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An Examination of Plant Community Composition in Six Carolina Bays on the Coastal Plain of South Carolina

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AN EXAMINATION OF PLANT COMMUNITY COMPOSITION IN SIX CAROLINA BAYS ON THE COASTAL PLAIN OF SOUTH CAROLINA

By

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In loving memory of Mackie Altman III and Nick Altman.

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List of Symbols and Abbreviations

ha	hectare
m	meters
G1	critically imperiled
G2	imperiled
G3	vulnerable
G4	apparently secure
G5	secure
NWI	National Wetland Inventory
HGS	hydrogeologic setting
ACOE	Army Corp of Engineers
CWA	Clean Water Act
GIS	geographic information system
SCDNR	South Carolina Department of Natural Resources
PFO	palustrine forested
PSS	palustrine scrub-shrub
PEM	palustrine emergent
Dbh	diameter at breast height
GPS	global positioning system
P	phosphorous
K	potassium
Ca	calcium
Mg	magnesium
Zn	zinc
Cu	copper
B	boron
Mn	magnesium
IUCN	International Union for Conservation of Nature
NO3N	nitrate as nitrogen

INTRODUCTION

Aerial reconnaissance and early biological naturalists, during the late 19th and early 20th century, found the landscape of the South Carolina Coastal Plain dotted with elliptically shaped landforms, often wetland depressions, initially called “bays” (Glenn 1895), because of the dominant vegetation expressed. Since then, much investigation has followed (Buell 1939, Prouty 1952, Whitehead and Barghoorn 1962, Schalles and Shure 1989, Sharitz 2003), though many unanswered questions regarding Carolina bays, of the Atlantic coastal plain, still remain.

Carolina bays are recognizable due to their characteristic, elliptical shape and long axis orientation (e.g., from northwest to southeast), often with the presence of a prominent sand rim. These depressions range widely in size across the Coastal Plain. Early estimates stated sizes ranging from “a few acres to stretches a mile or two long” (Glenn 1895) or “from a few hundred feet to about 7 miles” (Prouty 1952). More sophisticated aerial and satellite imagery has allowed improved estimates of size, ranging from less than 0.01 ha to 1289.20 ha with a mean size of 23.62 ha (Marlowe 2008). These landforms have been documented along much of the Atlantic coast, as far north as Maryland (Tyndall et al 1990), but Carolina bays are most abundant in the Carolinas (i.e., NC, SC), and potentially the boundaries of Georgia (Bennet and Nelson 1991, Marlowe 2008). For example, Marlowe (2008) has documented more than 300 Carolina bays in Horry County, SC, and nearly 2,600 bays within SC. Carolina bays are commonly “geographically” isolated, meaning they lack surface water inputs, and, as such, are currently at great risk of continued and accelerating human impacts and degradation (Tiner 2003).

Some large Carolina bays, such as Lake Waccamaw in North Carolina, are permanently flooded and contain unique, aquatic environments, with levels of endemism that rival any of the Global biodiversity hotspots (Myers et al. 2000, Mittermeier et al. 2011). However, hydrology within most Carolina bays, especially in the Carolinas, is highly dynamic and fluctuates widely in space and time (Sharitz 2003). In most bays, a lack of hydrologic connectivity with permanent water sources means water levels fluctuate seasonally, based on precipitation and evapotransporation rates. Generally, Carolina bays are inundated with water during winter and peak periods of recharge in the spring, but may be drier during summer months (Whigham 1999). Such fluctuations create wetland habitats that may be ill suited for many aquatic species, though often critically important to other organisms, with complex lifecycles (Semlitsch 1981). Herpetofauna that experience a brief aquatic stage in their lifecycle, find valuable refuge from aquatic predators in seasonally ponded Carolina bays (Semlitsch 1981).

Carolina bays typically have a gradual slope from the outer sand rim to the interior of the bay that produces a hydrologic gradient and, often, distinct vegetation zonation (Prouty 1952, Whitehead and Barghoorn 1962, Poiani and Dixon 1995, Battaglia and Collins 2006). Carolina bays vary greatly in size, soil/substrate depth, hydropattern (i.e., water level, period of inundation, presence of subsurface lateral flows), and land use history (Keddy 1992, Sharitz 2003, De Steven and Toner 2004). As a result, plant community types may vary with time and space in a single Carolina bay. Bennett and Nelson (1991) described eleven bay community types, while Nifong (1998) described nine broad vegetation classes with six sub classes and 65 specific communities.

Poiani and Dixon (1995) stated that open water, trees, shrubs, or herbaceous vegetation commonly dominate bays.

Carolina bays provide habitat for several rare, endemic, and threatened species and ecological communities (Bennett and Nelson 1991, Luken 2005, NatureServe 2016). Bennett and Nelson (1991) reported twenty-three species considered rare, threatened, or endangered within Carolina Bays of South Carolina. In 2012, NatureServe reported a global conservation rank of G1 (critically imperiled) or G2 (imperiled) to 27 community associations found within Carolina bays (reported in Marlowe 2008). The variation in plant communities among bays and the presence of rare and endemic species within them is purported to contribute greatly to the biotic diversity of the regional landscape (Poiani and Dixon 1995). Further research is needed, throughout the range of Carolina bays, to substantiate reports of high biodiversity and endemism (De Steven and Toner 2004) and to aide in classification.

Research conducted at Coastal Carolina University, in support of the Coastal Marine and Wetland Studies (CMWS) Master's Program, has advanced our understanding of these unique wetland assemblages. Laliberte (2007) sampled plant communities and environmental variables in the ecotone between six Carolina bays and the uplands surrounding them. She found that high diversity and more endemic or near endemic plants were found in the ecotone, outside of the jurisdictional wetland boundary (Laliberte et al 2007). Zoellner (2007) identified multiple abiotic conditions that correlated with differences in plant species composition within two vegetation classes common among Carolina bays in northeastern South Carolina. Zoellner also found that sampled vegetation did not match a priori communities, determined using digital aerial photographs, NWI maps, published records from the South Carolina Department of Natural Resources, and collaborating land managers. This suggested the need for more accurate *a priori* identification tools (Zoellner 2007). Marlowe's research (2008) identified significant spatiotemporal patterns related to Carolina bays, including trends in human land use within and around bays, and provided a hydrogeologic setting (HGS) model, that distributed the bays she sampled into three general classes (palustrine forested, scrub shrub, and emergent) and includes information on the distribution and disturbance of Carolina bays in South Carolina (Marlowe 2008).

The contribution of Carolina bays to the biodiversity of the Coastal Plain, their global rarity, and their role as habitat for rare plants and semi-aquatic fauna, should make them of high concern for conservation (Sharitz 2003, NatureServe 2016). However, bays have historically been at high risk for anthropogenic impacts, with Marlowe (unpublished data, 2008) reporting that human land use dominated more than 60% of SC bays. Marlowe (2008), and Bennett and Nelson (1991), suggested that more than 95% of all bays in South Carolina have been directly impacted by humans. Carolina bays that are not directly impacted are often still located within an, increasingly hostile, upland matrix of human activity. Marlow (2008) found that the majority of land within 250 meters of Carolina bays in South Carolina is human influenced, specifically by agriculture (43.8%) and/or planted pine (22.5%). Upland terrestrial landscapes can have multiple negative impacts on the biotic integrity of the bay interior including reduction in dispersal success in animals with a large home range and low probability of establishment for seeds dispersed outside of the bay (Diggelen et al 2006, Middleton et al 2006). To protect species that migrate or disperse to other wetland and upland habitat, it is necessary to protect an upland buffer area or a complex of multiple, connected Carolina bays rather than individual bays within a landscape of low connectivity (Burke and Gibbons 1995).

Jurisdictional protection of wetlands, including Carolina bays, has long fallen to the US Army Corps of Engineers (ACOE) under the Rivers and Harbors Act (1899) and The Clean Water Act (CWA) (1972). Two recent US Supreme Court cases [i.e., Solid Waste Agency of Northern Cook County v. U.S. Army Corps of Engineers (2001) and United States v. Rapanos (2007)], have hampered the ability of ACOE to protect isolated, potentially at-risk wetlands to continued dredge and fill activities. By narrowing the scope of the CWA, these court cases have shifted the burden for protecting wetlands to state and local governments (Christie and Hausman 2003), requiring states to quantify wetland resources and identify wetlands that have potentially lost federal protection and are not currently protected by state mandate. Kusler (2004) reported that only eighteen states now provide protection for isolated freshwater wetlands with the remainder lacking basic enabling statutes, funding/staff, and/or public support.

While SC has imposed jurisdiction in a landmark wetland case (i.e., Spectre LLC v. SC Department of Health and Environmental Control, 2010), there currently is no definition of "adjacency" or what constitutes a "water of the US." Nor has any specific language been established to protect and conserve these locally abundant, yet globally rare national wetland resources (Sharitz 2003), in a region that has more Carolina bays than anywhere else on the planet.

Geographic information system (GIS) and digital mapping programs may help alleviate strain on state regulatory offices, caused by issues of understaffing, by allowing some jurisdictional decisions to be made with fewer field inspections. GIS are becoming increasingly valuable to conservation and restoration efforts. They allow a paring down of potential sites for conservation, restoration, or mitigation and eliminate extraneous trips to unsuitable sites (SCDNR Planning Summary Document 1999). GIS are being used to assess factors such as human impacts and community types across the landscape. The use of historical aerial imagery can also afford valuable insights into patterns of habitat degradation and community change over time (Mast et al 1997). The potential for increased reliance on GIS and digital mapping data suggests a need for more studies assessing the accuracy of these tools.

Conservation efforts should be established based on applied ecological data, disseminated to policy makers and the public and then used to develop clear protection criteria for the long-term protection of Carolina bay wetlands. Due to recent court cases, the legal protection of isolated wetlands throughout the United States has been called into question (Sharitz 2003). Carolina bays, which are commonly isolated, may be at an increased risk for further human impacts and degradation when they occur on lands outside of preserves and refuges. If limited resources exist to establish protected lands, it may become important to prioritize Carolina bay wetlands for conservation, using a set of criteria that addresses rarity and diversity.

To this end, I evaluated plant community composition, diversity, richness, rarity, and soil parameters of six Carolina Bays, using a replicated ecological approach, across the three general palustrine vegetation classes (i.e., forested, scrub-shrub, and emergent). Also, because the bays that were sampled in my study either occur on protected land or have low levels of impact, they can, potentially, serve as reference wetlands for future bay conservation, restoration, or functional assessment (sensu Brinson 1993, Uranowski et al. 2003).

