A GEOGRAPHIC ONTOLOGY AND GIS MODEL FOR CAROLINA BAYS

A Thesis
by
JACOB RICHMOND TURNER

Submitted to the Graduate School
Appalachian State University
in partial fulfillment of the requirements for the degree of
MASTER OF ARTS

August 2010
Department of Geography and Planning

A GEOGRAPHIC ONTOLOGY AND GIS MODEL FOR CAROLINA BAYS

A Thesis
by
JACOB RICHMOND TURNER
August 2010

APPROVED BY:

____
Christopher A. Badurek
Chairperson, Thesis Committee

____
Gabrielle Katz
Member, Thesis Committee

____
Zack E. Murrell
Member, Thesis Committee

____
James E. Young
Chairperson, Department of Geography of Planning

____
Edelma D. Huntley
Dean, Research and Graduate Studies

Copyright by Jacob Richmond Turner 2010
All Rights Reserved

ABSTRACT

A GEOGRAPHIC ONTOLOGY AND GIS MODEL FOR CAROLINA BAYS
(August 2010)

Jacob R. Turner, B.A., University of Georgia.

M.A., Appalachian State University

Chairperson: Christopher A. Badurek

Carolina bays are a unique geomorphologic entity located along the Atlantic coastal plain. Even without the benefit of an overhead view, they have been noted as a distinct feature of the coastal plain as first described by the South Carolina Geological Survey of South Carolina in 1848. The first aerial photographs in the 1930 coastal South Carolina region revealed that the unique depression wetlands were more than just a strange local phenomenon. Aerial photos enabled observers to see qualities in addition to their relative distribution that make them unique: their oval shape, northwest to southeast orientation and the presence of raised sand rims along their eastern and southeastern edges in many instances.

Being such a distinctive surface feature and recognized for their ecological value, it would seem that Carolina bays would have been defined within their own map coverage across the Atlantic Coastal plain. However, just two statewide inventories have been completed for South Carolina and Georgia, and one for North Carolina has never been conducted. While previous inventories have employed onscreen digitization with Geographic Information Systems (GIS) in order to inventory bays, researchers have raised concerns over

how individuals define Carolina bay as a geographic entity. The differences in human perception make the classification of geographic entities that exist on a continuum such as Carolina bays a challenge and may have contributed to widely varying estimates of their numbers.

In order to explore the classification issues related to Carolina bays, and the usefulness of geographic ontology and cartographic modeling for inventory, a cartographic model was constructed for use within the Ocean Bay quad in Francis Marion National Forest in Berkeley and Charleston Counties, South Carolina. To test the model's selective ability, a comparison was made between Carolina bay features that a researcher selected and bays identified by a cartographic model. The model positively identified 76 percent of Carolina bays that a researcher identified in an image within a single quadrangle. The approach used in this model showed that the initial identification rule of any pixel within a bay's border counted as a positive identification was inadequate. Other aspects not accounted for, including false positive identification, neither researcher nor model being able to identify a bay, or bays that the model was able to select that the researcher was not were added into a subsequent model. Results from the amended model show fewer researcher identified instances of Carolina bays, but a slightly higher rate of mutual identification by the model and the researcher. With these complications in mind, a similar approach was taken with Bladen County North Carolina, but with significant revisions.

A cartographic model was created for Bladen County North Carolina in which bay characteristics were selected from the North Carolina Gap Analysis Program (GAP) land use/landcover dataset, the Soil Survey Geographic Database (SSURGO) and National Wetlands Inventory (NWI). The predictive ability of the model was assessed by manually

selecting Carolina bays from a high resolution image and comparing the manually selected bays with the model identifications. In order to remedy the issue of forcing all instances of bays into one of two categories (either an object is a bay or it is not), a ranking system was developed that was based upon a core/radial cognitive model, and the approach taken with the Savannah River Ecology Lab (SREL) inventory. The rule for positive identification was changed from a single pixel to a visual estimation of 50 percent coverage of a Carolina bay. As a whole, the predictive model identified 57 percent of the features also identified manually by the researcher, but the bay ranking system gives a different breakdown of how well the model worked within each category: exemplar (86 percent), less distinct (79 percent), bay-like (53 percent), and destroyed (19 percent) show significant differences. In addition to the ranking system, other attributes were assessed, such as the presence or absence of a sand rim, water visibility, overlap, diverging, long axis length and orientation.

The analysis shows that the model has the potential to identify well defined bays with at least 50 percent areal coverage, and as such offers the first iteration of a computational ontology for the Carolina bays of Bladen County, North Carolina. Results from this research may provide a basis for modeling the entire range of Carolina bays, defining one of the most curious features of the Atlantic Coastal Plain and uniting differing definitions under one digital concept.

ACKNOWLEDGEMENTS

I would like to thank my committee members, Chris Badurek, Gabrielle Katz, and Zack Murrell for their patience and guidance through the research process. Committee chairperson Chris Badurek deserves special mention. Through him, I was introduced to the world of Geographic Information Systems and Science. A scholarship award was gratefully received from the North Carolina Arc Users Group, and travel awards were graciously given by the Appalachian State University Office of Student Research. Technical assistance with GIS software and theoretical knowledge were provided by Stephanie Smith, Lloyd Edwards, James Waynick, Jeff Colby, and Robert Norman Brown.

There were many who offered insight on the Carolina bay phenomenon, but a few deserve special mention due to their expertise on the subject and their willingness to assist me in a better understanding of bays. They include: Hans Rohr- NC Division of Forest Resources- Guided tour of the Bladen Lakes State Forest and the high resolution imagery used in the Bladen County North Carolina study, Bruce Sorrie- NCDENR for confirming the need for a statewide Carolina bay inventory and field identification of the natural communities common to Carolina bays in Bladen Lakes State Forest, Ralph Willoughby- South Carolina Geological Survey for introductory knowledge on age and formation of Carolina bays, Shan Cammack- GADNR, for allowing me to examine the Georgia GIS Inventory of Carolina bays and Thomas Ross- UNC Pembroke for insight into the semantic issue and other general information about the state of bay research past and present. An extra special thank you goes to Kathy Brown for rescuing me from word processor issues, and to Sandra Ziegler who assisted me with editing and text justification issues. Last but not least, my family, Carrie Turner, David Turner, and Patricia Sherrer, for their support both financial and emotional. Without you, it would have been a much harder row to hoe.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

The Carolina bay is a unique geomorphologic entity. Even without the benefit of an overhead view, they have been noted as a distinct feature of the coastal plain of the Carolinas. Michael Toumey (1848) first described them in the Geological Survey of South Carolina in 1848 as “flat and shallow…reminding one of a race course” (133-134). The first aerial photographs in the 1930 coastal South Carolina region revealed that the unique depression wetlands were more than just a strange local phenomenon (Savage 1982; Ross 2003). The overhead visibility enabled observers to see qualities in addition to their relative distribution that make them unique: their oval shape, northwest to southeast orientation and the presence of raised sand rims along their eastern and southeastern edges in many instances (Savage 1982).

The geographic information technology that revealed Carolina bays to the scientific community has continued to advance. Aerial photography is now commonplace, as is satellite imagery. Advanced image retrieval and processing in conjunction with geographic information systems (GIS) have made the surface of the earth visible on many scales, with many derivative datasets based on the aerial view. Being such a distinctive surface feature and with the abundance of data available today, it would be expected that Carolina bays would have been defined within their own map coverage across the entire Atlantic Coastal plain. However, there are just two statewide inventories that exist in South Carolina and

Georgia, and one smaller area specific inventory on the Department of Energy's (DOE) Savannah River Ecology Laboratory (SREL), that have laid the ground work for future efforts. A statewide bay mapping project for North Carolina has yet to be conducted. Older methods have employed GIS and onscreen digitization in order to inventory bays, but there exists the issue of what to include within the database. How does a researcher define a Carolina bay? The time has come to tie past experience into the present, creating a body of knowledge that will shed light on the distribution of Carolina bays in Bladen County, North Carolina and to contribute to the ongoing research in cartographic modeling and classification systems in geographic information science (GIScience).

1.1 Research Significance

While a bay mapping project is significant to several fields, the disciplines of GIScience and ecology will benefit the most from this study. Carolina bays are considered to be isolated wetlands and have been removed from federal protection previously afforded them by the Clean Water Act of 1977 (Sharitz 2003) by a court case known as the Solid Waste Agency of Northern Cook County, Maryland (SWANCC) versus the United States Army Corps of Engineers (Sharitz 2003; Batzer and Sharitz 2006). This potentially could have negative effects, as bays are known breeding grounds for amphibian life (Pechmann et al. 1989; Semlitsch and Bodie 1998; Gibbons et al. 2006). Their typical isolation from flowing water insures the absence of predatory fish (Sharitz 2003; Gibbons et al. 2006), thus during wet periods, bays become extremely viable breeding grounds (Pechmann et al. 1989; Semlitsch and Bodie 1998; Batzer and

Sharitz 2006), which have in one case been observed to have “one of the highest species diversities known for amphibians” (Semlitsch and Bodie 1998, 1131) .

In addition to amphibian breeding grounds, bays provide habitat for rare and regionally endemic plants (Bennett and Nelson 1991; LeBlond 2001; Van De Genachte and Cammack 2002). Many varieties of carnivorous plants are included, such as Venus flytrap, pitcher plants (Semlitsch and Bodie 1998), sundew, and bladderwort (Luken 2005). The evolution of carnivorous plants in particular, it is thought, proceeded under the influence of fire as a natural part of the ecological landscape (Luken 2005). Currently they are imperiled due to the lessened presence of fire in modern land management practices (Luken 2005). Thus, it is likely that the carnivorous plants will receive additional pressure from the loss of habitat that can occur with the removal of protection of Carolina bays.

Even prior to the SWANCC case, Carolina bays were recognized for their ecological value (Bennett and Nelson 1991; Schalles et al. 1989). This was the purpose behind the work done in South Carolina both on the state level and at the SREL (Schalles et al. 1989). In light of the SWANCC Case, Georgia followed the path of South Carolina and created an inventory using ArcGIS to digitize Carolina bays onscreen.

In addition to the benefits of a GIS inventory for ecological research, the creation of an inventory of Carolina bays will contribute to the body of growing knowledge within the field of GIScience. Even without new technology improving research and inventory capabilities, differences in human perception make the classification of geographic entities that exist on a continuum such as varieties of wetlands a challenge. This is a significant issue within the Carolina bay literature, and may have contributed to widely varying estimates of their numbers (Lide 1997; Sharitz 2003; Ross 2003). While classification difficulties are an important issue within bay research, they are not unique to it. The problems related to classification are a common theme in the GIScience field, where they are known as geographic vagueness (Worboys and Duckham 2004). How a researcher defines a particular entity may seem to be a straightforward process, but when observing natural phenomenon, it may be hard to draw a line between classes (Mark 1993). The natural world exists on a continuum beyond the constructs of time and language that the human mind imposes upon it, making absolute classification impossible. How classifications are derived has been explored, but not within the entwined contexts of GIScience and Carolina bays. The GIScience research field of geographic ontology is dedicated to defining entities so that they may be represented digitally within a database using an explicit set of criteria. According to Mark (1993), the practical application of this approach is realized through cartographic modeling. Carolina bays have traditionally been mapped by marking their known locations on hard copies of aerial imagery (Bennett and Nelson 1991), or creating polygons using a GIS (Van De Genachte and Cammack 2002) or image processing software. By using a cartographic modeling approach, GIS has the potential to predict the likelihood that a Carolina bay exists in a particular place, and while doing so, to create a computationally tractable definition of Carolina bays, potentially making an inventory an easier and automated process. In addition to aiding inventory efforts, geographic ontology and cartographic modeling may alleviate the definition problems experienced with other inventories by defining bays digitally.

1.2 Justification

There is much that is not understood about Carolina bay wetlands, including age, origin, and hydrological function. Considering these things in conjunction with their known ecological importance and the removal of Federal protection after SWANCC, a better understanding of Carolina bays distribution is important if a case is to be made to protect them; it can be used as a "baseline" for other bay conservation efforts (Van De Genachte and Cammack 2002). This baseline knowledge of the distribution of bays is an established need by many natural resource agencies. Agencies such as the South Carolina Non Game and Heritage Trust Program (Bennett and Nelson 1991), The North Carolina Department of Environment and Natural Resources (NCDENR) (Bruce Sorrie, pers. com. 2009), the Georgia Department of Natural Resources (Van de Genachte and Cammack 2002) and the SREL (Schalles et. al. 1989) have all seen the value of such an inventory in the past, and have devised research plans to create inventories and studies of Carolina bays within each of their respective domains.

1.3 Research Contributions

Through the use of GIS and high resolution imagery, it is possible to create a realistic estimation of the distribution of Carolina bays within Bladen County. It is hypothesized that with the creation of a model to indicate their locations, that bays can be identified and mapped easily. In addition to ease of mapping, the layers added to the model represent characteristics that offer a way of defining Carolina bays digitally. This approach has the potential to unite all previous studies, becoming a growing knowledge base for a unique and threatened wetland of the Carolina coastal plain.

CHAPTER II

LITERATURE REVIEW

2.1 Introduction

In 1848, geologist Michael Toomey was charged with writing a report to describe the available natural resources within the state of South Carolina. It is in this account that one of the first reports of an odd, distinctive landform is mentioned. Among his descriptions of surface features, there stands an anomaly:

> A peculiar feature in the topography of this sand hill region is the number of *circular depressions* that are scattered over the surface. They are *not deep and conical, like "lime sinks," but flat and shallow, at first sight reminding one of a racecourse*. They are numerous in Barnwell district, and may be seen between the Courthouse and Aiken; *some filled with water and others dry*. Between Orangeburg and Rocky Swamp, on the Edisto there are several - *some of them many acres in extent, quite level, and having the edges somewhat raised above the ordinary surface*. They have quite an *artificial appearance* and it was not before I had examined the ponds, above Vaucluse, on Horse Creek, that I was able to make them out… Other examples were pointed out to me of *ponds of considerable extent that were known for years with water, but becoming dry, now present the depressions* of which I have spoken. (Tuomey 1848, 143-144 italics added for emphasis)

Toumey's (1848) description is unmistakable. His terms "flat and shallow…reminding one of a racecourse…some filled with water and others dry…quite level and having the edges somewhat raised above the ordinary surface…depressions…"(143-144) are characteristics of what is now known as a Carolina bay. While Toumey (1848) and L.C. Glenn (1895) noted that this phenomenon was observable in more than one place in South

Carolina, the magnitude of which this anomalous landform covered the coastal plain landscape was not discovered until the 1930s.

Carolina bays were first recognized as more than just a localized depression wetland phenomenon with the 1930 aerial photography survey of a timber company's land holdings in Horry County, South Carolina (Figure 2.1) (Savage 1982). The famous series of photographs revealed that Carolina bays tend to be oval in shape, some have sand rims on their edges, and are oriented northwest to southeast, many showing parallel axes (Savage 1982).

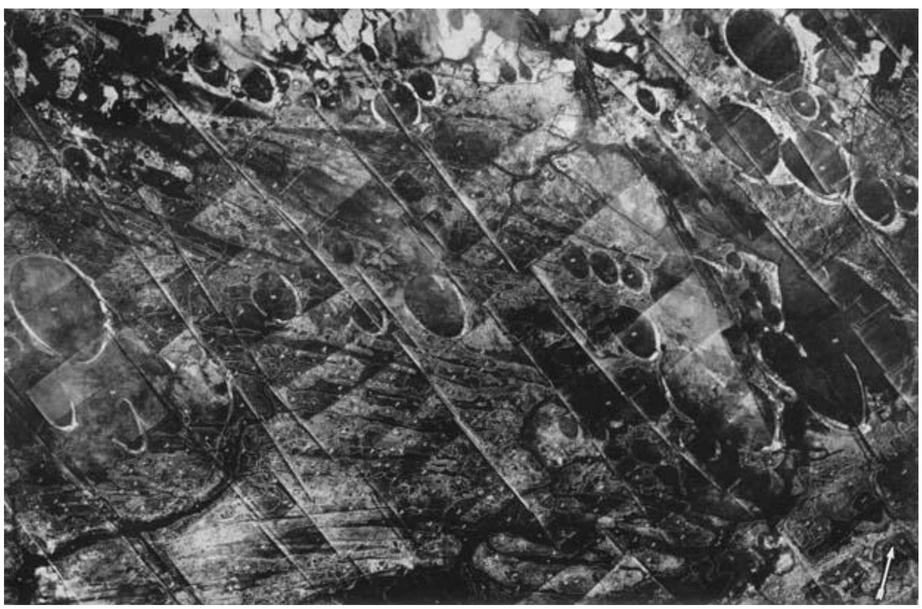

Figure 2.1 1930s Era Aerial Photograph of Carolina Bays in Horry County, South Carolina.

The aerial photography that enabled the discovery of bay characteristics helped to spark the long running debate over the circumstances of their origin, and opened the door to future bay research (Savage 1982; Ross 2003). While debate over origin theories raged during the 1930s and 40s between surficial geologic processes and a meteor strike, hypotheses were never completely resolved (Sharitz and Gibbons 1982; Savage 1982; Ross 1987; Horton and Zullo 1991; Ross 2003), research interest in Carolina bays has continued, but with new priorities.

According to Carolina bay scholar and bibliographer Thomas Ross (1987), there have been several changing trends in Carolina bay research. Starting with origin theories, research trends have moved toward soils and ecology (Ross 1987), a pattern that deals more with their function as wetlands (Nifong 1998; Ross 2003). In addition to the changing nature of inquiry associated with Carolina bays, geographic information technology which introduced the aerial view of bays has also been growing, developing its own questions. Today, there exists a need to use research from GIScience toward the goals of Carolina bay conservation and knowledge base development for GIS.

