Smith, Tammy Capps, M.A. Spatial Analysis of *Helianthus schweinitzii* (Schweinitz's Sunflower), An Endangered Species Endemic to the Piedmont of North Carolina. (2008) Directed by Dr. Roy Stine and Dr. Zhi-Jun Liu. 65 pp.

This paper examines the influence of several biotic and abiotic variables on the spatial distribution of the Schweinitz's sunflower, a local endemic and endangered species. A variety of spatial, statistical, and analytical procedures were performed using a GIS and statistical software. Historical maps and primary data were also used to provide spatial context and evidence for the Piedmont prairie of which Schweinitz's sunflower is a remnant species. In general, the spatial distribution appears to be influenced by soil characteristics and areas with exposure to routine disturbance, most notably, along roadsides which receive regular right-of-way maintenance.

SPATIAL ANALYSIS OF HELIANTHUS SCHWEINITZII (SCHWEINITIZ'S SUNFLOWER), AN ENDANGERED SPECIES ENDEMIC TO THE PIEDMONT OF NORTH CAROLINA

by

Tammy Capps Smith

A Thesis Submitted to
the Faculty of The Graduate School at
The University of North Carolina at Greensboro
in Partial Fulfillment
of the Requirements for the Degree
Master of Arts

Greensboro
2008

Approved by

____
Committee Co-Chair

____
Committee Co-Chair

APPROVAL PAGE

This thesis has been approved by the following committee of the Faculty of The Graduate School at The University of North Carolina at Greensboro.

Committee Co-Chair ______________________________

Committee Co-Chair ______________________________

Committee Members ______________________________

____

____

____
Date of Acceptance by Committee

____
Date of Final Oral Examination

TABLE OF CONTENTS

LIST OF TABLES

Page

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Schweinitz's Sunflower, *Helianthus schweinitzii*, is one of the rarest species in the nation. It is a perennial that belongs to a large genus of the Aster family and has been on the US Fish and Wildlife's federally endangered list since June of 1991. It is endemic to a small region of the Carolina Piedmont and is generally found within a 60-100 mile radius around the Charlotte area, most specifically the lower Piedmont of south-central North Carolina and north-central South Carolina (US Fish and Wildlife, 1994). This area is part of a rare and endangered piedmont prairie ecosystem. *Helianthus schweinitzii* is threatened by development, encroachment of exotic species, highway construction and maintenance, roadside utility right-of-way maintenance, the loss of historic levels of natural disturbance, i.e., fire, grazing by native herbivores, and by old-field succession (US Fish and Wildlife, 1994). The species was named after Lewis David von Schweinitz in 1842. Schweinitz was a clergyman from Salem, North Carolina and was often called the founder of American mycology because of his 1818 published work on fungi in North Carolina.

Once scattered throughout the Piedmont region of the southeast, the Piedmont prairie ecosystem is now found only in disturbed sites such as roadsides, railway or power line right-of-ways, and field margins. The Piedmont prairie, which has undergone great physiographic changes, was once a large expanse of prairie and open grassy savannas, instead of the commonly believed dense forests. There were occasional trees, but grasses, broomsedge, forbs and sunflowers dominated these open pockets. Many of these same plant species exist in shortgrass and tallgrass prairies, much like those found in the Midwest today (Davis *et al*., 2002). DNA sequence analysis studies and the species' morphological and molecular distinctiveness suggests the possibility that the lineage ancestral to *Helianthus* was restricted to an area within the extreme southeastern US, occupying a relatively narrow geographic region with subsequent divergence occurring from there (Schilling *et al*., 1998). Matthews and Howard (1999) speculate that *Helianthus schweinitzii* existed as one or several large contiguous populations across the species' range with human settlement fragmenting the population.

Early European explorers found prairie landscapes in the Piedmont of North Carolina and South Carolina. Between the 1500's and the 1850's, many credible observers described the occurrence of prairies and extensive savannas and how fire was used by Native Americans on the grasslands (Lorimer, 2001; Helms, 2000). These Piedmont prairies or savannas were mentioned by Hernando DeSoto (1540's), John Lederer (1670), in the 1700's by Guillaume DeLisle, John Lawson, and Mark Catesby (Davis *et al*., 2002). This type of landscape was historically managed by fires, both natural and anthropogenic (Davis *et al*., 2002; Helms, 2000). Native Americans maintained the open expanses for agricultural purposes, travel, and to improve hunting by enticing local game, like bison, elk, and deer to the open grassland (Davis *et al*., 2002, Helms, 2000; Lorimer, 2001). In some cases, grassland fires were used to herd game into a central location so that hunters could easily kill and prepare their game (Lorimer, 2001).

Many of the Native American tribes in the piedmont prairie were agriculturally based and several local plant species served as a food source. *Helianthus schweinitzii*, which has a tuberous root much like the Jerusalem artichoke (*Helianthus tuberosus*), is edible and could have been ‘farmed’ or traded with neighboring tribes (Davis *et al*., 2002; Matthews & Howard, 1999).

The species may have simply taken advantage of the disturbed areas along the numerous trading or animal pathways that crisscrossed the region, or the open canopy areas that were created and maintained by fire. Rather than clearing new paths, early explorers and traders from the early 1700’s on, simply followed the “savanna-like warrior’s path created by Native Americans” or the well traveled animal trails (Helms, 2000, page 738).

These open, grassy prairie lands began disappearing with the arrival of the Europeans. Early settlers coveted these open areas for their homesites, fields and pastures and forcefully took possession of them from the Native Americans. As the prairies were converted and the bison disappeared, prairie plant species also began to disappear. However, there is still evidence of these historic piedmont prairies from the persistence of prairie flora that exists primarily in right-of-ways, road sides and field margins. Many of these remnant prairie plant species are genetically related, most likely dispersed from a central location. Other research has shown that *Helianthus schweinitzii* is not affected by translocation and that many of the populations are genetically very closely related (Davis et al., 2002) which further supports dispersal from a common population.

Documented *Helianthus schweinitzii* sites tend to be sunny or semi-sunny, on poor soils, and open habitat. Another common aspect of *Helianthus schweinitzii* sites is their occurrence in landscapes of subdued topology like upland interstream flats and gentle slopes (US Fish and Wildlife, 1994). Variation in the textural composition of the soil and topography leads to distinct differences in water availability to germinate seeds. The number of individuals that become established in a model population is a function of the number of suitable microsites provided on the soil surface while the maximum population size is determined largely by the physical environment. Soil types control the general vigor and productivity of plants (Raynal *et al*., 1973). Any of these characteristics may prove to be a critical factor in the location of the plant. Often species identification can be made accurately with only knowledge of the soil type and its general geographic location (Thompson *et al.*, 1981). Geology and soils appear to be important determining factors in the occurrence of *Helianthus schweinitzii* (US Fish and Wildlife, 1994). Since Schweinitz's sunflower seems to prefer grassy open areas with shallow poor soils, utility and highway right-of-ways, old fields and field margins are the most likely areas to find the few known remaining populations.

In order to protect and possibly discover additional populations of *Helianthus schweinitzii*, it is vital to understand not only the species' unique habitat requirements, using physical habitat attributes like soil properties, slope, aspect, elevation, and distance from rivers or streams, but also historical changes in the landscape. Land use and environmental changes have a significant impact on the spatial distribution and long term dynamics of many rare species. A species' spatial distribution results from complex interactions between geological history, climatic influences, humans, and animals both past and present (Lavergne, *et al*., 2005). Historic maps, images, and primary sources can provide a backdrop or overlay for contemporary spatial data analysis and may hold an important key to understanding the species. A Geographic information system (GIS) and a variety of data types (i.e., archaeological, historical sources, soil, elevation) can be used to study, visualize, and understand the endangered species and the landscape through time and space (Wilson, 2001). Biotic attributes, along with historic changes may further our understanding of the spatial dispersal and variability (or lack of variability) of the sunflower's ecosystem and provide a systematic way of locating additional populations. The goal of this paper is to find relationships between various biological, ecological and anthropogenic attributes and the spatial distribution of Schweinitz's sunflower.

CHAPTER II

METHODS AND DATA

GIS Data Sources

The literature review on the *Helianthus schweinitzii* yielded both obvious and potential data source needs for spatial analysis of the species, for example, documented sunflowers exist only in the Piedmont regions of south central North Carolina and north central South Carolina in a region dominated by two geological belts frequently occurring along roadsides or open areas. Other species studies include analysis on elevation, aspect, and distance to rivers or streams. Also frequently mentioned was the potential influence that Native Americans had on the distribution of the species. The primary GIS data sources used for this paper are summarized in *Table 1*. Most of the data sets were already projected in NAD83, North Carolina state plane coordinate system (Lambert conformal conic). Those that were not, were re-projected.

Table 1: Data sources

Type of Data	Source	Contact/URL
Archaeological data elements for Randolph County (point, line, polygon)	NC Office of State Archaeology (NCOSA), NC Dept. of Transportation	Delores Hall, Deputy State Archaeologist Matt Wilkerson, DOT Archaeologist
Helianthus schweinitzii element occurrences; (point, line, polygon)	North Carolina Natural Heritage Program (a division of NC Dept. of Environment and Natural Resources)	Suzanne Mason, Environmental Biologist
Railroads: 1:24,000 & 1:100,000 Primary and secondary roads 1:24,000 1:100,000	NC Dept. of Transportation	www.ncdot.org/it/gis/DataDistribution/default.html
Soil shape files 1:250,000	NC One Map & US Department of Agriculture	www.nconemap.com and soils.usda.gov/survey/geography/
Slope and Elevation 80ft. x 80ft. cell	NC One Map	www.nconemap.com
Streams & Rivers 1:24,000	NC One Map	www.nconemap.com

Species Sites

The North Carolina *Helianthus schweinitzii* site specific (element occurrences) GIS data includes extant, destroyed and historic populations contained in point, line and polygon shape files. Most of the element occurrences are noticeably concentrated along a natural corridor running through the Piedmont, namely Anson, Cabarrus, Davidson, Gaston, Mecklenburg, Montgomery, Rowan, Randolph, Stokes, Stanly, Surry, and Union counties (*Figure 1*).

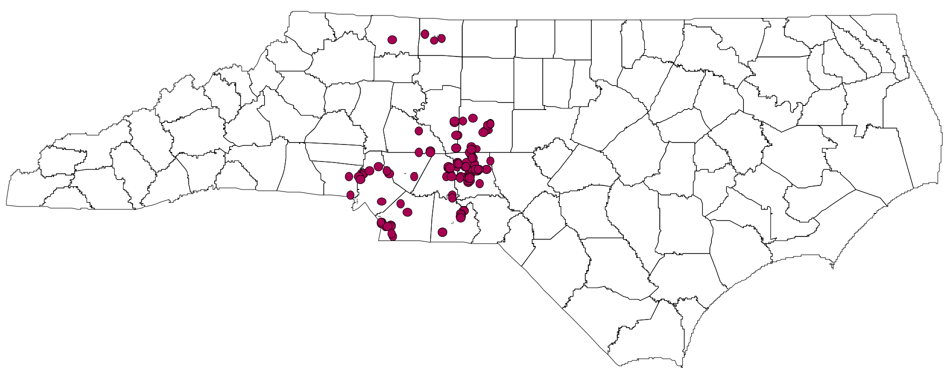

Figure 1: North Carolina counties with occurrences of Helianthus schweinitzii

Spatial patterns are the result of physical and cultural-human processes that take place on the earth's surface and describing these patterns provides an opportunity to explore and identify underlying spatial processes (Wong and Lee, 2005). Spatial pattern analysis can be used with the sunflower data to quantify and identify the pattern of the plants which may further refine our understanding of the unique ecological processes that are occurring (Woodall & Graham, 2004) and help explain these patterns (Ackerman &

Murray, 2004). Pattern analysis measures the similarity, or dissimilarities of neighboring objects, in essence, the magnitude of spatial autocorrelation. This spatial correlation is attributable to the geographic ordering or locations of the object and measuring the significance of it is essential before additional statistical analysis is conducted (Wong and Lee, 2005).

The point shape file was analyzed using nearest neighbor distance to determine whether the point data were clustered or random. The analysis indicates that the point data are clustered with a significance level of 0.01 and a critical value of -2.58 (*Figure 2*) meaning that there is a less than 1% likelihood that the clustered point pattern was the result of random chance. The points exhibit a general southwest to northeast tendency (*Figure 3*).

