Prioritization of Carolina Bays as Mitigation Projects from Herpetofaunal Perspectives

By

James Edwards

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Director of Thesis: Dr. Dan Marcucci

Major Department: Geography

Carolina bays are landform features of the southeastern United States that contain isolated depressional wetlands. These unique ecosystems are particularly valuable for herpetofauna and are at risk of being extirpated from the landscape because of recent legal developments. There are few available inventories of these landform features and associated wetlands, most notably the South Carolina Department of Natural Resources inventory. No known peer reviewed published inventory exists for North Carolina, which contains a high concentration of Carolina bays in the southeastern coastal plain. Wetland inventories offer planners and landscape managers a source of information that can be integrated with other information to aid in rapid natural resource assessment and planning. This research is designed to develop a methodology that directs limited resources and funds towards Carolina bays that contain attributes necessary to provide habitat, refuge, and hibernacula for general herpetofauna while meeting regulatory needs. The implications of the research are that it uses existing data and builds upon them to prioritize Carolina bays while still being generalizable to other regions containing depressional isolated wetlands. By not using specific organisms, the research is intended to serve as a tool to direct efforts to locales where ground based surveys and truthing can be conducted for target species.

Prioritization of Carolina Bays as Mitigation Projects from a Herpetofaunal Perspective

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James Edwards

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By

James Dean Edwards Jr.

Approved By:

Director of Thesis: ____
(Dan Marcucci, PhD)

Committee Member: ____
(Thomas Crawford, PhD)

Committee Member: ____
(David Chalcraft, PhD)

Chair of the Department of Geography ______________________________
(Burrell Montz, PhD)

Dean of the Graduate School______________________________________
(Paul J. Gemperline, PhD)

Dedication

Jimmy Edwards

(1961 – 2010)

This thesis is dedicated to all those who have supported me through my academic career, especially my father. My father was a jack of many trades and master of none who had a passion for nature. It was his dream that I continue my education.

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I would like to thank the Department of Geography for accepting me and creating one of the best academic environments I have been part of. I am honored to have conducted this thesis as a geography student and the experience I received will be with me the rest of my life.

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Chapter 1: Executive Summary

Carolina bays are unique topographic features of the southeastern United States with dense concentrations occurring in the coastal plain and sandhills of North and South Carolina. The physical characteristics of these landscape features support the development of depressional wetlands, many of which are hydrologically isolated. These wetlands are at an increased risk of being altered or destroyed because of recent legal challenges that have reduced federal jurisdiction and human encroachment. Isolated wetlands are important breeding sites for many herpetofaunal species, particularly the amphibians, and function as sources for biological diversity in a primarily terrestrial landscape.

Isolated wetlands are generally those areas that have no physical surface contact with navigable waters of the United States and are completely surrounded by upland (Leibowitz 2003; Tiner 2003; Whigham and Jordan 2003). These wetlands serve many functions, particularly as sources for biodiversity. Semlitsch and Bodie (1998) argue that the presence and abundance of these wetlands are directly related to ecological processes and community dynamics. These attributes are lost when isolated wetlands are destroyed and may not be enhanced or improved in a mitigation process that focuses solely on hydrology. The most important court cases affecting isolated wetlands have been the Solid Waste Agency of Northern Cook County (SWANCC) vs. United States Army Corps of Engineers (USACE) and Rapanos vs. USACE. The rulings of these cases by the United States Supreme Court have limited federal jurisdiction to navigable waters and have placed an emphasis on individual states to manage their wetlands. South Carolina does not offer statewide protection to its isolated wetlands. In 2003, the North Carolina Ecosystem Enhancement Program (NCEEP) was enacted as the state's authority to protect its wetlands, including isolated. However, this system fails to address terrestrial landscapes surrounding wetlands that may be important for herpetofaunal use. Cushman (2006) suggests that non-spatial plans implemented at a site-specific basis are unlikely to provide conservation to populations that depend on complex geomorphic and biogeographic landscapes.

Herpetofauna, particularly the amphibians, typically depend on aquatic habitats for breeding. However, these organisms do not exclusively depend on these habitats and frequently inhabit the surrounding terrestrial landscape as adults for foraging and hibernacula. Populations of these organisms, especially the amphibians, are experiencing population declines and generally lack inclusion in resource evaluation outside of species lists despite their position in food webs and value as indicators of habitat quality (Beiswenger 1998; Hanlin et. al 2000). Amphibian use of terrestrial landscapes depends on two types of movement, migration and dispersal (Semlitsch 2008). These directional movements have been used in the herpetofaunal literature to determine that, on average, these species as a collective group generally migrate up to 250m from the wetland edge into terrestrial habitat and can disperse distances as far as 1,000m in search of suitable breeding sites (Burke and Gibbons 1995; Semlitsch and Bodie 1998, 2003; Marsh and Trenham 2001; Semlitsch 2002; Smith 2005; Rittenhouse and Semlitsch 2007). These distances have provided quantitative buffers that can be used to determine the condition of each Carolina bay and the surrounding terrestrial landscape for herpetofauna.

This thesis has been designed to develop a methodology that directs limited resources and funds towards Carolina bays that contain attributes necessary to provide habitat, refuge, and hibernacula for general herpetofauna while meeting regulatory needs. The implications of the research are that it uses existing data and builds upon them while still being generalizable. By not using specific organisms, the research is intended to serve as a tool to direct efforts to locales where ground based surveys and truthing can be conducted for target species.

Analysis

Carolina Bay Inventory

Despite the numerous studies of the Carolina bays, digital databases are generally not available. Through a comprehensive search, only two sources have been identified. One database is associated with the Advance Identification of Carolina Bays for South Carolina Wetlands Protection prepared by the South Carolina Department of Natural Resources (1999). The other database exists as a Google Earth file available from George Howard (2007) that was created by draping elevation data and digitizing believed Carolina bays. The methodology for this analysis will adapt standards used by the South Carolina Department of Natural Resources (1999) to verify polygons delineated as Carolina bays by Howard (2007) using Earth Systems Research Institute ArcGIS 9.3 software. Data to be used during this process includes North Carolina Floodplain Mapping Program LiDAR, United States Geological Survey NC Topographic Quadrangles, Soil Survey Geographic Database NC soil layer, and National Wetlands Inventory wetland polygons for NC.

Carolina Bay Herpetofaunal and Mitigation Attributes

Agricultural edge**.** Agricultural edge represents the percent of the Carolina bay and landscape (250m) that is fragmented by agriculture. Agricultural use of the land brings several concerns for herpetofauna. Amphibian skin is highly permeable and amphibians therefore have a stringent dependence on moisture (Smith and Green 2005). Semlitsch (2002) reported that disease, pathogens, invasive species and chemical contamination contribute to amphibian declines. The Landscape Fragmentation Tool (Parent 2009) is used in conjunction with Hawth's

Analysis Tools (Beyer 2004) to enumerate the total area of natural landcover classes that have been fragmented up to 30m by agriculture.

Road edge**.** Road edge represents the percent of natural landcover in each Carolina bay and landscape (250m) that has been fragmented by major roads. One of the most significant anthropogenic modifications of terrestrial habitats in the past century is the network of roads (Roe et al. 2006). Direct herpetofaunal mortality has been shown to be highly correlated with traffic volume (Gibbs and Shriver 2005). Andrews et al. (2006) suggest that social views of herpetofauna lead to direct targeting on roadways, in which drivers will deliberately kill snakes and turtles in particular. An additional impact of increased traffic volume on herpetofauna is the presence of toxins that degrade breeding habitat (Calhoun et al. 2005). Andrews et al. (2006) suggest that roads influence herpetofaunal populations as far as 100m. The Landscape Fragmentation Tool (Parent 2009) and Hawth's Analysis Tools are used to enumerate the total area of each Carolina bay fragmented by major roads.

Percent pine**.** Percent pine represents the proportion of the Carolina bay and landscape (250m) containing the dominant vegetation type of the southeastern coastal plain in which many herpetofaunal species have evolved. Southeast Gap Analysis Project (SeGAP) landcover data was reclassified to a binary classification scheme representing only pine habitats. Hawth's Analysis Tools were used to enumerate the total area containing pine habitats.

Biodiversity and wildlife habitat analysis (BWHA) rated. The Biodiversity and Wildlife Habitat Analysis identifies high quality habitat contributing to aquatic and terrestrial ecosystem processes (NC NHP n.d.). Overlay analysis was conducted to identify the total area of BWHA polygons within each Carolina bay and landscape (250m).

Patch cohesion. Lehtinen et al. (1999) reported that herpetofaunal richness in both fragmented and urban landscapes has a positive relationship with landscape connectivity. Patch cohesion was introduced by Schumaker (1996) as a unitless measure of patch connectivity to represent dispersal success. Patch cohesion is calculated using SeGAP landcover data and the FRAGSTATS patch cohesion index presented (McGarigal and Marks 1995). Each landcover value was extracted and analyzed separately in to obtain information on number of cells and perimeter representing the corresponding landcover type.

Patch diversity. Landscape heterogeneity is important to the sustainability of herpetofaunal diversity. The requirements of many herpetofaunal species, particularly the biphasic amphibians, for multiple habitat types during their life make them susceptible to habitat alterations (Welsh et al. 2005). Chen and Wang (2007) report higher herpetofaunal species richness in spatially heterogeneous landscapes. Patch diversity is calculated using the Simpson's Diversity Index as described in FRAGSTATS (McGarigal and Marks 1995).

Carolina bay density and variability. Wetlands in close proximity to other wetlands have higher abundances of herpetofaunal species than their more isolated counterparts (Attum et al. 2007). Density and variability of Carolina bays can provide information on their availability for herpetofaunal use and size. Density is calculated using Hawth's Analysis Tools to identify the number of Carolina bays occurring within 1,000m of the focal bay while variability is calculated using a spatial join to derive the standard deviation of sizes of all bays occurring within 1,000m of the focal bay.

Road density. Roads represent a landscape modification that make a site unsuitable for mitigation from a hydrological perspective and can contribute to pollutant loadings that are detrimental to herpetofauna. Hawth's Analysis Tools are used to enumerate the total length of all roads within the basin of the Carolina bay.

Swine lagoon count. Manure borne steroids, such as estrogen, can adversely affect the reproductive health of amphibians (Hanselman et al. 2003). Deep basins and steep slopes of most artificial ponds inhibit vegetation and result in functionally different systems (Shulse et al. 2010). Hawth's Analysis Tools are used to identify the total number of swine lagoons within each Carolina bay and landscape (250m).

Parcel count. Ownership is a major concern when implementing mitigation plans. Increasing owners may make it more problematic to achieve co-operation among owners or to obtain the property. Hawth's Analysis Tools are used to identify the total number of owners of each Carolina bay basin.

Restorability. The North Carolina Department of Coastal Management has produced a dataset that identifies Potential Wetland Restoration and Enhancement Sites (PWRES) (NCDCM 2008). These sites represent former wetlands that have been degraded but have not been destroyed and are most suitable for mitigation projects. A spatial join is used to calculate the total area of each Carolina bay basin that has been identified by NCDCM.

Carolina Bay Prioritization

Hierarchy. A hierarchy is a simple structure used to represent the simplest type of functional (contextual or semantic) dependence of one level or component of a system on another in a sequential manner (Saaty 1987). The hierarchy for this thesis (Figure 26) has been developed to identify a single priority value for each Carolina bay based on a summation of the products of each attribute score and their respective weights.

Stakeholder participation. A major problem related to generalizing species such as herpetofauna is the lack of species specific empirical models. To effectively deal with lacking empirical models, expert knowledge may be used (Store and Kangas 2001). Stakeholders for this thesis are identified from Local, State, and Federal agencies responsible for making landuse decisions that affect the Carolina bays. A total of 35 participants were given the survey presented in Appendix D to derive their expert opinions on the relative importance of one criterion over another.

Analytic hierarchy process (AHP). Stakeholder information obtained from the survey is analyzed with methods developed for the AHP. Participant matrices are constructed from the expert opinions and eigenvalues are calculated to determine participant criterion weights and consistencies as described by Saaty (1980). To obtain weights of each attribute across all participants, the aggregation of individual priorities method (Escobar et al. 2004) has been chosen to derive group preferences (i.e. weights). This method assumes that each individual is acting independently and has equal importance in the process.

Scaling and scoring. Raw values for each attribute are transformed to normality and converted to a Z-score. Z-score values are used to group the data into scores representing similar locations from the mean (Figure 27). To obtain priority values for the Carolina bays, a weighted linear combination procedure described by Holzmueller et al. 2011 is prescribed. This procedure uses the attribute score and its derived weight to sum the products as described in Figure 27.

Conclusions

This analysis has produced 1,863 inventoried Carolina bays, 769 of which are in Bladen County with the remaining 1,094 in Sampson County. County statistics of the Carolina bays suggest that Bladen County contains the largest bays and variability of bay sizes while Sampson County consistently contains smaller bays (Table 5). Data presented in Table 8 describes statistics of the attributes only in bays containing values for the attribute (*N*). The attribute data suggests that on average, Carolina bays and landscapes have been 9.43% fragmented by agriculture and 18.33% fragmented by roads. Carolina bays containing pine habitats are covered by 19.01%. The Carolina bays that have BWHA values have been 29.49% rated by the NC NHP. Attributes of landcover suggest that the natural habitats are fairly diverse and connected (Diversity = 0.65; Cohesion = 0.84) while those representing dispersal processes (Carolina Bay Density and Variability) suggest that each Carolina bay contains 1.65 Carolina bays within 1,000m and that these bays are heterogeneous in size. Carolina bays that contain roads in their basins are found to have an average road density of 363.09m/100Ha. Swine lagoons are found minimally in the Carolina bays (1.61 per bay) and each bay is owned by an average of 6.49 owners. Each Carolina bay that has been rated as restorable by NC DCM is described as being 59.39% restorable on average.

Prioritization of the Carolina bays yielded 33 rated as high preservation, 286 as high restoration, 598 as medium restoration, 646 as low restoration, 259 as low mitigation: severely altered, and 41 as low mitigation: possibly lost (Table 14). Distributions of these priority classes show that most of the high priorities exist in Bladen County and the distribution shifts to Sampson County for the low priorities (Figures 28 and 29). Data presented in Table 15 display the average values of the attributes per each priority class. The data suggest that the highest priority Carolina bays exist in the least altered condition and have the most natural landscape while the lowest priority Carolina bays are the most altered and exist within an anthropogenic dominated landscape.

Chapter 2: Literature Review and Problem Formulation

Fresh water is a strategic resource that structures the nation's natural and cultural landscapes and is a major determinant of regional economies and demographic patterns (Naimen et al. 1995). Freshwater wetlands have historically been degraded or destroyed by direct use practices. These practices have mainly been for agriculture and natural resource extraction such as minerals, trees and peat. The federal government has been in charge of regulating the nation's navigable waters since its inception under the constitution (Downing et al. 2003). This authority has led to many acts being implemented, none more important to wetland protection than the Clean Water Act (CWA). Under the CWA, modern policy was created and has been reinterpreted through legal challenges. The issue of isolated wetlands has arisen from these challenges and includes the Carolina bays.

Isolated wetlands are generally those areas that have no physical surface contact with navigable waters of the United States and are completely surrounded by upland (Leibowitz 2003; Tiner 2003; Whigham and Jordan 2003). This description should not be confused with a definition, as there is not a scientifically accepted one (Leibowitz 2003). Many types of wetlands can be isolated, but most depression wetlands are isolated because of their topographic position in the landscape. These wetlands serve many functions, particularly as sources for biodiversity. Semlitsch and Bodie (1998) argue that the presence and abundance of these wetlands are directly related to ecological processes and community dynamics. These attributes are lost when isolated wetlands are destroyed and may not be enhanced or improved in a mitigation process. Mitigation decisions treat wetlands as units often with little consideration given to the spatial configuration of the surrounding landscape (Attum et al. 2007; White and Fennessy 2005).This non-spatial treatment creates a condition that is narrowly focused on the wetland itself such that functional linkages to uplands are neglected (Porej et al. 2004; Roe et al. 2006). Cushman (2006) suggests that non-spatial plans implemented at a site-specific basis are unlikely to provide conservation to populations that depend on complex geomorphic and biogeographic landscapes. Amphibians and reptiles generally lack inclusion in resource evaluation outside of species lists despite their position in food webs, value as indicators of habitat quality, and overall decline (Beiswenger 1998; Hanlin et. al 2000). Given the urgency of the crisis facing herpetofauna, it is imperative that conservation planners make the most effective use of currently available information by taking landscape level approaches that integrate species biology with spatial evaluation of the composition and configuration of both breeding and non-breeding habitats (Cushman 2006). Understanding of the distribution and disturbance patterns of these wetlands would aid in the identification of management practices that could promote herpetofaunal biodiversity.

Carolina bays are geomorphic features and contain depressional wetlands of the coastal southeastern United States, most of which are believed to be isolated (Ross 2003). These features are most commonly recognized by their elliptical shape and the basins' general northwest to southeast orientations. The presence of a sand rim along the eastern and southern sides, which is suggested to be height proportional to the depth of the bay, is a characteristic feature (Buell 1946; Lees 2004). However, this has yet to be quantified and some bays lack a rim altogether. The sand rims, when present, have been described by Melton and Schreiver (1933) to have a gentle slope. The distributions of these unique features extends from northern Florida through the Delmarva Peninsula but are most concentrated on the coastal plain of northeastern South Carolina and southeastern North Carolina (Ewing 2003). Depression wetlands of the Carolina bays are important ecologically because they are the dominant lentic (static freshwater) habitat on a large portion of the southeastern coastal plain (Calhoun et al. 2005; Sharitz and

Gibbons 1982). These wetlands are particularly important to herpetofauna because most of them lack predatory fish. Short hydroperiods and hydrologic isolation from permanent water sources make these wetlands unsuitable for fish populations while simultaneously being conducive to explosive reproduction typical of the amphibians. These wetlands are at risk because of past alterations, recent legal challenges to the CWA, and human population growth and associated landuse and cover change. One of the key problems associated with herpetofaunal use of the depressional wetlands of the Carolina bays is a lack of understanding regional disturbance patterns and initiating conservation plans outside of protected areas.

The goal of this project is to prioritize Carolina bays for conservation and restoration opportunities from a herpetofaunal perspective. Specifically, the intent of this project is to:

- Identify the condition of herpetofaunal habitats within the Carolina bays and surrounding uplands.
- Define the status of Carolina bays in Bladen and Sampson Counties, NC with respect to degree of alteration and land-use/land-cover for strategic mitigation opportunities.
- Utilize the Analytic Hierarchy Process (AHP) with this information to develop a strategic conservation plan that would promote herpetofaunal diversity and persistence.

Ultimately, the project is designed to answer the following three questions:

- What is the condition of the Carolina bays from a herpetofaunal standpoint in these counties?
- How can these conditions be grouped into an ecologically meaningful way to potentially promote biodiversity?

- How are high priority locations distributed throughout the landscape-are they clustered, uniform, or random?

Answering these questions would aid in directing management priorities and contribute to the growing knowledge of the Carolina bays.

This project is unique and would contribute considerable knowledge because it is designed to treat the Carolina bay and surrounding herpetofaunal-perceived landscape as landscape elements that will be used to detect disturbance patterns at the local scale. A thorough search of the literature indicates no such study exists of the bays. It is predicted for this thesis that many of the bays are moderately to highly disturbed, exist in a complex mosaic of surrounding land use, and can be effectively prioritized by using the AHP and expert knowledge. An understanding of the condition of the Carolina bays and herpetofaunal landscapes would contribute in identifying and defining a conservation strategy of Bladen and Sampson counties. However, such a strategy begins with understanding what a Carolina bay is, the common vegetative communities of the region, how herpetofauna utilize these habitats, and how landscape condition is quantified. Such a strategy would facilitate regional herpetofaunal biodiversity and sustain isolated wetlands of the Carolina bays within a growing region.

Background

Legal Interpretations

The most important court cases affecting isolated wetlands have been the Solid Waste Agency of Northern Cook County (SWANCC) vs. United States Army Corps of Engineers (USACE) and Rapanos vs. USACE. These challenges have restricted federal jurisdiction of wetlands to navigable waters and increased pressure on individual states to protect their wetlands.

In SWANCC, the Supreme Court was asked whether specific isolated waters could be considered a water of the United States and protected by the CWA based solely on the migratory bird rule (Nadeau and Leibowitz 2003). The migratory bird rule was a practice the USACE used for applying legal protection to isolated wetlands. The general idea was that the presence of waterfowl represented inter-state commerce and thus federal jurisdiction. The USCACE received a 404 permit application for the filling of abandoned gravel pits and eventually rejected the permit because of the use of the site by migratory birds (Petrie et al. 2001). The Supreme Court ruled in favor of SWANCC 5-4 on January 9, 2001 finding that the USACE had exceeded its authority under the CWA by applying jurisdiction over isolated waters based solely on the presence of migratory birds (Leibowitz 2003; Nadeau and Leibowitz 2003). Since the SWANCC decision, the scope of the CWA and the authority of the USACE have been narrowed. Wetlands that are not adjacent to or contributing significant nexus with navigable waters of the United States are no longer subject to jurisdiction under CWA. The jurisdiction of isolated wetlands now lies within state authority, which weakens the protection status by inconsistencies between state policies.

The *Rapanos* case brought with it the issue of what constitutes jurisdiction over isolated waters. The first part of the case initiated with Mr. John Rapanos violating the CWA by filling in wetlands on his property without a section 404 permit while the second part began with Mr. Keith Carabell filing suit over the denial of a section 404 permit (Persell 2006). The issue at hand with both suits was that the site was a distance far enough away from the nearest navigable water such that there was no significant nexus (i.e. major influence) to federal water. There was no majority opinion in the case, and the Supreme Court justices were divided sharply over the issue at hand (Environmental Law Institute 2007). Confusion over significant nexus and how continuous or often the nexus is has deeply questioned which waters are covered under the CWA. A significant nexus to navigable water can be thought of as a contributor to water quality through surface or groundwater connections. Isolated wetlands were further limited in protection from the *Rapanos* decision.

Wetland mitigation and North Carolina

Mitigation typically encompasses two practices: Conservation and preservation, and restoration, while focusing directly on water quality. Conservation and preservation are used collectively to keep an area in its current condition, typically completely natural, and to avoid future detrimental activities. These practices are intended to keep un-altered habitats in a high quality condition for environmental functioning. Restoration of wetlands focuses on rehabilitating a disturbed site to natural conditions and begins with the selection of sites. Traditionally, areal impact of wetland loss is mitigated by replacement to meet the 'no net loss' goal set by the federal government. However, the SWANCC and Rapanos decisions make it increasingly difficult to afford protection to small, hydrologically isolated wetlands. Due to their size and ephemeral hydrology, single large isolated wetlands are preferred in restoration plans while the biological importance is overlooked (Calhoun et al. 2005; Russell and Guynn 2002). Biologically, isolated wetlands support high species diversity compared to surrounding terrestrial uplands (Copeland et al. 2010; Gibbons et al. 2006). Restoration activities, being site specific, typically give little thought to processes operating at larger scales resulting in decoupling from management of the surrounding landscape and creating widely varying conditions for species utilizing both (Kershner 1997; Porej et al. 2004). North Carolina has begun addressing this problem by attempting to mitigate wetland function in lieu of area.

Water quality and hydrologic regimes are the primary foci of many mitigation activities. Hydrologic regimes of disturbed isolated wetlands are typically returned by plugging ditches and canals. Once hydrologic regimes have been restored, water quality improvements can be targeted. The most common method used to increase water quality is a vegetative buffer. However, buffer zones intended to protect water quality are typically 30 meters and do not adequately protect the quality of adjacent terrestrial habitat, particularly for amphibians which require both aquatic and terrestrial habitat (Harper et al. 2008). These shortcomings are often enhanced when wetland mitigation is performed for water quality.

North Carolina, like every other state, faces the challenge of achieving responsible growth while simultaneously protecting the environment (Gilmore 2005; Gilmore 2006). North Carolina has wetland resources, historically covering approximately 3.2 million ha (Cashin et al. 1992). The coastal plain contains much of the state's wetland resources. In the last 40 years, approximately 51.3% of the state's total wetland resources have been altered or destroyed (1992). During the 1990's a large- scale shift in the public's perceived valuation of wetlands occurred when wetlands became widely recognized for performing valuable environmental functions (Heath 1999). When addressing wetlands, functions and values must be distinguished. Functions refer to the natural processes that the wetland performs. Notable functions have been found by the scientific community to include flood control, water purification, groundwater recharge, and habitat for endangered species. (Meindl 2004). Values on the other hand, refer to societal valuation of these functions that are often what is being protected by law (Cashin et al. 1992). Prior to the 1990's, the status quo of wetlands mitigation was to provide a creation, restoration, or enhancement of an equal amount of wetlands disturbed without consideration of large scale wetland functions. This practice created situations in which contributing to offsite mitigation banks resulted in loss of wetland functions due primarily to the loss of wetland type. It has been widely addressed in the literature and the basis of the hydrogeomorphic (HGM) classification that differing wetland types do not perform identical functions (Brinson 1993). In 2003, the North Carolina Ecosystem Enhancement Program (NCEEP) was enacted as the state's primary mitigation practice. This program is designed to address functional equivalency and mitigate functions lost instead of values or acreage. This program provides the foundation necessary to meet the 'no net loss' goal set forth under the CWA.

Carolina bays

Origins of the Carolina bays have been the basis of debate in the literature. Theories of origins range from meteor showers, extraterrestrial launch pads, and iceberg thaws (Lees 2004; Melton and Schreiver 1933).Melton and Schreiver (1933) describe a set of geomorphic facts that any theory must address and cast doubts on most of the common theories in their review of Carolina bays of northeastern South Carolina. Thom (1970) used these suggestions in part and considered the shape of bays to be a result of the combination of the prevailing winds and wave action of existing depressions despite the unknown origins of the original depression. This possible explanation is the most widely accepted of the theories (Ewing 2003). Other than their definitive shape, Carolina bays can be described by their hydrology and vegetation.

Hydrology. Regional hydrology is the single most important factor influencing the structure and function of wetland ecosystems (Russell et al. 1997). Hydrology is dynamic, varying annually, seasonally and daily from wetland to wetland in such a manner that no two wetlands are exactly alike (Tiner 1999). The USACE definition "wetlands are those areas that are inundated or saturated by surface or groundwater at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas." incorporates this hydrologic variability. The definition links vegetation with soils that are produced by the hydrologic regime. Brinson (1993) developed the hydrogeomorphic classification system in which the hydrologic, geomorphologic, and hydraulic properties of a site group with sites of similar properties because of hydrologic variability. The hydrogeomorphic classification system identifies seven hydromorphic classes: depressional, organic flats, mineral flats, riverine, slope, lucastrine, and estuarine (Brinson 1993; Tiner 1999). Under the hydrogeomorphic classification, depression wetlands are ombrotrophic habitats meaning that they receive the majority of their water either from precipitation or groundwater (Brinson 2003).

Depression wetlands of the Carolina Bays receive much of their water from precipitation by virtue of their relatively high position in the landscape but have been found to receive groundwater inputs and in some circumstances surface water runoff (Kirkman et al. 2000;Kolka and Thompson 2006; Lees 2004; Mulhouse et al. 2005; Sharitz 2003; Whigham and Jordan 2003). Regional climate such as a relatively long growing season with hot, typically dry summers creates periods of fluctuating water tables in many bays. In the southeastern United States, major precipitation events occur most commonly in the winter and spring when evapotranspiration is low creating saturated conditions or in the fall with land-falling tropical systems. Fluctuating water tables and the ephemeral nature of inundation in Carolina bays distinguish bay types (Sharitz 2003).

Water delivered through precipitation is generally lower in nutrients than groundwater is. Carolina bays with shallow peat layers overlaying a mineral substrate (clay based) are typical of this type of input (Kirkman et. al. 2000). Evapotranspiration and low rainfall during the growing season creates a gradual drying of these systems (Sharitz 2003). The drawdown of the water table in these wetlands creates conditions in the soil that allow the survival of nutrient dependent vegetation which will be discussed in the vegetation section of this review.

Groundwater is generally higher in nutrients than precipitation is. Groundwater inputs usually keep the bay saturated longer and more frequently than precipitation creating conditions that favor growth of scrub and shrub like vegetation. Carolina bays that have a groundwater connection typically have a thick peat layer (peat based) (Kolka and Thompson 2006; Leibowitz 2003). These bays are generally less affected by precipitation patterns than the "clay-based" bays but are ironically associated with nutrient efficient vegetation.

Hydrology can be considered as the master variable controlling redox status, pH, nutrient cycling, community composition, and wetland development (Bruland et al. 2003). Hydrology has been incorporated in the USACE's wetland definition in part of these reasons. Bay types, clay versus peat, have been found to be associated with water inputs, but hydrology has not been addressed as a causative variable. However, hydrology has been attributed the role of regulating soil chemistry which in turn regulates vegetation.

Vegetation. Vegetation is perhaps the most noticeable and readily available estimate of wetland presence. The United States Fish and Wildlife Service's classification system relies on vegetation cover as the basis for the classification system (Brinson 1993; Cowardin et al. 1979). Vegetation estimates are made available from the use of remote sensing and direct field surveys.

Many wetlands have characteristic cover, but overlap can occur between covers. There are no defining plant communities of the Carolina bays (Bruland et al. 2003). The high variability of the hydrology and soil properties of Carolina bays is expressed through the plant communities. Cover types range from woody, shrub-scrub, herbaceous, and some aquatic vegetation (2003).

Nutrient availability is perhaps the influencing factor affecting community composition, particularly phosphorous (Richardson 2003). It should be apparent that the abundance of plant material in organic soils creates a rich concentration of nutrients. After the depletion of oxygen, oxidation-reduction (redox) reactions begin to occur. Under these conditions, common soluble elements such as iron, manganese, and nitrogen are reduced to provide electron acceptors for metabolic processes, which limit the availability for uptake by plants (Lees 2004). It is believed that the high concentrations of acids produced in organic soils further complicate the availability of limited nutrients (Ewing 2003). Nutrient availability is highly influential in developing plant communities.

Fire frequency is critical in wetland communities. The prevalence of fire has historically driven community structure along the coastal plain. Wetlands with frequent fires typically have a canopy representative of fire tolerant species such as longleaf pine and an understory of grasses and sedges that occur as a pioneer species. In the absence of fire, characteristic structure is thick with dense shrubs and vines that are not fire resistant. The role of fire in wetland community evolution is typically well understood and is recognized as an important event; however, little information is available on the long term effects of fire specifically on Carolina bay communities (Kirkman et al. 2000).

Even though Carolina bays are not pocosins, Richardson (2003) acknowledges that under the USFWS classification system, both are defined as palustrine wetlands and that there can be substantial overlap of vegetation. A broad definition of pocosin vegetation would include all shrub and forested bogs, Atlantic White Cedar stands, and some pine stands on the coastal plain (2003). The soils that pocosin vegetation is found on can range from sand to mineral soils to peat (Richardson 2003; Sharitz 2003; Whitehead 1981). Other general classes of vegetation found throughout Carolina bays include swamps, savannahs, meadows and marshes, and open water.

Pocosin vegetation is perhaps the most confusing of the vegetation types found in the bays. Low pocosin and high pocosin are both synonyms for general pocosin vegetation (Nelson 1986). Richardson's (2003) shrub and forested bog communities correspond to low and high respectively. The terms low and high are also referred to as short and tall. Low pocosin vegetation is characterized by vegetation that is six meters or less occurring on deep peat (greater than one meter) while high pocosin vegetation is six meters or more and found on shallower peat (fifty to one hundred centimeters) (Cowardin et al. 1976; Nelson 1986; Richardson 2003). These two types of pocosin inherently must be mentioned together because of their enormous overlap in species. There are two theories suggesting the relationship between low and high pocosin: Fire frequency and vegetative composition, and fire intensity and nutrient availability (Richardson 2003). Under the former, it is believed that the frequency and intensity of fires regulates the succession from low pocosin to tall pocosin while the latter assumes that as nutrients are consumed the vegetation evolves into the low pocosin. Common species associated with pocosin communities include: white cedar (*Chamaecy paristhyoides*), red bay (*Persea barbonia*) sweet bay (*Magnolia virginiana*), loblolly bay (*Gordonia lasinathus*), red maple (*Acer rubrum*), black gum (*Nyssa sylvatica)*, pond pine (*Pinus seretina*), fetterbush (*Lyonia lucida*), black ti-ti (*Cyrilla racemiflora*), honeycup (*Zenobia pulverulenta*), and inkberry (*Ilex glabra*) (Nelson 1986; Richardson 1981; Shartiz 2003; Whitehead 1981).

Swamps are often perceived by humans as dreadful places and are typically applied to describe wetlands. There are two main types of swamps, shrub and forested, which are separated based on the height of the dominant vegetation (less than 6.1m is shrub and more than 6.1m is forested) (Bruland et al. 2003; Cowardin et al. 1976; Tiner 1998). Swamps are areas that are permanently to semi-permanently flooded with a closed canopy. The shrub swamp vegetation has been described in the pocosin section of this review. Forested swamps of the Carolina bays have been described as Atlantic white cedar (Buell 1939; Richardson 2003), bay forests (Buell1939; Richardson 2003; Shartiz 2003), non-alluvial swamp forests (Bruland et al. 2003; Kirkman et al. 2000; Sharitz 2003), hardwood swamps (Newman and Schalles 1990), and cypress-gum swamps (Kirkman et al. 2000). Each swamp can be characterized by its dominant vegetation.