Before Carolina bay conservation efforts can proceed, bay locations must be known. Before a distribution map can be created, a Carolina bay must be defined in a way that can be readily expressed and agreed upon by other researchers, and be easily translated from characteristics within human language and into a computationally tractable form. A computationally tractable form becomes a digital definition of Carolina bays and a growing knowledge base. The knowledge base is not an entirely abstract thing: it is a relational database created for representing these surface features, and their relationships with other datasets. To begin the process, Carolina bays must be examined: one- within their place in the overall spectrum of wetlands, two- by considering the need for conservation efforts , and three- within the context of previous research pertaining to Carolina bays and the use of GIS and remote sensing technology.

2.2 Carolina Bays and the General Spectrum of Wetlands

Wetlands throughout their global range have many different names such as carr, bog, fen, swamp, marsh, seeps, pocosin, Carolina or Delmarva bay (Richardson 1995; Sharitz 2003). Throughout the world, there are definitions of wetland types that overlap in concept, but with slightly different meanings to different cultures, language speakers, and individuals (Richardson 1995; Mark 1993). Before the widely accepted system for their classification was used, a wetland was defined based upon the perspective of the researcher (Richardson 1995). The United States Fish and Wildlife Service (USFWS) devised a classification system for wetlands that attempts to diffuse the vagueness of words that make wetland definitions by colloquial names difficult (Cowardin et al. 1979). Through their system, vagueness in wetland definitions in the United States has been lessened to a great degree, giving scientists and planners a common ground upon which to assess wetland area and structure (Cowardin et al. 1979; Richardson 1995).

Wetlands in general are described by the USFWS as land existing upon a gradient between permanent inundation with water and permanently dry uplands (Cowardin et al. 1979; Richardson 1995). Along the continuum from wet to dry, the presence of water loving (hydrophytic) vegetation, hydric soils, and water "at or near the surface" of the earth exist in different combinations that also help to define ephemeral wetland boundaries (Cowardin et al. 1979, 11). Today, the National Wetlands Inventory (NWI) utilizes a classification system that attempts to categorize wetlands roughly along this gradient while also taking into consideration topographic position on the landscape, and the source of hydrologic input (Cowardin et al. 1979; Richardson 1995). Known as the Cowardin classification, it has five topographical/ecological categories as described in the manual (Cowardin et al. 1979):

1-**Marine:** Mostly deep water habitat that includes the sea and shoreline.
2-**Estuarine:** Wetlands associated with land as opposed to the open ocean, but still including the influence of salinity and tidal change.
3-**Riverine:** Moving, deep water wetlands within the confines of a river channel.
4-**Lacustrine:** Contain standing, non-flowing water where "trees, shrubs and emergent plants do not make up more than 30 percent aerial coverage in areas less than 2 meters in depth" (Richardson 1995, 538).
5-**Palustrine:**

> …the Palustrine System was developed to group the vegetated wetlands traditionally called by such names as marsh, swamp, bog, fen, and prairie, which are found throughout the United States. It also includes the small, shallow, permanent or intermittent water bodies often called ponds. Palustrine wetlands may be situated shoreward of lakes, river channels, or estuaries; on river floodplains; in isolated catchments; or on slopes. They may also occur as islands in lakes or rivers. The erosive forces of wind and water are of minor importance except during severe floods (Cowardin et al. 1979, 23).

In addition to the main topographical/ecological categories, wetlands are placed in classes that correspond to their sources of water (Figure 2.2). There are three inputs that come into consideration: precipitation, groundwater, and surface flow (Cowardin et al. 1979; Richardson 1995). The three sources can factor together to some degree, with varying levels of influence existing between inputs, or one input may have a dominant influence (Richardson 1995).

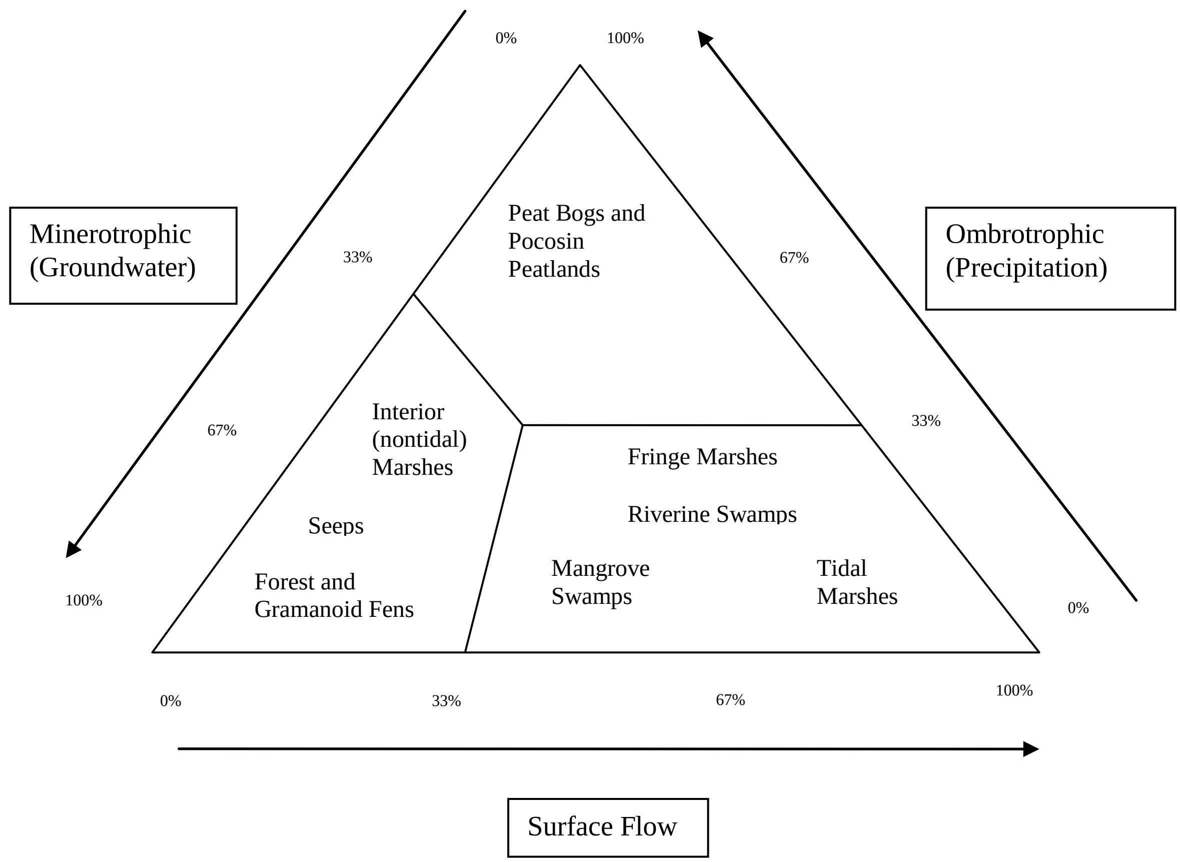

Figure 2.2 Relative Importance of Water Source to Major Wetland Types On the Landscape. Adapted from *The Encyclopedia of Environmental Biology Volume 3: Wetlands Ecology* (Richardson 1995).

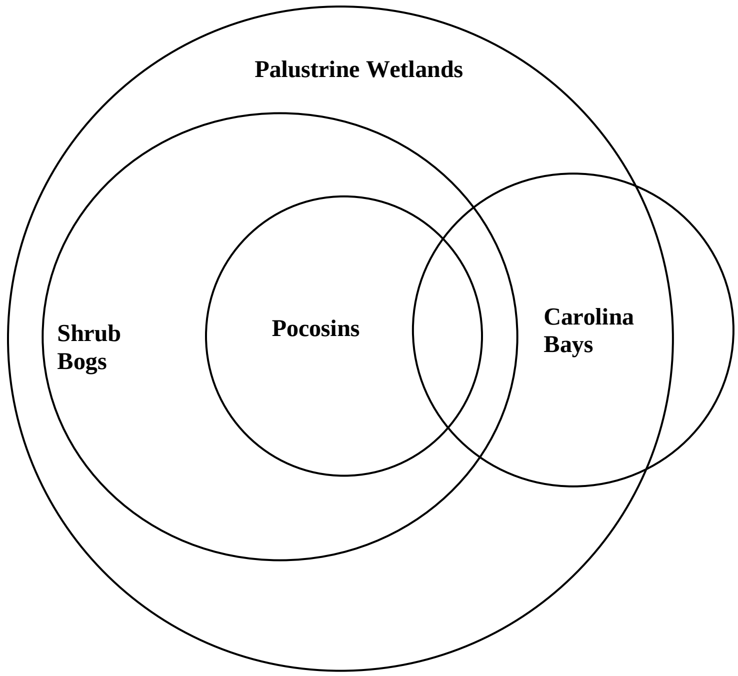

Figure 2.3 The Relation of Shrub Bogs, Pocosins, and Carolina Bays to Each Other and to the General Class of Palustrine Wetlands.(E.C. Pendleton, US Fish and Wildlife Service, Slidell LA). Adapted from *The Ecology of Southeastern Shrub Bogs (Pocosins) and Carolina Bays: A Community Profile* (Sharitz and Gibbons 1982).

A majority of Carolina bays fit within the palustrine class of the Cowardin system (Figure 2.3) (Sharitz and Gibbons 1982; Ross 2003). While a few may fit within the lacustrine system that have parts that are permanently inundated, generally bays tend to go through cycles of wet and dry periods, placing them on the “dry end” of the wetlands continuum, especially as they diminish in size (Sharitz 2003, 551). The dry end descriptor means that Carolina bays are typically ombrotrophic (rain fed), and oligotrophic (nutrient poor) (Sharitz and Gibbons 1982; Schalles et al. 1989; Richardson 1995). The primary source of water being rainfall and lack of a connection to moving surface water (Sharitz and

Gibbons 1982; Schalles et al. 1989; Sharitz 2003) has in recent history led to Carolina bays being referred to as an isolated wetland (Leibowitz 2003; Sharitz 2003). Since this vague descriptor has many implications and has an impact on the legal protection status of Carolina bays, further examination is necessary.

2.3 Isolation and its Importance to Carolina Bays

An influential court case affecting wetlands known as SWANCC has, as of 2001, reduced the protection status of isolated wetlands (Batzer and Sharitz 2006). The term isolation when used in reference to wetlands can lead to confusion and may lack a scientifically sound definition (Leibowitz 2003). Isolation in its most basic sense according to Leibowitz (2003), "…suggests an object that is completely separate from and lacks interaction with other objects" (518). The definition of isolated wetlands given by Tiner (2003) and suggested by Leibowitz (2003) typically means "geographic isolation, or being surrounded on all sides by upland" (Tiner 2003, 637). This is related to but not the same as the concept of hydrological isolation, which has typically referred to wetlands with no direct connection to streams or rivers (Leibowitz 2003). Isolation in the ecological/biological sense has different implications. Ecological isolation is such that barriers exist that would keep populations of living things from interacting (Leibowitz 2003). Each one of these different definitions of isolation apply to Carolina bays and are useful to demonstrate their functions and importance as ecosystems.

2.4 Hydrological Isolation

Carolina bays may exist in geographic isolation by Tiner's (2003) definition, and lack surface flow from springs and streams in most cases, but there are exceptions (Lide 1997; Sharitz 2003). Some bays may be connected to streams via human disturbances such as ditching, which has been a common practice to drain land for agricultural purposes (Sharitz and Gibbons 1982; Sharitz 2003). They may also serve as the headwaters of perennial streams (Lide 1997) and may have connections to groundwater in some instances although this interaction has not been thoroughly examined within the Carolina bay context throughout its complete range (Sharitz 2003). Isolated wetlands in general may also become connected to one another through surface flow during flooding events (Leibowitz 2003) although this may be rare among Carolina bays (Sharitz 2003). It has been suggested that isolation of wetlands be considered on an "isolation-connectivity continuum" (Leibowitz 2003, 520) because the circumstances of their hydrological inputs can vary by particular instance and water year. This makes the categorization of Carolina bays or any wetland type as hydrologically isolated a difficult and perhaps impossible task. The bays that do display a tendency toward being primarily ombrotrophic and oligotrophic provide critical habitats for organisims that have adapted to and rely upon these conditions for their survival (Sharitz 2003). Among many other organisims, two have distinctly appeared in the literature and are considered here in context of ecological isolation: amphibians and the Venus flytrap.

2.5 Amphibian Decline and Effects of Biological/Ecological Isolation

Amphibians are currently experiencing a rapid global decline in population. Estimates show that amphibians have been in existence around 350 million years (Miller 1998), and as such are considered to be resilient lifeforms having survived four known eras of major biodiversity loss (Wake and Vredenburg 2008). As of late they may be regarded as "multipurpose sentinels of environmental health" (Wake and Vredenburg 2008, 11467) or more specifically as an indicator species: They "…serve as an early warning that a community or ecosystem is being damaged" (Miller 1998, 133). Many causes have been implicated, but two general anthropogenic categories apply: habitat destruction (Miller 1998; Semlitsch and Bodie 1998; Stuart et al. 2004; Gibbons et al. 2006; Wake and Vredenburg 2008) and climate change (Stuart et al. 2004; Wake and Vredenburg 2008). In the Southeastern United States the primary cause of decline is thought to be habitat loss (Semlitsch and Bodie 1998; Stuart et al. 2004).

Carolina bays have shown in the past to be extremely healthy breeding habitats for amphibians (Semlitsch and Bodie 1998; Batzer and Sharitz 2006). One study has shown that within a single small bay there was, "…observed one of the highest species diversities known for amphibians" (Semlitsch and Bodie 1998, 1131) Ponding of water in Carolina bays is determined primarily by precipitation, and lack of connection to streams (Sharitz and Gibbons 1982; Sharitz 2003). As such, some of the smaller bays and depression wetlands on the landscape will dry completely for part of the year and not sustain fish populations that would normally eat eggs and young (Semlitsch and Bodie 1998). These conditions create temporary breeding sites in Carolina bays that support large numbers of amphibians (Pechmann et al. 1989; Semlitsch and Bodie 1998).

While smaller bays are indicated as the most likely preferred breeding habitat, overall wetland loss affects the physical distribution and therefore the biological connectivity of wetlands, and can create instances of biological isolation (Semlitsch and Bodie 1998). As Carolina bays and other depression wetlands on the landscape are destroyed or altered, the space between other bays and wetlands increase, potentially isolating populations of amphibians from one another (Semlitsch and Bodie 1998). This lessens the likelihood that amphibian populations experiencing reproductive challenges can reach other viable rescue populations (Semlitsch and Bodie 1998). While Carolina bays are not usually examples of isolated habitats, they are in danger of becoming so. This makes Carolina bays an immediate conservation priority, the distribution and condition of which is only known in a relative sense in the state of North Carolina.

2.6 Carolina Bays and *Dionaea Muscipula*, The Venus Flytrap

In addition to providing habitat for amphibians, Carolina bays can provide habitat for regionally endemic and rare plants (Schalles et al. 1989; Bennett and Nelson 1991; LeBlond 2001; Van De Genachte and Cammack 2002). Carolina bays taken as geomorphologic features are not themselves zones of endemism for plants, and only in one known case do they support endemism in animals (Van De Genachte and Cammack 2002). The largest of the bays, Lake Waccamaw in North Carolina supports several species of fish not found elsewhere (Van De Genachte and Cammack 2002). However, several species of carnivorous plants, such as the sundew, pitcher plant, and Venus flytrap prefer the well drained, xeric, low nutrient ecotone present along the rims of some Carolina bays (Luken 2005). The Venus flytrap is a well documented example. It is endemic to the Cape Fear Arch region of the coastal plain of the Carolinas (LeBlond 2001), a region which overlaps very closely with the greatest global concentration of Carolina bays and Bladen County, North Carolina (LeBlond 2001; LeBlond 2008). The Venus flytrap has been successfully transplanted to other environs (Luken 2005), but is known to occur naturally only within a cluster of counties within the Cape Fear Arch region of the coastal plain of the Carolinas (LeBlond 2001). It is thought that the Venus flytrap evolved with fire as a naturally occurring part of its life cycle (Luken 2005). Because of liability issues, fire is not a part of current land management practice in some areas, and therefore has a lessened presence on the natural landscape where these plants and bay rims exist. If more bay wetlands are lost, then potential natural habitat for this federal species of concern will also be lost, placing additional pressure on a plant that also is struggling to exist without the natural influence of fire.

After these considerations, it is easy to see that an exhaustive inventory is needed as a base line for conservation efforts. Some work had been done toward this end in other states before the SWANCC case in 2001, indicating some have always considered Carolina bays a conservation priority. Past inventories have used different methods, occurred during different time periods, or used different resources and technology. Thus, the output of these studies have had slightly different definitions of Carolina bays. Their mission however, had a common goal of quantifying and understanding Carolina bay distribution and are the beginnings of knowledge base construction.