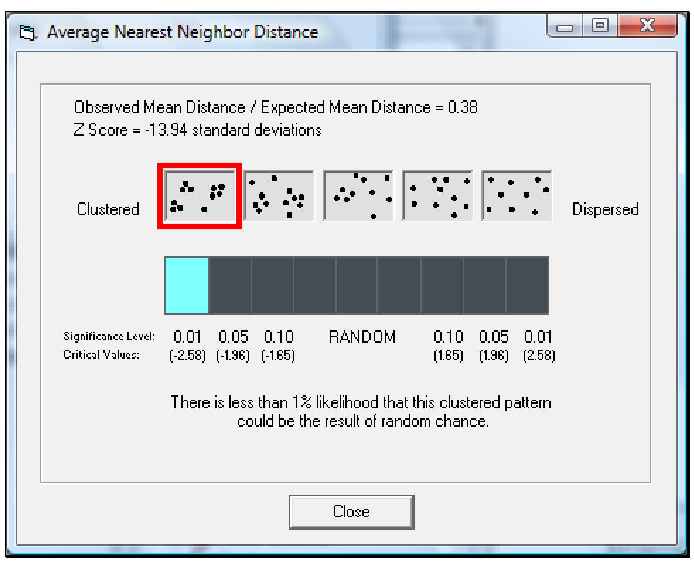

Figure 2: Nearest Neighbor Distance Statistics in ArcGIS

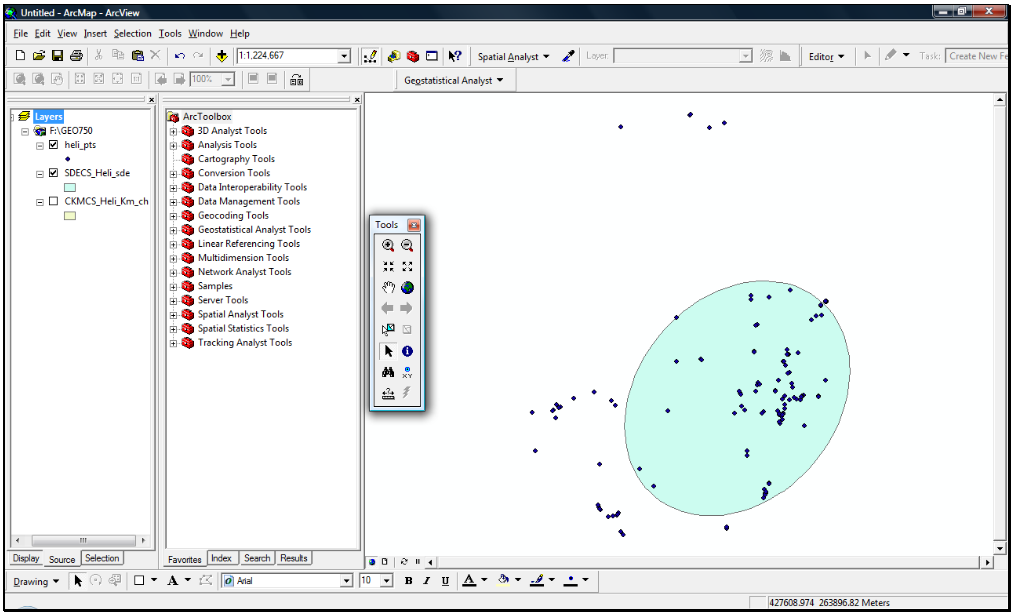

Figure 3: Directional tendency of the point data

According to O'Sullivan and Unwin (2003), there are two approaches to describing point patterns, point density and point separation. Point density measures the first order property of the points. Point separation (distance based) measures second order effects. In distance based approaches, interactions between locations and relative location are important (O'Sullivan & Unwin, 2003). Nearest neighbor distance statistics, a first order statistic, is the simplest distance based method (Anselin, 2003). It calculates the distance between points and uses the distribution of these nearest neighbor distances to determine if the points are clustered or dispersed. If this value, called the nearest neighbor index, is small, then it suggests the points are clustered. If it is large, it suggests the points are dispersed or random (Anselin, 2003). The nearest neighbor index is the ratio of the observed mean nearest neighbor distance to the mean random distance. Generally a value less than 1 suggests clustering (Anselin, 2003). Point pattern analysis helps determine if the observed spatial pattern is the result of specific spatial, natural or anthropological processes. The data appear to be clustered with a southwest-to-northeast tendency which is important information to know as the analytical process progresses and predictive models are created. Preliminary cluster analysis can provide valuable information in the initial stages of indentifying the underlying natural and/or anthropological processes influencing the pattern of spatial distribution.

Soil and Soil Properties

Soils result from older processes and events and indicate interactions between climate and landcover over hundreds, even thousands of years, so the current location of a species or vegetation type does not always indicate the long term or potential spatial pattern of its ecosystem. A soil's classification is based upon known ecological processes and is not explicitly linked to the current landcover. Mann, *et al*., (1999) believe that the US soil classification can be used to predict the spatial distribution of threatened ecosystems because the resulting soil maps inherently incorporate current and historic vegetation, landcover and ecosystem information. Soil based models assume soils have developed in response to similar spatial and long term temporal gradients of edaphic and landcover types (Mann, *et al*., 1999).

Soils and their properties have a great influence on a society's culture, agricultural regimes, and its economic markets (Helms, 2000). A soil's value may change over time as technological advancements are implemented. Understanding the chemical and physical properties of soils and how they have historically influenced the piedmont region may give further insight on the current spatial distribution of the *Helianthus* *schweinitzii*. The piedmont region is dominated by ultisols, as is much of the state, with parallel areas of alfisols dissecting the central piedmont. Alfisols are base rich soils derived from rocks rich in bases and produce superior grasses (typical of those found in the Midwest and Kentucky) compared to the surrounding ultisols which are low in bases and are limited at supporting natural grasses (Helms, 2000). There are also small areas of inceptisols dotted among the alfisols and ultisols. Inceptisols are often found on fairly steep slopes, young geomorphic surfaces, and on resistant parent materials, most noticeably in the mountainous regions of NC. Inceptisols found in the eastern US support mixed or hardwood forest but can be cleared and used as cropland or pasture (USDA, 2007).

The soil data were prepared using the SSURGO database template with instructions provided on the Natural Resources Conservation Service's (NRCS) web site. The state soil shape file was brought into ArcGIS and the attribute data relating to the soil shape files were consolidated into a soil attribute table using the SSURGO Metadata Relationships documentation also found on the NRCS's site at http://soildatamart.nrcs.usda.gov/SSURGOMetadata.aspx. The component and chorizon SSURGO tables were joined with the soil shape file attribute table yielding among other things the soil's composition name, order name, and the representative sand/silt/clay percentages for all soil types in North Carolina.

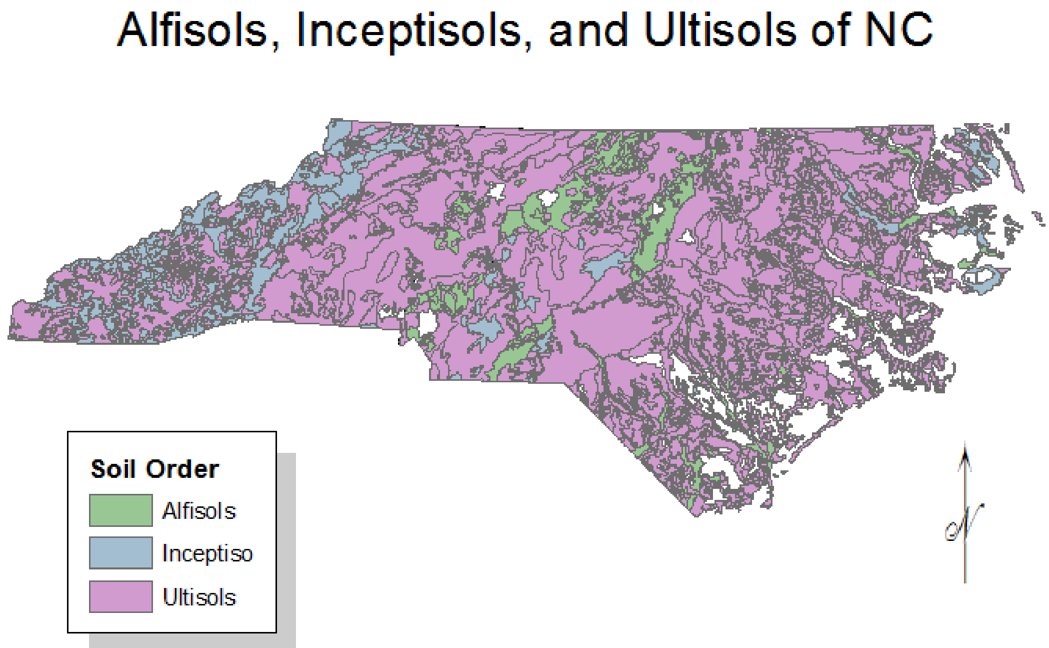

Figure 4: Alfisols, Inceptisols, and Ultisols of North Carolina. Note the parallel segments of alfisols (green) running from southwest to northeast through the Piedmont as noted by Helms (2000).

A map displaying the distribution of alfisols, inceptisols, and ultisols (*Figure 4*) was created and the *Helianthus schweinitzii* element occurrences were used to determine the number of sites in each soil order (*Figure 5*).

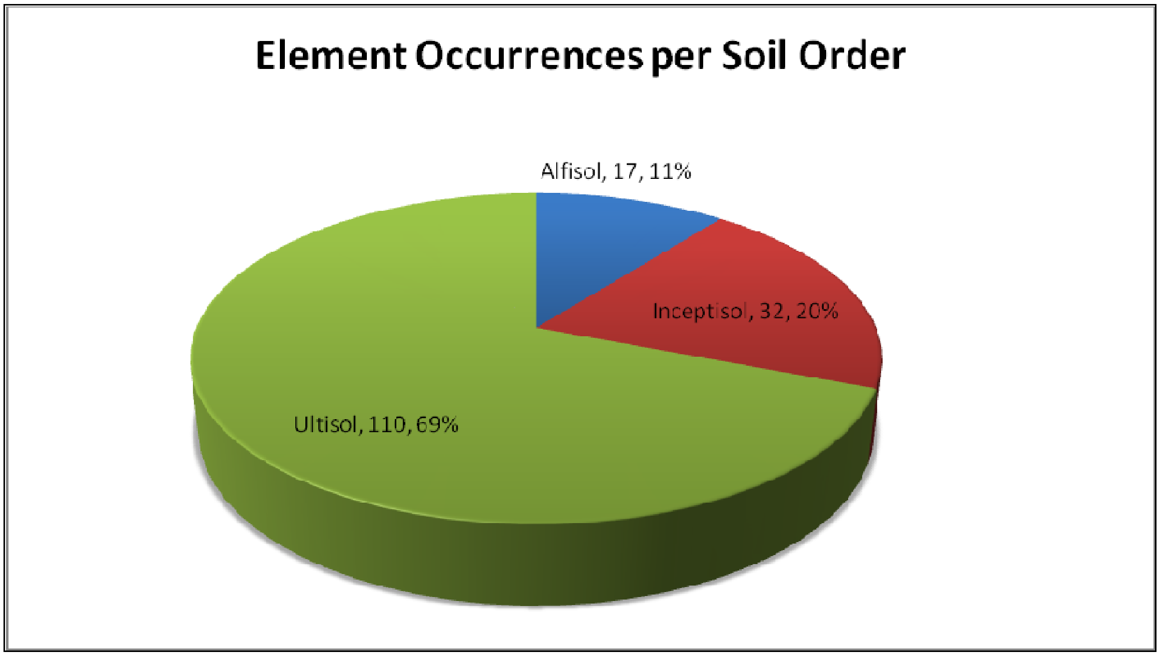

Figure 5: Number of sunflower element occurrences per soil order.
Of the 159 element occurrences, 110 or 69% were located in ultisols.

The *Helianthus schweinitzii* site point, line, and polygon files and the soil shape file were queried using a query by location (i.e., sites intersecting soil types) to produce data relating to the sites. These data were sorted and yielded the soil site's composition names; Enon, Goldston, Herndon, Hiwassee, Iredell, Pacolet, Tallapoos, Tatum, Wedowee, White Store and Wilkes (*Figure 6*).

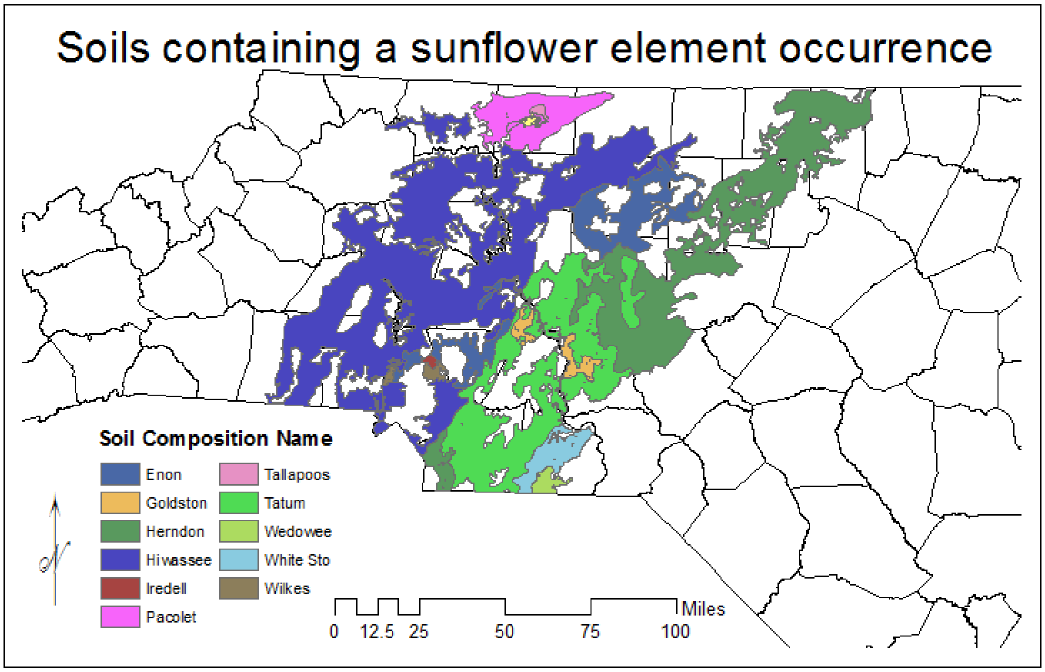

Figure 6: Soils containing documented sunflower element occurrences. Soils include: Enon, Goldston, Herndon, Hiwassee, Iredell, Pacolet, Tallapoos, Tatum, Wedowee, White Store and Wilkes

An extract file containing sand/silt/clay percentages for the soils that contained a *Helianthus schweinitzii* element occurrence was created. A second query was run for soils that did not contain a *Helianthus schweinitzii* element occurrence. Both data sets were combined, and duplicate records removed. A record was considered unique based on the soil composition name, and sand, silt, clay percentages. A soil composition name may appear more than once if its sand/silt/clay percentages were different. The new data file contained all soil types, with representative sand/silt/clay values, within the state's boundaries and included a designation of 0 for non-sunflower soils or 1 for sunflower site soils based on prior analysis.