Atlantic White Cedar (*Chamaecy paristhyoides*) was once a major source of revenue for local economies. Atlantic white cedar is the dominant species of the cover and is often associated with tall pocosin vegetation (Nelson 1986). This type of swamp is typically found in the lower coastal plain (Tiner 1998). The dynamics of this forest are generally not understood and the role of fire is believed to have an important impact on development (Nelson 1986). Korstian (1924) suggested that fire occurrence will open enough canopies from the thick vegetation typical of pocosins to allow protected seeds to germinate and flourish while killing the adult trees.

Bay forests are also deeply associated with pocosin vegetation and are believed to be a succession stage from tall pocosin (Richardson 2003). Characteristic species are typically red bay, sweet bay, and loblolly bay (Sharitz 2003). These swamps have been found to occur in mineral soils overlain with a layer of peat (Richardson 2003; Sharitz 2003). Since this forest can be viewed as mature, under either of the succession theories discussed in the pocosin section it should be assumed that a low fire frequency supports this system. These swamps are perhaps the most frequently encountered of the forested swamps being distributed throughout the coastal plain.

Non alluvial swamp forests are characteristic of lentic habitats where sediment deposits are rare. These forests are characterized by a closed canopy of various hardwoods and a sparse understory. Common species of the canopy include: red maple (*Acer rubrum*), bald cypress (*Taxodium distichum*), tulip poplar (*Liriodendron tulipifera*), pond cypress, and black gum (Bruland et al. 2003; Nelson 1986; Sharitz 2003). These communities have been found on poorly drained mucky mineral or organic soils that are frequently saturated or shallowly flooded (Nelson 1986; Shartiz 2003). Nelson (1986) has noted that the dynamics of this system are poorly understood and shares some dynamics with riverine swamps and pocosins. Fire frequency should be assumed to be low in this community because of the sensitivity of the vegetation to fire. Non alluvial swamps of the Carolina bays are not abundant and should be conserved.

Cypress gum swamps are a particular type of non-alluvial swamp forest. This community is characterized by bald cypress mixed with black gum and bay poplar (*Nyssa aquatic*) (Kirkman et al. 2000; Nelson 1986). Nelson (1986) describes this community as the most deeply flooded of the palustrine wetlands with herbaceous vegetation only appearing on stumps and logs protruding from the water. Along with Atlantic white cedar, cypress has historically been a cash crop for the southeast. Extensive harvests of cypress has left unaltered forms of this community rare (1986). The best preserved of this community within the Carolina bays are in extremely remote areas that are surrounded by native upland vegetation.

Savannahs are characteristic of the southeastern United States. They are characterized by expansive areas of graminoids with scattered trees (Walker and Peet 1984). Typical graminoids of the ecosystem include maiden cane (*Panicum hemitomom*) mixed with various grasses (*Dicanthelium* spp.), sedges (*Carex* spp.) and rushes (*Rhynchospora* spp.) (Kirkman et al. 2000; Nelson 1986; Sharitz 2003). The two types of savannahs found among Carolina bays are cypress and pine. The cypress savannah is characterized by sparse pond cypress (*Taxodium ascendens*) and black gum (*Nyssa sylvatica*) trees growing in an abundance of graminoids (Kirkman et al. 2000; Nelson 1986; Sharitz 2003). Pine savannahs are characterized by various species of pine (*Pinus* spp.) (Nelson 1986). Regionally, savannahs can be viewed as the cover occupying the mid-range of a moisture gradient from that of pocosins to that of uplands (Walker and Peet 1984). Savannas tend to occur predominantly on mineral soils that are seasonally to temporally flooded (Nelson 1986; Sharitz 2003). The pine savannah is typically not mentioned in the literature as bay vegetation because they are commonly found on or near the rims of the bays where inundation is not frequent. This spatial distribution is suggested by Nelson (1986) to be the result of the tolerance of cypress species to longer hydroperiods than pine species. Savannahs have long been maintained by frequent fire (Walker and Peet 1984). Fires preserve the ecosystem by keeping shrubs from the understory and maintain the graminoid dominance. Under the prevention of fire, Nelson (1986) suggests that pine savannahs would eventually succeed to a closed canopy system beginning with pine flatwoods. Savannahs have been characterized as being highly diverse and should be maintained as a viable ecosystem.

Meadows and marshes are communities that are separated by the duration and frequency of inundation. Marshes are areas that are covered by a shallow layer of water for most of the year while meadows are areas that the water table is at or fairly close to the surface (Tiner 1998). Typically, these systems have no distinct canopy but a few *Pinus* sp. or pond cypress (Kirkman et al. 2000). Grass and sedge marshes have been attributed to Carolina bays (Kirkman et al. 2000; Mulhouse et al. 2005; Newman and Schalles 1990) and are typically dominated by various species of panic grasses (*Panicum* sp.) and sedges (*Carex* sp.) (Kirkman et al. 2000). Depression meadows have been poorly described but briefly mentioned in the literature. Sharitz (2003) offers the best description of typical vegetation of a depression meadow as rich herbaceous variety of grasses (*Panicum* spp.), sedges (*Rhynchospora* spp.), netted nutrush (*Scleria reticularis)*, meadow beauty (*Rhexia virginica)*, Carolina redroot (*Lachnanthes caroliniana)*, yellow eyed grasses (*Xyris* spp.), and many others. The meadows and marshes are often found on mineral soils (Kirkman et al. 2000; Sharitz 2003) of the upper coastal plain. These systems can exhibit high species diversity and represent a boundary between permanently flooded areas and the surrounding wetland areas of Carolina bays.

Permanently saturated sections of Carolina bays are rare. The best known example of a permanently flooded bay is Lake Waccamaw in southeastern North Carolina. Given the physical characteristics of the bays, any permanently flooded area would occur in the southeastern most section of the bay. This is evident in the bay lakes of Bladen County, North Carolina. The type of community present in these conditions has been described as lakes (Sharitz 2003), ponds (Mulhouse et al. 2005; Sharitz 2003) and pools (Sharitz 2003; Tiner 2003). These communities are found only in flooded conditions.

Lake communities of the bays are found in permanently flooded areas (Sharitz 2003). These communities have been poorly described in the literature. Species of this community are floating and emergent macrophytes, specifically: fragrant waterlilies (*Nymphaea odorata*), yellow water-lily (*Nuphar lutea*), Panic grasses, and common rush (*Juncus effesus*) (Sharitz 2003). These communities should be most prevalent near the water edge where gently increasing elevations typically raise the surface from the water level.

Ponds and pools are semi-permanently flooded areas of the bays. Ponds and pools, like the lake communities, are poorly documented in the literature. The most common pond community encountered in the literature is pond cypress ponds (Nelson 1986; Sharitz 2003). The authors have attributed the dominant canopy species as pond cypress with sparse black gum and bay poplar. Tiner (1998) has described pools as being extremely small, typically the size of a swimming pool or smaller and dominated by various sedges, grasses, and rushes. The small size and rareness of these communities make them a small proportion of the vegetation types found in the bays. Nelson (1986) suggested the fire disturbance is virtually absent from these systems except in extremely dry years. These communities may be rare and small, but their importance should not be overlooked.

Agricultural practices have historically been the major agent in Carolina bay alteration. The physical properties of Carolina bays make them a prime target for agriculture. Soils that have limitations such as frequent flooding can become prime farmland once these limitations are overcome by hydrologic management (Leab 1990). This type of management effectively decouples the hydrology-vegetation relationship resulting in nutrient rich terrestrial soils needed for row crop production. Further, the economic value of the natural vegetation (i.e. Cypress, Atlantic White Cedar, Pine, etc.) makes the bays a direct target for timber cultivation and harvest. Ewing et al. (2005) conducted a historical review of Juniper Bay, a mitigation site in Robeson County NC, and found from aerial photography and previous owner interview that the bay was subjected to both harvesting of its Atlantic White Cedar and row crop production. Further, Bladen Lakes State Forest is a large tract of land owned and operated by the North Carolina Forest Service for timber production, mostly loblolly plantations (Hall et al. 1999). Carolina bays, by virtue of their physical properties, have been targeted for agriculture and the result has been either a shift away from functioning wetland habitat or a change in natural community presence.

Landscape ecology

Landscape ecology is a sub-discipline with its roots in geography and ecology. Geography has contributed to the discipline through the spatial approach and map development (Opdam et al. 2002). Maps can convey information in a meaningful way across space, time, or both. The information obtained from landscape ecology portrayed in maps is obtained from pattern analysis linked to ecosystem function. Patterns originate from heterogeneity and can be grouped into three levels: patch (individual habitats), class (habitat types across the landscape), and landscape (all habitat types present) (Peng et. al. 2010). Pattern analysis of landscapes can yield valuable insights into how the landscape is configured through isolation, size, shape, and the interactions between patches that make the landscape. These patches can be represented by any classified data (i.e. vegetation types, soils, landforms, etc.) that can describe the patterns of interest. Landscape ecology is an important discipline that came from a variety of sources, studies the patterns caused by heterogeneity through metrics, and is being linked to other environmental practices.

Heterogeneity. Heterogeneity of a landscape is the property of being complex with many interacting parts. Malanson and Cramer (1999) define complexity as a system property that has information but is neither completely random (at deterministic chaos) nor ordered (self-organized) at all scales. Scale is defined by the grain and the extent of the study area. Grain is the resolution of the data while extent refers to the physical study area. Scale is important to consider because patterns may be noticed at one scale and extrapolated to similar scales before breaking down at drastically different scales (Gustafson 1998). Therefore, landscapes may have some distinct patterns at different scales and the distinction between what is mapped and what is ecologically relevant to the resource under consideration is blurred (1998).

Ecological relevance is governed by the questions being asked and the patterns of significance. Because patterns originate from heterogeneity and are classified into five components (number of patch types, proportion of patch types, spatial arrangement, shape, and contrast between neighboring patches) at three scales (patch, class, landscape), landscape metrics vary in their sensitivity to scale (Botequilha-Leitão and Ahern 2002; Haines-Young and Chopping 1996; Peng et al 2010; Turner et al. 2001).

Metrics. Quantification and identification of landscape pattern is performed through the use of landscape metrics. These metrics are the heart of landscape ecology and have received attention in the literature with regard to their purpose, redundancy, and correlation to scale. Metrics are designed to describe a particular component of a heterogeneous landscape and can be grouped into those describing landscape composition or landscape configuration (Turner et al. 2001). Landscape composition refers literally to what patches are in the landscape and what are their characteristics, while configuration refers to how the patches are interacting.

Landscape ecology links. Although landscape ecology was developed to analyze fragmented terrestrial environments, efforts have been made to link the discipline with aquatic systems, restoration, and planning (Bell et al. 1997; Opdam et al. 2002; Wiens 2002). These combinations have added to the utility of the discipline through ecological considerations of function.

Aquatic systems are considered to be characterized by a stronger connectivity through the treatment of aquatic systems as the mosaic (dominant and most connected cover type of a landscape), consideration of boundary dynamics, and internally heterogeneous (Wiens 2002). These treatments arise because of the ability of water to influence many properties of the surrounding environment, particularly soil and vegetation. Restoration and spatial planning have been introduced as a possible link because of the ecological correlations between landscape structure and ecological function. These practices either focus to rehabilitate a previously fully functional area back to capacity or to manage a landscape for a particular purpose. The role of landscape ecology in these practices is to utilize the ability of metrics to quantify the relationship between a patch and its surroundings. Water and ecological considerations are the driving forces linking landscape ecology to environmental practices. An underlying assumption in environmental decisions is that before the interaction between landscape structure and ecological processes can be understood, landscape patterns must be identified and quantified (Ekström 2003; Peng et al. 2010).

Herpetofaunal landscape and terrestrial upland use

Amphibians have generally been viewed as highly philopatric (i.e. returning to their natal ponds) organisms with poor dispersal abilities (Marsh and Trenham 2001). The literature refutes this view and provides quantitative evidence of herpetofaunal use of uplands surrounding breeding sites. Amphibian use of landscapes depends on two types of movement, migration and dispersal (Semlitsch 2008) along with habitat preference. Migration is defined as movement primarily by adults toward upland overwintering habitat and back to natal breeding sites while dispersal refers to a unidirectional movement, mainly by juveniles, from the natal pond to another breeding pond (2008). These directional movements have been used in the literature to determine how far species travel from their breeding sites to seek refuge, and how far individuals typically travel to find suitable breeding sites.

In a study evaluating the emergent spatial patterns of herpetofauna in Alabama, Chen and Wang (2007) described the herpetofauna as exhibiting complex life cycles and only utilize wetland habitat for a portion of their lives. Semlitsch (2002) and Semlitsch and Bodie (1998; 2003) determined that adult amphibians require foraging and overwintering habitat up to 290m into the surrounding uplands. To determine the portion of amphibian population using terrestrial uplands, Rittenhouse and Semlitsch (2007) studied the distribution of amphibians in habitat surrounding wetlands and found that 95% of amphibians utilize terrestrial habitat within 664m of the wetland boundary. Burke and Gibbons (1995) suggested that freshwater turtles move up to 275m from isolated wetlands to seek upland habitat. Although the South Carolina Department of Natural Resources (1999) did not use amphibians as the basis of their 250m Carolina bay buffer, the literature suggests that 250 meters is adequate to analyze upland habitat surrounding Carolina bays. Figure 1 shows the distribution of all amphibian species around an isolated wetland studied by Rittenhouse and Semlitsch (2007). It can clearly be seen that around the 250m distance from the wetland boundary, there is a sharp decline in the density of amphibians present. From these migration studies, a buffer of 250m is justified for measuring habitat attributes. However, these studies do not confirm how far the average amphibian disperses to find a suitable breeding site.

Herpetofaunal populations depend on colonization for persistence. The stochastic nature of local precipitation patterns coupled with varying hydroperiods at each breeding site creates fluctuating breeding and extinction rates for herpetofaunal populations (Marsh and Trenham 2001). To effectively overcome local extinctions, colonization must occur from surviving populations. Dispersal distances vary drastically and distances up to 1 km have appeared independently in the literature beyond which populations would be isolated from dispersal events (Smith 2005). Marsh and Trenham (2001) reported annual distances of interpond migrations for 13 species of amphibians, the majority of which fall under the typical 1 km threshold. In a review of 166 journal articles covering 90 amphibian species, Smith (2005) reported 44 percent of anuran species exceeded the 1 km threshold while 94 percent of salamanders exhibited dispersal distances less than the 1 km threshold. However, as a group, an overwhelming majority have dispersal distances below the 1 km threshold (2005). Results from Marsh and Trenham (2001) support this conclusion and are presented in Table 1. The literature has been even less conclusive regarding the dispersal distances of reptiles. The best available literature suggests that a maximum dispersal distance of 1 km is suitable to account for the dispersal capabilities of most herpetofauna.

Study Area

Bladen and Sampson counties have been chosen as the study area because they lie within the center of the lower Cape Fear River Basin (Figure 2), have known Carolina bays and important herpetofaunal species, and are experiencing urban encroachment. The highest concentrations of Carolina bays have been described as restricted to the southeastern middle coastal plain from the Ogeechee River in Georgia to the Cape Fear River in North Carolina (Sharitz and Gibbons 1982). The Cape Fear is a unique river in North Carolina. The 24,144 square kilometer (9,322 square mile) drainage area is completely within the state beginning in the piedmont near Greensboro flowing southeast through Wilmington and directly into the Atlantic Ocean (Cape Fear River Basin n.d.). The fall line separating the piedmont and coastal plain near Fayetteville, NC can be assumed to divide the basin into an upper and a lower portion. Within the lower portion, numerous natural communities and Carolina bays exist among anthropogenic land covers of agriculture and urbanization.

The North Carolina Natural Heritage Program refers to the Carolina bays of northern Bladen County as the Bladen Lakes Megasite characterized as containing the largest number of unaltered Carolina bays in the state (Hall et al. 1999). Many of these bays are protected from development by being within Bladen Lakes State Forest, Jones Lake State Park, Salters Lake State Park, or the North Carolina Wildlife Resource Commission (NCWRC) gamelands. Further, the heritage program indicates the presence of ecologically significant Carolina bays and natural elements in Sampson County (NCNHP 2007). Figure 3 shows the distribution of these protected areas and element occurrences within the study region. Within these numerous habitats are 16 imperiled herpetofaunal species (Table 2) that may utilize Carolina bays, the surrounding uplands, or both during their lifespan (LeGrand et al. 2010).

Bladen and Sampson counties are largely rural counties with farmland and natural vegetation comprising most of the landcover. Agriculture accounted for 22.7 percent of Bladen County and 53.2 percent of Sampson County in 2007 (North Carolina Department of Agriculture and Consumer Services 2010). The counties also rank in the top 10 of the state for turkey and swine production (2010). Significant urban areas generally occur to the east and west (Figure 2). To the southeast of the study area is Wilmington and developed beaches. Fayetteville and Fort Bragg are located to the northwest. A housing density map (Figure 4) produced by the Cape Fear

Arch Conservation Collaboration (2011) indicates that widespread urbanization is spreading towards the study region. This encroachment is expected to continue with population growth and further stress will be directed towards the area’s natural resources.

Figure 1: Kernel Density Estimate of all amphibian species studied vs. distance from wetland edge. Adapted from Rittenhouse and Semlitsch 2007.

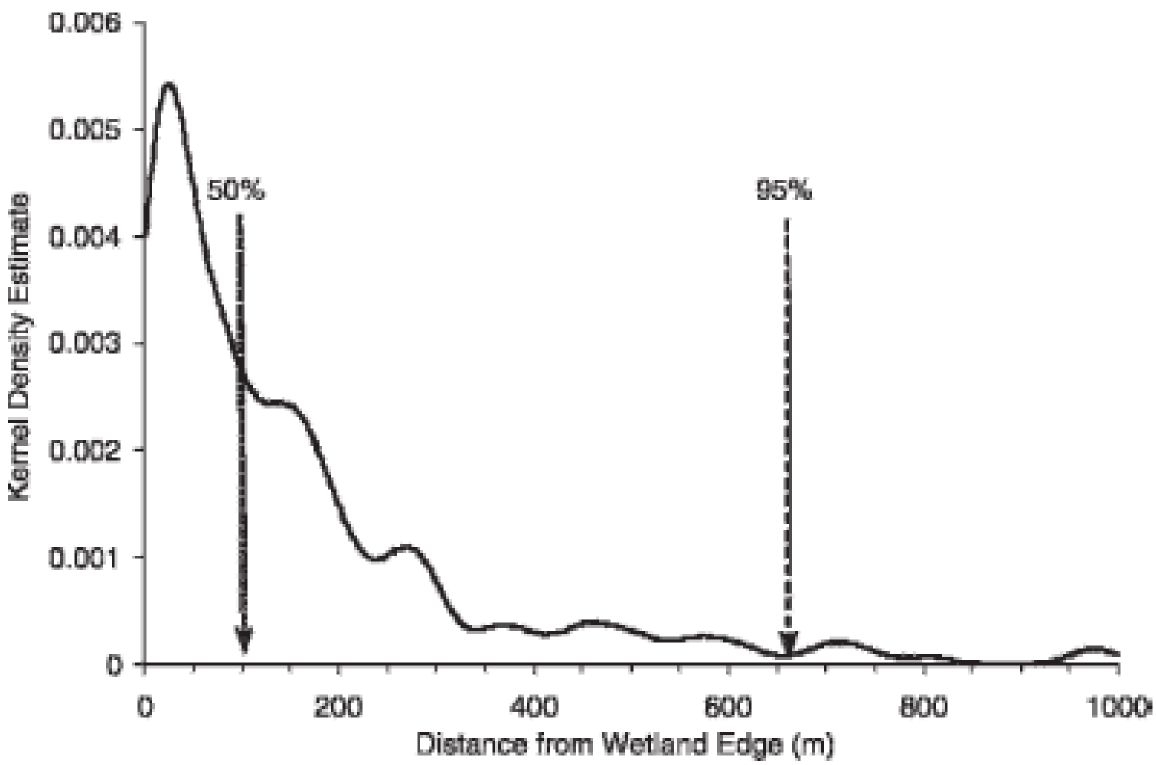


Figure 2: Proximity of Urban Areas to Bladen and Sampson Counties with Protected Area Distribution.

Figure 3: Conservation lands located within the study region. A majority of the conservation lands exist as Bladen Lakes State Forest.

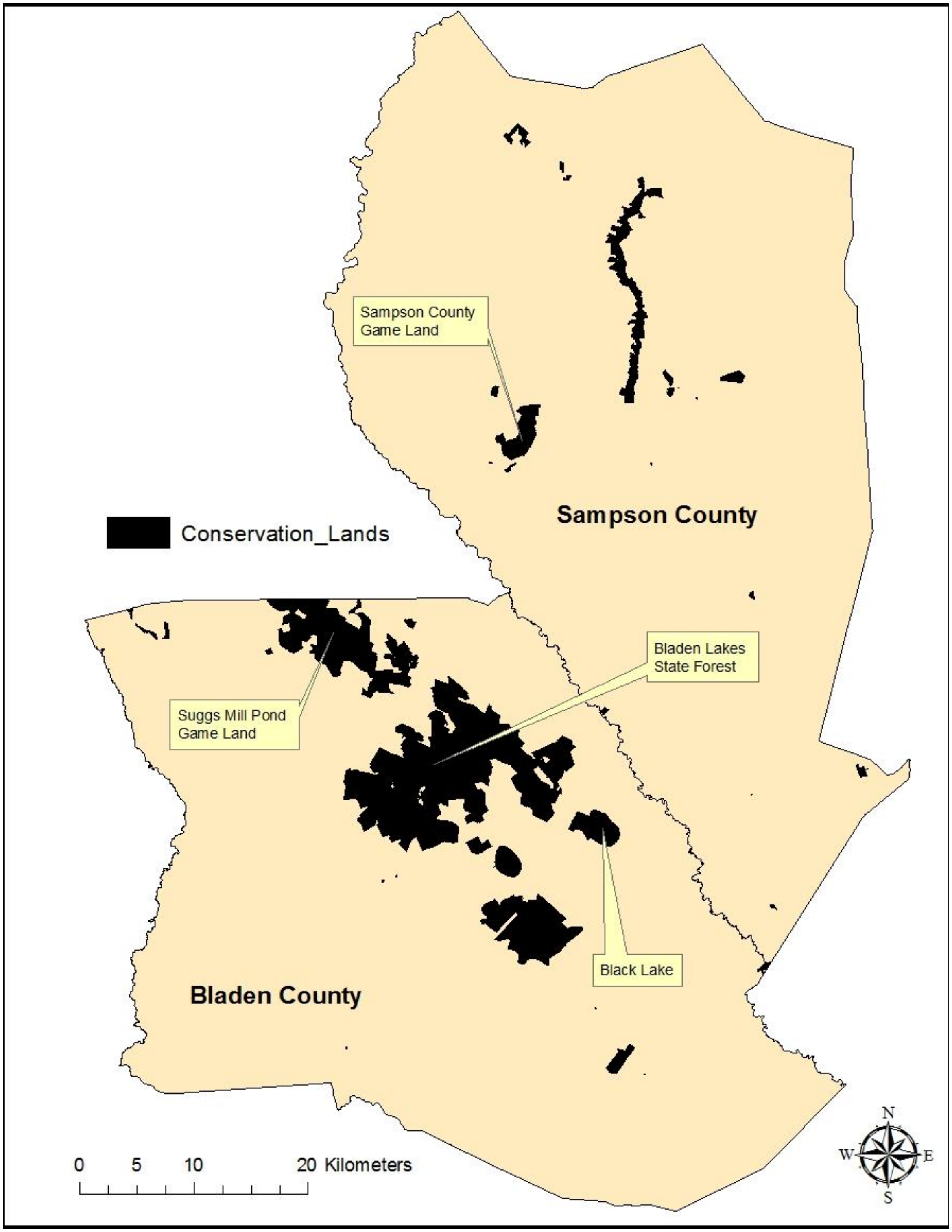


Figure 4: 1940 – 2000 Southeastern US Housing Density. Black circle in southeastern North Carolina denotes approximate location of study region. Adapted from Cape Fear Arch Conservation Collaboration (2011).

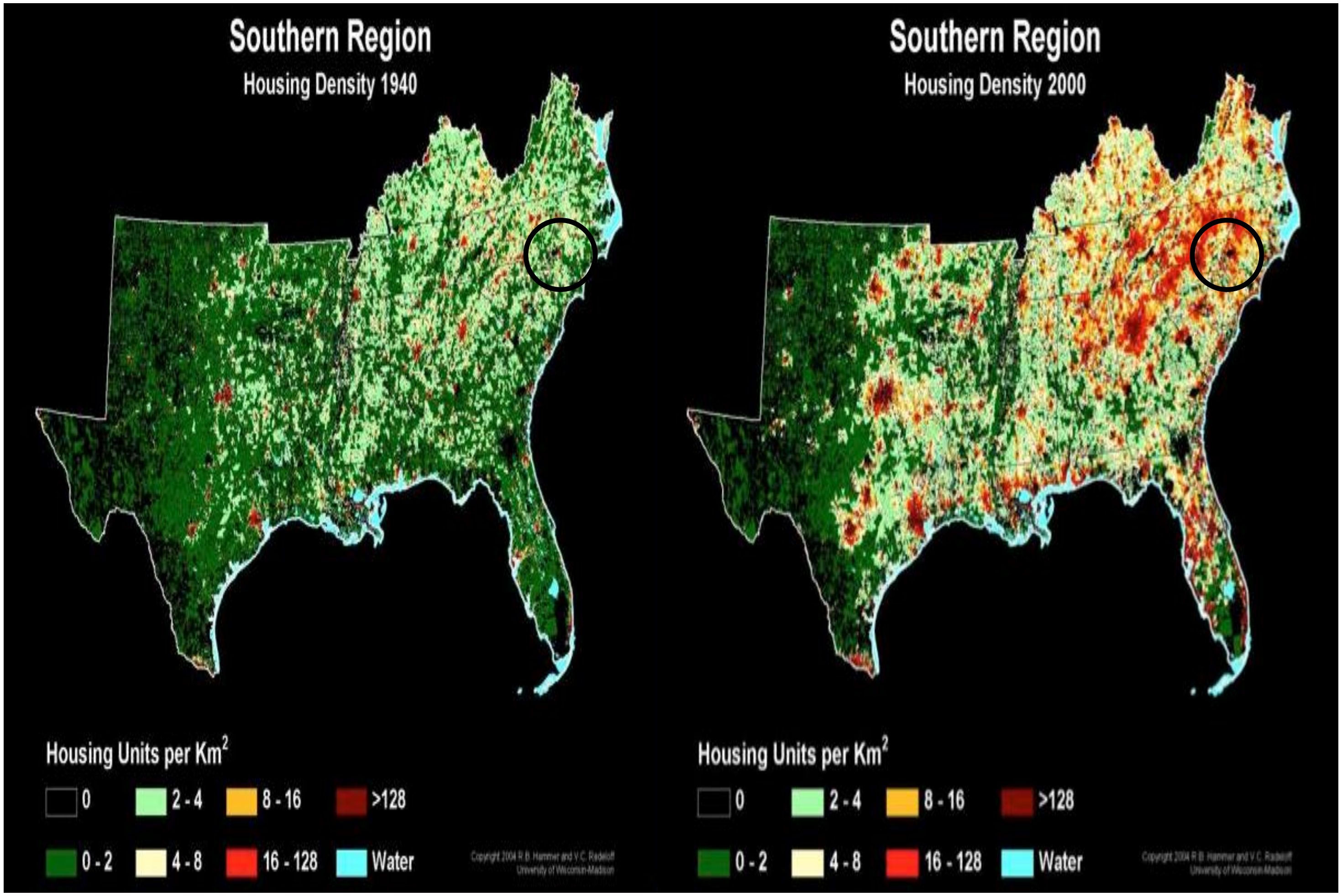


Table 1: Annual interpond migration rates adapted from Marsh and Trenham 2001.

Amphibian	Meters
Salamanders and newts	
Ambystoma californiense	300-670
Ambystoma maculatum	800
Ambystoma opacum	NR
Ambystoma talpoideum	150-400
Notophthalmus viridescens	1000
Taricha torosa	60-1260
Frogs and toads	
Bufo americanus	30-250
Bufo bufo	60-180
Bufo calamita	NR
Bufo woodbousei	200-2000
Rana catesbeiana	150-1600
Rana lessonae	NR
Rana sylvatica	264-2530

NR = Not Recorded

Table 2: North Carolina Natural Heritage Program Rare Herpetofaunal Species Occurrences in Bladen and Sampson Counties

Scientific Name	Common Name	NC Status*	Bladen	Sampson
Alligator mississippiensis	American Alligator	T	Y	Y
Crotalus adamanteus	Eastern Diamondback Rattlesnake	E	Y	Y
Crotalus horridus	Timber Rattlesnake	SC	Y	Y
Deirochelys reticularia	Chicken Turtle	SR	Y	Y
Hetero donsimus	Southern Hognose Snake	SC	Y	Y
Masticophis flagellum	Coachwhip	SR	Y	Y
Micrurus fulvius	Eastern Coral Snake	E	Y	N
Ophisaurus mimicus	Mimic Glass Lizard	SC	Y	Y
Regina rigida	Glossy Crayfish Snake	SR	Y	N
Sistrurus miliarius	Pygmy Rattlesnake	SC	Y	Y
Ambystom amabeei	Maybee's Salamander	SR	Y	Y
Eurycea quadridigitata	Dwarf Salamander	SC	Y	N
Hemidactylium scutatum	Four-toed Salamander	SC	Y	N
Hyla andersonii	Pine Barrens Treefrog	SR	Y	Y
Pseuda crisornata	Ornate Chorus Frog	SR	Y	Y
Rana capito	Carolina Gopher Frog	T	Y	Y
Rana heckscheri	River Frog	SC	N	Y

* NC Status Codes
E = Endangered
T = Threatened
SC = Special Concern
SR = Significantly Rare

Chapter 3: Carolina Bay Inventory

Carolina bays are distinct landform features of the southeastern United States (Ross 2003). These landform features exist as depressions and contain depressional wetlands under the hydrogeomorphic classification (Brinson 1993) or palustrine wetlands under the national classification (Cowardin et. al 1979). Spatially explicit wetland inventories are a very instructive source of information for planners, as these data can be integrated with other layers in a Geographic Information System (GIS) to allow for more effective planning and management (Murphy et. al 2007). Such inventories must be compiled from manual delineation or in some cases automated techniques, and as a result, are typically time consuming and expensive. Wetland boundary delineation is an attempt to determine the boundary in an ecotone or moisture gradient between wetland and upland (Pearsell and Mulamoottil 1994). Recent jurisdictional challenges and subsequent changes in federal authority under the Clean Water Act (CWA) have created urgency in conserving isolated wetlands. Few extensive surveys or inventories of isolated wetlands have occurred, resulting in very little published information on their spatial characteristics (Brooks 2005). Creating an isolated wetland inventory can be problematic. Wetland scientists contend that the exact boundary of wetlands cannot be conclusively defined from a combination of soils, hydrology, and vegetation (Pearsell and Mulamoottil 1994). United States Geological Survey (USGS) topographic quadrangles, aerial photography, digital elevation models (DEM), and soil inventories have been used in the literature to produce wetland inventories.

Topographic Maps and Aerial Photography

Aerial photography generally is used to map landscape patterns of soils, wetlands, or land use and has an inherent margin of error (Moorhead and Cook 1992). Both the NWI and Soil

Survey Geographic Database (SSURGO) developed by the United States Department of Agriculture Natural Resource Conservation Service (NRCS) utilize aerial photography to delineate map units. Aerial photography was chosen to produce the NWI over satellite imagery to overcome spatial resolution and spectral overlay disadvantages (Ozesmi and Bauer 2002). In a review of Carolina bays, Sharitz (2003) acknowledges that many depressional wetlands remain un-inventoried in the Savanna River Site (SRS) as a result of the size being below the minimum NWI mapping unit. In response to increasing demands for high detail maps during post World War II, the United States Geologic Survey (USGS) used aerial photography to produce its 7.5 minute topographic quadrangle maps at a resolution of 1:24,000 (Usery et al. 2010). These maps contain cultural features delineated in black plate, transportation and urban features in red plate, vegetation in green plate, hydrographic features in blue plate, and elevation contours in brown plate (2010). Contour lines are the signature feature of USGS topographic maps, and until recent developments of airborne laser and radar technologies, were the best data available (Moore 2000). Larger depression wetlands, particularly those associated with the Carolina bays, are delineated on topographic maps in part or whole as coastal hydrographic features (Clemson 2011; USGS 2002). Figure 5 shows a portion of the Singletary Lake Quadrangle in Bladen County and a series of oval hydrographic features characteristic of Carolina bays to the southeast of Singletary Lake, some of which are named.