2.7 Previous Inventories

The first statewide inventory of Carolina bays was initiated by the South Carolina Heritage Trust program in 1983. Its primary purpose was to gain an understanding of the distribution and status of bays within South Carolina so that relatively intact bays could be selected for protection and conservation (Bennett and Nelson 1991). Their methods included visually selecting Carolina bays from aerial photography provided by the Agricultural Stabilization and Conservation Service, spanning the years 1972 and 1983 (Bennett and Nelson 1991). Carolina bays were defined by Bennett and Nelson (1991) "based solely on their elliptical shape"(1). Long axis orientation was measured and used as a cutoff for analysis, due to bays tendency to lose ellipticity as their size diminishes, thus making their identification from aerial photos difficult (Bennett and Nelson 1991). Vegetation was also considered at first, but was excluded due to the potential error involved with identifying vegetation communities this way (Bennett and Nelson 1991). Estimations of disturbance were made from the aerial photographs, and was the basis for selection of Carolina bays for field visits (Bennett and Nelson 1991).

Around the same time, the Savannah River Plant National Environmental Research Park Program in Aiken, South Carolina, published an inventory of the bays located within the park boundaries in 1989. The purpose of their study was similar to the statewide survey in that the research was driven by conservation concerns and in addition to the inventory compiled existing information about factors common to bay ecology of the region (Schalles et. al. 1989). Their methods involved reviewing color infrared photography at a scale of 1:15,840, then marking their positions on United States Geological Survey (USGS) topographic maps. From this study an inventory was born that became the basis for other studies (Semlitsch and Bodie 1998; Sharitz 2003). It also laid the groundwork for what would become a GIS inventory for the Carolina bays of the SREL (Semlitsch and Bodie, 1998).

In light of the SWANCC decision and the prior efforts of SREL and the state of South Carolina, the Georgia Department of Natural Resources undertook a statewide GIS Inventory of Carolina bays (Van de Genachte and Cammack 2002). Their objective was the same as the efforts that came before them: a distribution and status baseline for conservation efforts of Carolina bays (Van de Genachte and Cammack 2002). Their work proceeded in phases, similar to Bennett and Nelson's (1991) work in South Carolina. The first phase involved creating an inventory of Carolina bays by digitization and attribution with a GIS. Following this step, an assessment of disturbance was made from aerial photography, which was then used to select and prioritize bays for field visits (Van de Genachte and Cammack 2002). This project used a combination of methods from older studies in conjunction with the latest GIS technology to provide an assessment of Carolina bays within Georgia's borders.

2.8 An Inventory for North Carolina?

Considering the previous efforts to locate and evaluate the condition of Carolina bays prior to the SWANCC case and the renewed efforts to understand distribution of depression wetlands in general after the ruling (Tiner 2003; Munoz et al. 2009), One would assume that North Carolina would also begin an inventory of Carolina bays. According to Bruce Sorrie, a botanist with the North Carolina Department of Environment and Natural Resources, North Carolina has no distribution map of Carolina bay wetlands and is in need of such an inventory (personal communication 2009). While large scale ecological studies have been conducted within the state, these were surveys of plant communities common to Carolina bays in the Carolinas (Nifong 1998). They were not a distribution map of North Carolinas bays.

Motivated by the SWANCC ruling, the North Carolina Division of Water Quality has been working on a GIS based project to estimate the extent of depression wetlands in a test area spanning eight counties in North and South Carolina (Munoz et al. 2009) While this project uses commonly available datasets to create a probability surface of depression wetlands within the ArcGIS platform, it is not exclusive to Carolina bays (Munoz et al. 2009).

While previous inventories have created an estimation of the number and location of Carolina bays in other states, there have been issues related to what features should be classified a bay (Lide 1997; Ross 2003). Robert F. Lide, a former research affiliate at the SREL in Aiken, South Carolina was concerned previous studies included features that, "lack some or all of the specific criteria" (Lide 1997, 91). Additionally, as observed of the Carolina bays of Lewis Ocean Bay Heritage preserve in South Carolina, bays are "…imbedded within a mosaic of non-bay depression wetlands…" (Laliberte et al. 2007, 874) in which definitive bay shapes grade into the ambiguous. This may have caused differences in the overall estimates of their numbers (Lide 1997; Sharitz 2003). Lide's minimum requirement for a terrain feature to be defined as a Carolina bay is that it must be at least oval or round in shape (Lide 1997). When evaluating bays from satellite imagery or aerial photography, this rule has allowed their digitization such as in the SREL and Georgia efforts, or to be marked on a hard copy of an image (Bennett and Nelson 1991).

2.9 Classification in GIScience

The identification problem is not unique to Carolina bays. As discussed by Mark (1993), the placement of a geographic entity within a category is not always an easy task.

Classification within the sciences has traditionally forced its subjects into binary or Boolean (Fisher, Cheng, and Wood 2007) classification systems: either an instance of a thing "…is a member of a particular set or it is not" (Mark 1993, 271). This common scientific practice does not match the complexities evident in the real world and complicates the task of formally representing phenomena that exist as a continuum without crisp boundaries. According to Phillips (2007), "…landforms and landscapes are circumstantial, contingent results of deterministic laws operating in a specific environmental context, such that multiple outcomes are possible…all landscapes are perfect" (159). The infinitely complex, perfect surface of the earth requires the human mind to employ the generalizations of language to facilitate cognition and communication:

> We cut nature up, organize it into concepts, and ascribe significance as we do, largely because we are parties to an agreement to organize it in this way- an agreement that holds throughout our speech community and is codified in the patterns of our language. (Whorf 1940 as quoted by Mark 1993)

The colloquialisms commonly used as a part of everyday speech to describe the world have difficulty being translated into commonly defined geographic entities (Mark 1993). For instance, what an English speaking person considers a lake, pond, or lagoon and what a French person considers as such are proven to be significantly different (Mark 1993). Considering the differences in definitions between languages alone makes the communication of information about our world in today's age of light speed information transfer a difficult task. When considering the differences in definition among speakers of the same language that study Carolina bays, it is easy to see that definitions of natural world phenomena can be different within the *same* language (Mark 1993) and as implied by Lide's research, quite possibly within the *same discipline* (Lide 1997). This poses a problem with modern information systems and data transfer. The problem of generalization and language meet with the variability of landscapes and are combined in a term used within the field of GIScience known as geographic vagueness (Worboys and Duckham 2004).

The term vagueness encompasses the questionable cases of geographic objects and entities that are hard to categorize (Worboys and Duckham 2004).Vagueness is part of research challenge within the field of GIScience known as uncertainty within geographic information (Mark 2000). The representation challenge within GIScience is focused on ways to communicate ideas about the highly variable, perfect surface of the earth within the comparatively limited digital realm of computers (Mark 2000; Phillips 2007). Overlapping this challenge is the concept of uncertainty. Mark (2000) lists the potential types of uncertainty as "… measurement error, error due to imperfect interpolation between measurements, gaps (incomplete data), artifacts of graphic or digital processing, and occasional blunders…" or perhaps more importantly when considering Carolina bays and geographic vagueness, "… it may be due to the nature of the phenomenon themselves, such as the extents of objects with indistinct or graded boundaries" (3). The study of formal geographic concepts is known as ontology (Smith and Mark 2003) and may offer a solution to the problems inherent with defining vague geographic entities.

Ontology, in its original sense, is a branch of philosophy that examines the rules of existence (Smith and Mark 2003). Within the domain of artificial intelligence and information science, the term has been appropriated and applied to specific tasks (Guarino 1998). The most common definition held in the literature today is that offered by Gruber (1995) ontology is "a specification of a conceptualization" (1). According to Mark (2003), computational ontology seeks to establish formal tokens and types of geographic entities through the use of computers, the end result of which becomes a "computationally tractable taxonomy" (3). When visualized through GIS, Mark's taxonomical idea can be used to represent entities through the use of cartographic modeling, which can be seen as "the applied side of ontology" (Mark 2003, 3).

Ontology should be considered within the context of information science as an entirely practical pursuit (Smith and Mark 2003). In leaning away from the philosophical meanings, someone constructing an ontology might ask, similarly to Smith and Mark,"How would I represent a Carolina bay within a knowledge base? What characteristics can be included within a database to represent a Carolina Bay?"(6) The process begins by examining the conceptualizations of geographic entities people use to perceive and express the character of their world (Guarino 1998; Smith and Mark 2003). These conceptualizations are broken down, into, "…a clear and rigorous vocabulary" (Guarino 1998, 1) so that entities may be represented digitally as tokens (instances) and types (kinds) (Mark 2003). Smith and Mark identify a common tool within the realm of ontology that perhaps bridges the gap between the cognitive perception and classification of the world and its expression as knowledge: "Existence is then identified as that which is expressed by the existential quantifier of the predicate calculus: 'To be' is then 'To be the value of a bound variable'" (4).

2.10 Cognition and Classification of Bays

Practical cognitive conceptual models are a known starting point for the building of an ontology (Guarino 1998; Badurek and Flewelling 2000; Smith and Mark 2003). GIScientists have explored the pertinent work done toward the understanding of human conceptualization and classification (Mark 1993; Badurek and Flewelling 2000). Many theories have been offered, but Mark (1993) distills them into a sequence of ideas leading to those that most effectively apply to the analysis of geographic entities, offering the work of Rosch (1978), and Lakoff and Johnson (1980) as a framework for understanding categorization. According to Rosch (1978) there are prototypes of an entity or object. These prototypes can be considered to be prime examples of a class or type. Mark (1993) compares the ideas of Rosch (1978) to the work of Lakoff and Johnson (1980), who offered further that the prototypes of entities belong within a central or core position of a concept, with examples having diminishing associated characteristics moving away from the core, until they are no longer included within the class. If an entitiy is considered through the lens of this system, the problems of geographic vagueness and uncertainty are most pronounced on the outside edge of the radial concept, and may assist in offering a workable mental map from which to begin with the formalization of a geographic entity into a knowledge base.

Considering Carolina bays within the context of Lide (1997), Rosch (1978), and Lakoff and Johnson (1980), a preliminary example of how this framework might function can be demonstrated. Lide's (1997) review of bay literature compiles the traditional, prototypical or *core* characteristics of a Carolina bay: "(1) Being elliptical, ovate or circular, (2) Having a long axis orientation that is usually northwest-southeast; and (3) often having a sand rim that is best developed along the eastern and southeastern perimeter" (91). Lide also states that the most common characteristic to bay studies is the elliptical ovate or circular shape (1997). As a GIS analyst tries to classify entities as a Carolina bay, these characteristics are the most exemplary or prototypical, and are the starting point for the development of a measureable descriptive ontology. It begins the task of determining what conceptual characteristics are key for identification, and may be translatable into the aforementioned tokens and types, or bound variables, that exist within a database.

When making the transition from the mental model to the digital world, there are considerations to be made. How does one structure a knowledge base? What terms define our structural works or attributes? A few key words and concepts are worth defining in order to make the process clear. The term “entity” as used thus far in this review has referred to the real world objects or phenomena that are going to be represented as an end result of ontological studies and its applied cartographic model (Mark 2003; Bolstad 2008). “Entity” within the context of database management and design relates to the aforementioned concept, but is used to describe the row**,** record (Bolstad 2008) or tuple within the database itself that ontology would consider a digitally formalized instance of a real geographic phenomenon. The terms “token” and “type” used by Mark (2003) to describe the structure of an ontology overlap within these definitions. Type can be thought of as a general class, while tokens can be thought of instances of that class. The terms class, instance and entity are the conceptual building blocks of programming and database design used in the unified modeling language (UML), (Fowler and Scott 1999) and therefore are the key elements involved with the construction of a computational ontology.

Defining classes is the first step to building a computational ontology (Noy and McGuiness 2001). There are differences in the approach between classes defined for programming purposes and classes devised for ontology. Noy and McGuiness (2001) state that their knowledge of ontologies necessarily start with the object-oriented programming literature, but the structure of the classes involved tends to be different. Object-oriented programming is more concerned with function or action than structure (Noy and McGuiness 2001). Ontological classes are employed to define form (Noy and McGuiness 2001).

Following the earlier cognitive model, the utility of UML can be demonstrated by assuming that Carolina bays are a class. A class diagram illustrates the name of the class, attributes, and operations. Figure 2.4 displays a Carolina bay class diagram where class name describes the overarching class in which all instances or tokens of Carolina bays will occur. While attributes list all possible characteristics available to describe an entity, in both of the aforementioned senses, tokens or instances are derived from these descriptors. Operations describe possible actions or functions of a class.

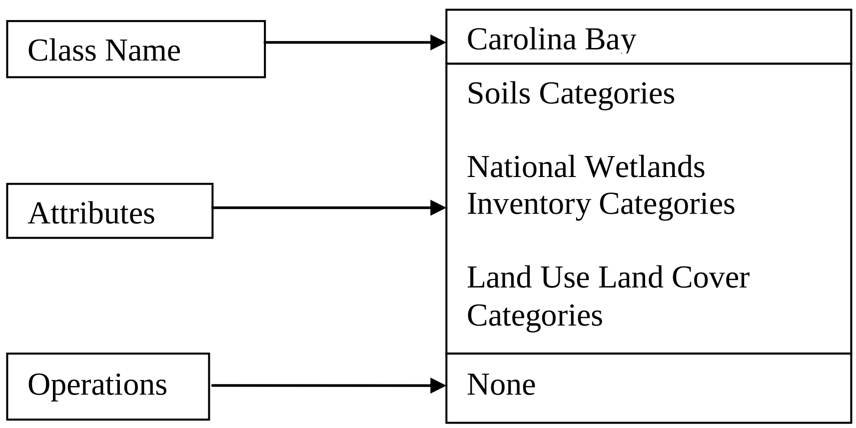

Figure 2.4 Example of a Carolina Bay Class Diagram.

According to Noy and McGuiness (2001) the construction of an ontology or knowledge base is a repetitive process. As they describe it, a knowledge base is constructed, then analyzed with a list of competency questions that generally test the effectiveness of its content and structure. Several iterations are examined before a structure is discovered, but the ontology itself is ever growing and expanding. Additionally they state that no two ontologies are the same. There are many ways to organize and measure concepts, and no two people will produce the same structure and relation within a design (Noy and McGuiness 2001)

Designing an ontology requires converting abstract thought into quantifiable expression within the limited sphere of digital space. It begins by observing the infinitely variable surface of the earth and grouping phenomena into categories in our minds. This preliminary examination has introduced the possibilities of the application of current work in ontology to the Carolina bay problem. The problem is twofold: one- there is a strong core concept of a Carolina bay, but what researchers actually include with that description fits under a much broader set of characteristics according to Lide (1997), and two-the state of North Carolina has no inventory of Carolina bays. This research examines the potential of cartographic modeling as an applied side to ontology and as a solution to differences in bay definitions. By creating cartographic models using characteristics from other datasets, a digital definition of Carolina bays will be built that can determine what features to include within an inventory.

CHAPTER III

METHODS

3.1 Introduction

Cartographic models were constructed to digitally define Carolina bays within two study areas: Francis Marion National Forest, South Carolina, and Bladen County, North Carolina. Model construction was the first step in both studies and utilized three GIS datasets: the Soil Survey Geographic Database (SSURGO), the USGS Gap Analysis Program (GAP) land use/land cover dataset, and the NWI. The second step assessed the effectiveness of the models, where bays and bay-like features were identified manually from an image for comparison. The comparison of the Francis Marion National Forest study to the Bladen County study reveals several significant differences in approach.

3.2 Francis Marion National Forest South Carolina Study

The Francis Marion National Forest study was conducted to determine if a model can successfully select bays and bay like features based on the data characteristics of known bays in Francis Marion National Forest in Charleston and Berkeley Counties, South Carolina.

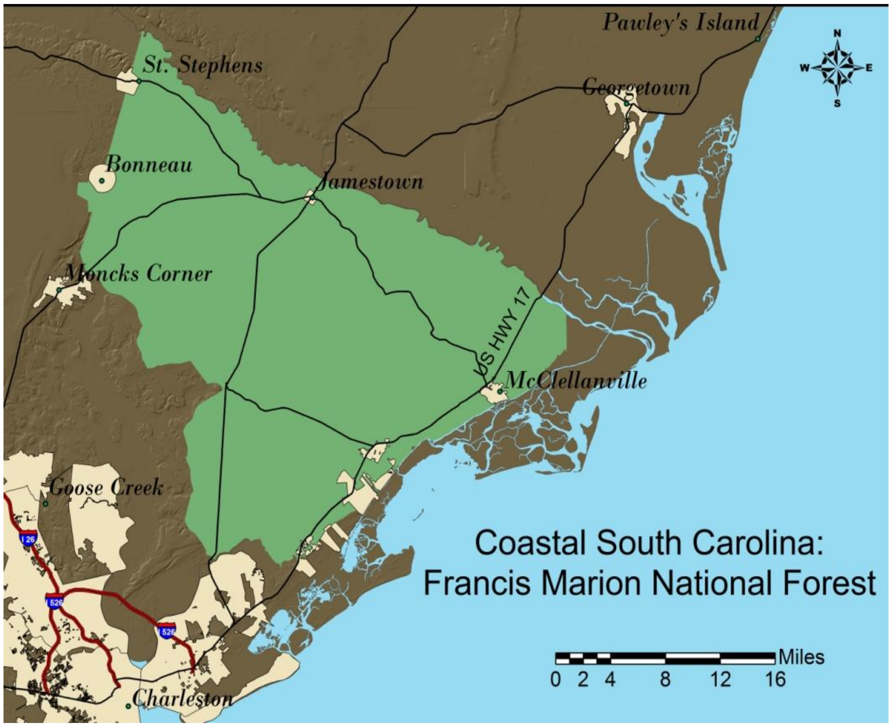

Figure 3.1 Francis Marion National Forest, South Carolina.