Since the data analysis compares 'Sunflower' site soils and 'Non-Sunflower' site soils, an analysis of variance was performed. The tab-delimited text file was input and each record was evaluated to determine if it was a 'Sunflower' site (1) or a 'Non-Sunflower' site (0). A preliminary printout confirmed that the general linear model (GLM) procedure would be required because of the unbalanced observations of sand/silt/clay data between sunflower and non-sunflower soils. The GLM procedure was used with Student-Newman-Keuls test and Scheffe's test to evaluate post-hoc the sand, silt, clay percentages of site/non-site soils. The number of unique soil types was 68. The MEANS procedure was also performed on the data set.

Streams-Rivers, Roads, Railroads, Elevation, and Aspect

Aspect was generated from the 80ft. x 80ft. elevation raster using ArcGIS. These data can be used for spatial analysis to determine if they are correlated with the distribution of the sunflower. Powell *et al*'s (2005) endangered species study revealed a correlation with elevation, slope or aspect and the species' spatial distribution. The study also found that 50% of the species occupy sites having an aspect in the southerly sector. According to the USFW, *Helianthus schweinitzii* favors road and railroad right-of-ways with the largest plants (5m) located on south-facing railroad right-of-ways. Abrupt transitions from oak savannas and prairies have been observed on the south and west sides of rivers (Lorimer, 2001). Since the species has a strong prairie association, abrupt changes in the spatial distribution of the species may also be evident on the south and west sides of rivers.

The *Helianthus schweinitzii* element occurrence data layer was spatially joined with the road, the river-stream, and railroad data layers. Relocated or reintroduced element occurrences were removed from the sunflower data for this analysis because they would introduce bias, i.e., their locations was pre-determined using scientific parameters. All naturally occurring sunflower element occurrences, extant and historical, were given all the attributes of the line data including a distance field showing how close it was to the element occurrence. This would be the distance of the sunflower to the river-stream, road, or railroad. These data can be used for spatial analysis to determine if it is correlated with the distribution of the sunflower. All distances are in meters. Elevation is in feet. Aspect was categorized using the following (*Table 2*):

Table 2: Aspect translation table

Cardinal Direction	Aspect Value	Reclassified Aspect
Flat	-1	-1
North	0-22.5; 337.5-360	1
Northeast	22.5-67.5	2
East	67.5-112.5	3
Southeast	112.5-157.5	4
South	157.5-202.5	5
Southwest	202.5-247.5	6
West	247.5-292.5	7
Northwest	292.5-337.5	8

Historic Data – Primary Sources and Maps

Primary sources included John Lawson's *A New Voyage to Carolina,* an account of his travels through the Carolina's in the early 1700's, most notably his travel through the piedmont of North Carolina (*Figure 7*). He gives detailed information on the places, the landscape and the inhabitants he encounters. His account supports the existence of the piedmont prairie or savannas and trading paths, the Native American tribes and their lifestyles including their utilitarian use of fire, and most interestingly a reference to a "branched sunflower".

Figure 7: Lawson's exploration path through South Carolina and North Carolina. (A New Voyage to Carolina by John Lawson, H. Lefler, ed., 1967).

Prairie/savannas (<u>A New Voyage to Carolina,</u> H. Lefler, Ed., 1967):

"..we traveled about twenty miles, lying near a savanna.." (page 20)

> “Next morning, very early, we waded through the savanna..” (page 20)
>
> “..we traveled this day about twenty-four miles over pleasant savanna ground, high and dry having very few trees upon it” (page 43)
>
> “..we passed by several fair savannas..” (page 23)
>
> “..dry marshes and savannas adjoining to it.” (page 24)
>
> “..several pleasant fields of cleared ground …now well spread with fine bladed grass and strawberry vines.” (page 28)
>
> “..abundance of storks and cranes in their savannas..” (page 25)
>
> “..we saw fine bladed grass six foot high, along the banks of these pleasant riverlets..” (page 43)
>
> “..a sort of savanna-ground that had very few trees in it..” (page 52)
>
> “..other [parts] being savannas or natural meads where no trees grow for several miles..” (page 80)

Many of these savannas can be roughly pinpointed because of Lawson’s inclusion of location names. For example, Lawson’s reference to Keyauwee and Heighwaree (now called the Uwharrie) places him in Randolph and Montgomery counties. These areas are also in the general vicinity of current *Helianthus schweinitzii* sites.

> “..fifteen miles farther to the Keyauwees..the land is more mountainous with rich valleys” “passing another stony river.. this is called Heighwaree which contained blue stones..” (<u>A New Voyage to Carolina,</u> H. Lefler, Ed., 1967, page 48)
>
> “Five miles from this river, to the N.W. stands the Keyauwees town” which is “fortified with mountains” “having corn-fields adjoining to their cabins and a savanna near the town at a foot of these mountains that is

> capable of keeping some hundred heads of cattle" (A New Voyage to Carolina, H. Lefler, Ed., 1967, page 48)

Trading/Hunting/Game Path(s) (A New Voyage to Carolina, H. Lefler, Ed., 1967)

> "..took the great trading path from Virginia to Georgia and followed it into North Carolina as far as Occaneechi village" encountering the Sugeree, Saponi, Keyauwee and crossing several rivers and small streams most notably at the trader's ford near the site of Salisbury" "Sapona River where stands the Indian town and fort" (*ix*)
>
> "..the path lying there; and about ten o clock came to a hunting quarter of a great many Santees.." (page 20)

Fire and landscape modification (A New Voyage to Carolina, H. Lefler, Ed., 1967):

> "..where we were very short of victuals, but finding the woods newly burnt, and a fire in many places, which gives us great hopes that Indians were not far off." (page 20)
>
> "..they go and fire the woods for many miles and drive the deer and other game into small necks of land.." (page 219)

Rostlund (1960) also used primary sources to extrapolate the geographic range of the bison, a species strongly associated with prairies and open grasslands. There are several sources, according to Rostlund (1960) that reference bison in the piedmont areas of North and South Carolina.

North Carolina Piedmont

> John Lawson (1700's) "..Toteros…having great plenty of Buffalos..I have know some [buffalo] killed.." (page 399)
>
> John Brickell (1700's) "..The buffalo…its chiefest haunts being savannas..there were two taken alive in the year 1730.." (page 399)

South Carolina Piedmont

> Mark Catesby (1722) "..the buffalo, they range in droves feeding in the open savannas.." (page 399)
>
> Alexander Hewat (1779) " herds of buffaloes were found grazing in the savannas.." (page 399)

Rostlund (1960) finds other support for the presence of buffalo in the piedmont area of North Carolina by looking at place names, for example, Buffalo Wallow located in the southeast corner of Randolph County and reported by locals to have been a former buffalo wallow. The decline of the buffalo was caused by several factors, most notably the fact that there was a decline in an adequate food supply, i.e., the grasslands were disappearing because of increasing human settlement and habitat destruction. Rostlund (1960) concludes that humans helped prepare and then abandoned an ecological niche suitable for the bison. Primary source information like this further supports the existence of prairies, open savannas and game paths in the same region that *Helianthus schweinitzii* occupies. It is feasible that the sunflower may have favored the pathways that the bison utilized. Although it is not a ‘roadway’ per se, it would have been regularly ‘disturbed’ by the hooves of the bison. A study by Shinn (1996) on the effects of soil disturbance, herbivore grazing and rockiness of soil on *Helianthus schweinitzii* revealed that soil disturbance significantly increased the germination rate of the *Helianthus schweinitzii.* Disturbance in this study included simply raking the top 3-4cm of the soil or raking the top 3-4cm of the soil and applying a loose layer of quartz river pebbles. While soil disturbance via raking significantly increased the germination rate, it did not significantly affect seedling survival or plant height. However, there was a significant difference in the survival rate and height of the sunflower in the soils that were raked and pebbled compared to those not raked and not pebbled. Soil disturbance appears to clear out competition allowing the *Helianthus schweinitzii* to germinate and establish itself in the first year. The pebbles appeared to act as mulch by slowing down evaporation, decreasing erosion, preventing weeds, and allowing water to enter the soil thus increasing infiltration and soil moisture which allows the sunflower to grow taller. Or the sunflower may have prospered from the fires that were used to keep the grasslands open for the foraging bison.

Historic maps were downloaded from David Rumsey Map Collection or provided by NC Office of State Archaeology (NCOSA). Historic maps used for analysis included Henry Mouzon’s 1777 map (*Figure 8*) and a map generated by Simpkin and Petherick (1985) based on their research on late aboriginal settlements and historic path references. Included on their map, is the Indian Trading Road referenced on Edward Moseley’s 1733 map (*Figure 9*), the Occoneechi Path and the Wilmington Trail both of which were researched by William E. Myer in 1928. Because of their physical size, many of the historic maps for the state were pieced together, which created a line of slight distortion running through the middle of the state, affecting counties like Randolph, and Montgomery.

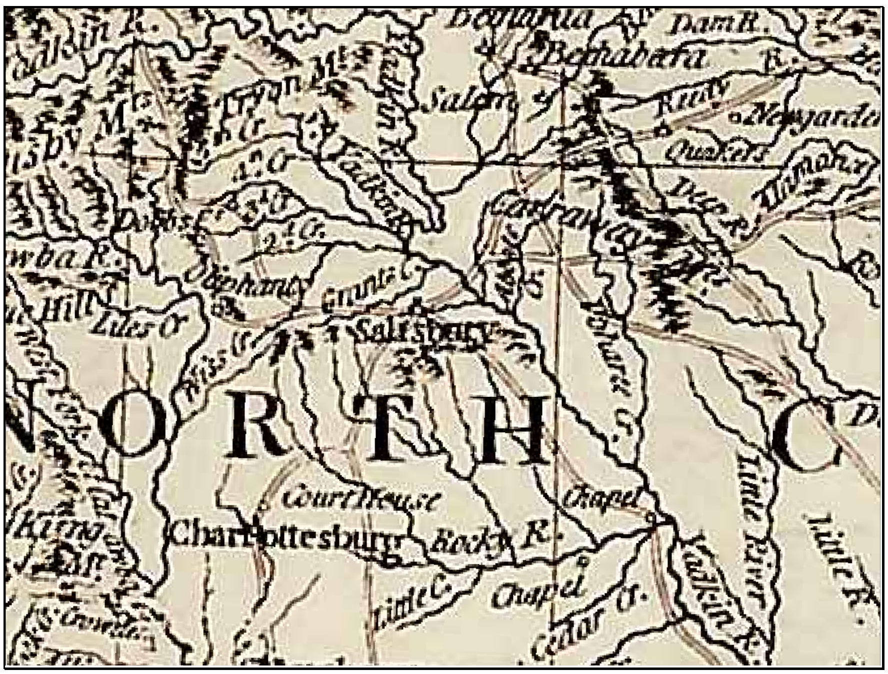

Figure 8: Piedmont area of North Carolina with Mouzon mapped trading paths. (from Mouzon's 1777 map showing the southern British colonies)

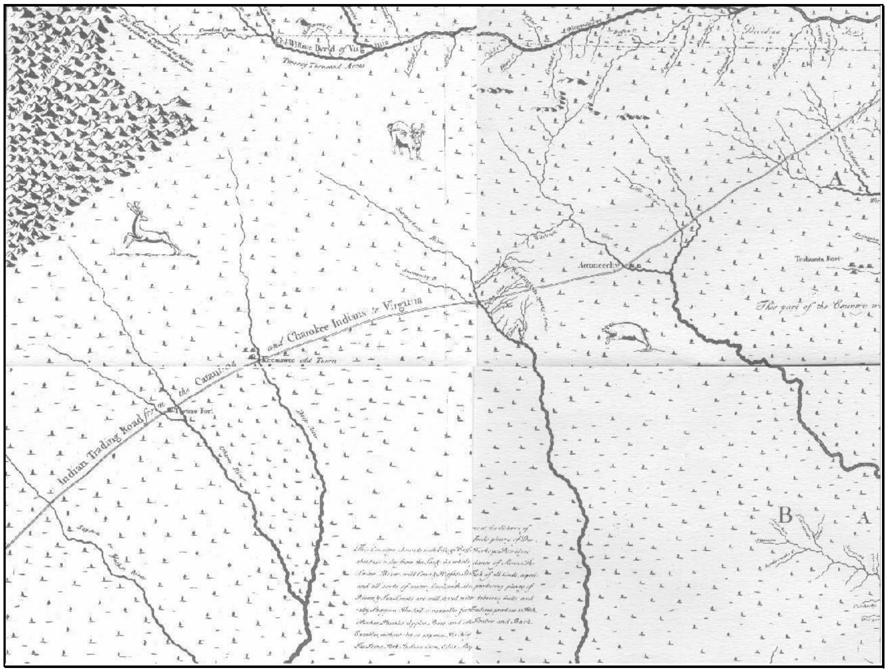

Figure 9: Edward Moseley's map of 1733 showing the Indian Trading Path.

