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CHARACTERIZATION OF PIEDMONT PRAIRIE SITES IN NORTH AND SOUTH CAROLINA

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CHARACTERIZATION OF PIEDMONT PRAIRIE SITES IN NORTH AND SOUTH CAROLINA

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ABSTRACT

Grassland habitats have essentially disappeared from the Piedmont. This study was conducted to determine which site characteristics in remnant Piedmont prairie sites could be used as indicators of suitable sites. Eight prairie remnant sites located in the Piedmont of North and South Carolina were evaluated based on soil series, slope, aspect, landform index, temperature, and precipitation. Geographic Information System technology was used to create layers of these characteristics to predict potential restoration sites throughout the North and South Carolina Piedmont. It was found that southern aspects, slopes generally less than 15%, upper slope positions, and occurrence on Enon (Fine, mixed, active, thermic Ultic Hapludalfs), Iredell (Fine, montmorillonitic, thermic, Oxyaquic Vertic Hapludalfs), Mecklenburg (Fine, mixed, active, thermic Ultic Hapludalfs), Wilkes (Loamy, mixed, active, thermic, shallow Typic Hapludalfs and Wynott (Fine, mixed, active, thermic Typic Hapludalfs) soil series were common to all sites. All sites had been disturbed in some manner. Analysis of soil chemical and physical properties showed no significant differences for C, N, and Zn among locations. Significant site differences were found for P, K, Ca, Mg, B, Cu, Mn, Na, Zn, acidity, pH, buffer pH, C/N ratio, K base saturation, Ca base saturation, Mg base saturation, Na base saturation, total base saturation, CEC, and percent sand, silt, and clay. When soil nutrients were rated for growth sufficiency, N, P, and K were found deficient, and other nutrients were sufficient or greater. Base saturation ranged from 29-70%, but averaged 52% for all sites.

Soil texture to a 15 cm depth was loamy with sand comprising the greatest volume (mean 45%), followed by silt (33%) then clay (21%). Ordination of five prairie remnants indicated that the sites group based on moisture. Winter bentgrass (*Agrostis hyemalis* (Walt.) B.S.P.), yellowfruit sedge (*Carex annectens* (Bickn.) Bickn.), scarlet Indian paintbrush (*Castilleja coccinea* (L.) Spreng.), spotted water hemlock (*Cicuta maculata* L.), chickasaw plum (*Prunus angustifolia* Marsh.), needletip blue-eyed grass (*Sisyrinchium mucronatum* Michx.), and spring lady's tresses (*Spiranthes vernalis* Engelm. & Gray) are preferential to the most mesic site. Remaining locations were divided based on the occurrence of Indian hemp (*Apocynum cannabinum* L.). One location contained this species while four did not. Thirty-eight species did not show a preference to site with twenty-two having an association with prairies. Qualification of landscape position, soil chemical and physical characteristics, and species occurrence will assist restorationists and land managers by aiding them in choosing better sites thus increasing restoration success. Results may also give insight into whether present management and selection methods are suitable.

DEDICATION

This dissertation is dedicated to all the people that have encouraged and stood behind me over the years. My grandparents, Homer and Hattie Benson, believed education was the vehicle to a better life and instilled this in their children, thus instilling this idea in me. My aunts (Eather, Lula and Edna) have been an endless source of support and encouragement especially Aunt Eather. She would review my school work and say, “You could have done better”, even when I received an “A”. My uncles (Harold, James, William, Roscoe and Thomas) wrote the problem solving manual then loaned it to me. Each would have a slightly different spin on a solution just to prove there is always more than one way to “skin a cat”. My mother, Wilma, has been an unending aquifer of, “You can do that. What’s the problem?” Dr. Robert Allen took it upon himself to see me through my freshman year in college. He gave selflessly of his time and energy to aid and encourage my scholarship. Dr. Allen decided I was going to be a success even if it killed me. He also decided I was going to earn a Ph.D. My wife, Ida, strongly encouraged me to pursue this degree process then gave of her time and energy to assist in any way possible. She constantly reminds me that failure only generates new opportunities. My children, Candy and Denita, seem to have the attitude that Dad only succeeds. How could I burst their bubble? I will forever be indebted to these individuals for any achievement or success I may have in my life.

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CHAPTER ONE

INTRODUCTION

Fire and soils shaped grasslands and their diverse species composition (Anderson 2006). Grasses and forbs occurred in grasslands creating a diversity that provided food and cover for Native Americans and wildlife. With the decline of grassland habitat vital habitat resources have declined as well (McCraken 2005). Eastern meadowlark (*Sturnella magna)*, common barn owl (*Tyto alba)*, Henslow's sparrow (*Ammodramus henslowii)*, and grasshopper sparrow (*Ammodramus savannarum)* all require grassland habitat for feeding, nesting and brood rearing (NRCS 1999). Insects which are critical in the diets of newly hatched birds are commonly found in grasslands (Tscharntke and Greiler 1995). Other animals such as the white-tailed deer graze and bed in in these habitats along with small mammals and predators (Murphy et al. 1985; Philips et al. 2004). Grasslands also provide protection from erosion, filter rain water as it percolates through the soil profile, are a store house for medicinal plants, and have great aesthetic appeal through there flowering plants. Unfortunately, grasslands are disappearing throughout the areas where they were common and widespread (Nickens 2010). This is especially true in the southeastern Piedmont, an area that once contained widespread prairies and savannas (Tompkins 2010).

Today the southeastern Piedmont is noted for its expanses of hardwood and pine forests that seemingly stretch from horizon to horizon, but this was not always the case. As early as 1540, the Spanish explorer Hernando De Soto noted three or four open grasslands on his travels along the Catawba River (Barden 1997). These were not the deep, black soil plains or prairies characteristic of the Midwest, but were widespread grasslands maintained by Native Americans through the use of fire.

According to Barden (1997), between 1540 and 1750, early European explorers recorded seeing many plains on their travels through the Piedmont of North and South Carolina. These openings were up to 40 km (25 miles) across. Juan Pardo, a Spanish explorer in 1567, reported "very large and good plains…clear land…beautiful plains" near Charlotte, North Carolina. At a point north of Charlotte, German explorer John Lederer stated that, "The country here, by the industry of these Indians, is very open, and clear of wood. He found forests on the land, yet where it was inhabited by Indians, it lay open in spacious plains". During the winter of 1701, John Lawson reported a dozen large savannas while traveling "about 20 miles (33 km) near a savanna..., the woods being newly burnt and on fire in many places" as he traveled from Charleston, South Carolina to Charlotte, North Carolina and on to Pamlico Sound on the North Carolina coast. Mark Catesby during his travels through the interior of the Carolinas reported, "In February and March the inhabitants have a custom of burning the woods, which causes such a continual smoke, that not knowing the cause, it might be imagined to proceed from fog… an annual custom of the Indians in their huntings, of setting the woods on fire many miles in extent".

These early reports suggest the existence of prairies in the Piedmont of North and South Carolina and their maintenance by Native Americans mainly through the use of fire.

Native Americans used dormant season burning to clear land and improve habitat for hunting (Van Lear and Harlow 2000). Lightning was most likely not the cause of all southeastern prairie burning since thunderstorms that bring lightning generally occur during the summer months, but prairie burning was generally observed during the dormant season (Van Lear and Waldrop 1989; Fowler and Konopik 2007). Piedmont streams, rivers, lush vegetation, and moist valleys act as natural fire breaks confining burn off to relatively small areas. For such large continuous tracts to burn, man must have been involved.

When Europeans started settling the Piedmont in the mid -1700's, they chose cleared areas first, but left untouched areas containing xeric soil conditions and a slowly permeable clay subsoil (Davis et al. 2002). Settlement resulted in change or removal of much of the natural vegetation, a process which fragmented the landscape. Fire suppression along with the fragmented landscape caused a decrease in fire frequency and intensity resulting in prairies becoming more densely forested. Hence, the prairie became more forested until it virtually disappeared (Sparks et al. 1998). Prairie loss in the Southeast is the result of landscape modifications, the most significant of which are the removal of fire from the landscape and widespread agriculture.

Today, remnants of these prairies are found in areas having certain edaphic conditions along unsprayed utility rights-of-way, less disturbed roadsides, dry forest edges, recently logged areas, and burned areas. Only the presence of selected native understory species indicates the historical prairie condition (Wagner et al. 1998).

Soil moisture plays an important role in maintaining prairies. Piedmont prairie remnants inhabit sites having limited soil water availability in conjunction with relatively high evaporative demand during the growing season and disturbance to discourage invasion by tree and shrub species (Brye et al. 2004; Johnson and Schmidt 1998). Hanson studied a prairie inclusion occurring in southeastern Nebraska within a deciduous climax forest on a steep south facing slope. He found the main reason other vegetation did not invade this patch was low soil moisture caused by the evaporative power of exposure to wind and sun. Soil moisture often fell below the available point (Hanson 1922). Soil and air temperature increases from edge to center of open patches with the increase being greater in larger openings (Phillips and Shure 1990). Similar conditions occur in North and South Carolina especially during the summer creating an environment favorable to species that can tolerate low moisture conditions.

Ultisol, the most widespread soil order in the Piedmont, occurs on older, stable landscapes that have been heavily leached and have low native fertility. Base saturation in these soils is less than 35%, and there are subsurface accumulations of red or yellowish clay resulting from the presence of iron oxides

(NRCS 2010). Significant areas of Alfisols also occur in the Piedmont. Piedmont prairies occur mainly on the Alfisol soil order (Juras 1997). Alfisols are well developed moderately leached soils with a base saturation greater than 35% (NRCS 2010). Subsurface accumulation of clay occurs in these soils and they have high native fertility (McDaniel 2006). Both soils contain clay subsurface horizons that may dry out during the growing season causing droughty conditions. Montmorillonite is the major clay in Alfisols and accounts for their high shrink-swell capacity. When wet, this clay becomes impermeable possibly causing a perched water table, but develops wide cracks when dry. Alfisols develop from mafic rock (metamorphosed igneous rock high in magnesium, iron, calcium and sodium) and tend to be basic. Southern grasslands except balds and shale barrens tend to include Alfisols among the soil orders on which they occur (Juras 1997).

Prairies in the Black Belt region of Alabama and Mississippi occur predominantly on Alfisols, Inceptisols and Vertisols that swell, shrink, and then crack when dry (Barone 2005). Black Belt prairies occur on xeric, shallow soil locations which are unsuitable for plowing (Trager 2003). In the Piedmont of Virginia and North Carolina, prairie remnants occur on sites containing mafic rock and having an impermeable layer of clay, but with sufficient rainfall (Leachy 2003). In contrast, Midwestern grasslands are found on soil orders Mollisols and Aridisols which are neutral to basic, fertile, and high in organic matter (Juras 1997).

Piedmont prairie remnants often occur as glades (grassy openings within woodlands caused by edaphic conditions) scattered across the landscape (Davis et al. 2002). They do not have the expanse of the Midwestern prairies nor are they uniform in species composition. Glades contain grasses such as Indian grass (*Sorghastrum nutans* (L.) Nash), purpletop (*Tridens flavus* (L.) A.S. Hitchc.), broomsedge (*Andropogon virginicus* L.), gamagrass (*Tripsacum dactyloides* (L.) L.), and panic grasses (*Panicum spp.*). Forbs include asters (*Symphiotrichum spp.*), goldenrods (*Solidago spp.*), beggars-lice (*Desmodium spp.*), bushclovers (*Lespedeza spp.*), and sunflowers (*Helianthus spp.*). A study of six Piedmont prairie remnant sites in the North Carolina Piedmont found 277 species from 163 genera in 58 families. Families containing the greatest number of species were Asteraceae, Poaceae, and Fabaceae respectively (Davis et al. 2002).

Remnant sites also contain flora that is characteristic of the tallgrass prairie. Some common tallgrass prairie species reported to occur on remnant sites include big bluestem (*Andropogon gerardii* Vitman), Indian grass (*Sorghastrum nutans* (L.) Nash), little bluestem (*Schizachyrium scoparium* (Michx.) Nash), pasture rose (*Rosa carolina* L.), goat's rue (*Tephrosia viriginiana* (L.) Pers.), butterfly milkweed (*Asclepias tuberosa* L.), old-field goldenrod (*Solidago nemoralis* Ait.), showy goldenrod (*Solidago speciosa* Nutt.), flowering spurge (*Euphorbia corollata* L.), wild quinine (*Parthenium integrifolium* L), rattlesnake master (*Eryngium yuccifolium* Michx.), and New Jersey tea (C*eanthus americanus* L.) (Davis et al. 2002; Wagner et al. 1998).

Interest in restoring prairies is increasing, whether to reestablish a diverse species environment or to recreate the function of the original ecosystem. Restoration could be as simple as applying herbicide to a site during spring then waiting for the vegetation to expire, followed by disking the area, then planting native prairie seeds collected locally, and maintaining control of invasive species through burning. During the first growing season, mostly annuals and biennials fill the planting site, but after the second growing season native perennials become common. Warm season (C_4) grasses should be a significant portion of the vegetative cover by the third growing season (Camill et al. 2004).

McRae and Barden (2002) found that herbicide in conjunction with burning is a method for stimulating prairie species reproduction without causing invasion by a high level of non-prairie species while restoring Mineral Springs Barrens in North Carolina. They also showed that girdling invading woody competition in conjunction with fire also increased prairie species counts, although not to the same degree as herbicide applications and that more non-prairie species occurred in plots using this method. In another North Carolina restoration at Temple Flat Rock, Nicholas (2005) began by mowing for woody species control and used herbicide to control invasive species before burning. Biennial burns were applied to encourage prairie vegetation to fill the site.

When seeding is attempted, seeds collected from near (100 – 150 km) the planting site should be better adapted to local conditions and have better survival than non-local sources, thus recreating natural species diversity. Additionally, non-local seeds are genetically different and tend to grow dissimilarly from local sources (Gustafson et al. 2005). Also, genetic diversity does not seem to be related to population size. Small prairie species populations have genetic diversity similar to that of much larger ones making collections from large populations unnecessary (Gustafson et al. 2005).

Restored prairies do not normally exhibit the diversity found in a natural prairie. Monitoring has been conducted primarily for species richness and not abundance, but low abundance levels can lead to local extinctions thus reducing species richness and diversity (Polley et al. 2005). Results from Kansas and Illinois indicated diversity declines within 25 to 35 years of establishment without reaching the species rich stability of a natural prairie (Camill et al. 2004).

Early restoration attempts have met with varying results suggesting a need for better site selection methods and/or cultural methods. Choosing sites that are more conducive to prairie species growth and survival could greatly increase the chance of success, now and into the future, and reduce associated with maintaining a failing restoration.

A technique for identifying which sites have the necessary characteristics for increased success is needed. This dissertation attempts to give insight into new methods and considerations.

<u>Site Descriptions</u>

After searching scholarly publications, conservation organizations' websites, natural heritage programs, and general internet websites, eight sites were identified that contained prairie vegetation or indicative species. Each site contains species such as Schweinitz's sunflower (*Helianthus schweinitzii* Torrey & A.Gray) and Black-eyed Susan (*Rudbeckia hirta* L.) that are associated with prairies. Sites occurred in areas of disturbance such as rights-of-way that retarded the encroachment of invading vegetation. All locations, except one, are managed by conservation organizations for protection and restoration. One site is located near Durham, North Carolina, and another is located near Rock Hill, South Carolina. All other sites are located near Charlotte, North Carolina. Three sites are located along rights-of-way, four are prairie remnants, and one is a mixed hardwood stand. Soils at all locations are mafic with shrink swell ratings of moderate to very high. Solum depths range 10 – 60 inches and surface texture is loam (sandy, sandy clay, silt, and clay).

Mountain Island Dam Rare Plant Site

Mountain Island is located along a power line right-of-way near Mountain Island Lake in Mecklenburg County, North Carolina, north of Charlotte. Schweinitz's sunflower has been identified at this steep rolling location.

Figure 1.1: An electrical utility right-of-way (top) and vegetation (bottom) at Mountain Island Dam Rare Plant Site.

Shuffletown Prairie

Shuffletown is located in Mecklenburg County, North Carolina, north of Charlotte. This site is very rocky containing boulder sized rock in some locations. Federally endangered species smooth purple coneflower (*Echinacea laevigata (C.L. Boynt. & Beadle) S.F. Blake*) and Schweinitz's sunflower (*Helianthus schweinitzii Torr. & A. Gray)* occur here.

Figure 1.2: Shuffletown Prairie grasses in right-of-way

Figure 1.3: Shuffletown Prairie rock outcrops.

Rock Hill Blackjacks Heritage Preserve

The Blackjacks Heritage Preserve is located in York County, South Carolina, in the town of Rock Hill. A cable and an electrical utility right-of-way support a variety of prairie species. This site and is a good example of a xeric hardpan forest and contains gabbro outcrop and upland wet depression community types.

Figure 1.4: Fall blooming plants along a buried cable right–of-way at the Rock Hill Blackjacks Heritage Preserve.

Figure 1.5: Fall blooming plants along an electrical utility right-of-way at the Rock Hill Blackjacks Heritage Preserve.

McCoy Road Sunflower Site

McCoy Road is a prairie remnant located in Mecklenburg County, North Carolina, north of Charlotte. This site is being managed by the Mecklenburg County Parks and Recreation Department to encourage growth of Schweinitz's sunflower (*Helianthus schweinitzii* Torr. & A. Gray), a federally endangered species. A program of burning and woody vegetation removal has been instituted to encourage its occurrence.

Figure 1.6: Star tickseed (*Coreopsis pubescens* Elliot.) and oxeye daisy (*Leucanthemum vulgare* Lam.) blooming in the spring at McCoy Road Sunflower Site.

Figure 1.7: Schweinitz's sunflower (*Helianthus schweinitzii* Torr. & A. Gray) blooming during Fall at McCoy Road Sunflower Site.

Mineral Springs Barren

Mineral Springs is a prairie remnant that is located in Union County, North Carolina, near Waxhaw. This site was used for agriculture in the past but was abandoned. Encroachment by shortleaf pine (*Pinus echinata* Mill.), blackjack oak (*Quercus marilandica* Münchh.), and post oak (*Quercus stellate* Wangenh.) is being controlled through a burning program.

Figure 1.8: Pine and hardwood encroachment at Mineral Springs Barren.

Figure 1.9: Pine and hardwood encroachment at Mineral Springs Barren.

Penny's Bend State Nature Preserve

Penny's Bend prairie is located in Durham County, North Carolina, northeast of the city of Durham. This site is on a peninsula in a bend of the Eno River. Eastern redcedar (*Juniperus virginiana* L.) occurs on the site while loblolly pine and mixed hardwoods surround the entire area. The area appears to have been a pasture based on fencing along one side.

Figure 1.10: Eastern redcedar (*Juniperus virginiana* L.) growing on Penny's Bend State Nature Preserve's prairie.

Figure 1.11: Eastern redcedar (*Juniperus virginiana* L.) growing on Penny's Bend State Nature Preserve's prairie.

Winget Road Sunflower Site

The Winget Road site is located in Mecklenburg County, North Carolina, south of Charlotte. Recent construction of Winget Park Elementary School has damaged parts of this site. Addition of sidewalks, drainage, and general construction procedures have reduced the size of the site and cut through it in several places. Eastern redcedar (*Juniperus virginiana* L.) covers much of the site, but light enters from the sides. Woody shrubs are encroaching especially through construction disturbances.

Figure 1.12: Grasses, shrubs, and eastern redcedar dominate the Winget Road site.

Figure 1.13: Eastern redcedar covers the Winget Road site.

Catawba Wildflower Glenn

Mixed oaks dominate this site located in Mecklenburg County, North Carolina, north of Charlotte. Trees in the overstory are likely dying from the droughty conditions of the past five summers, allowing light to the forest floor encouraging the growth of herbaceous vegetation. Slopes are steep ranging up to 30%.

Figure 1.14: Grasses and herbaceous vegetation growing in openings created by dying overstory trees.

LITERATURE CITED

Anderson, R. C. 2006. Evolution and origin of the central grassland of North America: climate, fire, and mammalian grazers. *The Journal of the Torrey Botanical Society* 133:626-647.