Francis Marion was chosen because the author is familiar with the forest from previous work experience. The study does not include the entire forest, but only one quad within its borders, using 2006 one meter resolution digital ortho quarter quadrangle (DOQQ) photography, the NWI (2008), SSURGO (2008), and South Carolina GAP land use /land cover data (2008). Based on the characteristics of Little Ocean Bay, Echaw Road Bay and the soil characteristics of an unnamed bay, a GIS was used to make a predictive model that selects similar features.

Due to the high variability of vegetation, soils, human impacts, and geographic vagueness, it was expected that a model would produce modest results. The use of high resolution elevation data would be helpful in the case of smaller wetlands, but it was not available for inland South Carolina, and the existing elevation datasets were too coarse to show the very slight changes in elevation that represent bays. Following the example set by the SREL inventory, aerial imagery was also used to confirm the presence of a Carolina bay. The South Carolina Department of Natural Resources (SCDNR) website provided one meter resolution DOQQs, the SSURGO dataset by USGS quadrangle, and the South Carolina GAP coverage, a highly detailed land use/land cover dataset. The NWI was obtained from the USFWS website. Following the reprojection and clipping of the data into the shape of Francis Marion National Forest, a cartographic model was constructed by selecting the characteristics common to Carolina bays from each dataset. The process of extraction of relevant characteristics is known as reclassification.

3.2.1 Francis Marion Model

The Francis Marion model used a reclassification process that used a ranking system of one through five, five being the most desirable characteristic for each raster dataset. The selection of the palustrine wetland type from the NWI was due to its mention in the literature by Sharitz (1982) as well as the selection of the pocosin category from the land use coverage. Palustrine was the only selection criteria for the model from the NWI. Table 3.1 displays the criteria and rank for each coverage.

Table 3.1 Model Attributes and Ranking For Francis Marion National Forest Study.

National Wetlands Inventory(NWI)	South Carolina GAP Land Use	SSURGO Soils
Palustrine 5	Pocosin 5	Pamlico Muck 5
	Marsh/Emergent Wetland 4	Rutledge Loamy Fine Sand 5
	Bottomland Floodplain Forest 4	Witherbee Fine Sand 4
	Swamp 3	Pickney Loamy Fine Sand 4
	Wet Scrub/Shrub thicket 3	Leon Fine Sand 4
	Dry Scrub/Shrub thicket 2	Chipley/Echaw Complex 3
	Wet Evergreen 1	Bayboro Loam 2
	Cultivated Land 1	Cainhoy Fine Sand 1
	Wet Soil 1	

The selected criteria were chosen (other than palustrine and pocosin) based on the process of overlaying the data layers on Little Ocean Bay, Echaw Road Bay and soils from an unnamed but well defined bay within the southeastern boundary of the forest. After inspecting the data layers individually for their characteristics within these bays, the ranked reclassification categories were then assigned based on visual estimation of prominence. The model was then created using the following weighted formula: (NWI reclass *0.5) + (LULC relcass *0.25) + (Soils *0.25). The palustrine class was thought to be the dataset most likely to include previously delineated Carolina bay wetlands; therefore, it received the heaviest weight.

3.3 Bladen County, North Carolina Study

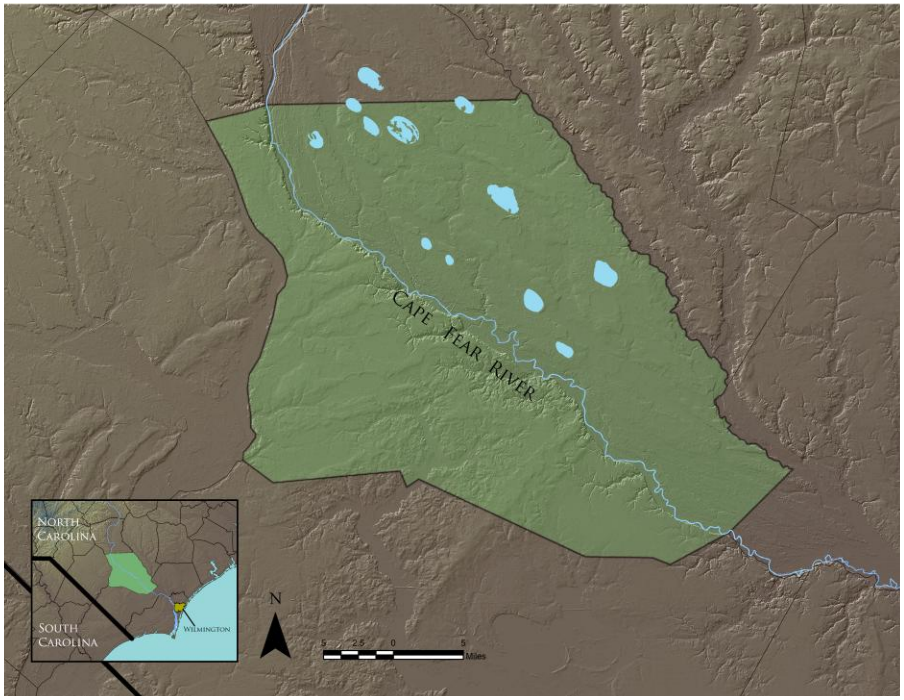

Figure 3.2 Bladen County, North Carolina.

Datasets used for the model within Bladen County, North Carolina included SSURGO (2009), The North Carolina GAP land use/ land cover database (2009), and the NWI (2009) for Bladen County, North Carolina. In addition to these datasets, a set of 6 inch resolution, infrared orthophotos taken in 2008 were provided by Hans Rohr, a forester with Bladen Lakes State Forest. All processing and analysis were done using ArcGIS 9.3 (2009)

The orthophotos came projected in North Carolina State Plane feet. Being the largest raster dataset, and not mosaiced together, the state plane projection and coordinate system was chosen for the other datasets. The NWI and North Carolina GAP files were statewide coverages, so they were clipped to the Bladen County extent. The soils layer came from the NRCS as a county file; therefore, no clipping was necessary.

After all files were clipped to the proper extent, each was reprojected to fit the North Carolina State Plane Coordinate System with feet as their linear unit. Following reprojection, the NWI and SSURGO files were converted to raster so that they could be reclassified and combined using Raster Calculator in ArcGIS 9.3 (2009).

3.3.1 Bladen County Model

In order to build a model of the bays of Bladen County, an approach similar to the Francis Marion study was taken. Characteristics of Carolina bays within the NWI were chosen based upon their inclusion in the literature (Cowardin et al. 1979). The volumes consulted are USFWS reference works, and the community profile (Sharitz and Gibbons 1982) states that a majority of Carolina bays exist within the palustrine class of the Cowardin classification system used to structure the NWI. Therefore, all wetlands within the boundaries of Bladen County that were classified as palustrine were selected from the NWI for inclusion in the model.

The North Carolina GAP land use/land cover selection process began by using a similar approach. Naturally occurring land cover that are identified within bays or on their sand rims were selected using Schafale and Weakely (1990) as a guide. The land cover classes selected from the GAP coverage did not match perfectly with the natural communities guide: not all land cover in Bladen County is a naturally occurring, minimally disturbed, vegetation community, and the generalization of types due to the thirty meter spatial resolution of the data. Included with the dataset was a table that indicated how the GAP coverage categories fit within the natural communities established by Schafale and Weakley. Additional land cover classes were chosen based on their absence in the Schafale and Weakley volume and their appearance within oval shapes that could be seen within the GAP coverage. Soil selections were made based upon their appearance within oval shapes in the SSURGO shapefile of Bladen County soils.

Creating the model was an iterative process. Initially, the model characteristics were selected from each dataset and then reclassified, ranked on a common scale of one through five, rank five having the highest likelihood of being associated with Carolina bay wetlands (Table 3.2).

Table 3.2 Model Attributes and Rank for Bladen County, North Carolina Study.

National Wetlands Inventory (NWI)	South Carolina GAP Land Use	SSURGO Soils
Palustrine 5	Coastal Plain Mixed Bottomland Forest 1	Lynchburg fine sandy loam 1
	Coastal Plain Mixed Bottomland Forest 1	Centenary sand 1
	Seepage and Streamhead Swamps 1	Autryville loamy sand 0-3 percent slopes 1
	Coniferous Regeneration 2	Goldsboro sandy loam 1
	Cypress Gum Floodplain Forest 2	Duplin sandy loam 0-3 percent slopes 2
	Peatland Atlantic White Cedar Forest 2	Woodington loamy sand 2
	Water 3	Rains fine sandy loam 3
	Xeric Longleaf Pine 3	Pantego loam 3
	Coastal Plain Nonriverine Wet Flat Forests 4	Water 3
	Coastal Plain Fresh Water Emergent 5	Croatan muck rarely flooded 4
	Pocosin Woodlands and Shrublands 5	Lynn Haven and Torhunta Soils 4
		Torhunta mucky sandy loam 4
		Croatan muck rarely flooded 4
		Pamlico muck rarely flooded 5

Eight weighted, linear models were run with different rank values and different weights given to each reclassified dataset in order to examine the effects of weight on the distribution of the areal coverage of the model. There was no difference in the distribution of or the total number of pixels using this method. Therefore, each reclassified characteristic was given a value of one and each dataset was added together without weight. This produced a surface that was identical in pixel distribution and number to the other eight models, but without different pixel ranks. Each pixel occurrence within the model held a value of three and was representative of the co-occurrence of three characteristics within the same pixel column and thirty square meter coordinate space.

Model = (NWI_Reclass)+(SSURGO_Reclass)+(GAP_Reclass)

3.4 Evaluating the Cartographic Models

After the creation of cartographic models within both studies, the effectiveness of each model’s ability to delineate Carolina bays was assessed. In order to accomplish this, the researcher created a point file marking the Carolina bays and bay-like features manually on an image. Following the creation of the manual identification file, researcher identifications of Carolina bays were then compared to the model identifications. There were many notable differences in the approach taken to accomplish this assessment in each study, but the results mainly focus on the comparison of grouping systems into which the researcher placed manually identified bays. The Francis Marion model employed a binary classification of Carolina bays while the Bladen County model used a ranked classification.

3.4.1 Model Evaluation: Francis Marion National Forest

Within the Francis Marion study, any feature that was manually identified on an image was called a Carolina bay. Complicating this binary classification approach is the fact that the Carolina bay phenomenon is not identical in every instance. GIScientist David Mark (1993) points out in his review of cognitive categories that some objects are better examples of category members than others. Bays grade from excellent examples to questionable forms. This particular fact has been noted by Lide (1997) and this problem with identifying geographic entities is demonstrated through the results in the Francis Marion model. In addition, it is possible that the characteristics selected to represent Carolina bays exist outside of the landforms. While their co-occurrence may increase the likelihood that a location is an instance of a bay, it may not necessarily be so. False positives exist within the Francis Marion model but have not been represented within the results. While the possibility is less within the limited geographic range contained within a quadrangle, there may be instances of bays that neither the model nor the researcher was able to identify. Compounding these evaluation problems, it may be too liberal to allow the identification of a Carolina bay to called positive with any appearance of overlying pixels (Figure 3.3).

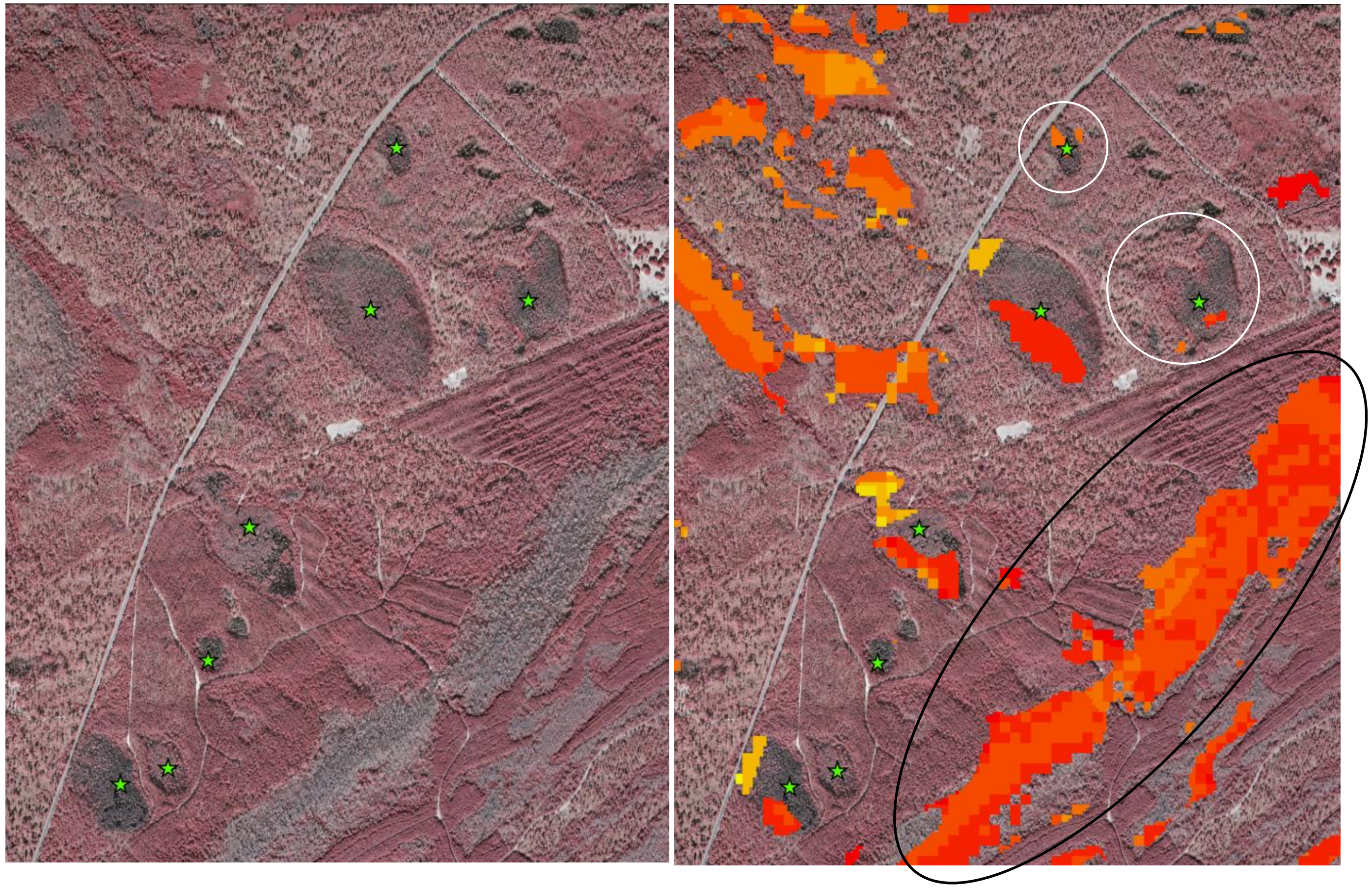

Figure 3.3 Francis Marion National Forest Model Selection Issues. Green stars = researcher selection. Red, orange and yellow pixels = cartographic model of Carolina bays. White circles = ambiguous features counted as positive identifications by model. Black circle = false positive identification

3.4.2 Model Evaluation: Bladen County North Carolina

Evaluation of the model within Bladen County has forgone the creation of polygons representing Carolina bays anticipating that the model will represent them by defining them digitally based upon the co-occurrence of their characteristics in other datasets. Bays were identified in the orthophotos and marked within a point shapefile layer. The points were attributed with a rank of "bayness" that combines Mark's (1993) work on human cognition and classification of geographic entity types, and the terminology and thinking of the SREL inventory to create a core-radial cognitive model of the Carolina bay concept (Figure 3.4).

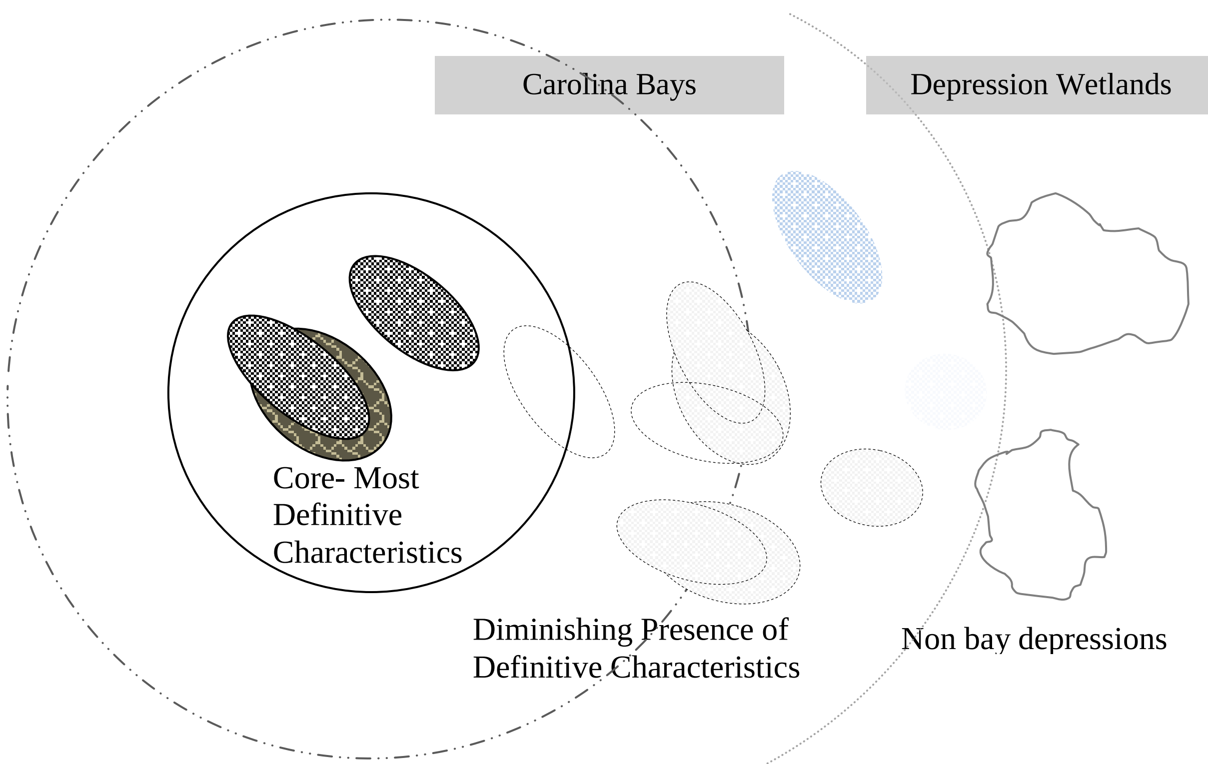

Figure 3.4 A Core/Radial Cognitive Model of Carolina Bays.