Wetland Mapping

The National Wetland Inventory was produced from color infrared photography at a scale of 1:24000 (Cowardin et. al 1979; Cowardin and Golet 1995; Ozesmi and Bauer 2002; Sutter 1999). The hierarchical classification relies largely on vegetative cover because of the reliability of data that can be interpreted from aerial photographs (Brinson 1993). This dependency results in many of the recognized cover types of Carolina bays being mapped as palustrine systems. These systems are characterized as all non-tidal wetlands dominated by trees, shrubs, persistent emergent, mosses or lichens, and all such wetlands that occur where salinity is below five parts per thousand (Cowardin et. al 1979). Cowardin et al. (1979) grouped these vegetative covers together to include the small, shallow, permanent or intermittent water body's common throughout the United States. In the opinion of the North Carolina Division of Coastal Management (DCM), NWI provides the most accurate base of wetlands in NC, however it is unsuitable to be used alone because it is based primarily off of vegetation, and many hydrogeomorphic types share vegetative communities (Sutter 1999). The Division of Coastal Management utilized NWI along with soil data and Thematic Mapper imagery to create the NC inventory. This inventory groups NC wetlands into twelve types based on overlay analysis of the input data (Sutter 1999). Classifications based on vegetation, such as NWI and DCM hinder the development of published inventories of Carolina bays. The major drawback to such approaches is that Carolina bays contain many cover types that overlap cover types of recognized wetland classes (i.e. pocosins) (Ross 2003). Figure 6 depicts this overlap. This overlap causes the depressional wetland associated with the Carolina bay to be inseparable from the larger map unit. Despite this hindrance, NWI data represent the best available wetland inventory for use in developing a Carolina bay inventory.

Soils

Soil development depends largely on the parent material; however climate, relief, time, and biological activity also influence soil development (Whitehead and Tan 1969). Most Carolina bays of Bladen County, NC have been found to be associated with the aeolian sands geomorphic surface between the Cape Fear River and associated terraces and the Black River and associated terraces (Leab 1990). Aeolian sands developed by deposition of sands from frequent flooding by local rivers. The majority of bays within the Bladen County Soil Survey were found to have soils from the Pamlico and Lynn Haven classes with thick layers of peat, sandy soils with stained subsoil, and soils with thin loamy subsoil (1990). These are characteristic hydric soils of the region (Moorhead 1990).

Hydric soil was first used by the United States Fish and Wildlife Service in its national wetland classification system (Cowardin et. al 1979; Tiner 1999). There are two major categories of hydric soils, organic and mineral (Moorhead 1990; Tiner 1999). Carolina bays have been classified as peat and clay based and these correspond to organic and mineral respectively (Kirkman et. al 2000; Leibowitz 2003; Sharitz 2003). Moorhead (1990) offers a description of the diversity and relative percentages of hydric soils in North Carolina. In this description he lists alfisols, inceptosols, spodosols, and ultisols as typical hydric mineral soils with ultisols being the most common and histosols as the hydric organic soil found in NC. Histosols are organic soils that have more than half of the upper eighty centimeters consisting of organic material (USDA Soil Survey Staff 2006).

Organic soils form under waterlogged conditions. The duration and frequency of inundation of soils by water creates specific conditions for wetland soil pedogenisis. When terrestrial soils are flooded, aerobic organisms deplete oxygen levels to the extent that anoxic conditions prevail and these conditions effect the accumulation of organic material (Lees 2004; Tiner 1999). Under these conditions, organic material that arrives into the bay will be slow to decompose, particularly the lignin rich cells of limbs, roots, and branches. Fluctuations of the water table that result in soils being exposed to oxygen create varying degrees of decomposition of plant fibers within the soil. This soil is collectively referred to as peat. For many of the organic-based bays, hydrologic cycles have created peat layers that vary drastically in depth.

The manner of which peat has filled the Carolina bays is not well understood. There tends to be a general correlation with increasing elevation and decreasing depth of peat as suggested by Newman and Schalles (1990). Generally, filling is believed to have occurred from the northwest as a result of basin shape, plant growth, and prevailing wind direction (Buell 1939). Under Buell's description, there is a long sloping shelf along the northern portions of Jerome Bay (Bladen County, NC) that accumulates into a large deep basin towards the southern center of the bay that supports an inward growing mat of vegetation. The resulting vegetation would have delivered sediment and organic materials into the bay slowly filling it in. This scenario is also supported by evidence of a gradient from a mineral periphery of bays to an organic center (Caldwell et al. 2007). This valuable information adds a published and recognized inventoried data layer that can be used to create a Carolina bay inventory.

Digital Elevation Models

DEM's are used for many applications, particularly geomorphic, contour, and topographic change detection mapping. These models are produced from a variety of data. The National Elevation Dataset (NED) was produced from aerial photogrammetry, is the primary data product produced and distributed by the USGS, and has a spatial resolution of 30 meters (Gesch 2009). Despite their availability and variety of successful applications, USGS DEM's are not adequate for identifying micro-relief features such as depressions (Liu and Wang 2008). Recent technological advances have allowed for acquisition of high resolution Light Detection and Ranging (LiDAR) data.

The production of contour and geomorphic maps traditionally requires expert opinion, mapping techniques, and subjective delineation. Mitasova et al. (2005) and Mitasova et al. (2009) utilized LiDAR-based DEM's to map Jockey's Ridge and quantify its temporal movement. Jones et al. (2007) used classification techniques to visually enhance LiDAR derived DEM's such that geomorphic features could be digitized. Products produced by manual delineation are time consuming and expensive. However, recent methods have been proposed to automate the process, making products more available. LANDFORM is a customized GIS extension that addresses the problem of subjectivity in delineation of landform units using traditional methods (Klingseisen et. al. 2008). The product of LANDFORM is a semi-automated classification of landforms such as crests and depressions. Liu and Wang (2008) utilize a depression detection algorithm that floods topographic depressions in DEM's allowing for rapid detection. Although these automated techniques speed processing time and make products more available, they have not been tested or verified for delineating Carolina bays and traditional methods are preferred.

Objective

The goal of this analysis is to produce a base layer that represents Carolina bays that can be used to meet the data needs of this thesis. Specifically, the objective is to ensure the representation of Carolina bays with the best available data and applications. To meet this objective, the employed methodology uses USGS topographic maps, North Carolina Floodplain Mapping Program (NCFMP) LiDAR DEM's, SSURGO soil maps, and NWI maps to delineate and define Carolina bays as geomorphic features existing as topographic depressions. Through this methodology, a final shapefile representing delineated Carolina bays will be available for use in subsequent chapters of this thesis.

Methodology

Despite the numerous studies of the Carolina bays, digital databases are generally not available. Through a comprehensive search, only two sources have been identified. One database is associated with the Advance Identification of Carolina Bays for South Carolina Wetlands Protection prepared by the South Carolina Department of Natural Resources (1999). Bays were identified from USGS 7.5 minute topographic quadrangles and field sampled for attributes. In the Distribution and Status of Carolina Bays in South Carolina conducted by Bennett and Nelson (1991), the parent project and data source for Advanced Identification, black and white aerial photography was used to locate bays with long axis lengths greater than 126.8 m (416 ft.) for field sampling. This cutoff was utilized because depressions smaller than this threshold began to lose Carolina bay characteristics, most notably oval shape, and it became increasingly difficult to distinguish topographic depression from Carolina bay. The other database exists as a Google Earth file available from Howard (2007) (Figure 7). The database was created from draping elevation data on a Google Earth Satellite layer and digitizing bay features (2007). From these sources, a methodology is proposed to manipulate and mine the Howard data to accurately depict the Carolina bays of Bladen and Sampson counties.

The methodology for this project will utilize data from the NCFMP, USGS, SSURGO, NWI, and the Howard website in conjunction with Environmental Systems Research Institute (ESRI) ArcGIS 9.3 software. The project design will follow closely with that prescribed by Bennett and Nelson (1991), South Carolina Department of Natural Resources (1999), and Aspinall and Pearson (2000) by placing a size criterion and treating Carolina bays as geomorphic features with distinct catchments. Google Earth data obtained from the Howard (2007) will be manipulated using data overlay to represent the Carolina bays of the study region. Table 3 depicts the data requirements for this project.

Data manipulation

A single vector layer representing Bladen and Sampson counties is used as the clip layer for all data. The layer was created by utilizing county boundary data from the North Carolina Center for Geographic Information Analysis (NC CGIA). The data is projected in North American Datum (NAD) of 1927, Stateplane North Carolina FIPS 3200. This projection is used as the base projection for all data used in the inventory.

Carolina bays. The Carolina bay Google Earth File (.kml) was downloaded from the Howard (2007) and converted to an ArcMap shapefile (.shp) with the proper projection using a downloaded file converter tool created by Parent (2009). The resulting shapefile was clipped to the study area, named and an area field (ha) was calculated in the attribute table. To reduce uncertainty and error believed to be associated with the original data, the clipped data are further reduced. Bennet and Nelson (1991) used a 0.81 ha (2 acre) threshold to reduce their data while the Georgia Department of Natural Resources Wildlife Resources Division (n.d.) uses a 4.05 ha (10 acre) threshold in their delineation. Areal thresholds were employed because depressions smaller than this threshold were difficult to identify as Carolina bays. All polygons smaller than 0.81 ha are removed and excluded from data analysis based on recommendations from the South Carolina Department of Natural Resources (1999).

Elevation, soil, topographic, and NWI datasets. Elevation data and soil, topographic, and NWI maps for Bladen and Sampson counties will be used to verify and edit any abnormally shaped polygon representing a bay from the clipped layer. Topographic maps were downloaded from the North Carolina Department of Transportation (NCDOT n.d.) as Mr. Sid files, had the datum converted from NAD 27 to NAD 23, and were projected to the study projection. All bays delineated in part or full on a topographic map were retained. Any bays not conforming to the mapped contours were edited. Bays that are not delineated on topographic maps are verified as a depression on 6.1m (20 ft.) LiDAR DEM obtained from NCFMP (n.d.). These bays will be edited to conform to the boundary of the DEM elevation contour. To make the contours more visible and appropriate for the inventory, the data were visually enhanced and spatially restricted. To visually enhance the data, a hillshade was used with standard deviation stretch. The data were spatially restricted to map the data in the Bladen and Sampson County extent. This process ignores data outside the viewed extent. Georgia Department of Natural Resources Wildlife Resources Division (n.d.) used a scale of 1:12,000 to delineate Carolina bays in Georgia to ensure accuracy at the 1:24,000 scales of USGS topographic maps. Lathrop et al. (2005) used a scale of 1:5,000 to compromise between the high resolution of the photography used and the visible extent of the vernal pools being delineated. Size histograms of Carolina bays from Semlitsch and Bodie (1998) and Bennet and Nelson (1991) are presented in Figures 8 and 9 respectively. A scalar restriction of 1:5,000 was used to delineate Carolina bays from LiDAR data for this analysis. Figure 10 depicts the comparison of the two scales on Bandeau Bay, southwest of Lake Singletary in Bladen County. This comparison demonstrates that a scale of 1:5,000 is appropriate for this analysis. These delineated bays will further be subjected to verification of hydric soil presence from NRCS SURRGO soil layers and wetland presence from NWI maps.

The SSURGO soil layer was built from spatial and tabular data downloaded from USDA NRCS (n.d.) and re-projected to the NAD 1983 projection. The data layer comes directly with little usable information. Of the original information, the most usable is the map unit because it allows tables to be built from the tabular data that can be joined to the database. The classification criteria in Table 4 were used with tabular data to develop Appendixes B and C for Bladen and Sampson Counties respectively. These appendixes were joined to the original databases for further use. Sand rims surrounding Carolina bays, particularly on the southeast portion, are elevated relative to the surrounding topography and are thus not hydric. These areas typically are a different type of soil than the surrounding soils. Figures 11 and 12 show Sheriff White Bay, located northwest of Elizabethtown NC, and demonstrates how soil hydric rating and order can be used to distinguish characteristic sand rims and relative boundary shape respectively. NWI data was downloaded for the entire state from NC CGIA (n.d.), projected to NAD 1983, and clipped to the study region. Figures 13 and 14 show the distribution of NWI classes and their relationship to the Carolina bays in Bladen and Sampson Counties respectively. Figure 15 shows Dickenson Meadow, just North of Jones Lake, being represented as a palustrine wetland. This demonstrates that NWI data can be effectively used to determine a digitized polygon as a wetland. These data are used to determine if a digitized polygon not delineated on USGS topographic maps are representing Carolina bays. These verification procedures reduce the data and ensure that the polygons are representing Carolina bays with the best available data. The remaining polygons represent Carolina bays and are saved in a separate layer to be used for landscape scale analysis.

Data reduction

Reduction processes are needed to filter the Carolina bays existing in protected areas. Conservation area data were obtained from NC CGIA (n.d.).These datasets consist of conservation tax credit properties; state owned lands (state owned lands and gamelands exist as two separate layers); and federal owned lands. These datasets were merged into a single conservation lands layer, projected to NAD 1983, and clipped to the study region. Figure 16 illustrates the conservation lands in the study region. All polygons representing Carolina bays located completely within a protected area (i.e. state park or forest, game land, conservation easement, etc.) are removed. A further reduction consisted of removing all delineated bays that are not completely within Bladen and Sampson counties. These steps are needed because these bays are either already protected or partially outside of the study region (i.e. existing completely within a conservation land or straddling multiple counties) thereby limiting their ability to be used as focal bays in the remainder of the thesis. These bays are not prioritized for protection or restoration, but are used to analyze landscape connectivity of the Carolina bays.

Results

This analysis has produced 1,863 inventoried Carolina bays across Bladen and Sampson counties that are not currently in protection status. Figures 17 and 18 show the distribution of the Carolina bays across Bladen and Sampson Counties respectively. Descriptive statistics for these bays are presented in Table 5 and as histograms in Figures 19 and 20. Seven hundred and sixty nine Carolina bays within Bladen County range from 0.81 ha to 949.47 ha, has a mean of 32.27 ha and a standard deviation of 82.72 ha. Sampson County contains 1,094 Carolina bays that range from 0.81 ha to 1256.32 ha with a mean and standard deviation of 17.83 ha and 76.80 ha respectively.

Conclusion

The results of this analysis corroborate with previous studies. A comparison of Figures 8 and 9 with Figures 19 and 20 elaborates the similarities of Carolina bay size distribution with South Carolina. Descriptive statistics of the data presented in Table 5 suggest that the majority of

Carolina bays found in Sampson County is smaller and more variable than those found in Bladen County. Comparing the Carolina bays of both counties with LiDAR and NRCS soils data reveals patterns that are consistent with published data. Figure 17 depicts the Carolina bays of Bladen County existing south of the Cape Fear River on elevated uplands and on the finger like interfluves north of the Cape Fear River in the floodplain. Of these, the bays lower in elevation along the floodplain interfluves are larger than the higher elevation counterparts. Figure 18 of Sampson County elevation shows the Carolina bays on three broad interfluves. Thom (1970) described the landscape position of Carolina bays in Marion and Horry counties, South Carolina as being flat interfluves, dune depressions, and terrace contact. Of these three types, the flat interfluves are the most common occurring on ancient floodplains. Figures 21 and 22 depicting the distribution of soil orders with Carolina bays suggests that the dominant order associated with the Carolina bays of northern Bladen County are histosols while ultisols are dominant elsewhere. This is supported by Kirkman et al. 2000; Kolka and Thompson 2006; Leibowitz 2003; and Newman and Schalles 1990 in which bays lower in elevation (i.e. in the floodplain) would have longer hydroperiods due to increased groundwater contact, and are described as peat based (histosols) while bays higher in elevation typically have shorter hydroperiods and contain typical hydric mineral soils (ultisols). The produced inventory of Carolina bays in Bladen and Sampson counties have spatial and statistical characteristics in agreement with previous studies.

Figure 5: USGS topographic map showing a portion of the Singletary Lake quadrangle and Bladen Lakes State Forest. There are named and un-named hydrographic features representing Carolina bays delineated to the southeast of Singletary Lake.

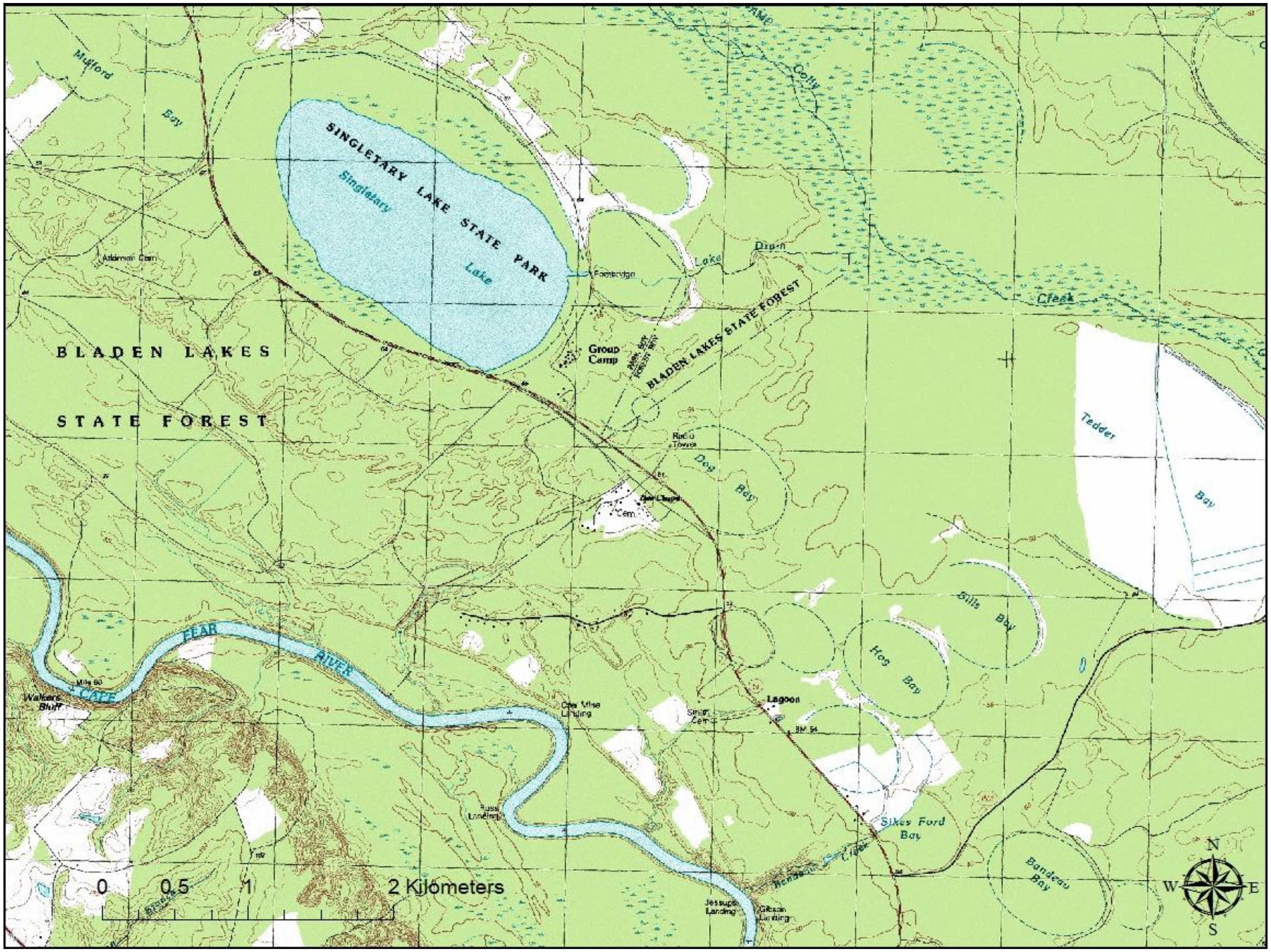


Figure 6: Relationship between Carolina bays and wetland classes based on vegetative cover (Richardson 2003). Carolina bays have a range of vegetation that makes most of them palustrine wetlands under the NWI classification. However, there is a portion of Carolina bays that does not fall under the palustrine classification.

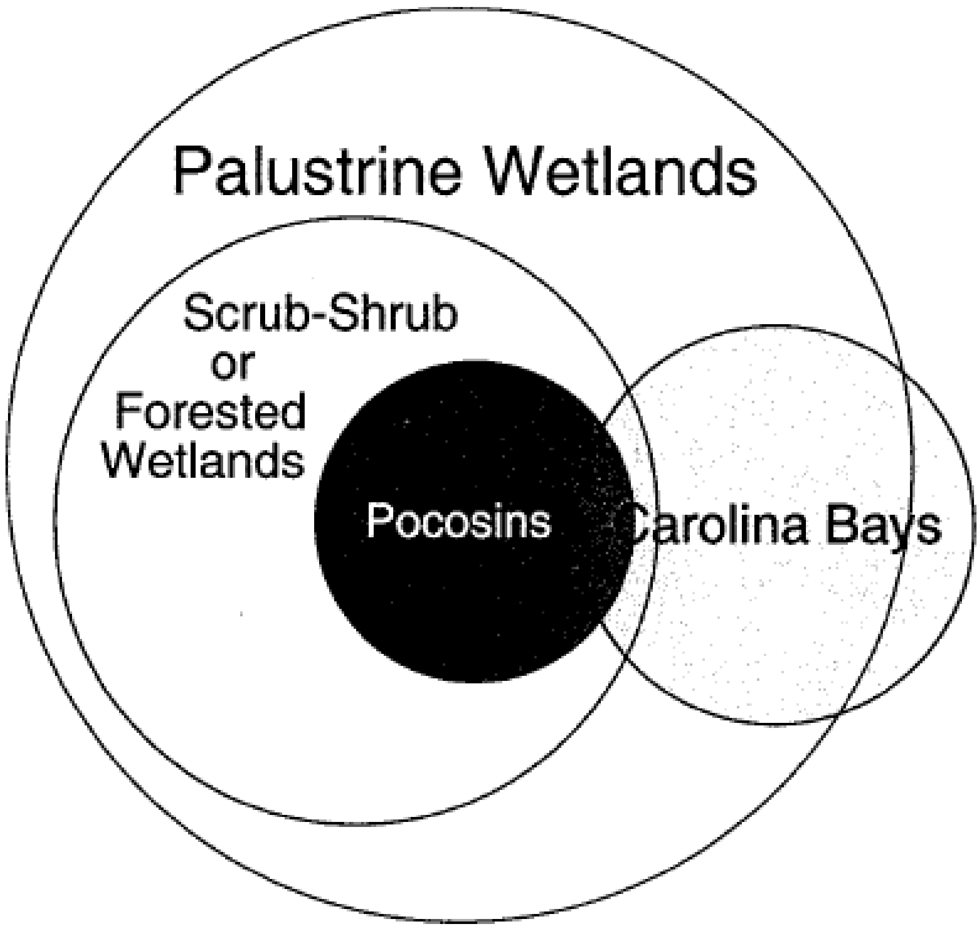


Figure 7: Howard (2007) delineated Carolina bays as a Google Earth image. The Carolina bays are depicted as white outlined polygons with characteristic increasing density on the inner southeastern coastal plain near Fayetteville. Inset in lower right depicts the delineated Carolina bays around White Lake, NC.

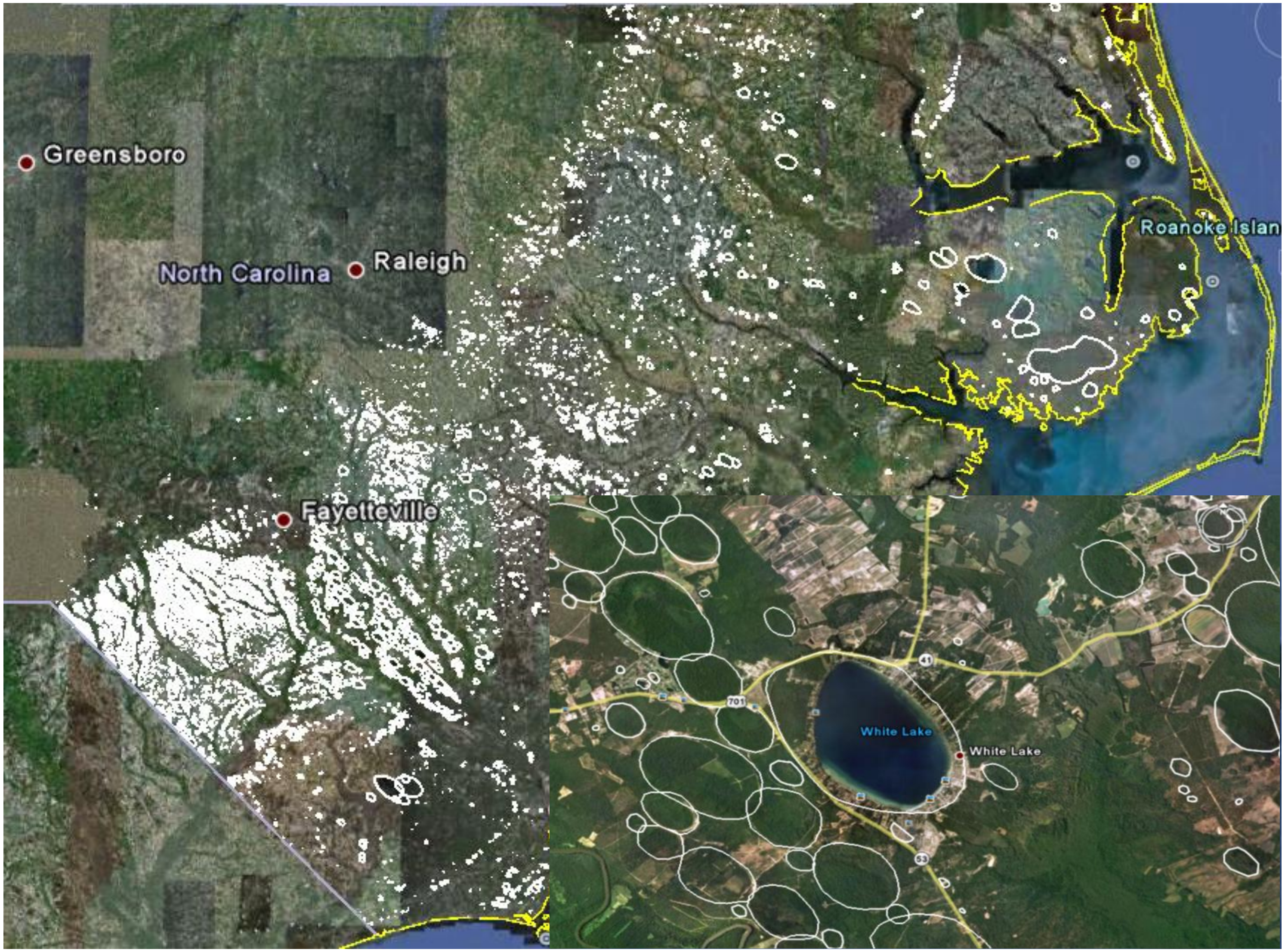


Figure 8: Savannah River Site (Aiken, South Carolina) Carolina bay size histogram produced by Semlitsch and Bodie 1998. Smaller bays are more frequent and numerous than increasingly larger bays.

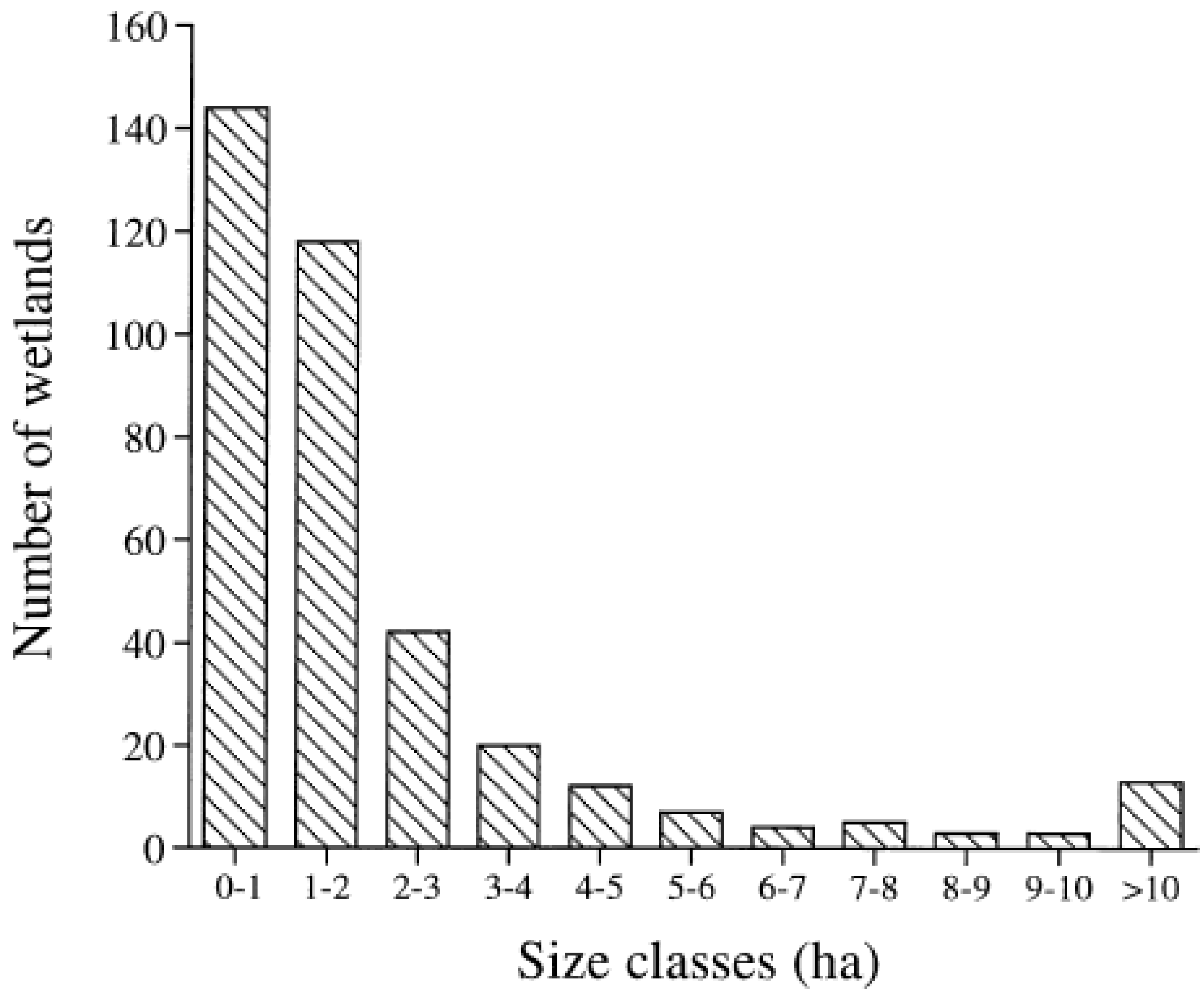


Figure 9: Carolina bay size histogram produced by Bennet and Nelson (1991) for coastal South Carolina. Long axis length (m) was used instead of hectares. However, comparisons can be made to area because increasing long axis length correlate with increasing area. *N* = 2,651

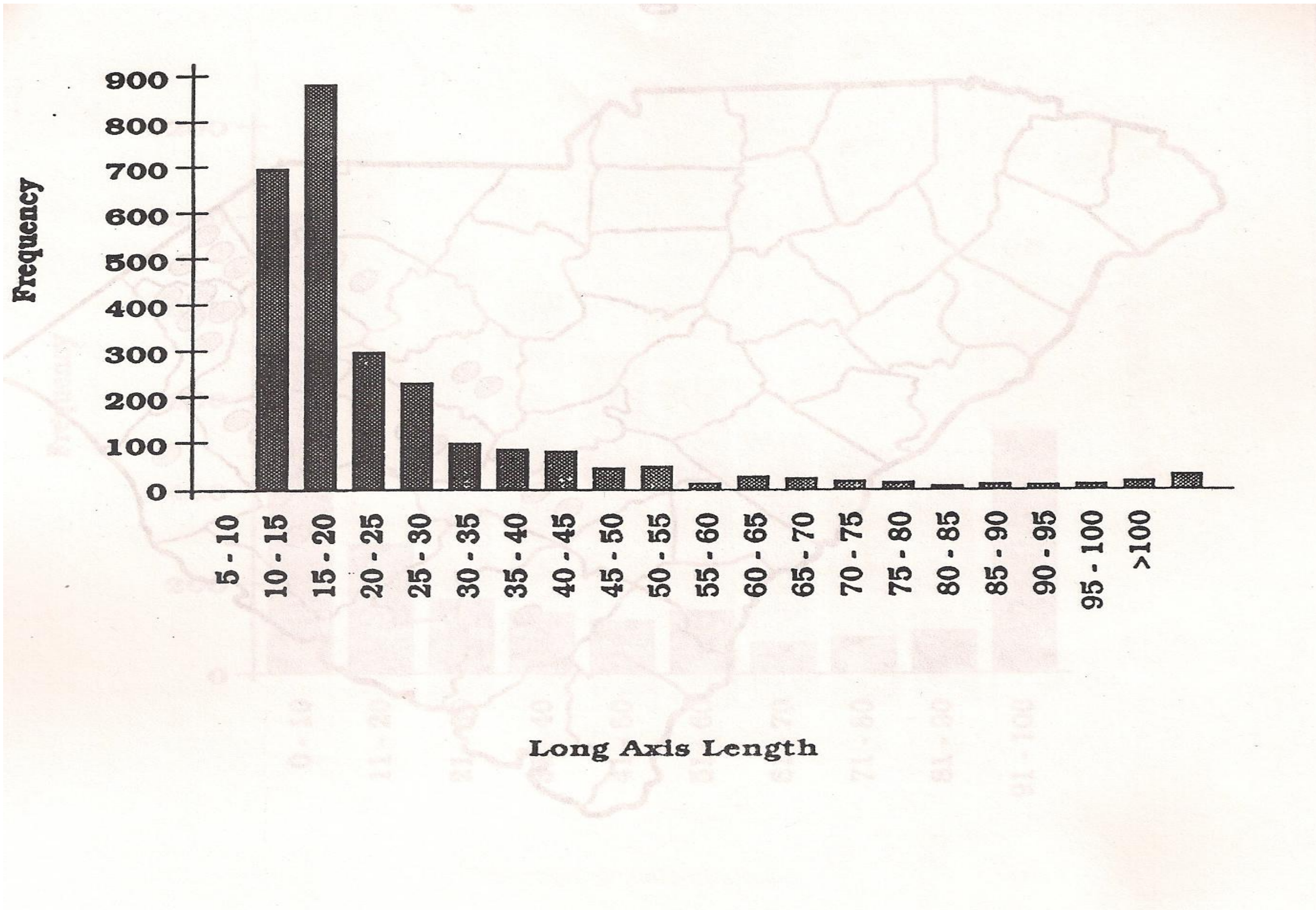


Figure 10: Bandeau bay 1:5,000 (top) and 1:12,000 (bottom) scale LiDAR comparison. The bay is delineated on USGS topographic map Singletary Lake quadrangle and is located southeast of Singletary Lake on the far side of the series of bays delineated in Figure 1. A boundary can be seen in both scales, but the 1:5,000 scale produces more detail and can be more effectively utilized to determine topographic depressions.