Barden, L. S. 1997. Historic prairies in the Piedmont of North and South Carolina, USA. *Natural Areas Journal* 17:149-152.

Barone, J. A. 2005. Historical presence and distribution of prairies in the Black Belt of Mississippi and Alabama. *Castanea* 70:170-183.

Byre, K. R., C. P. West, and E. E. Gbur. 2004. Soil quality differences under native tallgrass prairie across a climosequence in Arkansas. *American Midland Naturalist* 152:214-230.

Camill, C., M. J. McKone, S. T. Sturges, W. J. Severud, E. Ellis, J. Limmer, C. B. Martin, R. T. Navratil, A. J. Purdue, B. S. Sandel, S. Talukder, and A. Trout. 2004. Community and ecosystem-level changes in a species-rich tallgrass prairie restoration. *Ecological Applications* 14:1680-1694.

Davis, Jr., J. E., C. Mc Rae, B. L. Ester, L. S. Barden, and J. F. Matthews. 2002. Vascular flora of Piedmont prairies: evidence from several prairie remnants. *Castanea* 67:1-12.

Fowler, C. and E. Konopik. 2007. The history of fire in the Southern United States. *Human Ecology Review* 14:165-176.

Gustafson, D. J., D. J. Gibson, and D. L. Nickrent. 2005. Using local seeds in prairie restoration – data support the paradigm. *Native Plants* 6:25-28.

Hanson, H. C. 1922. Prairie inclusions in the deciduous forest climax. *American Journal of Botany* 9:330-337.

Juras, P. 1997. The presettlement Piedmont savanna: A model for landscape design and management. 6 August 2006 http://philipjuras.com/thesis/chapter5.htm.

Johnson, P. D. and J. M. Schmidt. 1998. Colonization of cleared patches of hardwood forest bordering a southeastern Piedmont prairie remnant. P. 35. In Abstracts, Annual Meeting, Botanical Society of America. *American Journal of Botany* 85:1-183.

Leahy, M. J. 2003. Prairies of the Old Dominion. *Missouri Prairie Journal* 24:8-12.

McCracken, J. D. 2005. Where the bobolinks roam: the plight of North America's grassland birds. *Biodiversity* 6:20-29.

McDaniel, P. 2006. The twelve soil orders: soil taxonomy. University of Idaho, College of agricultural and Life Sciences, Moscow, ID. 6 August 2006 http://soils.ag.uidaho.edu/soilORDERS/index.htm.

McRae, C. and Barden, L. S. 2002. Herbiciding and girdling trees: two techniques for restoring a Piedmont prairie. Association of Southeastern Biologist's 63rd Annual Meeting.

Murphy, R. K., N. F. Payne, and R. K. Anderson. 1985. White-tailed-use of a irrigated agriculture-grassland complex in central Wisconsin. *The Journal of Wildlife Management* 49:125-128.

Nicholas, D. 2005. Fires restore habitat at Temple Flat Rock. *Triangle Land Conservancy News* 22:1.

Nickens, T. E. 2010. As the continent's grasslands disappear, the songs of the birds that depend on them are also fading away. 6 April 2011. http://www.nwf.org/News-and-Magazines/National-Wildlife/Birds/Archives/2010/Grasslands-Birds-Disappearing.aspx.

NRCS, 2010. Ultisols. 4 April 2010. http://soils.usda.gov/technical/classification/.

NRCS. 1999. Grassland birds. USDA Natural Resources Conservation Service, Wildlife Habitat Management Institute, Madison, MS.

Phillips, D. L. and D. J. Shure. 1990. Patch-size effects on early succession in southern Appalachian forests. *Ecology* 71:204-212.

Phillips, M. L., W. R. Clark, S. M. Nusser, M. A. Sovada, and R. J. Greenwood. 2004. Analysis of predator movement in prairie landscapes with contrasting grassland composition. *Journal of Mammalogy* 85:187-195.

Polley, H. W., J. D. Derner, and B. J. Wilsey. 2005. Patterns of plant species diversity in remnant and restored tallgrass prairies. *Restoration Ecology* 13:480-487.

Sparks, J. C., R. E Masters, D. M. Engle, M. W. Palmer, and G. A. Bukenhofer. 1998. Effects of late growing-season and late dormant-season prescribed fire on herbaceous vegetation in restored pine-grassland communities. *Journal of Vegetation Science* 9:133-142.

Tompkins, R. D., C. M. Luckenbaugh, W. C. Stringer, K. H. Richardson, E. A. Mikhailova, and W. C. Bridhges Jr. *Castanea* 75:232-244.

Trager, J. C. 2003. Dixieland prairies and glades. *Missouri Prairie Journal* 24:13-14.

Tscharntke, T. and H. J. Greiler. 1995. Insect communities, grasses, and grasslands. *Annual Review of Entomology* 40:535-558.

Van Lear, D. H. and R. F. Harlow. 2000. Fire in the Eastern United States: Influence on wildlife habitat. In: Ford, W. Mark; Russell, Kevin R.; Moorman, Christopher E., eds. Proceedings: the role of fire for nongame wildlife management and community restoration: traditional uses and new directions; 2000 September 15; Nashville, TN. Gen. Tech. Rep. NE-288. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Research Station. 145 p.

Van Lear, D. H., and T. A. Waldrop. 1989. History, uses, and effects of fire in the Appalachians. General Technical Report SE-54. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 20 pp.

Wagner, L. K., W. C. Stringer, and T. P. Spira. 1998. Restoration of a Piedmont prairie: a preliminary report (South Carolina). *Restoration & Management Notes* 16:82-83.

CHAPTER TWO

Suitability Analysis for Potential Prairie Restoration Sites in the Piedmont of North and South Carolina

Written and formatted for submission to:

CASTANEA

J. D. Benson, J. D. Lanham, E. A. Mikhailova, W. C. Stringer, J. L. Walker and V. B. Shelburne

ABSTRACT

As a result of recent land use, Piedmont prairie sites are often overgrown and difficult to identify. This study was conducted to determine which site and climate characteristics among known prairie remnants may be useful for predicting suitable Piedmont prairie restoration sites. Based on an extensive literature search, eight prairie and rare plant sites were identified in the Piedmont of North and South Carolina. Soil series, slope, aspect, elevation, landform index, maximum annual temperature, and July precipitation were determined for each location. Characteristics common among these sites were used in a Geographic information System (GIS) to create raster data layers containing each characteristic. When these raster data layers were added using a raster calculator in ArcGIS, a rating of Piedmont prairie site suitability for North and South Carolina was produced. Based on site characteristics, Piedmont prairie restoration is predicted to be more successful on sites having eastern to western aspects, slopes generally less than 15%, upper slope positions, and occurring on Enon, Iredell, Mecklenburg, Wilkes, and Wynott soil series. Forty-eight randomly selected checkpoints selected from a ten km grid across the Piedmont of South and North Carolina found nine predicted restoration sites occurred in locations open enough to be prairie or grassland while all others occurred in forested locations. Of fifteen prairie remnants used as an additional check, only one was predicted as prairie. Soil series found at all check plot locations, except one, was different from that occurring on the eight sampled prairie sites.

INTRODUCTION

The Southeastern Piedmont is noted for its extensive hardwood and pine forests; however, this was not always the case. As early as 1540, the Spanish explorer Hernando De Soto noted three or four grasslands on his route along the Catawba River (Barden 1997). These were not the deep, black soil grasslands characteristic of the Midwest but were grasslands kept open through the use of fire and often extending into the understory of surrounding woodlands. Between 1540 and 1750, other European explorers noted grasslands up to 40 km across during their travels in the Piedmont of North and South Carolina (Barden 1997). These early reports suggest the existence of prairies in the Piedmont of North and South Carolina and their maintenance by Native Americans, mainly through the use of fire. Lightning may have started some of these fires; but most likely, it was not the entire cause of the prairie burning since thunder storms with lightning usually bring heavy downpours that retard fire spread. Native Americans used dormant season burning for land clearing and habitat improvement for hunting since grasslands were important for their subsistence (Williams 2000; Brown 2000).

When Europeans settled the Piedmont in the mid 1700's, they chose grasslands first. Settlers often left areas containing dry soils with impermeable clay subsoil untouched (Davis 2002). Settlement resulted in change or removal of much of the natural vegetation thereby fragmenting the landscape. Fire suppression along with fragmented landscapes caused a decrease in fire frequency and intensity allowing forests to encroach into prairies until they virtually disappeared (Sparks et al. 1998).

Today, there are only remnants of these prairies existing in areas with certain edaphic conditions (Wagner et al. 1998). Piedmont prairie remnants have been found along unsprayed utility rights-of-way, roadsides, dry forest edges, recently logged areas, and in recently burned areas that contain native understory species (Wagner et al. 1998). We are continuing to lose prairie-like habitat to urbanization and other human activities. However, interest in restoring prairies has increased in order to reestablish diverse plant species communities and to restore the original ecosystem function. A method for screening sites based on their potential restoration success should ultimately increase overall success by reducing restoration attempts on unsuitable sites.

Suitability analysis is a method for determining the most appropriate location for a land use. It has been useful in defining land suitability/habitat for animal and plant species (Malczewski 2004), but has also been used to identify potential land use conflicts Car and Zwick (2005), locate suitable nuclear waste disposal/storage sites Huang et al. (2006), locate soil and water conservation structures Durbude (2004), and predicting future suitability Carey and Brown (1994). An analysis may show which land use has the least impact or it may show the most and least appropriate sites for specific uses (Collins et al. 2001). Informed management decisions can be made by public and private officials based on these analyses as well as making sound policy decisions.

Prior to the early 1970's, suitability analysis was performed manually by overlaying maps, but as more complex analyses needed to be performed, overlaying became impractical (Collins et al. 2001). After this time, computer technology began to be employed with mapping software allowing a greater number of map layers to be handled (Lein 1990). Using present day GIS software, many layers of mixed data types (vector and raster) can be utilized.

The Food and Agricultural Organization (FAO) recommended use of a suitability rating system for classifying crop sites into classes ranging from highly suitable to not suitable based on climatic, terrain, and soil properties (Ahamed et al. 2000). When this approach was tried on a portion of the Kalyanakere watershed located in Karnataka, a state in southwestern India, using eight soil parameters (base saturation, cation exchange capacity, pH, percent surface gravel, percent subsurface gravel, surface texture subsurface texture, and drainage) and one topographic parameter (percent slope) for three local crops finger millet, *Eleusine coracana*, paddy, *Oryza sativa*, and ground nut, *Arachis hypogaea* (Ahamed 2000). Suitability analysis indicated the best crop choice was ground nut while the crop planted in greatest area was finger millet (Ahamed 2000). This information can be given to farmers and land managers so the best suited crops can be planted, increasing yields and profits.

Habitat for a declining grassland bird was modeled by Lauver et al. (2002) on the Fort Riley Military Reservation located in northwestern Kansas. The loggerhead shrike, Lanius *ludovicianus,* has been experiencing population declines throughout its range. Evidence indicates that these declines are related to loss of breeding habitat and winter ranges thought the precise cause is unknown (Lauver et al. 2002). Habitat utilization characteristics of this species have been studied and are well documented (Lauver et al. 2002). Using this information, it was determined that percent cover of potential grassland foraging habitat, percent cover of usable foraging habitat, and number of potential nesting trees were good predictor of habitat quality. Using generally available GIS datasets (land cover and digital orthophoto quarter quadrangles), a suitability analysis was performed. Independent sightings of loggerhead shrike were used to evaluate the model's validity. High quality habitat was predicted to occur on 46% (18,900 ha) of Fort Riley (Lauver et al. 2002).

An advantage of suitability analysis using GIS technology is that large areas can be evaluated quickly and relatively efficiently. Also, numerous types of inexpensive or no cost datasets are available. Many can be downloaded on demand greatly reducing the effort needed to perform the analysis. The methods and specific models created become portable when standard datasets are used giving the models a wider range of applicability.

Ecological restoration is defined as, the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed (SER 2004). Restoration also implies to renew, replace, or bring back to health (Anderson 1995). Proposed restorations should be evaluated for feasibility during project planning as land use and land cover have a direct bearing on what may be restored. Parts of the Piedmont have experienced such heavy erosion that it may not be possible to restore habitat that was once prevalent. Landscapes with a greater percentage of natural land cover are more likely to support native vegetation than those under intense human land use pressure (Miller 2007). Many species tend to be absent in areas with greater than 70% habitat loss (Andren 1994). Restoration goals must be chosen realistically with consideration for what can actually be accomplished.

Habitat losses in the last 50 years are central to the need for restoration (Anderson 1995). Increased urbanization and growing awareness of human caused environmental changes seem to spark a feeling of environmental destruction. Other reasons for increased restoration interest may deal with reducing global warming through carbon sequestration, increasing habitat for endangered species, protecting water quality, increasing biodiversity, increasing natural beauty, or preserving cultural heritage. People gain benefit from restorations and their interest in and support of conservation increases, particularly if they are personally involved in the restoration (Anderson 1995). Restoration guidelines are readily available in the form of videos and downloadable manuals providing needed information to anyone interested in attempting restoration on a small or large scale.

Restoration of feltleaf willow, *Salix alaxensis,* on the North Slope of Alaska was attempted after habitat destruction caused by riparian gravel mining during construction of the Trans-Alaska Pipeline System (Densmore et al 1987).

Feltleaf willow is an important winter forage for moose, *Alces alces*. A restoration program was instituted after pipeline construction was completed, but failed. Not enough was known about willow habitat requirements for success. Feltleaf willow establishes itself on gravel bars that have a shallow water table not in the silty sediment that remained. All remaining gravel was submerged, not suitable for feltleaf willow establishment (Densmore et al 1987). Other willow species could establish themselves in the silty bottom, but they were not important forage species for moose (Densmore et al 1987). Restorationists must be aware of target species requirements to be successful.

Kush et al. (2004) reported on longleaf pine restoration at the Flomaton Natural Area, Alabama. A 25 ha virgin longleaf pine stand was becoming infested with hardwood sapling and seedlings preventing longleaf seedlings from establishing themselves. Investigation of habitat conditions indicated that the only apparent change was 45 years of fire suppression (Kush et al. (2004). Hardwood encroachment was mechanically removed and a program of prescribed burning was instituted. Longleaf seedling regeneration was reestablished and hardwoods were controlled Kush et al. (2004).

Restoration occurred at Flomaton Natural Area Kush et al. (2004) because the site was not degraded beyond repair. Research indicated the main component causing the change was the removal of fire, a problem that could be corrected. The feltleaf willow restoration project failed because not enough research was put into determining the species biology and habitat requirements could not be met by the degraded site.

MATERIALS AND METHODS

Study Area

The study area (Figure 2.1) encompasses the central Piedmont in North Carolina from Charlotte to Durham, and the northeastern Piedmont in South Carolina near Rock Hill. It covers the area within 35º - 36.5º north latitude and 78 - 82º west longitude. Topography is rolling with elevation ranging from 61 to 427 m. Precipitation is spread evenly throughout the year with the greatest monthly amount, 10 - 13 cm, occurring in July. Daily high temperatures range from 10º C in January to 32º C in July while daily low temperatures range from -1º C in January to 21º C in July (Boyles et al. 2004). The study area is primarily forested with oak-pine, oak-hickory, and pine plantations. Non-forested portions are in cropland, pasture, and urban-manufacturing influence (Griffin et al. 2002). Specific study sites occurred in disturbed areas (rights-of-way, old fields, or old pasture).

Sampling

A literature search for references to prairie locations in the Southeastern Piedmont was conducted identifying twelve prairie and rare plant sites. Of these, three were prairie restoration sites and are excluded from this analysis. Permission could not be obtained to sample another location leaving eight sampling sites. Soil series, elevation, slope, aspect, maximum annual temperature, July precipitation, and landform index were determined for each location. Slope, aspect, and landform index were determined by direct measurement on site; elevation was determined from a digital elevation model (Table 2.1); soil series was determined from the Soil Survey Geographic Database 2.2 (SSURGO) (Table 2.1); and July precipitation and maximum annual temperature were determined from shapefiles obtained from the Natural Resources Conservation Service (Table 2.1).

Laboratory Analysis

July precipitation, maximum annual temperature, and elevation were found to be very similar throughout the local area and were excluded from the analysis (Table 2.2). Soil series, elevation, slope, and aspect were used in the suitability analysis (Table 2.3). ArcGIS 9.3.1 (ESRI, Redlands, CA) was used to perform all GIS analyses (Figure 2.2). All layers were projected to the Universal Transverse Mercator (UTM), North American Datum 1983, zone 17 north, coordinate system by the ArcCatalog module of ArcGIS. Measurement units were meters. Spatial analyst, an ArcGIS module, was used to produce an aspect and slope layer using digital elevation model (DEM) data. A landform index grid was produced using the landform.aml program written by Jeffrey Evans, downloaded from http://arcscripts.esri.com (2007). SSURGO 2.2 data were downloaded as individual county datasets for the Piedmont region then combined and converted to a soil series grid or raster. All layers were clipped using an extracted Piedmont polygon from the level 3 ecoregion layer obtained from the United States Environmental Protection Agency (Table 2.1). A new raster was created for each of the four characteristics. Cells that contained the desired character state were assigned a value of 1. The four rasters were added to produce a new raster containing a rating of each cell's suitability with 4 being the maximum value (Taverna et al. 1999). Cells that contained all the chosen characters were considered suitable.

Error Checking

A GIS layer containing only herbaceous cover was produced in an attempt to limit, as much as possible, scrutinizing locations that may not contain prairie-like vegetation. Otherwise, locations such as pavements, forests, lakes, streams, buildings, or barren ground could be examined. A 10-km grid was laid across the Piedmont region within the herbaceous cover type. Forty-eight grid points were selected by use of a random number generator. The cell classified as prairie habitat closest to the grid point was examined on an aerial image to determine if it could actually be prairie not forest, agriculture or urban. In addition, check plots were employed. Check plots, prairie remnants located by Dr. William Stringer (unpublished data), were compared against the predicted locations. Prairie remnant check plots were discovered previously based on species composition. Prairie species such *as Sorghastrum nutans* (L.) Nash*, Lespedeza sp.* Michx., *and Silphium sp.* L. occurred on these sites.

RESULTS AND DISCUSSION

Temperature, precipitation, and elevation were very similar among all sites because of their proximity. Hence, they were not used to discriminate between sites.

Slopes ranged between 1 and 15%, except one area along a utility right-of-way was 26% (Table 2.2). Steeper slopes increase runoff rates possibly causing sites to be drier. Dry or droughty site conditions favor prairies by reducing the vigor of invading vegetation (Changnon et. al. 2002).

All sites, except one, had an exposure that ranged from eastern to western (Table 2.2). McCoy Road Sunflower site had a northern aspect but contained an intermittent stream creating an eastern and western facing slope. More weight was given to the eastern and western aspects as a greater biomass occurred there. Southern aspects tend to be drier due to longer hours of sun exposure while northern aspects tend to be more mesic due to fewer hours of sun exposure. Southern aspects ranged from 135º to 270º while the Northern aspect was 10º. Our results matches the findings of Smith (2008) in a study to analyze the site characteristics of Schweinitz's sunflower, *Helianthus schweinitzii,* a species though to be an indicator of prairie habitat. The species occurred most commonly on southerly and southeasterly aspects.

Landform index is a measure of landscape position (McNab 1993). Eight slope measurements spaced 45º apart were taken from the center of each sampling location to the horizon. A landform index value of 0.0 indicates the current landscape position is level with the visible horizon. When the index becomes negative, the current position is higher than the visible horizon indicating a more exposed location, while the converse is true for positive index values. Landform index values for these plots ranged from -0.001 to 0.07 (Table 2.2). The positive value was rounded to 0.1 for use in the analysis. It was felt that since the determinations were made in the center of each site, the full effect of the upper landscape was not being represented especially when dealing with very irregularly shaped sites. In some instances a ridgeline that marked the greatest extent of the site was higher than the surrounding landscape. This extent would not have been indicated by a measurement taken from the sites center. To account for this -.1 was used in the analysis.

