouborg and Erikkson (2004). In this context, roadside corridors provide an avenue for savanna vegetation dispersal. Historically, savanna communities were allegedly more extensive where they occurred (Barden 1997), and were not interrupted by frequent constructed or exotic plant-dominated landscapes. Given the current disjunct nature of open community types in the Piedmont, conservation biologists might infer that dispersal corridors are crucial pieces of the persistence of these community types.

Species were often present in more than one group, as represented by the constancy values in **Appendix 2.3** The overlapping nature of the taxa, in terms of their roadside group affinities, may reflect a more generalist nature of the taxa on the sites sampled. The wide reach of many species will leave managers wishing to use the species lists with a great deal of flexibility on applying appropriate species assemblages in restoration. This flexibility could be interpreted as a weakness in the appropriateness of the use of these species lists in savanna rehabilitation projects. However, this high level of overlap may ultimately reflect that heliophilic plants are highly adapted to a wide range of conditions in the Piedmont, as long as management ensures open canopies. Additionally, there are species in the indicator tables (**Table 2.1 – 2.4**) with high fidelity to groups, and these should be prioritized in the application of species assemblages to their preferred environmental habitats (in terms of edaphic variables) in local rehabilitation studies or projects.

Ultimately, the use of these species lists for restoration appears to be appropriate, as long as environmental attributes on the restoration sites are used as the determinant factors. Further study is needed to capture a more comprehensive picture of roadside native vegetation, especially in a larger geographic region. It would be interesting to know whether indicators found in this study are similar to those that might be derived from other studies in different areas of the Piedmont.

There is an ongoing effort by conservation biologists in the Piedmont to push for management of roadsides and rights-of-way to conserve what is sometimes a high-quality example of native vegetation. Duke Energy, a local rights-of-way manager, touts the application of herbicide on these sites as "environmentally responsible" (Duke Energy

Corporation 2011). This is a highly debatable claim, as they have no evidence to show that the effects on soil and surface runoff are negligible. Additionally, they do not mention native plant conservation. The Federal Highway Administration is seemingly taking a different approach, promoting the value of native vegetation to roadsides on their website (Harper-Lore 2010). Here, the author goes into great detail regarding the use of native plants as on the roadsides of federal highways. The amount of baseline information is quite extensive and suggests that management include invasive species control, supporting faunal habitat (e.g., butterflies and small mammals), erosion control, and native wetland value in pollution filtering.

This study is largely preliminary in the establishment of Piedmont savanna vegetation lists, and expanding it to incorporate a larger area might help us understand the variability of the Piedmont savanna throughout its range. However, this study does provide lists that can certainly be useful for savanna restoration within a limited range. As such, conserving the suite of plants found on roadsides and rights-of-way is an extremely important conservation objective in the southeastern Piedmont. Restoration of savanna and other open communities that support the species found on these often artificial sites is critical in the context of the somewhat whimsical management of rural sites where they currently thrive. Additionally, if roadsides and rights-of-way are viewed as a valuable source of seeds, dispersal corridors, and habitat for floral and faunal species alike, perhaps these sites should be prioritized for conservation as well.

CHAPTER 3: THE APPLICABILITY OF RIGHTS-OF-WAY VEGETATION AS REFERENCE DATA FOR SAVANNA RESTORATION IN THE NORTH CAROLINA PIEDMONT

3.1 Introduction

At the Mason Farm Biological Reserve (Mason Farm) of the North Carolina Botanical Garden in Chapel Hill, NC (University of North Carolina at Chapel Hill), the upland oak-hickory forests show signs of fire-suppression, as the canopy is nearly closed and the ground layer vegetation is sparse. A portion of these uplands is the focus of an effort to restore savanna-like conditions that are thought to have been present here, at least within the past two centuries. Although the exact character of the savanna-like conditions on uplands at Mason Farm are largely unknown, the canopies of upland forests were likely more open and supported a ground layer with heliophilic, savanna herbs (North Carolina Botanical Garden Staff 2006). Thus far, managers have implemented prescribed fires on parts of the uplands to open up the understory. Adjacent to these now closed-canopy upland forests are also old agricultural fields that are currently fire-managed and now support a suite of native heliophilic plant species. There is much interest in reestablishing a ground layer of native forbs and grasses in both the future open woodland and old fields, which will involve actively sowing seeds or planting plugs of a prescribed mixture of such plants.

As discussed in the first chapter, many ground layer plant species that occur in documented natural communities with more open canopies in the Piedmont (i.e., open woodlands and savannas), also occur on rural roadsides and utility rights-of-way

(ROWs). An open canopy is maintained on these sites due to frequent mowing (and sometimes other methods), favoring the persistence of heliophilic plants. The communities of heliophilic, savanna-like vegetation occurring on ROWs are critical remnant or refugial pieces of a historically more-widespread temperate savanna in the Piedmont. Although rights-of-way harboring this vegetation probably do not represent perfect remnants of the Piedmont savanna, the vegetation occurring on these sites does provide an approximation of what we would expect to find on a disturbance-dependent savanna.

In the previous chapter I characterized 31 ROW sites harboring high quality, native herbaceous vegetation. I found four distinct communities among the ROW plots. Plant lists from each of these communities were compiled in order to provide a basis for target community recommendations for restoration projects in a localized (50 km radius) area centered on Chapel Hill, NC (see **Appendix 2.2**). This study focused on demonstrating the use of reference data accumulated on local sites that harbor similar vegetation to the target community sought. I use the data accumulated in Chapter 2 to establish a prescription for the target herbaceous plant communities on the Southern Shagbark Hickory Forest (SSHF), a portion of the complex of upland plant communities at Mason Farm Biological Reserve. Specifically, I use a statistical comparison of the edaphic conditions on the proposed restoration site with those on local reference sites identified on roadsides and ROWs. The objective of this chapter is to compare the edaphic conditions on the ROW sites (from Chapter 2) with those on the SSHF to prescribe the plant community composition that might be expected in a natural savanna on the SSHF site.

Background

Documentation of ongoing restoration efforts on open plant communities in the southeastern Piedmont region is not extensive. Most studies are focused on Piedmont prairies, a subset of the variety of open canopy conditions where native herbaceous heliophilic plants can occur. Studies on the management of prairies are largely, and appropriately, focused on implementing an appropriate fire regime for the site of interest (e.g., McRae and Barden 2002, as cited in Benson 2011; Wagner et al. 1998). Additionally, suitability studies, based on the botanical and physical characteristics of remnant Piedmont prairies, have also been presented. For example, Taecker (2007) used two multivariate modeling tools in Geographic Information Systems (GIS) to predict potential Piedmont prairie habitat, and found that cation exchange capacity and percent clay were the two most important indicators of current occurrences of remnant Piedmont prairies. Benson (2011) similarly used GIS to predict sites suitable for prairie restoration based on a rating system of overlapping environmental variables on remnant sites. Both of these authors noted that those soil series associated with "hardpan" conditions are highly correlated with prairie remnants (e.g., Enon and Iredell). However, Benson (2011) found that of 15 extant prairie sites, only one was predicted to occur, according to the GIS tool. Moreover, given the anthropogenic use of fire in ensuring historically widespread open plant communities in the Piedmont, suitability may be a less-narrow concept than presented by Taecker (2007) and Benson (2011) for potential restoration sites.

White and Walker (1997) emphasized the importance of capturing as much variation in reference sites as possible, so that the species pool is most accurately represented in restoration or rehabilitation projects. The fewer the sites referred to, the higher the probability that those sites do not accurately represent the natural variation of the complete species pool. Additionally, given the limited amount of natural Piedmont savanna communities in the immediate area, more reference sites are needed to guide Piedmont savanna restoration. The ROWs sought out and sampled in Chapter 2 were selected to represent "high-quality" native savanna proxy communities.

Study area

Mason Farm is a 148.5-hectare tract managed by the North Carolina Botanical Garden (NCBG) of the University of North Carolina at Chapel Hill. As discussed in Chapter 2, ROW sites were selected based on a set of criteria that ultimately reflected vegetative characteristics that local, knowledgeable botanists and ecologists think of as savanna-like. Sites (**Figure 3.1**) were sampled within a 50 km radius of the Mason Farm. The immediate area surrounding Mason Farm is a mixed matrix of mostly urban areas, closed-canopy forests, and active or abandoned farmland.