METHODS

SITE SELECTION

Carolina bays in my study were dominated by one of three palustrine wetland vegetation types (Cowardin et al. 1979); forested (PFO), scrub-shrub (PSS), or emergent (PEM). Sites were selected from a database of Carolina bays (Marlowe 2008), using ARCGIS 10.0 (ESRI 2011)., and I used National Wetland Inventory (NWI) data, provided by The U.S. Fish and Wildlife Service (2010) and local knowledge to select my sites. Each bay type was replicated twice for a total of six bays (Figure 1). I further constrained my sampling efforts to bays selected from protected lands or those which have sustained low levels of anthropogenic impact, and were covered with at least 70% of the dominant vegetation type. Of the six bays, the two scrub shrub bays, were located within Lewis Ocean Bay Heritage Preserve, a 1,473-hectare tract managed by the State of South Carolina since 1989 that includes 22 Carolina bays (Luken 2005). The two, forested bays, occurred in the Francis Marion National Forest, a site that spans nearly 105,000 hectares and is managed by the U.S. Forest Service (U.S. Forest Service). Bays dominated by PEM vegetation are rare and were found to be under-represented on protected lands outside of the Savannah River Ecological Laboratory (De Steven and Toner 2004). Therefore, the PEM bays I selected, were located on private land where I was graciously provided access. The bays that I studied, were "mostly" unimpacted, but I caution in suggestion that they are "pristine" or "natural.” Bay area ranged from 15 to 50 hectares, derived from available digital data (e.g., NWI interactive mapper, ARCGIS ESRI 2011).

VEGETATION SAMPLING

Vegetation was sampled from June 2011 through October 2012, with a centerline transect positioned along the long axis of each bay beginning 10 meters outside the southeast boundary, with sampling stations placed every 100 meters along the centerline (Figure 2). Following Uranowski et al (2003), a circular plot with a radius of 11.3 meters was established to measure overstory, with species and diameter at breast height (dbh) recorded for all trees within the plot. Two smaller circular subplots (radius of 3.6 m) were established randomly within the overstory plot to sample understory vegetation using simple percent cover by species. Four randomly placed, 1 m^2 herbaceous subplots were established, within each sampling station, to estimate percent cover of herbaceous species, and I estimated coarse woody debris (CWD), along two 15m transects, to quantify coarse woody debris, into one of three size classes; Size Class 1 included all woody debris between 6 and 25mm, Size Cass 2, those between 25 and 76 mm, and Size Class 3, those above 76 mm in diameter (Figure 2). Species were identified in the field, to the lowest taxonomic level possible, and species that could not be identified were photographed, collected, and identified using Weakley (2006). If a unique plant community fell on the transect, but not inside a sampling plot, an additional sampling station was established in the center of that plant community. This practice was adopted because zonation in vegetation is of particular interest in my study and it is important that the diversity of plant communities within the bay be accurately assessed.

ENVIONMENTAL VARIABLE SAMPLING

At each sampling station GPS coordinates and a single soil sample were taken. from the centroid of the sampling station. Soil samples were used to assess extractable elements (e.g. P, K, Ca, Mg, Zn, Cu, B, Mn), nitrogen and soil pH. These samples were sent to Clemson Extension for analyses, and were included in subsequent statistical analyses.

STATISTICAL ANALYSES

Biotic and abiotic parameters were assessed using a range of statistical techniques. In all cases, I pooled the data derived from two bays of each community type (i.e., PEM, PSS, and PFO), though limitations potentially exist, that I will identify as encountered. I feel this is valid, since comparisons between sites (e.g., PSS1 versus PSS2) resulted in no statistically significant difference, though variability did exist, which I will address. Additionally, since most data failed to meet parametric assumptions (e.g., much of the data were not normally distributed), I employed Kruskal Wallis H test using data describing richness, diversity, and rarity status. Shannon Weiner diversity was compared among bay type, using a Shannon-Weiner Diversity t-test (Magurran 1988). Extractable nutrients (e.g. P, K, Ca, Mg, Zn, Cu, B, Mn), nitrogen and soil pH) were assessed using analogous statistics, in PAleontological STatistics (PAST; Hammer 2016), with an a priori 95% confidence level ($p \leq 0.05$), though I will include all p values for individual interpretation.

RESULTS

Over two sampling seasons (2011 and 2012), I sampled vegetation, soil parameters, and coarse woody debris in 6 Carolina bays, equally divided among forested (PFO), scrub/shrub (PSS) and emergent (PEM) communities (i.e., 2 of each) on the South Carolina Coastal Plain (Figure 1). Mean bay area and long axis length varied among community types; shrub (i.e. 28.1 ha, 743.32 m), followed by emergent (14.8 ha, 518.66 m), and forested (21.4 ha, 666.74 m). However, this comparison is not statistically significant ($p=0.2765$). In light of small sample size (i.e., only two of each bay community type), I suggest caution in interpretation of results, with post hoc power analysis (sensu Gibbs 2002) suggesting that it would require a minimum of five of each bay type for statistical significance to be reached. The number of sampling stations, corresponding to overstory sampling station (10 m radius), in each bay varied from 6 to 9, depending on long axis length and abundance of unique communities, resulting in a total of 49 overstory plots across all bays, 98 shrub plot (2 plots per sampling station at $5m^2$ each), and 196 herbaceous plots (i.e., four $1m^2$ plots per sampling station).

I report cumulative species richness, across all 6 bays, of 89, ranging from 14 to 45 at each bay. Forested bays presented the highest species richness (i.e., 67), followed by emergent (i.e., 49), and shrub (i.e., 30; Figure 2). Most of the species I identified, would be considered “of least concern” (IUCN 2015), several species or communities warrant protections (Table 1). NatureServe (2016) reports that more than seven community types as vulnerable or imperiled. Five communities are listed as vulnerable, including *Pinus serotina / Cyrilla racemiflora – Lyonia lucida – Ilex glabra* woodland and *Taxodium ascendens / Ilex myrtifolia* Depression Forest. *Taxodium ascendens /*

Panicum hemitomon - Polygala cymosa Woodland is listed as imperiled/vulnerable and *Chamaedaphne calyculata / Carex striata - Sarracenia (flava, purpurea, rubra ssp. rubra)* Dwarf-shrubland is currently reported to be critically imperiled.

Following Magurran (1988), Shannon-Weiner Diversity varied significantly by treatment, with emergent bays exhibiting the highest species diversity (H'= 2.8020), followed by forested (H'= 2.3679), and shrub (H'= 2.3019) being the least diverse. Shannon-Weiner diversity was significantly different (Figure 2) between emergent and forested bays (p= 3.50 E-16: Figure 2), and between emergent and shrub bays (p= 3.02 E-55: Figure 2), but not significantly different between forested and shrub bay communities (p=0.1956: Figure 2).

For bays in this study classified as PSS, the most common species encountered was *Lyonia lucida and Cyrilla racemiflora*. Other common species included *Ilex glabra, Ilex coriacea,* and *Smilax laurifolia*. PSS bays had a very sparse overstory, consisting of only one species (*Pinus serotina)*. The woody understory was dense, not allowing opportunity for herbaceous plant growth throughout many of the sampling plots. Within the bay marked PSS1, bands of tall woody understory vegetation were separated by patches of understory no more than 2 feet in height. In these patches of shorter understory vegetation, herbaceous species, such as *Woodwardia virginica, carex sp., and Sarracenia flava, were observed*. Both PSS bay rims exhibited a distinct, exposed sand rim. The sand rim was present only on the southwest and northeast sides of bay PSS1, with adjacent bays either directly abutting or overlapping the bay of interest on the northwest and southeast sides (Figure 1). In between the first and second sampling seasons, a dirt road was cut through the northern corner of the bay marked PSS12 in this study. None of the sampling plots fell within the area directly impacted by this event, but it is representative of the overall trend of human impacts that historically and currently effect Carolina bay habitats.

The most common overstory species was *Nyssa biflora* in PFO19 and *Taxodium ascendens* with patches of *Nyssa biflora* in PFO21. The most common woody understory species encountered in both PFO bays was *Lyonia lucida*, being common in PFO19 and mostly sparse with occasional denser patches in PFO21. Herbaceous vegetation other than moss was very rare in both PFO bays with the exception of the terminal sampling plot at the northwest end of the transect through PFO21. This sampling point was established outside of the wetland boundary where the overstory became less dense and several ruderal species were able to thrive.

Bays classified as PEM in this study were both dominated by grass communities. In bay PEM22, the most common species encountered was by *Rhynchospora careyana* with the exception of one sampling plot that was dominated by *Rhynchospora careyana* and *Woodwardia virginica.* In bay PEM25, the vegetation formed bands of *Panicum hemitomon* and stands of young *Taxodium ascendens*. Woody understory vegetation was sparse in both PEM bays other than patches of *Ilex myrtifolia* in PEM22 and one young stand of *Liquidambar styraciflua* in PEM25. The most common overstory species was *Taxodium ascendens* with multiple stands of *Nyssa biflora*. One terminal overstory plot of each PEM bay was dominated by *Liquidambar styraciflua*.

Average number of woody debris stems encountered at each sampling point was highest in PFO bays in size class 1 (6-25 mm) and in size class 2 (25-76 mm). However, average number of woody debris stems was highest in PEM bays for size class 3 (above

76 mm). Averages for all woody debris classes were higher at PEM25, which contained bands of forested vegetation, than at PEM22 (Figure 12).

Many extractable elements tested in soil were significantly different among bays dominated by different communities (Figures 5-10. Soil pH was significantly different among PSS, PFO, and PEM dominated bays (Kruskal Wallis, H=21.73, p=1.71E-05). PSS bays had the lowest average pH (3.77), followed by PFO bays (4.14), and PEM bays had the highest average pH (4.43). Phosphorous levels were significantly different among PSS, PFO, and PEM bays (Kruskal Wallis, H=13.89, p=0.0009), with PFO bays having nearly twice the amount of phosphorous as both PSS and PEM bays. I also found significant differences in NO_3 (Kruskal Wallis, H=16.59, p=6.189E-05), with PEM bays having the highest levels (3.28 ppm), followed by PFO (2.5 ppm), and PSS having the lowest (0.11 ppm). Likewise, potassium (Kruskal Wallis, H=7.40, p=0.0247) and sodium (Kruskal Wallis, H=21.16, p=2.495E-05) levels were also significantly different. Calcium and magnesium levels were not significantly different.

NWI community data was compared to observed community data at each sampling station to assess NWI field accuracy, across my 49 sampling station sites. NWI data matched observed community data at 74.5%, of my sampling stations (i.e., PFO=83%, PSS=83%, PEM=68%).

The average accuracy rate of PSS bays was 83% (PSS1=67%, PSS12=100%). NWI maps listed all plots inside of the bay rim of PSS12 as palustrine scrub-shrub and both plots found outside the bay rim as upland, which matched observations in the field. At PSS1, all plots were listed as palustrine forested/scrub-shrub by NWI maps. Six plots in PSS1 were found to be dominated by scrub-shrub vegetation and overstory species were sparse or not present.

