APPLICATIONS OF ISLAND BIOGEOGRAPHY:

PLANT DIVERSITY AND SOIL CHARACTERISTICS OF

BACK-BARRIER ISLANDS NEAR SAPELO ISLAND, GEORGIA

by

GAYLE L. ALBERS

(Under the Direction of Merryl Alber)

ABSTRACT

This work reviews Georgia coastal policy with respect to the bridging of back-barrier islands (BBIs), or marsh hammocks. It characterized plant and soil composition on BBIs near Sapelo Island, Georgia. Species richness of fourteen BBIs was examined according to the theory of island biogeography. Eighty-three species were observed in 52 100 m^2 plots. *Quercus virginiana* and *Ilex vomitoria* were the dominant overstory and understory plants, respectively, in these maritime forest communities. Linear regression analyses showed that biogeographic variables contributed to ~30% of the variance; island size and origin were important predictors of diversity. Soil analyses indicated fine sands with low nitrogen (≤ 2%) and variable carbon values (1.7-48%). Nonmetric multidimensional scaling showed differences in species composition based on plot location and soil C:N ratios that were not reflected in diversity analyses. Resource managers may use these findings to designate sensitive areas and develop policies that promote their sustainable use.

INDEX WORDS: Back-barrier island, marsh hammock, biogeography, plant species richness, maritime forest, soil nutrients, coastal policy, NMDS

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DEDICATION

I dedicate this thesis to my devoted husband, Christopher W. Kuhar, who has shared in the many joys and challenges, throughout our academic journeys together. I love you to the moon and back. I also dedicate this work to my dear family, who have always cheered me along and traveled far and wide to visit me, despite their puzzlement at my career choice; the many wonderful friends across the states who have inspired me in ways that they may not even realize; and my two incredible dogs who have given me much comic relief and stress therapy. I cherish all of you. I also acknowledge the memories of Dr. Eugene Odum, who had the intellect, vision and dedication to help forge the bridge between coastal science and policy and Dr. Suess, the late creator of my favorite conservation-minded character, the Lorax, who had the courage to "speak for the trees."

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TABLE OF CONTENTS

APPENDIX

LIST OF TABLES

LIST OF FIGURES

Page

CHAPTER 1

GEORGIA MARSH HAMMOCK POLICY DEVELOPMENT

OVERVIEW OF GEORGIA COASTAL POLICY

Georgia's coast has a diverse landscape that includes barrier islands, extensive marshlands, and estuaries, all of which are experiencing increased development pressure. Georgia's Coastal Management Program primarily governs activities in the state's coastal areas in order to balance economic development with the preservation of coastal resources for the benefit of Georgia's present and future generations (NOAA and GDNR, 1997, 2003). The rich natural and historic resources and recreational opportunities that exist on the coast support thousands of people who are employed in the tourist, commercial fishing, shipping, manufacturing, and timber industries. These same natural attributes continue to draw development to the Georgia coastline, and increased tourism and sustained industrial activities have been identified as contributing factors to the coast's rapid urbanization (NOAA and GDNR, 1997, 2003). A 25% increase in population was predicted for Georgia's coastal counties between 1990 to 2010, exceeding the average national coastal population growth rate by 5% (US Census). In the face of these pressures, there have been increased challenges to public policies that were designed and enacted to protect the state's valuable coastal areas for the benefit of its people. In particular, Georgia's coastal wetlands and beaches continue to be threatened by intense development interests. This chapter provides a review of Georgia's existing coastal policy in light of current litigation regarding proposed development activities in sensitive coastal areas.

Georgia's Coastal Management Program (GCMP) was federally approved in January 1998, six years after the initial state efforts were begun, making Georgia the 32nd state to participate in the National Coastal Zone Management Program. The GCMP is consistent with The Federal Coastal Zone Management Act of 1972, as amended (CZMA; 16 U.S.C. § 1451 et seq.), which is a voluntary program that was created to help states to develop and administer comprehensive coastal programs. By definition, Georgia's coastal zone extends 2,344 miles north to south and approximately 60 miles inland to encompass eleven counties: Brantley, Bryan, Camden, Charlton, Chatham, Effingham, Glynn, Liberty, Long, McIntosh, and Wayne. Georgia's Coastal Management Program was framed by three important legislative policies that were implemented during the past three decades: the Georgia Coastal Management Act (OCGA § 12-5-320, et seq.), the Coastal Marshland Protection Act (OCGA § 12-5-280, et seq.), and the Shore Protection Act (OCGA § 2-5-230, et seq.). Together, these laws serve to protect the "natural resource system that is costly, if not impossible, to reconstruct once adversely affected by human activities and is important to conserve for the present and future use and enjoyment of all citizens and visitors to this state" (Code 1981, §12-5-231 and §12-5-281, enacted by Ga. L. 1992, p. 2294, §1 and 1362, §1).