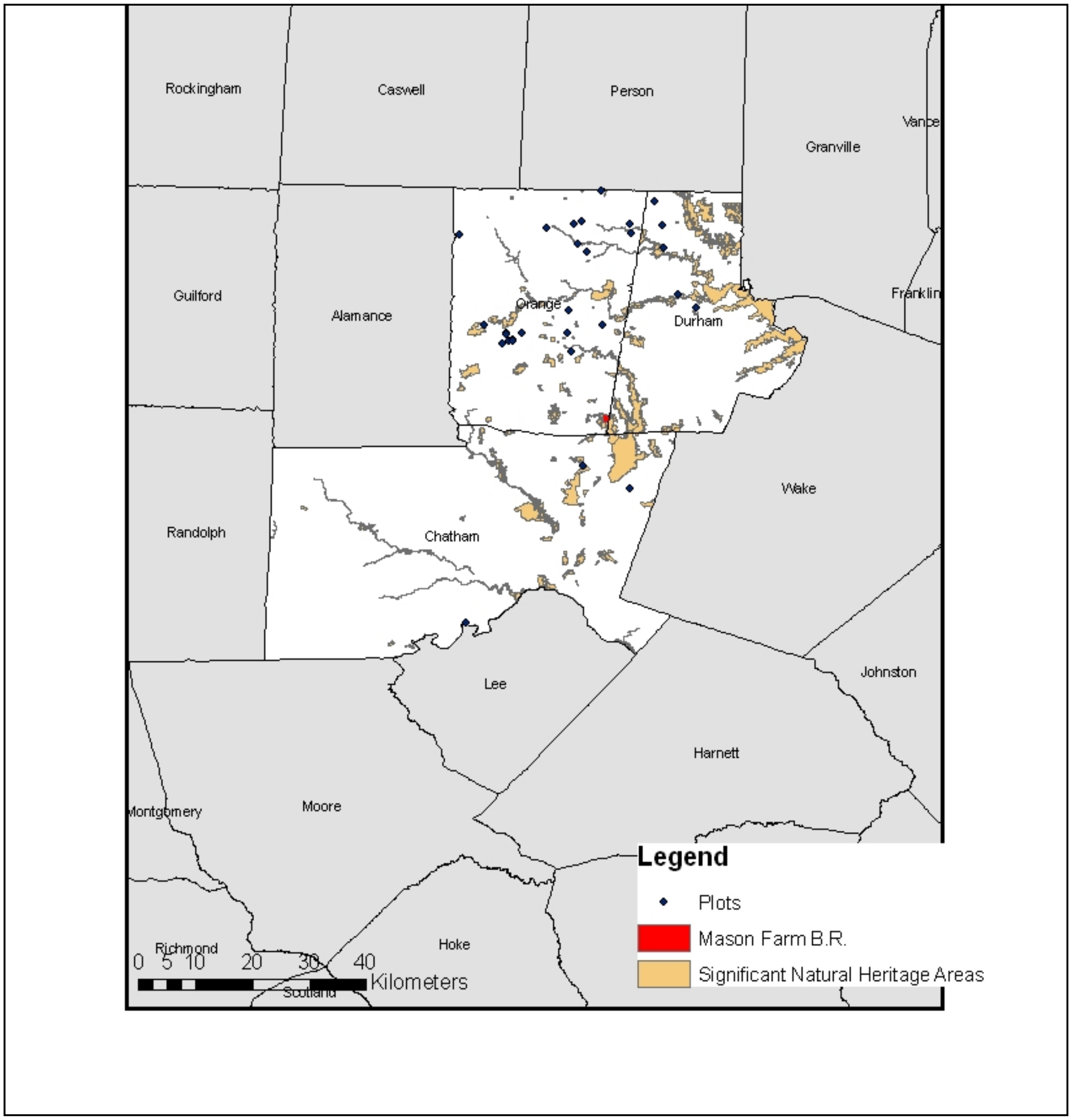

Figure 3.1 ROW plots ("Plots") in relation to the restoration site (Mason Farm B.R.), and Significant Natural Heritage Areas for those counties (demonstrating the disparate nature of natural areas in this region).

The restoration site is an oak-hickory forest known as the Southern Shagbark Hickory Forest (SSHF), which is listed as a Significant Natural Heritage Area by the Natural Heritage Program of North Carolina. There are two diabase dikes that cross a portion of the SSHF oak-hickory forest. Diabase is an uncommon substrate type well known for weathering to soils with a circumneutral pH with hardpan-like conditions and typically harboring regionally uncommon plant communities. Plant communities that occur on diabase in the Piedmont are well documented as being species-rich, and often supportive of rare native plants (e.g., Davis et al. 2002; Walker 2009). The Natural Heritage Program identified the SSHF as the largest forest stand on diabase in the area, and noted that there are many species that prefer soils with relatively high pH (Sorrie and Shaw 2004).

The Southern Shagbark Hickory Forest has a “striking uneven-aged tree distribution.” For example, white oaks range from 50cm – 80cm dbh, post oaks range from 50cm – 95cm dbh, and shagbark hickories range from 48cm – 71cm dbh. In contrast, there are many smaller trees, ranging from 10cm – 30cm dbh (including oaks, hickories, maples, sourwoods, and others). There are not many trees representing a middle-aged cohort, which might indicate that this woodland was likely kept more open for quite some time. This forest in particular was likely subject to livestock grazing (Johnny Randall, pers. comm.).

3.2 Methods

Twenty-two soil samples were collected from the SSHF on an established grid network in an approximate 12.5-hectare area (**Figure 3.2**). Samples were collected every 125 m along an east-west transect. The same process was applied to six east-west transects separated by 50 m. Two exceptions apply, due to on-site limitations. Eighteen edaphic variables were used in the analysis. Soil nutrient and texture analysis were performed by Brookside Laboratories, and the methods are detailed in Chapter 2. To keep the process simple in the statistical program, existing grid name locations on the SSHF were translated to the numbers shown in **Table 3.1**.

Table 3.1 Legend for renamed SSHF grid locations shown in **Figure 3.2**

SSHF grid locations in **Figure 3.2**	Corresponding ID for the remaining tables and figures in Chapter 3
E14	55
E8	56
N6	57
N12	58
I6	59
I12	60
O8	61
O14	62
F10	63
F16	64
YY6	65
YY12	66
J8	67
J14	68
K16	69
P10	70
P16	71
A10	72
ZZ8	73
ZZ14	74
D6	75
D12	76

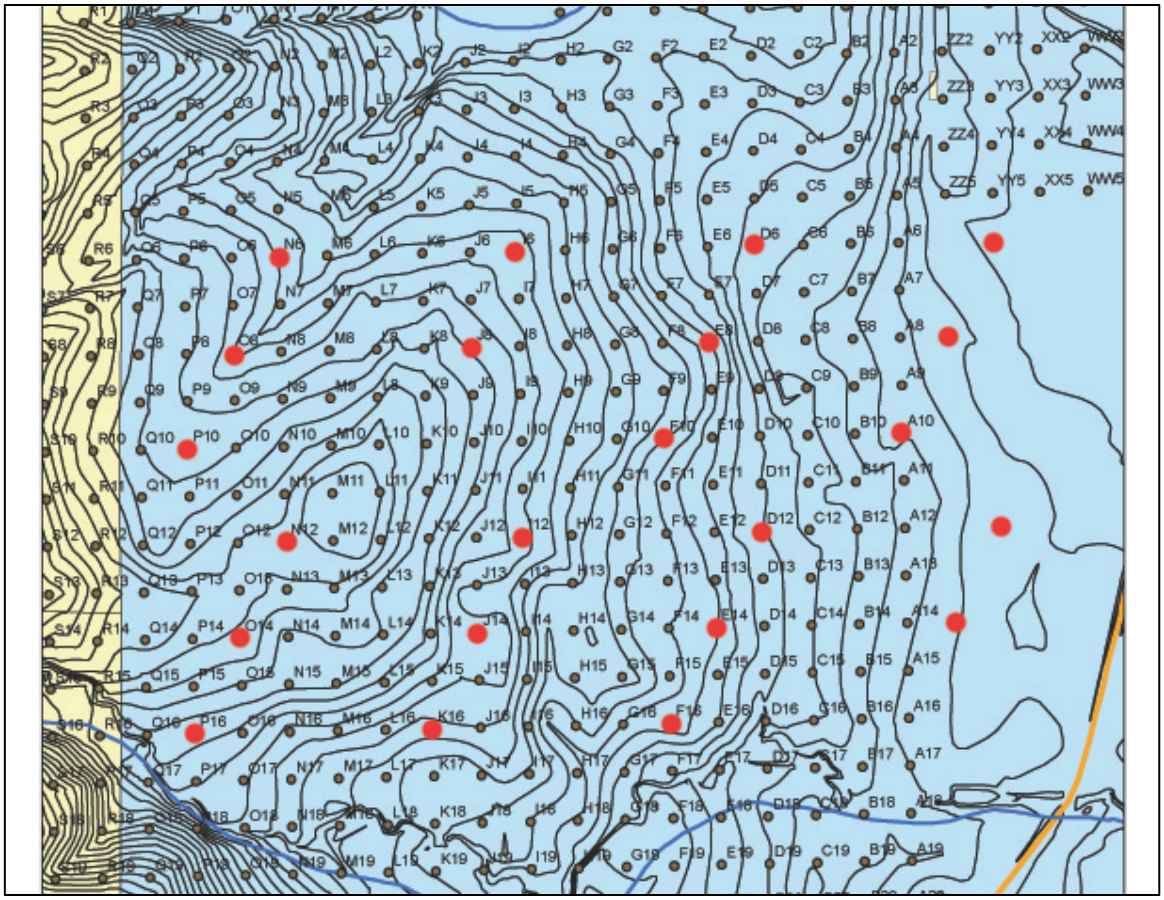

Figure 3.2 A portion of the Southern Shagbark Hickory Forest, with soil-sampled points (red points) on the existing research grid. The grid is marked in 25 m increments. Elevation contours are marked in 2 ft. intervals. Map reproduced from M. Kunz, NCBG (2007).

Analysis of edaphic variables

A principal components analysis (PCA; Legendre & Legendre 1998) was performed to display the edaphic data, from ROW and SSHF location points, in ordination space. Edaphic variables were first standardized and transformed using the same methods identified in Ch. 2. The weight of the edaphic variables is represented by vectors on a biplot. The plot groups from Chapter 2 are represented by color.

Comparison using a distance matrix

To identify the best prescription for SSHF sites based on the reference material, the matrix of dissimilarity was more closely examined. The values in the matrix represent the Euclidean distances between the edaphic variables of the SSHF sites and ROW plots (**Tables 3.2 – 3.5**). I looked for the lowest average distance value of edaphic variable for each ROW group (instead of individual plots), with the guiding assumption that the group is a better representative of community types on ROWs, than are individual plots.

3.3 Results

Target species lists

The analysis for this study included open plant communities found along rural roadsides in Orange, Durham, and Chatham Counties. From the species data recorded in this study, it was determined that the ROWs are divided into four dominant assemblage groups. These groups were identified through cluster analysis of species data and cluster diagnostics and are treated as possible herbaceous community targets for the savanna rehabilitation.

Roadside and SSHF environmental ordination (PCA)

A total of 18 edaphic variables were used in the ordination of both roadside/ROW plots and SSHF sites, and are presented in **Table 3.6**. In **Figure 3.3** (below), the SSHF points are pink points, labeled 55 – 76. Roadside plots retain their group cluster color. There is considerable overlap of edaphic characteristics between some SSHF sites and ROW plot groups. However, the overlap is most skewed toward two plot groups from the roadside study, Groups 1 and 4 (Group 1 is represented by the black hull, Group 4 is represented by the blue hull). The environmental vectors reveal that the first and second axes are both cation driven, while texture is proving an additional influence on the second axis.

Distance comparison

The PCA does not clearly identify or designate which groups should be prescribed to the SSHF. The distance matrix (**Tables 3.2-3.5**) more clearly represents how roadside plots are edaphically related to SSHF sites. An examination reveals that 20 of the 22 SSHF sites are most edaphically similar to different individual plots in Group 1. There is one site most similar to plot 32 in Group 3 and one site most similar to plot 27 in Group 4. When SSHF sites are compared to mean distances of each group, results differ (**Figure 3.6**). Thirteen SSHF sites are most similar, given the mean values of each roadside/ROW plot group, to Group 1. Six SSHF sites are most similar to Group 2. Three SSHF sites are most similar to Group 4. Most sites retain a smaller mean distance to Group 1. However, the mean of groups approach better represents similarities to Groups 2 and 4.