The average accuracy rate of PFO bays was also 83% (PFO19=83%, PFO21=83%). At both PFO19 and PFO21, one plot located outside the bay rim was listed by NWI maps as being upland, but was found to be dominated by palustrine forest vegetation.

The average accuracy rate of NWI maps in regards to PEM bays was 68% (PEM22=80%, PEM25=56%). At PEM22, two plots were misclassified. At one end of the bay transect a plot containing upland vegetation was classified as palustrine forested. At the opposite end of the transect, the last 2 plots were classified as upland by NWI maps, but sampled vegetation showed only the last plot as upland, while the other contained palustrine forested vegetation. At PEM25, four plots were classified by NWI as palustrine scrub-shrub. All four of those plots were mixed palustrine emergent and palustrine forested according to observed vegetation.

DISCUSSION

Although Carolina bays are documented along much of the Atlantic coast of North America, Carolina bays on the Savannah River Ecological Laboratory site constitute a large portion of ecological studies published about bays (Sharitz and Gibbons 1982, Kirkman and Sharitz 1994, Mulhouse et al 2005). The geographic concentration of bay studies around the southern border of South Carolina has likely skewed scientific knowledge about the composition and setting of bay-associated wetlands. Bennett and Nelson (1991) noted that Carolina bays in the Northeastern part of South Carolina and those in North Carolina are predominately peat-based, whereas those farther south are more often clay-based. In an effort to sample bays with the lowest possible human impacts, an attempt was made to include only bays located on protected lands. However, due to the high concentration of ecological studies already performed at SREL and the lack of PEM dominated bays outside of that site, both PEM bays in this study are located on privately owned lands. Aside from the size and dominate community requirements, these bays were selected because they had not been heavily impacted by human land use and because access was granted by landowners.

Local ecological knowledge and NWI map data were used to select bays to be sampled. Wetland managers and regulators often use GIS and NWI maps to aid in planning and protection. Zoellner (thesis 2007) found that only one plot in her study was misclassified by NWI maps, but this accounted for an error rate of 11%. Zoellner assessed the accuracy of NWI data at a finer level than was assessed in this study and only included bays dominated by pocosin, bay forest, and pond cypress vegetation. NWI data used in this study, across 49 plots, was accurate 74.5% of the time at the level of palustrine vegetation class (forested, scrub-shrub, or emergent).

In a study of small, isolated wetlands in South Carolina's Piedmont and Blue Ridge areas, Pitt et al (2012) suggest a two-pronged approach to locating and identifying cryptic ecosystems, using both remote sensing and local ecological knowledge. Local ecological knowledge may also be useful in identifying dynamic ecosystems, or those affected by recent disturbance. This may be of particular importance in Carolina bays and other depression wetlands in South Carolina, as the relationship between hydrologic regime and disturbance is an important factor affecting plant community composition

(Kirkman 1995). Depth to the water table was not significantly different between bays dominated by different vegetation classes in my study (Figure 11), but a more thorough study of hydrology fluctuations over time may show more variance between the wetlands studied. Disturbance by fire likely played a role in determining the type of vegetation present. In my study, PEM25 contained four plots classified by NWI as palustrine scrub-shrub. All four of those plots were mixed palustrine emergent and palustrine forested according to observed vegetation. This discrepancy is most likely due to a recent fire, which likely thinned scrub-shrub vegetation and allowed emergent vegetation to dominate those plots (Kirkman et al 2000).

Species richness in the current study ranged widely (14-56 species per bay). PSS bays had the lowest average species per bay with 18, followed by PEM (28.5), and PFO had the highest average species per bay (40.5). Previous studies on Carolina bay vegetation have found wide ranging species numbers. Kirkman and Sharitz (1994) reported 56-105 species per bay from a sample of four depression-meadow bays at the Savannah River Site. Poiani and Dixon (1995) reported only 13-19 species per bay in their study of seven bays on the Savannah River Site, though they did report 16-35 species per bay in the seedbank. Total species richness across all bays also varies widely for different Carolina bay studies. Poiani and Dixon (1995) reported 69 species and Laliberte et al (2007) reported 56 species. The overall species richness of the current study was higher (89) than the previous studies mentioned, likely because of the wide geographic range of the bays sampled compared to many similar studies (from northeast to southeast South Carolina). Kirkman and Sharitz (1994) did not report their total species richness across all bays sampled but it was higher than the current study, as they reported 108 total species in the seed bank of all bays sampled and one of their bays contained 105 species growing in the field.

Many of the abiotic parameters that I measured were significantly different between bays of differing vegetation types, including pH, phosphorus, potassium and nitrate (Figures 4-7). These differences potentially answer some of the questions regarding Carolina bay vegetation relative productivity and species richness (sensu Grime 1979, Grace 1999). The relationship between plant community and soil nutrient concentration and availability has been long documented (Clements 1916, Monk 1966, Walbridge 1991, Newman and Schalles 1990), with several recent studies suggesting, as seen in my research, that plant composition changes in response to pH (Bedford et al. 1999), and varied levels of nitrogen, phosphorus, and potassium (Bedford et al 1999, Chapin et al. 2000). For example, while most of my PEM sites had low N concentrations, this community type remained the most specious, and contained the greatest number of rare elements (i.e., 4). They also exhibited the highest pH, fitting the general rule that the in more circumneutral site, greater species richness will likely occur (Lambers et al. 2008). Bedford et al. (1999) and Bedford and Godwin (2003) note that N:P ratios can be informative regarding biodiversity and productivity, I believe that the co-limitation of nutrients (i.e., N, P, K) in Carolina bays warrant further investigation, to include *in situ* nutrient additions (Venterink et al 2002, Klaus et al 2013) and field studies across spatial levels from microsite to landscape (Bedford 1996). Although gradients in nutrients (Laliberte et al 2007) and hydrology (Bruland et al 2003, Battaglia and Collins 2006) have been reported across bay rims in previous studies, neither were apparent in my data.

Palustrine emergent is one of the least common dominant vegetation communities found in Carolina bays of South Carolina (Bennett and Nelson 1991, Marlowe 2008). More plant species and communities considered rare or vulnerable, found in this study, were observed only in bays dominated by PEM vegetation. Four of the seven vulnerable or imperiled plant communities (see table 1) and three of the four vulnerable or imperiled plant species (*Rhexia aristosa*, *Eleocharis equisetoides*, and *Iris tridentata*) found in this study were in bays dominated by PEM vegetation. Palustrine emergent dominated bays are also the least represented on protected lands. Only eight Carolina bays dominated by PEM vegetation fall on protected, heritage, or state owned lands in South Carolina and all but one of those bays are more than 5% impacted by human activity (Marlowe 2008).

CONCLUSION

Carolina bays are unique geomorphic features found only on the Atlantic coastal plain of the United States and are most common in North and South Carolina. Hydrology of bays varies across their distribution but bays often contain isolated, ephemeral wetlands that provide valuable habitat for rare flora and fauna. Due to recent Supreme Court rulings, and indeterminate legal definitions, these geographically isolated wetlands are ill protected from continued, heavy human land-use. Carolina bays dominated by palustrine emergent vegetation are some of the rarest and may contain the highest diversity of vulnerable or imperiled plant species and communities but are heavily impacted by human activity and poorly represented on protected lands. Diversity, soil pH, and extractable nutrients vary significantly by dominant vegetation expressed in Carolina bays included in my study but further research is needed to confirm these results and establish baseline data from bays that have sustained low levels of human impact to serve as reference wetlands for restoration and conservation efforts.

Of the six Carolina bays in my study, those dominated by palustrine emergent (PEM) vegetation had the highest level of plant community diversity and the most vulnerable or imperiled plant species and communities. Bays dominated by PEM vegetation are also the rarest throughout South Carolina and are the least represented on protected lands. If the six bays I studied were prioritized for conservation, based on the criteria measured, PEM bays would have the highest priority (Figure 13). More research is needed to assess a larger selection of bays throughout South Carolina and to assess other potential conservation criteria.

LITERATURE CITED

Battaglia, L. L., & Collins, B. S. (2006). Linking hydroperiod and vegetation response in Carolina bay wetlands. Plant Ecology, 184(1), 173-185.

Bedford, B. L. (1996). The need to define hydrologic equivalence at the landscape scale for freshwater wetland mitigation. Ecological Applications, 6(1), 57-68.

Bedford, B. L., & Godwin, K. S. (2003). Fens of the United States: distribution, characteristics, and scientific connection versus legal isolation. Wetlands, 23(3), 608-629.

Bedford, B. L., Walbridge, M. R., & Aldous, A. (1999). Patterns in nutrient availability and plant diversity of temperate North American wetlands. Ecology, 80(7), 2151-2169.

Bennett, S. H., & Nelson, J. B. (1991). Distribution and status of Carolina bays in South Carolina. Nongame & Heritage Trust Section, South Carolina Wildlife & Marine Resources Department.

Brinson, M. M. (1993). A hydrogeomorphic classification for wetlands. East Carolina University. Greenville, NC.

Bruland, G. L., Hanchey, M. F., & Richardson, C. J. (2003). Effects of agriculture and wetland restoration on hydrology, soils, and water quality of a Carolina bay complex. Wetlands Ecology and Management, 11(3), 141-156.

Buell, M. F. (1939). Peat formation in the Carolina Bays. Bulletin of the Torrey Botanical Club, 66(7), 483-487.

Burke, V. J., & Gibbons, J. W. (1995). Terrestrial buffer zones and wetland conservation: a case study of freshwater turtles in a Carolina bay. Conservation Biology, 9(6), 1365-1369.

Chapin III, F. S., Zavaleta, E. S., Eviner, V. T., Naylor, R. L., Vitousek, P. M., Reynolds, H. L., & Mack, M. C. (2000). Consequences of changing biodiversity. Nature, 405(6783), 234-242.

Christie, J., & Hausmann, S. (2003). Various state reactions to the SWANCC decision. Wetlands, 23(3), 653-662.

Clements, F. E. (1916). Plant succession: an analysis of the development of vegetation (No. 242). Carnegie Institution of Washington.

Cowardin, L.M., V. Carter V., F.C. Golet, E.T. LaRoe (1979). Classification of Wetlands and Deepwater Habitats of the United States. U.S. Fish and Wildlife Service Report No. FWS/OBS/-79/31.Washington, D.C.

De Steven, D., & Toner, M. M. (2004). Vegetation of upper coastal plain depression wetlands: environmental templates and wetland dynamics within a landscape framework. Wetlands, 24(1), 23-42.

Diggelen, R., Middleton, B., Bakker, J., Grootjans, A., & Wassen, M. (2006). Fens and floodplains of the temperate zone: present status, threats, conservation and restoration. Applied Vegetation Science, 9(2), 157-162.

ESRI 2011. ArcGIS Desktop. Redlands, CA: Environmental Systems Research Institute.