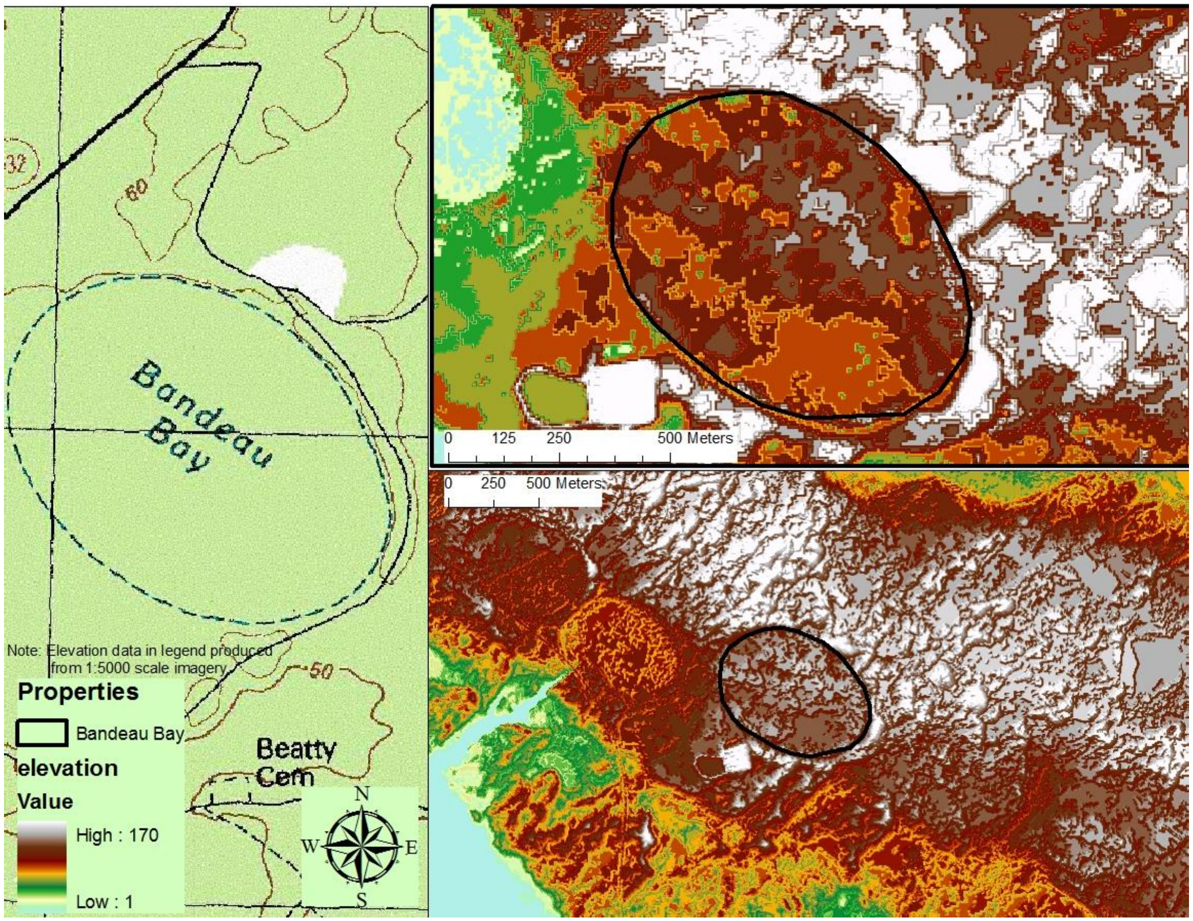


Figure 11: Hydric soil rating overlaid on USGS delineated Sheriff White Bay located northwest of Elizabethtown in Bladen County, NC. Carolina bays have characteristic sand rims that are elevated relative to the surrounding topography and are not hydric. This sand rim is most prominent of the southeast margin and can be used as a defining feature of Carolina bays.

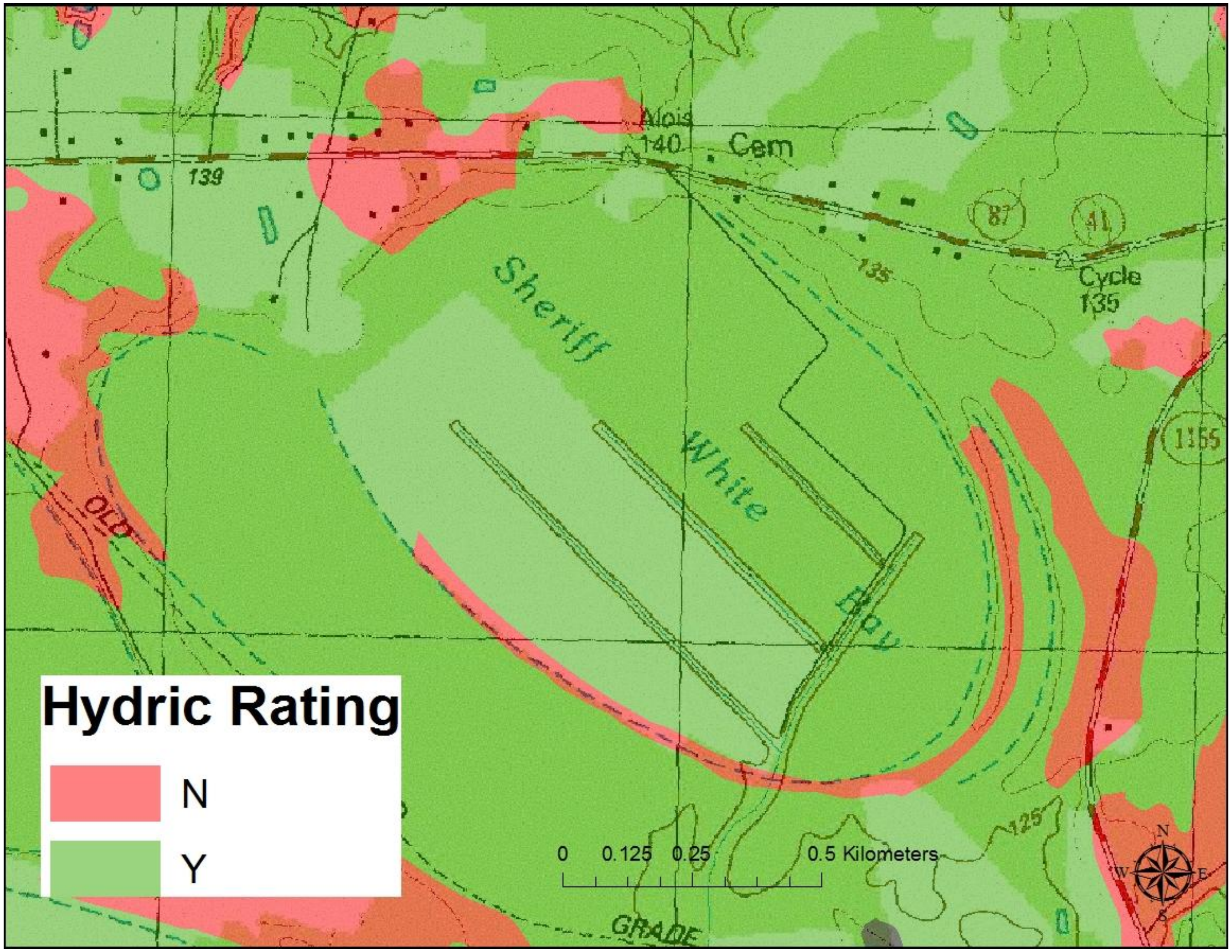


Figure 12: Soil order overlaid on USGS delineated Sheriff White Bay located northwest of Elizabethtown in Bladen County, NC. Histosols are prominent on the interior of many depressional wetlands. A narrow band of ultisol, a prominent upland soil, can be seen where the hydric delineated sand rim is located southeast of the bay in Figure 11.

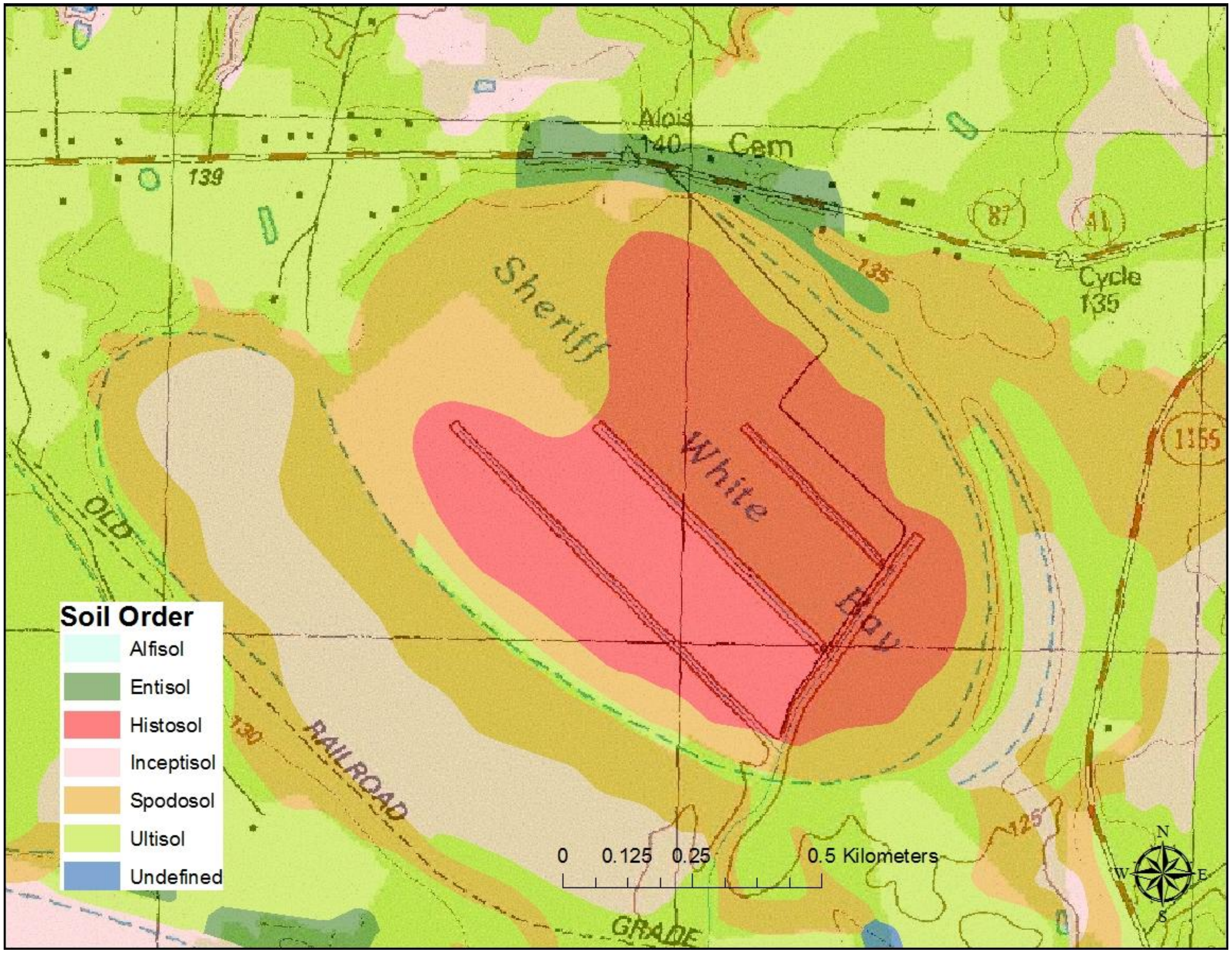


Figure 13: Distribution of NWI classes in Bladen County and the relationship to the Howard (2007) delineated Carolina bays. Many of the bays are accurately represented by palustrine wetland polygons. However, some of the bays do not overlap NWI coverage well. This may be a result of the bay being clearly discernable from LiDAR, but has been highly disturbed and all wetland vegetation removed.

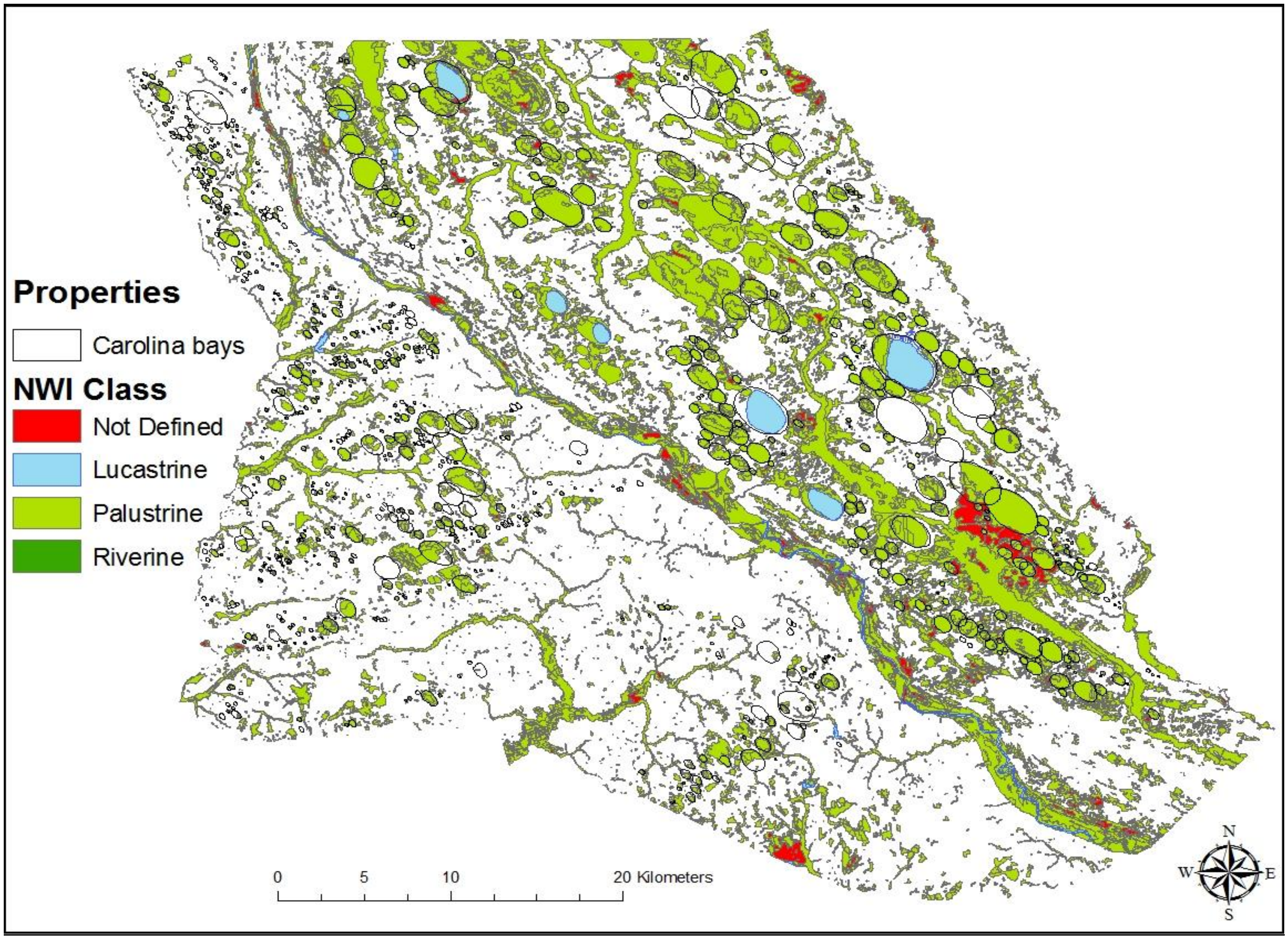


Figure 14: Distribution of NWI classes in Sampson County and the relationship to the Howard (2007) delineated Carolina bays. Many of the bays are accurately represented by palustrine wetland polygons. However, some of the bays do not overlap NWI coverage well. Sampson County has been largely converted to agriculture and much of the vegetation used to classify NWI has been removed.

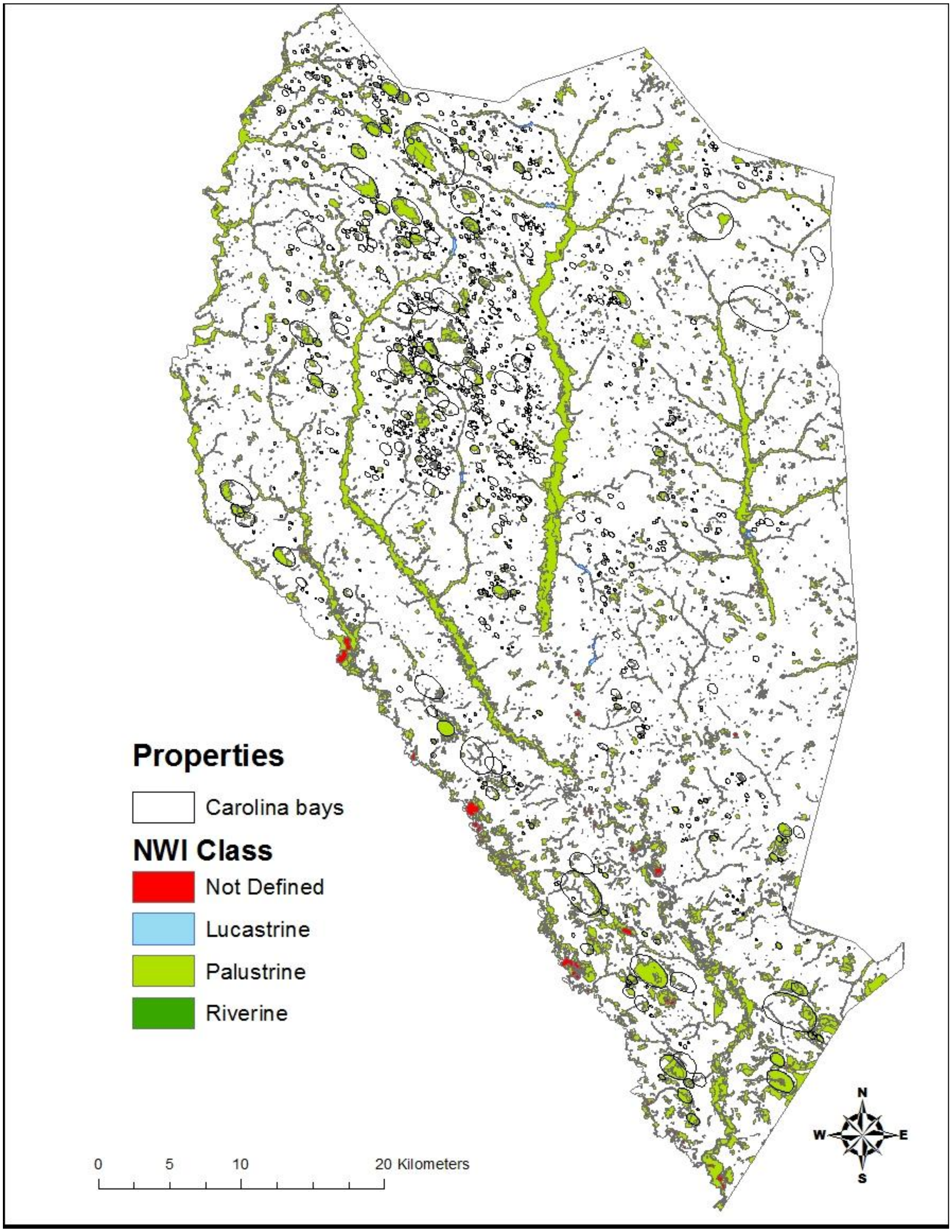


Figure 15: USGS delineated Dickenson Meadow in the Bladen Lakes State Forest and the relationship with NWI polygon. This is a specific fine scale example of Figure 9 demonstrating at the utility of NWI in defining depression wetlands contained within Carolina bays.

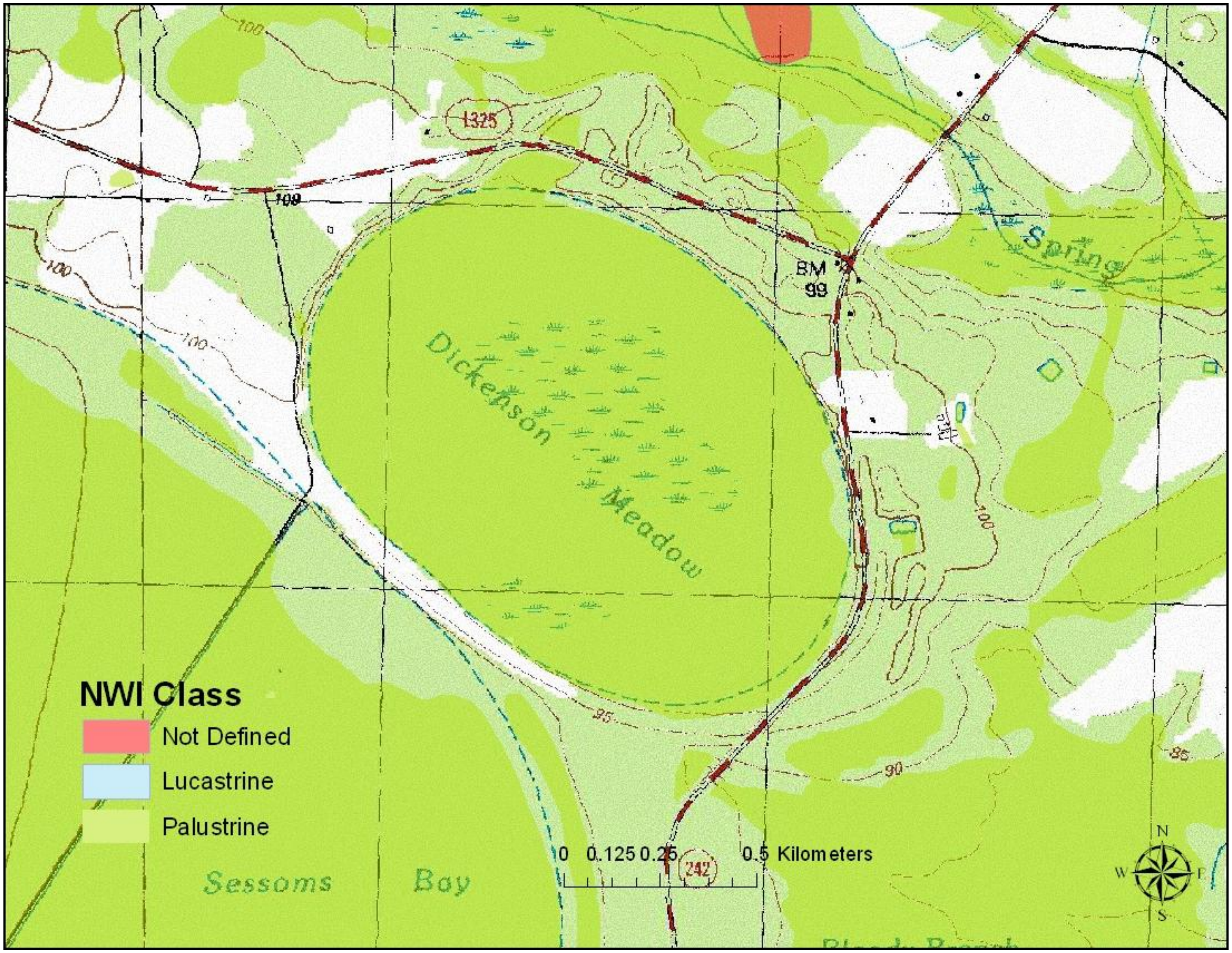


Figure 16: Conservation lands located within the study region. A majority of the conservation lands exist as Bladen Lakes State Forest.

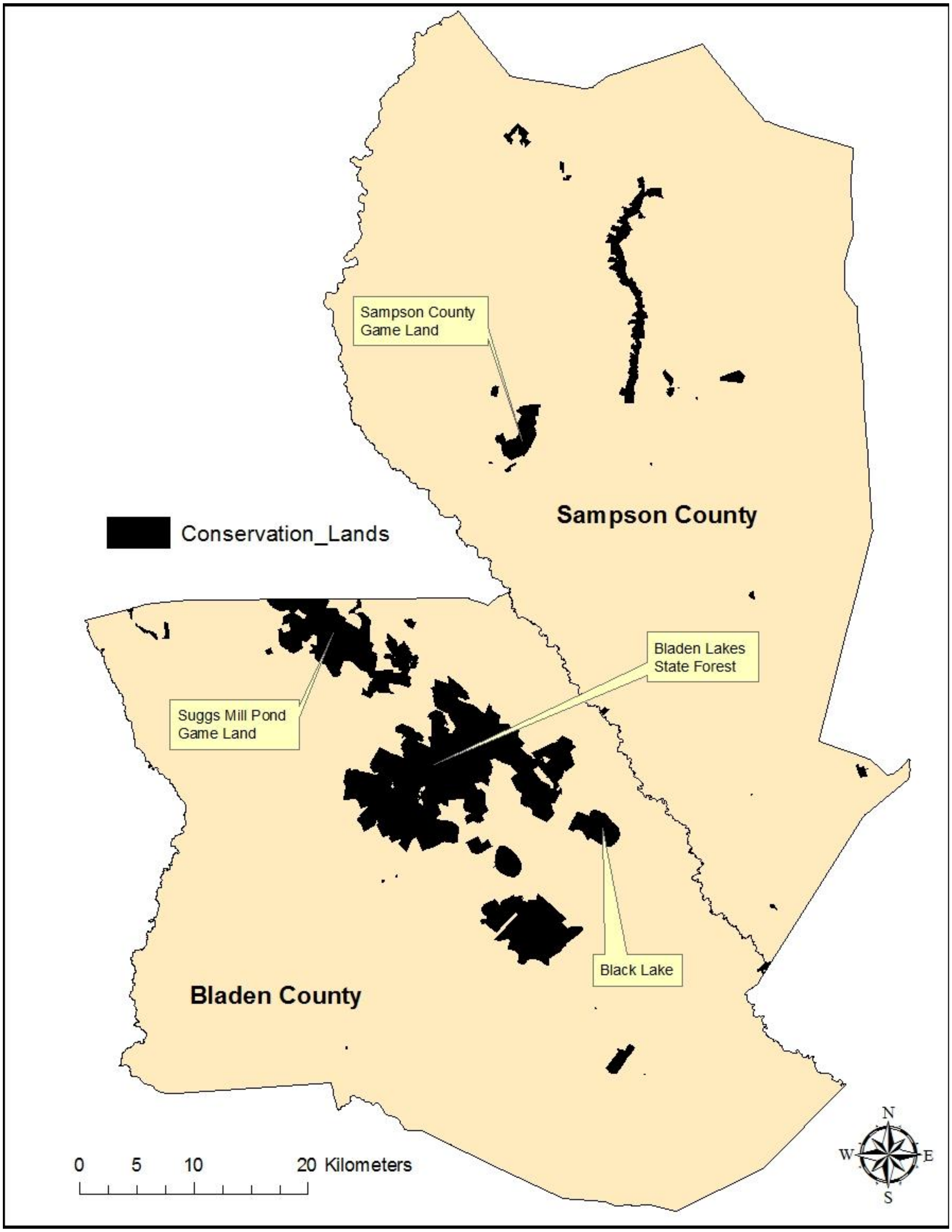


Figure 17: Bladen County LiDAR imagery and Carolina bay distribution. Most of the Carolina bays in Bladen County are found on the uplands, southwest portion of the county, or on interfluves in the Cape Fear River floodplain (northern portion of the county).

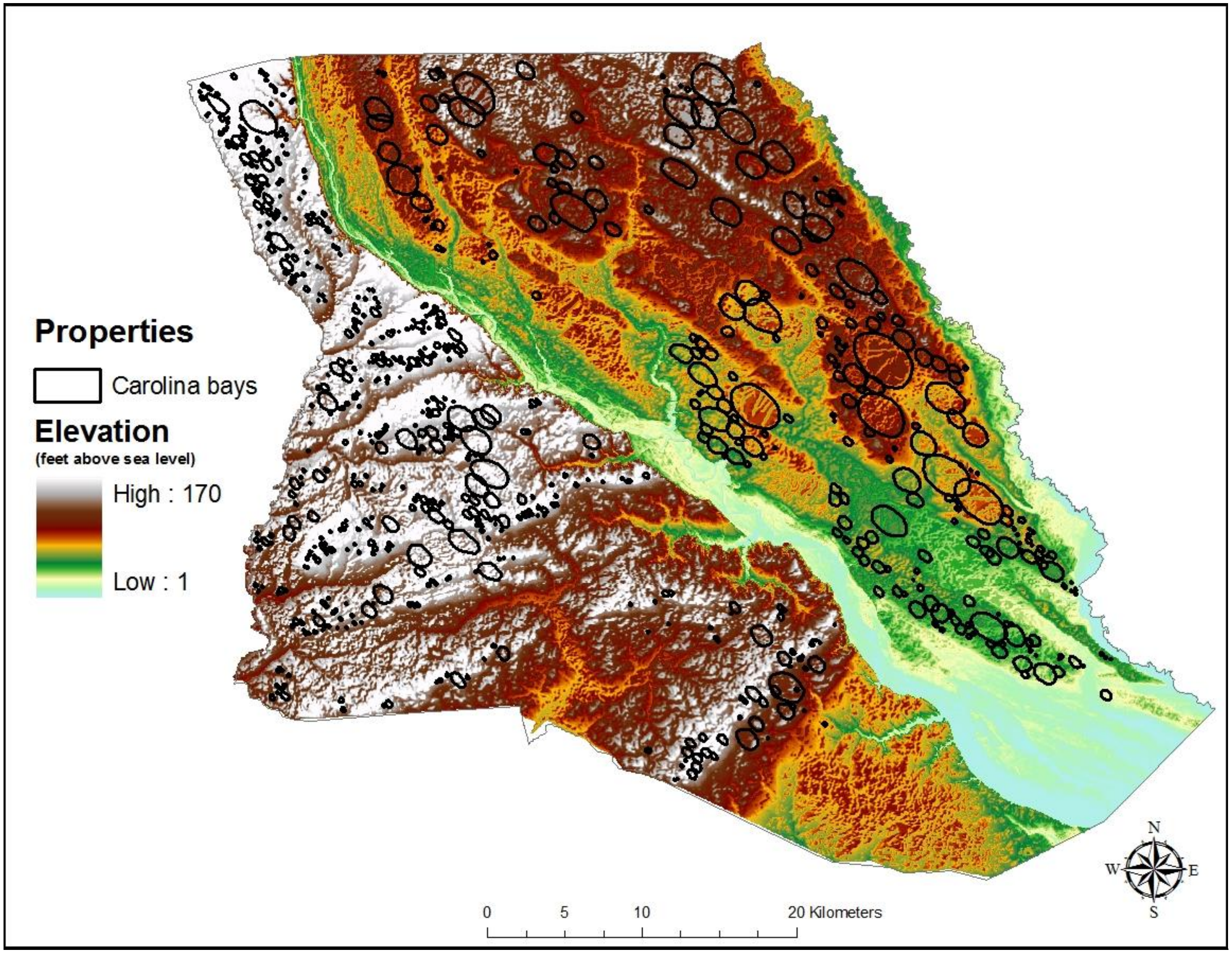


Figure 18: Sampson County LiDAR imagery and Carolina bay distribution. Most of the Carolina bays in Sampson County are found on upland in the northwest portion of the county or on one of the broad north-south oriented interfluves.