Within the core of the Carolina bay concept, there are the characteristics that are the most definitive ones offered by Robert Lide (1997) and many others: oval- shaped depressions, oriented, and sometimes having a sand rim. Adding to the commonly observed characteristics of form is the idea of crispness (Worboys and Duckham 2004), which is a term used in describing degrees of geographic vagueness. Crispness means that a discernable boundary exists between a feature or object and its surroundings (Worboys and Duckham 2004). When using imagery to identify Carolina bays, the visible definition or crispness of their boundaries may be the most important factor.

The core or bays that exhibit exemplary form in reality grade into bays and other bay-like depressions that may not be as perfectly shaped. They may show variation in orientation, appear to be more round than oval, or have only part of their oval shape unobscured by the overlap of other bays, sand rims or disturbances. Even with these variations, objects can still be identified with a reasonable degree of certainty as Carolina bays. However, as one moves further away from the center of the bay concept, questionable forms begin to present themselves. The reality that bays are not perfectly formed in every instance has been acknowledged within past bay research at the SREL (Schalles et al. 1989), noted by Shan Cammack of the Georgia Department of Natural Resources (personal communication 2010), and within the research in Francis Marion. Based on cognitive modeling and previous attempts to categorize Carolina bays, ranking were developed to remedy issues with forcing bays into a binary class system. As the imagery was examined, bays were marked with a point shape file and ranked as follows:

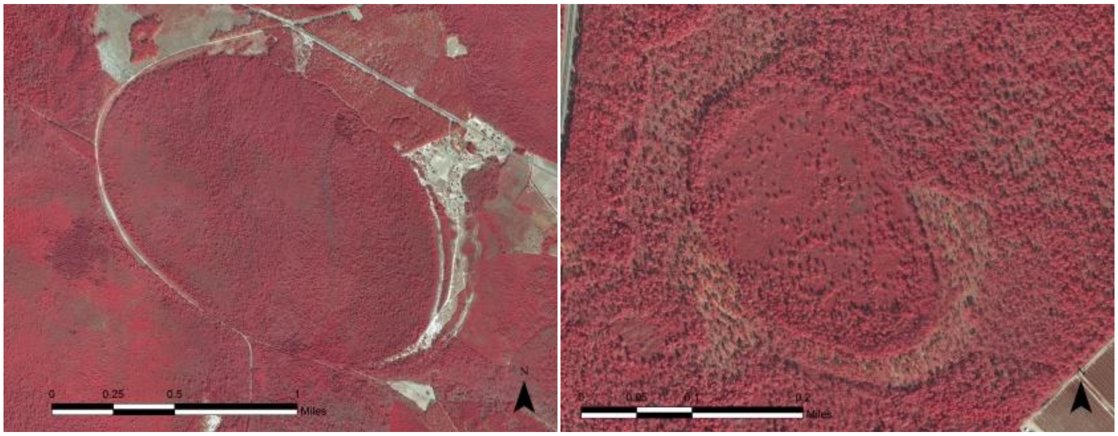

Figure 3.5 Examples of Bays Included Within the Exemplar Rank.

Bays that fit the exemplar category (Figure 3.5) are unmistakably Carolina bays. Within this category, bays tend to have well defined edges, are oval in shape, are oriented northwest to southeast, and may or may not have a sand rim. Bays within this class tend to exhibit less disturbance, although no attempt was made to quantify or rank disturbance levels, and there are cases in which the above characteristics are all present, but the feature appears to have been significantly altered from its natural state.

The term exemplar was chosen from Mark's (1993) review of cognitive classification concepts. However, this research does not use the term in the sense that Mark reported. The term exemplar, in its original sense, assumes that there is but one prime example of an entity or an object and that any example of an object within the given class will exhibit all of the features of that class. It does not make allowances for cases that may be missing some core characteristics but contain enough characteristics so that it does not belong in any other class. Rosch (1978) developed a model for cognitive classification in which there are central members or "prototypes," and her work was further developed by Lakoff and Johnson (1980) into a core/radial classification system in which the central members are prototypes. As one moves away from the core concept of a feature or object, the fewer definitive attributes are present (Lakoff and Johnson 1980; Mark 1993). The word exemplar is used here interchangeably with the concept of prototype. Exemplar as a descriptive term within the context of this research has been shifted to the core or center of the core/radial model, and represent Carolina bays with all of the above, crisply defined boundaries and features.

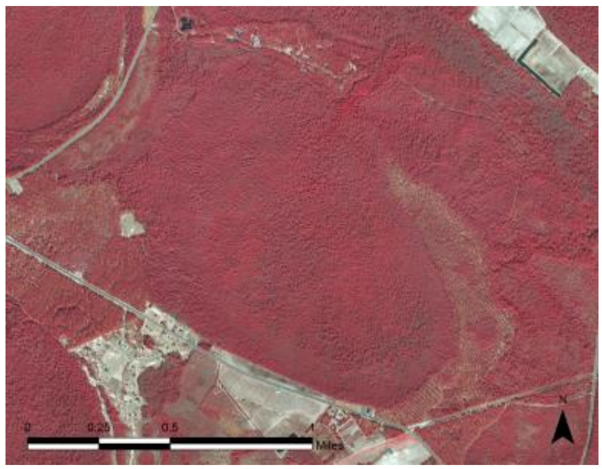

Figure 3.6 Example of Bays Included Within the Less Distinct Rank.

The name "less distinct" (Figure 3.6) was taken directly from the scheme used to inventory the Carolina bays of the SREL. It represents entities that are bays, but have a diminishing quality or presence of bay characteristics. Bays in this class typically have enough of their borders intact to show a portion of an oval, but may be indistinct in places. This category generally shows increasing levels of disturbance, which may affect the crispness of bay boundaries. In other cases, vegetation may be too thick to show a definable edge, or bays may appear within other bays, sometimes overlapping or underlying each other. Each of these cases make the bays less distinctive in some way, to the point that the feature in question is still considered a bay but is not a well formed example.

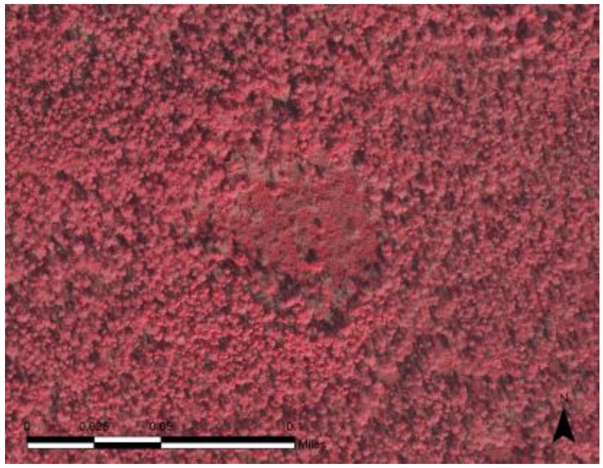

Figure 3.7 Example of Bays Included Within the Bay-like Rank.

The category “bay-like” (Figure 3.7) also has been appropriated from the SREL inventory. Perhaps the greatest challenge of creating an inventory is deciding what should go into this particular class and what should be left out altogether. The SREL inventory has accounted for this difficulty by including ambiguous or questionable features; it, “may be more appropriate to consider ‘Carolina bays and similar wetland depressions’” (Sharitz 2003, 550; Lide et al. 1995). By creating a category- depression wetland “bay-like” the SREL included features that fit on the outside of the core radial cognitive model reviewed by Mark (1993). Features here can show very indistinct boundary lines, or they may be round than elliptical. This category grades into the amorphous, most questionable features.

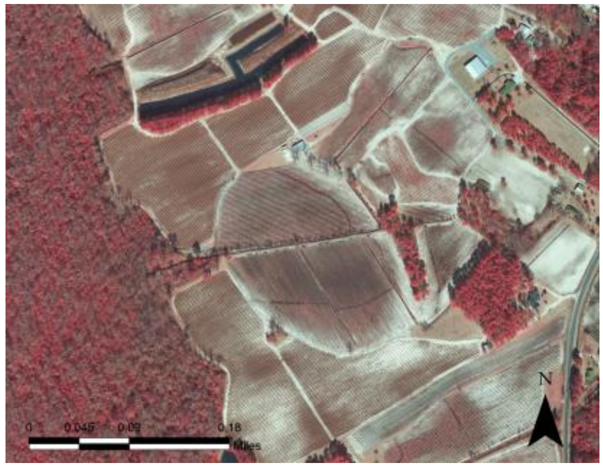

Figure 3.8 Example of Bays Included Within the Destroyed Rank.

The category “destroyed” (Figure 3.8) was taken from an integrity ranking employed by the Georgia inventory. Dark, oval, oriented shadows of soil often occur in the plowed agricultural fields of Bladen County. These shapes can occur near one another, displaying parallel axes, sometimes showing what used to be a sand rim. In a few cases, water can be seen ponded within part of the ellipse. A large majority of the features included within this class fit this barren description, but others may be included. Generally speaking, the feature had to be destroyed completely or very nearly so. This category may prove useful for future research in assessing the effectiveness of orthophotography in comparison with digital elevation models for identifying Carolina bay wetlands and methods of estimating wetland loss.

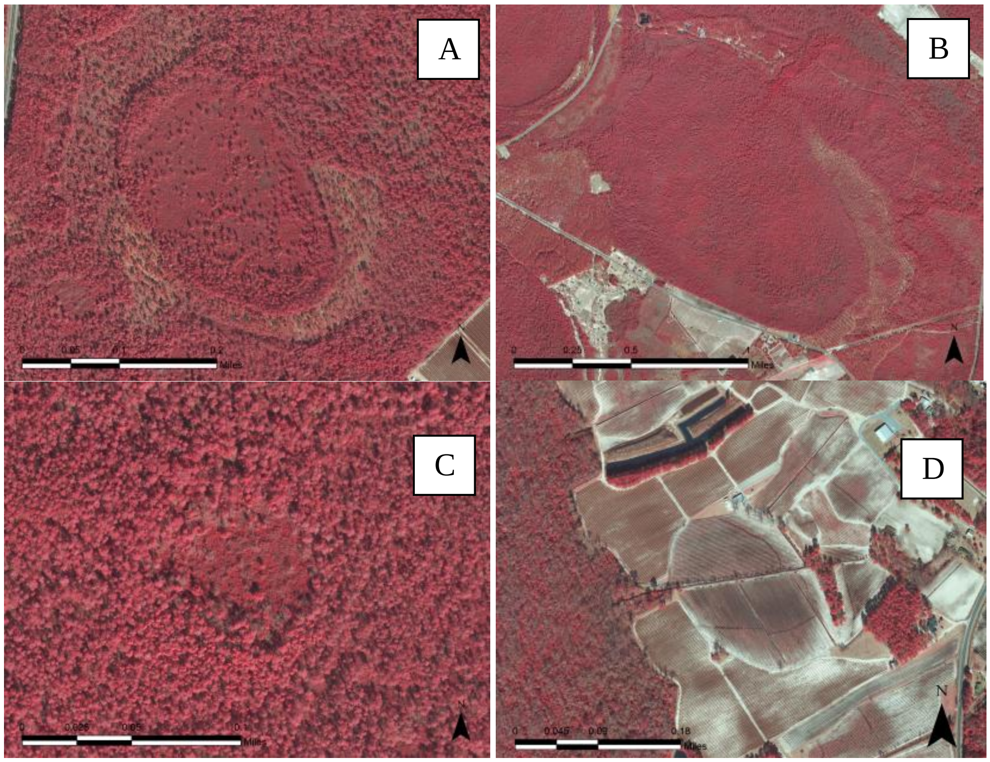

Figure 3.9 Examples of Carolina Bays By Rank. (A) Exemplar, (B) Less Distinct, (C) Bay-like, (D) Destroyed

3.5 Discussion of Attributes in Bladen County

In addition to a ranking of how identifiable a Carolina bay is, several other attributes were added to the manually selected bay layer as it was created. This part of the project was structured by some of the attributes described in the South Carolina statewide inventory and included characteristics such as the presence or absence of a sand rim, whether or not bays were overlapping or underlying one another, whether they seemed to be diverging, or whether standing water was present. As well as these characteristics, if the edges of the southeastern and northwestern parts of the ellipse were intact, an attempt was made to measure long axis length and orientation. While the attributes selected for quantification came from the South Carolina inventory, the database design and method of describing visually how metrics are applied are taken from the results of the Georgia inventory.

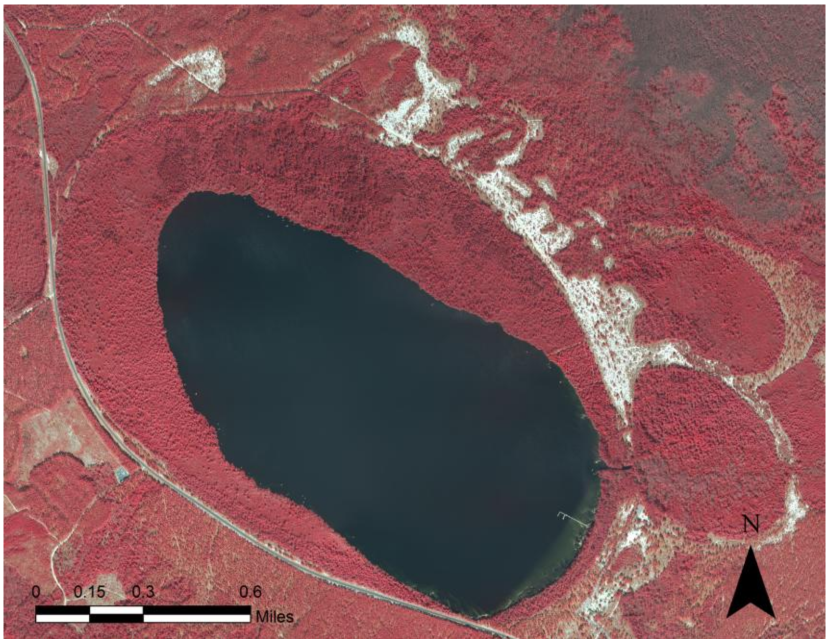

Figure 3.10 Singletary Lake: An Instance of Water Visibility, Sand Rim and Overlap.

3.5.1 Sand Rim

Carolina bay sand rims were included in the database initially by using a ranking system that attempted to categorize them by the amount of disturbance visible. The ranking system of zero through three was appropriated from Georgia's Carolina bay inventory and as such had the same intent: to indicate the presence and condition of a sand rim. Following their system: zero- none exists, one -undisturbed, two- some disturbance, and three- heavy disturbance. This arbitrary ranking proved difficult to apply and the results do not show consistency. However, it is a good indicator of the number of Carolina bays within the county having a sand rim. Therefore, the results shown here are simply the presence or absence of a rim. It should also be noted that if any indication of a sand rim was perceived to be present, it was included in the count. As with bay features in general, rims are better defined in some cases than others **(**Figure 3.10).

3.5.2 Overlapping/Underlying Bays

In many instances, bays seem to have formed within one another, along the borders of another or have formed upon the sand rim of another bay (Figure 3.10). Following the South Carolina inventory's inclusion of this information in their state inventory, (Bennett and Nelson 1991) it is included here. A single numeral system was used to quantify this characteristic, a technique used by the Georgia inventory to quantify and describe other characteristics. The presence of an overlapping condition was indicated by the numeral one in the database, two indicates a Carolina bay underlying another, and zero indicates the absence of the characteristic.