Archaeological Data

Archaeological site data for Randolph County were supplied by the NCOSA and NCDOT. These data included all recorded incidents which may or may not be certified archaeological sites, rather areas of interest awaiting further research. The data tend to be biased since federal and state funded projects require archaeological studies before work can begin. A majority of the data was the result of these studies and tends to be clustered in spots, for example, concentrated areas in and around future dam sites, federal highways, etc. For some areas, there is much data while other areas have little to no data limiting the usefulness. However, the data may reveal large scale spatial relationships with topographic features on the landscape (Fry *et al*., 2004). The archaeological layers (points, lines, and polygons) were joined with the species element occurrence data based upon spatial location. The shortest distance between a sunflower site and the potential archaeological location was determined.

Using Spatial Analysis for Species Predictions

Draper *et al*., (2003) believe the main factors used to determine the spatial distribution of organisms are climate, availability of suitable habitat, edaphic factors, influence of competitors, and historical factors. Since current *Helianthus schweinitzii* sites are the result of abiotic and biotic factors, both past and present, utilizing a GIS to analyze the various forms of data is an obvious choice. A comprehensive knowledge of the species' biology, ecology and distribution can be used to extrapolate the habitat requirements and assess spatial relationships among suitable habitat patches. The potential spatial distribution of a species may be predicted by using a set of characteristics such as climate, soil, slope, aspect, terrain or vegetation type. In combination, these attributes can provide a set of unique mapping areas that align with that of the species. However, the present locations of the *Helianthus schweinitzii* may actually be an artifact of its remaining unaltered habitat range rather than a representation of its past distribution. The absence of the species in a suitable habitat may also have meaning. Areas of suitable habitat may be unoccupied due to historical factors such as fire regimes, low rates of dispersal or elimination of dispersal methods, and large scale habitat disturbances (natural and anthropogenic). A simple rule based, non-statistical model may be an effective tool in locating additional populations of rare species while the development of an environmental envelope for the species will further enable analysis vital for saving the species from extinction (Powell *et al*., 2005). Identifying the spatial patterns of distribution of the species will promote understanding of how humans threaten the sunflower (Lavergne *et al*., 2005). Many physical variables (slope, bedrock, elevation) can broadly influence plant species distribution on the mesoscale, for example, Lavergne et al., (2005) found that unusual bedrock many times supports and is associated with rare or endemic plants. But it is also critical to understand how small scale, anthropogenic variables (land use, population & livestock density), can affect the plant species (Lavergne *et al*., 2005). If there is a strong relationship between the presence of an organism and physical or environmental variables, then the prediction of its distribution may be possible. Draper *et al*., (2003) determined that the distribution of a species follows an environmental gradient which exhibits a Guassin distribution, with the optimum preference point for the variable in the center of the distribution and two marginal limits (upper & lower) on opposite ends. Since the areas occupied by a species are not homogenous and the factors affecting the distribution may differ from place to place, a GIS is necessary for analysis of the spatial distribution of the *Helianthus schweinitzii*.

Powell *et al*., (2005) created a matrix using various attribute ranges of known *T. robusta* sites identifying the potential habitat probabilities using a designation of 1-3 (highest to lowest). Cantamutto *et al.,* (2008) used many of the same attributes, but instead used Shapiro-Wilkes, Kruskal-Wallis nonparametric analysis, principal component and cluster analysis. Serneels and Lambin (2001) and Apan and Peterson (1998) use multiple logistic regression (MLR) to estimate the parameters for a multivariate explanatory model because of the dichotomous dependent variable, i.e., presence/absence, and independent variables that are categorical or continuous. The

CHAPTER III

RESULTS

Soil and Soil Properties

Sixty-nine percent of the *Helianthus schweinitzii* element occurrences are found in ultisols (*Table 3*). Chi-square tests showed significant differences in the frequency of the species' association with soil orders. Of the 3 soil orders, utlisols are the poorest, supporting the USFW's finding that the sunflower is found mostly in poor soils in the piedmont region of the state. Sunflowers occur frequently in Tatum and Herndon, both ultisols, and in Goldston, an inceptisol (*Table 4*). Over 72% of sunflower element occurrences are found in these three soil compositions. For further analysis, 154 points were randomly selected from the counties containing one of the element occurrence soil compositions (see *Figure 6* for reference).

Table 3: Soil order analysis for sunflower element occurrences and random points. (using the FREQ procedure)

Freq. Percent Row Pct Col Pct	Ultisols	Alfisols	Inceptisols	Total
Random	112 36.48 72.73 51.85	32 10.42 20.78 64.00	10 3.26 6.49 24.39	154 50.16
Sunflower	104 33.88 67.97 48.15	18 5.86 11.76 36.00	31 10.10 20.26 75.61	153 49.84
Total	216 70.36	50 16.29	41 13.36	307 100.00

Table 4: Frequency statistics for sunflower element occurrences by composition name. (Chi-Sq. = 183.9281, DF=9, p-value = <.0001).

Comp.Name	Freq	Percent	Cum Freq	Cum Percent
Tatum	58	37.91	58	37.91
Goldston	31	20.26	89	58.17
Herndon	22	14.38	111	72.55
Hiwassee	13	8.50	124	81.05
Pacolet	9	5.88	133	86.93
White St	6	3.92	139	90.85
Enon	5	3.27	144	94.12
Wilkes	5	3.27	149	97.39
Wedowee	3	1.96	152	99.35
Iredell	1	0.65	153	100.00

Helms (2000) postulates that the broken strings of alfisols that run through the Shenandoah Valley over the Blue Ridge and south to Georgia, supported the Great Philadelphia Wagon road, a major historical transportation route. Native Americans travelled along particular paths because of the availability of food, and, over time these paths became linked to other areas rich in game. Alfisols supported the excellent grasses that attracted this game. Alfisols contain greater amounts of phosphorus (a base) attracting larger animals like deer and bison which need phosphorus for bone growth. These grasslands, many fire-maintained, contained root-restricting clays that retarded deep rooted plants like trees from becoming established thus keeping wide swaths of land open. Alfisols also tended to be more level than the surrounding areas in the Piedmont which aided travel because of the slower moving rivers and streams. Prime settlement areas were at the intersections of these alfisols and watercourses where there was access to abundant upland wildlife, fertile floodplains, and water. Many times soil boundary areas exhibit abrupt changes because of the unique combination of the soil's properties, climate and fire regimes (Helms, 2000).

Ultisols are the ultimate product of the continuous weathering of minerals in a humid climate taking hundreds of thousands of years to form. They are surprisingly rare but were probably very common in the Mesozoic and Tertiary paleoclimates. They are the dominant soil in the southeastern US with a northern limit sharply defined by the maximum limits of Pleistocene glaciers. They are quite acidic and lack calcium, potassium, and sufficient levels of phosphorus (bases). In the Piedmont uplands, phosphorus was added to the soil by felling and burning trees which released carbon that became available as nutrients for plants in the upper soil (Helms, 2000). These ultisols require long recycle periods, for example, 17 years of trees to yield 3 years of crops (Helms, 2000). Historically Native Americans and settlers simply shifted their cultivation to a new site repeating the cycle. This burning cycle could have provided the disturbance that *Helianthus schweinitzii* needed for an open canopy. Unlike ultisols, inceptisols are considered to be very young and in the beginning stages of horizon development. These soils are commonly found forming in young geomorphic surfaces like alluvium on floodplains or steep slopes in mountainous areas. Larger areas of inceptisols are found in the Appalachian Mountains and along the coast of NC.

Preliminary analysis of the soils in which the sunflower is found will initiate the exploration of the sunflower's uniqueness. The GLM procedure, with an alpha of 0.10, was used to compare the sand/silt/clay % of non-sunflower soils and sunflower soils. The F-value for sand was 3.12, silt 1.37, and clay 3.74. The critical value at alpha 0.10, (1, 66) is 2.79. The F-value was greater than the critical value for both sand and clay, thus allowing a rejection of the null hypothesis that sunflower site soil's sand/silt/clay % is equal to non-sunflower site soil's sand/silt/clay %. A t-test (*Table 5*) of the sand, silt, clay content for sunflower and non-sunflower soils shows that the sand and clay results were significant.

*Table 5: T-Test results for sand-silt-clay, sunflower soils vs. non-sunflower soils. (group means using Pooled method)(*significant at alpha 0.10)*

Variable	Non-sunflower soils	Sunflower soils	*p*-value for the *t*-test
Sand	60.93	49.09	0.0837*
Silt	25.75	32.55	0.2169
Clay	13.79	19.00	0.0812*

Streams-Rivers, Roads, Railways, Elevation and Aspect

The GLM procedure, with an alpha of 0.05, was used to analyze distance to a river-stream (rdist), distance to a road (shortrd), distance to a railroad (rrdist), and elevation (elev) for 153 sunflower element occurrences and 154 randomly generated points from within the counties containing a sunflower soil type (*Figure 10*).

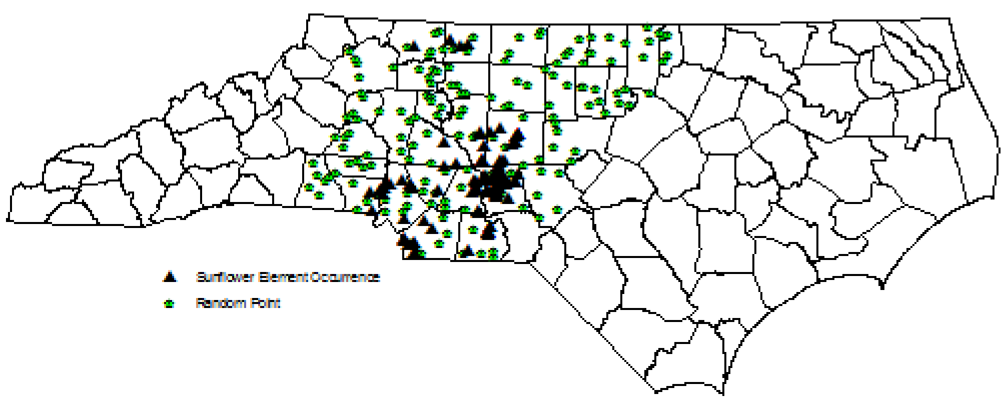

Figure 10: Sunflower Element Occurrences and Randomly Selected Points

The F-value for rdist was 0.54, shortrd 107.79, rrdist 13.68, and elev 6.99. The critical value at alpha 0.05, (1, 305) is 3.87. The F-value was greater than the critical value for shortrd, rrdist, and elev. The F-value was less than the critical value for rdist. A t-test (*Table 6*) shows a significant *p*-value for elevation, distance to road, distance to railroad.

Table 6: Comparison of elevation, distances to road, railroad, and river; random points and sunflower element occurrences
*(t-test of the group means using Pooled method)(*significant at alpha 0.05)*

Variable	Random	Sunflower	*p*-value for the *t*-test
Elevation	732.86	650.86	0.0053*
Distance to road	334.500	55.866	<.0001*
Distance to river	169.36	158.29	0.4787
Distance to railroad	6166.80	4245.30	0.0003*

The sunflower element occurrence means for rdist (158.29m), shortrd (55.87m), and rrdist (4245.30m) is less (closer to the phenomenon) than the mean values for random points, 169.36m, 334.50m, 6166.80m respectively. The mean elevation for sunflower element occurrences, 650.86ft., is less than the mean value for random points, 732.86ft. The minimum elevation of the sunflower element occurrences and random point data set collectively, was 226ft. and the maximum, 2307ft., a range of 2081ft.

The aspect for the random points and sunflower element occurrences was analyzed using the FREQ procedure in SAS (*Table 7*). Aspect 4 (southeasterly), and 5 (southerly) accounted for over 60% of the sunflower element occurrences with aspect 4 (southeasterly) being the most frequent. A Kolmogorov-Smirnov test (*Figure 11*), as described by Wong and Lee (2005) was used to compare cumulative frequency for both sets of data. The K-S D statistic (D=max|$cp_{random} - cp_{sunflower}$| was used to determine the significance between the two groups of data. The K-S D statistic, .1867, is greater than a *p*-value of 0.005, meaning that the two distributions are significantly different.