Glenn, L. C. (1895). Some Notes on Darlington (SC), Bays. Science, 2(41), 472-475.

Grace, J. B. (1999). The factors controlling species density in herbaceous plant communities: an assessment. Perspectives in plant ecology, evolution and systematics, 2(1), 1-28.

Grime, J.P. 1979. Plant strategies and vegetation processes. John Wiley, Chichester.

Hammer, Ø. (2016). PAST-PAlaeontological STatistics, ver. 3.11. Natural History Museum, University of Oslo. Retrieved from http://folk.uio.no/ohammer/past/

IUCN 2015. The IUCN Red List of Threatened Species. Version 2015-4. <http://www.iucnredlist.org>. Downloaded on 19 November 2015.

Keddy, P. A. (1992). Assembly and response rules: two goals for predictive community ecology. Journal of Vegetation Science, 3(2), 157-164.

Kirkman, L. K. (1995). Impacts of fire and hydrological regimes on vegetation in depression wetlands of southeastern USA. In Fire in wetlands: a management perspective. Proceedings of the Tall Timbers Fire Ecology Conference No. 19, 10-20.

Kirkman, L. K., Goebel, P. C., West, L., Drew, M. B., & Palik, B. J. (2000). Depressional wetland vegetation types: a question of plant community development. Wetlands, 20(2), 373-385.

Kirkman, L. K., & Sharitz, R. R. (1994). Vegetation disturbance and maintenance of diversity in intermittently flooded Carolina bays in South Carolina. Ecological Applications, 4(1), 177-188.

Klaus, V. H., Hölzel, N., Boch, S., Mueller, J., Socher, S. A., Prati, D., ... & Kleinebecker, T. (2013). Direct and indirect associations between plant species richness and productivity in grasslands: regional differences preclude simple generalization of productivity-biodiversity relationships. Preslia, 85, 97-112.

Kusler, J. (2004). The SWANCC decision: state regulation of wetlands to fill the gap. Association of State Wetland Managers, Windham.

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

Lambers, H., Raven, J. A., Shaver, G. R., & Smith, S. E. (2008). Plant nutrient-acquisition strategies change with soil age. Trends in Ecology & Evolution, 23(2), 95-103.

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

Marlowe, M. J. (2008). Status and trends of a globally imperiled Atlantic Coastal Plain wetland: links to hydrogeologic setting and conservation (master's thesis). Retrieved from Coastal Carolina University Library.

Magurran, A.E. (1988). Ecological diversity and its measurement. — Princeton University Press, Princeton, New Jersey

Mast, J. N., Veblen, T. T., & Hodgson, M. E. (1997). Tree invasion within a pine/grassland ecotone: an approach with historic aerial photography and GIS modeling. Forest ecology and management, 93(3), 181-194.

Middleton, B., Diggelen, R., & Jensen, K. (2006). Seed dispersal in fens. Applied Vegetation Science, 9(2), 279-284.

Mittermeier, R. A., Turner, W. R., Larsen, F. W., Brooks, T. M., & Gascon, C. (2011). Global biodiversity conservation: the critical role of hotspots. In Biodiversity hotspots (pp. 3-22). Springer Berlin Heidelberg.

Monk, C. D. (1966). An ecological study of hardwood swamps in north-central Florida. Ecology, 47(4), 649-654.

Mulhouse, J. M., De Steven, D., Lide, R. F., & Sharitz, R. R. (2005). Effects of dominant species on vegetation change in Carolina bay wetlands following a multi-year drought 1. The Journal of the Torrey Botanical Society, 132(3), 411-420.

Myers, N., Mittermeier, R. A., Mittermeier, C. G., Da Fonseca, G. A., & Kent, J. (2000). Biodiversity hotspots for conservation priorities. Nature, 403(6772), 853-858.

NatureServe. 2016. NatureServe Explorer: An online encyclopedia of life [web application]. Version 7.0. NatureServe, Arlington, VA. U.S.A. Available http://explorer.natureserve.org. (Accessed: January 1, 2016)

Newman, M. C., & Schalles, J. F. (1990). The water chemistry of Carolina bays: A regional survey. Archiv fur Hydrobiologie. Stuttgart, 118(2), 147-168.

Nifong, T. D. (1998). An ecosystematic analysis of Carolina bays in the coastal plain of the Carolinas (doctoral dissertation). Retrieved from http://labs.bio.unc.edu/Peet/theses/Nifong_PhD_1998.pdf

Pitt, A. L., Baldwin, R. F., Lipscomb, D. J., Brown, B. L., Hawley, J. E., Allard-Keese, C. M., & Leonard, P. B. (2012). The missing wetlands: using local ecological knowledge to find cryptic ecosystems. Biodiversity and conservation, 21(1), 51-63.

Poiani, K. A., & Dixon, P. M. (1995). Seed banks of Carolina bays: potential contributions from surrounding landscape vegetation. American Midland Naturalist, 134(1), 140-154.

Prouty, W. F. (1952). Carolina bays and their origin. Geological Society of America Bulletin, 63(2), 167-224.

Schalles, J. F., & Shure, D. J. (1989). Hydrology, community structure, and productivity patterns of a dystrophic Carolina bay wetland. Ecological monographs, 59(4), 365-385.

Semlitsch, R. D. (1981). Terrestrial activity and summer home range of the mole salamander (Ambystoma talpoideum). Canadian Journal of Zoology,59(2), 315-322.

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

Sharitz, R. R., & Gibbons, J. W. (1982). Ecology of southeastern shrub bogs (pocosins) and Carolina bays: a community profile (No. FWS/OBS-82/04). Savannah River Ecology Lab., Aiken, SC (USA).

Tiner, R. W. (2003). Geographically isolated wetlands of the United States. Wetlands, 23(3), 494-516.

Tyndall, R. W., McCarthy, K. A., Ludwig, J. C., & Rome, A. (1990). Vegetation of six Carolina bays in Maryland. Castanea, 55(1), 1-21.

Uranowski, C., Lin, Z., DelCharco, M., Huegel, C., & Garcia, J. (2003). A regional guidebook for applying the hydrogeomorphic approach to assessing wetland functions of low-gradient, blackwater riverine wetlands in peninsular Florida (No. ERDC/EL-TR-03-3). Engineer Research and Development Center Vicksburg MS Environmental Lab.

U. S. Fish and Wildlife Service. (2010). National Wetlands Inventory website. U.S. Department of the Interior, Fish and Wildlife Service, Washington, D.C. http://www.fws.gov/wetlands/

U.S. Forest Service. "Francis Marion National Forest." http://www.fs.usda.gov/detail/scnfs/home/?cid=FSBDEV3_037393

Venterink, H. O., Pieterse, N. M., Belgers, J. D. M., Wassen, M. J., & De Ruiter, P. C. (2002). N, P, and K budgets along nutrient availability and productivity gradients in wetlands. Ecological Applications, 12(4), 1010-1026.

Walbridge, M. R. (1991). Phosphorus availability in acid organic soils of the lower North Carolina coastal plain. Ecology, 72(6), 2083-2100.

Weakley, A. S. (2006). Flora of the Carolinas, Virginia, Georgia and surrounding areas. University of North Carolina Herbarium (NCU), North Carolina Botanical Garden, University of North Carolina at Chapel Hill.

Whigham, D. F. (1999). Ecological issues related to wetland preservation, restoration, creation and assessment. Science of the Total Environment,240(1), 31-40.

Whitehead, D. R., & Barghoorn, E. S. (1962). Pollen analytical investigations of Pleistocene deposits from western North Carolina and South Carolina. Ecological Monographs, 32(4), 347-369.

Zoellner, D. C. (2007). Ecological characterization of plant communities in nine Carolina bays of northeastern South Carolina (master's thesis). Retrieved from Coastal Carolina University Library.

Table 1. Conservation status of six Carolina bays, distributed among emergent (PEM), scrub shrub (PSS) and forested (PFO). These designations, both federal and state, were assigned using NatureServe (2016), and primary literature, using the following descriptors: 1. critically imperiled, 2. imperiled, 3. vulnerable, 4. apparently secure, and 5. secure.

Species/Community	Global Status	National Status (species only)	SC State Status (species only)
Sarracenia flava	G5	N5	S3S4
Iris tridentate	G3G4	NNR	SNR*
Eleocharis equisetoides	G4	N1	SNR**
Rhexia aristosa	G3G4	N3	S3
woodland - *Pinus serotina / Cyrilla racemiflora – Lyonia lucida – Ilex glabra*	G3		
Depression Forest - Taxodium ascendens / (Nyssa biflora) / Leucothoe racemosa - Lyonia lucida - Morella cerifera	G3		
Taxodium ascendens / Ilex myrtifolia Depression Forest	G3		
Stringer Woodland - Taxodium ascendens - Nyssa biflora / Carex striata - Rhynchospora (careyana, cephalantha, microcephala)	G3		
Depression Woodland -Taxodium ascendens / Carex striata - Iris tridentata - (Woodwardia virginica)	G3		
Woodland -Taxodium ascendens / Panicum hemitomon - Polygala cymosa	G2G3		
Dwarf-shrubland - Chamaedaphne calyculata / Carex striata - Sarracenia (flava, purpurea, rubra ssp. rubra)	G1		

*Not rated in South Carolina but is rated in Georgia (S2) and North Carolina (S2S3).

**Not rated in South Carolina but is rated in Georgia (S3) and North Carolina (S3).

Table 2. Species richness of six Carolina bays relative bay community type (i.e., emergent (PEM), scrub-shrub (PSS) and forested (PFO)) and a description of bay replicates used in this plant community assessment, with two bays of each community type. Locations of specific sites can be found in Figure 1.

PSS (total)	PSS 1	PSS 12
30	14	22
PFO (total)	PFO 19	PFO 22
67	36	45
PEM (total)	PEM 22	PEM 25
49	34	23

Table 3. Total number of Carolina bays dominated by palustrine emergent (PEM), forested (PFO), or scrub-shrub (PSS) vegetation on all protected, heritage, or state-owned lands in South Carolina based on National Wetland Inventory and SCDNR Stewardship coverage and adapted from Marlowe (2008).