Piedmont prairies include Alfisols in the soil orders on which they occur (Juras 1997). These soils have clay layers that shrink and crack when dry, and swell when wet, keeping moisture from penetrating, sometimes causing a perched water table (Juras 1997). Swollen clays can serve as a barrier to root penetration creating an artificially shallow soil rootzone. Larger plant species could have difficulty anchoring themselves creating grassland, shrubland, savanna, or becoming inhabited by blackjack oak (*Quercus marilandica* Münchh) a species common on very dry sites. Alfisols have been found to be fertile (McDaniel 2006). All eight sampling sites contained Alfisols (Table 2.2). Smith (2008) found Schweinitz's sunflower occurred on Alfisols, Inceptisols, and Ultisols in North Carolina. Ultisols, the predominant soil order occurring in the

Piedmont, are highly weathered and tend to be deficient in major plant nutrients (McDaniel 2006). Kaolinite, the dominant clay mineral in Ultisols, has no shrink-swell property.

Approximately 137,382 hectares of potential restoration sites across the North and South Carolina Piedmont were predicted from the suitability analysis (Figure 2.3). However, Taecker (2007) predicted 1,069,406 hectares of prairie occurring in Anson, Cabarrus, Davidson Gaston, Mecklenburg, Randolph, Rowan, and Stanly counties North Carolina using Classification and Regression Tree (CART) and Maximum Entropy (Maxent) modeling. Our sample size is small and located in a limited area; predictions are most reliable near the area sampled in the study. Conditions could change as distance increases from the sampled area. For instance, the soil series Wynott occurs in only five counties in North Carolina and one county in South Carolina. Figure 2.4 shows potential sites in closer proximity to the sampling area. South Carolina has a greater clustering of sites while North Carolina sites are more widely scattered and tend to contain fewer cells. The distribution of soil series found at the sampling locations is more limited in the North Carolina Piedmont. When an acceptable landform index was combined with locations containing the proper soil series, a greater number of acceptable sites resulted. South Carolina had a greater density of locations with acceptable soil series and landform index values. Slope and aspect occurrence do not appear to limit potential restoration site selection.

Taecker (2007) determined that soil is a good predictor of prairie habitat after modeling Piedmont prairie lands for restoration in North Carolina.

Although precipitation was not used in the analysis, it was found that July precipitation drops from 21 cm along the Carolina coast to 10 cm in the area of Charlotte, NC, but ranged from 10 to 15 cm in the piedmont (Figure 2.5). Near Charlotte, maximum annual temperature reaches a high of 32 to 33º C (Figure 2.6). High temperature along with low precipitation creates droughty conditions. This can be especially true on soils that have low available moisture holding capability. Drought or long dry spells are necessary to sustain prairies (Changnon et al. 2002). These conditions are likely to occur near Charlotte since low precipitation and high temperature occur there during summer and may help explain why there are a number of prairie remnants in this area. In fact, five of the remnants and two of the restoration sites visited in this study are within 1.5 km of the center of the 10 cm precipitation zone. Fire, the other important element for prairie maintenance, has all but been eliminated. However, anthropogenic vegetative disturbances at the study sites have taken its place.

Error checking based on the 10,000 km grid found 9 cells occurring in locations that were open enough to be grassland or prairie (Figure 2.7). All other locations occurred within forest stands. Of the fifteen Stringer sites assessed for verification, only one fell in an area chosen by the analysis as a potential restoration site (Table 2.4). Seven sites met all criteria except soil series; two sites met only the aspect and slope criteria; four met the slope and landform index criteria; one met all requirements except aspect; and one site met all four criteria. Soil was the most limiting factor; two plots met this requirement. Only six check plots occurred in the area of South Carolina where the soil series from the original sampling locations were found. However, all check plots occurred on sandy or silt loam soils indicating that soil surface texture may be more important than the specific soil series for Piedmont prairie occurrence. These plots occurred most commonly on the Cecil (Fine, kaolinitic, thermic, Typic Kanhapludults) soil series. Check plots were located on disturbed sites, generally, rights-of-way. All check plots met the slope requirement and all except two meet the Landform index criteria. Ten met the aspect requirement.

CONCLUSIONS

Large areas of potential sites for prairie restoration were determined by the suitability analysis throughout the North and South Carolina Piedmont. Sites were found to occur on locations with eastern to western aspects; slopes less than 15%; slope positions greater than 80%; and soil series Enon, Iredell, Mecklenburg, Wilkes, and Wynott, all Alfisols. Soil series and slope position had the greatest influence on occurrence. Disturbance creates an earlier successional stage removing encroaching vegetation. This was important as the study sites occurred at locations with recent (rights-of-way) or near past (old field) disturbances. July precipitation, maximum annual temperature, and elevation were not useful predictors in the model as their values were consistent over the prairie and rare plant sites.

Predictions should be made close to sampling sites. Therefore, analysis on a localized area may be more useful and meaningful in identifying suitable sites in a specific locale. Local site characteristics associated with prairie habitat should be taken into account in selecting potentially suitable restoration sites. If a soil series common to prairie sites does not occur in the local area then the necessary soil must be determined for the local area before site selections can be made. Restoration success and cost savings could be realized by using this method for restoration site selection.

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LITERATURE CITED

Ahamed, T. R. N., K. G. Rao, J. S. R. 2000. GIS-based fuzzy membership model for crop-land suitability analysis. Agricultural Systems 63:75-95.

Andren, A. 1994. Effects of habitat fragmentation on birds and mammals in landscapes with different proportions of suitable habitat: a review. Oikos 71:355-366.

Barden, L. S. 1997. Historic prairies in the Piedmont of North and South Carolina, USA. Natural Areas Journal 17:149-152.

Boyles, R. P., C. Holder, and S. Raman. 2004. North Carolina climate: a summary of climate normals and averages at 18 agricultural research stations. North Carolina Agricultural Research Service, North Carolina State University. Technical Bulletin 322.

Brown, H. 2000. Wildland burning by American Indians in Virginia. Fire Management Today 60:29-39.

Carr, M. H. and P. Zwick. 2005. Using gis suitability analysis to identify potential future land use conflicts. Journal of Conservation Planning 1:58-73.

Changnon, S. A., K. E. Kunkel, and D. Winstanley. 2002. Climatic factors that caused the unique tall grass prairie in the Central United States. Physical Geology 23:259-280.

Collins, M. G., F. R. Steiner, and M. J. Rushman. 2001. Land-use suitability analysis in the United States: historical development and promising technological achievements. Environmental Management 28:611-621.

Davis ,Jr., J. E., C. Mc Rae, B. L. Ester, L. S. Barden, and J. F. Matthews. 2002. Vascular flora of piedmont prairies: evidence from several prairie remnants. Castanea 67:1-12.

Densmore, R. V., B. J. Neland, J. C. Zasada, and M. A. Masters. 1987. Planting willow for moose habitat restoration on the north slope of Alaska, U.S.A. Artic and Alpine Research 19:537-543.

Drbude, D. G. and B. Venkatesh. 2004. Site suitability analysis for soil and water conservation structures. Journal of the Indian Society ofRemoteSensing 32:399-405.

Griffith, G., J. Omernik, and J. Comstock. 2002. Ecoregions of North Carolina regional descriptions. USDA Natural Resources Conservation Service. August 2002.

Huang, L. X., G. Sheng, and L. Wang. 2006. GIS-based hierarchy process for the suitability analysis of nuclear waste disposal site. Environmental Informatics Archives 4:289-296.

Juras, P. 1997. The presettlement Piedmont savanna: A model for landscape design and management. 7 August 2006 http://philipjuras.com/thesis/ chapter5.htm.

Kush, J. S., R. S. Meldhal, and C. Avery. 2004. A restoration success: longleaf pine seedlings established in a fire-suppressed, old-growth stand. Ecological Restoration 22:6-10.

Lauver, C. L., W. H. Busby, and J. L. Whistler. 2002. Testing a gis model of habitat suitability for a declining grassland bird. Environmental Management 30:88-97.

Lein, J. K. 1990. Exploring a knowledge-based procedure for developmental suitability analysis. Applied Geography 10:171-186.

Malczewski, J. 2004. GIS-based land-use suitability analysis: a critical overview. Progress in planning 62:3-65.

McDaniel, P. 2006. The twelve soil orders: soil taxonomy. University of Idaho, College of agricultural and Life Sciences, Moscow, ID. 6 August 2006 http://soils.ag.uidaho.edu/soilORDERS/index.htm.

McNab, W. H. 1993. A topographic index to quantify the effect of mesoscale landform on site productivity. Canadian Journal Forest Research 23:1100-1107.

Miller, J. R. and R. J. Hobbs. 2007. Habitat restoration-do we know what we're doing? Restoration Ecology 15:382-390.

Naeem, S., F. S. Chapin III, R. Costanza, P. R. Ehrlich, F. B. Golley, D. U. Hooper, J. H. Lawton, R. V. O'Neill, H. A. Mooney, O. E. Sala, A. J. Symstad, and D. Tilman. 1999. Biodiversity and ecosystem functioning: maintaining natural life support processes. Issues in Ecology 4:1-12.

SER (Society for Ecological Restoration International Science and Policy Working Group). 2004. The SER international primer on restoration. Society for Ecological Restoration International. 13 April 2011 http://www.ser.org/content/ecological_restoration_primer.asp.

Smith, T. C. 2008. Spatial analysis of Helianthus schweinitzii (Schweinitz's sunflower), an endangered species endemic to the Piedmont of North Carolina. MA thesis. The University of North Carolina Greensboro, Greensboro, North Carolina.

Sparks, J. C., R. E. Masters, D. M. Engle, M. W. Palmer, and G. A. Bukenhofer. 1998. Effects of late growing-season and late dormant-season prescribed fire on herbaceous vegetation in restored pine-grassland communities. Journal of Vegetation Science 9:133-142.

Taecker, E. M. 2007. Identification and prioritization of lands for restoration of Piedmont prairie in North Carolina. MF thesis. Duke University, Durham, North Carolina.

Taverna, K., J. E. Halbert, and D. M. Hines. 1999. Eastern Cougar *(Puma concolor puma)* habitat suitability analysis for the central Appalachians. Appalachian Restoration Campaign, Charlottesville, VA.

Wagner, L. K., W. C. Stringer, and T. P. Spira. 1998. Restoration of a Piedmont prairie: a preliminary report (South Carolina). Restoration & Management Notes 16:82-83.

Williams, G. W. 2000. Introduction to aboriginal fire use in North America. Fire Management Today 60:8-12.

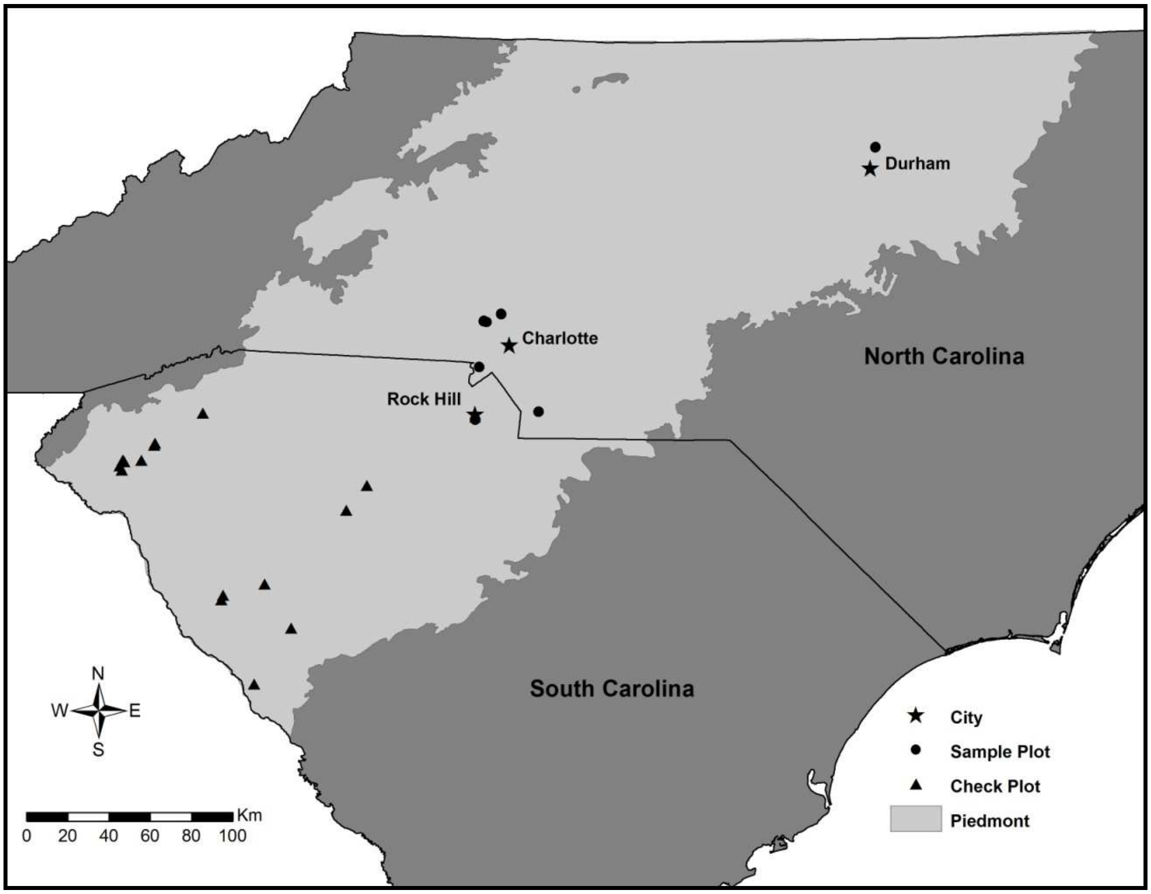


Figure 2.1. Sampling and check plot locations.

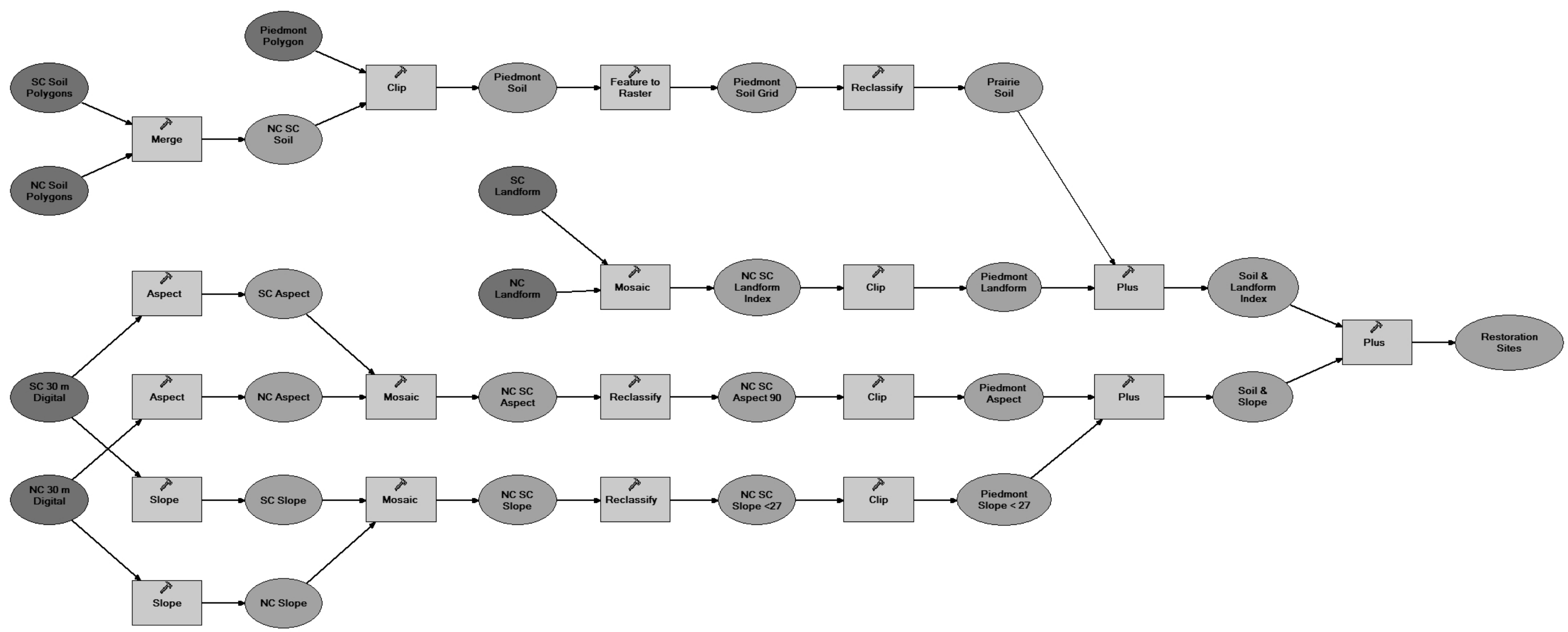


Figure 2.2. Model Builder diagram of suitability analysis process using soil series, landform index, aspect, and slope.

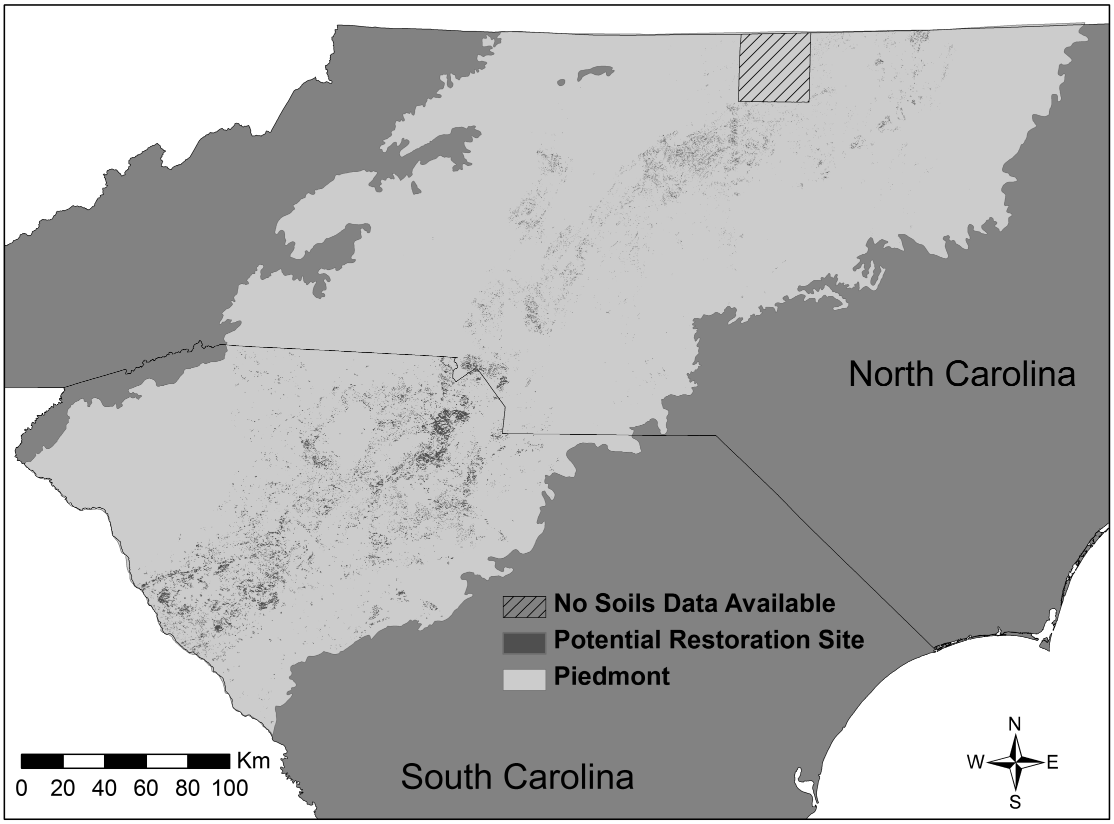


Figure 2.3. Potential Piedmont prairie restoration sites in the Piedmont of North and South Carolina.