3.5.3 Diverging Bays

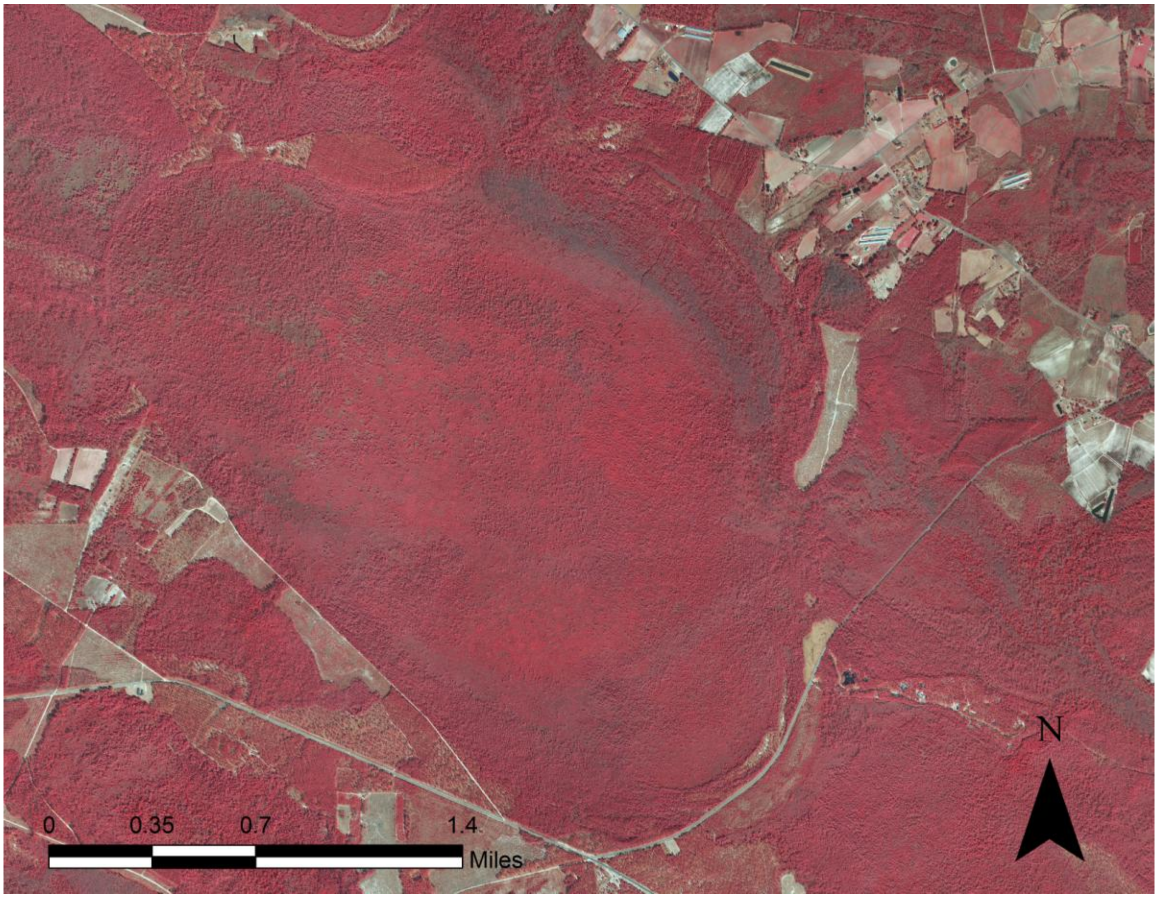

Figure 3.11 Diverging Bays.

Carolina bays can fan out from a common point in their southeastern end. This quality was a characteristic noted within the South Carolina statewide survey. Within the scope of this work, bays that seem to be diverging are quantified by a binary indicator of zero or one, one meaning that the characteristic was present.

3.5.4 Water Visibility

This category was included because the Carolina bays of Bladen County seem to be distinctive in this way. Many of the larger and well-known bays of the area hold standing water and are named locally as lakes, for example Jones Lake, Salters Lake, White Lake, and Singletary Lake. All are well known recreational areas within Bladen County. A look at the imagery available on a digital globe such as Google Earth will show that many larger bays in the Bladen County area have this characteristic, and it appears to be relatively rare for bays to have naturally formed, permanently standing, deep water within them. While some of the characteristics quantified here meet this specific description, other instances of visible standing water are also included, such as what appear to be swine lagoons, waste ponds or other man made water retention structures. Destroyed bays that show water in what is left of their basins were also included. This system is one of presence or absence and no attempt was made to sub-classify the types of standing water.

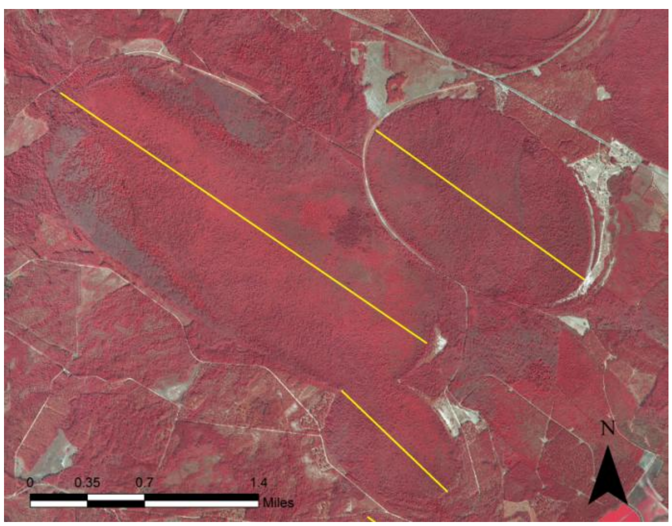

Figure 3.12 Long Axis Length and Orientation.

3.5.5 Long Axis Length and Orientation

While there are other methods available today that will render a more accurate estimate of bay area, South Carolina's inventory of Carolina bays was conducted in the 1980s, without the benefit of GIS. Within their milestone effort, axes were marked on printed copies of aerial photography, from which size classes and azimuth ranges were generated. The lack of readily adjustable scales, different photo resolutions and limited amounts of available imagery all would have affected their ability to survey bays. By measuring Bladen County's Carolina bays' long axis length and orientation (Figure 3.12), an estimate of size distribution and an azimuth range can be created, as well as generating statistics that can be readily compared with the South Carolina inventory. Long axis azimuth and length were measured by using Tools for Graphics and Shapes, an extension for ArcGIS software created by Jenness Enterprises (2008). Also, by using this method in conjunction with the bay ranking system, an estimate of what features would be missed by only selecting bays with most of their ellipses intact or visible is possible.

3.6 Comparison of Methods Between Francis Marion and Bladen County

3.6.1 Model Construction

Each study began by consulting the pertinent sources to inform the proper selection of characteristics. Although the same datasets were used, the models were different in their included characteristics due to the natural tendency of land cover and soils to vary in locations not close to one another. This means that the attributes selected for Francis Marion National Forest Carolina bays will not be equal to the attributes selected for the bays of Bladen County. In addition, the general characteristics taken from these volumes alone were not enough to complete a cartographic model. In the case of Francis Marion, two known bays within the forest were examined with the land cover and soils datasets overlaid. Upon examining the characteristics occurring within them and one other well defined but unnamed bay within the forest, the attributes were added to the model. The Bladen County models used the same sources as the Francis Marion model with an additional source not available in South Carolina: a listing of the natural communities of the state that corresponded partially with the land cover dataset. In addition to this difference, characteristics not included within the source material were included by examining each dataset clipped to the Bladen County extent for the occurrence of oval shapes and the attributes that describe them. Within the Bladen County study, this approach was taken with a portion of the land use file, and was the method used to compile all of the soils attributes.

3.6.2 Model Evaluation

After the construction of the two cartographic models, the predictive power of each was assessed. Generally the evaluation process began by manually marking the locations of Carolina bays on an image through the creation of a point file. In the Francis Marion National Forest study, all of the points were counted as researcher-identified instances of Carolina bays. Complicating this approach is the fact that not all instances of the bay phenomenon are well formed or within the limits of a designated resolution in an image. Bays exist in the real world on a continuum that grades from the typical to the questionable. Bays manually identified by the researcher in the Bladen County study were assigned to different ranks in order to alleviate the problems of forcing all instances of Carolina bays into a binary class system, allowing vague instances to be included.

Determining a positive identification of a Carolina bay by the cartographic model was also significantly different between studies. In the Francis Marion study, a positive identification was tabulated if any of the model's pixels landed within a Carolina bay selected by the researcher. This liberal rule, in conjunction with the acceptance of ambiguous features as Carolina bays, affected the evaluation of the models predictive ability. The Bladen County study employed a rule that accepted a Carolina bay as positively identified only if it was visually estimated to have 50 percent of its area covered by the model. In addition to the Francis Marion study being limited in this way, the area covered by a single quad limited the researchers ability to examine the model in conjunction with a variety of bays and bay-like features. Therefore the Francis Marion study was not able examine instances in which the model was able to select Carolina bays that the researcher did not identify and cases in which both the researcher and the model missed.

In the case of Bladen County, the study area covered the entire county and was visually assessed for each of the aforementioned model selection instances in addition to mutual identifications by both the model and the researcher. Instances of features identified by the model as Carolina bays that were not identified by the researcher as such were not quantified within either study. The limitations within the Francis Marion National Forest study were examined and, with the exception of false positive identification, were addressed within the larger scope and location of the Bladen County study. In addition to the more rigorous treatment and larger study area of the Bladen County research, other attributes were gathered and added to the database as Carolina bays and bay-like features were added to the point file. These differences led to a much shorter and limited analysis of the Francis Marion study itself, but most importantly allowed the comparison of binary and ranked systems of classification so that a more detailed study could be conducted with knowledge of potential weaknesses in approach.

CHAPTER IV

RESULTS

4.1 Francis Marion National Forest Study

Results were tabulated after selecting and marking the bays with points on a shape file over the Ocean Bay quad, then superimposing the cartographic model and counting the number of bays that the model also selected. Positive identification was tabulated if the model filled any part of the bay. USGS quadrangle Ocean Bay was selected to evaluate the power of the model. The first series of results are shown in Table 4.1.

Table 4.1 Researcher Versus Model Selections of Carolina Bays, Ocean Bay Quad, Francis Marion National Forest, December 2008.

Quarter Quad	Selected By Researcher	Selected By Model	Ratio (Percent)
NW	21	15	71
NE	14	12	86
SE	4	2	50
SW	29	23	79
Total	68	52	76

At a later date, a second attempt was made to identify the bays of Francis Marion to examine the role of uncertainty in the analysis. The results of the second assessment assert a different picture than the first. While no attempt was made to quantify the characteristics that comprise the bay concept in either case, a generally more conservative definition of what constitutes a Carolina bay was employed in the second analysis. Thus, the second analysis resulted in fewer manual identifications on the orthophoto, but a higher rate of selection by the cartographic model, as shown in Table 4.2.

Table 4.2 Researcher Versus Model Selections of Carolina Bays, Ocean Bay Quad, Francis Marion National Forest, November 2009.

Quarter Quad	Selected By Researcher	Selected By Model	Ratio (Percent)
NW	8	8	100
NE	8	7	87.5
SE	2	2	100
SW	28	21	75
Total	46	38	82.6

It is hypothesized that the differences in the results of the two analyses are affected by the binary approach of counting all manually identified features as Carolina bays even if questionable, and acceptance of a positive identification of a bay by the model as a single pixel occurrence within researcher identified Carolina bay boundaries. These ambiguities were considered during the structuring of the Bladen County study, and were remedied by the adaptation of a bay ranking system and a stricter requirement of 50 percent coverage of researcher identified bays by the pixels in the model overlay.

4.2 Bladen County North Carolina Study Results

The point file generated and attributed manually for Bladen County resulted in a total count of 736 identified bay or bay-like features. The ranks indicate how well formed each instance is. This is an assessment of the manually generated file independent of the model results. The rank breakdown of bays selected manually by a GIS technician is presented in Figure 4.1

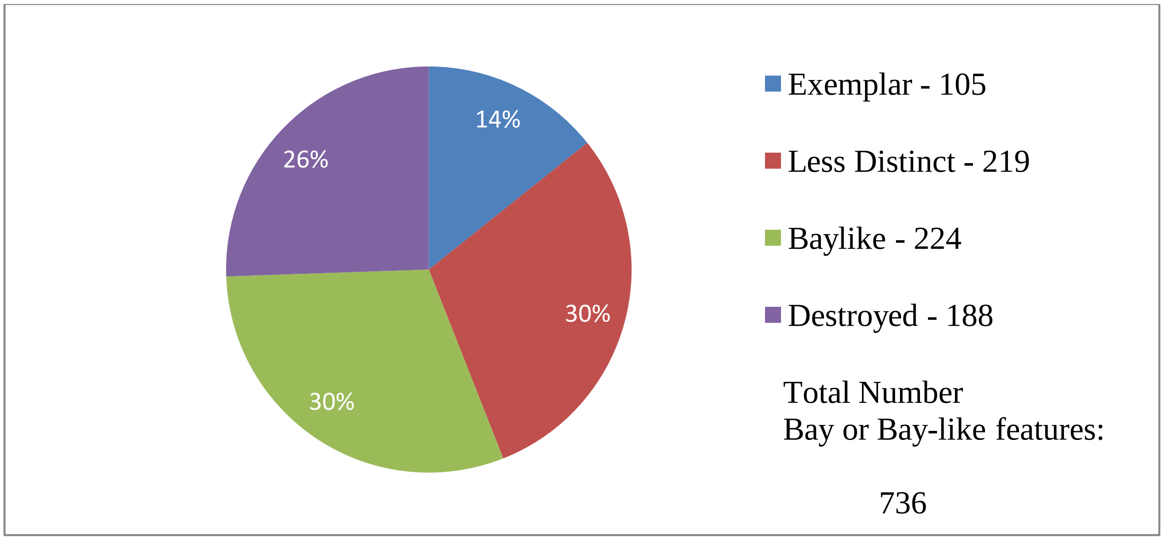

Figure 4.1 Bladen County Carolina Bays and Bay-like Features By Rank.

4.2.1 Attribute Summary

Each rank was clustered together with the measurement of bay attributes (Figure 4.3). The first two categories represent the features that are most easily identifiable. Both categories show that the bays of Bladen County have a high ratio of sand rims per instance. Taken together, the exemplar and less distinct categories total 324, 170 of which have sand rims, a 52.4 percent ratio for readily identifiable bays in Bladen County. The exemplar class had the greatest number of sand rims per instance, 85 of 105, an 81 percent ratio. In South Carolina as a whole, sand rims were found to be less common than previously thought, but as the state border between North and South Carolina is approached, the instances of sand rims increase by county, most notably on the counties bordering the state line (Bennett and Nelson 1991). Bladen follows the trend, as it is only one county east of the state border with South Carolina.

Overlapping bays were a prominent feature in the less distinct category, 60 of 219, a 27.4 percent ratio. The Exemplar category also shows a similar ratio at 31 percent. This bay characteristic can affect the crispness of their visible boundaries, so it was unexpected that the exemplars would exhibit a slightly higher rate of overlap or underlying edges. The diverging tendency appears less frequently per rank than one might expect with the physical results of other surficial processes evident, such as high rates of overlap and distinctive sand rim formation.

With the exception of Bladen County's Carolina bay lakes which are permanently inundated, water visibility is sensitive to the amount of prior rainfall and the time of year that the photos were taken. This is especially true in the case of smaller, completely destroyed bays with exposed bare soils. The photography used by the researcher in the Bladen County analysis was taken in February of 2008, and the precipitation record for the region (Figure 4.2) shows that the soils may have been close to field capacity due to previous heavy rainfall, including events in the months preceding, and during the same month, allowing wet soils to be seen.

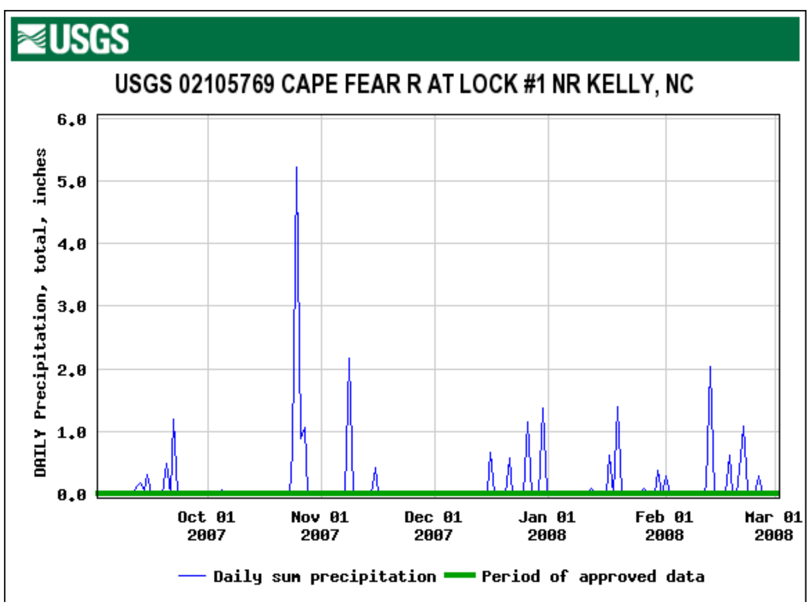

Figure 4.2 Bladen County Precipitation, September 2007–March 2008. Source: USGS

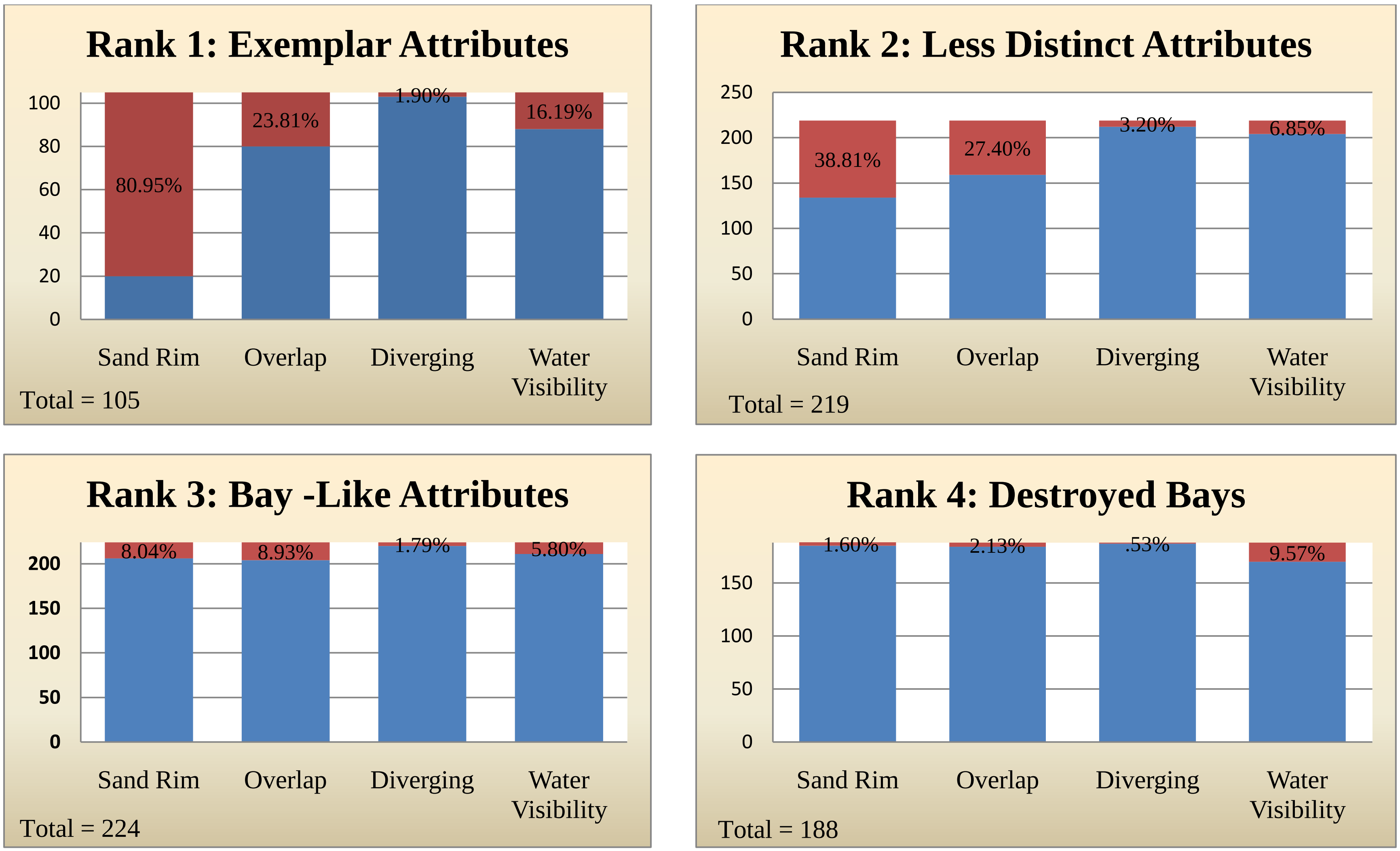

Figure 4.3 Carolina Bay Attributes Grouped By Rank. Red indicates the presence of indicated attribute.