Table 7: FREQ procedure results for aspect, natural sunflower element and random.

	Frequency		Percent		Cum. Freq.		Cum. Percent	
Aspgrp	SF	Random	SF	Random	SF	Random	SF	Random
4	60	21	39.22	13.64	60	21	39.22	13.64
5	33	34	21.57	22.08	93	55	60.79	35.72
3	28	32	18.30	20.78	121	87	79.09	56.50
6	13	29	8.50	18.83	134	116	87.59	75.33
7	8	3	5.23	1.95	142	119	92.82	77.28
2	7	27	4.57	17.53	149	146	97.39	94.81
1	3	8	1.96	5.19	152	154	99.36	100.00
8	1	0	0.65	0.00	153	154	100.00	100.00

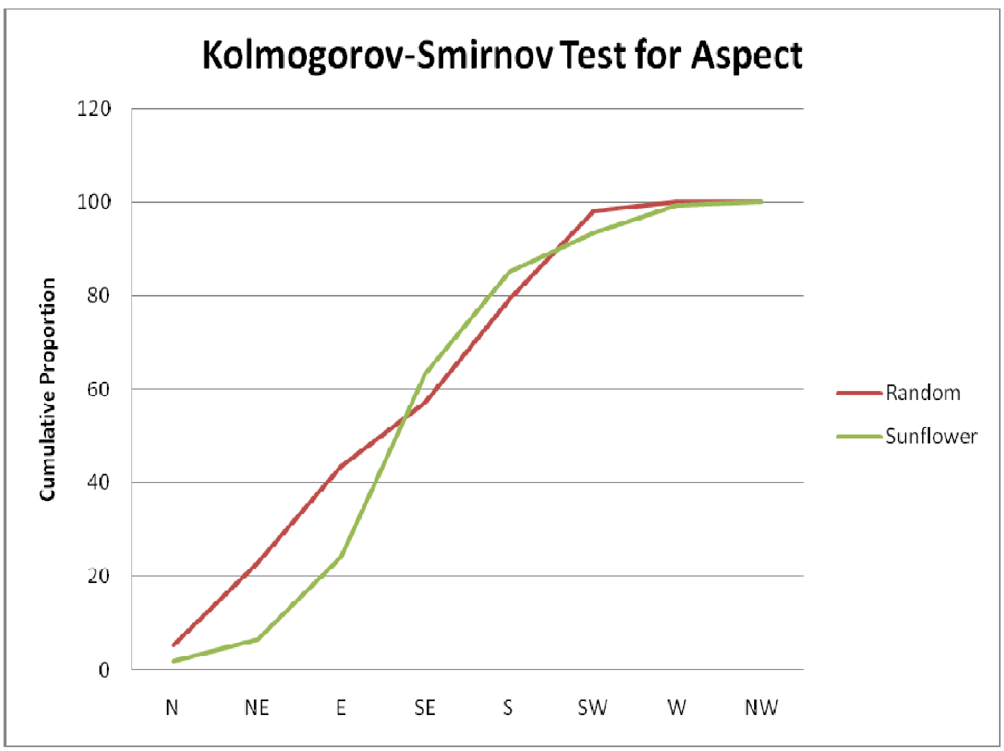

Figure 11: Kolmogorov-Smirnov test for aspect.
For random points and sunflower element occurrences (KS = 0.093349, KSa = 1.635606, D = .186699, Pr > KSa = 0.0095).

Powell *et al*., (2005) describe environmental envelopes as small, compact areas which vary in elevation, aspect, distance from watercourse and slope. A model using these attributes can be used to determine an environmental envelope within a defined geographic region that is suitable for a species then rank each envelope's suitability on a scale. Abiotic attributes may also be used to determine a species' environmental envelope. Draper *et al*., (2003), used a multiple linear regression with many of the same attributes used by Powell *et al*., (2005) to determine their influence on the spatial distribution of a species. By using site coordinates, elevation, elevation range within populations, mean aspect, slope, distance to nearest water course, topographic position, and a GIS, Powell, *et al*., (2005) were able to create a ranking system and model for the endangered species *Triunia robusta*. Populations that had all, several, and few attributes were assigned a habitat similarity value, 1, 2, and 3, respectively. With this priority ranking system, a model was created to identify other geographic areas matching the known populations.

Historic Data, Historic Maps and Archaeological Data

Mouzon's map was georeferenced with the hydro24k layer using river forks that were recognizable on the historic map, a method mentioned in Giordano and Nolan (2007). More than 25 points were initially identified. The points with the worse residual value were removed leaving 20 points and an RMSE of 3767 using the 1st order polynomial transformation. Although not an exact spatial match with an RMSE of over 3700, the historic map provides important clues on the region where *Helianthus schweinitzii* is located and can be used to determine basic topology. It is unrealistic, for reasons mentioned by Giordano and Nolan (2007), to expect a low RMSE when attempting to rectify an historic map. Once the Mouzon image was rectified, the trading paths were digitized to produce a new layer file which could be used with other layers to get an idea of where the trading paths are in relation to the sunflower (*Figure 12*). Because of time and resource constraints, Randolph County was chosen for analysis because there were more data for this county.

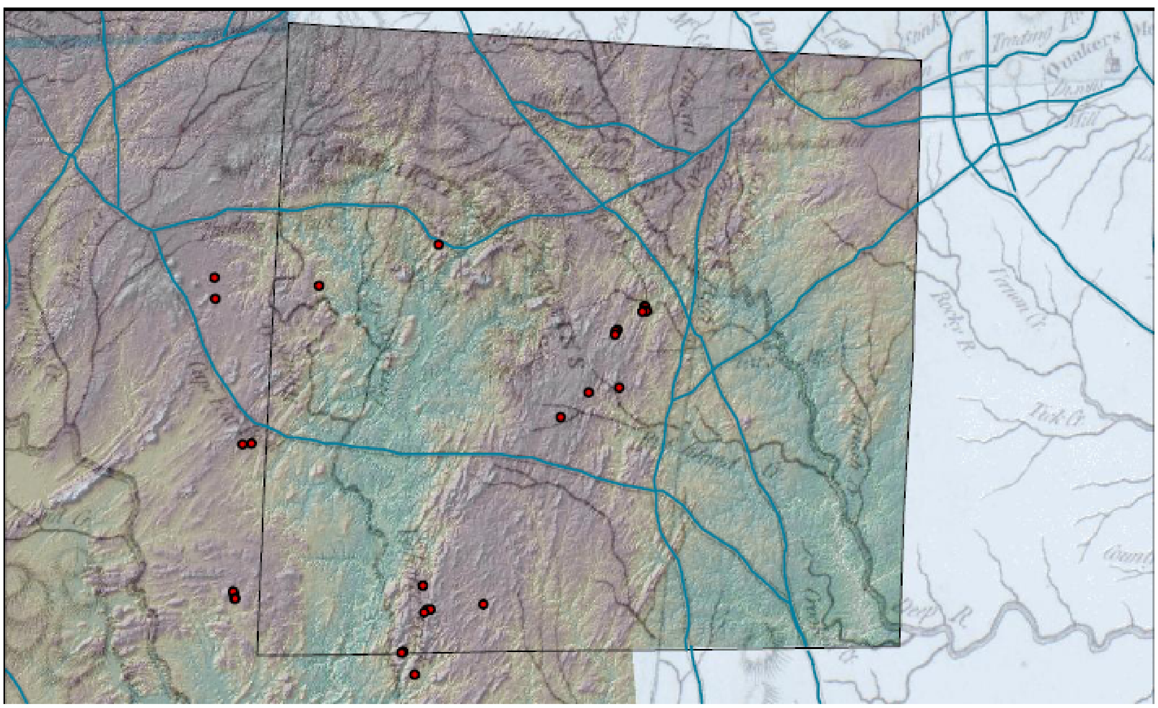

Figure 12: Henry Mouzon's 1777 map overlaid on elevation and hillshade raster files. (with the Helianthus schweinitzii site points and the digitized paths in Randolph County)

Simpkins' and Petherick's (1985) 'Figure 6' was used to digitize the Occoneechi Path, Wilmington Trail, and the Indian Trading Path (Moseley Path) (*Figure 13*).

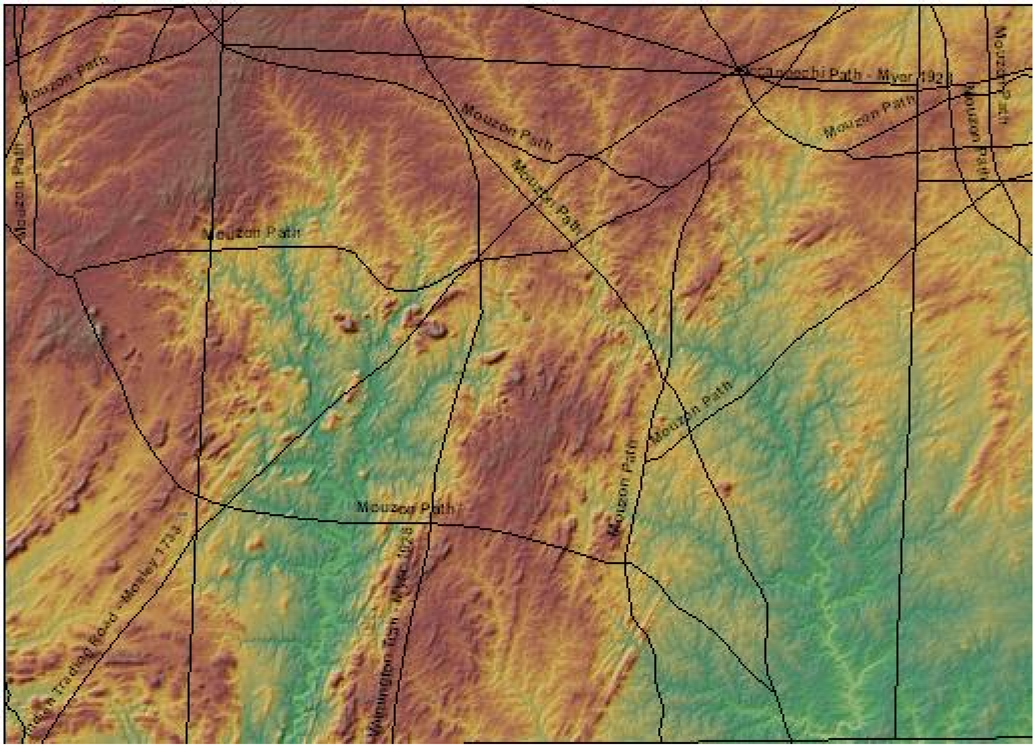

Figure 13: Simpkins and Petherick (1985) identified paths.
(also includes Mouzon digitized paths in Randolph County)

The SAS GLM procedure, with an alpha of 0.05, was used to analyze distance to a river-stream (rdist), distance to a road (shortrd), distance to a railroad (rrdist), elevation (elev), distance to nearest archaeological incident (larcdist), distance to Moseley's path (moseleydist), distance to the Wilmington Trail (wilmpathdist), and distance to paths identified on Mouzon's map (mouzpathdist) for the 18 sunflower element occurrences in Randolph county and 15 randomly generated points from within the county. The F-value for rdist was 1.66, shortrd 18.66, rrdist 0.03, elev 6.41, larcdist 12.28, moseleydist 0.75, wilmpathdist 18.36, and mouzpathdist 7.51. The critical value at alpha 0.05, (1, 31) is 4.160. The F-value was greater than the critical value for shortrd, elev, larcdist, wilmpathdist, and mouzpathdist. The F-value was less than the critical value for rdist, rrdist, and moseleydist. A t-test (*Table 8*) shows a significant *p*-value for elevation, distance to road, distance to an archaeological incident, distance to Moseley's path, distance to the Wilmington Trail and distance to Mouzon paths.

Table 8: Comparison of variables, Randolph County random points and sunflower element occurrences.
*(t-test of the group means using Pooled method)(*significant at alpha 0.05)*

Variable	Random	Sunflower	*p*-value for the *t*-test
Elevation	654.07	740.78	0.0078*
Distance to road	444.10	0.5716	<.0001*
Distance to river	182.14	117.81	0.2892
Distance to railroad	7536.10	7838.50	0.8749
Distance to archaeology incident	1195.10	319.95	0.0134*
Distance to Moseley's path	13367.0	10733.0	0.0037*
Distance to Wilmington Trail	14169.0	4927.9	0.0016*
Distance to Mouzon path	2905.10	6165.60	0.0188*

SNK found a significant difference between random points and sunflower element occurrences distance to the Mouzon path, however, the random points were closer to the path than the sunflower element occurrence. Road distance and elevation at both the county level and the broader range appear to be important sunflower attributes as indicated by the significant differences and shorter distances between the sunflower element occurrences and the random points.

Using Spatial Analysis for Species Predictions

The information about *Helianthus schweinitzii* can be analyzed using methodologies similar to those mentioned to create a habitat matrix for the known naturally occurring element occurrences which can be used to create a model for predicting possible locations of the sunflower. *Table 9* shows the t-test results of non-categorical data for all random and sunflower element occurrences.