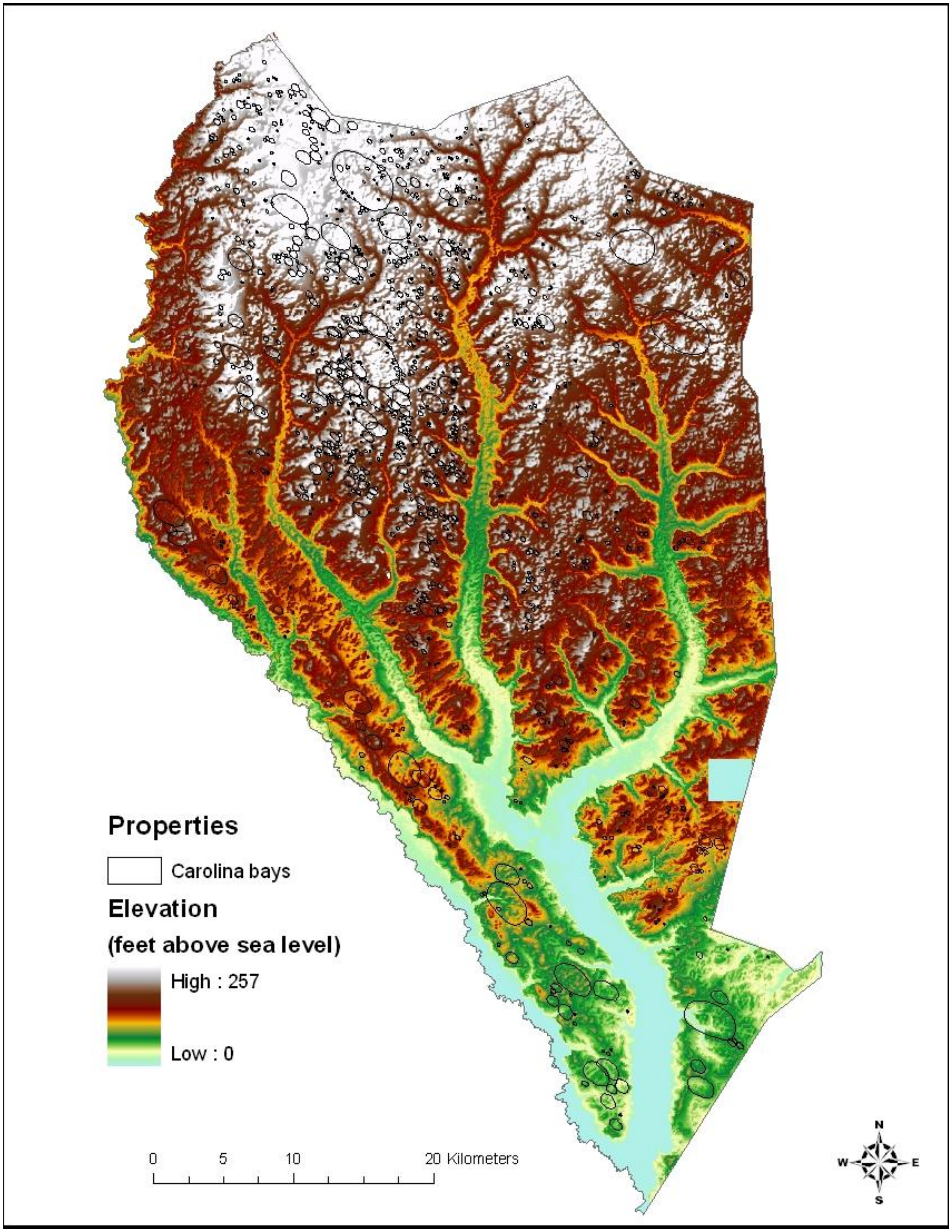


Figure 19: Bladen County Carolina bay size histogram (*N* = 769). The shape of the histogram agrees with Semlitsch and Bodie (1998) and Bennet and Nelson (1991) in that smaller bays are more frequent than increasingly larger bays. The large frequency associated with bays larger than 10 ha is misleading. This grouping contains all bays from 10.1 ha to 950 ha (*N* = 269), but only a few bays within each 1 ha interval are present.

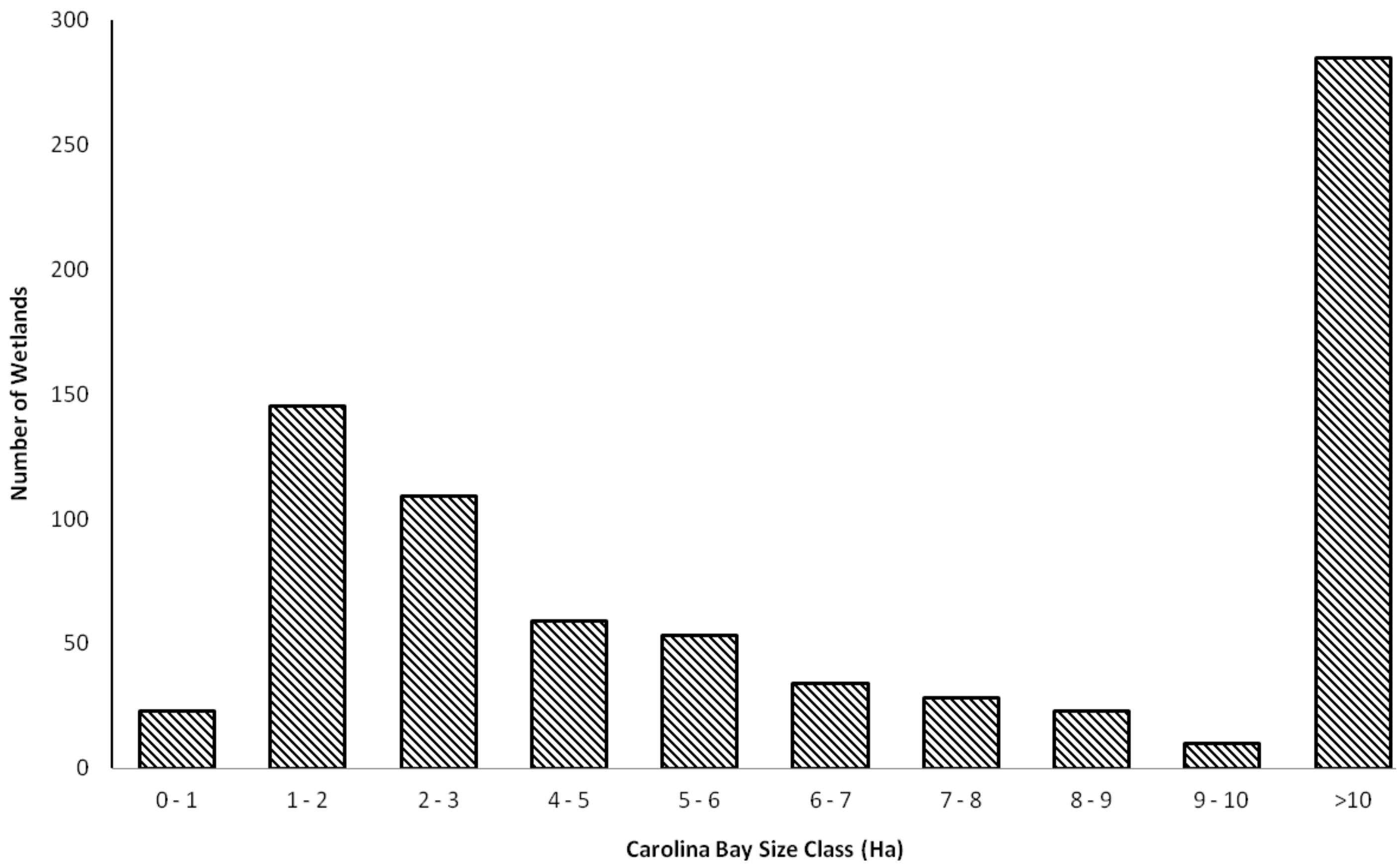


Figure 20: Sampson County Carolina bay size histogram (N = 1,094). The shape of the histogram agrees with Semlitsch and Bodie (1998) and Bennet and Nelson (1991) in that smaller bays are more frequent than increasingly larger bays. The large frequency associated with bays larger than 10 ha is misleading. This grouping contains all bays from 10.1 ha to 1,260 ha (N = 211), but only a few bays within each 1 ha interval are present.

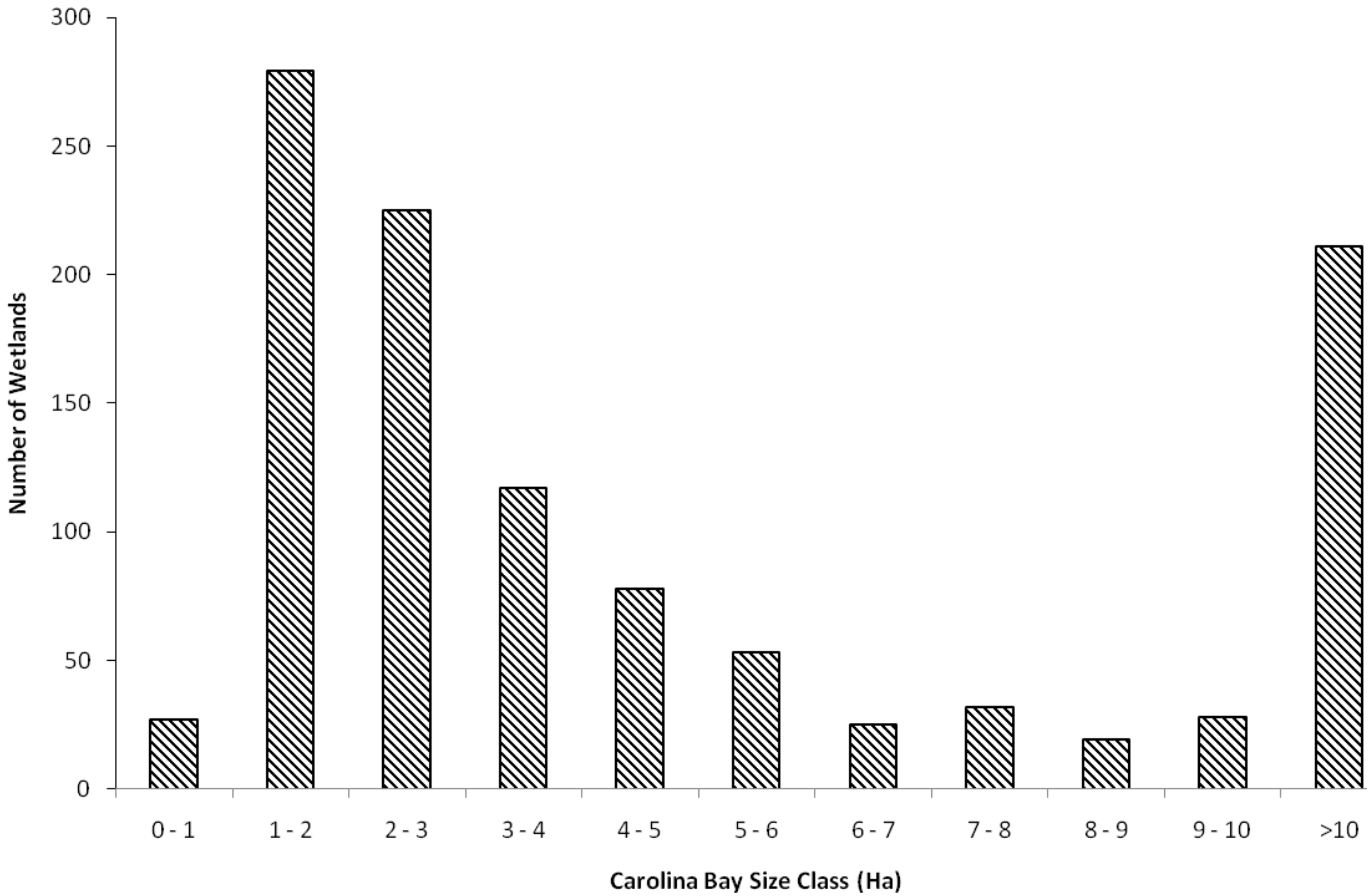


Figure 21: Distribution of soil orders and relationship with Carolina bays in Bladen County. Most of the histosols are found lower in elevation in the Cape Fear River floodplain where hydrologic conditions are present to create organic soils. Ultisols are found mainly south of the Cape Fear River.

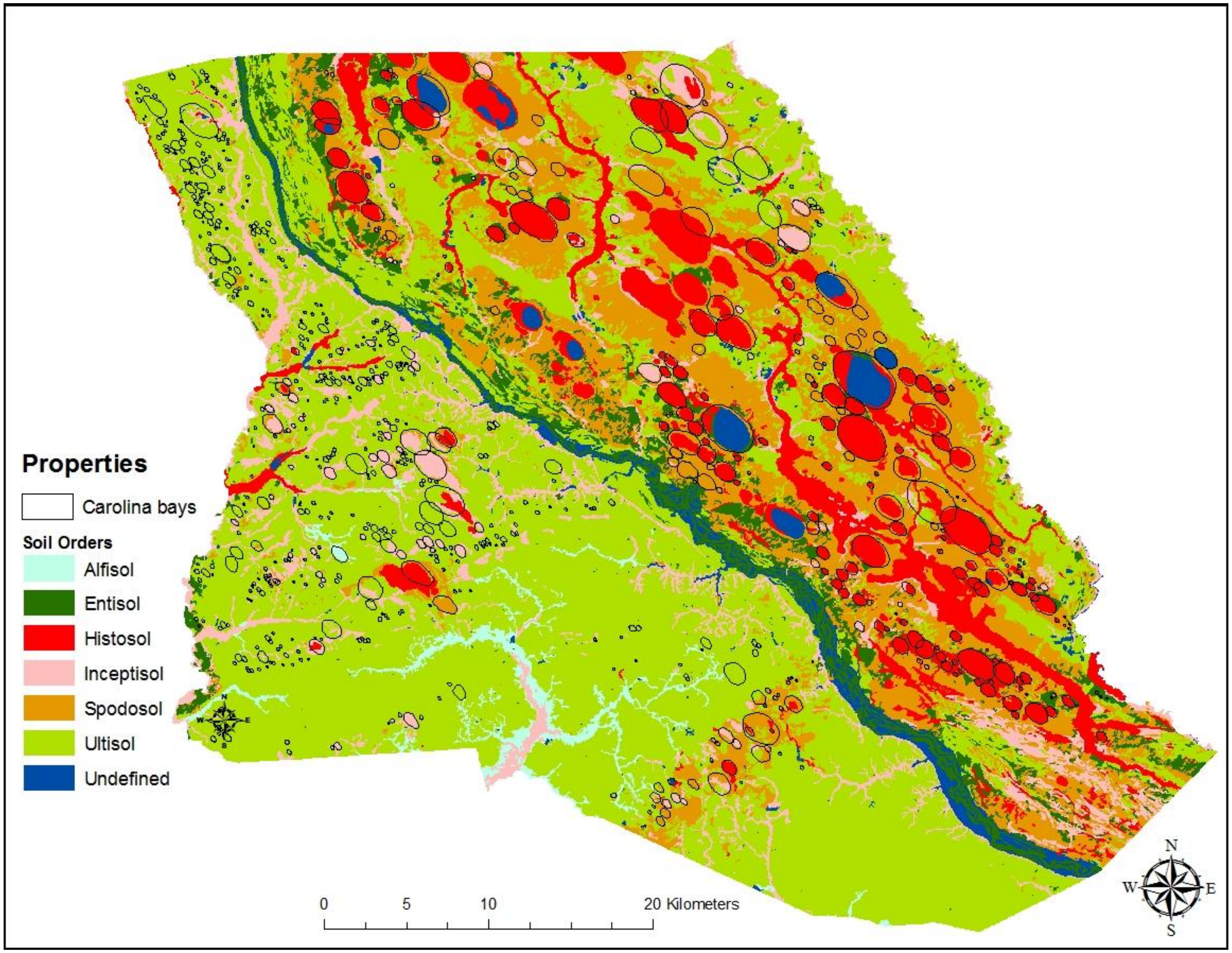


Figure 22: Distribution of soil orders and relationship with Carolina bays in Sampson County. Most of the county is ultisol, and as a result has been extensively converted to agriculture.

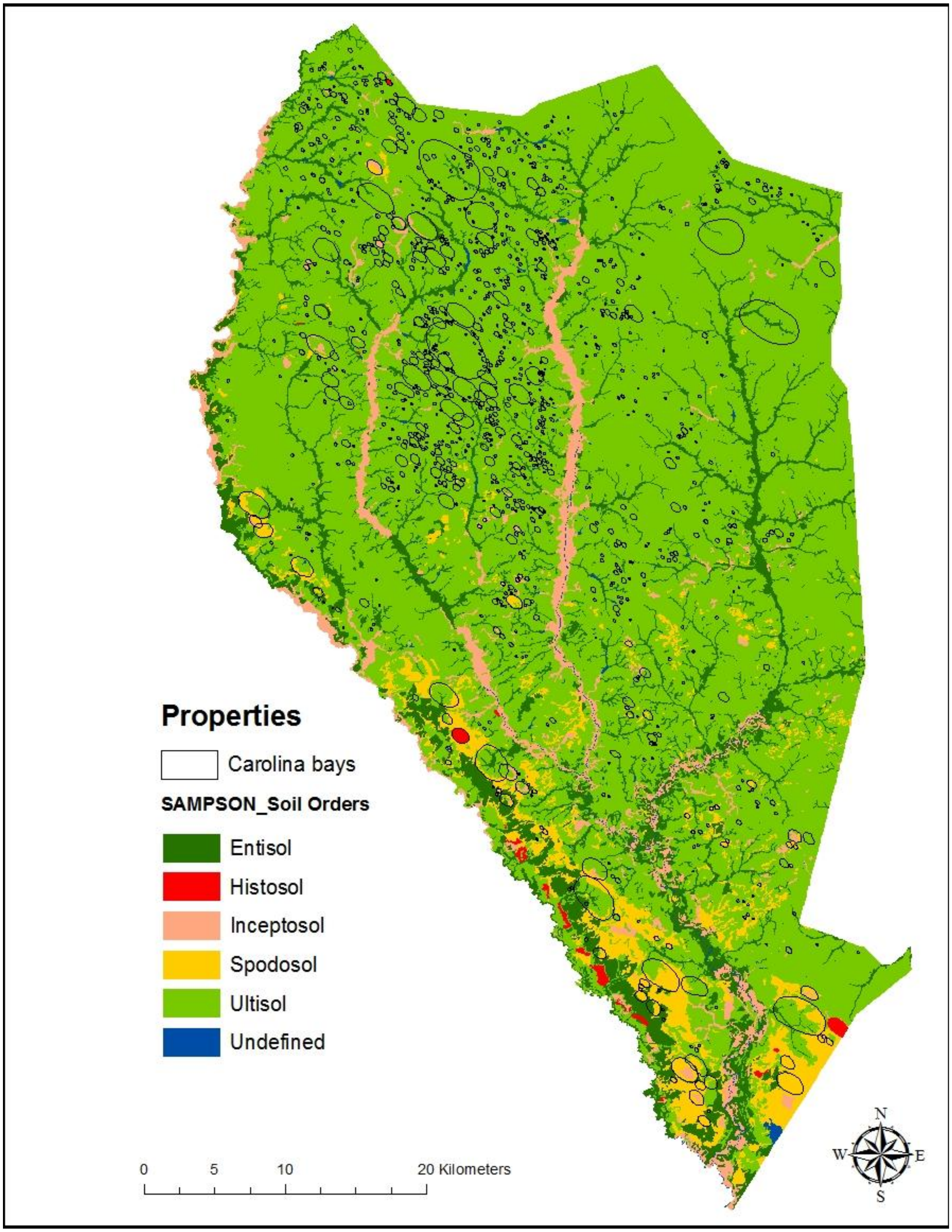


Table 3: Carolina bay inventory data requirements.

Data	Description	Source
Carolina bay base layer	Digitized polygons representing believed Carolina bays that will be edited.	http://georgehoward.net/surf%20the%20carolina%20bays.htm
USGS Topographic Quadrangles	Red, green, blue composite raster images representing topographic features.	http://www.ncdot.gov/it/gis/DataDistribution/USGSTopoMaps/default.html
SSURGO Soil	Digitized polygons representing soil series that were derived from aerial photography.	http://soildatamart.nrcs.usda.gov/Download.aspx?Survey=NC017&UseState=NC http://soildatamart.nrcs.usda.gov/Download.aspx?Survey=NC163&UseState=NC
NWI	Digitized polygons representing wetlands derived from aerial photography.	http://www.nconemap.com/default.aspx?tabid=286
LiDAR	Raster image representing elevation (ft.) above mean sea level.	http://www.ncdot.gov/it/gis/DataDistribution/ContourElevationData/contourDataDownload.html?bladen http://www.ncdot.gov/it/gis/DataDistribution/ContourElevationData/contourDataDownload.html?sampson

Table 4: USDA soil order defining suffixes. Data were used to update order field in Appendixes B and C.

Order	Defining Suffix
Alfisol	‘alf’
Entisol	‘ent’
Histosol	‘ist’
Inceptosol	‘ept’
Spodosol	‘od’
Ultisol	‘ult’
United States Department of Agriculture Soil Survey Staff (2006)	

Table 5: Bladen and Sampson County Carolina bay derived descriptive statistics.

	Bladen County	Sampson County
Descriptive	Statistic	
Count	769	1,094
Mean (Ha)	32.27	17.83
Median (Ha)	38.13	3.1
Variance	6,850.74	5,903
Standard Deviation	82.77	76.83
Minimum (Ha)	0.81	0.81
Maximum (Ha)	949.47	1,256.33
Skewness	5.225	10.866
Kurtosis	35.971	144

Chapter 4: Carolina Bay Herpetofaunal and Mitigation Attributes

Isolated wetlands such as those associated with the Carolina bays are important breeding sites for herpetofauna, most notably the amphibians. Small temporary wetlands typically have higher amphibian diversity and produce more metamorphs than either ephemeral pools or permanent ponds (Semlitsch 2002). However, such species do not use wetlands exclusively; they move into or through surrounding uplands for foraging, overwintering, and in search of breeding sites. Isolated wetlands make up the vast majority of total number of wetlands across the landscape, which holds especially true for those associated with the Carolina bays (Calhoun et al. 2005; Sharitz and Gibbons 1982). Despite their recognized importance for herpetofauna, mitigation projects view wetlands as units with little consideration to the surrounding landscape (Attum et al. 2007). Mitigation success and herpetofaunal persistence depend on a variety of attributes that have been addressed in the literature.

Mitigation Success

Mitigational applicability and success of a site depend on multiple factors, with hydrology as one of the most important. Hydrology is typically used as the benchmark because once it has been restored, re-growth of wetland vegetation occurs. Roads are generally detrimental to wetland mitigation because they represent hydrological modifications when constructed within a wetland, and act as sources of pollutants that contribute to deteriorating water quality (Andrews et al. 2006). Road density can be used to measure how concentrated roads are within an individual wetland, thus indicating a measure of hydrological modification using widely available data.

Size and ownership of a wetland can have additional effects on the usefulness of a wetland as a mitigation area. Wetlands with multiple owners can be viewed as harder to obtain or get consensus on appropriate mitigation strategies. Size of the area poses an additional issue. Federal standards under the Clean Water Act require a ‘no net loss’ policy in which area disturbed must be mitigated by an equal amount of area. Under this requirement, smaller wetlands would need to be obtained in higher numbers than increasingly larger ones to meet mitigation requirements. Further, the North Carolina Ecosystem Enhancement Program prefers sites greater than 5 acres to meet mitigation requirements (NC EEP n.d.). From these issues, knowing the size of a wetland and the number of owners it has, would contribute to understanding its applicability as a mitigation site.

North Carolina has produced two key datasets directly related to wetland mitigation and biodiversity: The Division of Coastal Management’s Potential Wetland Restoration and Enhancement Site (PWERS) identification and the Natural Heritage Program’s Biodiversity and Wildlife Habitat Analysis (BWHA). The PWERS procedure locates sites that are former wetland areas that have been altered from their natural condition to the extent that the site no longer meets the vegetative, hydrologic, and/or soil conditions required to be classified as jurisdictional wetlands (Sutter 1999). The Biodiversity and Wildlife Habitat Analysis identifies high quality habitat contributing to aquatic and terrestrial ecosystem processes (NC NHP n.d.). These datasets can aid in identifying an area that meets mitigational applicability and contributes to biodiversity through high quality habitat. However, these datasets were not constructed for herpetofauna and tell little about the composition and configuration of landscape components vital to herpetofauna.

Herpetofaunal Persistence

Dominant terrestrial habitat

Pine habitats are characteristic of the southeastern coastal plain. Historically, longleaf pine (*Pinus palastris*) dominated the coastal plain from Texas to southeastern Virginia (Landers et al. 1995). This natural resource has been extensively used and currently represents only a small portion of its former range. The historical dominance ultimately leads to many species evolving as specialist to the habitat type. Today, many of the endangered and threatened herpetofaunal species of the southeastern coastal plain depend on pine habitats at some point in their life. Pine habitat is used to represent longleaf, loblolly (*Pinus taeda*), and evergreen plantations. This grouping is based from Chen and Wang (2007) who reported that the highest herpetofaunal species richness values encountered occurred in loblolly and longleaf forests. Suitable pine habitat surrounding a breeding site may be conducive for maintaining the most imperiled species and thus contributes to maintaining overall herpetofaunal diversity.

Fragmentation

Habitat fragmentation is a process of degrading habitat and disrupting connectivity. Edge effects are the result of the interaction between two adjacent ecosystems when they are separated by an abrupt change (Murcia 1995). Edge effects are commonly used to quantify the extent to which fragmenting landscape uses have altered the surrounding natural vegetation. Agriculture is a major economy in the Southeastern United States and has been responsible for fragmenting large tracts of natural habitat. Meanwhile, transportation corridors, most notably roads, have been constructed to facilitate access to urban areas and exchange of goods. Collectively, these are the largest representation of habitat fragmentation in the study region and their effects have been examined in the literature.

Agriculture not only includes typical row crop production, but the harvesting of trees (silviculture) and the production of livestock. Agricultural use of the land brings several concerns for herpetofauna. Amphibian skin is highly permeable and amphibians therefore have a stringent dependence on moisture (Smith and Green 2005). Agricultural lands are typically a matrix of low biomass and complexity, and have numerous abiotic effects that are detrimental, if not fatal to herpetofauna (Murcia 1995). Semlitsch (2002) reports that disease and pathogens, invasive species, and chemical contamination contribute to amphibian declines. From a societal view, reptiles are unwanted in human dominated areas and are often killed when encountered, especially snakes. Further, the monotonous structure of many agricultural lands makes them unsuitable for amphibians due to elevated risk of desiccation. The most concerning abiotic effects revolve around chemicals. Because amphibians have permeable skin, any contact with polar chemicals such as those used in herbicides, pesticides, and steroids for livestock can result in them being absorbed and causing detrimental changes in the organism or death. An additional consequence of hog farming in particular is the potential for death associated with herpetofaunal species using swine lagoons. Manure borne steroids, such as estrogen, can adversely affect the reproductive health of amphibians (Hanselman et al. 2003). Deep basins and steep slopes of most artificial ponds inhibit vegetation and result in functionally different systems (Shulse et al. 2010). These factors coupled together make swine lagoons highly unsuitable for herpetofauna. An unsuspecting individual may seek refuge in a lagoon and may not be able to escape, resulting in death or may attempt to breed, in which case any steroids would alter reproductive success. The edge effect of fragmentation by agriculture has been widely addressed in the literature (Calhoun et al. 2005). Otto et al. (2007) concluded that wetlands in agricultural landscapes were unsuitable for herpetofauna because they often serve as sinks for pollutants and have altered hydroperiods.

Demaynadier and Hunter (1997) performed a regression analysis of a subset of the 13 species they observed and found that there was an asymptote of captures around 30m into the forest edge. This value is chosen as the edge effect of agriculture for this project. Not only has this value been derived and supported in the literature, 30m represents the minimum mapping unit of available landcover data.

One of the most significant anthropogenic modifications of terrestrial habitats in the past century is the network of roads (Roe et al. 2006). Roads affect herpetofauna in many ways, but two are critical for the maintenance of herpetofaunal biodiversity: connectivity barriers and mortality. Roads disrupt connectivity by serving as behavioral barriers to herpetofauna (Andrews et al. 2006; Attum et al. 2007; Weyrauch and Grubb 2004). Direct herpetofaunal mortality has been shown to be highly correlated with traffic volume (Gibbs and Shriver 2005). Andrews et al. (2006) suggest that social views of herpetofauna lead to direct targeting on roadways, in which drivers will deliberately kill snakes and turtles in particular. An additional impact of increased traffic volume on herpetofauna is the presence of toxins that degrade breeding habitat (Calhoun et al. 2005). Roads supporting a higher traffic volume can contribute higher pollutant concentrations in runoff. Further, these roads are typically considered priority roads and receive maintenance more frequently in adverse winter weather conditions, resulting in de-icing salts contributing to increased salinity in nearby areas. In a literature synthesis of roads, vehicles, and herpetofauna, Andrews et al. (2006) suggest that roads influence amphibian populations as far as 100m away. This value will be maintained to represent the road edge effect on herpetofauna. The overall literature suggests that traffic volume influences the effect of roads on herpetofauna more so than the road itself, therefore a distinction will be made between perceived high and low volume roads in the study region.

Heterogeneity and connectivity

Landscape heterogeneity is important to the sustainability of herpetofaunal diversity. The requirements of many herpetofaunal species, particularly the biphasic (i.e. dependent on aquatic habitats at birth and terrestrial habitats as adults) amphibians, for multiple habitat types during their life make them susceptible to habitat alterations (Welsh et al. 2005). Chen and Wang (2007) report higher herpetofaunal species richness in spatially heterogeneous landscapes. Similar results are reported by Weyrauch and Grubb (2004) in which agricultural landscapes containing diverse patches of remnant natural vegetation contain a higher richness of herpetofauna. These studies suggest that landscape diversity can be used to predict herpetofaunal richness. However, diversity is only a measure of landscape composition, not configuration. Configuration of landscape elements affects connectivity and therefore herpetofaunal movement.

Landscape diversity has been used in the literature as an indicator of environmental quality, with the assumption being that higher diversities within a landscape create a greater quality of habitat (Hanlin et al. 2000). There are two methods used to calculate diversity, the Simpson Diversity index and the Shannon Diversity index (Equations2 and 3 respectively). These two methods have been used extensively in the literature, measure landscape composition, and depend on both the number of patch types present and the proportional abundance of the patch types (McGarigal and Marks 1995). Despite their widespread use, one index has definitive advantages for this analysis. Simpson's index is less sensitive to the presence of rare types, has an interpretation that represents the probability that any two patches selected at random will be different types, and is much more intuitive than Shannon's index (1995). The values for this measure are distributed between 0 and 1 for any landscape with increasing values representing increasing richness and proportional distribution of area (1995). While diversity is only a measure of composition, a complementary index can be used to indicate the degree to which patches are adjacent.

Connectivity is related to both the persistence and diversity of herpetofauna. In a study of habitat loss and fragmentation, Lehtinen et al. (1999) reported that herpetofaunal richness in both fragmented and urban landscapes has a positive relationship with landscape connectivity. As a measure of connectivity, patch cohesion can represent the physical connectedness of patches within a landscape. Patch cohesion was introduced by Schumaker (1996) as a unitless measure of patch connectivity to represent dispersal success. This index represents an extension of island biogeography proposed by MacArthur (1967) in which patches located near other patches are more conducive to species dispersal. Although herpetofauna exhibit varying lengths of migration, knowing how potential habitats are configured within the landscape can provide insights into the suitability of the landscape for herpetofaunal diversity.

Wetlands in close proximity to other wetlands have higher abundances of herpetofaunal species than their more 'isolated' counterparts (Attum et al. 2007). As additional measures of heterogeneity, density and variability of breeding sites can provide information on their availability and size. These measures are important to sustaining herpetofaunal diversity because they inherently include the probability of successful dispersal to and colonization of breeding sites. As density of suitable habitat and breeding sites for herpetofauna in general increases, it can be assumed that the probability of an organism finding and utilizing the area also increases, particularly for those with limited dispersal capabilities. Further, size variability of breeding sites measures the size distribution of surrounding breeding sites. A large variability represents a mixture of large and small breeding sites. This spatial arrangement of landscape components can have profound effects on species utilizing them. Small wetlands have been found to be extremely important for maintaining regional diversity as species diversity and composition is typically different than that of neighboring larger, more permanent wetlands (Attum et al. 2007; Semlitsch and Bodie 2003). These additional measures of landscape heterogeneity will be used to describe how Carolina bays are distributed from herpetofaunal perspectives.

Objective

The objective of this analysis is to describe spatial patterns of Carolina bay disturbance that will aid in identifying those containing the most suitable landscape components for herpetofauna. To meet this objective attributes listed in Table 6 will be calculated for each Carolina bay. These attributes have been defended in the literature and chosen to describe the condition of each bay for its suitability to be used as a mitigation credit and simultaneously serve as sources of herpetofaunal diversity. These attributes are not intended to be used as an exhaustive list to completely describe the condition of the landscape nor are they intended to be used for species specific habitat modeling. These attributes are to be used as a rapid assessment tool to meet the objective of this analysis.