4.2.2 Long Axis Length

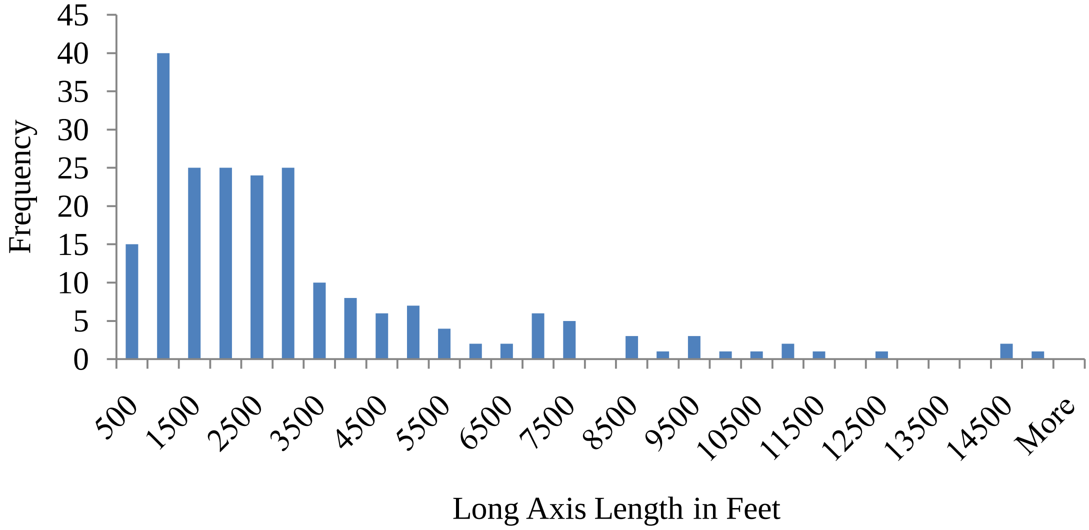

Figure 4.4 Frequency Distribution of Long Axis Length.

Table 4.3 Summary Statistics of Long Axis Length

.

Long Axis Length	Measurements (feet)
Count	220
Minimum	293.0
Maximum	14,763.0
Mean	2934.3
Median	2085.1
Standard Error	2784.7

Of the 736 Carolina bays and bay-like features in Bladen County, there were 221 (30 percent) with a measureable long axis (Figure 4.4 and Table 4.3). Within the ranking system, ninety-nine (41.8 percent) were exemplars, seventy- nine (35.75 percent) were less distinct, eleven were bay-like or questionable (5 percent), and thirty-two (14.5 percent) were destroyed. The most identifiable bays fit within the first two classes, which account for 80.5 percent of the total number of instances with a measured long axis. One outlier has been removed. Bays Inventoried at SREL, South Carolina and Georgia all reflect the general trend of having large numbers of smaller bays (Schalles et al. 1989; Bennett and Nelson 1991; Semlitsch and Bodie 1998; Van De Genachte and Cammack 2002). In the case of Bladen County, nearly half of the sample measurements are 2000 feet in length or less. SREL and Georgia inventories used polygons to create their inventories and therefore use area to calculate size distribution estimations in hectares. The Bladen County study has been conducted using feet as its unit of measure so that it might be readily compared with South Carolina counties.

4.2.3 Long Axis Orientation

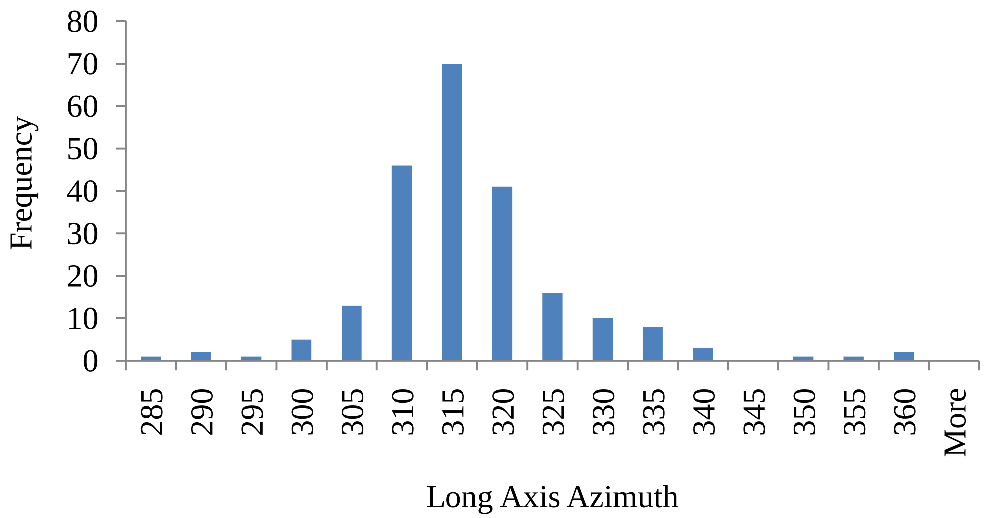

Figure 4.5 Frequency Distribution of Long Axis Orientation.

Table 4.4 Summary Statistics of Long Axis Azimuth.

Long Axis Orientation	Azimuth in Decimal Degrees
Count	220
Minimum	282.32
Maximum	359.08
Mean	314.23
Median	312.54
Standard Error	10.04

The orientation of a Carolina bay is one of its most distinctive qualities. The mean value of all azimuth measurements within Bladen County (314 degrees) is consistent with the often generalized observation that Carolina bays have a northwest to southeast orientation. While the distribution is not perfectly normal, Bladen County bays do show consistency in orientation and show only minor variation about the mean and median and a ten degree variation of standard error, representing a narrow range of azimuth variation.

The high rate of bay identification of the Francis Marion National Forest study was due in part to forcing bay-like features into a binary or positive/negative evaluation. The ranking system was employed to contain different grades of identifiable features as they appear to the eye in photography to deal with this issue. Other issues with the evaluation of the Francis Marion model are within the positive identification rule: any pixel within the borders of a researcher selected bay was considered a positive identification. This liberal rule allowed features to be identified having few pixels within them. If the goal of this research is to digitally define and cartographically identify Carolina bays as proof of concept, a more strict identification rule is necessary. For the scope of the Bladen County assessment, a new rule was established such that in order for the model to positively identify a Carolina bay, a visual estimate of 50 percent of a bay's total area had to be covered, but did not require that the pixels all fall completely within the bay's borders.

The total number of researcher selections identified by the model equal 418 out of 736, a 56.8 percent identification rate overall (Table 4.5). Each class was sensitive to how well a bay is identified. This fact is due in part to the use of imagery to create each dataset included here. It is assumed that if the bays were visible then they are usually represented somehow within each dataset used to build the model. In some situations, the model selected features that had been destroyed. In this case, the model identifies artifacts that are a result of the use of earlier imagery than the February 2008 base imagery.

Table 4.5 Researcher Versus Model Selections of Carolina Bays, Bladen County, North Carolina.

Rank	Total Identified by Model	Total Identified by Researcher	Ratio (percent)
1 exemplar	90	105	85.7
2 less distinct	173	219	79
3 baylike	119	224	53
4 destroyed	36	188	19
Rank Totals	418	736	56.8

A visual verification was conducted throughout the entire study area. First, using a reference grid downloaded from the North Carolina Floodplain Mapping Program as a guide, the point file was examined for mutual identification. Absent from the Francis Marion study were the other possibilities necessary for proper evaluation: that the cartographic model will identify features that the researcher did not, that both the model and the researcher will occasionally miss features that are on the image, and that the model will identify areas that are not Carolina bays which are considered to be false positives (Table 4.6).

Table 4.6 Exclusion Cases.

Positive Identification by Model- Researcher Missed	66
Features Missed by Researcher and the Model	10

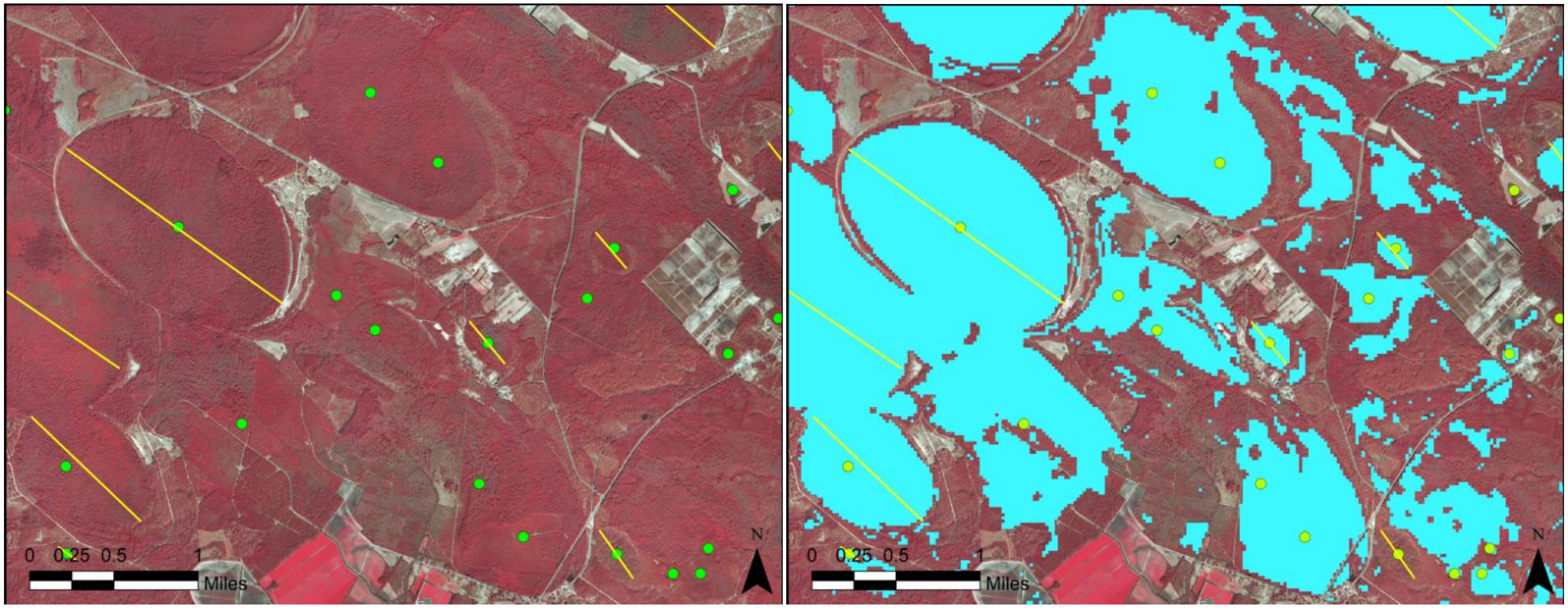

Figure 4.6 Researcher Selections With and Without Model Overlay. Green Dots= Researcher Selections, Yellow Lines= Long Axis Transects, and Turquoise Pixels = Cartographic Model

The characteristics chosen for the model, while common to Carolina bays, are certainly common to other places on the earth's surface. Statistically, these occurrences are known as false positives and are difficult to quantify. Selecting additional datasets specific to morphology may alleviate this if oval shaped, oriented depressions and sand rims can be defined within and extracted from digital elevation models. Including a digital representation of morphology will also bring the cartographic model closer to the characteristics that make Carolina bays the features that they are.

The spatial resolution for the model was chosen based upon the coarsest known resolution within the included datasets. The North Carolina GAP land use/ land cover dataset was made using Landsat TM imagery from 1992 in conjunction with videography and other pertinent data (USGS 2008). It is probable that as a result of the resolution of the Landsat TM imagery, the GAP land cover dataset has a thirty meter spatial resolution. A thirty meter resolution has been problematic in the past for identifying smaller Carolina bays (Sharitz 2003) within the NWI. While this resolution seems to positively identify Carolina bays within the scope of this research, it does so in a way that the smaller the bay is generally, the less definitively the model defines the oval shapes when it does identify them (Figure 4.2). This statement is a general observation that has not been quantified in any way within this research, and needs further investigation. By comparison of the model to a previously digitized inventory, such as the bay inventory at the SREL or the Georgia inventory, it may be possible to quantify the differences in area and identification size of Carolina bays at a thirty meter resolution and experiment with optimal resolutions for future iterations.

4.2.1 An Ontology of Carolina Bays

Using UML within the descriptive specification phase (Fowler and Scott 1999), an attempt to begin a digital definition of the Carolina bays of Bladen County can begin. As indicated by Noy and McGuiness (2001), this phase of knowledge base design is descriptive and has no functions, only descriptors. This research falls within one of the early iterations of the taxonomic organization of datasets related to Carolina bays, and as such does not include a database complete with attributes. With a more definitive formation of attributes, the model itself can be used to select the information from each dataset to be included, beginning the actual knowledge base where individual entities can be defined and attributed on a case specific basis. Figure 4.7 demonstrates the first iteration of a digital definition of Carolina bays for Bladen County, North Carolina. The UML diagram lists the characteristics chosen from each of the datasets used to build the model, and while each characteristic listed here is represented by a name, the characteristics are also representative of pixel groupings within each dataset. As such this research also offers the first computational definition of the Carolina bays of Bladen County, North Carolina.

Class Name

Carolina Bays

Attributes

SSURGO Soils Categories

- Lynchburg Fine Sandy Loam
- Centenary Sand
- Autryville Loamy Sand 0-3% slopes
- Goldsboro Sandy Loam
- Duplin Sandy Loam 0-3% slopes
- Woodington Loamy Sand
- Rains Fine Sandy Loam
- Pantego Loam
- Water
- Croatan Muck Rarely Flooded
- Lynn Haven and Torhunta Soils
- Torhunta Mucky Sandy Loam
- Croatan Muck Rarely Flooded
- Pamlico Muck Rarely Flooded

GAP Land Use Land Cover Categories

- Coastal Plain Mixed Bottomland Hardwood Forest
- Seepage and Streamhead Swamps
- Coniferous Regeneration
- Cypress Gum Floodplain Forest
- Peatland Atlantic White Cedar Forest
- Water
- Xeric Longleaf Pine
- Coastal Plain Non Riverine Wet Flat Forest
- Coastal Plain Freshwater Emergent
- Pocosin Woodlands and Shrublands

National Wetlands Inventory

- Palustrine system

Operations

None

Figure 4.7 An Ontology of Carolina Bays for Bladen County, North Carolina

CHAPTER V

CONCLUSION

> We are undergoing a paradigm shift from a hunter gatherer mode of doing research to a harvester mode with integrated, interdisciplinary databases
>
> - William Michener as quoted in Benson and Olson, (2002, 200)

The goal of this project was to explore a method that would automate the process of inventory of Carolina bays, while creating a digital definition that might lessen the issues involved with geographic vagueness. It was anticipated that if the model were to accurately predict the locations of bays, then the locations could be converted to polygons, attributed and analyzed. While this approach does show the potential to accomplish this, the cartographic model has itself, an amount of vagueness. Confronting this reality presents the greatest general challenge of GIS modeling. By starting simply and building upon the previous efforts of others, it may be possible to reconcile the fuzzy ways in which researchers identify Carolina bays with an acceptable computational definition that all may agree upon. This research offers the first step toward creating an ontology of Carolina bays in hope that it may become the foundation of a growing knowledge base. While this summarizes briefly the cumulative goals contained herein, it is also pertinent to consider the contributions that this research can make to the disciplines of GIScience, ecology, and the integrative field of ecoinformatics. By examining these contributions and their overlapping needs, needs for practical future research can be determined.