3.4 Discussion

The overall goal of Chapter 3 is to prescribe a target species list suitable to the restoration of the herbaceous layer on the SSHF. The species lists created in Chapter 2 (ROW plot groups) were assessed in their plausibility as possible targets. These lists represent a partial, though imperfect, picture of herbaceous savanna vegetation and their edaphic habitat. White and Walker (1997) caution those implementing ecological restoration or rehabilitation to not assume reference sites as silver bullets, as they likely only represent a portion of the entire species pool appropriate for the restoration site. Therefore, the reference sites used in this study should be appropriate, but not definitive. Other local references should be assessed and used as well (including the old fields adjacent to the SSHF). The applicability of these targets was assessed through a PCA and distance comparison between the edaphic conditions of the ROW plots and the SSHF sites.

Results show that Group 1 from Ch. 2 is the best reference for most of the area identified for rehabilitation on the SSHF (**Figure 3.6)**. While plot groups were shown to be different in Ch. 2, many of the taxa were not exclusive to their corresponding indicator group. For example, of the species indicators for all groups, only 6 of 36 were exclusive to their indicator group. The individualistic nature of plants proves to be a bit of a complication, as the prescription inherently lacks rigidity. Additionally, the PCA results show the SSHF sites very well separated from the ROW plot groups. The ROW plot groups are not very distinctive, given their edaphic characteristics. Simply put, the SSHF sites are generally a different group than the ROW sites that were sampled. ROW groups were shown to be not as environmentally distinct as they are taxonomically. The initial creation of many of the ROW sites sampled is a very destructive process for the soil. In the utilization of heavy machinery to grade roadsides and the often adjacent utility ROWs, the soil is greatly disturbed and subjected to a loss of many characteristics that define that soil type—for example, microbiota are lost and/or soil is mixed and homogenized in the process. Recovery of "intact" soil varies from site to site, and many of the ROWs sampled in Chapter 2 are likely still on a recovery trajectory.

The success of a savanna restoration on the SSHF is contingent upon the accurate prescription of a herbaceous community, as well as the return of fire to the site at regular intervals. Frost (1998) estimated that the historic presettlement fire interval for uplands in the Piedmont was 4-7 years. Fire will ensure that woody species do not colonize the understory and continue to dominate the site. Thinning of the SSHF would also be appropriate on this site, as current canopy closure is rather high.

The “target” concept for ecological restoration has been critiqued by many. Bakker et al. (2000) remind us that more studies are needed using a more broad approach than a focus on one aspect of the target community. The target community, its preferred abiotic conditions, the ecological processes paramount to the survival of that community, and monitoring, are all important aspects of the broader target. Consideration and incorporation of each of these facets will more likely lead to restoration success.

“Natural” savanna community types are not known or documented within the area where roadsides and ROWs were sampled. As noted in Ch. 2, the local natural occurrences of native herb-dominated communities tend to be open-canopied glades on extreme communities. Native savanna-like vegetation persists on an extensive network of roadsides and ROWs in assemblages that are not necessarily representative of what is expected on natural savannas. These peculiar sites may not be representative of the ideal Piedmont savanna community, but the large number of occurrences of high quality savanna-like vegetation speaks to their inherent value. Roadsides and ROWs are harboring these marginalized plants. Natural communities that have a fairly populated herbaceous layer (e.g., xeric hardpans, oak savannas that are not local, and natural glades) should also serve as reference sites, as the species present there are also part of the larger species pool appropriate for Piedmont savanna restoration. Davis et al. (2002) provide an extensive list of high-quality Piedmont prairie plants that might be appropriate components of the target.

Conservation practitioners should recognize the admittedly incomplete examples of native herb-dominated plant assemblages found on roadsides and ROWs as references and test their appropriateness through management and monitoring. They should also consult species lists from the few examples of natural occurrences of savannas. Not all roadsides and ROWs harbor high-quality native savanna-like vegetation. However, there is an extensive network of those that do. Peculiar as they are, they are inherently valuable as habitat for these plants, seed sources for conservation, habitat for microorganisms, habitat for insects and small mammals, dispersal corridors, as well as population sources. It is critical to view these sites as valuable ones in order to maintain organismal populations that depend on the structure of these sites. This study provides a case for the use of ROWs as reference information for Piedmont savanna restoration. The approach promotes a more rigorous method for applying a target community prescription in a restoration plan. By comparing the edaphic conditions of the herb-poor SSHF with edaphic conditions on the herb-heavy ROW sites, there is less guesswork on applying appropriate targets. The results showed that the study of more ROW sites is needed to provide a rigorous prescription for savanna restoration at Mason Farm. Managers should consult other references as well (e.g., on-site indicators in forest gaps and species lists from adjacent fields with similar soils). More reference sites on ROWs would be particularly helpful in capturing more edaphic variation. Also, future research for both this restoration and others in the Piedmont should compare the edaphic conditions of documented natural communities with those of the restoration site in order to capture a more complete picture. In turn, more sites studied will help build a larger target community pool for conservation and natural resource managers to use.

Table 3.2 Table of Euclidean distance measures between ROW edaphic data from plot group 1 (columns) vs. SSHF edaphic data (rows). Tables are divided by ROW plot groups. The lowest mean distance values are marked with a "*".

Group1	3	4	6	7	8	13	15	16	17	18	19	20	**Mean**
55	0.90	1.07	0.59	0.92	0.69	0.30	1.09	0.90	0.94	1.26	1.11	1.15	**0.91**
56	0.29	0.66	0.69	0.53	0.54	1.14	0.68	0.35	0.50	0.73	0.74	0.44	**0.61**
57	0.35	0.45	0.81	0.53	0.65	1.33	0.61	0.36	0.65	0.46	0.51	0.22	**0.58***
58	0.32	0.41	0.77	0.48	0.61	1.30	0.54	0.33	0.62	0.39	0.47	0.15	**0.53***
59	0.44	0.52	0.51	0.59	0.46	0.80	0.78	0.44	0.71	0.78	0.62	0.64	**0.61***
60	0.33	0.43	0.52	0.51	0.43	0.90	0.69	0.33	0.64	0.66	0.53	0.50	**0.54***
61	0.71	0.67	1.08	0.73	0.93	1.65	0.67	0.70	0.88	0.41	0.64	0.45	**0.79**
62	0.23	0.67	0.56	0.43	0.41	1.03	0.59	0.29	0.38	0.73	0.74	0.45	**0.54**
63	0.53	0.58	0.85	0.77	0.74	1.19	0.93	0.55	0.85	0.82	0.71	0.62	**0.76***
64	0.67	1.13	0.75	0.75	0.67	1.03	0.89	0.71	0.52	1.16	1.18	0.89	**0.86**
65	0.36	0.43	0.60	0.56	0.50	0.98	0.73	0.37	0.68	0.68	0.55	0.51	**0.58***
66	0.59	0.31	0.83	0.75	0.75	1.19	0.88	0.57	0.95	0.65	0.45	0.60	**0.71***
67	0.58	0.35	0.82	0.76	0.74	1.16	0.90	0.57	0.94	0.69	0.49	0.61	**0.72***
68	0.31	0.34	0.68	0.52	0.55	1.14	0.66	0.32	0.67	0.53	0.45	0.35	**0.54***
69	0.61	0.24	0.80	0.74	0.73	1.15	0.86	0.59	0.96	0.61	0.37	0.62	**0.69***
70	0.46	0.48	0.89	0.57	0.73	1.44	0.59	0.46	0.71	0.36	0.50	0.22	**0.62**
71	0.31	0.75	0.64	0.50	0.49	1.09	0.65	0.37	0.41	0.79	0.82	0.50	**0.61**
72	0.57	0.21	0.81	0.71	0.72	1.20	0.82	0.55	0.92	0.55	0.34	0.54	**0.66***
73	0.59	0.33	0.82	0.76	0.75	1.17	0.89	0.58	0.95	0.67	0.47	0.61	**0.72***
74	0.04	0.51	0.51	0.29	0.34	1.04	0.45	0.11	0.37	0.54	0.56	0.28	**0.42**
75	0.85	0.37	0.94	0.88	0.91	1.27	0.93	0.81	1.16	0.60	0.36	0.79	**0.82**
76	0.50	0.18	0.76	0.64	0.67	1.18	0.75	0.48	0.86	0.50	0.32	0.47	**0.61***

Table 3.3 Table of Euclidean distance measures between ROW edaphic data from plot group 2 (columns) vs. SSHF edaphic data (rows). Tables are divided by ROW plot groups. The lowest mean distance values are marked with a "*".

Group 2	5	9	10	11	12	**Mean**
55	0.85	0.87	1.04	0.97	0.63	**0.87***
56	0.47	0.52	0.61	0.73	0.55	**0.58***
57	0.55	0.59	0.51	0.96	0.75	**0.67**
58	0.51	0.54	0.44	0.93	0.72	**0.63**
59	0.55	0.59	0.66	0.93	0.52	**0.65**
60	0.47	0.52	0.57	0.90	0.51	**0.59**
61	0.80	0.81	0.62	1.18	1.06	**0.89**
62	0.36	0.40	0.54	0.60	0.41	**0.46***
63	0.74	0.78	0.81	1.09	0.80	**0.84**
64	0.65	0.67	0.90	0.42	0.53	**0.63***
65	0.53	0.58	0.61	0.94	0.58	**0.65**
66	0.76	0.81	0.74	1.24	0.87	**0.88**
67	0.76	0.80	0.75	1.22	0.85	**0.88**

68	0.52	0.56	0.53	0.96	0.65	**0.65**
69	0.76	0.80	0.71	1.26	0.87	**0.88**
70	0.61	0.64	0.50	1.03	0.84	**0.72**
71	0.43	0.47	0.61	0.59	0.47	**0.51***
72	0.73	0.77	0.67	1.23	0.86	**0.85**
73	0.77	0.81	0.75	1.24	0.86	**0.89**
74	0.26	0.31	0.37	0.67	0.42	**0.41***
75	0.93	0.96	0.79	1.47	1.07	**1.04**
76	0.67	0.71	0.60	1.17	0.81	**0.79**

Table 3.4 Table of Euclidean distance measures between ROW edaphic data from plot group 3 (columns) vs. SSHF edaphic data (rows). Tables are divided by ROW plot groups. The lowest mean distance values are marked with a "*".