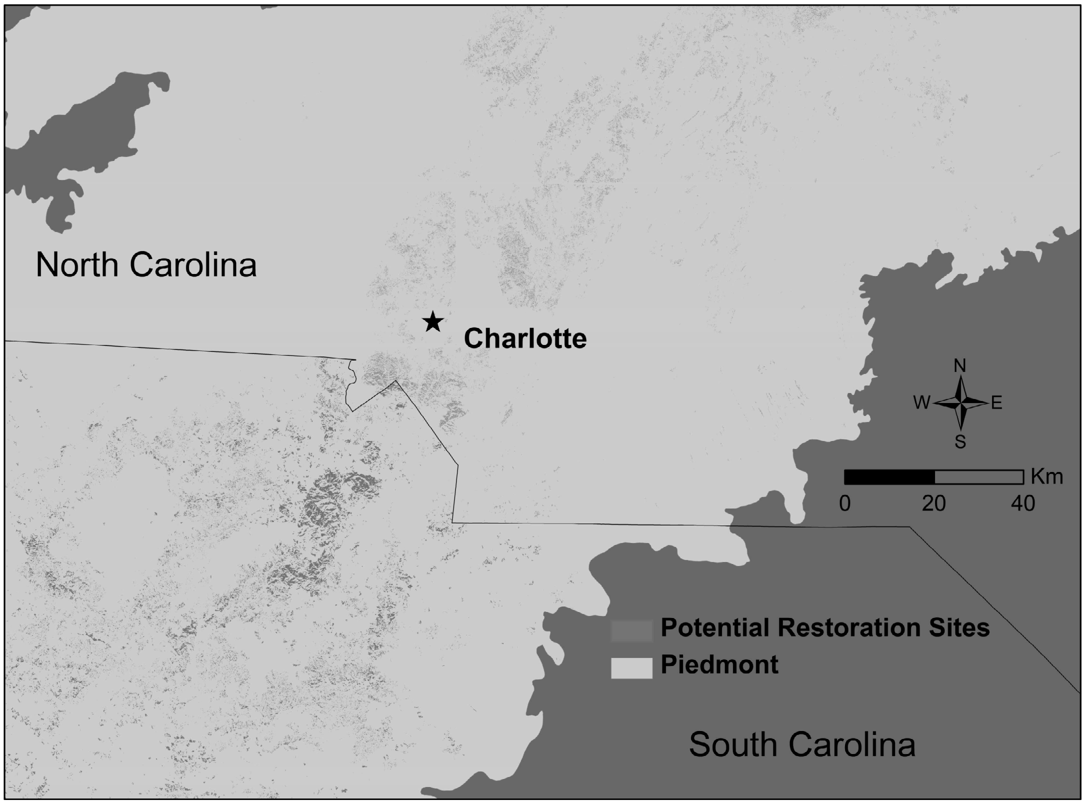


Figure 2.4. Potential Piedmont prairie restoration sites near Charlotte, North Carolina.

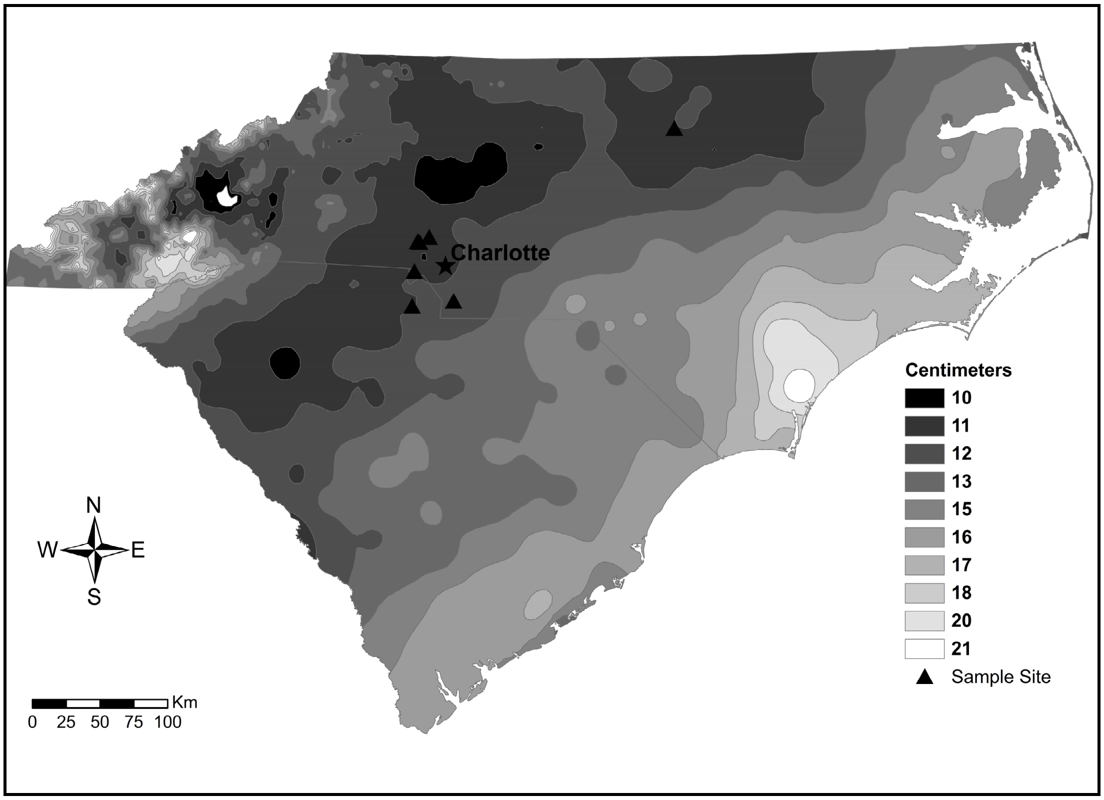


Figure 2.5. Average July precipitation in North and South Carolina.

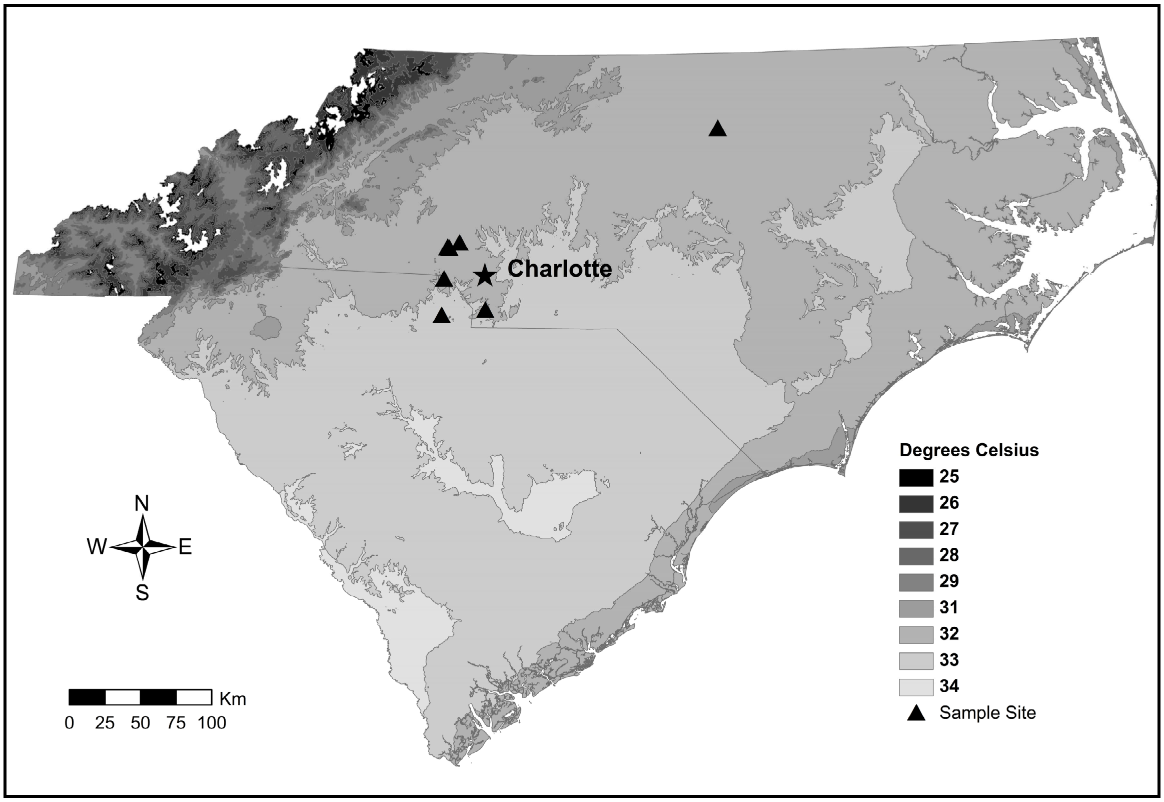
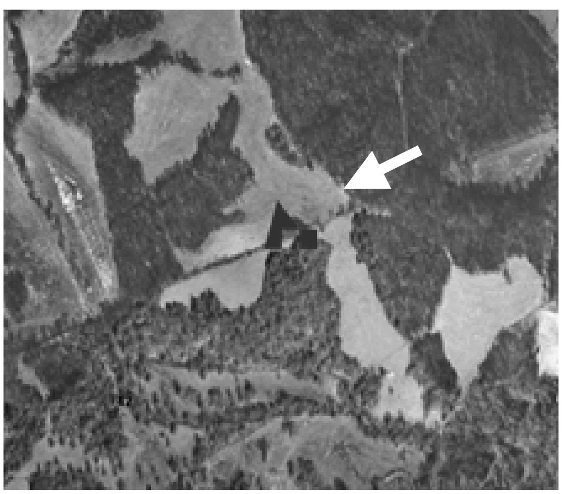


Figure 2.6. Maximum annual temperature in North and South Carolina.

(a)

(b)



(c)

(d)

Figure 2.7. Vegetation occurring at predicted prairie locations. Black triangles and squares are predicted locations containing all prairie conditions.

Table 2.1. Data sources and descriptions used for Piedmont prairie suitability analysis.

Data layer	Description	Source
Aspect (º)	Thirty (30)meter aspect grid	http://www.ncdot.org/it/gis/ & http://www.dnr.sc.gov/gis.html
Elevation (m)	Digital elevation model	http://www.ncdot.org/it/gis/ & http://www.dnr.sc.gov/gis.html
Herbaceous	Piedmont herbaceous covertype	http://www.cast.uark.edu/pif/main/southeast/ 11table.htm
Landform index	Thirty (30) meter landform index grid	Landform aml, http://arcscripts.esri.com
Piedmont	Piedmont of North and South Carolina	http://www.epa.gov/wed/
Precipitation (cm)	Maximum and minimum average annual and July average precipitation	http://datagateway.nrcs.usda.gov/
Slope (%)	Thirty (30) meter slope grid	http://www.ncdot.org/it/gis/ & http://www.dnr.sc.gov/gis.html
Soils	Soil Survey Geographic Database (SSURGO)	http://datagateway.nrcs.usda.gov/
Temperature (C)	Maximum and minimum average annual and July average temperature	http://datagateway.nrcs.usda.gov/
Urban	Urban area boundaries	http://www.census.gov/geo/www/cob/

Table 2.2. Characteristics measured at eight Piedmont prairie sites in the Piedmont of North and South Carolina.

Site	Aspect (º)	Slope (%)	LFI	Avg Temp (C)	Max Temp (C)	Avg July Precip (cm)	Avg Precip (cm)	Elevation (m)
Catawba Wildflower Glen	250	14	0.030	16	32	11	114	200-207
McCoy Road Sunflower	10	12	0.033	16	32	11	114	213-226
Mineral Springs Barren	135	10	0.068	16	33	12	119	195-201
Mountain Island Dam	260	26	0.016	16	32	11	114	198-207
Penney's Bend	145	13	0.015	15	32	13	119	79-94
Rock Hill BlackJacks	200	7	0.011	16	33	12	119	173-193
Shuffletown Prairie	270	8	0.001	16	32	11	114	204-229
Winget Road Sunflower	135	6	0.001	16	32	11	114	183-195

LFI. Landform index

Table 2.2. (Continued). Characteristics measured at eight Piedmont prairie sites in the Piedmont of North and South Carolina.

Site	Soil Series	Description
Catawba Wildflower Glen	Wilkes	Loamy, mixed, active, thermic, shallow Typic Hapludalfs
McCoy Road Sunflower	Enon	Fine, mixed, active, thermic Ultic Hapludalfs
	Wilkes	Loamy, mixed, active, thermic, shallow Typic Hapludalfs
Mineral Springs	Wynott	Fine, mixed, active, thermic Typic Hapludalfs
Mountain Island Dam	Wilkes	Loamy, mixed, active, thermic, shallow Typic Hapludalfs
Penney's Bend	Iredell	Fine, montmorillonitic, thermic, Oxyaquic Vertic Hapludalfs
Rock Hill Blackjacks	Iredell	Fine, mixed, active, thermic Oxyaquic Vertic Hapludalfs
Shuffletown Prairie	Mecklenburg	Fine, mixed, active, thermic Ultic Hapludalfs
Winget Road Sunflower	Iredell	Fine, mixed, active, thermic Oxyaquic Vertic Hapludalfs

Table 2.3. Values used in the Piedmont prairie suitability analysis.

Character	Value
Aspect	90 - 270
Landform Index	-0.1 – 0.1
Slope	< 27%
Soil Series	Enon, Iredell, Mecklenburg, Wilkes, and Wynott

Table 2.4. Suitability analysis criteria met by Stringer check plots.

Plot	LFI	Aspect	Slope	Soil Series
1	X		X	
2	X	X	X	
3	X		X	
4	X	X	X	
5	X	X	X	
6	X	X	X	
7	X	X		
8	X		X	
9	X	X	X	X
10	X	X	X	
11	X	X	X	
12	X		X	X
13		X	X	
14	X	X	X	
15		X	X	

CHAPTER THREE

Soil Chemical and Physical Properties of Selected Prairie Sites in the Piedmont of North and South Carolina

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ABSTRACT: Soil chemical and physical characteristics may affect Piedmont prairie restoration success. The objective of this study was to describe soil chemical and physical characteristics of selected prairie remnant sites in the Piedmont of North and South Carolina. Our approach was to compare soil characteristics among selected Piedmont prairie and rare plant sites. Three 2.5 cm diameter soil cores were taken to a depth of 15 cm at 20 locations within each of 5 prairie and 3 rare plant sites. Concentrations of C, N, P, K, Ca, Mg, B, Cu, Mn, Na, and Zn were measured. In addition, acidity, pH, buffer pH, C/N ratio, K base saturation, Ca base saturation, Mg base saturation, Na base saturation, total base saturation, CEC, and percent sand, silt and clay were determined. Concentrations of C, N, and Zn were not significantly different among locations, whereas significant differences were found in all other characters. Levels of C and N were low, mean 2.0 and 0.1% respectively, across all locations. Total base saturation ranged from 29 to 70%, mean 52%. When the elements were rated on their sufficiency for growth, N, P, and K were deficient; while, B, Ca, and Zn were sufficient, and Mg and Mn were high or excessive. Sand comprised the largest fraction of soils in all locations except one, mean 45%; followed by silt, 33%; and clay, 21%. Stepwise analysis created regression models containing Mg, Zn, C, CEC, sand, P, and Cu with R^2 values of 0.66, 0.72, 0.77, 0.83, 0.85, 0.86, and 0.88, respectively**.** Piedmont prairie remnants occured on sandy/silty surface Alfisols that are low in macronutrient content, high in micronutrient content and very high in Mg and Mn content.

Index terms: micronutrient, macronutrient, particle size, soil organic carbon, nutrient deficiency, soil organic matter, nitrogen, Magnesium, Manganese

INTRODUCTION

The tallgrass prairies that covered the presettlement mid-western United States have all but disappeared. Approximately 90% of the original area has been converted to agriculture (Polley et al. 2005) degrading the prairie and creating a loss of soil C and N (Camill et al. 2004). In the Piedmont of North and South Carolina, prairies existed before European settlement as well (Brown 2000). These prairies were, primarily, the result of burning by Native Americans creating savanna-like areas that were floristically rich. After settlement, prairie areas were converted to European style agriculture except those that were unsuitable (too rocky, etc.). Widespread burning was removed from the ecosystem at this point, resulting in invasion of prairies by woody vegetation (Williams 2000).

Loss of the prairie habitat has sparked a growing public interest in its restoration. Awareness that prairie habitat was unique and necessary for species such as Schweinitz's sunflower (*Helianthus schweinitzii* Torr. & A. Gray), smooth purple coneflower (*Echinacea laevigata* (C.L. Boynt. & Beadle) S.F. Blake), Georgia aster (*Symphyotrichum georgianum* (Alexander) G.L. Nesom), Henslow's sparrow (*Ammodramus henslowii)*, prairie warbler (*Dendroica discolor),* and Northern bobwhite (*Colinus virginianus*) reinforced the incentive for restoration (Emanual 1994; Herket 1994; Matthews and Howard 1999; Cram et al. 2002; Beachy and Robinson 2008; Echols and Zomlefer 2010). Plants thought to have been common in prairies occur along road sides, field edges, and in utility rights-of-way (Wagner et al. 1998). State and local governments along with public and private organizations have begun programs to locate prairie remnants and restore them. Restoration usually involves removing invading vegetation through the use of fire, herbicides, and mechanical means, then enhancing current populations through the use of prescribed fire and planting. However, the use of soil fertilization and amendment has received little attention as a means of enhancing or inhibiting the establishment of species in a prairie restoration (Rothrock and Squires 2003). Old farm fields tend to have high levels of nitrogen that cause high productivity in early restoration plantings resulting in lower diversity (Martin et al. 2005).

Macronutrients nitrogen (N), phosphorus (P), and potassium (K) are used in greatest quantity by plants making them most likely to be deficient in soils. The macronutrients calcium (Ca), magnesium (Mg), and sulfur (S) are required in smaller quantities. Quantifies that are usually available in soil. Vertical distribution of macronutrients in the soil profile depends on vegetative demand with the most limiting nutrients occurring at the most shallow depths. The distribution of nutrients in the soil profile from most shallow to deepest is P, K, Ca, Mg, and Na with P and K more concentrated in the upper 20 cm (Jobbagy and Jackson 2001).

Micronutrients (boron (B), copper (Cu), chlorine (Cl), iron (Fe), manganese (Mn), molybdenum (Mo), and zinc (Zn) are needed in very small quantities but are essential for growth. Soils generally contain sufficient amounts; however, only a small portion of the total is available to plants. Generally, concentrations decrease with increasing soil depth (Gupta et al. 2008). Micronutrient deficiency will result in poor or reduced production; although, deficiencies are more common in locations having intense leaching associated with high precipitation (Gupta et al. 2008).

Each nutrient has an effect on plant growth, but synergy can also occur or maybe a better explanation is the law of minimum. This law states that growth is limited by a single resource at any one time, and the limiting resource must become sufficient before another resource can enhance plant growth (Rubio et al. 2003). D'Antonio and Mack (2006) found the addition of P to a grassland in Hawaii Volcanoes National Park caused no increase in biomass production; but when N was added in conjunction with P, total biomass production was greater than N alone. Similarly, in a secondary savanna in the interior branch of the Coastal Range of Venezuela, additions of N, P+K, and N+P+K gave aboveground biomass increases of 718, 490, and 949 g/m^2 (Barger et al. 2002). N is the limiting factor in each of these situations.

While investigating the literature, numerous publications were found that addressed macronutrients in prairies, especially N, P, and K (Riser et al. 1982; Rhoades et al.). Likewise, soil organic matter (SOM) and its importance to N and soil organic carbon (SOC) were frequent topics (Jelinski et al. 2009; Constant et al. 2001). Soil texture, bulk density, and parent material were discussed (Van Haveren 1983; Barshad 1946), but few addressed micronutrients especially in conjunction with macronutrients. The objective of this study is to characterize the amounts of macro and micronutrients as well as physical properties on documented prairie sites in the Piedmont of North and South Carolina. Furthermore, this information can be incorporated into a restoration program for better site selection thus increasing restoration success.