Methodology

The methodology for this project will utilize landcover data along with publicly available datasets produced by state agencies to calculate twelve attributes (Table 6). Six of the twelve attributes being produced rely exclusively on landcover data produced by the North Carolina Department of Transportation (NC DOT) or the United States Geological Survey Biological Resources Division (USGS BRD). These attributes include road edge, agricultural edge, percent pine, patch cohesion, patch diversity, and road density. Carolina bay basin area has previously been calculated and bay density and variability will be calculated from these measurements. Data produced by the North Carolina Natural Heritage Program (NC NHP), North Carolina Division of Coastal Management (NC DCM), North Carolina Center for Geographic Information and Analysis (NC CGIA), Bladen County Planning Department, and Sampson County Planning and Development Department will be used to calculate the remaining attributes (biodiversity and wildlife habitat analysis rated (BWHA), swine lagoon count, parcel count, and restorability). Once enumerated, all attributes will be added to the original un-buffered Carolina bay attribute table by joining the 250m or 1,000m buffered Carolina bays attribute table through the unique feature identification field (FID).

Data

Southeast Gap Analysis Program (SeGAP) landcover data produced by USGS BRD is chosen as the primary landuse data. Although many other forms of landuse data exist such as USGS LANDFIRE and National Land Cover Dataset, NOAA CCAP, and NC GAP, SeGAP has a distinct advantage. To effectively meet the needs of this inventory, the primary landuse data needs to be produced from recent satellite imagery and be specific in classification. Although datasets such as the NLCD and CCAP are produced from 2006 imagery, they are classified by Anderson level 1 conservative thresholds (Xian et al. 2009). Such a classification scheme groups multiple landcover types together based off of dominant species in the imagery. Southeastern Gap Analysis Program dataset was produced from 1999 to 2001 multi-season Landsat Enhanced Thematic Mapper (Landsat ETM+) imagery (Biodiversity and Spatial Information Center et al. 2008: METADATA). The classification scheme used by all GAP data is the National Vegetation Classification (NVC) system (Comer et al. 2003). This system classifies vegetative associations based on dominant (upper stratum) and diagnostic (understory) species and as a result can reflect a greater ecological specificity than those classifications relying only on dominant cover of the upper stratum (Maybury 1999). Despite the temporal disadvantage SeGAP presents, the NVC classification used for GAP data makes the dataset more appropriate for this analysis. A sample of the Data is displayed in Figure 23.

<u>Procedure</u>

Buffer. The 250m and 1,000m buffer distances determined from the literature were separately applied to the Carolina bay inventory previously produced. To perform this task, a simple full buffer command was utilized. After all buffering is complete, there are 3 feature classes representing un-buffered, 250m buffered, and 1,000m buffered Carolina bays. These layers will be used to calculate the attributes.

Agricultural edge. Agricultural edge represents the percent of the Carolina bay and associated landscape that is fragmented by agriculture. The attribute uses the 250m buffered Carolina bays and was calculated by manipulating SeGAP landcover to be used in the Landscape Fragmentation Tool (Parent 2009). The purpose of the Landscape Fragmentation Tool is to map the types of fragmentation present in a land cover type of interest (2009). To effectively use this tool, the landcover must be recoded into a binary classification and a buffer distance specified (Figure 24). Table 7 represents the land cover classes that were re-coded to a value of 1 (fragmenting class), 2 (fragmented class), or No Data (developed areas). All developed areas were re-classified as no data to ensure that all remaining classes were representing vegetative classes or water. Of the remaining landcover values, only those representing agriculture (148 and 149) are re-coded values of 1; all others are re-coded to values of 2. Thirty meters was used as the buffer distance for this attribute. The output contains six classes representing Patch, Edge, Perforated, Core (<101 Ha), Core (101 - 202 Ha) and Core (> 202 Ha). For this attribute, only the edge class is needed. Therefore, it is extracted and represented as a single raster (Figure 25). Hawth's Analysis Tools were created to add GIS functionality in spatial ecology research (Beyer

2004). Hawth's Tools Raster Zonal Statistics was used to determine the number of cells representing agricultural edge occurring in each Carolina bay polygon. Each 30m by 30m cell covers an area of 0.09 ha. Knowing the number of cells that fall within each Carolina bay polygon allows for calculation of cumulative area that can then be used to derive a value representing percentage of total area for the agricultural edge attribute.

Road edge. Road edge represents the percent of natural landcover in each Carolina bay and landscape (250m buffer) that has been fragmented by major roads. The procedure used to calculate this attribute follows closely with that used for agricultural edge with key exceptions. Values representing agricultural classes that were coded as 1 for the agricultural edge attribute were coded as NoData for the road edge attribute. Agricultural lands being fragmented by roads are not needed for this attribute. The developed land classes within the SeGAP layer include all transportation corridors and urban areas. Roads cannot be uncoupled and separately analyzed from the other developed areas. To overcome this coupling, all developed classes were coded as NoData and NCDOT Linear Reference System (LRS) arc shape file representing all roads in the NCDOT state road system were used to identify major roads (NCDOT n.d.). Within this layer, a query was used to extract all roads with the route type I (Interstate), US (United States), and NC (North Carolina). The polyline features representing these routes were converted to a raster with a default 30m resolution to match the resolution of the SeGAP layer. The produced raster had three values representing each of the route types, all of which were re-coded to a value of 1. The recoded road and SeGAP rasters were merged to produce a single raster with two values, 1 for roads and 2 for all natural landcovers. This raster was used in the LFT with a buffer distance of 100 meters. The remainder of this procedure is identical to that used for calculating the agricultural edge attribute.

Percent pine. Percent pine represents the proportion of the landscape (250m buffer) containing the dominant vegetation type of the southeastern coastal plain in which many herpetofaunal species have evolved. The procedure to calculate this attribute uses only SeGAP landcover in conjunction with Hawth's Tools. Southeast Gap Analysis Project values representing evergreen plantations (71), upland longleaf pine (93) and wet longleaf pine savanna and flatwoods (183) were re-coded to a value of 1 while all others received a value of NoData (Table 7). Hawth's analysis tools was used the same way as for agricultural and road edge attributes to determine the cumulative number of pine pixels per each 250m buffered Carolina bay. Once obtained, these pixels are used with the cell area (0.09 ha) to obtain the total area and percentage of pine habitat.

Biodiversity and Wildlife Habitat Analysis (BWHA) rated. This attribute was produced from an original BWHA vector layer obtained from NC NHP clipped to the study region. All impervious area classified polygons (-1) were removed from further analysis while the remaining polygons representing moderate (1) to maximum (10) conservation value were dissolved such that a single classification could be used to represent conservation rated. An area field was calculated to enumerate the area (ha) for each polygon. A spatial intersect was used with the 250m buffered Carolina bays and the edited BWHA layer. This overlay produced only polygons from the BWHA layer that were completely within the 250m Carolina bay polygons. To obtain a cumulative area of BWHA rated for each buffered Carolina bay, the BWHA area field was updated to represent the new area, and the unique identification field (FID) of the buffered Carolina bays was summarized by the updated BWHA area. The final output for this attribute was calculated as a percentage of total buffered Carolina bay area.

Patch cohesion. Patch cohesion was calculated using SeGAP landcover data as presented in Table 7 and the FRAGSTATS patch cohesion index presented in Equation 1 (McGarigal and Marks 1995). Each landcover value was extracted and analyzed separately to obtain information on number of cells and perimeter representing the corresponding landcover type. Each landcover value was clipped to the 250m buffered Carolina bay to ensure that the following processes were commensurate in data used. Perimeter of an entire patch is most efficiently calculated if the patch exists as vector data. Each clipped landcover was converted to a polygon feature class with the simplify option unchecked to force the polygon edges to conform to the edges of the raster cells. Perimeter is then calculated through the attribute table as a field. To obtain number of cells of the representative landcover per each patch, an area field (ha) is calculated. Because the polygons were forced to conform to the raster cells, dividing the area by the raster cell size (0.09 ha) yields the number of cells per patch. From this information, all values required by Equation 1 can be calculated. For each patch, a new field (Products) was calculated to represent the product of its perimeter times the square root of its area (Equation 1). A spatial join is used to summarize across each 250m buffered Carolina bay the sum of the patch perimeters, patch products, and number of cells. These summed values are used directly in MacGarigal and Marks (1995) Fragstats Patch Cohesion Index (Equation 1).

Patch diversity. Patch diversity is calculated using the landcover values specified in Table 7 and Simpson's Diversity Index presented in Equation 2. The procedure used to create the base data follows closely with that used for Patch Cohesion in that individual landcover types are extracted, clipped to the 250m buffered Carolina bays, and analyzed separately. The total number of cells representing natural landcover previously produced (variable A in Equation 1) is multiplied by 0.09 to convert to total area (ha) of natural landcover in the buffered Carolina bay.

Hawth's Analysis Tools Zonal Statistics is used to enumerate the number of cells of the analyzed landcover that occur within each buffered Carolina bay. The resulting value is multiplied by 0.09 to convert to area of landcover type present. The area of landcover is divided by the total area of natural landcover to produce a proportion that can then be directly used in Equation 2. Once all landcovers have been analyzed, their proportions are squared, summed, and subtracted from 1as dictated by Equation 2 to produce a diversity value for each buffered Carolina bay.

Carolina bay density. Carolina bay density was calculated using 1,000m buffered Carolina bays, the original un-buffered Carolina bays shapefile and Equation 4. Hawth's analysis tools polygon in polygon analysis (PIPA) was used to enumerate the un-buffered Carolina bays intersecting each 1,000m buffered bay. This value is then used directly in Equation 4 to derive the density of Carolina bays within 1,000m of each individual bay. To accommodate for area differences between landscapes (i.e. Carolina bays), MacGarigal and Marks (1995) standardized Equation 4 to 100 ha.

Carolina bay variability. Carolina bay variability uses the 1,000m buffered Carolina bays and the original un-buffered Carolina bay shapefile. A spatial join was used to join the attributes of the original un-buffered Carolina bays to the 1,000m buffered shapefile. Under this analysis, it is specified that the 1,000m buffered bays were the target features with a one-to-many relationship to the un-buffered Carolina bays. This type of relationship allows for attributes from multiple Carolina bays that intersect the buffered polygon to be attributed to it by the FID field. From this analysis, the FID of the buffered Carolina bays is summarized by the standard deviation of the area of the un-buffered Carolina bays. To obtain a value on variability of the number of proximal Carolina bays, the standard deviation value is squared to yield the variance.

Road density. Road density is calculated using the original un-buffered Carolina bay shapefile and NCDOT LRS arc shape file. Hawth's Analysis Tools Sum Line Length in Polygon clips polyline features to zonal polygons and adds the summed length of all polylines as a field in the zonal layers attribute table (Beyer 2004). For this analysis, the original Carolina bay shapefile was used as the zonal layer such that a summed length of roads within the Carolina bay could be calculated. Equation 4 was used to calculate road density for each Carolina bay with the exception that number of features is replaced by cumulative length.

Swine lagoon count. Swine lagoon count utilizes NC CGIA swine lagoon point features to identify the total number of swine lagoons in each 250m buffered Carolina bay. To obtain this value, Hawth's Analysis Tools Count Points in Polygon is used. The tool automatically assigns

Parcel count. Parcel count uses parcel Shapefiles obtained from the Bladen County Geographical Information Service (2011) and Sampson County Planning and Development Department (2005). The Bladen County parcels are available for download while the Sampson County parcels were acquired from Mr. Jimmy Fannin as a compact disc. These two datasets were re-projected to match the NAD 27 NC FIPS 3200 projection used for the project and merged to reduce data processing. Hawth's Analysis Tools Polygon in Polygon Analysis was used to enumerate the number of parcels intersecting each un-buffered Carolina bay. Using this tool automatically adds the field to the Carolina bay attribute table.

Restorability. Restorability utilizes NCDCM PWRES shapefiles downloaded for Bladen and Sampson Counties (NCDCM 2008). To obtain a PWRES areal coverage of each un-buffered Carolina bay, a similar procedure was used to that calculating BWHA rated. All restoration types were dissolved such that a single classification could be used, an area (ha) field was calculated in the PWRES attribute table, and a spatial intersects is performed with the un-buffered Carolina bays. After the procedure, the newly calculated area field for the PWRES layer is updated to reflect the new area located inside each Carolina bay. To obtain a cumulative area of restoration potential inside each Carolina bay, the Carolina bay FID is summarized to reflect the sum of the updated area field. This value is used to calculate the percent of Carolina bay rated as restorable.

Results

Results for this analysis are presented in Table 8. The N reported denotes the number of Carolina bays containing measurable data for the attribute. All of the bays had measurements for Carolina bay area, parcel count, and diversity while a high percentage (i.e. >80%) of the Carolina bays exhibited values for agricultural edge, Carolina bay density and variability, BWHA rated, patch cohesion, percent pine, and restorability. Road density and edge along with swine lagoon count were measured in a low percentage of the Carolina bays. Skewness values were positive for all attributes except for patch cohesion and diversity, and restorability, all of which exhibited negative skew (-2.38, -0.897, and -0.305 respectively). Agricultural edge was measured in 96.3% of the Carolina bays inventoried with a mean of 9.42% and a skew of 0.557. Carolina bay density and variability were measured in 96.7% of the inventoried Carolina bays. Carolina bay density had a mean and skew of 1.65 and 0.720 respectively while variance exhibited a mean of 1.48×10^4 and skew 4.55. Biodiversity and Wildlife Habitat Analysis ratings were found in 95.5% of the inventoried bays with a mean and skew of 29.5% and 1.34 respectively. Patch diversity was measured in 100% of the inventoried bays with a mean of 0.648 while patch cohesion was measured in 97.9% with a mean of 0.837. Carolina bays were found to be dissected on average by 6.48 parcels with a skew of 25.3. Pine habitats were found in 98.12% of the inventory with a mean and skew of 19.0% and 1.51 respectively. Road edge and density were measured in 26.8%

and 21.8% of the inventory with means 18.3% and 363.0 respectively. Swine lagoons were found in 10.1% of the inventory and averaged 1.61 per Carolina bay with a skew of 3.34. North Carolina Division of Coastal Management Potential Enhancement and Restoration Sites were found in 83.9% of the inventory with a mean of 59.4 and skew of -0.305

Conclusion

A common feature of ecological data sets is their tendency to contain many zero values (Martin et al. 2005). For ecological data, true zeroes must be distinguished from no data zeroes to appropriately describe the distribution. Zero values are present in the attributes of this analysis as a result of presence or absence of the mapped landcover types. For example, a Carolina bay receiving a value of zero for swine lagoon count is a caused by no swine lagoons mapped within the boundary of the Carolina bay. True zeroes, however arise from the landcover type being mapped, but being spatially identical or segregated. Patch cohesion and diversity are the only attributes containing true zeroes for this analysis (Table 8). These attributes contain true zeroes for one of two reasons: either the landcovers mapped within each Carolina bay are of the same community resulting in zero diversity, or the landcovers present are spatially segregated resulting in zero connectivity. For this analysis, the total percentage of Carolina bays containing each attribute (Table 8) is reflective of removing zero values representing no data.

The results of this analysis are within an expected range for the measured attributes. The values for agricultural edge indicate that there are few Carolina bays that have not been fragmented by agriculture, a dominant economy in the region. Similar results have been documented in South Carolina (South Carolina Department of Natural Resources 1999). Carolina bay density indicates that from a herpetofaunal view, many of the Carolina bays are within most species' dispersal capabilities while size variability indicates that size classes are not selfclustering. High variability values indicate that bays are neighbored by bays of differing sizes from themselves. The values reported for percent BWHA rated and restorable indicate that the bays are important ecologically by containing patches of high quality habitat and most are restorable in the current condition. The values are not identical, presumably because some of the areas rated high for BWHA exist as fully functioning and undisturbed wetlands not suitable for mitigation, thus not appearing in the PWERS dataset. Patch diversity and cohesion explain the spatial configuration of the habitat patches within each bay. These results indicate that most herpetofaunal landscapes around the bays are heterogeneous in mapped SeGAP communities and that the existing patches are typically clustered together, providing potential habitats to a diversity of herpetofauna. The negative skew of these values indicate that the landscape around the bays exhibit high diversity and connectivity. Pine habitat, the dominant habitat type of the southeastern coastal plain, was found in a majority of the inventoried bays. This pattern is expected from a review of the Carolina bay literature and study region. Road density was found in fewer bays than expected. However, the high mean and low skew indicates that when a bay is intersected by roads, it typically has a high concentration and is thus unsuitable hydrologically for mitigation. Values for road edge were expected to be encountered in only a few bays because the peat located in the basins of many bays is unstable and often avoided by road developers. There are few major roads in the study region, increasing the probability that a major road will not be within the 100m buffer distance. The most surprising and unexpected result was the low percentage of Carolina bay landscapes containing swine lagoons. The study region is in the center of the swine industry of the state, and it was expected that a high percentage of bays would contain swine lagoons. The most skewed data obtained exists for parcel count. This indicates that most Carolina bays, particularly the large ones, are owned by many individuals.

Overall, the data confirm that many of the bays are fragmented and do not exist in ideal conditions, but are not completely lost either. The data particularly suggests that careful selection and management of Carolina bays can be beneficial to most herpetofauna.

Figure 23: SeGAP Landcover Classes near Elizabethtown, Bladen County NC.

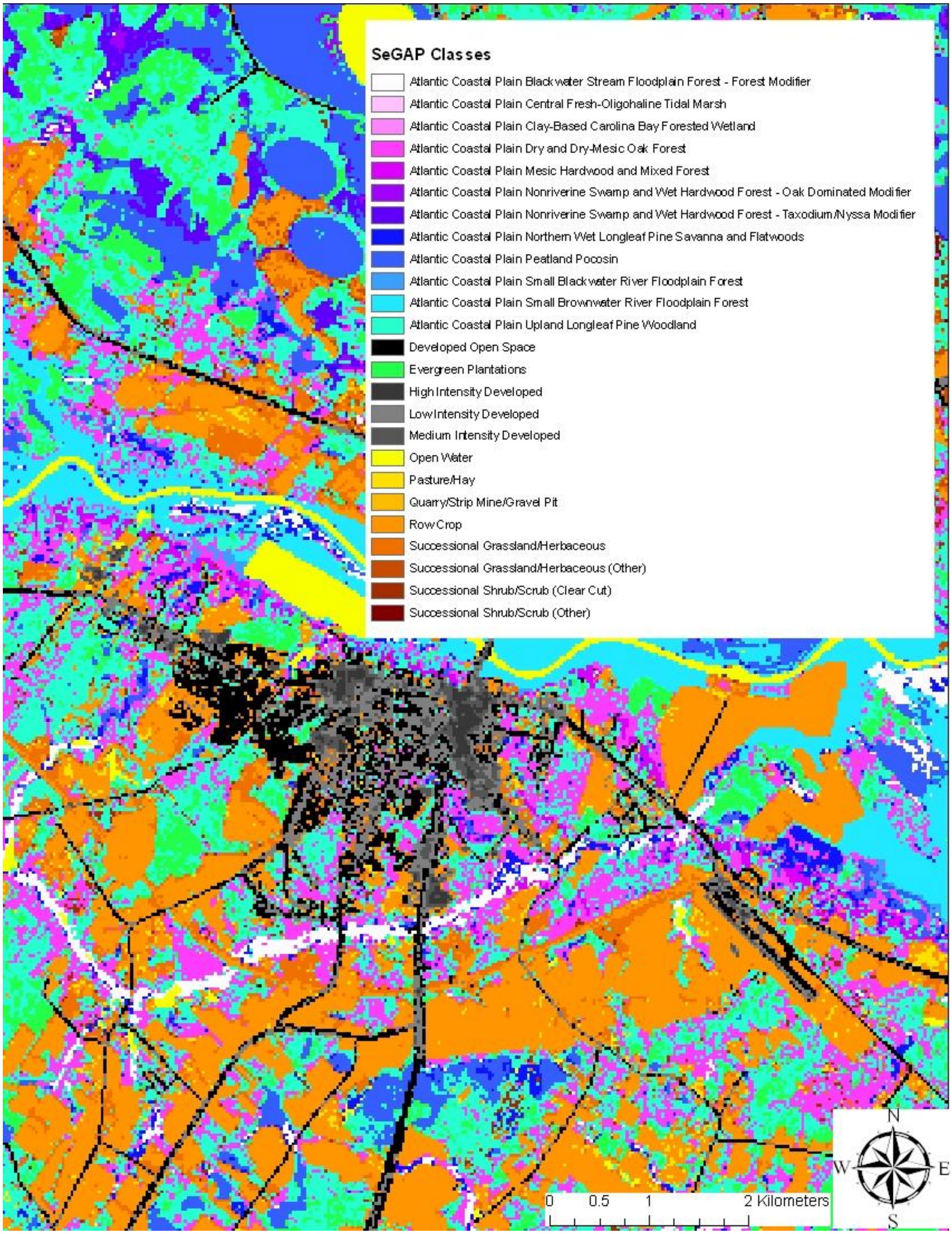


Figure 24: Landscape Fragmentation Tool Dialogue and Data Requirements.

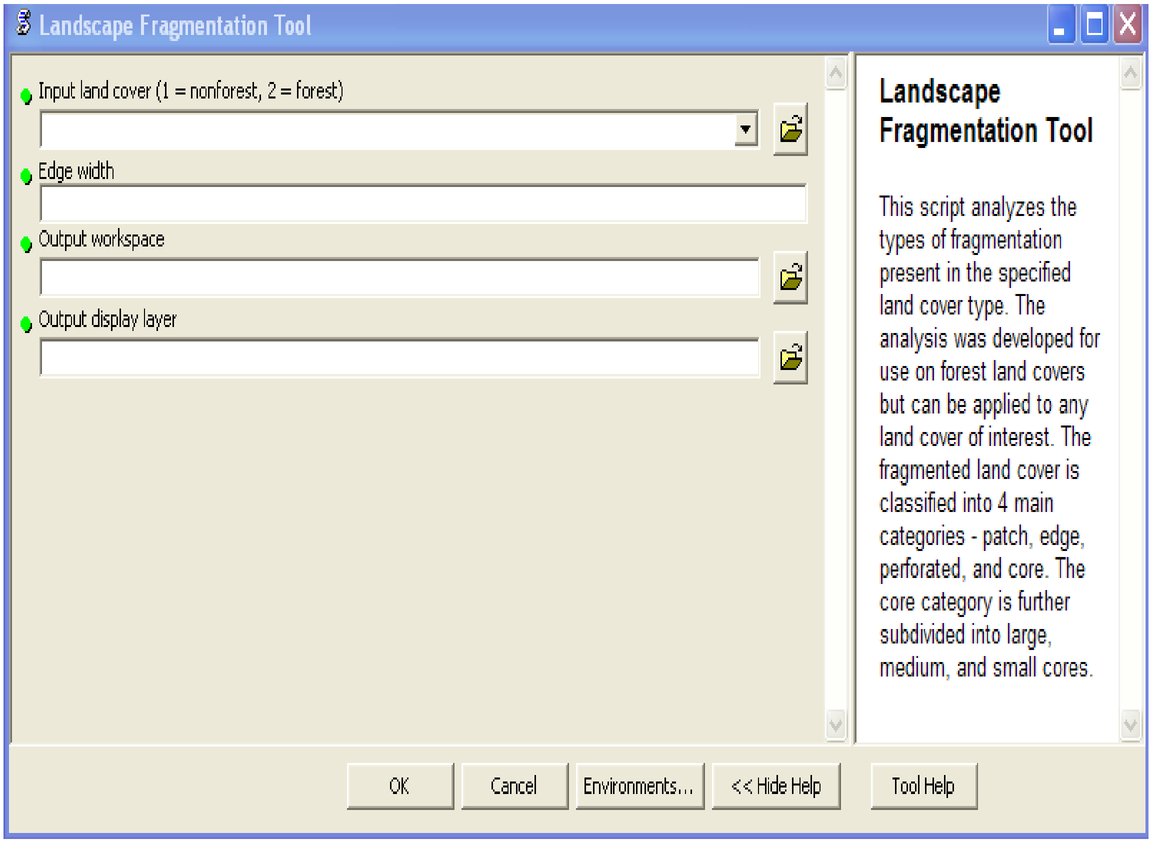


Figure 25: Landscape Fragmentation Tool fragmentation classes depicting a portion of the Cape Fear River Floodplain north of Elizabethtown, NC (bottom center).

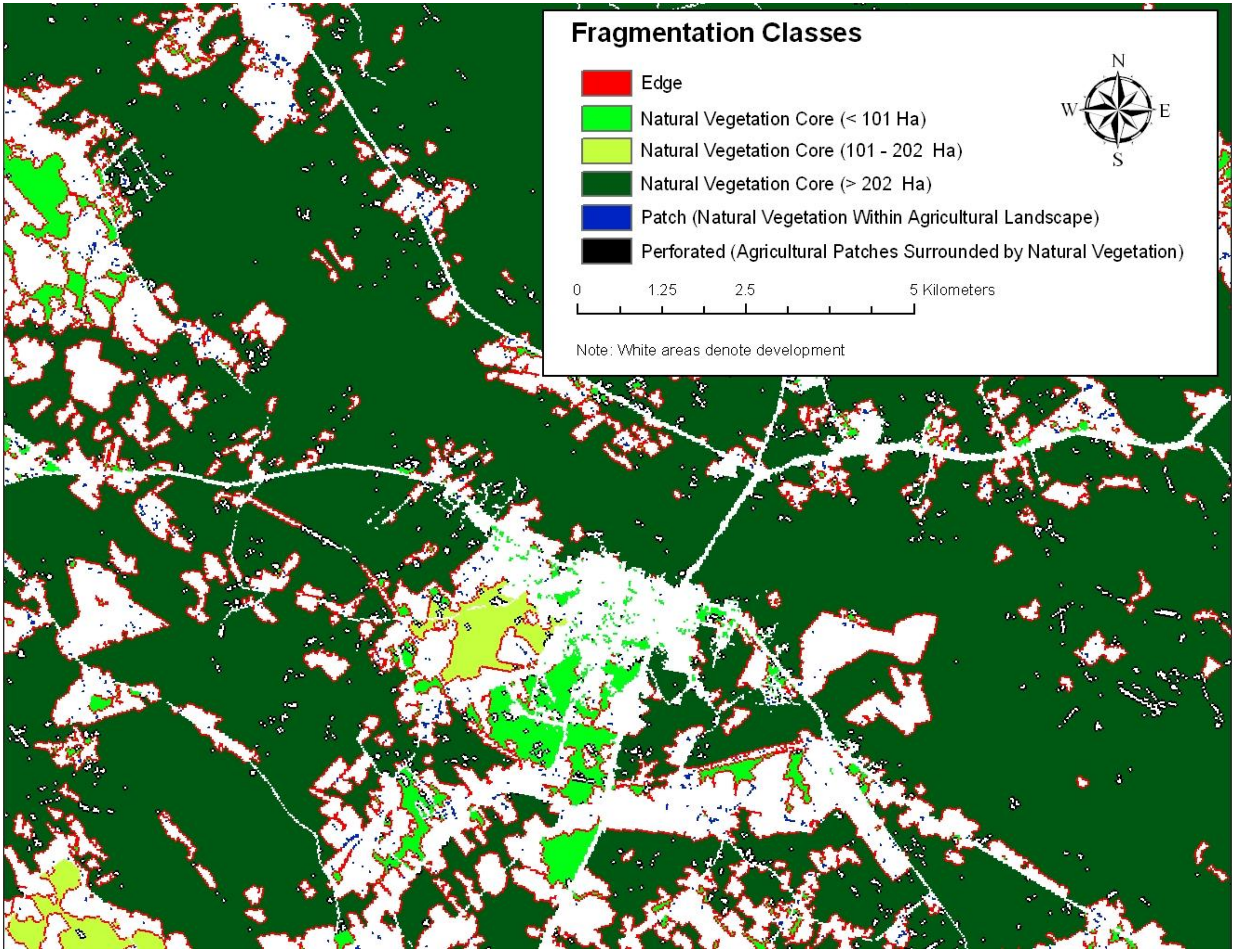


Table 6: Attributes and descriptions used for this analysis.

Attribute	Description
Agricultural Edge	Represents impact human alterations has on existing natural vegetation. (Invasive species, pesticides, etc.)
Road Edge	Represents threat of direct mortality ("road kill"), behavioral modification, and gene flow restrictions; Only includes Interstate, US, and NC roads
Percent Pine	Represents the proportion of the landscape containing the dominant vegetation type of the southeastern coastal plain that many herpetofaunal species have evolved life histories with.
BWHA Rated	Represents proportion of landscape identified by the Natural Heritage Program as high quality natural habitat contributing to aquatic and terrestrial processes.
Patch Cohesion	Represents the connectivity of habitat patches
Patch Diversity	Represents landscape heterogeneity using Simpson's Index
Carolina Bay Density	Represents the density of ponds in the herpetofaunal perceived landscape
Carolina Bay Variability	Represents the variance in bay size distribution within a herpetofaunal perceived landscape
Road Density	Represents loss of mitigation potential through fragmentation; Includes all road types (Interstate, US, NC, State routes, etc.)
Swine Lagoon Count	Represents mortality risk of use of these areas as habitat (Eutrophication/hypoxia, entrapment from steep banks, etc.)
Parcel Count	Represents the loss of mitigation potential through difficulty in cooperation between multiple owners
Restorability	Represents the proportion of bay that is rated as either existing or restorable by NC CREWS

Table 7: Southeast Gap Analysis Project landcover values and descriptions. Attribute columns describe the landcover classification used for analysis.

VALUE	SEGAP_NAME	Agricultural Edge	Road Edge	Percent Pine	Cohesion and Diversity
1	Open Water (Fresh)	2	2	NoData	1
4	Developed Open Space	NoData	NoData	NoData	NoData
5	Low Intensity Developed	NoData	NoData	NoData	NoData
6	Medium Intensity Developed	NoData	NoData	NoData	NoData
7	High Intensity Developed	NoData	NoData	NoData	NoData
18	Quarry/Strip Mine/Gravel Pit	NoData	NoData	NoData	NoData
39	Atlantic Coastal Plain Dry and Dry-Mesic Oak Forest	2	2	NoData	39
40	Atlantic Coastal Plain Mesic Hardwood and Mixed Forest	2	2	NoData	40
71	Evergreen Plantations	2	2	1	71
93	Atlantic Coastal Plain Upland Longleaf Pine Woodland	2	2	1	93
125	Successional Shrub/Scrub (Clear Cut)	2	2	NoData	125
127	Successional Shrub/Scrub (Other)	2	2	NoData	127
145	Successional Grassland/Herbaceous	2	2	NoData	145
146	Successional Grassland/Herbaceous (Other)	2	2	NoData	146
148	Pasture/Hay	1	NoData	NoData	NoData
149	Row Crop	1	NoData	NoData	NoData
151	Atlantic Coastal Plain Blackwater Stream Floodplain Forest - Forest Modifier	2	2	NoData	151
153	Atlantic Coastal Plain Small Blackwater River Floodplain Forest	2	2	NoData	153
154	Atlantic Coastal Plain Small Brownwater River Floodplain Forest	2	2	NoData	154
167	Atlantic Coastal Plain Non-riverine Swamp and Wet Hardwood Forest - Taxodium/Nyssa Modifier	2	2	NoData	167

Table 7 Continued.

168	Atlantic Coastal Plain Non-riverine Swamp and Wet Hardwood Forest - Oak Dominated Modifier	2	2	NoData	168
173	Atlantic Coastal Plain Clay-Based Carolina Bay Forested Wetland	2	2	NoData	173
175	Atlantic Coastal Plain Peatland Pocosin	2	2	NoData	175
183	Atlantic Coastal Plain Northern Wet Longleaf Pine Savanna and Flatwoods	2	2	1	183
213	Atlantic Coastal Plain Central Fresh-Oligohaline Tidal Marsh	2	2	NoData	213

Table 8: Descriptive statistics of Carolina bay herpetofaunal and mitigation attributes.