Group 3	14	23	28	30	31	32	34	**Mean**
55	0.92	0.96	1.42	1.07	1.17	1.22	1.23	**1.14**
56	1.18	0.79	0.76	0.52	0.58	1.12	1.06	**0.86**
57	1.49	0.97	0.74	0.54	0.45	0.92	0.93	**0.86**
58	1.47	0.93	0.70	0.49	0.38	0.88	0.85	**0.81**
59	1.23	0.93	1.10	0.74	0.77	0.85	1.00	**0.94**
60	1.26	0.89	0.99	0.65	0.65	0.81	0.93	**0.88**
61	1.78	1.15	0.71	0.69	0.50	1.00	0.86	**0.95**
62	1.05	0.65	0.72	0.43	0.53	1.11	0.98	**0.78**
63	1.47	1.13	1.11	0.84	0.83	1.00	1.21	**1.08**
64	0.65	0.57	0.88	0.70	0.89	1.52	1.27	**0.93**
65	1.32	0.95	1.01	0.68	0.68	0.84	0.99	**0.92**
66	1.65	1.23	1.18	0.88	0.80	0.67	1.04	**1.06**
67	1.61	1.21	1.19	0.89	0.82	0.71	1.07	**1.07**
68	1.42	0.97	0.90	0.61	0.56	0.81	0.93	**0.89**
69	1.66	1.23	1.21	0.90	0.80	0.54	0.97	**1.04**
70	1.59	1.01	0.70	0.55	0.41	0.91	0.86	**0.86**
71	1.04	0.67	0.71	0.47	0.58	1.19	1.05	**0.82**
72	1.66	1.20	1.13	0.84	0.73	0.58	0.95	**1.01**
73	1.64	1.23	1.19	0.89	0.81	0.67	1.05	**1.07**
74	1.16	0.67	0.67	0.35	0.38	0.95	0.82	**0.71**
75	1.88	1.39	1.34	1.05	0.90	0.21	0.86	**1.09**
76	1.61	1.14	1.06	0.77	0.67	0.60	0.91	**0.97**

Table 3.5 Table of Euclidean distance measures between ROW edaphic data from plot group 4 (columns) vs. SSHF edaphic data (rows). Tables are divided by ROW plot groups. The lowest mean distance values are marked with a "*".

Group 4	21	22	24	25	27	29	33	**Mean**
55	1.12	1.38	1.49	0.99	1.31	1.21	1.16	**1.24**
56	0.48	0.99	1.02	0.96	0.66	0.67	0.58	**0.77**
57	0.25	0.73	0.87	0.85	0.41	0.42	0.66	**0.60**

58	0.18	0.65	0.80	0.84	0.33	0.34	0.63	**0.54**
59	0.60	0.96	1.18	0.59	0.84	0.74	0.88	**0.83**
60	0.46	0.87	1.08	0.60	0.71	0.62	0.79	**0.73**
61	0.46	0.57	0.66	1.11	0.31	0.41	0.80	**0.62***
62	0.49	0.97	0.96	0.96	0.66	0.66	0.49	**0.74**
63	0.61	1.06	1.27	0.74	0.83	0.78	0.94	**0.89**
64	0.94	1.37	1.22	1.35	1.07	1.08	0.63	**1.09**
65	0.47	0.89	1.11	0.61	0.72	0.63	0.82	**0.75**
66	0.53	0.83	1.20	0.45	0.75	0.64	1.05	**0.78**
67	0.55	0.88	1.23	0.46	0.78	0.67	1.04	**0.80**
68	0.32	0.77	1.00	0.66	0.56	0.49	0.76	**0.65**
69	0.53	0.76	1.18	0.33	0.74	0.62	1.07	**0.75**
70	0.25	0.62	0.76	0.92	0.28	0.33	0.68	**0.55***
71	0.55	1.04	1.00	1.04	0.71	0.72	0.50	**0.79**
72	0.46	0.72	1.11	0.43	0.67	0.55	1.02	**0.71**
73	0.55	0.85	1.22	0.43	0.77	0.66	1.06	**0.79**
74	0.30	0.77	0.82	0.84	0.49	0.47	0.48	**0.60**
75	0.68	0.60	1.16	0.36	0.80	0.65	1.25	**0.79***
76	0.39	0.69	1.06	0.47	0.61	0.49	0.95	**0.66**

Table 3.6 Ranges and means of the raw edaphic data from the SSHF

Variables	Range	Mean
Total Exchange Capacity (TEC), meq/100g	2.24 – 15.1	5.89
pH	4.1 – 6.1	4.65
Organic Matter (OrgMa), %	1.46 – 6.91	2.77
Estimated Nitrogen Release (ENitR), lbs./acre	49 – 110	72.36
Sppm	15 – 30	20.45
Pppm	5 – 18	10.63
Cappm	83 – 1103	306
Mgppm	29 – 386	93.68
Kppm	22 – 80	40.36
Nappm	21 – 41	24.18
Bppm	0.1 – 0.31	0.13
Feppm	121 – 443	217.14
Mnppm	18 – 335	159.59
Cuppm	0.46 – 1.97	0.87
Znppm	0.61 – 4.38	1.26
Alppm	469 – 1153	767.95
Bulk Density (BDen)	1.01 – 1.35	1.20
Silt/Sand (ratio of percentages)	0.25 – 3.32	1.08

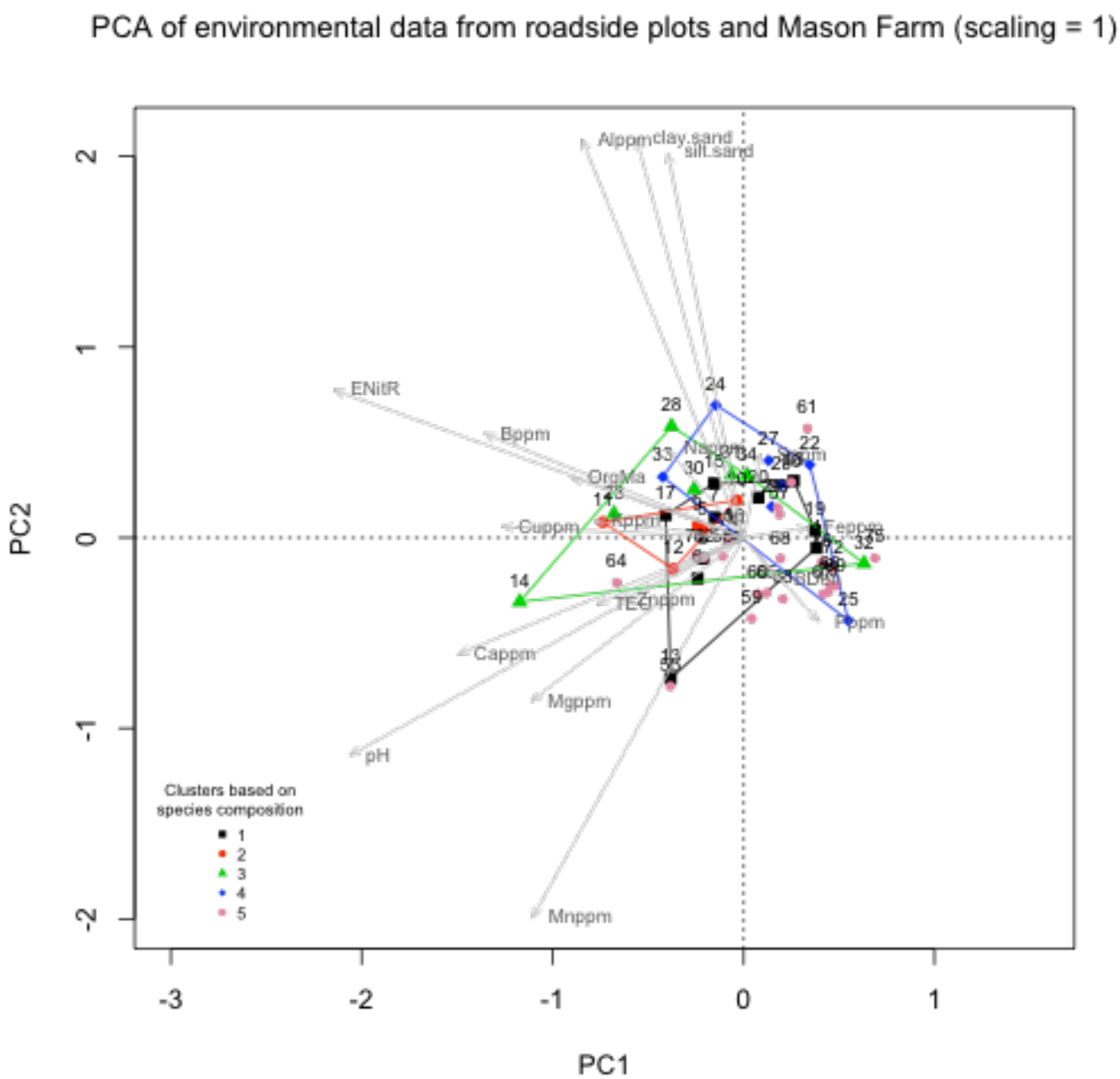

Figure 3.3 PCA biplot of SSHF sites and ROW plot groups. The ROW plots (referred to in the title as "roadside plots") retain their group color code from the cluster analysis, and the SSHF site points are colored pink; the legend denotes these points as "5". A total of 18 environmental variables were used for the ordination. Edaphic variables are represented as vectors.