*Table 9: Comparison of non-categorical variables, random points and sunflowers. (t-test of the group means using Pooled method)(*significant at alpha 0.05)*

Variable	Random	Sunflower	*p*-value for the *t*-test
Elevation	732.86	650.86	0.0053*
Distance to road	334.500	55.866	<.0001*
Distance to river	169.36	158.29	0.4787
Distance to railroad	6166.80	4245.30	0.0003*
Distance to Mouzon mapped path	13548.0	7069.50	<.0001*
Sand %	45.299	36.490	<.0001*
Clay %	21.948	18.418	0.0033*

A logistic regression analysis was performed using the proc logistic procedure in SAS to relate the various attributes, including categorical attributes, (elevation, SSEasp, shortest distance to road, distance to a stream/river, distance to a railroad, distance to a Mouzon identified path, sand/clay %'s, mingrp, compgrp, soilgrp) to the occurrences of this species. Binary logit model and Fisher's scoring optimization technique were used. Group designations were determined using prior analysis for each group with the highest frequencies carrying a 1 binary value. The soil group (soilgrp) was identified as ultisols.

The mineralogy group (mingrp) was felsic in nature. The composition group (compgrp) consisted of Tatum (60), Herndon (22), and Goldston (32) because they contained the majority of sunflower element occurrences, 114 in total. The geology group (geogrp) was the Uwharrie formation. This model had a concordant percentage of 93.0, discordant percentage of 6.9 and a percent tied of 0.1 (*Table 10*).

Table 10: Analysis of Maximum Likelihood Estimates – All data and all attributes. (elevation, SSEasp, shortest road distance, distance to stream/river, distance to railroad, Mouzon path distance, sand, clay, mingrp, compgrp, soilgrp, and geogrp)

Variable	Estimate	*p*-value	Odds ratio	Change in odds(%)
Intercept	1.7707	0.2706	-	.
Elev	-0.00023	0.7988	1.000	0.00%
SSEasp	1.0526	0.0037	2.865	186.50%
Shortrd	-0.00728	<.0001	0.993	(-) 0.70%
Rdist	-0.00297	0.0262	0.997	(-) 0.30%
Rrdist	-0.00005	0.2268	1.000	0.00%
Mouzdist	-0.00008	0.0013	1.000	0.00%
Sand	-0.00062	0.9764	0.999	(-) 0.10%
Clay	0.0142	0.5145	1.014	1.40%
Mingrp	0.5119	0.3566	1.668	66.80%
Compgrp	1.9429	0.0053	6.979	597.90%
Soilgrp	-1.3139	0.0155	0.269	(-) 73.10%
Geogrp	1.9969	0.0347	7.366	636.60%

The stepwise selection chose SSEasp, shortrd, rdist, mouzdist, compgrp, soilgrp, and geogrp with *p*-values of 0.0022, <.0001, 0.0244, 0.0008, <.0001, 0.0022, and 0.0086 respectively (*Table 11*). This model had a concordant percentage of 92.8, discordant percentage of 7.1 and a percent tied of 0.1. A southeasterly, southern aspect increases the odds of finding a sunflower element occurrence by 200.5%. An increase of 1 meter in distance to a road decreases the odds 7/10 of 1%. An increase of 1 meter in distance to a river/stream decreases the odds 3/10 of 1%. There is no change in odds for an increase in distance to a Mouzon mapped path. A soil composition of Tatum Goldston or Herndon, increases the odds of finding a sunflower element occurrence 720.5%. A location in an alfisol or inceptisol decreases the odds 71.2%. The odds increase 816.9% for locations in the Uwharrie formation.

Table 11: Analysis of Maximum Likelihood Estimates - Stepwise selected attributes. (SSEasp, shortest road distance, distance to stream/river, Mouzon mapped path distance comgrp, soilgrp, and geogrp)

Variable	Estimate	*p*-value	Odds ratio	Change in odds(%)
Intercept	1.5576	0.0022	-	
SSEasp	1.1004	0.0022	3.005	200.50%
Shortrd	-0.00727	<.0001	0.993	(-) 0.70%
Rdist	-0.00291	0.0244	0.997	(-) 0.30%
Mouzdist	-0.00009	0.0008	1.000	0.00%
Compgrp	2.1047	<.0001	8.205	720.50%
Soilgrp	-1.2449	0.0022	0.288	(-) 71.20%
Geogrp	2.2158	0.0086	9.169	816.90%

A model was created using information gathered from analysis in this paper to identify potential sunflower locations in Randolph County. Included in the model were areas with an aspect value of 3, 4 or 5; a distance from road of 25m or less; a distance from river of 120m or less; a Tatum, Herndon, or Goldston soil; geology that was Uwharrie formation and mineralogy that was felsic in nature. The results are shown in *Figure 14*. Field testing has not been performed.

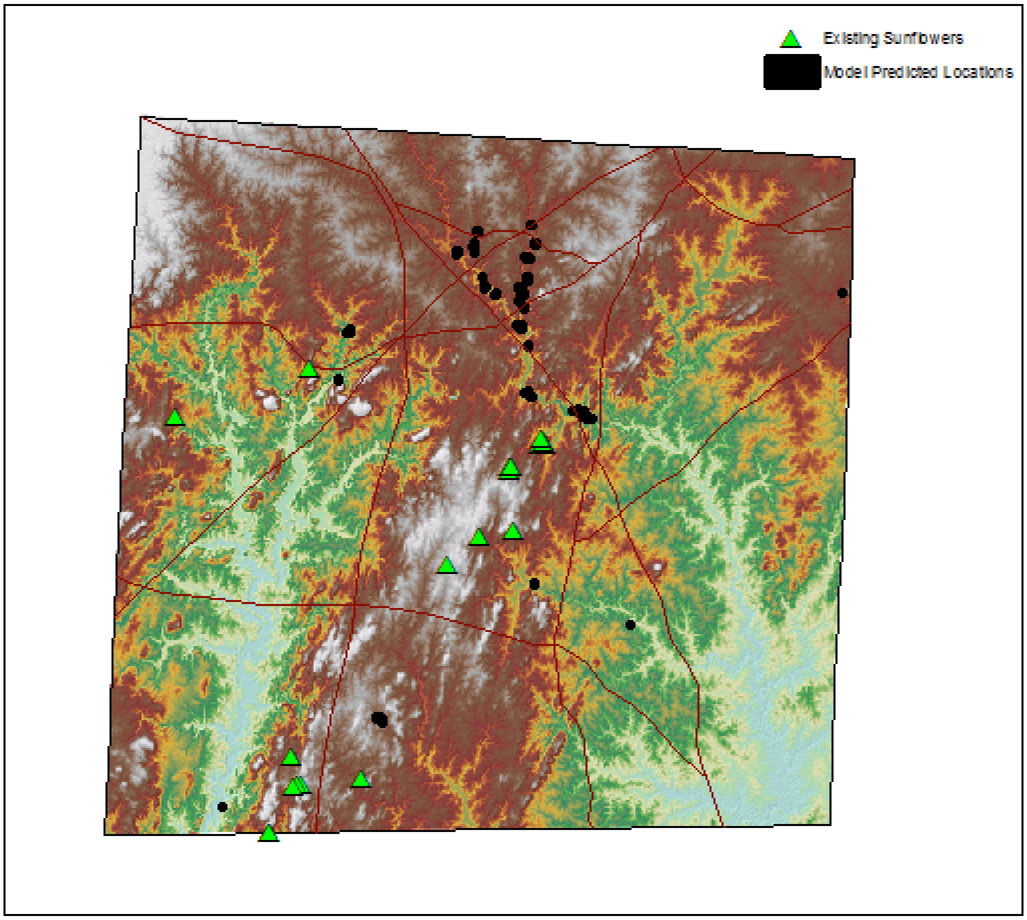

Figure 14: Existing and potential sunflower locations in Randolph County.

CHAPTER IV

DISCUSSION

Soils and Soil Properties

A soil's sand/silt/clay composition determines the soil's texture. Soil texture designates the proportionate distribution of the different sizes of mineral particles in a soil and is one of the most important characteristics (Brown, 2003). Various sizes of particles in a soil yield quite different physical characteristics, for example, a soil with a large amount of clay has quite different physical properties from one made up of mostly of sand and/or silt. As a general rule, sandy soils tend to be low in organic matter content, low in the ability to retain moisture and nutrients, low in cation exchange and buffer capacities and rapidly permeable (Brown, 2003; Helms, 2000). Since sandy soils are often quite droughty, deep-rooted plants are best adapted to them. As the relative percentages of silt and clay increase, the soil's properties are increasingly affected. Finer textured soils are generally more fertile, have a higher cation exchange and buffer capacities, contain more organic material, and permit less rapid movement of air and water. Clayey soils are often sticky when wet and hard when dry and exhibit shrink-swell characteristics (Brown, 2003).

A soil's texture has a direct influence on the pore space of the soil, for example, the smaller the particle, the more total pore space available for air and water (Bandel *et al.*, 2002). This means that soils higher in clay content have more pore space than those with higher sand or silt content. Ironically, there is an inverse texture effect with coarse-textured soils supporting higher amounts of groundcover than fine soils in dry climates (Epstein *et al*., 1997). Soils with higher clay content do have more pore spaces, but the pore spaces are smaller than those of coarser textured soils. However, a spoonful of clay has the surface area of a football field and 10,000 times the surface area than that of sand (Helms, 2000). With an increased surface area, there is a stronger capillary force in the smaller pores than the larger pores, thus the amount of moisture available to the plant is decreased (Bandel *et al*., 2002). This may be a good thing if an area receives little rainfall because finer soils limit evaporative losses of soil water (Epstein *et al*., 1997). In areas where rainfall is great, the fine, clay soils retain more moisture at the permanent wilting point than sandy soils, thus drowning the roots of plants, especially in lower lying areas (Bandel *et al*., 2002). The water table also interacts with the soil texture. Sandy soils in flat areas are likely to be saturated with water for longer periods of time, but sandy soils of sloped areas are unlikely to have a high water table at anytime (Brown, 2003). During floods, sand drops out first creating ridges, followed by silt then clays which settle farthest from the bank forming a sleeve that slopes away from the bank (Helms, 2000).

By knowing the sand/silt/clay percentages, a textural triangle such as the USDA triangle (*Figure 15*) can be used to classify the soil (Gerakis *et al*., 1999). An algorithm can be used along with the unique combination of sand and clay to determine the soil's texture, i.e., clay loam, sandy loam, etc. Using the on-line, interactive program created by Gerakis *et al*., (1999) the sunflower site soils could be classified. The soil data file was uploaded into the web page by Gerakis *et al*., (1999) and an analysis was run. The results

(*Table 12*) showed that the sunflower sites were classified as sandy loams, sandy clay, silt loam, or loam. It was not uncommon to have the same composition name with a different texture because of the different sand/silt/clay percentages. An example of this is the Pacolet soils. One of the Pacolet soil observations was classified as sandy clay with a sand percentage of 48% and a clay percentage of 50%, while another Pacolet soil observation was classified as sandy loam with a sand percentage of 68% and clay of 13%. Six of the soils were classified as sandy loam and three were classified as silt loams.

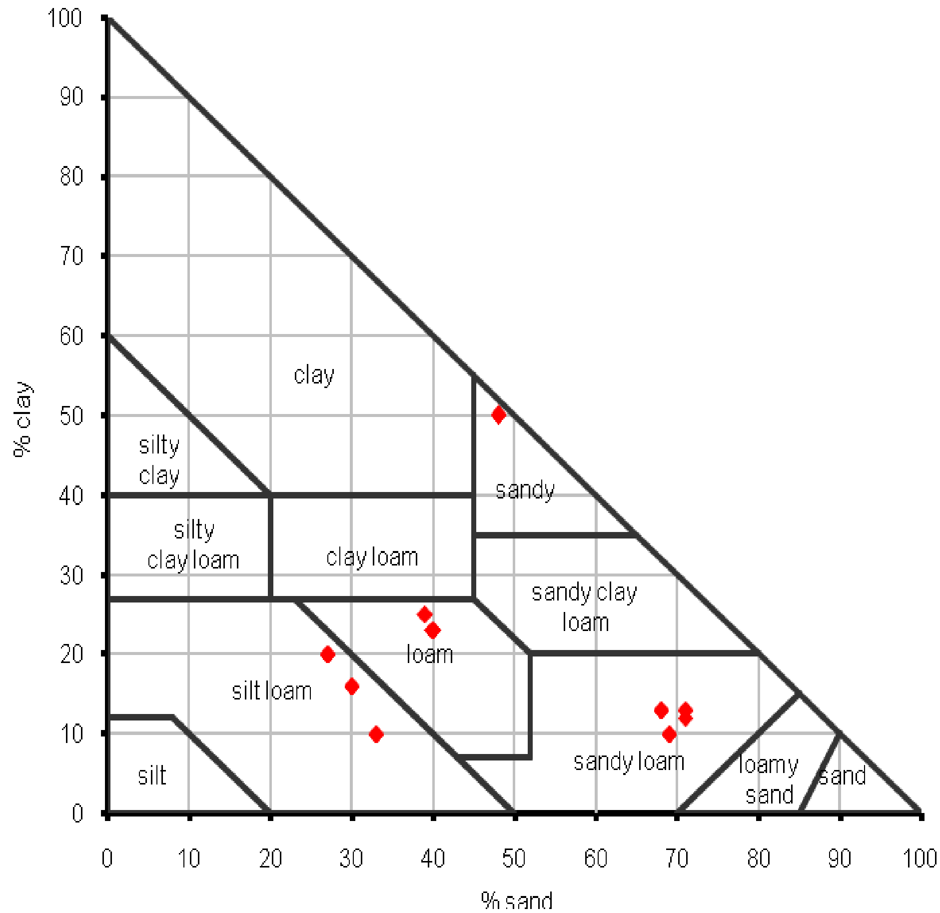

Figure 15: USDA Textural Triangle with sunflower site soils plotted.
(a plotting program by Gerakis, et al., (1999))

Table 12: Textural algorigthm results of sunflower site soils.