	Attribute	N	Minimum	Maximum	Percent of Total	Mean	Standard Deviation	Skewness
Ecological	Agricultural Edge (%)	1794	0.212	29.93	96.29	9.43	5.16	0.56
	Road Edge %)	407	0.1653	49.49	24.85	18.33	11.62	0.31
	Percent Pine (%)	1828	0.2047	100	98.12	19.01	15.72	1.5
	BWHA RATED (%)	1779	0.002	99.99	95.49	29.49	30.92	1.34
	Patch Cohesion (Unitless)	1824	0	1	97.91	0.84	0.14	-2.34
	Patch Diversity (Unitless)	1863	0	1	100	0.65	0.2	-0.9
	Carolina Bay Density (number/ 100 Ha)	1801	0.0543	5.40	96.67	1.65	1.07	0.72
	Carolina Bay Variability (Unitless)	1801	0.001	518250	96.67	1.48 E4	4.37 E4	4.55
Mitigation	Carolina Bay Area (Ha)	1863	0.81	1256.33	100	23.79	79.63	8.16
	Road Density (m/100 Ha)	500	0.625	2719.12	26.84	363.09	302.79	1.85
	Swine Lagoon Count (Unitless)	189	1	10	10.14	1.61	1.23	3.34
	Parcel Count (Unitless)	1863	1	944	100	6.49	27.14	25.32
	Restorability (%)	1564	0.023	100	83.95	59.39	27.13	-0.31

Equation 1: Patch Cohesion Index modified from Fragstats (McGarigal and Marks 1995)

$$Cohesion = \left[1 - \left(\sum_{j=1}^{n} pij\right) / \sum_{j=1}^{n} \sqrt[pij]{aij}\right] \left[1 - \left(1/\sqrt{A}\right)\right]^{-1}$$

pij = perimeter of patch *ij*

aij = area of patch ij in terms of number of cells

A = total number of cells in the landscape

Equation 2: Simpson's Diversity Index as calculated in Fragstats (McGarigal and Marks 1995)

$$SIDI = 1 - \sum_{i=1}^{m} Pi^2$$

Pi = proportion of landscape occupied by patch type i

Equation 3: Shannon's Diversity Index as calculated in Fragstats (McGarigal and Marks 1995).

$$SHDI = -\sum_{i=1}^{m}(Pi * lnPi)$$

Pi = proportion of landscape occupied by patch type *i*

Equation 4: Density equation as used in Fragstats (McGarigal and Marks 1995) modified to adjust for metric area used with data.

$$D = \frac{m}{A}(100)$$

m = number of occurrences or cumulative length (road density)

A = total landscape area (ha)

Chapter 5: Carolina Bay Prioritization

Natural resource management requires site selection as an initial consideration. Carolina bays, as a natural resource, exist in large numbers across the southeastern coastal plain particularly in North and South Carolina. When a large number of natural resources exist, there is a need for site evaluation to identify possible project sites (Strager et al. 2011). Large numbers of potential sites renders individual site evaluation by personnel expensive, time consuming, and in some cases impossible. There exists a need to use widely available data to remotely evaluate sites at a landscape level to direct personnel with limited funding to individual sites that contain attributes necessary to perform the functions being mitigated. However, despite widely available data, the decision process suffers from the inability to effectively analyze, integrate, query, and synthesize the data (Korschgen et al. 2005). Remote sensing based approaches to natural resource management (i.e. approaches using satellite imagery and aerial photographs) should be used as rapid assessment tools to identify remnant areas that may contain a significant biodiversity of native organisms, identify sites where restoration or enhancement can be best recommended, or to identify critical gaps in the distribution where priorities should be placed (Porej et al. 2004). To make appropriate decisions, natural resources should be prioritized in relation to each other. Prioritization involves scoring, weighting, and summing attributes for each natural resource. The Analytic Hierarchy Process has been used in the literature to derive weights for resource allocation that are used to derive priorities.

Analytic Hierarchy Process

The Analytic Hierarchy Process (AHP) was developed by Saaty (1980) to provide an objective framework for analyzing complex decisions. This process is a non-statistical mathematical technique that utilizes matrix algebra with expert opinion to produce the participant's relative preference of an attribute over another (Duke and Aull-Hyde 2002; Herath 2004). Ramanathan (2006) describes the AHP as a four-step process encompassing structuring the decision problem, making pair-wise comparisons, calculating local weights and consistency of comparisons, and aggregating these weights if multiple participants are used.

Hierarchy

Structuring the decision problem builds the hierarchy needed for AHP analysis. A hierarchy is a simple structure used to represent the simplest type of functional (contextual or semantic) dependence of one level or component of a system on another in a sequential manner (Saaty 1987). Hierarchies are based on the question being addressed and the relationships of the levels needed to answer the question. A major advantage of the AHP is that during hierarchy development, background research is coupled with expert opinion (Mardle et al. 2004). As the base of the AHP, the hierarchy allows users to define their relative importance for each attribute to derive a solution based on their personal expertise (Duke and Aull-Hyde 2002).

Pair-wise comparison

Pair-wise comparisons aim to elicit preferences by comparing criteria in pairs (Mardle et al. 2004). These comparisons form a matrix that has specific properties that make it particularly useful in decision making. Duke and Aull-Hyde (2002) discuss these properties as reciprocity, homogeneity, independence, and expectations. Collectively, these properties allow the user to calculate weights and a consistency ratio.

The most common method to mine information from matrixes with the AHP is the eigenvalue method (EM). The EM was developed in order to synthesize a pair-wise comparison matrix and to obtain a priority weight vector for several decision criteria and alternatives (Saaty 1980; Sekitani and Yamaki 1999). This weight vector represents the participant's relative importance for a set of criteria. However, when comparing more than two objects, there exists a natural potential for intransitivity to exist (Mardle et al. 2004). The consistency ratio was developed to measure coherence within each matrix compared to an equal number of random judgments (Ananda and Herath 2003; Saaty 1980). Typically, values of 10% or less are assumed to represent acceptable matrices to be used in AHP (Ananda and Herath 2003; Herath 2004). When multiple individuals participate in the AHP, aggregation methods have been proposed to elicit weights from the entire population.

Aggregation of weights

Group decision making involves weighted aggregation of different individual preferences to obtain a single collective preference (Ramanathan and Ganesh 1994). Forman and Peniwati (1998) propose that users of AHP should consider whether the group is a synergistic unit or a collection of independently acting individuals and how to appropriately aggregate the priority weights. Often in complex decision making, such as natural resource management, participants are from many agencies or stakeholder groups and have different objectives for the proposed project. In these situations, Escobar et al. (2004) suggest that each group member is acting independently and that their individual weights can be averaged. Although both the geometric mean and arithmetic mean have been used to aggregate weights, the geometric mean is less affected by extreme deviation between members than the arithmetic mean (Aull-Hyde et al. 2006; Ramanathan and Ganesh 1994). Once all weights have been determined, a composite weight for each criterion can be determined by aggregating all weights over the hierarchy (Lai et al. 2002). These criteria weights represent those used to sum the criteria to obtain a priority.

Objective

The objective of this analysis is to produce a remotely sensed prioritization method for rapid assessment of Carolina bays for their simultaneous suitability for mitigation and herpetofaunal persistence. Specifically, this analysis is being conducted to identify Carolina bays that contain the best available conditions from a herpetofaunal perspective such that herpetofaunal diversity and persistence are promoted after a mitigation project. To meet the objective, herpetofaunal and mitigation attributes previously defined and attributed to each inventoried Carolina bay will be analyzed with the AHP via expert opinion.

Methodology

The methodology for this project will utilize expert opinion, AHP, and criteria scores to develop a priority classification for the Carolina bays. To perform this task, a hierarchy will be established, stakeholders identified, a survey produced to elicit stakeholder preferences, and scoring of attributes. This product represents a remotely sensed rapid assessment tool that can be used to identify priority areas to direct staff for field reconnaissance.

<u>Hierarchy</u>

To meet the objective of this analysis, the hierarchy presented in Figure 26 was developed. This hierarchy demonstrates the tiered relationship between achieving a priority ranking for an individual Carolina bay and the pre-identified attributes used for describing the condition of the Carolina bays from a herpetofaunal perspective. The priority of any given Carolina bay to contribute to herpetofaunal diversity through wetland mitigation depends directly on two criteria, ecological and mitigation qualities. Ecological qualities represent collectively, those attributes that have been measured specifically for herpetofaunal consideration while mitigation qualities represent those attributes measured for mitigation purpose. This hierarchy, while depicting the relationship to produce a priority, does not identify the relative importance of each attribute for contributing to the criteria.

Stakeholder participation

One of the key problems associated with natural resource management, particularly those focusing on herpetofauna, is a lack of or inability to use empirical species models. It has been well documented in the literature that although herpetofaunal environmental needs vary drastically from species to species, generalizations can be made to encompass the entire herpetofauna. To effectively deal with the lack of empirical species models, expert knowledge may be used (Store and Kangas 2001). Stakeholders for this analysis are defined as individuals working in local (i.e. county), state, and regional organizations that are dedicated to understanding and protecting the natural history of the study region that have expertise as a practitioner of the subject material. These organizations have been defined as The Nature Conservancy, Environmental Protection Agency, United States Fish and Wildlife Service, North Carolina Ecosystem Enhancement Program, North Carolina Natural Heritage Program, North Carolina Department of Environment and Natural Resources, North Carolina Wildlife Resources Commission, Bladen and Sampson County Government, and the Cape Fear Arch Conservation Collaboration.

To effectively elicit participant weights in the absence of holding a group meeting, a survey was developed to collect individual preferences. This survey (Appendix D) has been developed to collect only information on the participant’s expertise and relative preference for attributes through a series of pair-wise comparisons covering all possible combinations under Figure 26. A total of 35 stakeholders were identified from the pool of organizations identified and were provided a copy of Appendix D.

Analytic hierarchy process

Stakeholder information obtained from the surveys was analyzed with methods developed for the AHP. Each returned survey was labeled with the stakeholder's expertise and corresponding preferences were placed into either an ecological or mitigation matrix with corresponding attributes (Appendix D). Criteria for matrix inclusion are presented in Table 9. These criteria were created to ensure the proper grouping of individuals to elicit attribute weights. It is assumed for this analysis that no 'super' stakeholder exists that can contribute unbiased preferences for both herpetofaunal ecology and mitigation needs. For this reason, the relative weights for each criterion have been determined *a priori* to be 50%. Once matrixes were derived the Analytic Hierarchy Process Decision Support Tool 1.1 for ArcGIS (Marinoni 2009) was used to calculate individual eigenvalues, or weights, and Consistency Ratios using the eigenvector method proposed by Saaty (1980).

The aggregation of individual priorities method (Escobar et al. 2004) has been chosen to derive group preferences (i.e. weights) for each attribute. This method assumes that each individual is acting independently and has equal importance in the process. The individual weights are averaged using the arithmetic mean across all participating individuals to obtain the group consensus on the weights. To obtain the weights of each attribute towards the overall priority score, each attribute weight was multiplied by the criteria weight (0.5).

Scaling and scoring

To obtain priority values for the Carolina bays, a weighted linear combination procedure described by Holzmueller et al. 2011 is prescribed (Equation 5). This function is an additive technique whose product is the weighted sum across all attributes. However, this function is ineffective if attribute scores are not comparable. Data, particularly those measuring ecological and anthropogenic phenomena, are non-comparable in their raw form because of the scale they are measured at and the units being used. To properly use these data in an additive function, they should be scaled in such a manner that natural groupings within the data can be identified and assigned a score.

The Gaussian distribution (Figure 27) is one of the most common data distributions in nature (Gauch and Chase 1974). This distribution has several properties that make it suitable for re-scaling and scoring raw data, most notably the symmetric bell shaped curve with data distributed evenly around the mean and the percentage of data points that fall within each standard deviation. Raw datasets typically exhibit skew, a property that exists when extreme values affect the mean, and can be normalized by data transformations. Each raw attribute was tested for normality using exploratory data analysis in PASW 18 (Norusis 2010) and transformed to a normally distributed dataset.

Explicit simplification of biological data is the goal in the use of indices for resource management (Gerritsen 1995). Scoring of attributes is a process used to reduce the variability of datasets by assigning unique values to groups of data points sharing similar properties. Individual attributes will have their transformed raw value scaled into a numerical index score (Table 10) that can then be aggregated to a priority score (Linn et al. 2006; Charles et al. 2000). Z-scores standardize data by constraining the mean of the data to zero and forcing values to standard deviation location around the mean, while not influencing the shape of the distribution. Each normally distributed attribute was re-scaled by assigning Z-scores (Equation6) with the direction of data importance (Figure 27; Table 11). Priority values (Figure 27) were assigned to the procedure output using the prescribed normality test and Z-score process. Table 14 presents the priority classes and number of Carolina bays within each class per county.

Results

Results for the AHP are presented in Table 12. Overall, there were eight participants that completed the survey. Of these eight participants, five had acceptable levels of inconsistency according to Ananda and Herath 2003 and Herath 2004in the pair-wise comparisons (< 0.10), two with moderate inconsistency (< 0.16), and one with extreme inconsistency (> 0.20). The latter two inconsistency thresholds were chosen from the distribution of the inconsistencies among the participants (Table 12). Data transformation methods used to force the data to approximate normality are presented in Table 13. All attributes were normalized except diversity and swine lagoon count. Diversity was distributed approximately normal in its raw format and data transformations were found to not change the skew. Swine lagoon count was distributed with a high positive skew, but contained to few observations to normalize. All of the Carolina bays ranked as high priority for preservation (33) are within Bladen County, as are the majority of bays ranked as high priority for restoration. Sampson County contains most of the Carolina bays rated as low priority. Figures 28 and 29 depict the spatial distribution of prioritized Carolina bays in Bladen and Sampson Counties, respectively. Average raw values of each criterion and priority Z-scores for the priority classes are presented in Table 15.

Conclusion

This analysis has produced a six class prioritization scheme for the current conditions of the Carolina bays. The classification scheme was adapted to base classes on current Carolina bay condition. The highest of these classes (Table 6) represent Carolina bays that exhibit above average suitability for both herpetofauna and mitigation while the lowest classes represent those sites that have been degraded by anthropogenic modification. The classification was chosen such that if a Carolina bay contained perfect suitability for one criterion and no suitability for the other, it would receive a priority score at the average. Further, the scores were constrained to fall between a value of 0 (no suitability) and 10 (perfect condition) by the ordinal scale of the attributes (Table 2).

The AHP results suggest that for the group comparing ecological attributes, cohesion was rated as the most important (0.1189) while percent pine (0.0155) was viewed as least important when identifying Carolina bays important for herpetofauna (Table 4). On the other hand, the group comparing mitigation attributes rated bay area (0.1363) most important and swine lagoon count (0.0676) least important when identifying Carolina bays for mitigation (Table 4). Escobar et al. (2004) describe aggregated weights as acceptable and achieving a consistency at least as consistent as the participant with the most inconsistent judgments (highest CR values). The weights elicited are at least 84% consistent for the mitigation group and 89% consistent for the ecological group.

Data representing average values of each attribute per priority class are presented in Table 15 and conform to the literature and expectations for this analysis. Agricultural Edge initially increases from the highest priority to the next highest value, but then begins to decrease. This trend can best be explained by the average values for the attributes describing the road network. For both Road Edge and Density, it can be seen that there are increases with decreasing priority classes. Road networks represent human development and areas with dense networks (i.e. fragmented by major roads and contain dense concentrations per Ha) most likely represent developments around towns and cities in the region. The most alarming statistic reported is the drastic decrease in Carolina Bay Area with decreasing priority value. It has been documented in the literature that small wetlands, particularly those with small Carolina bays, are not expendable and are critically important for pond breeding amphibians (Semlitsch and Bodie 1998).Further, values for the attributes measuring the natural landcover within each Carolina bay landscape (Percent Pine, Patch Cohesion and Diversity) all decrease with decreasing priority values. These trends suggest that as humans alter the landscape, the dominant vegetation cover (Pine) becomes increasingly scarce and the remaining habitats become homogenous and disconnected. Data produced by the NC NHP (BWHA) and NC DCM (restorability) also decrease with decreasing priority values, nearly 100% between the highest and lowest priorities. These results suggest that these datasets, even though not produced directly for isolated wetlands or herpetofauna, contribute significantly to the analysis and should not be overlooked. The data suggest that the highest priority Carolina bays exist in the least altered condition and have the most natural landscape while the lowest priority Carolina bays are the most altered and exist within an anthropogenic dominated landscape. These trends agree with findings produced by the South Carolina Department of Natural Resources (1999) in that the smallest bays inventoried exist in the most imperiled conditions.

Carolina bays exhibiting a high degree of suitability for herpetofauna (Figure 27 ecological criteria) and mitigation potential (mitigation criteria) are those areas that have been less affected by anthropogenic modification of the landscape and exist in a relatively pristine condition. These bays are those that should be approached from a mitigation standpoint for conservation and preservation. A review of Figure 28 indicates that most of these bays occur on interfluves of the Cape Fear River Floodplain in southeastern Bladen County. This area has been spared significant conversion to farmland because of its unique geography. The area is at the confluence of two rivers, the Cape Fear and Black, and serves as the flood plain for both. This unique geography has created frequent flooding and deep layers of peat that cannot be easily drained for agricultural purposes. The second highest classification is used to focus priority on

Carolina bays that should be restored. These bays have been slightly degraded and are primarily located in six distinct patches. Figure 28 depicts the high priority for restoration bays of Bladen county existing in the Cape Fear River Floodplain, the northwestern corner, south central area, and a narrow strip located near the southeastern corner (Surry Scarp). Figure 29 depicts two areas in Sampson County, one in the north central portion of the county and another along the Black River delineating the southern portion of the county. The lowest classes of Carolina bay priority represent those areas that have been degraded by large-scale anthropogenic modification.

The results of this analysis are expected and conform to what is reported in the literature. LeBlond (2007) reported the significant natural heritage areas of Bladen and Sampson Counties found by the Natural Heritage Program. These areas are primarily areas in and around the floodplains of the Black and Cape Fear Rivers. Hall et al. (1999) identified the Cape Fear River Floodplain and Surry Scarp (Leab 1990) as high priority areas in Bladen County that contain unaltered native vegetative communities that can function to provide possible links between the significant natural heritage areas of the NC southeastern coastal plain. The highest priority classes of this analysis coincide with these areas. Further, South Carolina Department of Natural Resources (1999) found a low percentage of high priority bays in their analysis. This analysis has indicated that of the 1,863 bays in Bladen and Sampson Counties, approximately 17% are rated as high priority. The high proportion of low priority Carolina bays in Sampson county can be attributed to the large scale agricultural conversion experienced during the last century (Brandon 1985). Sampson County is one of the largest agricultural producing counties in North Carolina and as a result many of the Carolina bays within this county have been destroyed and subsequently lost from the landscape or the landscape has been degraded to a point that it does not contain the conditions required for herpetofaunal persistence and mitigation opportunity simultaneously.

Figure 26: Carolina bay prioritization hierarchy. Carolina Bay Priority Value is a summation of each attribute across the global weights.

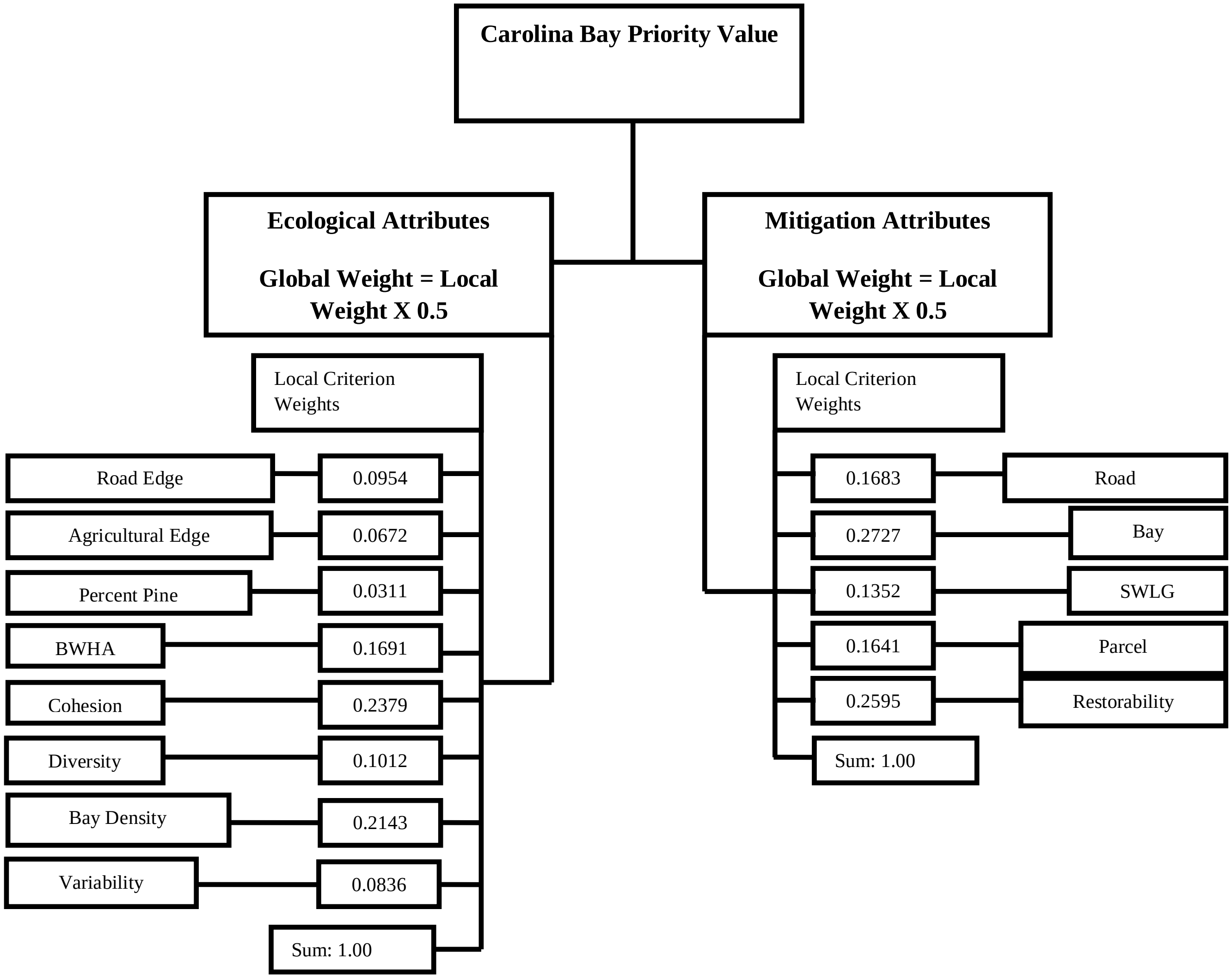
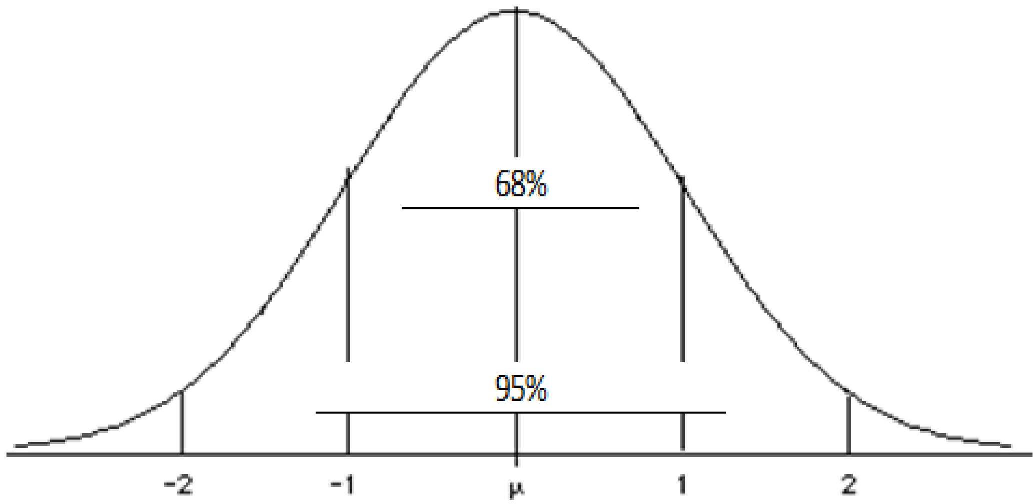


Figure 27: Gaussian distribution depicting Z-score location (x-axis) in relation to the mean (μ). Columns below x-axis depict the numerical scale used to categorize data.



Normal Scoring

1	3	5	7	9	10

Reverse Scoring

10	9	7	5	3	1

Priority Classes

1	2	3	4	5	6

Figure 28: Distribution of prioritized Carolina bays in Bladen County, NC.

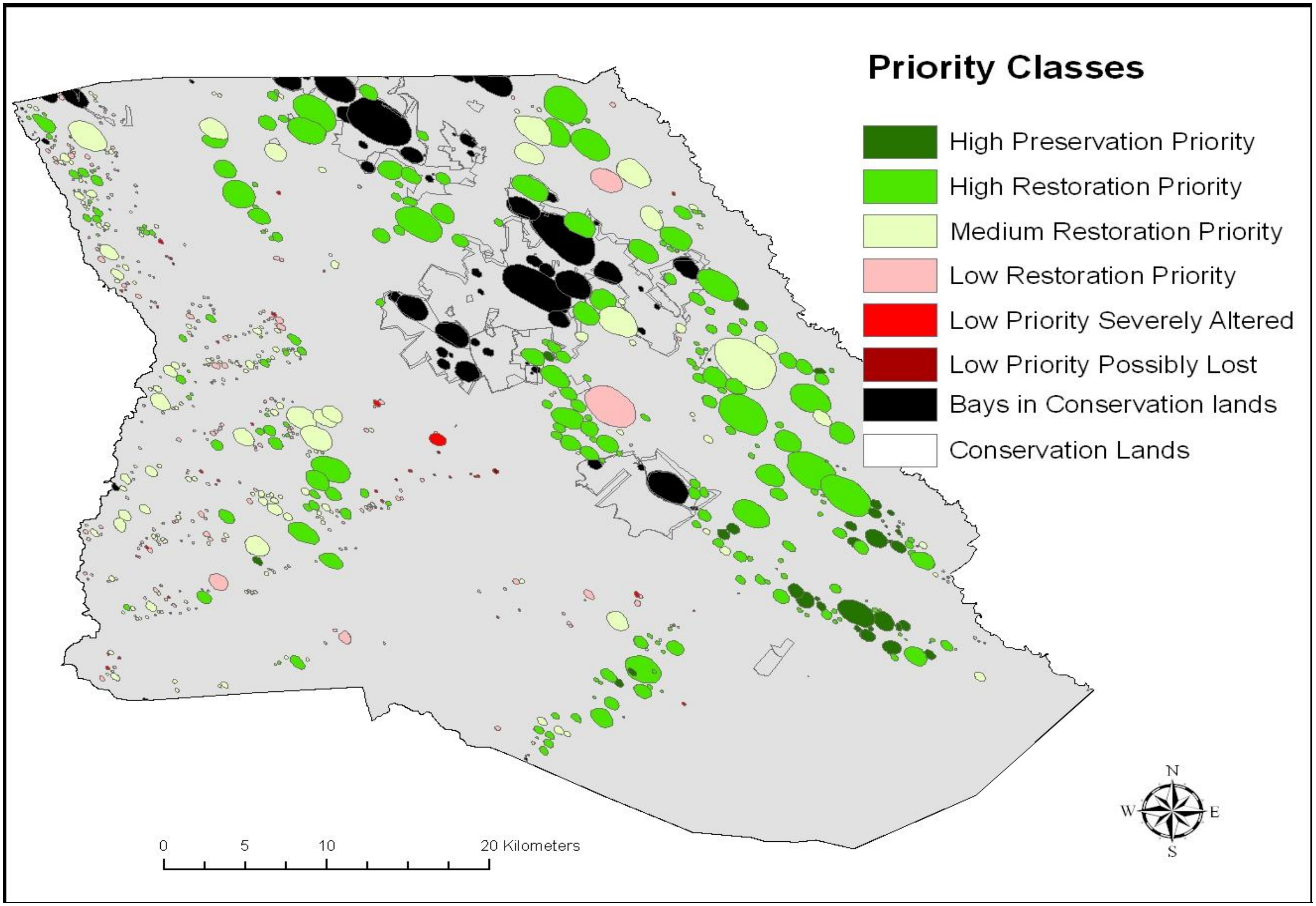


Figure 29: Distribution of prioritized Carolina bays in Sampson County, NC.

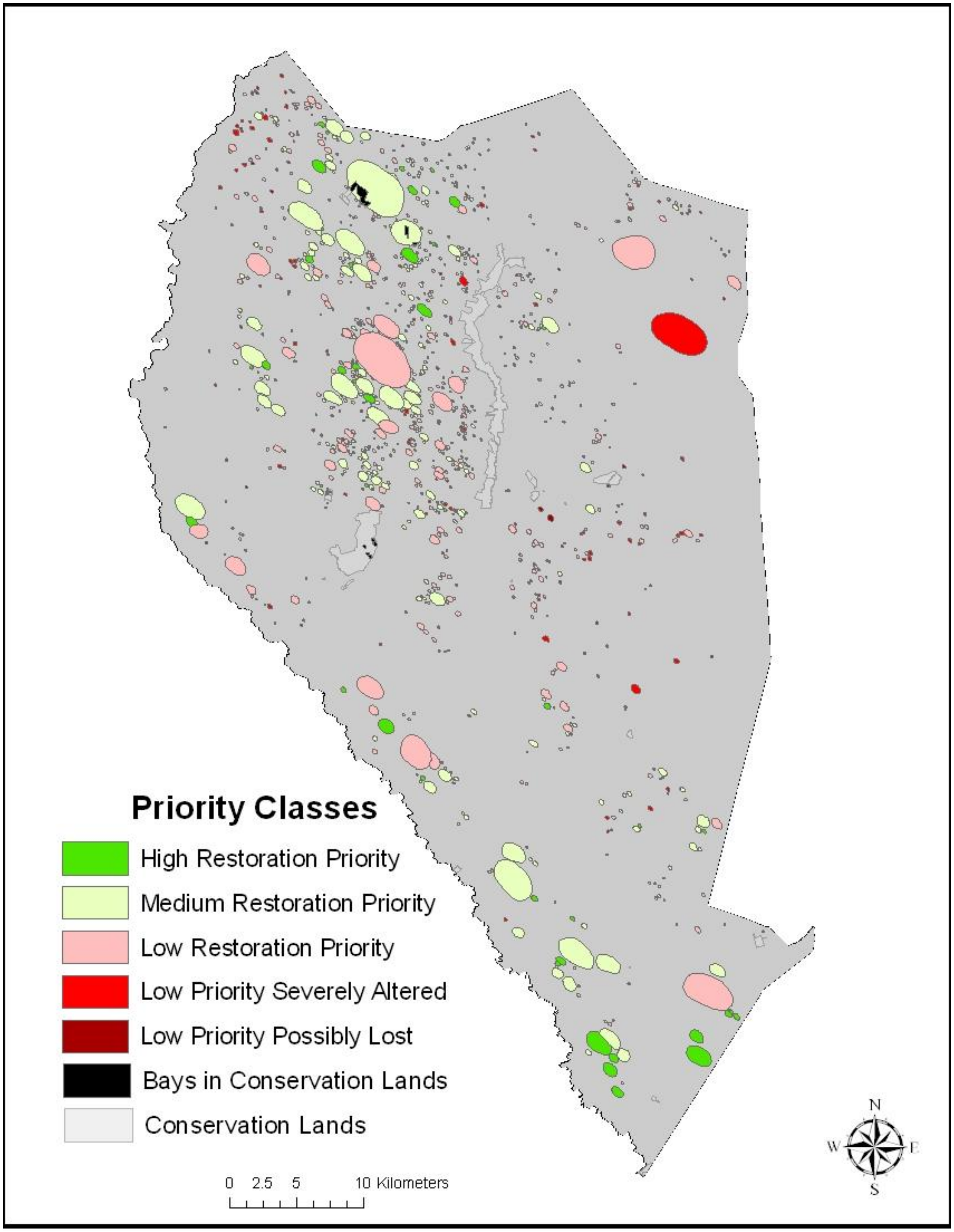


Table 9: Participant matrix inclusion rules.

Expertise	Matrix Inclusion
Ecologist	Ecological
Herpetologist	Ecological
Landscape Ecologist	Mitigation
Planner	Mitigation
Wetland Ecologist	Ecological
Natural Resource Manager	Mitigation
Other	Either depending upon consistency ratio

Table 10: Numerical index scores used to scale transformed data.

Score	Description
0	True zero; no data present
1	Sites representing the worst condition and containing 2.4% of data
3	Sites representing up to 13.6% of values above the worst condition
5	Sites containing scores up to 34% below the mean
7	Sites containing scores up to 34% above the mean
9	Sites representing 13.6% of values below the best condition
10	Sites representing the best condition and containing 2.4% of data

Table 11: Direction of Scoring for each attribute.

Attribute	Scoring
Road Edge	Reverse
Agricultural Edge	Reverse
Percent Pine	Normal
BWHA	Normal
Cohesion	Normal
Diversity	Normal
Bay Density	Normal
Variability	Normal
Road Density	Reverse
Bay Area	Normal
Swine Lagoon	Reverse
Restorability	Normal

Table 12: Analytic Hierarchy Process determined weights for ecological (top) and mitigation (bottom) attributes.

Participant	Expertise	Road Edge	Agricultural Edge	Percent Pine	BWHA	Cohesion	Diversity	Bay Density	Variability	CR
1	Wetland Ecologist*	0.0333	0.1166	0.0503	0.3972	0.2288	0.0448	0.0952	0.0338	0.3816
2	Ecologist	0.0245	0.0182	0.0207	0.1337	0.2665	0.1288	0.2935	0.1141	0.0487
3	Ecologist	0.0142	0.0286	0.0492	0.2555	0.2031	0.1123	0.228	0.1091	0.1136
4	Landscape Ecologist	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
5	Other**	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.2193
6	Herpetologist	0.2475	0.1549	0.0234	0.1182	0.2442	0.0625	0.1215	0.0278	0
7	Natural Resource Manager	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
8	Natural Resource Manager	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Group Weights***		0.0477	0.0336	0.0155	0.0845	0.1189	0.0506	0.1071	0.0418	

Continued on next page

Table 12 Continued

Participant	Expertise	Road Density	Bay Area	SWLG	Parcel Count	Restorability	CR
1	Wetland Ecologist*	N/A	N/A	N/A	N/A	N/A	N/A
2	Ecologist	N/A	N/A	N/A	N/A	N/A	N/A
3	Ecologist	N/A	N/A	N/A	N/A	N/A	N/A
4	Landscape Ecologist	0.1869	0.1869	0.3065	0.1244	0.1953	0.078
5	Other**	0.1737	0.5676	0.048	0.0314	0.1793	0.1564
6	Herpetologist	N/A	N/A	N/A	N/A	N/A	N/A
7	Natural Resource Manager	0.2552	0.2321	0.1515	0.0993	0.2618	0.1664
8	Natural Resource Manager	0.0575	0.1043	0.035	0.4016	0.4016	0
	Group Weights***	0.0841	0.1363	0.0676	0.082	0.1297	

*CI Ratio drastically exceeds 0.10 inconsistency threshold and results are discarded

**CI Ratios indicate participant makes more consistent choices with mitigation attributes

***Group weights are determined by averaging the attribute column and multiplying the product by 0.50

Table 13: Transformation used to normalize each attribute.