Dominant Vegetation	Number of Bays	<5% Impacted
PEM	8	1
PFO	81	22
PSS	42	9

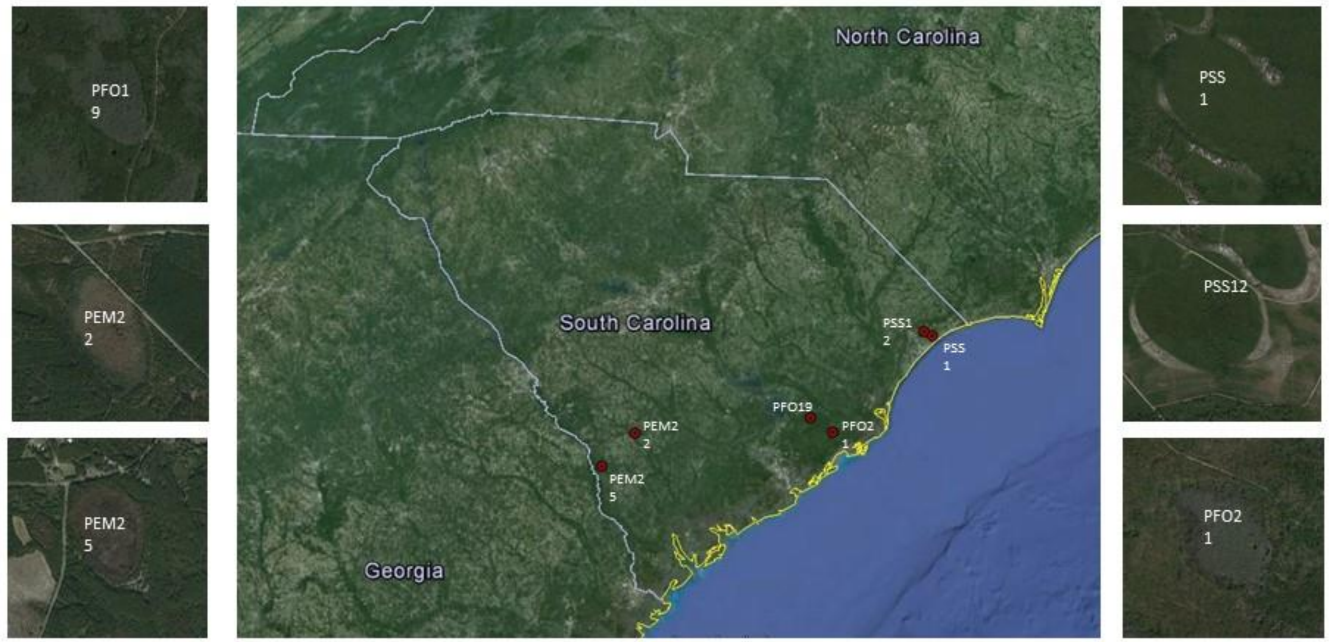

Figure 1. Aerial image of South Carolina, with red dots indicating the location of the six Carolina bays sampled in this study, accompanied by magnified aerial images of each bay. Both palustrine scrub-shrub (PSS) bays are located on Lewis Ocean Bay Heritage Preserve, both palustrine forested (PFO) bays are located on Francis Marion National Forest, and both palustrine emergent (PEM) bays are located on private land where landowners granted research access.

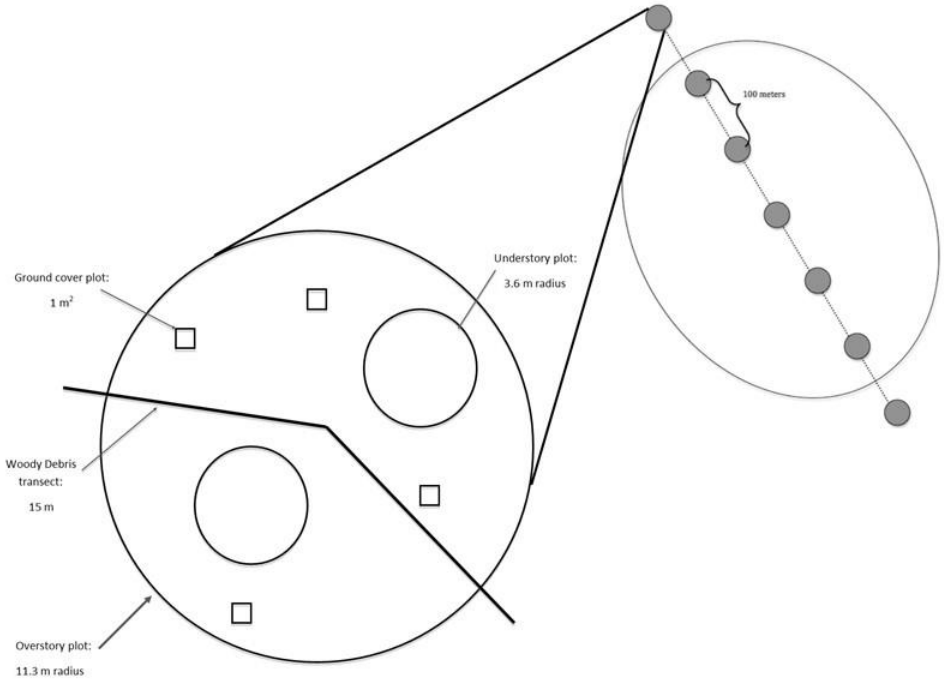

Figure 2. Diagram of transect through a Carolina bay, with enlarged sampling station showing sampling plots for vegetation and woody debris

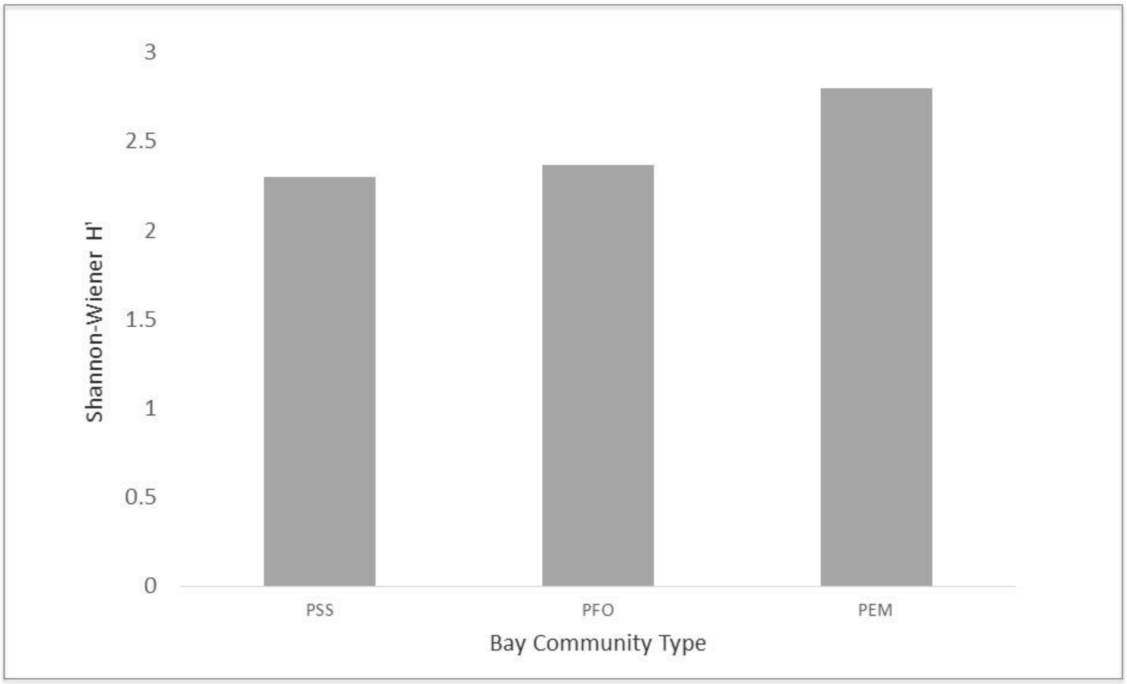

Figure 3. A statistical comparison among Shannon Weiner diversity (H') relative plant community type (i.e., emergent (PEM), scrub/shrub (PSS), and forested (PFO)). Using the SW diversity t-test (Magurran 1988), significant differences exist between PEM and PFO (p= 3.50 E-16) and between PEM and PSS (p= 3.02 E-55).

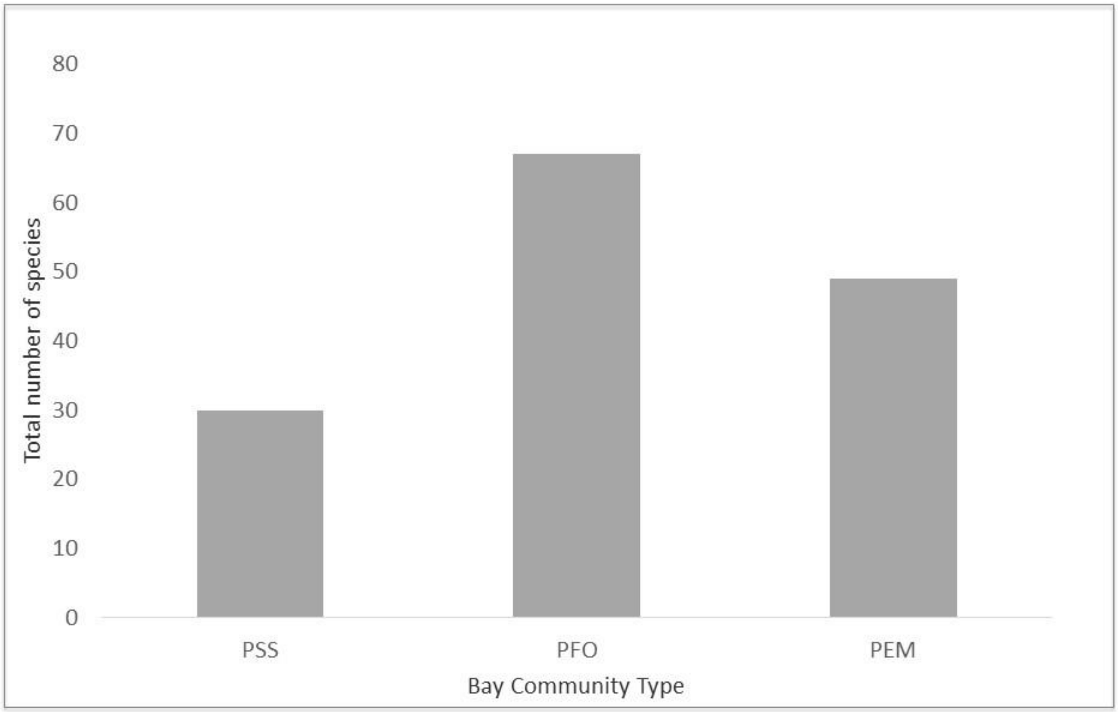

Figure 4. Species richness of three Carolina bay community types (i.e., emergent, scrub/shrub, and forested), reflective of two bays of each type, for a total of 89 species, divided among forested (67 spp.), emergent (49 spp.), and scrub/shrub (30 spp.)