MATERIALS AND METHODS

Study Area

The study area, Figure 3.1, encompasses five prairie (McCoy Road Sunflower Site (MR), Mineral Springs Barren (MS), Penney's Bend Nature Preserve (PB), Rock Hill Blackjacks Heritage Preserve (RH), and Shuffletown Prairie (ST)) and three rare plant sites (Catawba Wildflower Glenn (CW), Mile Island Dam Rare Plant Site (MI), and Winget Road Sunflower Site (WR)) throughout the central Piedmont in North Carolina ranging from Charlotte to Durham and the northeastern Piedmont in South Carolina near Rock Hill. It covers the area within 35º - 36.5º north latitude and 78º - 82º west longitude. Topography is rolling with elevation ranging from 61 to 427 m. Precipitation is spread evenly throughout the year with the greatest monthly amount, 10 - 13 cm, occurring in July. Daily high temperatures range from 10º C in January to 32º C in July. Daily low temperatures range from -1º C in January to 21º C in July (Boyles et al. 2004). The study area is primarily forested with oak-pine, oak-hickory, and pine plantations. Other portions are in cropland, pasture, and urban-manufacturing influence (Griffin et al. 2002ab).

Sampling

Two transect lines were established parallel to the long axis of each prairie site from one end to the opposite end. One transect was located to either side of the approximate site center. Transects were divided into 10 equally spaced points based on the width of the site at the transect location. At each point, three 2.5 cm diameter soil cores were taken to a depth of 15 cm and the GPS location of each sampling point was recorded. Transects ranged from 100 – 450 m, but 300 m was the most common length.

Laboratory Analysis

All samples were air dried then sieved through a 2 mm mesh screen. Four composite samples were produced for each site by mixing soil cores of the first five sampling points into one composite sample, then mixing cores from the second five sampling points to form the second composite sample, continuing until all four composite samples were produced (Lloyd et al. 1983). Samples were delivered to the Agricultural Service Laboratory, Clemson University, Clemson, South Carolina (http://www.clemson.edu/public/regulatory/ag_svc_lab/) for chemical analysis using the Mehlich 1 extraction procedure. Levels for C, N, P, K, Ca, Mg, Na, Zn, acidity, buffer pH, pH, cation exchange capacity (CEC), K base saturation, Mg base saturation, Na base saturation, and total base saturation were determined. Additionally, a particle size analysis was performed at the Agricultural and Environmental Services Laboratories, University of Georgia, Athens, Georgia (http://aesl.ces.uga.edu/).

Statistical analysis

Data analyses were performed using SAS 9.2 software (SAS Institute Inc, Cary NC). All data were tested for normality using the Univariate Procedure (α=0.05). Square root transformations were applied to P, K, Na, Mg, Mn, Zn, CEC, Na base saturation, K base saturation, percent sand, percent silt, and percent clay for normalization. An analysis of variance was performed on all variables using the General Linear Models Procedure (GLM) to test location effects (α =0.05). Tukey's HSD (Honestly Significant Difference) test was used for means separation. In order to determine which variables were most important in discriminating among the different locations, a stepwise regression was performed.

RESULTS

There were no significant differences in C, N, and Zn among locations (Table 1). Soil C content ranged from 1.38 to 2.66% averaging 2.00% across all locations. Nitrogen averaged 0.10% and ranged from 0.08 and 0.14%. Zinc content was variable among locations ranging from 4.04 to 13.97 kg/ha.

Significant differences were found among locations for soil P, K, Ca, Mg, Na, B, Cu, and Mn (Table 3.1). Mean P ranged from 4.53 to 16.01 kg/ha while mean K ranged between 50.74 to 277.91 kg/ha. Mean Ca, Mg, and Na varied across locations, but were higher at locations containing Iredell and Mecklenburg soil series. The other nutrients exhibited similar variability. Boron, Cu, and Mn content was smallest in the locations where the Wilkes and Zion soil series occurred.

Significant differences for soil pH, buffer pH, CEC, and acidity were found among locations. Soil pH was typically acidic with only one location having a mean greater than 6.0. Means for all other locations ranged between 4.80 and 5.98. Only two locations had mean values less than 5.0. Buffer pH means ranged from 7.4 to 7.7 but were significantly different. Cation exchange capacity means ranged from 6.5 to 11.7. Only three locations had values greater than 10.0 while three had values less than 7.0. Two locations have values between 7.0 and 10.0. Acidity, the concentration of acidic ions in the soil, ranged from 2.8 to 4.5 meq/100g.

All locations except two had total base saturation greater than 35%, a defining characteristic of Alfisols. The remaining locations had values of 28.5% and 33.8%. Mean Ca base saturation ranged from 15.5 to 41.8% while Mean K base saturation ranged from 0.5 to 4.7%. Mean Mg base saturation ranged from 6.6 to 26.3%. Mean Na base saturation ranged from 0.0 to 1.0%

Sand was the largest soil fraction at all locations except one where silt comprises the greater amount. Across all locations the average sand content was 45.7%. Silt content was as high as 65.2% at one location almost twice the next highest content of 35.0%, but overall the content averaged 38.7%. Clay was a minor constituent of these soils averaging 21.1%. Soil textures were sandy loam, sandy clay loam, clay loam, silt loam, and loam.

In the Stepwise analysis, magnesium content proved to be the most important characteristic for separating among locations. Other nutrients selected by the analysis in order of their contribution to the model include Zn, C, CEC, percent sand, P, and Cu. Model R^2 values were 0.66, 0.72, 0.77,0 .83, 0.85, 0.86, and 0.88, respectively.

DISCUSSION

Nitrogen levels found by Tompkins et al. (2010a) at Suther Prairie, a piedmont prairie located in Cabarrus County North Carolina, were 0.2% at the 0 - 10 cm depth, 0.1% at 11 - 20 cm, and 21 - 30 cm. This compares with the 0.1 - 0.2% found at our sites. Tompkins (2010c) also found nitrogen levels that ranged from 0.1% to 0.3% occurring on eight locations containing populations of big bluestem (*Andropogon gerardii*) a grass which occurs in the tallgrass prairie.

Nitrogen has been shown to be the most important nutrient affecting the structure and function of grassland ecosystems and is usually the only nutrient that increases herbage quantity (Riser and Parton 1982). Consequently, low N availability leads to lower aboveground net primary productivity (ANPP) (Baer et al. 2003), but species diversity is maintained, and richness increases over time (Baer et al. 2004). Additional biomass increases shading on desirable species resulting in poor growth or death. Rhoades et al. (2004), found forest total N and the availability and production of plant available N was 25 to 50% lower in glades occurring in the Kentucky Knobs region. Only species capable of surviving and growing in a reduced N soil would occur here. Higher demanding species would not survive or would be out competed by adapted species. Excessive N can lead to partial or total restoration failure. Thus, a reduction of N should be of high priority in the restoration of grass-dominated communities (Aude 2004).

Sites sampled for this study did not have appreciable amounts of litter on their soil surfaces; generally, the soil surface could be seen. However, the average SOC for all locations was 2.03%. This contrasts with 7.46% and 10.27% at 0 - 10 cm reported for two prairie remnants located in Wisconsin (Jelinski and Kucharik 2009). Prairie restoration sites ranging in age from 3 to 25 years located in Illinois were found to have SOC values ranging from 3.66 to 5.48% at 0-5 cm depth (Allison et al. 2005). Jelinski and Kucharik (2009) also found SOC ranging from 4.05 to 7.02% at the 0 - 10 cm depth in four prairie restorations ranging from 2 - 45 years old while Tompkins et al. (2010a) found 2.70% at Suther Prairie. On big bluestem sites surveyed by Tompkins et al. (2010c), SOC ranged from 0.90 - 4.20%. But, loblolly pine planted on old cotton fields located on the Calhoun Experimental Forest, Union County, South Carolina has an average 0.54% SOC in the top 15 cm (Li et al. 2008). Our samples contained 37 - 55% the SOC of prairie restorations, 20 - 27% as much SOC as remnant prairies Jelinski and Kucharik (2009) studied, and 51 – 99% the SOC as Suther Prairie, but contained 376% of that found in the loblolly pine stand Li (2008) examined. A longer growing season in conjunction with a higher average temperature, as is typical of the Piedmont, reduces SOM (Helms 2000)

Zinc, a micronutrient used by plants in physiological processes, is only required in small quantities (Pritchard and Fisher 1987). Although there was no significant difference in Zn content among locations, the actual amounts varied from 4.04 to 13.97 kg/ha. Higher concentrations, 11.32 and 13.97 kg/ha, occurred along utility rights-of-way. Lower concentrations, 4.04 and 4.54 kg/ha, occurred at locations surrounded by hardwood forests, while the other locations appeared to have been old fields or pastures. However, Suther Prairie contained 2.98 kg/ha Zn in the 0 - 10 cm depth (Tompkins et al. 2010a) 74% of the smallest amount found in our samples.

Phosphorus is required by plants in larger quantities, but its concentration in soil solution is usually very low (Pritchett and Fischer 1987). Its content varied among locations. Site WR contained the greatest amount at 16.07 kg/ha and had a cover of eastern redcedar (*Juniperus virginiana*) occurring on Iredell soil. This concentration was statistically different from all other sites except CW, a mixed oak (*Quercus sp.*) site, which had a content of 10.52 kg/ha. There was not a significant difference between CW and the other locations.

Potassium is another nutrient required in large quantities. Quantities found ranged from a high of 277.91 kg/ha at PB to 50.74 at MS. The PB concentration was roughly twice the next higher concentration of 142.68 kg/ha at MI. Perhaps this is the result of previous fertilization practices since PB appears to have been a pasture at one time. Troy prairie, a Piedmont prairie located in Montgomery County, North Carolina, contained 81.00 kg/ha K (Tompkins et al. 2010b) while Suther Prairie contained 160.80 kg/ha ((Tompkins et al. 2010a).

The calcium level at WR was highest of all locations at 2192.66 kg/ha. This amount is expected if the soil developed from gabbro which contains significant amounts of Ca. In addition, this site contained eastern redcedar as the only canopy tree species. This species has a high Ca content in its foliage and tends to cause soils to become neutral or slightly alkaline over time (Burns and Honkala 1990). Higher soil calcium contents most likely aid this process. It is likely the soils at ST, RH, MR, and PB developed from gabbro giving rise to their high Ca contents. A similar high Ca content, 2041.40 kg/ha, was found at Suther Prairie (Tompkins 2010a)

Copper is a micronutrient that is unlikely to be deficient except in organic or sandy soils (Prasad and Power 1997). Copper occurred in relatively small amounts at all locations when compared with other nutrients. Higher concentrations tend to occur in the O horizon because of its affinity for organic matter (Li et al. 2008). Li et al. (2008) found that the total amount contained in the O horizon was 0.56 kg/ha on the Calhoun Experimental Forest, Union

County, South Carolina. This is less than the average 2.17 kg/ha we found, but our samples were to a depth of 15 cm and included more than just the O horizon. However, a greater concentration, 4.90 kg/ha, was found at Suther Prairie (Thompkins 2010a).

Boron, in contrast to Cu, accumulates to a greater degree in plant biomass (Li et al. 2008). Li found the total content in the O horizon was 0.81 kg/ha compared with an average 0.69 kg/ha across all our samples. Contents ranged from 0.15 to 1.02 kg/ha. However, Tompkins et al. (2010a) found 0.80 kg/ha at Suther Prairie.

Magnesium content was greatest at ST, RH, and WR while CW was lowest. CW contained only 20% as much Mg as ST, RH, and WR. Manganese content was similar at MR, PB, RH, WR, and ST ranging from 80.99 to 111.67 kg/ha. However, MS had the smallest content, 24.08 kg/ha, but had the highest Na content of any location, 88.12 kg/ha. This was 232% greater than the next highest, 37.91 kg/ha at ST. The concentration at Suther Prairie was 717.10 kg/ha (Tompkins 2010a). Only ST contained a greater concentration 836.91 mg/ha.

Soil pH at MS, CW, MI, and MR was strongly acid (pH 4.80, 4.93, 5.33, and 5.50, respectively) as Tompkins et al. (2010b) found at Troy Prairie. Penney's Bend, RH, and WR were medium acid (pH 5.98, 5.68, and 5.83, respectively), Suther Prairie was slightly acid (5.7) Tompkins et al. (2010a) while ST was slightly acid 6.13. Typically, the more acidic the soil solution, the less available nutrients are to plants. Combining nutrients with other soil cations and anions forming insoluble compounds is pH dependent as is the breakdown of these compounds. For example, nitrogen is available to plants as ammonium (NH_4^+) and nitrate (NO_3^-). The conversion of ammonium to nitrate occurs rapidly near neutral pH (7); but in acid pH conditions, this conversion slows giving plants that can effectively use NH_4^+ an advantage (Potassium Nitrate Association 2011).

Base saturation was greater than 35% at all locations except MS and CW indicating the soil is mafic. However, MS does have a mafic soil, Wynott. Amounts of soil Ca and K were low compared to other locations giving a lower base saturation. Base saturation at CW is the result of sampling through a Cecil inclusion which lowered the result. The amount of iron and aluminum held on the exchange sites ranged from 30 to 45% at MR, PB, RH, ST, and WR. Mountain Island had a 56% content while MR had 66% Fe and Al but, CW contained the greatest amount, 72%. More than one half of the exchange sites (CEC) were taken up by these elements causing the site to become less fertile.

Sand was the greatest soil fraction at all locations but RH, ST, and MS which contained less than 50%. Mineral Springs contained only 20% sand but had 65% silt. The other two locations, RH and ST, contained 40 and 36% sand respectively. Smith (2008) found the sand content of soils at Schweinitz's sunflower sites, a species associated with Piedmont prairie occurrence, averaged 49.1% while 45.7% was the average in our samples. Silt ranged from

25 – 35% except MS and clay content ranged from 16 - 33%. Smith (2008) found and average 32.6% silt and 19.0% clay at Schweinitz's sunflower sites Soil texture is dependent upon particle size distribution and is an important determinant of drainage and aeration. Drainage is facilitated by sand and its large pore space. Finer textured clayey soils have a much greater water holding ability. Aeration is better in sandy soils and promotes root growth. Organic matter decomposes more rapidly in a sandy soil as a result of improved air supply. Cation exchange capacity and pH buffering tend to increase with clay content. However, erodibility increases with finer particle sizes, silt and clay. meaning the ideal soil has a mix of these particles, loam. Loam soils have a mix of all the characters brought about by their particle size distribution, i.e. they drain well, have good aeration, hold moisture, and hold nutrients. Soil textures found were loam (PB and RH), clay loam (ST), silt loam (MS), sandy loam (CW and WR) and sandy clay loam (MI and MR).

The SAS stepwise procedure was performed to determine which characters are important in discriminating between locations. Eight models were produced each with a greater R^2. Magnesium was the single variable model having a R^2 of 0.66. Additional variables added to the model along with R^2 values included Zn (0.72), C (0.77), CEC (0.83), Mg was dropped from the model (0.83), sand (0.85), P (0.86), and Cu (0.88).

Soil nutrient levels were variable from location to location and difficult to interpret and compare meaningfully. Sufficiency for growth is a more interpretable method of classifying and comparing sites. A rating system obtained from the Clemson University Soil Testing Laboratory was used to classify nutrient levels as excessive, high, sufficient, medium, or low for optimal plant growth (Dr. Kathy Moore, personal communication). A rating of excessive indicates the nutrient will adversely affect plant growth, while high indicates that growth may be affected. A rating of sufficient indicates adequate nutrients to meet requirements; medium means there are enough nutrients for moderate growth, while low indicates insufficient nutrient level. Table 3.2 shows that P was low at all locations. Potassium was low at MS, RH, and WR; medium at CW, MI, MR and ST; and excessive at PB. Micronutrients, Ca, B, Mg, Mn, and Zn were found at levels that were ideal or too great. Magnesium was high at all locations while Mn was excessive at all but two locations, MI and MS. Calcium was high at two locations sufficient at three and medium at three. Excessive and high levels of a nutrient can aid prairie development. Plants that can tolerate these levels establish themselves where others cannot survive. Lower than adequate macronutrients reduce growth allowing plants requiring lower levels to establish themselves and occupy a site. The NO_3^- form of nitrogen is easily washed from soil solution resulting in a soil N reduction (Alfred 2012). However, it has been shown that reduced nitrogen levels reduce the NPP of competing vegetation allowing prairie type species to establish themselves (Baer et al. 2003).

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LITERATURE CITED

Alfred, B. J. 2008. Cation effects on nitrate mobility in an unsaturated soil. American Society of Agricultural and Biological Engineers 51:1997-2012.

Allison, V. J., R. M. Miller, J. D. Jastrow, R. Matamala, and D. R. Zak. 2005. Changes in soil microbial community structure in a tallgrass prairie chronosequence. Soil Science Society of America Journal 69:1412-1421.

Aude, E. 2004. The effects of nutrients and disturbance on dry grass-dominated vegetation. PhD thesis. National Environmental Research Institute. Denmark.

Barger, N. H., C. M. D'Antonio, T. Ghneim, K. Brink, and E. Cuevas. 2002. Nutrient limitations to primary productivity in a secondary savanna in Venezuela. Biotropica 34:493-501.

Baer, S. G., J.M. Blair, S. L. Collins, and A. K. Knapp. 2003. Soil resources regulate productivity in newly established tallgrass prairie. Ecology 84:724-735.

Baer, S. G., J. M. Blair, S. L. Collins, and A. K. Knapp. 2004. Plant community responses to resource availability and heterogeneity during restoration. Oecologia 139:617-629.

Barshad, I. 1946. A peodologic study of California prairie soils. Soil Science 61:423-442.

Beachy, B. L. and G. R. Robinson. 2008. Divergence in avian communities following woody plant invasions in a pine barrens ecosystem. Natural Areas Journal 28:395-403

Berg, B. and C. McClaugherty. 2008. Plant litter: decomposition, humus formation, carbon sequestration. 2nd edition Springer-Verlag Berlin Heidelberg.

Blumenthal, D. M., N. R. Jordan, and M. P. Russelle. 2003. Soil carbon addition controls weeds and facilitates prairie restoration. Ecological Applications 13:605-615.

Boyles, R. P., C. Holder, and S. Raman. 2004. North Carolina climate: a summary of climate normals and averages at 18 agricultural research stations. North Carolina Agricultural Research Service, North Carolina State University. Technical Bulletin 322.

Brown, H. 2000. Wildland burning by American Indians in Virginia. Fire Management Today 60:29-39.

Burns, R.M. and B.H. Honkala. 1990. Silvics of North America, Vol. 1, Conifers. Washington DC: U.S.D.A. Forest Service Agriculture Handbook 654. 10 September 2010 http://www.na.fs.fed.us/pubs/silvics_manual/table_of_contents.shtm.

Camill, C., M. J. McKone, S. T. Sturges, W. J. Severud, E. Ellis, J. Limmer, C. B. Martin, R. T. Navratil, A. J. Purdue, B. S Sandel, S. Talukder, and A. Trout. 2004. Community and ecosystem-level changes in a species-rich tallgrass prairie restoration. Ecological Applications 14:1680-1694.

Conant, R. T., K. Paustian, and E. T. Elliott. 2001. Grassland management and conversion into grassland: effects on soil carbon. Ecological Applications 11:343-355.

Cram, D. S., R. E. Masters, F. S. Guthery, D. M. Engle, and W. G. Montague. 2002. Northern bobwhite population and habitat response to pine-grassland restoration. Journal of Wildlife Management 66:1031-1039.

D'Antonio, C. M. and M. C. Mack. 2006. Nutrient limitation in a fire-derived, nitrogen-rich Hawaiian grassland. Biotropica 38:458-467.

Echols, S. L. and W. B. Zomlefer. 2010. Vascular plant flora of the remnant Blackland Prairies in Oaky Woods Wildlife Management Area, Houston County, Georgia. Castanea 75:78-100.

Emanuel, C. M., T. A. Waldrop, J. L. Walker, and D. H. Van Lear. 1995. Silvicultural options for recovering the endangered smooth coneflower: preliminary results. p. 32-35. *In* M. B. Edwards (ed.) Proceedings for the Eighth Biennial Southern Silvicultural Research Conference, Auburn, AL. 1-3 November 1994. USDA Forest Service, Southern Research Station, Asheville, NC.