The Georgia Coastal Management Act (GCMA) was critical to the approval of GCMP, because it mandates cohesion among various statutory and regulatory authorities. It establishes the consistency and coordination necessary among 13 existing state agencies that are empowered in the coastal zone as defined above by 34 state laws and their associated regulations under one program. The legislation designates specific administrative authority within the coastal zone to the Georgia Department of Natural Resources (OCGA § 12-5-323). In addition, this legislation mandates that other local and state governmental entities (i.e., the Georgia Soil and Water

Conservation Commission) establish cooperative agreements with the GDNR to determine jurisdictional and regulatory duties related to the implementation of the Georgia Coastal Management Program.

The Marshland Protection Act was passed into law in 1970. The impetus for this law was a phosphate-mining project proposed by Kerr-McGee Corporation in 1968 that threatened the natural status of wetlands along the coast of Georgia. The late Dr. Eugene Odum at the University of Georgia worked with a coalition of concerned citizens, students, and legislators to raise awareness about both the ecological and economic significance of Georgia's marshes through a "Save Our Marshes" campaign. Their efforts brought national attention through a conservation article published by *Life* magazine (Craige, 2001). Along with Brunswick Representative Reid Harris, Odum helped to craft the legislation that serves to monitor development of Georgia's marshes. The Marshland Protection Act identifies the state's marshlands as "a vital natural resource system that affords habitat for species of marine life and wildlife, food for their survival, nursery areas for commercial and recreational fisheries, and for the control of flood, erosion, and pollution" (OCGA § 12-5-281). The jurisdictional area includes all tidally influenced waters, marshes, and marshlands lying below an elevation of 5.6 feet above mean tide level and below (OCGA § 12-5-282(7)). Although the CMPA does not prohibit construction in the marshes, it does require that any proposed activities meet specific criteria stated in the legislation in order to be permitted (OCGA § 12-5-286). For example, a permit applicant must satisfy the public interest test pursuant to OCGA § 12-2-286(g)[1] and verify that no feasible alternative sites exist for the proposed activity (OCGA § 12-2-286(h). The permit applicant must also demonstrate that the proposed project is water-dependent (OCGA § 12-5-288). The CMPA explicitly states that a bridge or causeway ("structure") that is constructed on or over the state's marshland must have a state permit (OCGA § 12-5-286(a)). Note, however, that private-use recreational docks are exempt under the CMPA. In these cases, a Revocable License from the state and a dock permit from the US Army Corp of Engineers, who administer a general permit for the state, are required.

The Shore Protection Act of 1979 serves to protect and manage the sand-sharing systems, which includes sand dunes, beaches, sandbars and shoals. This act limits construction activities to the minimum necessary impact by permit when the activity alters the natural topography or vegetation within the sand-sharing system. It prohibits motorized vehicular use on dunes and beaches and permanent construction in the dunes where feasible. The state has jurisdiction over all submerged shoreline lands to 3 miles seaward, sand beaches to the ordinary high water mark, and the "dynamic dune field." The dynamic dune field is the area that exists between the ordinary high water mark and landward boundary of the first live native tree 20 feet in height or greater, or of an existing structure on July 1, 1979 (OCGA § 12-5-232(8)). The Shore Protection Act also requires that the permit applicant demonstrate that the proposed project is within the

[1] Public interest considerations include: (1) whether or not unreasonably harmful obstruction to or alteration of the natural flow of navigational water within the affected area will arise as a result of the proposal, (2) whether or not unreasonably harmful or increased erosion, shoaling of channels or stagnant areas of water will be created; and (3) whether or not granting of a permit and the completion of the applicant's proposal will unreasonably interfere with the conservation of fish, shrimp, oysters, crabs, clams, or other marine life, wildlife, or other resources, including but not limited to water and oxygen supply.

public interest, that no feasible alternative sites exist, and that the sand-sharing system will not be significantly impaired.