5.1 Contributions to the Field of Ecology

This research has its most practical applications within the field of ecology and conservation biology. Previous attempts to inventory Carolina bays were driven by their perceived value as ecosystems and conservation needs. During the completion of those inventories and herein, attributes were listed in order to quantify certain aspects of the Carolina bay phenomenon. This information, while immediately satisfying some ecological needs, can be computationally descriptive as well and is a tool for developing further iterations of a cartographic model. Additionally, with the use of the bay ranking system in conjunction with selected attributes, the Bladen County study allows a researcher to decide what portion of the Carolina bay concept applies to them most specifically and provides subsets of information that will allow them to tailor research within the confines of selected categories. The creation of a database similar to the information generated for South Carolina will allow the comparison of Bladen County to South Carolina counties, and may offer some insight into how GIS can improve the process of inventory on older (tabulation by hand, digitization) and newer (cartographic modeling) terms.

5.2 Contributions to the Field of Ecoinformatics

The field of ccoinformatics integrates the issues approached within the scope of this work. Ecoinformatics is, “a broad, interdisciplinary science that incorporates both conceptual and practical tools for the understanding, generation, processing, and propogation of ecological information" (Benson and Olson 2002, 200). As data and computational resources grow in availability, there also exists the need to understand data interoperability, or how each may relate to the other and how they might be useful together. Creation of a cartographic model of Carolina bays is an example of the integrative capabilities of datasets to aid in the construction of an ecological domain, using previously measured attributes of the earth.

5.3 Contributions to GIScience

Within the realm of GIScience, this research has provided the opportunity to examine and begin the process of creating a knowledge base or an ontology of a unique geographic entity. By taking a landform with a distinctive core concept and applying gradations to its classification, a research instance has been created that explores human perception and its integration into a classification system for features that exist naturally on a continuum, and are difficult to bound within a single category. This approach has been applied to a smaller inventory in the past at SREL, and has been adapted in a simplified way so that its effectiveness within a larger geographic scale might be considered. Further, the cartographic model offers a glimpse of what is to become the digital composition of Carolina bays that will, in its more developed practical form, delineate bays in GIS with less confusion about the boundaries of their existence.

5.4 Future Research

In order to improve upon this model, several questions must be considered:

1- *Are the datasets and categories from each exhaustive in describing the bays of Bladen County?*

During the selection process, an essential category was excluded: the presence of standing water within the bays of Bladen County contained within the NWI. Initially it was assumed that the inclusion of water from the SSURGO soils dataset and the land use/ land cover data within a ranked system would be sufficient. As the model changed, this aspect was excluded. Future research should consider the presence of deep water Carolina bay habitats within Bladen County and surrounding counties that exhibit this attribute which seems to be unique to the Carolina bays of the Bladen region.

Additionally, there are other datasets that will assist in the elimination of false positive identifications. By using the known range of orientation generated within this research, the extraction of oval shaped depressions and fragments of ovals from elevation datasets, there may be the opportunity to add morphology directly to the model. By including shape, the model will be able to more directly integrate characteristics most researchers include when considering the Carolina bay concept: oval, oriented depressions. Elevation may also be useful in defining sand rims so that the xeric ecotone that is favorable to the Venus flytrap may be included. In order to usefully include elevation, it is anticipated that it will be necessary to use a higher spatial resolution, which is a general need explored in the next question.

2- *Are the models extensible to Carolina bays throughout their known range?*

There is an established general rule within the field of spatial analysis known as Tobler's Law: all things are related, but near things are more related than far things (Tobler 1970). Considering the law of spatial autocorrelation, It is hypothesized that the ontology created for Bladen County may offer a starting point for digitally defining bays within surrounding counties, but as the distance from this region increases, different aspects from each dataset will be dominant, both those that need to be added to embellish the Bladen model and the ones included herein. Therefore, what may be most important is the process in which categories are selected.

Further, the scale issue raised by Sharitz (2003) may be difficult to overcome when attempting to model Carolina bays throughout the coastal plain. While datasets such as the GAP land cover and the NWI have many categories, they are limited by their spatial resolution. This aggregation of space is necessary in order to cover the geographic areas included within the scope of each dataset, which are nationwide. The thirty meter resolution excludes bays less than an acre in size from the NWI. SREL used five meter SPOT satellite imagery to overcome some of the size detection issues, and this approach may have to be considered as well for the creation of an inventory that spans the known range of Carolina bays.

3- Does the model need to be developed so that each individual instance of bays and bay-like features stand out as they would with hard lines from a digitized inventory?

In the past GIS has been used to estimate area and shape by digitizing or tracing the shapes of Carolina bays on imagery. Considering the model results as a probability surface having bay-like characteristics and Semlitsch and Bodie's (1998) idea of biological connectivity, the model created here may show how bay habitats are connected to their surrounding environment. This means that the model may provide valuable information without the aforementioned separation of or crisp definition of the Carolina bay phenomenon. It is suggested that, for future research that iterations of the developing model of an area be considered for what they contain before false positives are removed by other characteristics. By proceeding in this way, tiers of information can be created in which researchers may more accurately determine what part of the bay concept is important to their research.

5.5 Conclusion

In beginning this complicated yet necessary task of classification, the practical issues involved with an inventory of geographic features can be examined in a new light. In this case of the Carolina bays, the established real world needs of the NCDENR can be met, but with greater definition, than previously acquired. This approach combines other digital data that the DENR is likely to be familiar with, while generating information using earlier methods that will be immediately useful for the protection of Carolina Bay ecosystems. Entwined with its usefulness to the management of natural resources and ecology, the definition issue and its ontological solution/approach to database design for Carolina bays can benefit GIScience as well. The opportunity presented for contributions to GIScience is rich in that it covers theoretical, cognitive background, but applies it to a specific problem. As such, the approach requires the reconciliation of the fuzzy nature of human thought and classification as examined by Mark (1993), to the technical issues involved with spatial resolution and combination of map layers to create new information in order to digitally define Carolina bays.

Of growing importance is the recognized combination of the two fields of ecology and GIScience within the developing field of ecoinformatics. The approach taken with this research interweaves other mapping efforts and knowledge, both Carolina bay specific and beyond, in which data specific to certain characteristics of a feature within a region are combined in an attempt to create a unique, digitally described ecological domain. Especially important in the ecoinformatics approach is that it relies upon the databases established by others, in which, by using Micheners, terms pushes forward into a new era of knowledge creation in which researchers have become harvesters rather than hunter gatherers (Benson and Olson 2002).

Considering this reality, perhaps the largest requirement for future research in the creation of an inventory of Carolina bays is that it be conducted by an interdisciplinary team of researchers rather than an individual. By creating a Carolina bay consortium, knowledge from different geographic areas, disciplines, collection processes, and analysis methods can be employed. By doing so, it is possible that future cartographic models and digital definitions will be improved to the degree that an ontology of Carolina bays can be described throughout their natural range, and represents the culmination of the work of Mark to the field of GIScience. It is a practical scenario in which the human mind is able to strengthen itself against the tendency towards generalization when science requires that an explicit set of rules be established.

CHAPTER VI

REFERENCES

ArcGIS 9.3. Environmental Systems Research Institute (ESRI). Redlands, California.

Badurek, C. A., and D. M. Flewelling. 2000. A model spatial information system for structures based on cognitive image schemata. In *GIScience 2000 abstracts: The first International Conference on Geographic Information Science, Savannah, GA*. Santa Barbara: NCGIA, 248-249.

Batzer, D. P., and R. R. Sharitz. 2006. *Ecology of freshwater and estuarine wetlands*. 1st ed. Berkeley: University of California Press.

Bennett, S., and J. B. Nelson. 1991. *Distribution and status of Carolina bays in South Carolina.* Columbia, SC: Nongame Heritage Trust Publications.

Benson, B. J., and R. J. Olson. 2002. Conducting cross-site studies: Lessons learned from partnerships between scientists and information managers. *Bulletin of the Ecological Society of America* 83 (3): 198-200.

Cowardin, L. M., V. Carter, F. C. Golet, and E. T. LaRoe. 1979. *Classification of wetlands and deepwater habitats of the United States*. FWS/OBS-79/31. Washington, D.C.: US Department of the Interior, Fish and Wildlife Service, Office of Biological Services.

Fisher, P., T. Cheng, and J. Wood. 2007. Higher order vagueness in geographical information: Empirical geographical population of type *n* fuzzy sets. *Geoinformatica* 11: 311-330.

Fowler, M., and K. Scott. 1999. *UML distilled: A brief guide to the standard object modeling language*. 2nd ed. Reading: Addison Wesley Professional.

Gibbons, J. W., C. Winnie, D. E. Scott, J. D. Willson, X. Glaudas, K. Andrews, B. Todd, L. A. Fedewa, L. Wilkinson, R. N. Tsalligos, S. J. Harper, J. L. Green, T. D. Tuberville, B.S. Metts, M.E. Dorcas, J. P. Nestor, C. A. Young, T. Akre, R. N. Reed, K.A. Buhlmann, J. Norman, D. A. Croshaw, C. Hagen, B. Rothermel. 2006. Remarkable amphibian biomass and abundance in an isolated wetland: Implications for wetland conservation. *Conservation Biology* 20 (5): 1457-1465.

Glenn, L. C. 1895. Some notes on Darlington (S.C.) “bays”. *Science* 2 (41): 472-475.

Gruber, T. R. 1995. Toward principles for the design of ontologies used for knowledge sharing. *International Journal of Human and Computer Studies* 43: 907-928

Guarino, N. 1998. Formal Ontology and Information Systems. In *Formal Ontology in Information Systems. Proceedings of FOIS, June 6-8, Trento, Italy.* Amsterdam: IOS Press. 3-15.

Horton, J. W., and V. A. Zullo. 1991. *The geology of the Carolinas: Carolina Geological Society fiftieth anniversary volume*. 1st ed. Knoxville: The University of Tennessee Press.

Lakoff, G.and M. Johnson. 1980. *Metaphors we live by*. Chicago: University of Chicago Press.

Laliberte, L, J. O. Luken, J. J. Hutchens, and K. S. Godwin. 2007. The ecological boundaries of six Carolina bays: Community composition and ecotone distribution. *Wetlands* 27 (4): 873-883.

LeBlond, Richard. 2001. Endemic plants of the Cape Fear arch region. *Castanea* 66: 83-97.

———. 2008. *An Inventory of the Significant Natural Areas of Bladen County, North Carolina*. North Carolina Natural Heritage Program.

Leibowitz, S.G. 2003. Isolated wetlands and their functions: An ecological perspective. *Wetlands* 23 (3): 517-531.

Lide, R. F., B. G. Meentemeyer, J. E. Pinder III, and L. M. Beatty. 1995. Hydrology of a Carolina bay located on the Upper Coastal Plain of western South Carolina. *Wetlands* 15:47–57.

———. 1997. When is a depression wetland a Carolina bay? *Southeastern Geographer* 37 (1): 90-98.

Luken, J. O. 2005. *Dionaea muscipula* (Venus flytrap) establishment, release, and response of associated species in mowed patches on the rims of Carolina bays. *Restoration Ecology* 13 (4): 678-684.

Mark, D. 1993. Toward a theoretical framework for geographic entity types. In *Spatial information theory*: *Lecture notes in computer science.*. A.Frank and I. Campari (Eds). 270-283. Berlin: Springer-Verlag.

———. 2000. Geographic information science: Critical issues in an emerging cross-disciplinary research domain. *URISA Journal* 12 (1): 45-54.

——. 2003. Geographic information science: Defining the field. In *Foundations of Geographic Information Science*. New York: Taylor and Francis.

Miller, G. T. 1998. *Living in the Environment*. 10th ed. Belmont: Wadsworth Publishing Company.

Munoz, B., V. Lesser, J. Dorney, and R. Savage. 2009. A proposed methodology to determine accuracy of location and extent of geographically isolated wetlands. *Environmental Monitoring Assessment* 150: 53-64.

Nifong, T. 1998. *An Ecosystematic Analysis of Carolina Bays in the Coastal Plain of the Carolinas*. Unpublished Dissertation, University of North Carolina, Chapel Hill.

Noy, F. N. and D. L. McGuinness. 2001. *Ontology development 101: A guide to creating your first ontology*. Technical Report SMI-2001-0880. Stanford: Stanford University

Pechmann, J. H. K., D. E. Scott, J. W. Gibbons, and R. D. Semlitsch. 1989. Influence of wetland hydroperiod on diversity and abundance of metamorphosing juvenile amphibians. *Wetlands Ecology and Management* 1 (1): 3-11.

Phillips, J. D. 2007. The perfect landscape. *Geomorphology* 84: 159-169.

Richardson, C. J. 1995. Wetlands ecology. In *Encyclopedia of environmental biology* 3: 535-550.

Rosch, E. 1978. Principles of categorization. In *Cognition and categorization,* E. Rosch and B. B. Lloyd (Eds.). 189-205. Hillsdale: Erlbaum.

Ross, T. 2003. Pocosins and Carolina bays compared. *The North Carolina Geographer* 11: 22-32.

———. 1987. A comprehensive bibliography of the Carolina bays literature. *The Journal of the Elisha Mitchell Scientific Society* 103 (1): 28-42.

Savage, H. 1982. *The mysterious Carolina bays*. 1st ed. Columbia: University of South Carolina Press.

Schafale, M. P, and A. S. Weakley. 1990. *Classification of the natural communities of North Carolina: Third approximation*. North Carolina Natural Heritage Program.

Schalles, J. F., R. R. Sharitz, J. W. Gibbons, G. J. Leversee, and J. N. Knox. 1989. *Carolina bays of the Savannah River Plant*. Aiken, SC: Savannah River Plant National Environmental Research Park Program.

Semlitsch, R. D., and J. R. Bodie. 1998. Are small, isolated wetlands expendable? *Conservation Biology* 12 (5): 1129-1133.

Sharitz, R. R. 2003. Carolina bay wetlands: Unique habitats of the southeastern United States. *Wetlands* 23 (3): 550-562.

Sharitz, R. R., and J. W. Gibbons. 1982. *The ecology of southeastern shrub bogs (pocosins) and Carolina bays: A community profile*. FWS/OBS-82/04. Washington DC: US Fish and Wildlife Service, Division of Biological Services.

Smith, B., and D. Mark. 2003. Do mountains exist? Towards an ontology of landforms. *Environment and Planning* B 30: 411-427.

South Carolina Department of Natural Resources. SCDNR GIS Data Clearinghouse. https://www.dnr.sc.gov/pls/gisdata/download_data.login (last accessed 1 December 2008).

Stuart, S. N., J. S. Chanson, N. A. Cox, B. E. Young, A. S.L. Rodrigues, D. L. Fischman, and R. W. Waller. 2004. Status and trends of amphibian declines and extinctions worldwide. *Science* 306: 1783-1785.

Tiner, R. W. 2003. Estimated extent of geographically isolated wetlands in selected areas of the United States. *Wetlands* 23 (3): 636-652.

Tobler, W. 1970. A computer movie simulating urban growth in the Detroit region. *Economic Geography* 46: 234-240.

Tools For Graphics and Shapes. 2008. Version 1.1.85. Jenness Enterprises. Flagstaff, Arizona. http://www.jennessent.com/arcgis/shapes_graphics.htm (last accessed 1 June 2010).

Tuomey, M. 1848. *Report on the geology of South Carolina*. Columbia: A.S. Johnston.

US Fish and Wildlife Service.2009. National Wetlands Inventory. GIS Data. http://www.fws.gov/ wetlands/Data/DataDownload.html (last accessed 1 June 2009).

University of Georgia. The First 'Bird's Eye' View of Carolina Bays. http://abob.libs.uga.edu/ bobk/cbaymbsc.html (last accessed 1 June 2010).

USDA 2009. Soil Survey Geographic (SSURGO) Database | NRCS Soils. http://soils.usda.gov/ survey/geography/ssurgo/ (last accessed 1 June 2009).

USGS 2009. NC Gap Analysis Project. land use/ land cover data. http://www.basic.ncsu.edu/ncgap/ (last accessed 1 June 2009).

Van De Genachte, E., and S. Cammack. 2002. *Conservation of Carolina bays in Georgia*. Georgia Department of Natural Resources. http://www.georgiawildlife.com/node/ 819?cat=conservation (last accessed 1 March 2008).

Wake, D. B., and V. T. Vredenburg. 2008. Are we in the midst of the sixth mass extinction? A view from the world of amphibians. *Proceedings of the National Academy of Sciences* 105 (1): 11,466-11,473.

Worboys, M., and M. Duckham. 2004. *GIS: A computing perspective*. 2nd ed. Boca Raton: CRC Press.

CHAPTER VII

VITA

Jacob Richmond Turner was born in Atlanta, Georgia in 1973. Graduating from the University of Georgia with a B.S. in Anthropology in December of 1999, he worked as an archaeological field technician for several years. He began a graduate education in Fall of 2008 at Appalachian State University in the Department of Geography and Planning, finishing Master's work in August of 2010. He began doctoral work in Geographic Information Science at the University of North Carolina at Greensboro in the fall of 2010.