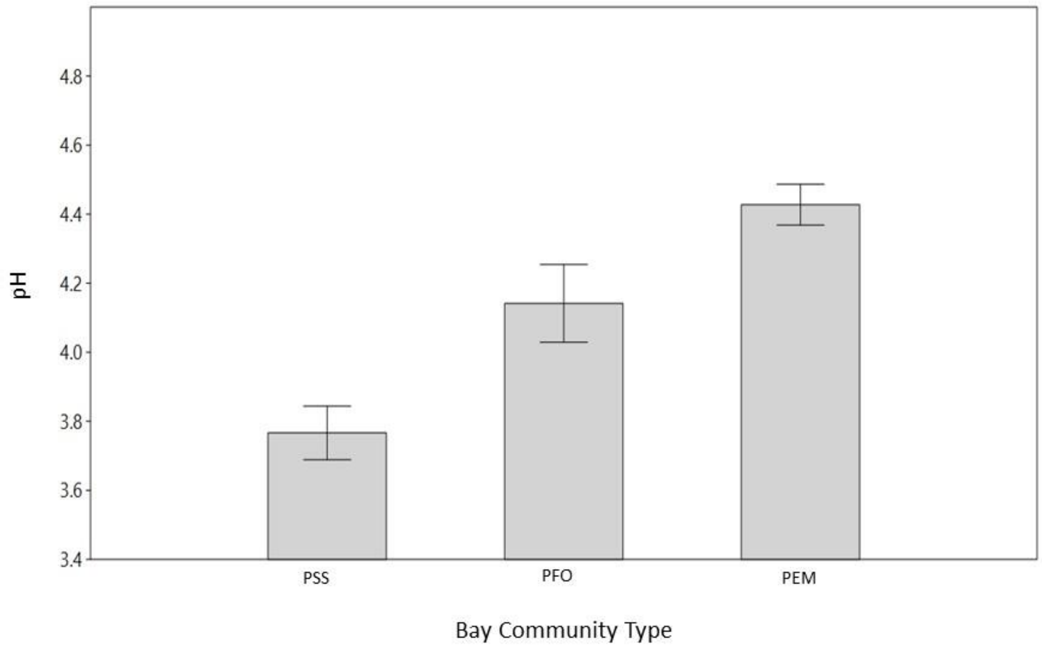

Figure 5. A comparison of average soil pH of six Carolina bays, relative bay type (i.e., palustrine scrub shrub (PSS), forested (PFO), or emergent (PEM)). Significant differences exist between all bay types (p=1.71E-05)

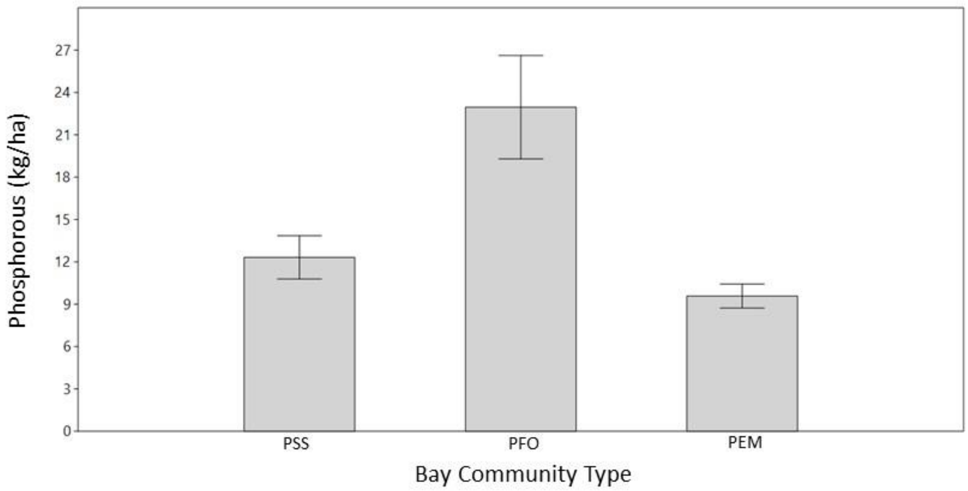

Figure 6. Mean soil phosphorous content (kg/ha) sampled across bays dominated by three palustrine vegetation classes (scrub-shrub (PSS), forested (PFO), and emergent (PEM)). Soil samples were taken from 49 plots across 6 bays (18 PSS, 12 PFO, and 18 PEM plots) and sent to Clemson Extension for analysis. (p=0.0009)

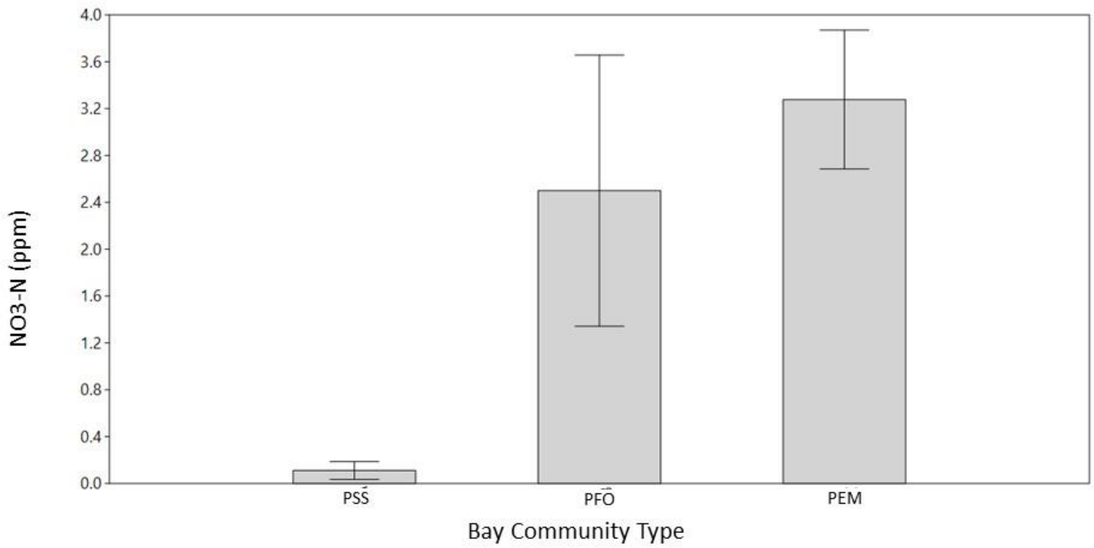

Figure 7. Mean soil nitrate (NO3-N) content (ppm) sampled across bays dominated by three palustrine vegetation classes (scrub-shrub (PSS), forested (PFO), and emergent (PEM)). Soil samples were taken from 49 plots across 6 bays (18 PSS, 12 PFO, and 18 PEM plots) and sent to Clemson Extension for analysis. (p=6.189E-05)

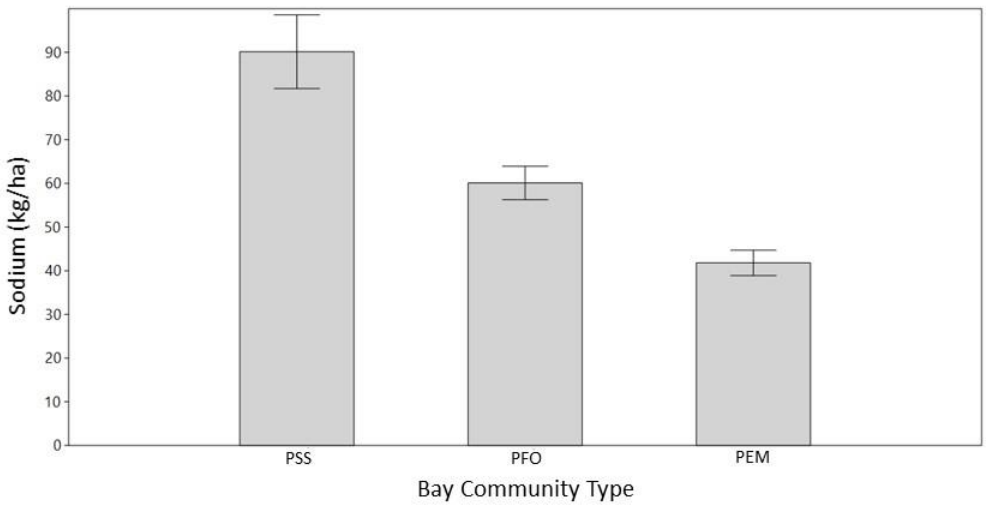

Figure 8. Mean soil sodium content (kg/ha) sampled across bays dominated by three palustrine vegetation classes (scrub-shrub (PSS), forested (PFO), and emergent (PEM)). Soil samples were taken from 49 plots across 6 bays (18 PSS, 12 PFO, and 18 PEM plots) and sent to Clemson Extension for analysis. (p=2.495E-05)

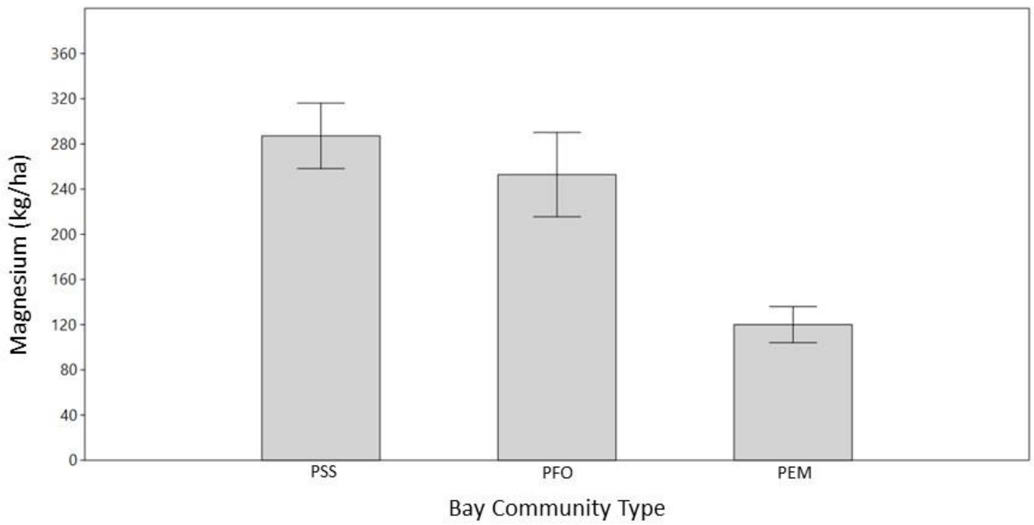

Figure 9. Mean soil magnesium content (kg/ha) sampled across bays dominated by three palustrine vegetation classes (scrub-shrub (PSS), forested (PFO), and emergent (PEM)). Soil samples were taken from 49 plots across 6 bays (18 PSS, 12 PFO, and 18 PEM plots) and sent to Clemson Extension for analysis. ($p=0.0001275$)