Permit applications that fall within the purview of either the Coastal Marshland Protection Act or the Shore Protection Act are reviewed by three-member committees appointed by the Board of the Georgia Department of Natural Resources (GDNR). The committee's role is to review the construction and development projects and issue an order for approval or denial within their jurisdiction within 90 days of completion of the application. Any person aggrieved or adversely affected by the outcome of a permit decision has the right to appeal the decision in an administrative hearing (OCGA § 12-5-283, OCGA § 12-5-244, respectively).

Presently, The Georgia Coastal Resources Division (GCRD) of GDNR administers all programs within the Georgia Coastal Management Program. With the approval of the GCMP, the state provides technical assistance through government grants, public education regarding coastal resources and their thoughtful management, federal consistency with existing projects, and improved monitoring of coastal natural resources. The program also designates four special management categories: 1) areas of particular concern, 2) areas of preservation and restoration, 3) shorefront access and protection planning and 4) shoreline erosion and hazard mitigation (NOAA CZM, 1997, 2003). Specifically, these areas include barrier islands, marsh hammocks, areas of historical, cultural and paleontological significance, aquifer management and protection areas, state wildlife management areas, Sapelo Island Estuarine Research Reserve, and beach and shorefront access areas. Because these areas are identified as unique and either environmentally fragile or economically significant to the coast and the State, increased management or regulatory controls may apply.

MARSH HAMMOCK CASE STUDY

The small islands surrounded by marshlands or tidal creeks and nested between the mainland and larger barrier islands are known in Georgia as marsh hammocks[2]. They range in size from less than an acre to more than one hundred acres. Accessing a hammock from the mainland often requires crossing state owned marshlands. Although over 100 hammock related bridges or causeways currently exist on the Georgia coast, many were constructed prior to the passage of the Marshland Protection Act. According to state records, only seven bridge permits to hammocks were granted between 1973 and 1993, but this has doubled to 14 during the recent decade (Williams, 2003). This is in keeping with a general increase in permitting; the Coastal Marshlands Protection and Shore Protection Committees issued a total of 83 permits for projects along Georgia's marshes and beaches in 2003 alone (GDNR, 2003). The increased development pressure in coastal Georgia has made marsh hammocks an attractive location for residential growth, which has tested the strength of the Coastal Marshland Protection Act.

A case in point, Emerald Pointe Development, LCC, applied for three bridge permits to plan a 40-unit residential development and marina on three hammocks (two of natural origin and one of dredge spoil) near Savannah on September 7, 2000. The Marshland Protection Committee granted CMPA Permit No. 404 on February 5, 2001, after considering public comments and requesting additional information from the applicant regarding clear title to the lands, bridge dimensions, and utility crossings. In the applicant's deed to the lands, the State Properties Committee had given the applicant explicit rights to cross state marshlands to access his property for development. The permit authorized three bridges to be built to accommodate

[2] Note that hammocks are formally defined as forested islands adjacent to salt marshes that exist as a result of a number of processes such as: the remnants of old barrier islands formed during times of higher sea level; islands separated from larger islands by erosion; formations from ballast dumped by ships during the colonial era; or dredge spoil sites (NOAA CZM, 1997, 2003).

water, sewer, etc., according to the following specifications: 22.5 ft. wide (by 240, 300 and 390 ft. long) and 12.5 ft. in elevation (5 ft. above mean high water) with piling spans at 30 ft. intervals. Additional conditions were imposed (i.e., incorporating the best technology available for containing bridge runoff, requiring a cultural survey of the impacted areas, and implementing vegetated buffer areas along the hammocks' perimeters) in order to satisfy criteria for minimizing impacts to the marsh. In response to public opposition to this decision, three conservation organizations (Center for Sustainable Development, The Altamaha Riverkeepers and Georgia Sierra Club) represented by The Southern Environmental Law Center (SELC), filed a suit against the Coastal Marshland Protection Committee, GNDR and Emerald Pointe Development, LCC, in March 2001, challenging the permit. The specifics of the case are discussed later in this chapter.