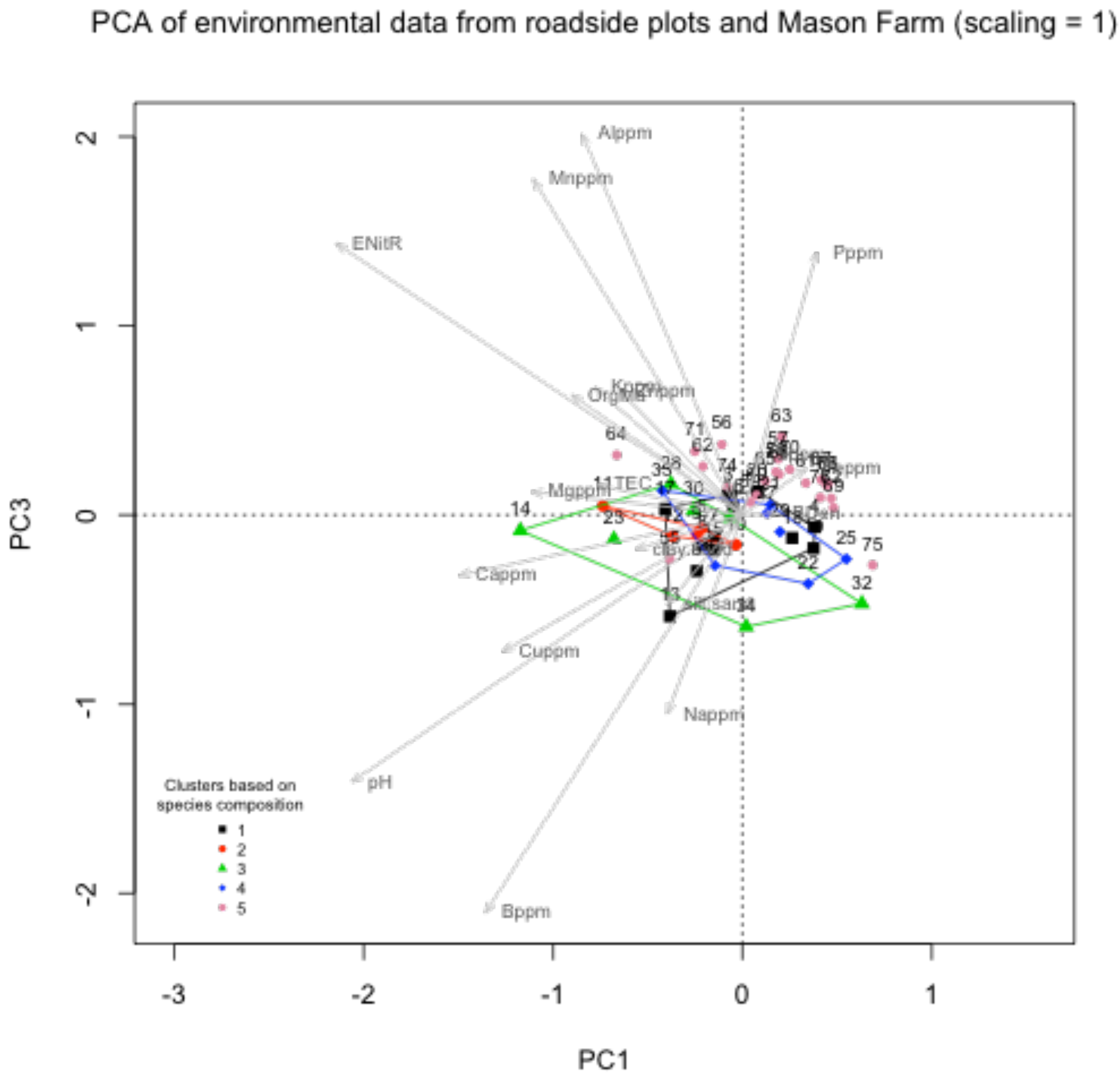

Figure 3.4 PCA of ROWs and SSHF; view of Axes 1 and 3.

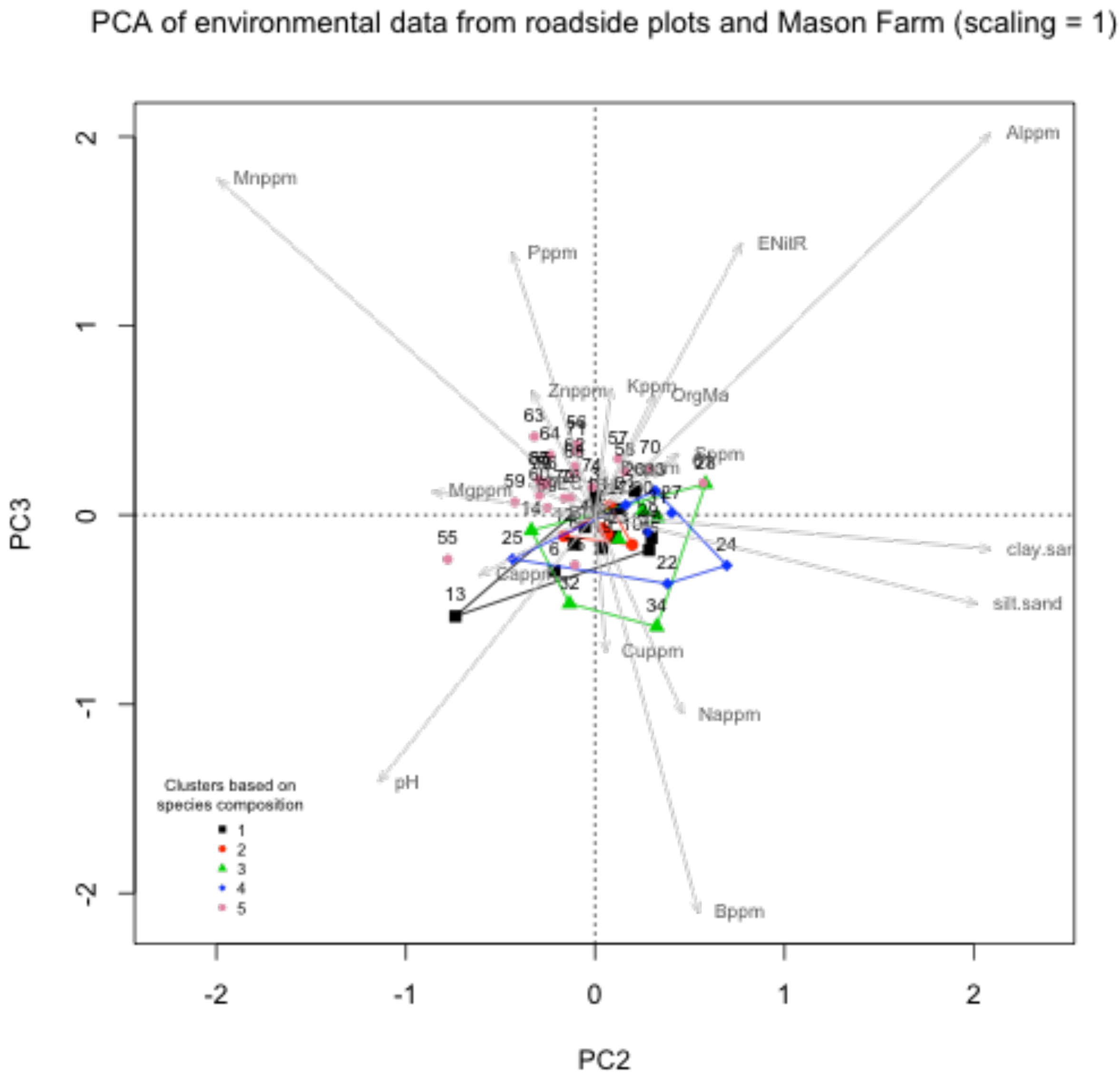

Figure 3.5 PCA of ROWs and SSHF; view of Axes 2 and 3.

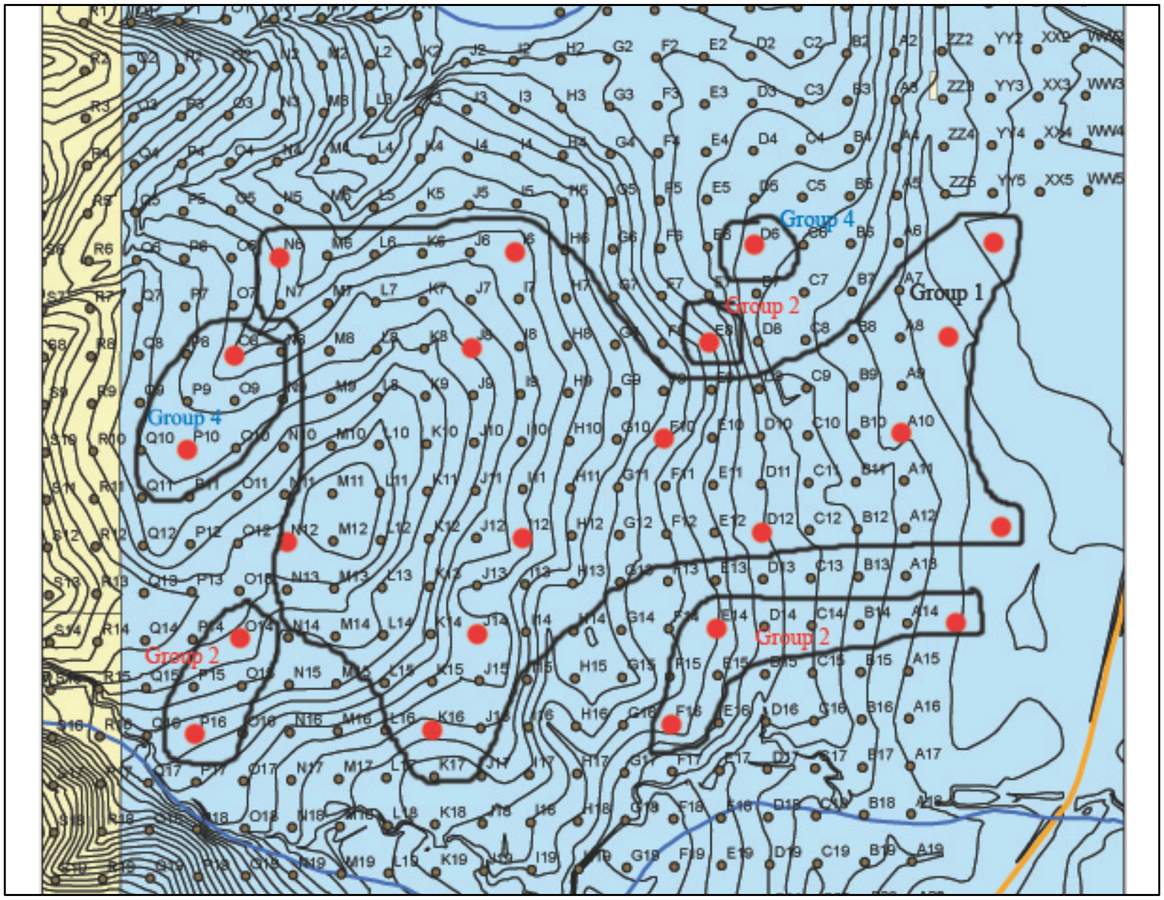

Figure 3.6 Hand-drawn polygons of ROW groups to recommend applied as partial prescriptions to the SSHF. The polygons are labeled by the color-coded groups identified in Chapter 2.