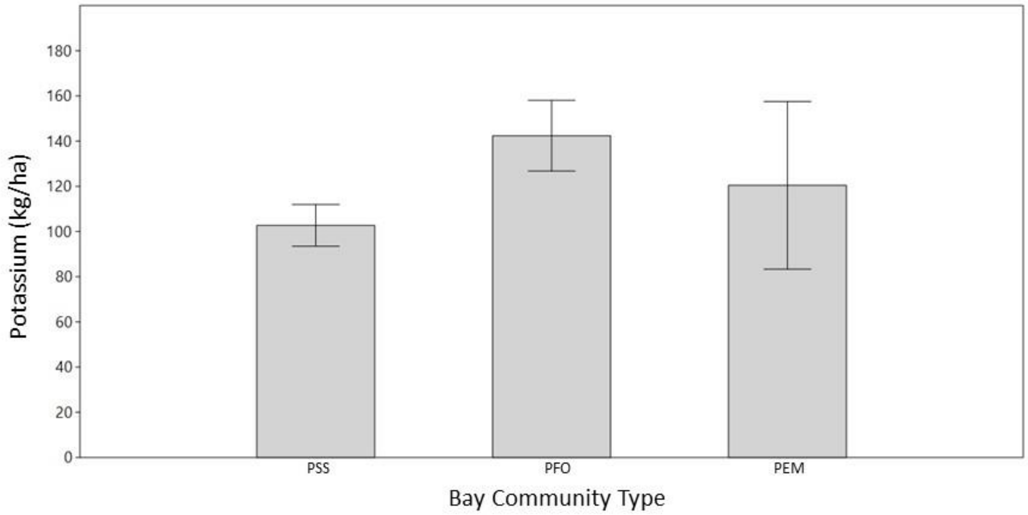

Figure 10. Mean soil potassium content (kg/ha) sampled across bays dominated by three palustrine vegetation classes (scrub-shrub (PSS), forested (PFO), and emergent (PEM)). Soil samples were taken from 49 plots across 6 bays (18 PSS, 12 PFO, and 18 PEM plots) and sent to Clemson Extension for analysis. (p=0.0247)

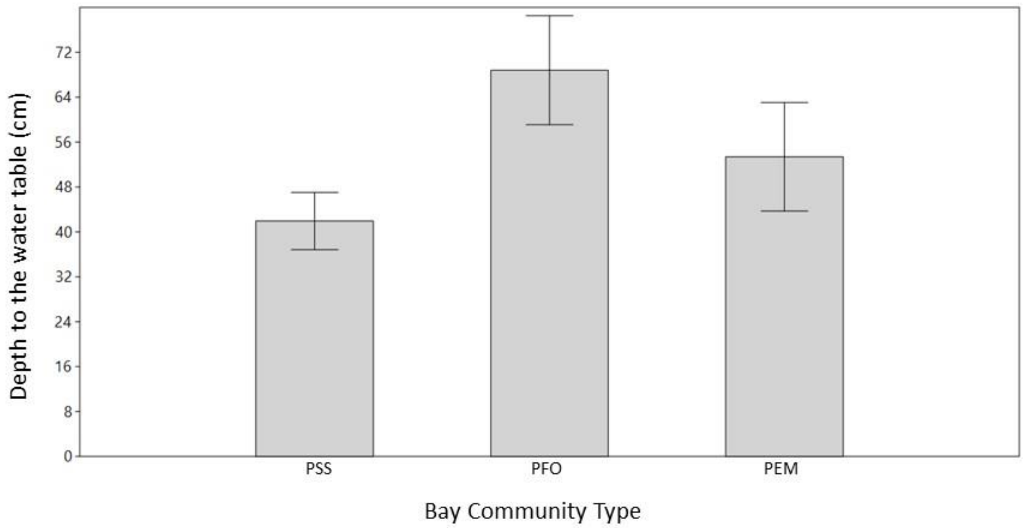

Figure 11. Mean depth to the water to the water table, sampled across bays dominated by three palustrine vegetation classes (scrub-shrub (PSS), forested (PFO), and emergent (PEM)). Measurements (up to 100 cm) were taken from 49 plots across 6 bays (18 PSS, 12 PFO, and 18 PEM plots) (p=0.2231)

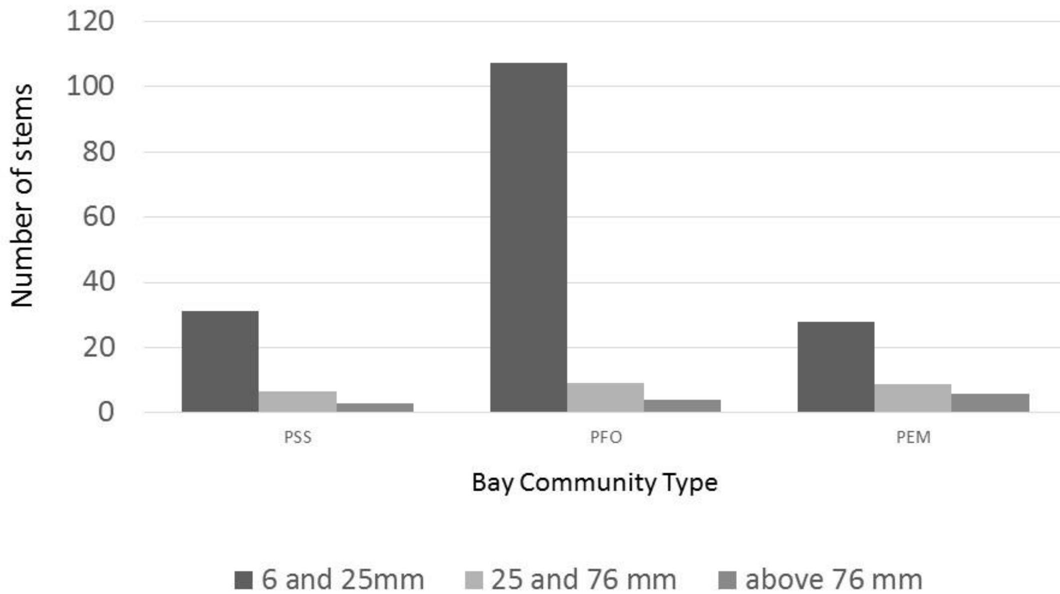

Figure 12. Average number of woody debris stems encountered at each sampling point classified by size (6-25 mm, 25-76 mm, or above 76 mm), across bays dominated by three palustrine vegetation classes (scrub-shrub (PSS), forested (PFO), and emergent (PEM)). Woody debris was measured along two 15m transects at each sampling point (total of 49 sampling points).

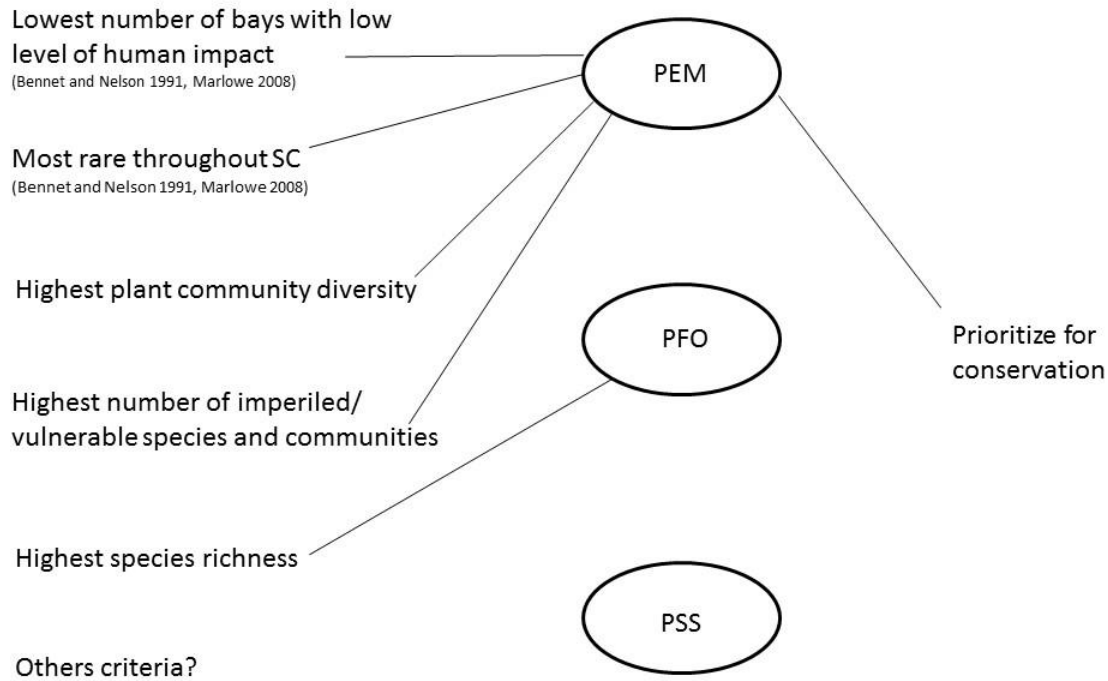

Figure 13. Three dominant vegetation classes evaluated in this study and the potential criteria for conservation prioritization that apply to each class within the six Carolina bays sampled.

Acer rubrum	Juncus effusus	Rhexia aristosa
Ampelopsis arborea	Juncus repens	Rhynchospora careyana
Aralia spinosa	Lachnocaulon beyrichianum	Rhynchospora inundata
Asplenium platyneuron	Leersia hexandra	Rhynchospora macrostachya
Aster sp.	Leucothoe axillaris	Rhynchospora microcephala
Berchemia scandens	Leucothoe racemosa	Rubus cuneifolius
Carex striata	Liquidambar styraciflua	Saccharum giganteum
Carex turgescens	Lycopus rubellus	Sarracenia flava
Carex walteriana	Lyonia lucida	Sarracenia rubra
Cassia fasciculata	Magnolia virginiana	Scirpus cyperinus
Celtis laevigata	Morella cerifera	Smilax laurifolia
Cephalanthus occidentalis	Nyssa biflora	Smilax rotundifolia
Chamaedaphne calyculata	Onoclea sensibilis	Taxodium ascendens
Cladium mariscus	Osmunda regalis	Toxicodendron vernix
Clethra alnifolia	Panicum hemitomon	Triadenum Virginicum
Cyrilla racemiflora	Panicum sp.	Ulmus alata
Dichanthelium wrightianum	Panicum verrucosum	Vaccinium angustifolium
Diospyros virginiana	Parthenocissus quinquefolia	Vaccinium corymbosum
Dulichium arundinaceum	Persea borbonia	Vaccinium crassifolium
Eleocharis equisetoidus	Pinus palustris	Viburnum nudum
Eupatorium capillifolium	Pinus serotina	Vitis rotundifolia
Gelsemium sempervirens	Pinus taeda	Woodwardia areolata
Gordonia lasianthus	Pleopeltis polypodioides	Woodwardia Virginica
Hypericum cistifolium	Pontederia Lanceolata	Xyris fimbriata
Hypericum fasciculatum	Prunus caroliniana	Zenobia pulverulenta
Ilex coriacea	Quercus austrina	Unk 1
Ilex glabra	Quercus laevis	Unk 2
Ilex myrtifolia	Quercus laurifolia	Unk 3
Ilex opaca	Quercus nigra	Unk 4
Iris tridentata	Quercus phellos	