Sample ID	% Sand	%Clay	Texture
Tatum	27	20	silt loam
Herndon	30	16	silt loam
Goldston	33	10	silt loam
Iredell	39	25	Loam
Hiwassee	40	23	Loam
Pacolet	48	50	sandy clay
Pacolet	68	13	sandy loam
Wedowee	68	13	sandy loam
White Store	68	13	sandy loam
Enon	69	10	sandy loam
Tallapoos	71	12	sandy loam
Wilkes	71	13	sandy loam

Sandy loams consist of soil materials containing somewhat less sand and more silt plus clay than loamy soils. The individual sand grains can be seen and felt, but there is sufficient silt and clay to give coherence to the soil so casts can be formed that can be handled carefully without breakage. Silt loams have rather small amounts of sand and clay and when dry are rather cloddy, but the clods are easily broken and the soil feels like flour. When moist or dry, casts can be formed and can be handled fairly freely without breakage. Loams tend to be soft and fairly smooth, slightly sticky and plastic when wet. Silty clay loam, as well as silty clay, are sticky and plastic when wet, firm when moist and forms casts that are hard when dry with silty clay being very hard when dry. With all factors being equal, it is generally believed that soils having sandy loam, or loam-textured surface soils, are better suited for a wider variety of vegetation (Brown, 2003).

Most of the literature suggests that *Helianthus schweinitzii* favors clayey soil. The GLM analysis, with an alpha of 0.10, did show that there is a significant difference between the non-sunflower soils' and the sunflower soils' clay percentage. Some of the literature places *Helianthus schweinitzii* in sandy soils (Thompson *et al.*, 1981). The GLM analysis also showed a significant difference between the non-sunflower soils' and the sunflower soils' sand percentage. Although the soils' sand/silt/clay percentage may not be the sole determinant of the location of the *Helianthus schweinitzii*, it can be a key component of it. Documented *Helianthus schweinitzii* populations are found in soils with sand/silt/clay percentages that are different from those soils without a documented sunflower population. While the silt percentages did not significantly differ between the two, the sand and clay percentages did.

In a 1999 study by Hook and Burke, vegetation and biogeochemical variables were strongly correlated with soil sand content. Their research also indicated that soil properties and plant cover patterns differed significantly between upland and lowlands. They postulate that topographic position and soil texture explain much of the landscape-scale variation in vegetation structure with soil texture being a key proximal control over biogeochemical processes and largely responsible for the observed landscape-scale patterns. In this case, landscape-scale is defined as the environmental envelope or range in which the vegetation or species may exist. Hook and Burke suggest using models that integrate the effects of sand/silt/clay content and topography to link landscape patterns. Spatial patterns of texture are controlled by surface geology and bedrock, erosion and deposition, and hillslope processes. Additional research on factors such as the general topography, parent material, temperatures and rainfall of the Schweinitz's Sunflower sites may prove beneficial as well. These factors, along with the soil's sand/silt/clay content may help explain the spatial dispersal and variability (or lack of variability) of the sunflower's ecosystem and provide a systematic way of locating additional populations (Hook & Burke, 2000).

Streams-Rivers, Roads, Railways, Elevation and Aspect

Cantamutto, *et.al*, (2008) found that two species of *Helianthus, annus* and *petiolaris*, were found mainly along roadways and were strongly related to disturbance. They also found that microhabitat conditions are unique for each species, for example, *Helianthus petiolaris* tended to prefer a lower elevation and soil where sand predominates, while *Helianthus annus* prefers a more humid habitat and soils associated with silt and clay. Other variables included in the Cantamutto *et.al,* (2008) study include the potential for water erosion and the landscape sharpness due to slope. Lowlands are generally depositional and gently concave while uplands tend to be erosional and gently convex. Uplands and lowlands differ significantly in soil properties and plant coverage patterns. Uplands, dependent upon the sand content, tend to have lower field capacity and more, larger openings, lower total plant coverage especially grasses and sedges. Lowlands are less affected by sand content, and show greater variation in vegetation. Hook and Burke (2000) found that most carbon and nitrogen pools are influenced by topographic position. The *Helianthus* populations in the Cantamutto *et.al,* (2008) study were located in what could be considered transitional boundary areas of disturbance, along roadways, in roadside ditches, along fences, and localized along the sides of river or streams. In their study, wild *Helianthus* populations were never found in non-disturbed habitats.

Historic Landscapes-Maps and References, and Archaeological Data

When analyzing historic data, it is important to understand the context in which these data were created, its intended purpose, and the technology used to obtain it. Take historical maps, for example, in order to evaluate their spatial accuracy, one must realize that there are variations due to the surveying methods being used, the way the information was collected, and the methods or technology used to create the map. Early American maps have a strong European influence which is reflected in the symbology used for the landscape and the units of measurement. Surveying methods also varied, for example, a topographic engineer conducted surveys by horseback counting hoof strikes to the ground, while sketching and making notes on only the most prominent landscape features. Other surveyors measured distances by walking off or counting paces. Angles may have been measured by using a pair of sights and a prismatic compass. If a surveyor was really good, he could measure angles to 1/2˚ and distances to within 50 feet in a mile. Some surveyors used metal chains and transits or theodolites to measure angles. There was always a struggle between accuracy and artistry with a greater concern for preserving the spatial relationships between landscape features than the accuracy of vertical and horizontal angles. With these things in mind, it is most beneficial to use historic maps to understand the persistence of objects over time and to use them to reconstruct or visualize historic landscapes (Giordano & Nolan, 2007). Historic maps can be overlaid or compared to contemporary maps to successfully interpolate spatial relationships. Primary sources, such as John Lawson's travel diary, can be used to enhance and support this interpolation.

Historic maps can be scanned and geo-referenced, but it is unreasonable to expect to obtain accurate distance or angle measurements. When geo-referencing historic maps, it is usually hard to find adequate control points and there will be warping. Physical features, such as coastlines and rivers, can be used to a degree, but should not be relied upon to provide accurate location information, in fact, some historic maps may bear little to no relation to reality. Historic maps may also suffer from physical damage, misplaced map elements, or features that are missing altogether. Focusing on differences between historic and contemporary maps may indicate changes through time, but it is important to understand the historic map's purpose and its intended audience (Wilson, 2001). Even with these limitations, it can be visually beneficial to attempt overlaying or comparing the historic map with contemporary maps and data to better understand how the landscape has changed over time. General topographic observations can be made, for example, a point lies north and west of the river, which may prove beneficial.

Archaeological site location incorporates many of the same approaches used to locate rare species, for example, using a landscape approach to identify sites. Fry *et al*., (2004) describes analyses at two scales for the potential location of a site, (1) regional scale which is a combination of environmental resources suitable for human use, and (2) local landscape scale. Different cultures and belief systems perceive, interpret, and utilize local landscape structures and land differently creating different land use patterns through time. Regional scale attributes are most likely driven by natural features, cover a broad area and create the environmental backcloth for human activities (Fry *et al*., 2004), a good example of a regional scale attribute is the presence of savannas and prairies.

Anthropogenic disturbances can be inferred from historic Native American sites and their archaeological evidence. Technological changes shift populations so it stands to reason that the incidence of anthropogenic fire and land clearing were also shifted across the landscape through time. Disturbances are dispersed and are highly influenced by soils, topology, human settlement patterns, and by long-term climatic change and air circulation patterns (Lorimer, 2001). Plants, animals and humans adapted over thousands of years.

Delcourt's (1997) research of Native Americans and their use of fire looks at fossil charcoal and pollen to understand humans' affect on the landscape. Paleo-ecological results indicate that Native Americans have played an important role in determining the composition of vegetation over most of the last 4000 years through the selective use of fire. Burning heightened the contrast across vegetation boundaries, and during Archaic, Woodland, and Mississippian times, human impact was concentrated in two areas of the landscape, (1) alluvial bottoms of major rivers and coves where temporary camps or villages were established and crops were cultivated, and (2) upper slopes and ridge tops where they hunted and gathered. Native Americans used fire that was focused on particular portions of the landscape while excluding others. Grasses (poaceae), many species indicative of savannas or prairies, reached 30% between 2000 BC to 1500 AD then diminished to only 4-10% of the current upland pollen assemblage (Delcourt, 1997). Herbs represented in the pollen record included, along with poaceae, plaintain, portulaca, maize, and sumpweed which indicate human activities and according to Davis, *et al*., (2002) are strongly associated with prairies and can be found in prairie remnants. Helms (2000) postulates that Native American settlement patterns emphasized the use of flood plains and terraces which have access to water, contain fertile, alluvial soils with loamy textures in which hand tools and implements could be used, and close to game.

Fry *et al*., (2004) hypothesize that prehistoric agriculture settlements were situated on lighter (sandy) soils which were well drained and easy to work and in areas that tend to be in or near currently open landscapes on convex slopes. Ridges and convex points are normally washed with a rocky or till surface while the sandy material is normally deposited on slopes below the ridge and clays dominating the depressions (Fry et al., 2004). Lorimer (2001), suggests that there is greater fire disturbance by Native Americans near floodplains of major rivers, and on sandy soils (instead of loamy) while settlements were frequent along the savannas, grasslands, and old fields, typically clustering along the floodplain of major rivers and streams. Lorimer (2001) also supports the use of fire by Native Americans to create extensive open habitats to keep travel paths open from village to village, to create habitat for game and to drive game, and on the sandy outwash plains to encourage berry production. There is a strong spatial correlation between pre-settlement fire frequency and independent historical estimates of human population.

Early successional habitats were quite numerous between the 1890's to 1950's (Lorimer, 2001). Remnants of past farming activities remain visible for hundreds of years and utilizing the hypothesis that the best farming land should be found on the sandy/silty soils with gentle slopes (Fry *et al*., 2004) may help identify potential *Helianthus* *schweinitzii* populations sites since the species has been associated with old-field succession and prefer sandy soils and subdued topology like upland interstream flats and gentle slopes (US Fish and Wildlife, 1994).

CHAPTER V

CONCLUSION

Information contained in this paper may prove to be useful as the state continues its efforts to re-establish and protect the sunflower populations with an ultimate goal of removing its endangered status. In fact one of the goals or actions listed in the Recovery Plan for Schweinitz's Sunflower written by the US Fish and Wildlife Service, is to find suitable habitat for additional populations and potential reintroduction sites.

Hirzel, *et.al.*, (2002) use 'ecogeographical' variables derived from various sources to determine the ecological niche of a species. They believe that a species' habitat is not comprised of simple, linear, monotonic relationships, but complex relationships with areas of marginality where a species' occupation decreases from either side of its optimum habitat. In the 1999 study by Hook and Burke, vegetation and biogeochemical variables were strongly correlated with soil sand content. Their research also indicated that soil properties and plant cover patterns differed significantly between upland and lowlands. They postulate that topographic position and soil texture explain much of the landscape-scale variation in vegetation structure with soil texture being a key proximal control over biogeochemical processes and largely responsible for observed landscape-scale patterns (Hook and Burke, 2000). Hook and Burke suggest using models that integrate the effects of sand/silt/clay content and topography to link landscape patterns. Spatial patterns of texture are controlled by surface geology and bedrock, erosion and deposition, and hillslope processes (Hook and Burke, 2000). Powell, *et al*., (2005) created models using elevation, slope and aspect. Canatamutto, *et.al*., (2008) found highly significant differences in the frequency of two *Helianthus* species' association with soil subgroup and disturbed areas like roadsides.

Analyses included in this paper shows that the spatial distribution of *Helianthus schweinitzii* to be closely associated with soil characteristics and disturbance. The sunflower soil's sand/silt/clay percentages appear to be uniquely associated with the species. The species is more likely to be found in ultisols, in the Uwharrie formation, and in felsic soils. The southeast to northeast pattern of sunflower element occurrences mimics the same general southeast to northeast trend that the sunflower soils' exhibit with the known occurrences found most frequently in Tatum, Goldston, and Herndon soil compositions. There is a strong association with areas that are open and routinely maintained especially locations near roadways. The sunflower is found most frequently in a southeasterly, southerly aspect. There are copious amounts of primary source data to support the existence of a Piedmont prairie. Historic maps detail many pathways and roadways crisscrossing central North Carolina. These historic pathways may have provided an inviting environment for the sunflower, or they may have dissected existing populations. Analysis of distances to historic paths and archaeological sites shows promise in understanding the spatial distribution of the sunflower as the sunflowers may have been a source of food or medicine. A model for locating additional populations should include many of these attributes.