Attribute	Raw Data Statistics: Mean	Raw Data Statistics: Standard Deviation	Raw Data Statistics: Skew	Transformation	Normalized Standard Data Statistics*: Mean	Normalized Standard Data Statistics*: Standard Deviation	Normalized Standard Data Statistics*: Skew
Road Edge	18.307	11.59	0.311	Square Root	0.0247	1.075	-0.678
Agricultural Edge	9.425	5.157	0.558	Square Root	-0.007	1.008	-0.250
Percent Pine	19.007	15.707	1.502	Cubic root	-0.002	1.005	0.009
BWHA	29.489	30.901	1.337	Cubic root	-0.019	1.002	0.328
Cohesion	0.836	0.143	-2.396	Cube Root of Cosine	-0.194	1.001	1.017
Diversity**	0.649	0.199	-0.873	N/A	0.016	1.001	-0.873
Bay Density	0.016	0.010	0.721	Square Root	-0.029	1.000	0.104
Variability	1.477	4.367	4.545	Log 10	-0.028	1.038	-0.161
Road Density	3.629	3.021	1.851	Inverted Cubic Root	0.479	0.849	-0.144
Bay Area	23.819	79.601	8.161	Inverted Cubic Root	0.000	0.999	-0.279
SWLG***	1.618	1.221	3.342	N/A	-0.407	0.715	3.342
Parcel Count	6.494	27.127	25.323	Inverted Cubic Root	0.000	0.999	-0.067
Restorability	59.372	27.121	-0.303	Inverted Cubic Root	0.000	0.999	-0.306

*Data represents Z-score distribution and approximate normality, a perfectly normal Z-distribution has $\mu = 0$, $\sigma = 1$, and skew = 0

** Datum was approximately normally distributed in raw format

** *Dataset contained too few observations to normalize, raw data was used

Table 14: Carolina bay priority classes by county.

Priority Score and Label	Bladen	Sampson	Total	% Total
High Preservation Priority (6)	33	0	33	1.771337
High Restoration Priority (5)	230	56	286	15.35158
Medium Restoration Priority (4)	271	327	598	32.09877
Low Restoration Priority (3)	180	466	646	34.67525
Low Mitigation Priority: Severely Altered (2)	48	211	259	13.90231
Low Mitigation Priority: Possibly Lost (1)	7	34	41	2.200751
Total	769	1094	1863	100

Table 15: Average raw attribute values per priority class.

	High Preservation (6)	High Restoration (5)	Medium Restoration (4)	Low Restoration (3)	Low Severely Altered (2)	Low Possibly Lost (1)
Agricultural Edge (%)	5.558	10.242	10.310	8.833	6.625	5.207
Road Edge (%)	0.000	1.635	3.792	4.327	6.121	8.397
Percent Pine (%)	30.173	30.090	20.666	14.923	11.207	6.022
BWHA RATED (%)	98.388	73.857	28.642	13.817	7.343	3.272
Patch Cohesion (Unitless)	0.977	0.938	0.875	0.802	0.716	0.663
Patch Diversity (Unitless)	0.853	0.789	0.682	0.591	0.540	0.583
Carolina Bay Density (number/100 Ha)	1.302	1.275	1.845	1.702	1.311	0.675
Carolina Bay Variability (Unitless)	10749.549	30272.466	17455.949	8940.867	3772.353	9345.932
Carolina Bay Area (Ha)	45.794	58.855	25.100	14.010	6.966	2.746
Road Density (m/100 Ha)	0.000	5.356	38.656	123.881	223.864	460.650
Swine Lagoon Count (Unitless)	0.000	0.108	0.184	0.193	0.104	0.293
Parcel Count (Unitless)	1.606	4.633	6.701	7.406	5.737	10.317
Restorability (%)	96.875	87.673	61.343	35.773	17.553	6.827
Priority Z (Unitless)	2.159	1.445	0.440	-0.456	-1.381	-2.330

Equation 5: Weighted Linear Combination Procedure (Holzmueller et al. 2011).

$$P = \sum_{i=1}^{I} WiXi$$

Where P = Priority score, W = weight of

attribute *i*, and X = score of attribute *i*.

Equation 6: Z-Score

$$Z = \frac{X - \mu}{\sigma}$$

Where Z = Z-score, X = transformed raw data score, μ = transformed attribute mean, and σ = transformed attribute standard deviation

Chapter 6: Discussion

The results of this project are expected to assist the states of North Carolina and South Carolina with understanding Carolina bay degradation from a herpetofaunal perspective. Currently, North Carolina offers some protection to isolated wetlands while those in South Carolina fall into federal jurisdiction under the Clean Water Act that has undergone radical amendments in the last decade. Much of the current literature on Carolina bays focuses on the vegetation-soil-hydrology relationships of a single bay or small group of proximal bays. This project is designed to capture this information and apply it to a pattern analysis and strategic conservation plan of Bladen and Sampson counties. Currently, the area contains perhaps the largest tract of protected land containing Carolina bays. The findings of this project would identify patterns of isolation, connectivity, and vegetation thereby providing an objective direction of management efforts in mitigation and restoration areas. The direct contributions of this project to the overall Carolina bay literature include: a generalizable method to quantitatively identify bays that should be protected and those that have the best chances for successful restoration, a prescribed strategic conservation plan addressing the habitats that would need to be protected to have a connected network, and finally an understanding of human alteration patterns of the bays. Further, an understanding of pattern dynamics would allow for conservation efforts to be developed that could potentially be used by NCEEP. Currently, there are no published pattern recognitions of the Carolina bays and management decisions are conducted on a site by site basis. An understanding of Carolina bay patterns and interactions as elements with the surrounding landscape would allow for immediate consideration of Carolina bays or other priority areas in other regions where management priorities may be immanently needed. This can be accomplished because the methodology was designed to use widely available data coupled with known locations of priority areas in such a way that it can be actively applied in other areas.

The purpose of this thesis has been to produce a classification of Carolina bay mitigation priority in Bladen and Sampson Counties, NC from both herpetofaunal perspectives and mitigation suitability. The results of this thesis are expected to assist agencies responsible for protecting isolated wetlands by providing a methodology to inventory Carolina bays that is rapid, uses the best available data, and directs limited resources to the most suitable areas. Currently, North Carolina has no known peer reviewed publicly available inventory devoted to the Carolina bays while South Carolina has digitized centroids representing Carolina bays in the best condition (South Carolina Department of Natural Resources 1999). Studies of the distribution and geography of the bays was predominant in the early to mid-1900s. These studies provided valuable knowledge of the bays, but no publicly available datasets. Much of the current literature on Carolina bays focuses on the ecology and hydrology of the bays. The study region has specific qualities that make it particularly beneficial for classification of Carolina bay priorities.

Currently, the study region contains perhaps the largest tract of protected land containing Carolina bays. The product of this analysis prioritizes Carolina bays and provides a base layer for direction of management efforts in conservation and restoration of Carolina bays. The direct contributions of this analysis to the overall Carolina bay literature include a generalizable method to remotely identify Carolina bays. A prioritization of Carolina bays would allow for immediate consideration of Carolina bays in the study region, or in other regions containing isolated wetlands where management priorities may be urgently needed. This can be accomplished because the methodology was designed to use widely available data coupled with known isolated wetland-containing regions.

Limitations to this study include the accuracy and temporal component of the data, the spatial representation of the inventoried Carolina bays, stakeholder consistency and participation, and the scoring method. The base data being used for the initial representation of Carolina bay locations is subjective and was hand digitized. National Wetlands Inventory for North Carolina was produced using early 1980's aerial photography (USFWS 1999). Topographic maps were produced from 1980's era aerial photography and 30 meter DEM. (1999). These datasets are older and less accurate than the NCFMP 6.1 meter (20 foot) LiDAR DEM. These temporal and accuracy limitations associated with the best available data force subjective decisions during the verification process. The polygons representing Carolina bays from Howard (2007) may not line up exactly with topographic maps or LiDAR DEM's and must be moved to conform to the respective boundaries. These limitations allow that the bays delineated on USGS topographic maps may not line up with bays delineated from the LiDAR DEM and vice versa. These limitations are present in the final layer despite data verification efforts. Further, the analysis does not use nor contribute to ground based surveys. Field based surveys would identify the accuracy of the Carolina bay inventory. It is plausible that a few of the identified bays after reduction are not bays, but cannot be identified as bays without field verification and that there are bays within the study region that remain unmapped. Despite ongoing efforts to identify and map Carolina bays and other topographic depressions by automated processes, it is beyond the scope of this analysis to contribute to the ongoing efforts. Such efforts must be intensively tested and results verified before being implemented to create such an inventory. However, despite the various limitations with the data and final product, the methodology utilizes the best available information existing that can be assimilated into a meaningful way for resource managers.

While 35 stakeholders were targeted for participation in this thesis, only 8 responded. The low number of participants creates a biased estimate of the weightings that may change if more stakeholders participated. Further, of the participants surveyed, 3 had elevated levels of inconsistency (i.e. CR > 0.10), but were included due to lack of statistical information on stakeholder preference for herpetofauna and isolated wetlands. Despite these limitations, the results conform to published reports conducted by agencies in North and South Carolina for the Carolina bays. However, the results could be statistically confirmed via a sensitivity analysis measuring how the weightings change with attribute exclusions. Such an analysis would ultimately require more participants and a determination of a statistically meaningful participation rate.

Cluster analysis is a set of statistical techniques used in the literature to mathematically determine break points for assigning classes to data. These techniques include principle components analysis and k-means clustering, to name a few, and have appeared extensively in the literature pertaining to natural resource classification. However, many of these methods are multivariate and are based on ordination space of the datasets. These methods are not appropriate for this thesis as it has been designed to classify prioritization ranking from expert opinion using current conditions of the Carolina bays. Few examples exist in the literature for univariate cluster analysis, such as the z-score classification process used for this thesis.

Future research should expand on this thesis by using developing geomorphology techniques to reduce user subjectivity when identifying topographic depressions, identifying methods to integrate herpetofaunal indicator species into the objective, and determining statistical procedures to understand how many participants are significant and how to cluster univariate data. By expanding these areas, this research can be strengthened and used to identify high priority areas that have specific benefits for local ecosystems as a whole.

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Appendix A: University and Medical Center Institutional Review Board Approval Letter.

EAST CAROLINA UNIVERSITY
University & Medical Center Institutional Review Board Office
1L-09 Brody Medical Sciences Building• 600 Moye Boulevard • Greenville, NC 27834
Office 252-744-2914 • Fax 252-744-2284 • www.ecu.edu/irb

Date: March 4, 2011

Principal Investigator: James Edwards, Student
Dept./Ctr./Institute: Dept. of Geography
Mailstop or Address: Brewster A-227, ECU

RE: **Exempt Certification** KK
UMCIRB# **11-0155**
Funding Source: Unfunded

Title: "Management Prioritization of Carolina Bays from a Herpetofaunal Perspective"

Dear Mr. Edwards:

On 3.3.11, the University & Medical Center Institutional Review Board (UMCIRB) determined that your research meets ECU requirements and federal exemption criterion #2 which includes research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures or observation of public behavior, unless: information obtained is recorded in such a manner that human subjects can be identified, directly or through identifiers linked to the subjects and any disclosure of the human subjects' responses outside the research could reasonably place the subjects at risk of criminal or civil liability or be damaging to the subjects' financial standing, employability, or reputation.

It is your responsibility to ensure that this research is conducted in the manner reported in your Internal Processing Form and Protocol, as well as being consistent with the ethical principles of the Belmont Report and your profession.

This research study does not require any additional interaction with the UMCIRB unless there are proposed changes to this study. Any change, prior to implementing that change, must be submitted to the UMCIRB for review and approval. The UMCIRB will determine if the change impacts the eligibility of the research for exempt status. If more substantive review is required, you will be notified within five business days.

The UMCIRB Office will hold your exemption application for a period of five years from the date of this letter. If you wish to continue this protocol beyond this period, you will need to submit an Exemption Certification Request at least 30 days before the end of the five year period.

Sincerely,

Chairperson, University & Medical Center Institutional Review Board

Pc: Dr. Dan Marcucci

Appendix B: Bladen County Soil Properties

Map Unit	Soil name	Family or Higher Taxonomic Classification	Order	Hydric Rated
AaA	Altavista	Fine-loamy, mixed, semiactive, thermic AquicHapludults	Ultisol	Yes
At	Augusta	Fine-loamy, mixed, semiactive, thermic AericEndoaquults	Ultisol	Yes
AuA	Autryville	Loamy, siliceous, subactive, thermic ArenicPaleudults	Ultisol	No
AyB	Aycock	Fine-silty, siliceous, subactive, thermic TypicPaleudults	Ultisol	Yes
BnB	Blanton	Loamy, siliceous, subactive, thermic GrossarenicPaleudults	Ultisol	Yes
BuA	Butters	Coarse-loamy, siliceous, semiactive, thermic TypicPaleudults	Ultisol	No
By	Byars	Fine, kaolinitic, thermic UmbricPaleaquults	Ultisol	Yes
Ca	Cape Fear	Fine, mixed, semiactive, thermic TypicUmbraquults	Ultisol	Yes
Ce	Centenary	Sandy, siliceous, thermic EnticGrossarenicAlorthods	Spodosol	Yes
Ch	Chastain	Fine, mixed, semiactive, acid, thermic FluvaquenticEndoaquepts	Inceptosol	Yes
Cn	Chewacla	Fine-loamy, mixed, active, thermic FluvaquenticDystrudepts	Inceptosol	Yes
Co	Congaree	Fine-loamy, mixed, active, nonacid, thermic OxyaquicUdifluvents	Entisol	Yes
Cr	Coxville	Fine, kaolinitic, thermic TypicPaleaquults	Ultisol	Yes
CT	Croatan	Loamy, siliceous, dysic, thermic TerricHaplosaprists	Histosol	Yes

DgA	Dogue	Fine, mixed, semiactive, thermic AquicHapludults	Ultisol	Yes
DO	Dorovan	Dysic, thermic TypicHaplosaprists	Histosol	Yes
Dr	Dunbar	Fine, kaolinitic, thermic AericPaleaquults	Ultisol	Yes
DuA	Duplin	Fine, kaolinitic, thermic AquicPaleudults	Ultisol	Yes
DyF	Dystrochrepts	Dystrochrepts	Inceptosol	No
ExA	Exum	Fine-silty, siliceous, subactive, thermic AquicPaleudults	Ultisol	Yes
Fo	Foreston	Coarse-loamy, siliceous, semiactive, thermic AquicPaleudults	Ultisol	Yes
GbA	Goldsboro	Fine-loamy, siliceous, subactive, thermic AquicPaleudults	Ultisol	Yes
GdA	Goldsboro-Urban	Fine-loamy, siliceous, subactive, thermic AquicPaleudults	Ultisol	Yes
Gh	Grantham	Fine-silty, siliceous, semiactive, thermic TypicPaleaquults	Ultisol	Yes
Gm	Grifton	Fine-loamy, siliceous, semiactive, thermic TypicEndoaqualfs	Alfisol	Yes
GrB	Gritney	Fine, mixed, semiactive, thermic AquicHapludults	Ultisol	No
GrD	Gritney	Fine, mixed, semiactive, thermic AquicHapludults	Ultisol	Yes
Jh	Johns	Fine-loamy over sandy or sandy-skeletal, siliceous, semiactive, thermic AquicHapludults	Ultisol	Yes
JO	Johnston	Coarse-loamy, siliceous, active, acid, thermic CumulicHumaquepts	Inceptosol	Yes
KaA	Kalmia	Fine-loamy over sandy or sandy-skeletal, siliceous, semiactive, thermic TypicHapludults	Ultisol	No
KeA	Kenansville	Loamy, siliceous, subactive, thermic ArenicHapludults	Ultisol	No

KuB	Kureb	Thermic, uncoated SpodicQuartzipsamments	Entisol	Yes
LaB	Lakeland	Thermic, coated TypicQuartzipsamments	Entisol	Yes
LeA	Leon	Sandy, siliceous, thermic AericAlaquods	Spodosol	Yes
Ln	Lynchburg	Fine-loamy, siliceous, semiactive, thermic AericPaleaquults	Ultisol	Yes
Ly	Lynn Haven	Sandy, siliceous, thermic TypicAlaquods	Spodosol	Yes
M-W	Miscelaneous Water	NA	Not Defined	Not Defined
Na	Meggett	Fine-silty, siliceous, subactive, thermic AericPaleaquults	Ultisol	Yes
NoA	Nahunta	Fine-silty, siliceous, subactive, thermic AericPaleaquults	Ultisol	Yes
NoB	Norfolk	Fine-loamy, kaolinitic, thermic TypicKandiudults	Ultisol	Yes
NuB	Norfolk-Urban	Fine-loamy, kaolinitic, thermic TypicKandiudults	Ultisol	No
Oc	Ocilla	Loamy, siliceous, semiactive, thermic AquicArenicPaleudults	Ultisol	Yes
Pa	Pamlico	Sandy or sandy-skeletal, siliceous, dysic, thermic TerricHaplosaprists	Histosol	Yes
PC	Pamlico	Sandy or sandy-skeletal, siliceous, dysic, thermic TerricHaplosaprists	Histosol	Yes
Pe	Pantego	Fine-loamy, siliceous, semiactive, thermic UmbricPaleaquults	Ultisol	Yes
Pp	Paxville	Fine-loamy, siliceous, semiactive, thermic TypicUmbraquults	Ultisol	Yes
Pt	Portsmouth	Fine-loamy over sandy or sandy-skeletal, mixed, semiactive, thermic TypicUmbraquults	Ultisol	Yes

Ra	Stallings	Coarse-loamy, siliceous, semiactive, thermic AericPaleaquults	Ultisol	Yes
Rn	Rains	Fine-loamy, siliceous, semiactive, thermic TypicPaleaquults	Ultisol	Yes
Ro	Roanoke	Fine, mixed, semiactive, thermic TypicEndoaquults	Ultisol	Yes
St	Stallings	Coarse-loamy, siliceous, semiactive, thermic AericPaleaquults	Ultisol	Yes
To	Toisnot	Coarse-loamy, siliceous, semiactive, thermic TypicFragiaquults	Ultisol	Yes
Tr	Torhunta	Coarse-loamy, siliceous, active, acid, thermic TypicHumaquepts	Ultisol	Yes
Ud	Udorthents	Udorthents	Entisol	No
W	Water	NA	Not Defined	Not Define d
WaB	Wagram	Loamy, kaolinitic, thermic ArenicKandiudults	Ultisol	Yes
WbB	Wagram	Loamy, kaolinitic, thermic ArenicKandiudults	Ultisol	No
We	Wahee	Fine, mixed, semiactive, thermic AericEndoaquults	Ultisol	Yes
WgB	Wakulla	Siliceous, thermic PsammenticHapludults	Ultisol	No
Wh	Wasda	Fine-loamy, mixed, semiactive, acid, thermic HisticHumaquepts	Inceptosol	Yes
WmB	Wickham	Fine-loamy, mixed, semiactive, thermic TypicHapludults	Ultisol	Yes
WN	Wilbanks	Fine, mixed, semiactive, acid, thermic CumulicHumaquepts	Inceptosol	Yes
Wo	Woodington	Coarse-loamy, siliceous, semiactive, thermic TypicPaleaquults	Ultisol	Yes

Appendix C: Sampson County Soil Properties

Map Unit	Soil Name	Family or Higher Taxonomic Classification	Order	Hydric Rated
Au	Autryville	Loamy, siliceous, subactive, thermic ArenicPaleudults	Ultisol	No
AyB	Aycock	Fine-silty, siliceous, subactive, thermic TypicPaleudults	Ultisol	Yes
BH	Bibb	Coarse-loamy, siliceous, active, acid, thermic TypicFluvaquents	Entisol	Yes
BoB	Blanton	Loamy, siliceous, subactive, thermic GrossarenicPaleudults	Ultisol	Yes
CaB	Cainhoy	Thermic, coated TypicQuartzipsamments	Entisol	No
ChA	Chipley	Thermic, coated AquicQuartzipsamments	Entisol	No
Co	Coxville	Fine, kaolinitic, thermic TypicPaleaquults	Ultisol	Yes
ExA	Exum	Fine-silty, siliceous, subactive, thermic AquicPaleudults	Ultisol	Yes
FaA	Faceville	Fine, kaolinitic, thermic TypicKandiudults	Ultisol	No
FaB	Faceville	Fine, kaolinitic, thermic TypicKandiudults	Ultisol	No
Fo	Foreston	Coarse-loamy, siliceous, semiactive, thermic AquicPaleudults	Ultisol	Yes
GoA	Goldsboro	Fine-loamy, siliceous, subactive, thermic AquicPaleudults	Ultisol	Yes
Gr	Grantham	Fine-silty, siliceous, semiactive, thermic TypicPaleaquults	Ultisol	Yes

GtC	Gritney	Fine, mixed, semiactive, thermic AquicHapludults	Ultisol	Yes
Jo	Johns	Fine-loamy over sandy or sandy-skeletal, siliceous, semiactive, thermic AquicHapludults	Ultisol	Yes
JT	Johnston	Coarse-loamy, siliceous, active, acid, thermic CumulicHumaquepts	Inceptosol	Yes
KaA	Kalmia	Fine-loamy over sandy or sandy-skeletal, siliceous, semiactive, thermic TypicHapludults	Ultisol	No
LeA	Leon	Sandy, siliceous, thermic AericAlaquods	Spodosol	Yes
Lm	Lumbee	Fine-loamy over sandy or sandy-skeletal, siliceous, subactive, thermic TypicEndoaquults	Ultisol	Yes
Ln	Lynchburg	Fine-loamy, siliceous, semiactive, thermic AericPaleaquults	Ultisol	Yes
Lu	Lynchburg	Fine-loamy, siliceous, semiactive, thermic AericPaleaquults	Ultisol	No
Ly	Lynn Haven	Sandy, siliceous, thermic TypicAlaquods	Spodosol	Yes
MaC	Marvyn	Fine-loamy, kaolinitic, thermic TypicKanhapludults	Ultisol	No
Na	Nahunta	Fine-silty, siliceous, subactive, thermic AericPaleaquults	Ultisol	Yes
NoA	Norfolk	Fine-loamy, kaolinitic, thermic TypicKandiudults	Ultisol	Yes
NoB	Norfolk	Fine-loamy, kaolinitic, thermic TypicKandiudults	Ultisol	Yes
NuB	Norfolk	Fine-loamy, kaolinitic, thermic TypicKandiudults	Ultisol	Yes
OrA	Orangeburg	Fine-loamy, kaolinitic, thermic TypicKandiudults	Ultisol	No

OrB	Orangeburg	Fine-loamy, kaolinitic, thermic TypicKandiudults	Ultisol	Yes
Pm	Pamlico	Sandy or sandy-skeletal, siliceous, dysic, thermic TerricHaplosaprists	Histisol	Yes
Pn	Pantego	Fine-loamy, siliceous, semiactive, thermic UmbricPaleaquults	Ultisol	Yes
Px	Paxville	Fine-loamy, siliceous, semiactive, thermic TypicUmbraquults	Ultisol	Yes
Ra	Rains	Fine-loamy, siliceous, semiactive, thermic TypicPaleaquults	Ultisol	Yes
Ro	Roanoke	Fine, mixed, semiactive, thermic TypicEndoaquults	Ultisol	Yes
Tn	Toisnot	Coarse-loamy, siliceous, semiactive, thermic TypicFragiaquults	Ultisol	Yes
To	Tomahawk	Loamy, siliceous, semiactive, thermic AquicArenicHapludults	Ultisol	Yes
Tr	Torhunta	Coarse-loamy, siliceous, active, acid, thermic TypicHumaquepts	Inceptosol	Yes
UD	Udorthents	Udorthents	Inceptosol	No
W	Not Defined	Not Defined	Not Defined	Not Defined
WaB	Wagram	Loamy, kaolinitic, thermic ArenicKandiudults	Ultisol	Yes
Wo	Woodington	Coarse-loamy, siliceous, semiactive, thermic TypicPaleaquults	Ultisol	Yes

Appendix D: Participant Analytic Hierarchy Process Survey.

CONSENT DISCLOSURE

You are being invited to participate in a research study "Management Prioritization of Carolina Bays from Herpetofaunal Perspectives" being conducted by James Edwards, a student at East Carolina University in the Department of Geography. You are being asked to submit your opinion as an expert and stakeholder on the relative pair-wise importance of a set of attributes. Your participation in the research is voluntary. You may choose not to answer any or all questions, and you may stop at any time. There would be no penalty for not taking part in this research study. It is hoped that your information will assist us to better understand how stakeholders value the environmental needs of herpetofauna when making mitigation decisions. Please email the principal investigator at Edwardsj03@students.ecu.edu or call 252-328-5197 for any research related questions or the UMCIRB at 252-744-2914 for questions about your rights as a research participant.

Dear Participant:

The project has been designed to identify Carolina bays that contain the best available attributes to promote herpetofaunal persistence and diversity in a predominantly agricultural landscape. Carolina bays contain isolated depressional wetlands and are important as breeding sites for many species of herpetofauna, particularly amphibians. The small size of Carolina bays coupled with their geographic position causes many of these sites to fall outside of wetland regulation. Many of these bays have been altered in the last century by agricultural practices and face an uncertain future as development pressures increase. Current mitigation practices are site specific and typically overlook herpetofaunal use of isolated wetlands. The goal of this project is to weight variables relating to both herpetofaunal ecology and mitigation site selection such that individual sites can be identified as candidates for both mitigation and herpetofaunal biodiversity.

There are two primary categories of attributes that have been measured for each Carolina bay: ecological, for their overall impact on herpetofauna and mitigational, for their overall impact to mitigation opportunity. All attributes are listed under their respective heading. These attributes describe components such as isolated wetland size, nearest neighbor, remnant natural vegetation patterns, and anthropogenic disturbance. Your opinion as an expert and stakeholder within the subject area is needed to help create a weighting matrix to analyze multiple criteria. Your answers will be combined with those from other professionals to obtain the weight importance of each attribute. The goal is to survey approximately 30 individuals experienced in wetland decision making or herpetofaunal ecology from local and state organizations. These organizations include the Bladen and Sampson County Governments, North Carolina Ecosystem Enhancement Program, North Carolina Natural Heritage Program, Cape Fear Arch Conservation Collaboration, South Carolina Department of Natural Resources, and Nature Conservancy. The survey will take approximately 15 minutes to complete.

Ecological Attributes

1. *Road edge (Percent)*
    - *a.* Represents threat of direct mortality ('road kill'), behavioral modification, and gene flow restrictions
    - *b.* Only includes Interstate, US, and NC roads
2. *Agricultural edge (Percent)*
    - *a.* Represents impact human alteration has on existing natural vegetation. (Invasive species, pesticides, etc.)
3. *Percent pine (includes plantations, upland longleaf, and wet longleaf)*
    - *a.* Represents the proportion of the landscape containing the dominant vegetation type of the southeastern coastal plain in which many herpetofaunal species have evolved life histories.
4. *BWHA: Percent Biodiversity and Wildlife Habitat Analysis (BWHA) rated*
    - *a.* Represents proportion of landscape identified by the Natural Heritage Program as high quality natural habitat contributing to aquatic and terrestrial processes.
5. *Cohesion (Patch)*
    - *a.* Represents the connectivity of habitat patches
6. *Diversity (Patch)*
    - *a.* Represents landscape heterogeneity
7. *Bay Density*
    - *a.* Represents the density of ponds in the herpetofaunal perceived landscape
8. *Variability*
    - a. Represents the variance in bay size distribution within a herpetofaunal perceived landscape

Mitigational Attributes

1. *Road density (all roads included; only measured within the bay)*
    - *a.* Represents loss of mitigation potential through fragmentation
    - *b.* Includes all road types (Interstate, US, NC, State routes, etc.)
2. *Bay area*
    - *a.* Represents physical area to be considered for mitigation
3. *SWLG: Swine lagoon count*
    - *a.* Represents mortality risk of use of these areas as habitat (Eutrophication/hypoxia, entrapment from steep banks, etc.)
4. *Parcel count*
    - *a.* Represents the loss of mitigation potential through increasing land owners and difficulty in cooperation
5. *Restorability*
    - a. Represents the proportion of bay that is rated as either existing or restorable by NC CREWS

Please return responses to James Edwards as an email attachment to Edwardsj03@students.ecu.edu or in paper form to Department of Geography Brewster A-227, East Carolina University, Greenville NC 27858**,** or Fax 252-328-6054.

Which of the following best indicates your profession?

(Check the single most appropriate choice)

Note: You can provide your option within this document by clicking the appropriate bubble.

○	**Ecologist**
○	**Herpetologist**
○	**Landscape Ecologist**
○	**Planner**
○	**Wetland Ecologist**
○	**Natural Resource Manager**
○	**Other**

Please indicate your assessment of relative importance by first deciding which attribute is more important (left or right) and then filling in the bubble corresponding to your degree of importance for that attribute.

Please fill only one bubble per comparison.

Example: In the row below, if I were to decide that road edge was more important than agricultural edge for herpetofauna using Carolina bays, I would only fill in a circle to the left of the grayed out center. I would then decide by relatively how much, in this example, I have stated that I believe road edge is extremely more important than agricultural edge.

Road Edge	◉	○	○	○	○	○	○	○	○	**Agricultural Edge**

Criteria	**Extreme**	**Very Strong**	**Strong**	**Moderate**	**Equal**	**Moderate**	**Strong**	**Very Strong**	**Extreme**	**Criteria**
Road Edge	○	○	○	○	○	○	○	○	○	**Agricultural Edge**
Road Edge	○	○	○	○	○	○	○	○	○	**Percent Pine**
Road Edge	○	○	○	○	○	○	○	○	○	**BWHA Rated**
Road Edge	○	○	○	○	○	○	○	○	○	**Cohesion**
Road Edge	○	○	○	○	○	○	○	○	○	**Diversity**
Road Edge	○	○	○	○	○	○	○	○	○	**Bay Density**
Road Edge	○	○	○	○	○	○	○	○	○	**Variability**
Agricultural Edge	○	○	○	○	○	○	○	○	○	**Percent Pine**
Agricultural Edge	○	○	○	○	○	○	○	○	○	**BWHA Rated**
Agricultural Edge	○	○	○	○	○	○	○	○	○	**Cohesion**
Agricultural Edge	○	○	○	○	○	○	○	○	○	**Diversity**
Agricultural Edge	○	○	○	○	○	○	○	○	○	**Bay Density**
Agricultural Edge	○	○	○	○	○	○	○	○	○	**Variability**
Percent Pine	○	○	○	○	○	○	○	○	○	**BWHA Rated**
Percent Pine	○	○	○	○	○	○	○	○	○	**Cohesion**
Percent Pine	○	○	○	○	○	○	○	○	○	**Diversity**
Percent Pine	○	○	○	○	○	○	○	○	○	**Bay Density**

Criteria	Extreme	Very Strong	Strong	Moderate	Equal	Moderate	Strong	Very Strong	Extreme	Criteria
Percent Pine	○	○	○	○	○	○	○	○	○	**Variability**
BWHA Rated	○	○	○	○	○	○	○	○	○	**Cohesion**
BWHA Rated	○	○	○	○	○	○	○	○	○	**Diversity**
BWHA Rated	○	○	○	○	○	○	○	○	○	**Bay Density**
BWHA Rated	○	○	○	○	○	○	○	○	○	**Variability**
Cohesion	○	○	○	○	○	○	○	○	○	**Diversity**
Cohesion	○	○	○	○	○	○	○	○	○	**Bay Density**
Cohesion	○	○	○	○	○	○	○	○	○	**Variability**
Diversity	○	○	○	○	○	○	○	○	○	**Density**
Diversity	○	○	○	○	○	○	○	○	○	**Variability**
Bay Density	○	○	○	○	○	○	○	○	○	**Variability**
Road Density	○	○	○	○	○	○	○	○	○	**Bay Area**
Road Density	○	○	○	○	○	○	○	○	○	**SWLG Count**
Road Density	○	○	○	○	○	○	○	○	○	**Parcel Count**
Road Density	○	○	○	○	○	○	○	○	○	**Restorability**
Bay Area	○	○	○	○	○	○	○	○	○	**SWLG Count**
Bay Area	○	○	○	○	○	○	○	○	○	**Parcel Count**
Bay Area	○	○	○	○	○	○	○	○	○	**Restorability**
SWLG Count	○	○	○	○	○	○	○	○	○	**Parcel Count**
SWLG Count	○	○	○	○	○	○	○	○	○	**Restorability**
Parcel Count	○	○	○	○	○	○	○	○	○	**Restorability**
Cumulative Ecological Attributes	○	○	○	○	○	○	○	○	○	**Cumulative Mitigational Attributes**