Griffith, G., J. Omernik, and J. Comstock. 2002a. Ecoregions of North Carolina regional descriptions. USDA Natural Resources Conservation Service. August 2002.

Griffith, G., J. Omernik, and J. Comstock. 2002b. Ecoregions of South Carolina regional descriptions. USDA Natural Resources Conservation Service. July 2002.

Gupta, U. C., W. Kening, and L. Siyuan. 2008. Micronutrients in soils, crops, and livestock. Earth Science Frontiers 15:110-125.

Helms, D. 2000. Soil and southern history. Agricultural History 74:723-758.

Herket, J. R. 1994. The effect of habitat fragmentation on Midwestern grassland bird communities. Ecological Applications 4:461-471.

Jelinski, N. A. and C. J. Kucharik. 2009. Land-use effects of soil carbon and nitrogen on a U. S. Midwestern floodplain. Soil Science Society of America Journal 73:217-225.

Jobbagy, E. G. and R. B. Jackson. 2001. The distribution of soil nutrients with depth: global patterns and the imprint of plants. Biogeochemistry 53:51-71.

Kluepfel, M. and B. Lippert. 2006. Soil Testing. 15 September 2010 http://www.clemson.edu/extension/hgic/plants/other/soils/hgic1652.html.

Li J., D. Richter, A. Mendoza, and P. Heine. 2008. Four-decade response of soil trace elements to an aggrading old-field forest: B, Mn, Zn, Cu, and Fe. Ecology 89:2911-2923.

Lloyd, F. T. and W. H. McKee, Jr. 1983. Replication and subsamples needed to show treatment responses on forest soils of the coastal plain. Soil Science Society of America 47:587-590.

Martin, L. M., K. A. Moloney, and B. J. Wilsey. 2005. An assessment of grassland restoration success using species diversity. Journal of Applied Ecology 42:327-336.

Matthews, C. R. and J. H. Howard. 1999. Genetic variation in the federally endangered Schweinitz's sunflower, *Helianthus schweinitzii* T. & G. (Asteraceae). Castanea 64:231-242.

Polley, H. W., J. D. Derner, and B. J. Wilsey. 2005. Patterns of plant species diversity in remnant and restored tallgrass prairies. Restoration Ecology 13:480-487.

Potassium Nitrate Association. 2011. Nitrate (NO_3^-) versus ammonium (NH_4^+). 4 April 2011. http://kno3.org/en/product-features-a-benefits/nitrate-no3-versus-ammonium-nh4.

Prasad, R. J. F. Power. 1997. Soil fertility for sustainable agriculture. CRC Press LLC.

Pritchett, W. L. and R. F. Fischer. 1987. Properties and management of forest soils. John Wiley & Sons, New York. 494 p.

Rhoades, C.C., S. P. Miller, and M. M. Shea. 2004. Soil properties and soil nitrogen dynamic of prairie-like forest openings and surrounding forest in Kentucky's knobs region. The American Midland Naturalist 152:1-11.

Rothrock, P. E. and E. R. Squires. 2003. Early succession in a tallgrass prairie restoration and the effects of nitrogen, phosphorus, and micronutrients enrichment. Proceedings of the Indiana Academy of Science 112:160-168.

Rubio, G., J. Zhu, and J. Lynch. 2003. A critical test of the two prevailing theories of plant response to nutrient availability. American Journal of Botany 90:143-152.

Riser, P. G., W. J. Parton. 1982. Ecosystem analysis of the tallgrass prairie: nitrogen cycle. Ecology 63:1342-1351.

Smith, T. C. 2008. Spacial analysis of Helianthus schweinitzii (Schweinitz's sunflower), an endangered species endemic to the Piedmont of NorthCarolina. MA thesis. The University of North Carolina Greensboro, Greensboro, NorthCarolina.

Tompkins, R. D., C. M. Luckenbaugh, W. C. Stringer, K. H. Richardson, E. A. Mikhailova, and W. C. Bridges Jr. 2010a. Suther prairie: vascular flora, species richness, and edapic factors. Castanea:75:232-244.

Tompkins, R. D. W. C. Stringer, K. Richardson, E. A. Mikhailova, and W. C. Bridges Jr. 2010b. A newly documented and significant piedmont prairie site with a *Helianthus schweinitzii* torrey& a.gray (S*chweinitz's sunflower*) population. The Journal of the Torrey Botanical Society 137:120-129.

Tompkins, R. D., W. C. Stringer, K. Richardson, E. A. Mikhailova, and W. C. Bridges Jr. 2010c. Big bluestem (*Andropogon gerardii*; poaceae) communities in the Carolinas: composition and ecological factors. Rhodora 112:378-395.

Van Haveren, B. 1983. Soil bulk density as influenced by grazing intensity and soil type on a shortgrass prairie. Journal of Range Management 36:586-588.

Wagner, L. K., W. C. Stringer, and T. P. Spira. 1998. Restoration of a Piedmont prairie: a preliminary report (South Carolina). Restoration & Management Notes 16:82-83.

Williams, G. 2000. Introduction to aboriginal fire use in North America. Fire Management Today 60:8-12.

Table 3.1. Mean chemical and physical property values for prairie and rare plant sites. Means with similar letters are not significantly different based on Tukey's Honestly Significant Difference Test (□=.05).

Parameter	Catawba Glenn (CW)	Mountain Island (MI)	McCoy Road (MR)	Mineral Springs (MS)	Penney's Bend (PB)	Rock Hill (RH)	Shuffletown Prairie (ST)	Winget Road (WR)
C (%)	2.66 a	2.01 ab	2.33 ab	1.78 ab	1.38 b	2.24 ab	1.79 ab	2.12 ab
N (%)	0.12 a	0.14 a	0.14 a	0.08 a	0.11 a	0.15 a	0.11 a	0.13 a
C/N	23.63 ab	14.94 c	17.21 bc	23.87 a	12.64 c	15.36 c	15.01 c	15.07 c
P (kg/ha)	10.51 ab	5.54 b	6.51 b	4.53 b	6.94 b	4.54 b	6.59 b	16.07 a
K (kg/ha)	101.33 bcd	142.68 b	115.19 bc	50.74 d	277.91 a	60.59 d	92.11 bcd	68.81 cd
Ca (kg/ha)	683.75 c	838.39 c	1584.77 ab	474.85 c	1120.10 bc	1759.45 ab	2173.88 a	2192.66 a
Cu (kg/ha)	1.18 c	1.48 c	2.35 bc	1.09 c	1.60 c	3.95 a	3.70 ab	2.01 c
B (kg/ha)	0.40 bc	0.65 ab	0.93 a	0.15 c	0.81ab	0.71 ab	0.87 ab	1.02 a
Mg (kg/ha)	135.69 d	212.99 d	327.96 bcd	287.78 cd	268.42 cd	683.13 ab	836.91 a	627.00 abc
Mn (kg/ha)	65.48 abc	37.74 bc	111.67 a	24.08 c	106.03 a	107.16 a	80.99 ab	88.41 a
Na (kg/ha)	14.62 bc	13.99 bc	14.91 bc	88.12 a	8.46 c	36.44 bc	37.91 b	25.62 bc
Zn (kg/ha)	4.04 a	11.32 a	7.97 a	8.44 a	10.80 a	4.54 a	13.97 a	6.05 a

Table 3.1 (continued). Mean chemical and physical property values for prairie and rare plant sites. Means with similar letters are not significantly different based on Tukey's Honestly Significant Difference Test (□=.05).

Parameter	Catawba Glenn (CW)	Mountain Island (MI)	McCoy Road (MR)	Mineral Springs (MS)	Penney's Bend (PB)	Rock Hill (RH)	Shuffletown Prairie (ST)	Winget Road (WR)
pH	4.93 d	5.33 cd	5.50 bc	4.80 d	5.98 ab	5.68 abc	6.13 a	5.83 abc
Buffer pH	7.35 d	7.55 ab	7.51 bc	7.44 cd	7.65 a	7.46 bc	7.56 ab	7.46 bc
CEC (meq/100g)	7.38 c	6.45 c	8.83 bc	6.85 c	6.63 c	10.90 ab	11.65 a	11.65 a
Acidity (meq/100g)	5.20 a	3.60 cd	3.90 bc	4.50 ab	2.80 d	4.30 bc	3.50 cd	4.30 bc
Ca BS (%)	20.00 cd	28.75 bc	39.50 ab	15.50 d	38.00 ab	35.75 ab	41.75 a	41.75 a
K BS (%)	1.75 bc	2.50 b	1.75 bc	1.00 cd	4.75 a	0.50 d	1.00 cd	1.00 cd
Mg BS (%)	6.50 d	12.25 cd	13.50 bcd	15.25 bcd	15.25 bcd	22.75 ab	26.25 a	20.00 abc
Na BS (%)	0.25 bc	0.25 bc	0.00 c	2.50 a	0.00 c	1.00 b	0.75 bc	0.25 bc
Total BS (%)	28.50 c	44.00 bc	55.00 ab	33.75 c	58.00 ab	59.50 ab	69.75 a	63.00 a
Sand (%)	59.00 a	54.00 a	49.50 ab	20.00 d	50.00 ab	40.00 bc	36.00 c	53.5 a
Silt (%)	25.10 c	26.10 c	27.60 bc	65.20 a	33.00 bc	35.00 b	31.00 bc	26.50 c
Clay (%)	15.90 b	19.90 b	22.90 a	14.80 b	17.00 b	25.00 ab	33.00 a	20.00 b

Table 3.2. Sufficiency of soil chemicals for plant growth.

Parameter	Catawba Glenn	Mile Island	Mc Coy Road	Mineral Springs	Penney's Bend	Rock Hill	Shuffletown Prairie	Winget Road
Phosphorous (P)	L	L	L	L	L	L	L	L
Potassium (K)	M	M	M	L	E	L	M	L
Calcium (Ca)	M	M	S	M	S	S	H	H
Boron (B)	S	S	S	S	S	S	S	S
Magnesium (Mg)	S	H	H	H	H	H	H	H
Manganese (Mn)	E	S	E	S	E	E	E	E
Zinc (Zn)	S	S	S	S	S	S	S	S

Ratings courtesy of the Agricultural Service Laboratory, Clemson University

L= Low, M= Moderate, S= Sufficient, H= High, E= Excessive

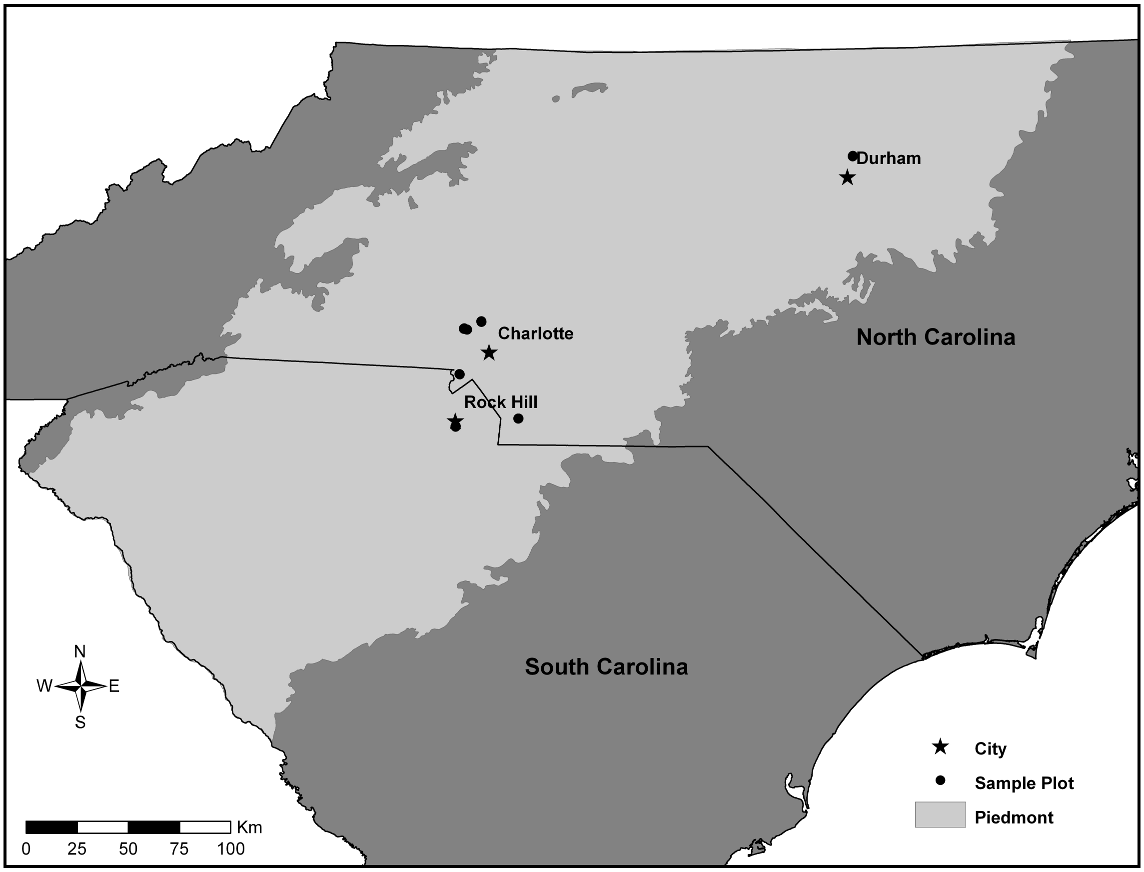


Figure 3.1. Soil sampling locations of eight prairie and rare plant sites.

CHAPTER FOUR

Ordination of Five Prairie Remnants in the Piedmont of North and South Carolina

ABSTRACT

The varied mix of species occurring on potential Piedmont prairie sites makes determining whether they are prairie or not difficult. The purpose of this study was to determine which species occurred at six different Piedmont Prairie remnant sites. Published floristic data was used to ordinate six Piedmont prairie remnant and rare plant sites located in North and South Carolina. Ordination by Non-Metric Multidimensional Scaling (NMS) separated the plots into xeric, mesic, and hydric types as defined by soil characteristics. Two-way Indicator Species Analysis (TWINSPAN) indicated the hydric location had no species in common with any other location. Remaining locations were separated on the presence of indianhemp (*Apocynum cannabinum* L.). Thirty-eight species were found not to have a preference for site among intermediate and xeric sites. Twenty-three of the thirty-eight species were associated with prairies. A list of expected species can be created, but the determination may be more useful if segregated by site moisture regime (xeric, mesic, or hydric).

Note: Not all sites used in this chapter are the same ones as in previous chapters.

INTRODUCTION

Growing public awareness of land management practices used by Native Americans and awareness of vast savannas and prairies created by them has sparked a growing interest in preserving this vanishing part of our natural heritage. Shortly after sighting the Virginia coast in 1607, colonists noticed large plumes of smoke coming from deep in the forest (Brown 2000). Settlers did not realize that the end of this practice and environmental change were about to come. Burning was stopped by barring the Indians from the (Williams 2000). Fire was feared by settlers as a very destructive and uncontrollable force. Also, prairie lands were the first to be settled and placed in crop production. This fragmented the land preventing fire from burning through prairies to retard woody and weedy vegetation. The Georgia Piedmont was mostly deforested and in crop production by 1850; but between the mid-nineteenth and early twentieth century, farmlands were abandoned (Cowell 1993). Abandoned farm fields were reclaimed by forests quickly reestablishing themselves on these disturbed soils. However, prairies did not reappear across the landscape as they once existed. Only small remnant patches existed in locations where edaphic conditions favored them (Wagner et al. 1998).

Today, with growing interest by the populace in the environment and environmental issues, interest in restoring prairie remnants and stopping their possible loss is a great concern. Plant species are expected to be lost from remnants because of habitat fragmentation alone (Leach and Givnish 1996), and there is always the threat of development. Identifying a remnant can be difficult as the mixture of species contained on the site may not be associated with a prairie. This study's goal is to determine which species found in six Piedmont prairie remnants occur without preference to site.

MATERIALS AND METHODS

Data

Vegetative data collected by Davis et al. (2002) and Schmidt and Barnwell (2002) were used for this study. Over a period of four years, Davis and his group used pedestrian surveys to record species occurring at six prairie locations (Figure 4.1) in North and South Carolina. Special attention was given to species having an association with prairies as defined by Fernald (1950) and Radford et al. (1968). Woodland, wetland, and non-native species were removed from the tally (Davis et al. 2002). Schmidt and Barnwell (2002) conducted a floristic survey of the Rock Hill Blackjacks Heritage Preserve from spring 1996 to summer 2000. The flora was classified as a member of one of six communities (bottomland forest, gabbro glade, montmorillonite forest/woodland, old field grassland/shrubland, old field woodland, or utility corridor grassland/shrubland). Species were further classified as exotic, prairie, outcrop, woody or herbaceous based on Packard and Mutel (1997) and Murdy and Carter (2000). Herbaceous species were either forbs or graminoid (Schmidt and Barnwell 2002). Species were identified to subspecies making some species different from those recorded by Davis who typically recorded only to species. In the cases where two species could be identified as being the same, they were coded identically for analytical purposes. Otherwise, species were coded as individual species. Moisture regime (hydric, mesic, or xeric) was determined from soil series information obtained from Web Soil Survey (http://websoilsurvey.nrcs.usda.gov/app/ HomePage.htm)

Analysis

Analysis begins by creating an ordination dataset in presence/absence (no abundance data were available) format from the data collected by Davis et al. (2002) and Schmidt and Barnwell (2002). Detrended Correspondence Analysis (DCA) using the program Decorana, contained in PC-ORD (McCune and Metford 2006), was performed on the data matrix to determine the number of ordination axes and for later comparison. Bray-Curtis ordination using Bray-Curtis as the distance measure was conducted on the data matrix for comparison. Non-metric Multidimensional Scaling (NMS) was run using the number of axes obtained from DCA and compared with output from DCA and Bray-Curtis as checks. In order to identify associations of species at the different sites, Two-way Indicator Species Analysis (TWINSPAN) in PC-ORD 5 with cut levels set to 0 (presence-absence) was used (McCune and Mefford 2006).

RESULTS

Ordination using DCA indicated that Suther Prairie (SP), the only hydric site, was very different from all other locations (Figure 4.1). Mineral Springs (MS) was the most xeric of all locations followed by the Rock Hill Heritage Preserve-Davis (RHD) and Rock Hill Heritage Preserve-Schmidt (RHS) sites. Shuffletown Prairie (ST) and Gar Creek (GC) were the most mesic. Bray-Curtis ordination produced similar results as DCA (Figure 4.2). Suther Prairie was found to be very different from all other locations and was one of the end points for this ordination. Gar Creek was the other end point. A 1-dimensional ordination solution was produced by NMS while the other two methods produced 3-dimensional solutions. Suther Prairie was found to be very different from other locations (Figure 4.3). Removing SP and rerunning the ordination resulted in a closer association of the remaining locations (Figure 4.4). Locations occurring above 0.0 on axis 2 (MS, RHD, and RHS) were the more xeric sites. Site RHS is not located near site RHD on the graph, but these are actually the same site with species identified by different individuals. Davis et al. (2002) collected vegetative information for RHD while Schmidt and Barnwell (2002) collected RHS information. After rerunning the ordination with RHS removed (Figure 4.5), the remaining sites clustered more closely together indicating similarity in vegetative composition.

TWINSPAN made two major divisions. The first division groups five locations excluding SP. Indian hemp (*Apocynum cannabinum* L) is the indicator species for sites GC, MS, RHS, RHD, and ST. Species that were preferential to SP are winter bentgrass (*Agrostis hyemalis* (Walt.) B.S.P.), yellowfruit sedge (*Carex annectens* (Bickn.) Bickn.), scarlet Indian paintbrush (*Castilleja coccinea* (L.) Spreng.), spotted water hemlock (*Cicuta maculata* L.), chickasaw plum (*Prunus angustifolia* Marsh.), needletip blue-eyed grass (*Sisyrinchium mucronatum* Michx.), and spring lady's tresses (*Spiranthes vernalis* Engelm. & Gray). These are all the species reported as occurring at site SP. No non-preferential species, species occurring in both groups, occurred at the first division. Further division of the remaining five locations separated RHS from the group. The occurrence of Indian hemp (*Apocynum cannabinum* L.) in RHS was used to separate it from the remaining four sites (GC, MS, RHD, and ST). Species were identified to the subspecies level at RHS with greater frequency causing it to break out differently, plus additional species were identified. Non-preferential species (Table 4.1) accounted for 38 of the total species; 23 were associated with prairies.