Future research utilizing power line right-of-way data, additional historical and archaeological data, land-use data, slope, and additional biological data may provide new information that can be added to the predictive model for locating additional populations of the endangered sunflower.

REFERENCES

Ackerman, W., Murray, A., 2004. Assessing spatial patterns of crime in Lima, Ohio. Cities, 21 (5): 423-437.

Allison, P.D., 2006. Logistic Regression Using the SAS System. SAS Institute, Inc., Cary, North Carolina.

Anselin, L., 2003. An Introduction to Point Pattern Analysis using CrimeStat. Department of Agricultural and Consumer Economics, University of Illinois, Urbana-Champaign. (http://sal.agecon.uiuc.edu).

Apan, A., Peterson, J., 1998. Probing tropical deforestation, The use of GIS and statistical analysis of georeferenced data. Applied Geography, 18 (2): 137-152.

Badano, E., Cavieres, L., Molina-Montenegro, M., Quiroz, C., 2005. Slope aspect influences plant association patterns in the Mediterranean matorral of central Chile. Journal of Arid Environments, 62(2005): 93-108.

Bandel, V.A., James, B.R., Mesinger, J.J., 2002. Basic Principles of Soil Fertility II: Soil Properties. Fact Sheet 640, Maryland Cooperative Extension, College of Agriculture & Natural Resources, University of Maryland Eastern Shore, http://www.agnr.umd.edu/MCE/Publications/Publication.cfm?ID=151.

Bishop, M., 2007. Point pattern analysis of eruption points for the Mount Gambier volcanic sub-province: a quantitative geographical approach to the understanding of volcano distribution. Area, 39 (2): 230-241.

Bourg, N., McShea, W., Gill, D., 2005. Putting a Cart before the Search: Successful Habitat Prediction for a Rare Forest Herb. Ecology, 86(10): 2793-2804.

Brown, R.B., 2003. Soil Texture. Fact Sheet SL-29, Soil and Water Science Department, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida, http://edis.ifas.ufl.edu.

Cantamutto, M., Poverene, M., Peinemann, N., 2008. Multi-scale Analysis of Two Annual *Helianthus* species naturalization in Argentina. Agriculture, Ecosystems and Environment, 123(2008), 69-74.

Cody, R.P., Smith, J.K., 2006. Applied Statistics and the SAS Programming Language. Pearson Prentice Hall, Upper Saddle River, New Jersey.

Cumming, W., 1938. Geographical Misconceptions of the Southeast in the Cartography of the Seventeenth and Eighteenth Centuries. The Journal of Southern History, 4(4): 476-492.

Davis, J.E., 1999. Rocky Microsites Prove Best for Establishment of Schweinitz's Sunflower, an Endangered Species of the Piedmont (North Carolina). Ecological Restoration, 17(3): 171-172.

Davis, J.E., McRae, C., Estep, B.L., Barden, L.S., Matthews, J.F., 2002. Vascular Flora of Piedmont Prairies: Evidence from Several Prairie Remnants. Castanea, 67(1): 1-12.

Draper, D., Rossello-Graell, A., Garcia, C., Gomes, C., Sergio, C., 2003. Application of GIS in plant conservation programmes in Portugal. Biological Conservation, 113(3): 337-349.

Epstein, H.E., Lauenroth, W.K., Burke, I.C., 1997. Effects of Temperature and Soil Texture on ANPP in the US Great Plains. Ecology, 78(8): 2628-2631.

Fry, G., Skar, B., Jerpasen, G., Bakkestuen, V., Erikstad, L., 2004. Locating archaeological sites in the landscape: a hierarchical approach based on landscape indicators. Landscape and Urban Planning, 67(1-4): 97-107.

Gerakis, A., Baer, B., 1999. A Computer Program for Soil Textural Classification. Soils Science Society of America Journal, 63: 807-808. (Interactive version of program at: http://nowlin.css.msu.edu/software/triangle_form.html).

Gesler, W., 1986. The Uses of Spatial Analysis in Medical Geography: A Review. Soc. Sci. Med., 23 (10): 963-973

Giordano, A., Nolan, T., 2007. Civil War Maps of the Battle of Stones River: History and the Modern Landscape. The Cartographic Journal, 44(1): 55-70.

Gong, X., Brueck, H., Giese, K., Zhang, L., Sattelmacher, B., Lin, S., 2008. Slope aspect has effects on productivity and species composition of hilly grassland in the Xilin River Basin, Inner Mongolia, China. Journal of Arid Environments, 72(2008): 483-493.

Gregory, I., Healey, R., 2007. Historical GIS: structuring, mapping and analyzing geographies of the past. Progress in Human Geography, 31(5): 638-653.

Haase, D., Walz, U., Neubert, M., Rosenberg, M., 2007. Changes to Central European landscapes – Analysing historical maps to approach current environmental issues, examples from Saxony, Central Germany. Land Use Policy, 24(1): 248-263.

Helms, D., 2000. Soil and Southern History. Agricultural History, 74(4): 723-758.

Hitchmough, J., de la Fleur, M., 2006. Establishing North American prairie vegetation in urban parks in northern England: Effect of management and soil type on long-term community development. Landscape and Urban Planning, 78(2006): 386-397.

Hook, P.B., Burke, I.C., 2000. Biogeochemistry in a Shortgrass Landscape: Control by Topography, Soil Texture, and Microclimate. Ecology, 81(10): 2686-2703.

Landis, A., Baily, J., 2005. Reconstruction of age structure and spatial arrangement of Pinon-Juniper woodlands and savannas of Anderson Mesa, northern Arizona. Forest Ecology and Management, 204: 221-236.

Laughlin, D., 2003. Geographic Distribution and Dispersal Mechanisms of Bouteloua curtipendula in the Appalachian Mountains. American Midland Naturalist, 146(2): 268-281.

Lavergne, S., Thuiller, W., Molina, J., Devussche, M., 2005. Environmental and human factors influencing rare plant local occurrence, extinction and persistence: a 115-year study in the Mediterranean region. Journal of Biogeography, 32: 799-811.

Lawson, J., 1967. A New Voyage to Carolina (H. Lefler, Ed.). The University of North Carolina Press, Chapel Hill, North Carolina (Original work published 1708).

Lorimer, C., 2001. Historical and Ecological Roles of Disturbance in Eastern North American Forests: 9,000 Years of Change. Wildlife Society Bulletin, 29(2): 425-439.

Li, F., Zhang, L., 2007. Comparison of point pattern analysis methods for classifying the spatial distributions of spruce-fir stands in the north-east USA. Forestry, via Forestry Advance Access published May 21, 2007.

Mann, L., King, A., Dale, V., Hargrove, W., Washington-Allen, R., Pounds, L., Ashwood, T., 1999. The Role of Soil Classification in Geographic Information System Modeling of Habitat Pattern: Threatened Calcareous Ecosystems. Ecosystems, 2(6): 524-538.

Matthews, C., Howard, J., 1999. Genetic Variation in the Federally Endangered Schweinitz's Sunflower, *Helianthus schweinitzii* T. & G. (Asteraceae). Castanea, 64(3): 231-242.

Maurer, B., Taper, M., 2002. Connecting geographical distributions with population processes. Ecology Letters, 5: 223-231.

McDaniel, P., 2008. The Twelve Soil Orders, College of Agricultural & Life Sciences, University of Idaho, http://soils.ag.uidaho.edu/soilorders/index.htm.

Merriam, R., 2003. The Abundance, Distribution and Edge Associations of Six Non-Indigenous, Harmful Plants across North Carolina. Journal of the Torrey Botanical Society, 130(4): 283-291

O'Sullivan, D., Unwin, D., 2003. Geographic Information Analysis. John Wiley & Sons, Inc., Hoboken, New Jersey

Powell, M., Accad, A., Shapcott, A., 2005. Geographic information system (GIS) predictions of past, present habitat distribution and areas for re-introduction of the endangered subtropical rainforest shrub *Triunia robusta* (Proteaceae) from south-east Queensland Australia. Biological Conservation, 123(2): 165-175.

Raynal, D.J., Bazzaz, F.A., 1973. Establishment of Early Successional Plant Populations on Forest and Prairie Soil. Ecology, 54(6): 1335-1341.

Rhoads, A., Thompson, L., 1992. Integrating Herbarium Data into Geographic Information System: Requirements for Spatial Analysis. Taxon, 41(1): 43-49.

Roose, A.,Sepp, K., Saluveer, E., Kaasik, A., Oja, T., 2007. Neighborhood-defined approaches for integrating and designing landscape monitoring in Estonia. Landscape and Urban Planning, 79: 177-189

Rostlund, E., 1957. The Myth of a Natural Prairie Belt in Alabama: An Interpretation of Historical Records. Annals of the Association of American Geographers, 47(4): 392-411.

Rostlund, E., 1960. The Geographic Range of the Historic Bison in the Southeast. Annals of the Association of American Geographers, 50(4): 395-407.

Russell, W., McBride, J., 2001. The relative importance of fire and watercourse proximity in determining stand composition in mixed conifer riparian forests. Forest Ecology and Management, 150(2001): 259-265.

Salem, B., 2003. Application of GIS to biodiversity monitoring. Journal of Arid Environments, 54(1): 91-114.

Schafale, M., Christensen, N., 1986. Vegetational Variation Among Old Fields in Piedmont North Carolina. Bulletin of the Torrey Botanical Club, 113(4): 413-420.

Schilling, E.E., Linder, C.R., Noyes, R.D., Rieseberg, L.H., 1998. Phylogenetic Relationship in Helianthus (Asteraceae) Based on Nuclear Ribosomal DNA Internal Transcribed Spacer Region Sequence Data. Systematic Botany, 23(2): 177-187.

Scott, J., Davis, F., Csuti, B., Noss, R., Butterfield, B., Groves, C., Anderson, H., Caicco, S., D'Erchia, F., Edwards Jr., T., Ulliman, J., Wright, R., 1993. Gap Analysis: A Geographic Approach to Protection of Biological Diversity. Wildlife Monographs, 123: 3-41.

Serneels, S., Lambin, E., 2001. Proximate causes of land-use change in Narok District, Kenya: a spatial statistical model. Agriculture, Ecosystem and Environment, 85: 65-81.

Simpkins, Daniel, L., Petherick, Gary, L., 1985. First Phase Investigations of Late Aboriginal Settlement Systems in the Eno, Haw, and Dan River Drainages, North Carolina. Research Laboratories of Anthropology, University of North Carolina at Chapel Hill.

Small, J.K., 1898. Studies in the Botany of the Southeastern United States-XIV. Bulletin of the Torrey Botanical Club, 25(9): 465-484.

Stoffle, R., Halmo, D., Evans, M., Olmsted, J., 1990. Calculating the Cultural Significance of American Indian Plants: Paiute and Shoshone Ethnobotany at Yucca Mountain, Nevada. American Anthropologist, 92(2): 416-432

Tian, Y., Davies-Colley, R., Gong, P., Thorrold, B., 2001. Estimating solar radiation on slopes of arbitrary aspect. Agricultural and Forest Meteorology, 109(2001): 67-74.

Thompson, T.E., Zimmerman, D.C., Rogers, C.E., 1981. Wild Helianthus as a Genetic Resource. Field Crops Research, 4: 333-343

US Fish and Wildlife Service. 1994 Schweinitz's Sunflower Recover Plan. Atlanta, GA. 28pp.

Weiers, S., Bock, B., Wissen, M., Rossner, G., 2004. Mapping and indicator approaches for assessment of habitats at different scales using remote sensing and GIS methods. Landscape and Urban Planning, 67(1-4): 43-65.

Wilson, A., 2001. Sydney TimeMap: Integrating Historical Resources using GIS. History & Computing, 13(1): 45-69.

Wong, D., Lee, J., 2005. Statistical Analysis of Geographic Information with ArcView GIS and ArcGIS. John Wiley & Sons, Inc., Hoboken, New Jersey.

Woodall, C., Graham, J., 2004. A technique for conducting point pattern analysis of cluster plot stem-maps. Forest Ecology and Management, 198: 31-37.

Yuill, R., 1971. The Standard Deviational Ellipse; An Updated Tool for Spatial Description. Geografiska Annaler. Series B, Human Geography, 53 (1): 28-39.

Data Sources

Helianthus schweinitzii site specific GIS data was supplied by Suzanne Mason, Environmental Biologist with the North Carolina Natural Heritage Program.

Soil maps and GIS data were downloaded from the NC One Map site (http://www.nconemap.com/data.html) and US Department of Agriculture's Natural Resources Conservation Service site (http://soils.usda.gov/survey/geography/).

Archaeological site specific GIS data Randolph and Cabarrus counties was supplied by the NC Office of State Archaeology (NCOSA).

Historic maps were obtained from the NC Office of State Archaeology and David Rumsey's historic map web site (http://www.davidrumsey.com/), and NC Office of Archives & History's web site, http://www.ah.dcr.state.nc.us/sections/hp/colonial/Maps/.

Primary and secondary roads and railroad GIS data was downloaded from the NC Department of Transportations web site (http://www.ncdot.org/it/gis/DataDistribution/default.html)