When the CMPA permit was opposed, it was clear to government officials that the hammock issue would require further attention. In February 2001, Lonice Barrett, Commissioner of GDNR, appointed the coastal marsh hammock advisory council (CMHAC) to investigate the issue. The CMHAC was a 15-member council comprised of professionals from various private, non-profit, and governmental sectors. They were charged with addressing several issues, including formally defining marsh hammocks, identifying their ecological significance, evaluating the impact of their continued development, and recommending a range of solutions to mitigate development impacts. The council also addressed research and management needs related to habitat loss, wastewater disposal, archeological resources, water quality due to runoff, and property rights, among others.

In their final report, issued in March 2002, the council stated that because "marsh hammock" is a colloquial term, there was difficulty in formally differentiating a back-barrier island from a marsh hammock (CMHAC, 2002). Specifically, the council failed to agree on a definition for a marsh hammock based on a size threshold (for example, less than 50 acres). Therefore, the CMHAC excluded barrier island complexes[3] and adopted the following working definition:

> Back–barrier islands are all other islands between the landward boundary of the barrier island complexes and the mainland. Natural back-barrier islands are erosional remnants of pre-existing upland, whereas man-made back barrier islands are comprised of dredge spoil matter or ballast stones. These islands may or may not have existing connections to the mainland by bridges, causeways, or other man-made structures (CMHAC, 2002).

Council members did agree that a marsh hammock is a small back-barrier island, but they recommended that if the General Assembly finds that protecting hammocks is in the public interest, it would need to define hammock as a back-barrier island of a certain size. The CMHAC report also catalogued the current status of back-barrier islands with regard to size, location, ownership, and development status. This initial effort determined that approximately 1200 hammocks exist along the coast, 85% of which are less than ten acres in size. However, only about 40 hammocks greater than 100 acres in size accounted for the majority of total acreage (17,000 acres) comprised by all Georgia hammocks. While county tax records indicated that more than half of the hammocks are privately owned, clear title to ownership was unavailable for many hammocks (CMHAC, 2002).

One of the things the CMHAC noted was the paucity of scientific information specifically related to the ecology of back-barrier islands, which hindered its ability to "seek an acceptable balance between conservation and development" (CMHAC, 2002). Beginning in

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[3] The Georgia barrier island complexes and their component units are: Cumberland Island (Cumberland Island and Little Cumberland Island) Jekyll Island, St. Simons Island (St. Simons Island, Sea Island and Little St. Simons Island), Wolf Island, Sapelo Island (Sapelo Island and Blackbeard Island), St. Catherines Island, Ossabaw Island, Wassaw Island and Tybee Island (Tybee Island, Little Tybee and Williamson Island) (CMHAC, 2002).

October 2001, a series of surveys was carried out by volunteer researchers to begin to address this issue. The Georgia Conservancy and Southern Environmental Law Center led intensive efforts to inventory the species of plants and birds on back-barrier islands, supported in part by grants from The Sapelo Foundation. Over a two-year period, they conducted three sampling trips, during which they visited a total of 23 back-barrier islands, ranging in size from 0.5 to 375 acres. A summary report was completed and published in September 2003 (Fabrizio and Calvi, 2003), indicating that small back-barrier islands (5-10 acres) support maritime forest habitats with a significant diversity of plant and bird species. In total, 16 bird species were observed on back-barrier islands that are rated as "high" or "highest" conservation priority for the region or federally listed as threatened and endangered. Furthermore, they showed that floral diversity tends to increase with island size up to 50 acres, at which point it reaches equilibrium.

A series of public hearings began on April 30, 2002 to discuss the CMHAC report and to propose management options to the GDNR Board. Some members of the council expressed concerns that the potential existed to permit too many bridges to back-barrier islands (CMAH, 2002) and documented comments regarding habitat loss, wastewater disposal, archeological resources, water quality, and maintaining scenic views. They also proposed management options that included the state's acquisition of high priority natural lands. Other proposals ranged from allowing structures that can adversely impact the surrounding estuarine system (i.e., bulkheads and on-site septic systems), to adopting new rules and regulations that would prohibit them altogether on back-barrier islands. Ultimately, these efforts were unsuccessful at reaching consensus on the myriad of alternatives being considered.