CONCLUSION

The historic Piedmont savanna is a critical piece of the natural heritage of the Piedmont of the southeastern US. Human stewardship of nature has shifted dramatically over the past several of centuries, and reports of the "ubiquitous" open conditions of the presettlement Piedmont landscape document this change. Herbaceous species finding refuge on the few remaining documented examples of open-canopied natural communities, as well as roadsides and other ROWs, were much more prominent on the presettlement landscape. The push by natural resource and conservation managers to restore savanna-like communities in the Piedmont requires more investigation of remnant savanna-like vegetation. In addition to the few remaining documented natural areas with savanna-like vegetation, ROWs serve as valuable reference areas for the habitat preference of the heliophilic herbaceous plants likely once found in Piedmont savannas. In terms of applying a target community for a savanna restoration, local knowledge and GIS models can only take us so far. Species and environmental data collected on sites where savanna vegetation still occur are crucial pieces of references for restoration projects. My study followed this approach in order to inform a proposed restoration project, and was successful in that partial target species lists were matched to different portions of the restoration site. In addition to restoring more areas of Piedmont savanna, the conservation of native heliophilic herbaceous plants also relies on protecting ROW sites where they occur. These sites are subject to increasing use of herbicides because of its convenience and low cost. It would be wise to follow action that has already begun aimed at protecting these high quality sites in order to protect a wider range of variation of habitat for Piedmont savanna vegetation.

Appendix 2.1 Species list from the ROW plots

Taxon	Plot Group	Indicator value
Andropogon virginicus	1	0.40
Anthoxanthum odoratum	1	0.11
Aristida oligantha	1	0.08
Aristida purpurascens	1	0.08
Avena sativa	1	0.08
Baccharis halimifolia	1	0.08
Bidens aristosa	1	0.28
Bidens sp.	1	0.08
Bromus sp.	1	0.11
Castilleja coccinea	1	0.08
Chamaecrista nictitans	1	0.36
Chrysopsis mariana	1	0.47
Danthonia sericea	1	0.23
Desmodium ciliare	1	0.24
Desmodium paniculatum	1	0.17
Dichanthelium depauperatum	1	0.08
Dichanthelium laxiflorum	1	0.17
Dichanthelium longiligulatum	1	0.08
Dichanthelium polyanthes	1	0.08
Dichanthelium scoparium	1	0.20
Dichanthelium sphaerocarpon	1	0.08
Digitaria sp.	1	0.08
Diodia teres	1	0.08
Eupatorium capillifolium	1	0.27
Eupatorium rotundifolium	1	0.32
Eupatorium sp. #1	1	0.17
Eupatorium sp. #2	1	0.08
Gelsemium sempervirens	1	0.25
Gymnopogon brevifolius	1	0.50
Houstonia caerulea	1	0.08
Hypericum cruxandreae	1	0.08
Hypericum hypericoides	1	0.13
Lactuca sp.	1	0.20
Lespedeza cuneata	1	0.49
Liatris sp.	1	0.08
Lobelia nuttallii	1	0.08
Lobelia puberula	1	0.17
Lobelia siphilitica	1	0.08
Lysimachia quadrifolia	1	0.08
Muhlenbergia capillaris	1	0.65
Oldenlandia uniflora	1	0.08
Packera anonyma	1	0.17
Packera aurea	1	0.21
Panicum dichotomiflorum	1	0.16
Paspalum spp.	1	0.17
Pinus taeda	1	0.32

Quercus marilandica	1	0.08
Quercus nigra	1	0.08
Rhexia mariana	1	0.08
Rubus argutus	1	0.30
Rumex crispus	1	0.08
Saccharum giganteum	1	0.08
Salvia lyrata	1	0.18
Scutellaria integrifolia	1	0.18
Scutellaria serrata	1	0.08
Sericocarpus asteroides	1	0.26
Solidago odora	1	0.33
Solidago patula	1	0.08
Solidago rugosa	1	0.39
Solidago spp.	1	0.43
Solidago speciosa	1	0.20
Sporobolus sp.	1	0.08
Symphyotrichum grandiflorum	1	0.24
Symphyotrichum pilosum	1	0.52
Symphyotrichum racemosum	1	0.32
Ulmus alata	1	0.31
Vaccinium stamineum	1	0.15
Vernonia acaulis	1	0.08
Verbascum thapsus	1	0.08
Viola sp.	1	0.08
Aletris farinosa	2	0.51
Andropogon elliottii	2	0.25
Apocynum cannabinum	2	0.47
Asclepias variegata	2	0.60
Carya glabra	2	0.24
Carex spp.	2	0.27
Chrysogonum virginianum	2	0.31
Coreopsis auriculata	2	0.40
Coreopsis major	2	0.35
Dactylis glomerata	2	0.20
Desmodium strictum	2	0.40
Dichanthelium dichotomum	2	0.09
Dichanthelium spp.	2	0.28
Erigeron spp.	2	0.17
Euphorbia spp.	2	0.23
Festuca spp.	2	0.70
Fraxinus americana	2	0.58
Ilex opaca	2	0.11
Juncus sp.	2	0.07
Lespedeza procumbens	2	0.10
Lespedeza stuevei	2	0.34
Leucanthemum vulgare	2	0.30
Liquidambar styraciflua	2	0.38
Lonicera japonica	2	0.39
Marshallia obovata	2	0.09

Oenothera fruticosa	2	0.40
Oxydendrum arboreum	2	0.27
Parthenocissus quinquefolia	2	0.39
Penstemon spp.	2	0.35
Phlox carolina	2	0.20
Potentilla canadensis	2	0.41
Pseudognaphalium obtusifolium	2	0.38
Pycnanthemum tenuifolium	2	0.28
Quercus velutina	2	0.12
Rosa spp.	2	0.38
Rubus cuneifolius	2	0.16
Schizachyrium scoparium	2	0.30
Scutellaria nervosa	2	0.11
Sisyrinchium angustifolium	2	0.25
Sisyrinchium mucronatum	2	0.12
Toxicodendron radicans	2	0.28
Vaccinium pallidum	2	0.64
Vicia caroliniana	2	0.20
Zizia spp.	2	0.11
Ageratina aromatica	3	0.09
Albizia julibrissin	3	0.19
Allium sp.	3	0.08
Ampelopsis spp.	3	0.29
Andropogon sp.	3	0.20
Anemone virginiana	3	0.43
Asclepias tuberosa	3	0.20
Aureolaria virginica	3	0.37
Castanea pumila	3	0.14
Ceanothus americanus	3	0.23
Cercis canadensis	3	0.57
Clematis glaucophylla	3	0.14
Clematis ochroleuca	3	0.14
Clitoria mariana	3	0.21
Corylus americana	3	0.43
Cornus florida	3	0.39
Daucus carota	3	0.13
Desmodium sp.	3	0.19
Dichanthelium aciculare	3	0.14
Dichanthelium acuminatum	3	0.15
Dichanthelium boscii	3	0.29
Dichanthelium consanguineum	3	0.06
Dichanthelium commutatum	3	0.29
Dichanthelium leucothrix	3	0.21
Dichanthelium meridionale	3	0.07
Diospyros virginiana	3	0.11
Echinacea laevigata	3	0.14
Elephantopus carolinianus	3	0.10
Elephantopus tomentosus	3	0.08
Elymus spp.	3	0.58

Erigeron strigosus	3	0.23
Euonymus americanus	3	0.36
Eupatorium altissimum	3	0.14
Eupatorium torreyanum	3	0.20
Fragaria vesca	3	0.29
Fragaria virginiana	3	0.14
Galium circaezans	3	0.39
Galium pilosum	3	0.14
Hieracium venosum	3	0.06
Houstonia purpurea	3	0.13
Hypericum punctatum	3	0.57
Hypericum stragulum	3	0.46
Iris sp.	3	0.07
Juglans nigra	3	0.14
Juniperus virginiana	3	0.21
Lespedeza repens	3	0.18
Lespedeza sp.	3	0.10
Lilium michauxii	3	0.14
Liriodendron tulipifera	3	0.67
Lobelia sp. 1	3	0.14
Lonicera sempervirens	3	0.20
Parthenium auriculatum	3	0.14
Passiflora spp.	3	0.21
Physalis pubescens	3	0.14
Pinus virginiana	3	0.14
Pityopsis graminifolia	3	0.12
Poa arachnifera	3	0.10
Polygonatum biflorum	3	0.14
Polygala sp.	3	0.14
Prenanthes altissima	3	0.37
Prenanthes trifoliolata	3	0.06
Prunus serotina	3	0.34
Prunella vulgaris	3	0.29
Quercus alba	3	0.33
Quercus phellos	3	0.34
Quercus stellata	3	0.17
Rhus copallinum	3	0.21
Sassafras albidum	3	0.17
Sericocarpus linifolius	3	0.11
Silphium asteriscus	3	0.10
Silphium terebinthinaceum	3	0.14
Silene virginica	3	0.14
Smilax bonanox	3	0.09
Solidago bicolor	3	0.16
Solanum carolinense	3	0.08
Sorghastrum nutans	3	0.28
Stylosanthes biflora	3	0.12
Symphyotrichum patens	3	0.11
Trifolium campestre	3	0.06

Tridens flavus	3	0.20
Uvularia perfoliata	3	0.29
Vaccinium tenellum	3	0.09
Verbesina occidentalis	3	0.43
Viburnum dentatum var. dentatum	3	0.14
Viburnum rafinesquianum	3	0.30
Acer rubrum	4	0.30
Agalinis tenuifolia	4	0.08
Aristida spp.	4	0.17
Baptisia tinctoria	4	0.50
Campsis radicans	4	0.28
Carya tomentosa	4	0.34
Coreopsis verticillata	4	0.28
Danthonia spicata	4	0.22
Desmodium lineatum	4	0.09
Desmodium nudiflorum	4	0.09
Dicentra sp.	4	0.14
Eupatorium album	4	0.22
Eupatorium godfreyanum	4	0.14
Eupatorium hyssopifolium	4	0.20
Eutrochium fistulosum	4	0.14
Gillenia stipulata	4	0.14
Helianthus hirsutus	4	0.14
Hexastylis arifolia	4	0.26
Hypericum drummondii	4	0.10
Hypericum gentianoides	4	0.21
Hypoxis hirsuta	4	0.29
Lespedeza bicolor	4	0.09
Lespedeza virginica	4	0.14
Ligustrum sinense	4	0.14
Lyonia mariana	4	0.10
Nyssa sylvatica	4	0.26
Parthenium integrifolium	4	0.26
Pinus echinata	4	0.18
Pycnanthemum incanum	4	0.11
Quercus rubra	4	0.24
Silphium compositum	4	0.49
Smilax glauca	4	0.09
Smilax rotundifolia	4	0.32
Tephrosia virginiana	4	0.75
Toxicodendron pubescens	4	0.14
Vaccinium spp.	4	0.25
Vitis rotundifolia	4	0.31