DISCUSSION AND CONCLUSION

Ordination of the prairie remnant sites has shown all are not identical. Suther Prairie is different from other sites because of its hydric nature. Its location along the flood plain of Dutch Buffalo Creek provides moisture year round (Tompkins 2010). Species adapted to growing in constantly moist soil are more prevalent here than other locations. However, species requiring less soil moisture would not grow well on a hydric site, if at all. Management practices are important to help keep the site an open prairie. A burning cycle of 2-3 years is practiced as well as using the site for haying (Tompkins et al. 2010). Both practices keep woody species from taking over the site and making it a forest. Conversely, Mineral Springs Barrens is a very dry upland site containing post oak (*Quercus stellata* Wangenh.), blackjack oak (*Quercus marilandica* Münchh.), shortleaf pine (*Pinus echinata* Mill.), sparse herbs and sparse grass cover. The soil is Wynott series which tends to be very wet or very dry depending on the time since the last precipitation (Davis et al. 2002). Species composition is much different than Suther Prairie; only species that can survive droughty conditions are found here. Trees are slowly occupying the site as well, but their progress is retarded by a lack of moisture in conjunction with prescribed burning conducted by The Nature Conservancy. Shuffletown prairie is intermediate between Suther Prairie and Mineral Springs Barrens. Medium to tall graminoids occur with various vines and herbs. Woody invaders are not moisture deprived compared with Mineral Springs and could grow tall rapidly if allowed. The other two sites examined for this study (GC and RH) are intermediate in moisture allowing them to contain more species and have greater productivity. However, 38 species were found to be non-preferential among GC, MS, RHD, RHS, and ST with 23 of these species previously associated with prairies (Davis et al. 2002, Edgin and

Ebinger 2000, Leidolf and McDaniel 1998, Schmidt and Barnwell 2002, Tompkins et al. 2010). Non-preferential species can be used to identify potential Piedmont prairie sites since they showed no preference for site other than not occurring on wet sites.

All Piedmont prairies do not occur on the same site type, especially in terms of moisture. Nor do they have the same mix of flora, but they do have a subset of flora that can be used to identify them. Potential Piedmont prairie sites are being located without a method to quickly validate them. By using the species that did not have a preference to a particular Piedmont prairie site type, a quick assessment can be made. While the species determined in this study are most appropriate near Charlotte, North Carolina, local species lists can easily be developed saving time and effort. Species determined here do not apply to one location, Suther Prairie. Site conditions were different at that location creating a different species mix.

LITERATURE CITED

Brown, H. 2000. Wildland burning by American Indians in Virginia. Fire Management Today 60:29-39.

Cowell, C. M. 1993. Environmental gradients in secondary forests of the Georgia Piedmont, U. S. A. Journal of Biogeography 20:199-207.

Davis, Jr., J. E., C. Mc Rae, B. L. Ester, L. S. Barden, and J. F. Matthews. 2002. Vascular flora of Piedmont prairies: evidence from several prairie remnants. Castanea 67:1-12.

Edgin, B. and J. E. Ebinger. 2000. Vegetation of a successional prairie at Prairie Ridge State Natural Area, Jasper County, Illinois. Castanea 65:139-146.

Fernald, M.L. 1950. Gray's manual of botany, 8th ed. American Book Company, New York.

Leach, M. K. and T. J. Givnish. 1996. Ecological determination of species loss in remnant prairies. Science 273:1555-1558.

Leidolf, A. and S. McDaniel. 1998. A floristic study of Black Prairie plant communities at Sixteen Section Prairie, Oktibbeha County, Mississippi. Castanea 63:51-62.

McCune, B. and M. J. Mefford. 2006. PC-ORD. Multivariate analysis of ecological data. Version 5. MjM Software, Gleneden Beach, Oregon, U.S.A.

Murdy, W. H. and M. E. B. Carter. 2000. Guide to the granite outcrops. University of Georgia Press, Athens, Georgia.

Packard, S. and C. F. Mutel. 1997. The tallgrass restoration handbook for prairies, savannas, and woodlands. Island Press, Washington, DC.

Radford, A. E., H. E. Ahles, and C. R. Bell. 1968. Manual of the vascular flora of the Carolinas

Schmidt, J. M. and J. A. Barnwell. 2002. A flora of the Rockhill Blackjacks Heritage Preserve, York County, South Carolina. Castanea 67:247-279.

Tompkins, R. D., C. M. Luckenbaugh, W. C. Stringer, K. H. Richardson, E. A. Mikhailova, and W. C. Bridges. 2010. Suther Prairie: vascular flora, species richness, and edaphic factors. Castanea 75:234-244.

Wagner, L. K., W. C. Stringer, T. P. Spira. 1998. Restoration of a Piedmont prairie: a preliminary report (South Carolina). Restoration & Management Notes 16:82-83.

Williams, G. 2000. Introduction to aboriginal fire use in North America. Fire Management Today 60:8-12.

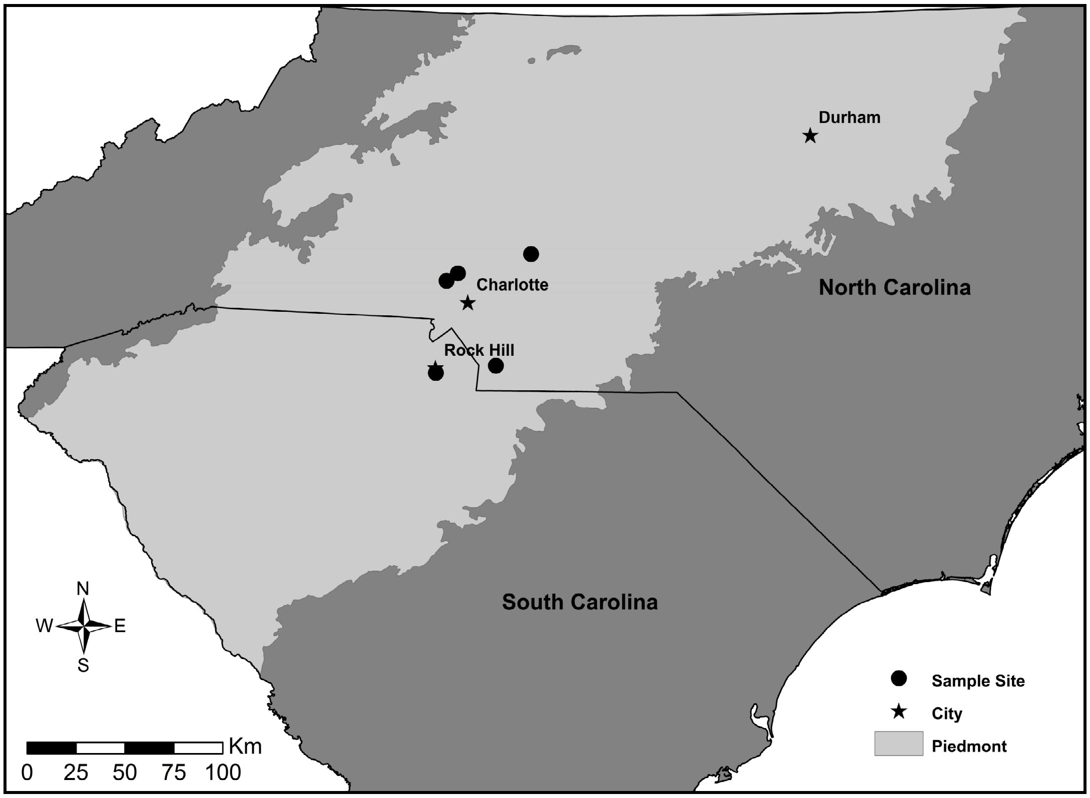
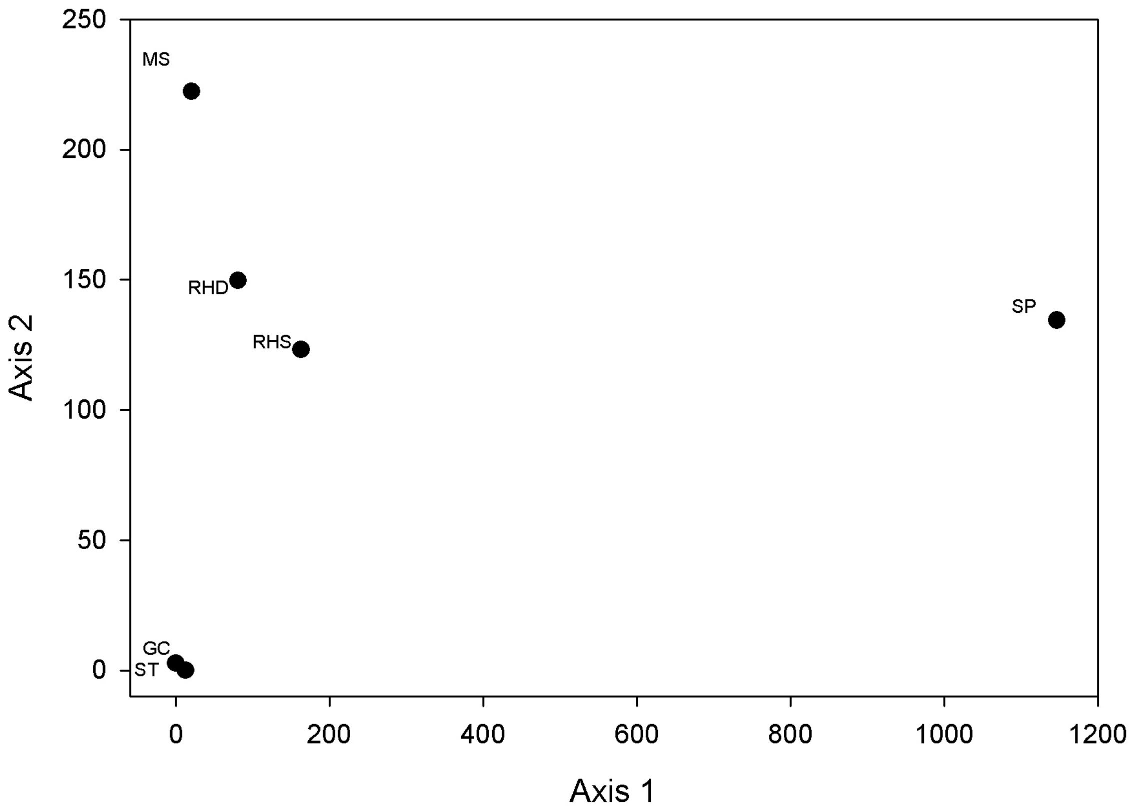


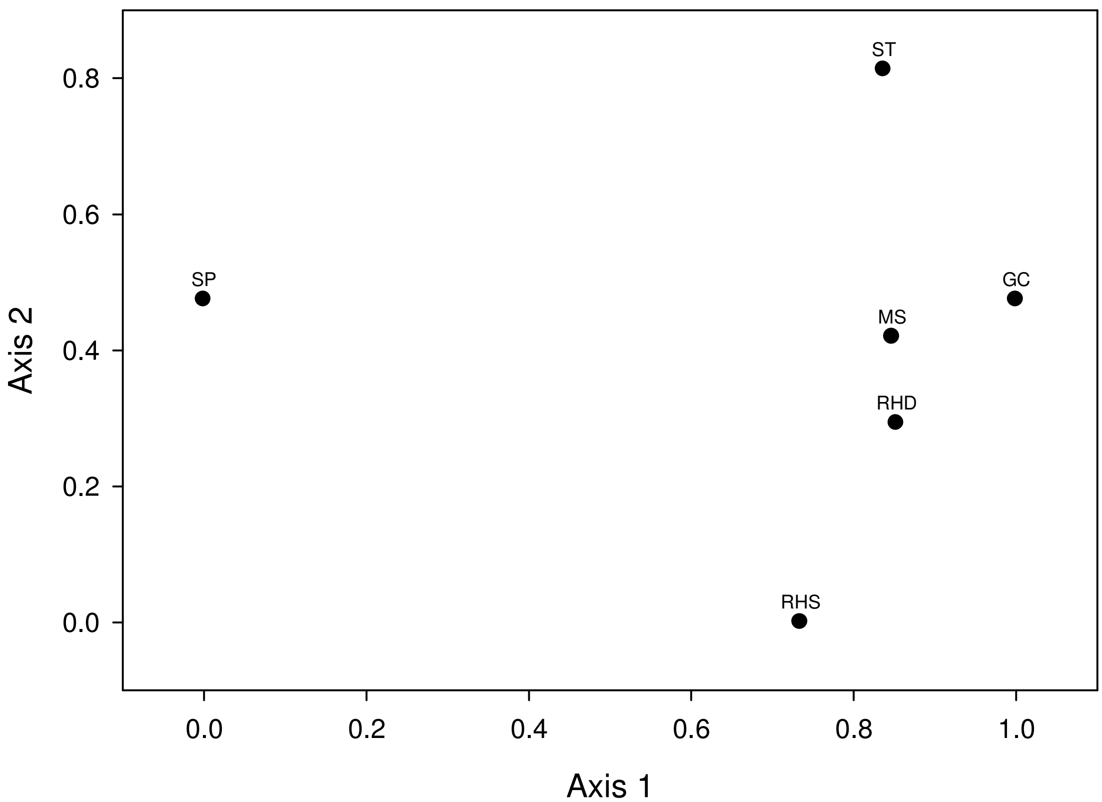
Figure 4.1. Piedmont prairie ordination sites.



Legend

GC Gar Creek
MS Mineral Springs
RHD Rock Hill Blackjacks Heritage Preserve (Davis)
RHS Rock Hill Blackjacks Heritage Preserve (Schmidt)
SP Suther Prairie
ST Shuffletown Prairie

Figure 4.2. Ordination of six Piedmont prairie sites in North and South Carolina using Detrended Correspondence Analysis (DCA).



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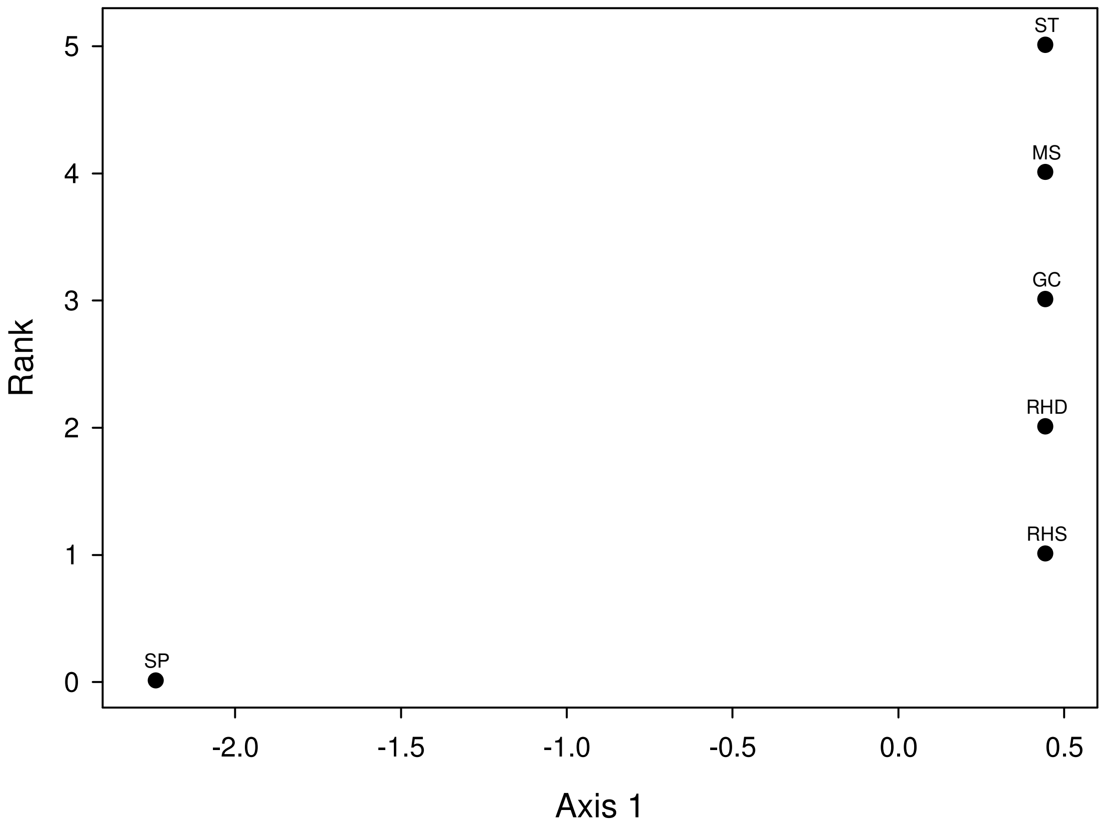
GC Gar Creek
MS Mineral Springs
RHD Rock Hill Blackjacks Heritage Preserve (Davis)
RHS Rock Hill Blackjacks Heritage Preserve (Schmidt)
SP Suther Prairie
ST Shuffletown Prairie

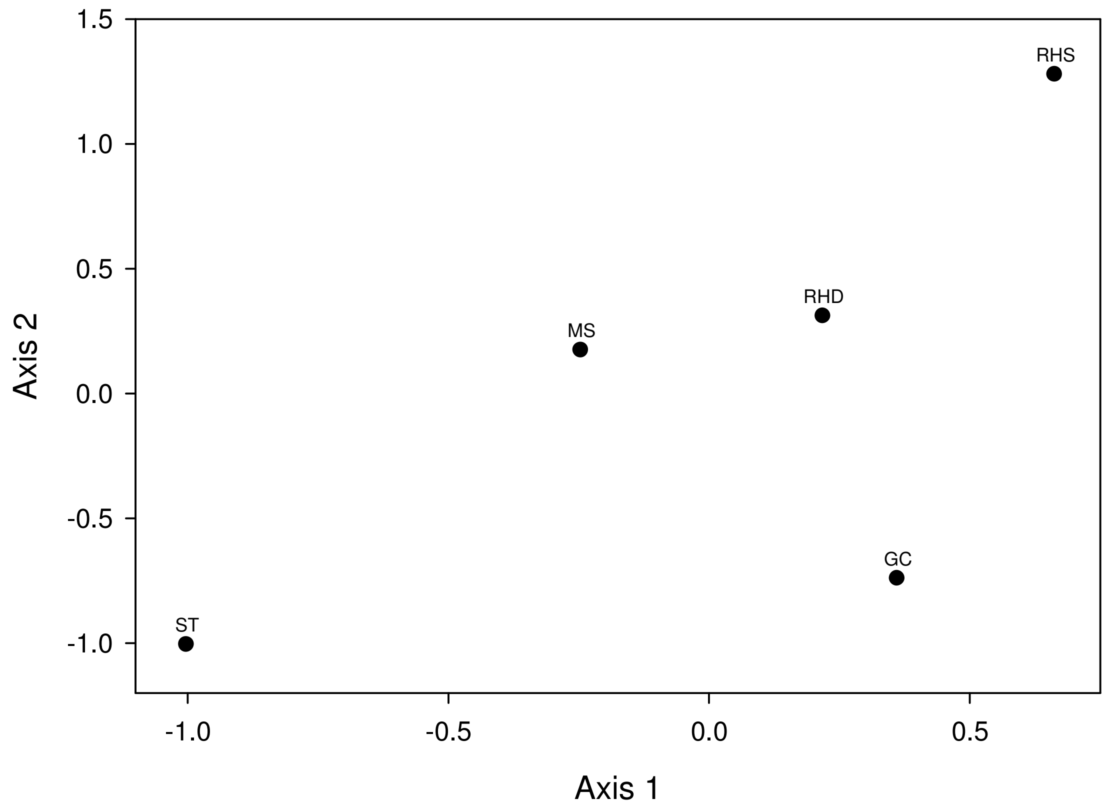
Figure 4.3. Ordination of six Piedmont prairie sites in North and South Carolina using the Bray-Curtis method.