Appendix 1. Plant species encountered in sampling plots from all six bays sampled (PSS 1 and 12, PFO 19 and 21 and PEM 22 and 25)

U.S. Department of Commerce
National Oceanic & Atmospheric Administration
National Environmental Satellite, Data, and Information Service

Annual Climatological Summary
(2011)
Generated on 04/13/2016

National Centers for Environmental Information
151 Patton Avenue
Asheville, North Carolina 28801

Elev: 39 ft. Lat: 33.754° N Lon: 78.822° W
Station: **MYRTLE BEACH, SC US COOP:386153**

Date	Temperature (F)														Precipitation (inches)									
Elem->	MMXT	MMNT	MNTM	DPNT	HTDD	CLDD	EMXT		EMNT		DT90	DX32	DT32	DT00	TPCP	DPNP	EMXP		TSNW	MXSD		DP01	DP05	DP10
											Number Of Days						Greatest Observed		Snow, Sleet			Number Of Days		
Month	Mean Max.	Mean Min.	Mean	Depart. from Normal	Heating Degree Days	Cooling Degree Days	Highest	High Date	Lowest	Low Date	Max >=90	Max <=32	Min <=32	Min <=0	Total	Depart. from Normal	Day	Date	Total Fall	Max Depth	Max Date	>=.10	>=.50	>=1.0
1	48.8X	29.1X	39.0X			0	66	02	16	24	0	1	18	0	2.00X		0.77	26	0.0			6	2	0
2	59.2X	41.2X	50.2X				75	22	29	13	0	0	3	0	4.16X		1.85	05	0.0			6	3	1
3							85	24	34	13									0.0					
4	72.7X	54.1X	63.4X				87	21	38	06	0	0	0	0	0.46X		0.21	01	0.0			2	0	0
5	78.8	62.2	70.5		19	199	91	28	46	05	2	0	0	0	4.88	1.90	2.22	11	0.0			6	2	2
6	87.6	71.1	79.4		0	440	97	21	66	06	7	0	0	0	0.64	-3.02	0.33	24	0.0			3	0	0
7	87.5X	73.0X	80.3X		0		93	27	66	17	8	0	0	0	3.16X		1.10	26	0.0			4	3	1
8	87.9	71.5	79.7		0	464	96	03	65	31	10	0	0	0	4.82	-0.76	2.20	27	0.0			5	3	3
9	81.9	65.2X	73.6X				88	11	58	19	0	0	0	0	4.93	-0.65	1.90	23	0.0			7	3	2
10	74.1	49.5	61.8		117	24	86	01	34	31	0	0	0	0	3.31	0.08	1.40	19	0.0			4	4	1
11	70.9X	41.5X	56.2X				76	24	31	20	0	0	6	0	3.86X		1.47	29	0.0			5	4	1
12	64.1X	38.7X	51.4X			0	75	17	31	30	0	0	7	0	0.60	-2.85	0.20	28	0.0			3	0	0
Annual	74.0*	54.3*	24.3		136*	1127	97	Jun	16	Jan	27*	1*	34*	0*	32.82	-5.30	2.22*	May*	0.0*			51*	24*	11*

Notes

(blank) Data element not reported or missing.
+ Occurred on one or more previous dates during the month. The date in the Date field is the last day of occurrence. Used through December 1983 only.
A Accumulated amount. This value is a total that may include data from a previous month or months or year (for annual value).
B Adjusted total. Monthly value totals based on proportional available data across the entire month.
E An estimated monthly or annual total.
X Monthly means or totals based on incomplete time series. 1 to 9 days are missing. Annual means or totals include one or more months which had 1 to 9 days that were missing.
T Trace of precipitation, snowfall, or snowdepth. The precipitation data value will equal zero.
Elem Element types are included to provide cross-reference for users of the NCDC CDO system.
Station Station is identified by: COOP ID, Station Name, State
S Precipitation amount is continuing to be accumulated. Total will be included in a subsequent monthly or yearly value. Example: Days 1-20 had 1.35 inches of precipitation, then a period of accumulation began. The element TPCP would then be 00135S and the total accumulated amount value appears in a subsequent monthly value.
* Annual value missing; summary value computed from available month values.

Appendix 2. Annual climatological summary from the National Oceanic and Atmospheric Administration for Myrtle Beach, SC (Near PSS1 and PSS12).

U.S. Department of Commerce
National Oceanic & Atmospheric Administration
National Environmental Satellite, Data, and Information Service

Annual Climatological Summary
(2011)
Generated on 04/13/2016

National Centers for Environmental Information
151 Patton Avenue
Asheville, North Carolina 28801

Elev: 49 ft. Lat: 33.242° N Lon: 79.987° W
Station: **MONCKS CORNER 4 N, SC US COOP:385946**

Date	Temperature (F)														Precipitation (inches)									
Elem->	MMXT	MMNT	MNTM	DPNT	HTDD	CLDD	EMXT		EMNT		DT90	DX32	DT32	DT00	TPCP	DPNP	EMXP		TSNW	MXSD		DP01	DP05	DP10
											Number Of Days						Greatest Observed		Snow, Sleet			Number Of Days		
Month	Mean Max.	Mean Min.	Mean	Depart. from Normal	Heating Degree Days	Cooling Degree Days	Highest	High Date	Lowest	Low Date	Max >=90	Max <=32	Min <=32	Min <=0	Total	Depart. from Normal	Day	Date	Total Fall	Max Depth	Max Date	>=.10	>=.50	>=1.0
1	53.5				688	0	77	02	19	14	0	0	19	0	2.44		0.73	11	0.0			7	1	0
2	65.5				297	18	83	04	30	13	0	0	4	0	4.05		1.46	05	0.0			7	3	1
3	70.8				245	26	86	24	34	30	0	0	0	0	4.12		1.17	28	0.0			7	4	1
4	79.3				79	150	89	25	39	02	0	0	0	0	2.31		0.56	22	0.0			7	2	0
5	85.3X	60.9X	73.1X				96	23	44	07	9	0	0	0	3.48X		0.86	07	0.0			6	5	0
6	95.4				0	560	100	24	63	11	30	0	0	0	0.68		0.34	24	0.0			3	0	0
7	95.8				0	620	103	23	66	07	29	0	0	0	5.08		1.80	10	0.0			7	4	2
8	94.1				0	574	101	05	65	16	26	0	0	0	5.36		2.45	01	0.0			9	4	1
9	86.9				4	336	95	16	54	21	14	0	0	0	5.45		1.69	07	0.0			7	5	1
10	75.8				98	70	88	01	31	30	0	0	1	0	1.70X		0.54	11	0.0			4	2	0
11	71.8				220	27	83	17	30	19	0	0	3	0	2.04		1.18	29	0.0			3	1	1
12	66.2						82	23	27	02					0.47		0.20	26	0.0			3	0	0
Annual	78.4*	60.9*	0.0		1631*	2381	103	Jul	19	Jan	108*	0*	27*	0*	37.18		2.45*	Aug*	0.0*			70*	31*	7*

Notes

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E An estimated monthly or annual total.

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T Trace of precipitation, snowfall, or snowdepth. The precipitation data value will equal zero.
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Station Station is identified by: COOP ID, Station Name, State

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* Annual value missing; summary value computed from available month values.

Appendix 3. Annual climatological summary from the National Oceanic and Atmospheric Administration for Moncks Corner, SC (near PFO19 and PFO21).

U.S. Department of Commerce
National Oceanic & Atmospheric Administration
National Environmental Satellite, Data, and Information Service

Annual Climatological Summary
(2011)
Generated on 04/13/2016

National Centers for Environmental Information
151 Patton Avenue
Asheville, North Carolina 28801

Elev: 245 ft. Lat: 33.256° N Lon: 81.242° W
Station: **BARNWELL 5 ENE, SC US COOP:380490**

Date	Temperature (F)														Precipitation (inches)									
Elem->	MMXT	MMNT	MNTM	DPNT	HTDD	CLDD	EMXT		EMNT		DT90	DX32	DT32	DT00	TPCP	DPNP	EMXP		TSNW	MXSD		DP01	DP05	DP10
											Number Of Days						Greatest Observed		Snow, Sleet			Number Of Days		
Month	Mean Max.	Mean Min.	Mean	Depart. from Normal	Heating Degree Days	Cooling Degree Days	Highest	High Date	Lowest	Low Date	Max >=90	Max <=32	Min <=32	Min <=0	Total	Depart. from Normal	Day	Date	Total Fall	Max Depth	Max Date	>=.10	>=.50	>=1.0
1	54.5	30.2	42.4		695	1	76	31	15	14	0	1	21	0	1.94		0.49	11	0.0			7	0	0
2	65.0	38.0	51.5		371	3	83	28	25	12	0	0	8	0	3.91		1.35	05	0.0			6	3	2
3	71.6	43.0	57.3		261	31	90	20	27	12	1	0	5	0	5.17		1.61	27	0.0X	0		7	5	2
4	80.9	52.0	66.5		90	142	92	10	35	06	4	0	0	0	1.55		0.65	05	0.0X	0		5	1	0
5	87.3	59.0	73.2		25	286	101	24	44	18	14	0	0	0	1.43		0.45	27	0.0			5	0	0
6	97.1	68.7	82.9		0	545	101	27	64	11	30	0	0	0	4.92		2.78	29	0.0			4	3	2
7	95.8	71.6	83.7		0	589	102	22	65	18	28	0	0	0	6.79		3.00	10	0.0X	0		5	4	3
8	94.9	70.7	82.8		0	560	104	04	64	28	29	0	0	0	7.23		1.50	07	0.0			11	7	2
9	87.5	63.3	75.4		3	322	97	16	54	10	14	0	0	0	4.76		0.80	23	0.0			9	5	0
10	76.0	48.3	62.2		124	45	89	01	32	30	0	0	1	0	1.80		0.92	19	0.0			4	1	0
11	71.4	42.6	57.0		261	26	83	17	25	12	0	0	5	0	1.40		0.70	17	0.0			2	2	0
12	65.7X	38.7X	52.2X				79	07	25	29	0	0	9	0	1.28X		0.54	27	0.0X	0		5	1	0
Annual	79.0*	52.2*	61.2		1830*	2550	104	Aug	15	Jan	120*	1*	49*	0*	42.18		3.00*	Jul*	0.0*	0*	Dec*	70*	32*	11*

Notes

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Appendix 4. Annual climatological summary from the National Oceanic and Atmospheric Administration for Barnwell, SC (near PEM22 and PEM25).