Appendix 2.2.1 Raw environmental data from ROW plots. These data are divided into 3 tables, and in each table the rows are divided by plot groups

Plots (group 1)	TEC	pH	OrgMa (%)	ENitR	Sppm	Pppm	Cappm
3	10.61	4.6	1.88	58	17	9	440
4	8.12	4.6	1.2	44	13	14	359
6	7.04	5.4	3.04	80	14	5	491
7	6.64	4.8	3.83	88	17	5	366
8	5.77	5.3	3.04	80	16	3	487
13	10.63	5.8	2.12	62	10	4	886
15	4.92	5.2	3.46	85	23	5	354
16	5.99	4.9	3.42	84	17	5	323
17	8.09	5.2	3.46	85	20	4	577
18	4.22	4.6	2.08	62	24	4	196
19	3.98	4.7	1.78	56	15	4	204
20	6.76	4.6	2.27	65	15	5	270
Group 2							
5	5.6	5	2.79	76	21	7	354
9	7.2	5.1	3.75	88	18	6	546
10	4.88	4.8	2.6	72	21	4	270
11	7.87	5.6	4.62	96	16	6	740
12	7.11	5.2	3.12	81	17	6	563
Group 3							
14	17.84	6	7.51	113	15	5	1720
23	6.74	5.7	3.83	88	16	3	678
28	6.91	4.8	5.28	101	25	6	340
30	7.39	4.8	3.26	83	26	4	403
31	4.57	4.9	3	80	16	8	269
32	3.83	4.6	0.75	30	17	8	187
34	4.29	4.7	2.17	63	19	4	216
Group 4							
21	4.57	4.5	2.41	68	19	9	187
22	3.93	4.4	2.33	67	24	5	162
24	5.59	4.5	2.91	78	35	3	241
25	3.6	4.9	0.85	34	17	4	198
27	4.77	4.6	2.68	74	24	4	201
29	4	4.8	2.73	75	17	7	207
33	5.28	4.8	5.32	102	23	8	253

Appendix 2.2.2

Plots (group 1)	Mgppm	Kppm	Nappm	Bppm	Feppm	Mnppm	Cuppm	Znppm
3	187	59	48	0.1	197	40	11.2	3.81
4	120	43	56	0.1	226	11	0.99	1.85
6	175	33	58	0.21	158	60	2.98	0.98
7	89	28	52	0.25	213	77	1.68	1.1

8	64	26	61	0.1	131	167	2.93	1.07
13	362	52	46	1.13	155	154	1.84	2.45
15	61	44	61	0.25	193	12	1.82	1.77
16	92	33	58	0.1	215	50	1.26	1.66
17	120	100	52	0.34	133	77	1.12	2.93
18	46	39	40	0.1	188	17	1.45	1.68
19	45	23	41	0.1	170	32	0.68	1.22
20	114	50	45	0.1	124	48	0.89	1.53
Group 2								
5	69	35	53	0.27	187	127	5.53	1.12
9	77	32	47	0.34	237	58	1.21	1.71
10	59	23	48	0.21	111	52	4.01	0.92
11	132	106	43	0.4	105	204	4.22	1.82
12	82	49	49	0.53	162	288	2.73	1.18
Group 3								
14	609	75	77	1.45	128	254	4.55	8.43
23	112	72	49	1.05	137	278	1.56	0.74
28	94	83	66	0.29	125	27	1.56	1.23
30	103	52	43	0.3	93	71	1.75	1.7
31	53	35	46	0.22	123	63	0.96	0.69
32	35	15	51	0.47	80	28	0.52	0.1
34	46	27	52	2.57	135	24	2.47	0.61
Group 4								
21	56	31	44	0.32	146	53	0.79	1.81
22	36	25	41	0.49	231	11	0.71	0.62
24	56	44	60	1.79	171	24	1.39	0.77
25	42	22	55	0.1	142	85	0.48	1.21
27	63	45	47	0.1	180	23	1	0.99
29	52	22	47	0.1	194	18	0.89	0.86
33	84	56	40	0.79	209	72	2.23	4.1

Appendix 2.2.3

Plots	Alpp m	BDen	Silt (%)	Sand (%)	Clay (%)	CPYOPN	Aspect	Slope
3	1061	1.23	30.04	50.25	19.71	41.92	135	0.51
4	932	1.27	24.99	60.64	14.37	44.82	86.19	5.37
6	589	1.14	48.82	36.81	14.37	51.19	154.98	5.91
7	680	1.13	65.81	19.2	14.99	47.83	225	1.52
8	650	1.14	59.38	23.99	16.63	65.56	135	4.04
13	412	1.27	19.33	66.9	13.77	52.09	203.20	5.44
15	897	1.13	43.13	31.96	24.91	47.63	4.40	4.66
16	830	1.1	43.16	40.81	16.03	45.64	296.57	3.20
17	980	1.04	39.28	31.29	29.43	44.25	184.40	4.66
18	832	1.11	56.35	23.27	20.38	48.58	90	3.58
19	714	1.15	55.44	31.07	13.49	39.14	181.85	10.97
20	1039	1.08	48.97	29.17	21.86	43.7	186.34	9.64
Grou								

p 2								
5	852	1.06	56.11	27.83	16.06	36.92	210.96	2.09
9	779	1.08	55.12	27.85	17.03	40.91	11.30	1.83
10	851	1.09	49.89	26.04	24.07	36.68	96.34	6.46
11	981	0.97	47.35	22.55	30.1	29.05	265.60	4.66
12	734	1.16	54.4	31.15	14.45	37.25	263.66	3.24
Group 3								
14	835	0.92	31.22	49.28	19.5	68.52	225	3.54
23	997	1	50.54	19.61	29.85	28.53	128.66	4.58
28	1178	0.98	42.41	19.48	38.11	52.98	288.43	4.52
30	966	1.03	48.14	23.57	28.29	49.8	96.34	3.24
31	910	1.02	63.21	14.94	21.85	38.07	338.20	3.85
32	665	1.32	31.71	54.06	14.23	18.21	291.80	7.67
34	698	0.98	61.48	18.81	19.71	41.31	296.57	3.20
Group 4								
21	962	1.07	47.46	36.51	16.03	40.83	195.26	8.11
22	672	1.04	65.98	18.66	15.36	29.64	265.60	4.66
24	1018	1.02	55.77	11.69	32.54	40.27	296.57	1.60
25	636	1.33	17.54	68.81	13.65	43.27	359	0.05
27	938	1.05	47.13	20.97	31.9	35.67	10.30	7.96
29	822	1	58.79	23.01	18.2	36.57	270	1.43
33	1003	0.9	46.89	26.2	26.91	39.78	120.96	2.09

Appendix 2.3 Constancy values for each taxon. Species indicators are in bold.

Taxon	Group 1	Group 2	Group 3	Group 4
Acer rubrum	0.58	0.6	0.71	0.85
Agalinis tenuifolia	0.08	0	0	0.14
Ageratina aromatica	0.08	0	0.14	0
Albizia julibrissin	0.33	0	0.42	0.14
Aletris farinosa	0.08	**0.6**	0	0
Allium sp.	0.16	0	0.14	0
Ampelopsis spp.	0	0	0.28	0
Andropogon elliottii	0	0.4	0	0.14
Andropogon sp.	0.08	0	0.28	0
Andropogon virginicus	0.83	0.4	0.57	0.57
Anemone virginiana	0	0	**0.42**	0
Anthoxanthum odoratum	0.25	0	0.14	0.28
Apocynum cannabinum	0.25	**0.8**	0.57	0
Aristida oligantha	0.08	0	0	0
Aristida purpurascens	0.16	0	0	0.14
Aristida spp.	0.16	0	0	0.28
Asclepias tuberosa	0.08	0.4	0.42	0
Asclepias variegata	0	**0.6**	0	0
Aureolaria virginica	0	0	**0.42**	0.14
Avena sativa	0.08	0	0	0
Baccharis halimifolia	0.08	0	0	0
Baptisia tinctoria	0.25	0	0	**0.71**
Bidens aristosa	0.41	0	0.14	0.14
Bidens sp.	0.08	0	0	0
Bromus sp.	0.16	0	0.14	0
Campsis radicans	0.66	0	0.42	0.71
Carex spp.	0.66	0.8	0.57	0.57
Carya tomentosa	0.25	0.6	0.57	0.85
Carya glabra	0.25	0.6	0.28	0.42
Castanea pumila	0	0	0.14	0
Castilleja coccinea	0.08	0	0	0
Ceanothus americanus	0	0.4	0.42	0
Cercis canadensis	0	0.2	**0.71**	0
Chamaecrista nictitans	**0.58**	0	0.28	0
Chrysogonum virginianum	0	0.4	0.14	0
Chrysopsis mariana	**0.75**	0	0.14	0.42
Clematis glaucophylla	0	0	0.14	0
Clematis ochroleuca	0	0	0.14	0
Clitoria mariana	0.08	0	0.42	0.42
Coreopsis auriculata	0	**0.4**	0	0
Coreopsis major	0.33	1	0.28	0.85
Coreopsis verticillata	0.08	0	0.28	0.42
Cornus florida	0	0.6	**0.71**	0.14
Corylus americana	0	0	**0.42**	0
Dactylis glomerata	0	0.2	0	0
Danthonia sericea	0.58	0.2	0.28	0.71