Legend

GC Gar Creek
MS Mineral Springs
RHD Rock Hill Blackjacks Heritage Preserve (Davis)
RHS Rock Hill Blackjacks Heritage Preserve (Schmidt)
SP Suther Prairie
ST Shuffletown Prairie

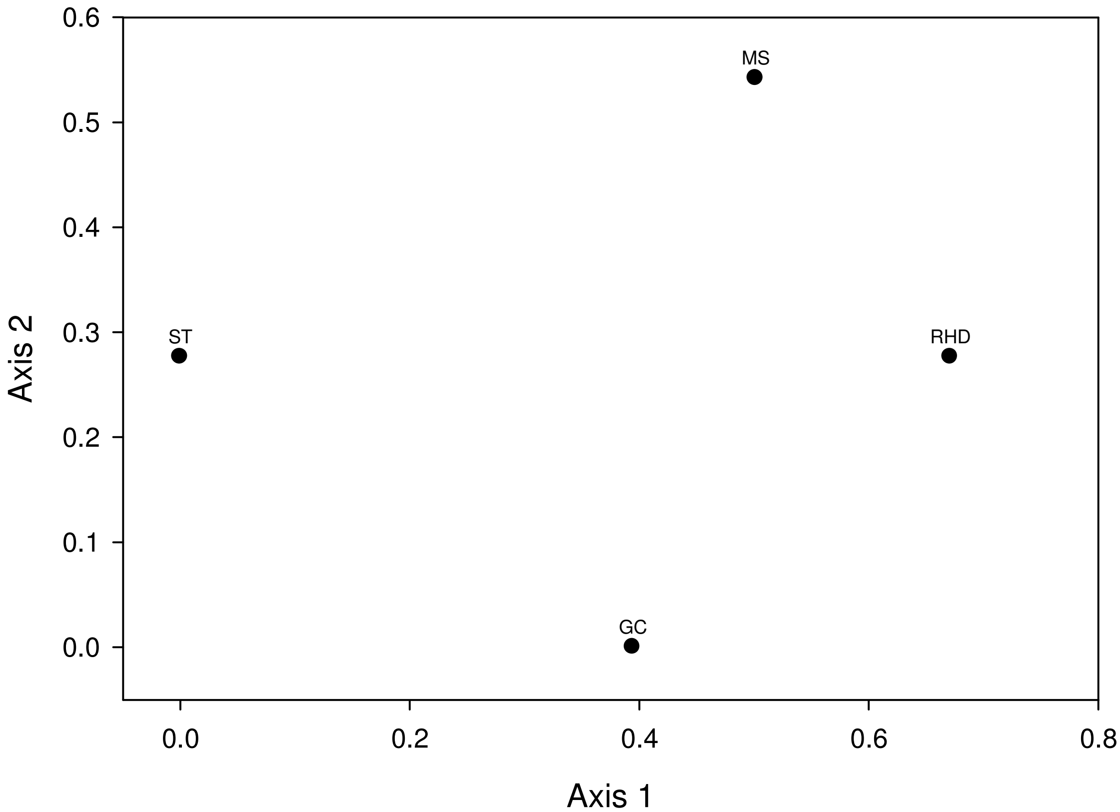
Figure 4.4. Ordination of six Piedmont prairie sites in North and South Carolina using Non-parametric Multidimensional Scaling (NMS).



Legend

GC Gar Creek
MS Mineral Springs
RHD Rock Hill Blackjacks Heritage Preserve (Davis)
RHS Rock Hill Blackjacks Heritage Preserve (Schmidt)
ST Shuffletown Prairie

Figure 4.5. Non-parametric Multidimensional Scaling Ordination of Piedmont prairie locations in North and South Carolina. Site SP has been removed.



Legend

GC Gar Creek
MS Mineral Springs
RHD Rock Hill Blackjacks Heritage Preserve (Davis)
ST Shuffletown Prairie

Figure 4.6. Non-parametric Multidimensional Scaling Ordination of Piedmont prairie locations in North and South Carolina. Sites SP and RHS have been removed.

Table 4.1. Non-preferential species from TWINSPAN analysis of selected Piedmont prairie sites. Species in bold are associated with prairies (Davis et al. 2002, Schmidt and Barnwell 2002).

***Andropogon virginicus* L.**	***Liatris squarrosa* (L.) Michx.**
Apocynum cannabinum L.	*Lobelia puberula* Michx.
***Asclepias tuberosa* L. ssp. tuberosa**	*Lonicera sempervirens* L.
***Asclepias verticillata* L.**	***Manfreda virginica* (L.) Salisb. ex Rose**
Campsis radicans (L.) Seem. ex Bureau	***Oenothera fruticosa* L.**
Carex complanata Torr. & Hook.	***Packera anonyma* (Wood) W.A. Weber & A. Löve**
***Clitoria mariana* L.**	*Passiflora incarnata* L.
Coreopsis major Walt.	***Potentilla canadensis* L.**
***Diodia teres* Walt.**	***Prunella vulgaris* L.**
***Diospyros virginiana* L.**	*Rhus copallinum* L.
Erianthus contortus Ell.	***Rhus glabra* L.**
Eupatorium capillifolium (Lam.) Small	***Ruellia caroliniensis* (J.F. Gmel.) Steud.**
***Eupatorium hyssopifolium* L.**	***Schizachyrium scoparium* (Michx.) Nash**
Helianthus atrorubens L.	*Scutellaria integrifolia* L.
***Helianthus divaricatus* L.**	***Sorghastrum nutans* (L.) Nash**
***Helianthus schweinitzii* Torr. & Gray**	***Stylosanthes biflora* (L.) B.S.P.**
Hypericum hypericoides (L.) Crantz	***Symphyotrichum concolor* (L.) Nesom**
***Lespedeza repens* (L.) W. Bart.**	*Symphyotrichum georgianum* (Alexander) Nesom
Liatris pilosa (Ait.) Willd.	***Tephrosia virginiana* (L.) Pers.**

SUMMARY CONCLUSIONS

This study was undertaken to evaluate characteristics found on Piedmont prairie remnant sites in the hope that these findings would be used in Piedmont prairie restoration programs. These habitats are used by eastern meadowlark (*Sturnella magna*), grasshopper sparrow (*Ammodramus savannaru*), Henslow's sparrow (*Ammodramus henslowii*), field sparrow (*Spizella pusilla*) (Helzer and Jelinski 1999, Marx et al. 2008, Reinking 2006, Shochat et al. 2005), white-tailed deer (*Odocoileus virginianus*) (Pietz and Granfors 2000), fox (*Vulpes sp.),* Meadow Vole *(Microtus pennsylvanicus*), and the Common Green Darter (*Anax junius*) for shelter, feeding, and breeding. Unique and specialized conditions for certain plant species are provided as well.

Piedmont prairie sites were located on upper slope positions, on slopes < 15%, on eastern to western facing slopes, and on Alfisols. Basically, locations that are more xeric than lower slope positions and subject to less competition were utilized. Nitrogen levels lower than necessary for optimal plant growth benefits their reestablishment. Additional amounts likely encourage excessive vegetative growth shading desired plants and possibly killing them. Phosphorus increases growth, but has a synergistic effect when combined with N. These nutrients in combination produce excessive growth shading desirable species in a restoration. Invasive species utilize these nutrients better than the desired species out competing them as a result (Tyler et al. 2007). Potassium caused the same reaction as N and P indicating that lower levels of these are beneficial;

micronutrient concentrations were usually higher than necessary but did not cause excessive growth or kill the prairie species.

Prairie sites are actually different and contain many different plant species. Some plants are unique to a site, but others are common at many locations. Prairie sites occur on many site types ranging from wet to very dry, but all seemed to have been disturbed in some manner. For example, some occur along rights-of-way where woody vegetation is not allowed to grow; there is haying and burning at Suther Prairie; and very xeric conditions at Mineral Springs. When all these site, nutrient, and floral factors are combined, a picture of the best locations appears. However, in this study, only seven locations around Charlotte, North Carolina, and one near Durham, NC were sampled to characterize the prairie types. A good idea of Charlotte area prairie characteristics has been gathered, but away from this area different parameters may be important. Sampling in the local area is imperative for successful prairie restorations.

LITERATURE CITED

Changnon, S. A., K. E. Kunkel, and D. Winstanley. 2003. Quantification of climate conditions important to the tall grass prairie. Transactions of the Illinois State Academy of Science 96:41-54.

Helms, D. 2000. Soil and southern history. Agricultural History 74:723-758.

Helzer, C. J. and D. E. Jelinski. 1999. The relative importance of patch area and perimeter-area ratio to grassland breeding birds. Ecological Applications 9:1448-1458.

Marx, D. E., S.J.Hejl, and G. Herring. 2008. Wintering grassland bird habitat selection following summer prescribed fire in a Texas Gulf Coast tallgrass prairie. Fire Ecology Special Issue 4:46-62.

Pietz, P. J., and D. A. Granfors. 2000. White-tailed deer (*Odocoileus virginianus*) predation on grassland songbird nestlings. American Midland Naturalist 144(2):419-422.

Reinking D. L. 2006. Fire in the tallgrass prairie balance of burning for birds. Birding 40:32-38.

Shochat, E., D. H. Wolfe, M. A. Pattern, and D. L. Reinking. 2005. Tallgrass prairie management and bird nest success along roadsides. Biological Conservation 121:399-407.

Tyler, A. C., J. G. Lambrinos, and E. D. Grosholz. 2007. Nitrogen inputs promote the spread of an invasive marsh grass. Ecological Applications 17:1886-1898.

APPENDICES

APPENDIX A

Sampling Site Identification

Sample ID	Site
CW	Catawba Wildflower Glen
MI	Mile Island Rare Plant Site
MR	McCoy Road Sunflower Site
MS	Mineral Springs Barren
PB	Penney's Bend
RH	Rock Hill Heritage Preserve
SP	Shuffletown Prairie
WR	Winget Road Sunflower Site

APPENDIX B

Particle Size Analysis Results

Sample ID	Soil Texture	Sand	Silt	Clay
		-----------------	%	-----------------
CW1-5	Sandy Clay Loam	56.0	23.6	20.4
CW11-15	Sandy Loam	60.0	25.6	14.4
CW6-10	Sandy Loam	54.0	29.6	16.4
CW16-20	Sandy Loam	66.0	21.6	12.4
MI1-5	Loam	46.0	29.6	24.4
MI11-15	Sandy Clay Loam	60.0	19.6	20.4
MI6-10	Sandy Loam	56.0	25.6	18.4
MI16-20	Sandy Loam	54.0	29.6	16.4
MR1-5	Sandy Loam	62.0	23.6	14.4
MR11-15	Loam	44.0	29.6	26.4
MR6-10	Sandy Clay Loam	38.0	29.6	32.4
MR16-20	Sandy Loam	54.0	27.6	18.4
MS1-5	Silt Loam	18.0	65.6	16.4
MS11-15	Silt Loam	22.0	65.6	12.4
MS6-10	Silt Loam	20.0	67.6	12.4
MS16-20	Silt Loam	20.0	62.0	18.0
PB1-5	Loam	48.0	34.0	18.0
PB11-15	Sandy Loam	56.0	32.0	12.0
PB6-10	Loam	48.0	34.0	18.0
PB16-20	Loam	48.0	32.0	20.0
RH1-5	Loam	40.0	40.0	20.0
RH11-15	Loam	44.0	34.0	22.0
RH6-10	Clay Loam	34.0	30.0	36.0
RH16-20	Loam	42.0	36.0	22.0
ST1-5	Clay Loam	32.0	28.0	40.0
ST11-15	Loam	38.0	36.0	26.0
ST6-10	Clay Loam	30.0	30.0	40.0
ST16-20	Loam	44.0	30.0	26.0
WR1-5	Sandy Loam	56.0	26.0	18.0
WR11-15	Sandy Clay Loam	56.0	22.0	22.0
WR6-10	Loam	50.0	32.0	18.0
WR16-20	Sandy Clay Loam	52.0	26.0	22.0

APPENDIX C

Soil Carbon and Nitrogen Analysis

Sample ID	N	C
	----------- % -----------	
CW1-5	0.90	2.32
CW6-10	0.18	3.28
CW11-15	0.12	2.35
CW16-20	0.09	2.67
MI1-5	0.12	2.05
MI6-10	0.09	2.32
MI11-15	0.18	3.28
MI16-20	0.12	2.35
MR1-5	0.09	2.67
MR6-10	0.12	2.05
MR11-15	0.14	1.86
MR16-20	0.16	2.18
MS1-5	0.12	1.93
MS6-10	0.11	1.89
MS11-15	0.10	1.66
MS16-20	0.15	2.76
PB1-5	0.18	3.02
PB6-10	0.11	2.10
PB11-15	0.06	1.56
PB16-20	0.07	1.84
RH1-5	0.07	1.62
RH6-10	0.10	1.27
RH11-15	0.12	1.51
RH16-20	0.10	1.33
ST1-5	0.15	2.56
ST6-10	0.15	2.09
ST11-15	0.16	2.23
ST16-20	0.12	2.13
WR1-5	0.11	1.41
WR6-10	0.13	1.90
WR11-15	0.12	1.86
WR16-20	0.19	2.66

APPENDIX D

Soil Chemical Analysis Results

Sample ID	Ca	Mg	P	K	Zn	Mn	Cu
	--			Kg/ha		--	
CW1-5	761.73	133.16	16.35	95.70	4.45	89.88	1.45
CW6-10	1119.62	228.32	11.53	122.62	6.28	92.66	1.20
CW11-15	540.92	127.78	5.88	120.16	2.02	52.24	1.08
CW16-20	312.72	53.52	8.31	66.87	3.37	27.14	0.96
M11-5	905.76	296.46	5.40	125.09	7.48	41.98	1.86
M16-10	1010.78	238.85	6.23	171.71	7.20	35.91	1.12
M111-15	698.74	137.86	5.73	140.33	19.63	38.11	1.21
M116-20	738.30	178.78	4.78	133.61	10.96	34.97	1.74
MR1-5	1659.98	284.58	10.06	149.63	7.91	118.47	1.95
MR6-10	950.03	272.59	1.76	51.68	4.89	69.18	2.30
MR11-15	1727.23	350.71	6.59	122.85	11.53	145.93	3.09
MR16-20	2001.84	403.95	7.64	136.63	7.53	113.09	2.08
MS1-5	518.39	300.95	3.77	52.39	10.52	13.78	1.00
MS6-10	343.20	191.55	3.37	40.29	6.52	14.71	0.76
MS11-15	409.67	179.90	6.80	44.87	8.51	26.82	1.06
MS16-20	628.12	478.72	4.19	65.39	8.22	40.99	1.55
PB1-5	1201.55	289.07	7.41	286.83	9.90	119.26	1.46
PB6-10	1155.60	258.02	6.03	248.60	7.81	121.39	2.02
PB11-15	1025.35	241.66	9.15	277.52	14.71	94.27	1.63
PB16-20	1097.87	284.92	5.19	298.71	10.80	89.22	1.32
RH1-5	1557.98	571.07	4.97	66.94	4.97	80.84	2.70
RH6-10	1276.65	453.05	4.51	39.73	4.44	116.46	4.89
RH11-15	1761.98	604.03	4.79	74.11	4.43	136.52	4.18
RH16-20	2441.21	1104.37	3.89	61.60	4.33	94.84	4.00
WR1-5	2619.43	484.88	26.95	79.80	5.19	86.70	2.09
WR6-10	2333.61	585.53	15.27	65.68	4.27	86.56	1.89
WR11-15	2176.69	697.39	15.36	71.30	4.90	98.44	1.99
WR16-20	1640.92	740.21	6.73	58.43	9.86	81.96	2.04
ST1-5	2263.00	1080.61	9.28	93.24	1.39	65.50	2.54
ST6-10	2186.78	1027.03	2.40	82.98	2.58	71.66	2.36
ST11-15	2195.75	479.72	9.88	105.54	34.67	100.42	5.00
ST16-20	2050.03	760.27	4.79	86.70	17.23	86.38	4.90

APPENDIX D (CONTINUED)

Soil Chemical Analysis Results (Continued)

Sample ID	B	Na	Soil pH	Buffer pH	CEC	Acidity
	------- Kg/ha -------		---------------- Meq/100g ----------------			
CW1-5	0.52	12.25	5.10	7.40	7.10	4.80
CW6-10	0.58	17.36	5.20	7.35	8.70	5.20
CW11-15	0.28	20.18	4.80	7.30	7.50	5.60
CW16-20	0.22	10.30	4.60	7.35	6.20	5.20
M11-5	0.64	23.45	5.30	7.55	6.90	3.60
M16-10	0.81	12.78	5.50	7.55	7.00	3.60
M111-15	0.62	9.72	5.20	7.55	5.80	3.60
M116-20	0.54	9.99	5.30	7.55	6.10	3.60
MR1-5	1.07	9.57	5.70	7.55	8.60	3.60
MR6-10	0.56	16.32	5.00	7.45	7.60	4.40
MR11-15	1.12	13.92	5.50	7.50	9.30	4.00
MR16-20	0.96	19.84	5.80	7.55	9.80	3.60
MS1-5	0.12	114.44	4.90	7.40	7.40	4.80
MS6-10	0.09	100.06	4.70	7.45	6.10	4.40
MS11-15	0.16	48.64	4.70	7.45	6.10	4.40
MS16-20	0.20	89.34	4.90	7.45	7.80	4.40
PB1-5	0.86	9.08	6.00	7.65	6.90	2.80
PB6-10	0.79	8.76	5.90	7.60	7.00	3.20
PB11-15	0.76	7.74	6.10	7.70	5.90	2.40
PB16-20	0.81	8.27	5.90	7.65	6.70	2.80
RH1-5	0.60	42.29	5.70	7.50	9.80	4.00
RH6-10	0.43	30.25	5.40	7.45	9.00	4.40
RH11-15	0.86	31.31	5.70	7.45	10.70	4.40
RH16-20	0.91	41.90	5.90	7.45	14.10	4.40
WR1-5	1.28	22.17	6.20	7.55	11.40	3.60
WR6-10	1.15	24.84	5.70	7.45	11.90	4.40
WR11-15	0.97	25.95	5.90	7.45	12.00	4.40
WR16-20	0.70	29.53	5.50	7.40	11.30	4.80
ST1-5	0.45	55.24	6.50	7.65	12.10	2.80
ST6-10	0.79	47.62	6.20	7.55	12.50	3.60
ST11-15	1.24	17.60	6.00	7.55	10.40	3.60
ST16-20	0.99	31.15	5.80	7.50	11.60	4.00

APPENDIX D (CONTINUED)

Soil Chemical Analysis Results (Continued)

	Base Saturation				
Sample ID	Ca	Mg	K	Na	Total
	------------------- % -------------------				
CW1-5	24	7	2	0	33
CW6-10	29	10	2	0	40
CW11-15	16	6	2	1	25
CW16-20	11	3	1	0	16
M11-5	29	16	2	1	48
M16-10	32	13	3	0	48
M111-15	27	9	3	0	39
M116-20	27	11	2	0	41
MR1-5	43	12	2	0	58
MR6-10	28	13	1	0	42
MR11-15	41	14	2	0	57
MR16-20	46	15	2	0	63
MS1-5	16	15	1	3	35
MS6-10	13	12	1	3	28
MS11-15	15	11	1	2	28
MS16-20	18	23	1	2	44
PB1-5	39	16	5	0	59
PB6-10	37	14	4	0	55
PB11-15	39	15	5	0	60
PB16-20	37	16	5	0	58
RH1-5	35	22	1	1	59
RH6-10	32	19	0	1	51
RH11-15	37	21	1	1	59
RH16-20	39	29	0	1	69
WR1-5	51	16	1	0	68
WR6-10	44	18	1	0	63
WR11-15	40	22	1	0	63
WR16-20	32	24	1	1	58
ST1-5	42	33	1	1	77
ST6-10	39	31	1	1	71
ST11-15	47	17	1	0	66
ST16-20	39	24	1	1	65