Danthonia spicata	0.66	0.6	0.85	0.85
Daucus carota	0.16	0	0.28	0.14
Desmodium ciliare	0.33	0	0	0.14
Desmodium lineatum	0.08	0	0	0.14
Desmodium nudiflorum	0.08	0.2	0.14	0.28
Desmodium paniculatum	0.16	0	0	0
Desmodium sp.	0.16	0.2	0.42	0.14
Desmodium strictum	0.41	**0.8**	0.28	0.28
Dicentra sp.	0	0	0	0.14
Dichanthelium aciculare	0	0	0.14	0
Dichanthelium acuminatum	0.33	0	0.28	0.14
Dichanthelium boscii	0	0	0.28	0
Dichanthelium commutatum	0	0	0.28	0
Dichanthelium consanguineum	0.16	0	0.14	0.14
Dichanthelium depauperatum	0.16	0	0	0.14
Dichanthelium dichotomum	0.08	0.2	0	0.14
Dichanthelium laxiflorum	0.58	0.6	0.57	0.57
Dichanthelium leucothrix	0.08	0	0.28	0
Dichanthelium longiligulatum	0.08	0	0	0
Dichanthelium meridionale	0	0	0.14	0.14
Dichanthelium polyanthes	0.08	0	0	0
Dichanthelium scoparium	0.33	0	0.14	0.14
Dichanthelium spp.	0.66	0.8	0.71	1
Dichanthelium sphaerocarpon	0.08	0	0	0
Digitaria sp.	0.08	0	0	0
Diodia teres	0.08	0	0	0
Diospyros virginiana	0.16	0	0.28	0.28
Echinacea laevigata	0	0	0.14	0
Elephantopus carolinianus	0	0	0.14	0.14
Elephantopus tomentosus	0	0	0.14	0.14
Elymus spp.	0	0	**0.71**	0.14
Erigeron spp.	0.16	0.4	0.28	0
Erigeron strigosus	0.33	0	0.42	0
Euonymus americanus	0	0	**0.42**	0.14
Eupatorium album	0.08	0	0	0.28
Eupatorium altissimum	0	0	0.14	0
Eupatorium capillifolium	0.41	0	0.14	0.14
Eupatorium godfreyanum	0	0	0	0.14
Eupatorium hyssopifolium	0.5	0.4	0.42	0.71
Eupatorium rotundifolium	0.91	0.8	0.28	0.85
Eupatorium sp. #1	0.25	0	0.14	0
Eupatorium sp. #2	0.08	0	0	0
Eupatorium torreyanum	0.16	0.2	0.42	0.14
Euphorbia spp.	0.08	0.6	0.28	0.57
Eutrochium fistulosum	0	0	0	0.14
Festuca spp.	0.16	**1**	0.14	0
Fragaria vesca	0	0	0.28	0
Fragaria virginiana	0	0	0.14	0
Fraxinus americana	0.25	1	**0.42**	0.14

Galium circaezans	0.25	0.2	**0.71**	0.28
Galium pilosum	0	0	0.14	0
Gelsemium sempervirens	0.25	0	0	0
Gillenia stipulata	0	0	0	0.14
Gymnopogon brevifolius	**0.5**	0	0	0
Helianthus hirsutus	0	0	0	0.14
Hexastylis arifolia	0.08	0	0	0.28
Hieracium venosum	0.08	0	0.14	0.14
Houstonia caerulea	0.08	0	0	0
Houstonia purpurea	0.16	0	0.28	0.14
Hypericum cruxandreae	0.08	0	0	0
Hypericum drummondii	0.08	0	0	0.14
Hypericum gentianoides	0.33	0	0	0.42
Hypericum hypericoides	0.33	0.2	0.28	0.28
Hypericum punctatum	0	0	**0.57**	0
Hypericum stragulum	0.16	0.2	**0.71**	0.14
Hypoxis hirsuta	0	0	0	0.28
Ilex opaca	0.08	0.2	0	0
Iris sp.	0	0	0.14	0.14
Juglans nigra	0	0	0.14	0
Juncus sp.	0.08	0.2	0.14	0.14
Juniperus virginiana	0.41	0.2	0.57	0.42
Lactuca sp.	0.25	0	0.14	0
Lespedeza bicolor	0.08	0	0.14	0.28
Lespedeza cuneata	0.75	0	0.28	0.28
Lespedeza procumbens	0.08	0.2	0.14	0.14
Lespedeza repens	0.08	0	0.28	0.14
Lespedeza sp.	0.16	0	0.28	0.28
Lespedeza stuevei	0.41	0.6	0.14	0.57
Lespedeza virginica	0	0	0	0.14
Leucanthemum vulgare	0.33	0.6	0.14	0
Liatris sp.	0.08	0	0	0
Ligustrum sinense	0	0	0	0.14
Lilium michauxii	0	0	0.14	0
Liquidambar styraciflua	0.83	**1**	1	0.85
Liriodendron tulipifera	0.08	0.2	**0.85**	0
Lobelia nuttallii	0.08	0	0	0
Lobelia puberula	0.16	0	0	0
Lobelia siphilitica	0.08	0	0	0
Lobelia sp. 1	0	0	0.14	0
Lonicera japonica	0.75	**1**	0.57	0.71
Lonicera sempervirens	0.08	0.4	0.42	0.14
Lyonia mariana	0.16	0	0	0.14
Lysimachia quadrifolia	0.08	0	0	0
Marshallia obovata	0.16	0.2	0	0.28
Muhlenbergia capillaris	**0.75**	0	0	0.14
Nyssa sylvatica	0.33	0.6	0.57	0.71
Oenothera fruticosa	0.58	**0.8**	0	0
Oldenlandia uniflora	0.08	0	0	0

Oxydendrum arboreum	0.08	0.6	0.42	0.28
Packera anonyma	0.16	0	0	0
Packera aurea	0.41	0	0.14	0.28
Panicum dichotomiflorum	0.41	0.2	0.28	0.28
Parthenium auriculatum	0	0	0.14	0
Parthenium integrifolium	0.5	0.4	0.14	0.71
Parthenocissus quinquefolia	0.25	0.8	0.71	0.57
Paspalum spp.	0.16	0	0	0
Passiflora spp.	0	0.2	0.28	0
Penstemon spp.	0.16	0.6	0.28	0
Phlox carolina	0	0.2	0	0
Physalis pubescens	0	0	0.14	0
Pinus echinata	0.08	0	0.28	0.42
Pinus taeda	0.5	0.2	0	0.28
Pinus virginiana	0	0	0.14	0
Pityopsis graminifolia	0.25	0	0.28	0.14
Poa arachnifera	0	0.2	0.14	0
Polygala sp.	0	0	0.14	0
Polygonatum biflorum	0	0	0.14	0
Potentilla canadensis	0.83	**1**	1	0.71
Prenanthes altissima	0.08	0	**0.42**	0
Prenanthes trifoliolata	0.08	0	0.14	0.14
Prunella vulgaris	0	0	0.28	0
Prunus serotina	0.25	1	0.85	0.57
Pseudognaphalium obtusifolium	0.91	1	0.57	0.71
Pycnanthemum incanum	0	0	0.14	0.28
Pycnanthemum tenuifolium	0.5	0.6	0.42	0.14
Quercus alba	0.33	0.4	0.85	0.57
Quercus marilandica	0.08	0	0	0
Quercus nigra	0.08	0	0	0
Quercus phellos	0.25	0.6	0.85	0.42
Quercus rubra	0	0	0.28	0.42
Quercus stellata	0.16	0.4	0.42	0.42
Quercus velutina	0.08	0.4	0.14	0.28
Rhexia mariana	0.08	0	0	0
Rhus copallinum	0.25	0.4	0.57	0.57
Rosa spp.	0.33	0.8	0.42	0.14
Rubus argutus	0.66	0.2	0.28	0.42
Rubus cuneifolius	0.25	0.4	0.28	0.14
Rumex crispus	0.08	0	0	0
Saccharum giganteum	0.08	0	0	0
Salvia lyrata	0.33	0.2	0.14	0
Sassafras albidum	0	0.2	0.28	0
Schizachyrium scoparium	0.91	1	0.57	1
Scutellaria integrifolia	0.5	0.4	0.42	0.28
Scutellaria nervosa	0.16	0.2	0.14	0
Scutellaria serrata	0.08	0	0	0
Sericocarpus asteroides	0.33	0	0	0.14
Sericocarpus linifolius	0.16	0	0.28	0.14

Silene virginica	0	0	0.14	0
Silphium asteriscus	0.08	0	0.14	0
Silphium compositum	0.16	0	0.42	**0.85**
Silphium terebinthinaceum	0	0	0.14	0
Sisyrinchium angustifolium	0.33	0.4	0	0
Sisyrinchium mucronatum	0	0.2	0.14	0
Smilax bonanox	0.08	0	0.14	0
Smilax glauca	0.08	0	0	0.14
Smilax rotundifolia	0.58	1	0.42	1
Solanum carolinense	0	0.2	0.14	0
Solidago bicolor	0.08	0	0.28	0.28
Solidago odora	0.33	0	0	0
Solidago patula	0.16	0	0.14	0
Solidago rugosa	**0.66**	0	0.28	0
Solidago spp.	**0.91**	0	0.57	0.42
Solidago speciosa	0.33	0	0.14	0
Sorghastrum nutans	0.58	0	0.71	0.57
Sporobolus sp.	0.08	0	0	0
Stylosanthes biflora	0.16	0.2	0.28	0.28
Symphyotrichum grandiflorum	0.33	0	0	0.14
Symphyotrichum patens	0.08	0	0.14	0
Symphyotrichum pilosum	**0.75**	0	0.42	0
Symphyotrichum racemosum	0.5	0	0.28	0
Tephrosia virginiana	0.16	0	0	**0.85**
Toxicodendron pubescens	0	0	0	0.14
Toxicodendron radicans	0.5	0.8	0.57	0.28
Tridens flavus	0.33	0	0.42	0.28
Trifolium campestre	0.08	0	0.14	0.14
Ulmus alata	0.66	0.2	0.42	0.14
Uvularia perfoliata	0	0	0.28	0
Vaccinium pallidum	0.16	1	0	0.28
Vaccinium spp.	0.25	0.2	0.28	0.57
Vaccinium stamineum	0.33	0.2	0	0.14
Vaccinium tenellum	0.08	0	0.14	0
Verbascum thapsus	0.08	0	0	0
Verbesina occidentalis	0	0	0.42	0
Vernonia acaulis	0.08	0	0	0
Viburnum dentatum var. dentatum	0	0	0.14	0
Viburnum rafinesquianum	0.08	0	0.42	0.14
Vicia caroliniana	0	0.2	0	0
Viola sp.	0.08	0	0	0
Vitis rotundifolia	0.58	0.8	0.71	1
Zizia spp.	0.16	0.2	0.14	0

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