In June 2002, the CRD hired Consensus Solutions, Inc. of Atlanta, an independent facilitator, to assemble a representative stakeholder group and to reassess the options to best protect marsh hammocks. Twenty-four participants representing five stakeholder sectors (development and realty, private landowners and state citizens, environmental organizations, and federal, state and local government) were involved in this effort. The stakeholder group was specifically directed by Commissioner Lonice Barrett to provide guidance concerning policies that are most protective of hammocks without violating private property rights or exceeding GDNR's statutory authority. This council made further progress in areas related to defining private and public property rights, governmental roles, and incentives for hammock preservation through simplified mechanisms for donations and acquisitions; yet, many of the same issues were left unresolved (i.e., addressing best management practices, scenic views, and wildlife and habitat losses). They produced a second advisory report that was published on June 30, 2003 (Consensus Solutions, 2003). Although the Board of Natural Resources approved the document, it directed smaller working groups to continue to develop relevant recommendations to be presented at the May 2004 GDNR Board meeting. Additional public hearings were held in early February 2004 to gauge public sentiment related to hammocks and to take comments on the 2003 report.

The issues associated with the development of Georgia's marsh hammocks received both regional and national attention. In November 2001, Scenic America, a conservation organization based in Washington, designated marsh hammocks among its top 10 "Last Chance Landscapes" because they were recognized as "endangered places of beauty and distinctive community character that face both a pending threat and a potential solution" (Davis, 2001). In addition, Sea Island Co., a locally owned development company donated four marsh hammocks to the state. These hammocks located in Glynn County totaled 10.2 acres and were valued at $2.3 million (Tharpe, 2002). The company followed with 2 more acres valued at $750,000 (Landers, 2002).

The litigation surrounding the contentious Emerald Pointe bridge permits is ongoing. The initial petition to sue Emerald Pointe Development, LCC, and the Marshland Protection Committee was filed on March 7, 2001. At the heart of the issue was the question of whether the Marshland Protection Committee should have considered the potential impact of the bridges more broadly. That is, the Committee based its decision to grant the permit based on considerations of the direct impact of the proposed bridges on the marsh rather than taking into consideration the indirect effects that development activities on the hammock might have on the marsh or cumulative impacts from similar projects. The lawsuit was filed on the following grounds:

1) the proposed project will destroy marsh habitat and unreasonably interfere with the conservation of fish, shrimp, oysters, crabs, clams and other wildlife in violation of the CMPA § 12-5-286(f)(3),
2) the developer failed to demonstrate that the project is in the public interest as required by CMPA § 12-5-286(h),
3) the developer failed to demonstrate that no feasible alternative sites exist as required by CMPA § 12-5-268(h),
4) permits should not be granted for projects that are not water related or dependent on waterfront access or that can be satisfied by the use of an alternative non-marshland site pursuant to CMPA § 12-5-288.
5) the application is incomplete because the developer failed to obtain a water quality certification from the State,
6) Federal and State permit conditions prohibit residential development of the largest hammock,
7) issuance of the permit would establish precedent that would lead to substantial adverse cumulative impacts to Georgia's coastal marshlands in violation of a legislative mandate to conserve this vital natural resources system (SELC, 2001).

In a hearing held October 29-31, 2001, Administrative Law Judge (ALJ) Jessie Altman found that under the CMPA the state permitting committee could only consider direct impacts of the bridge to the marshlands and that Emerald Pointe was within its rights to move forward with its construction process. The final order was handed down March 21, 2002 (Docket No. OSAH DNR-CM-01-19138-25-JRA).

This decision was appealed to the Superior Court of Fulton County, and on October 24, 2002, Justice Constance Russell determined that the ALJ erred in his narrow interpretation of the Act and in shifting the burden of proof to the petitioners. The ruling stated that the Marshland Protection Committee does have the right to consider how a proposed project *in its entirety* affects the marshes, including the residential development on marsh hammock uplands (Civil Action No. 2002CV52219). Justice Russell specifically stated that “a project *in the marsh* does not exist in a vacuum” and that “bridges…are not roads to nowhere”. Therefore, the case was reversed and remanded to the administrative court.

On June 7, 2003, Judge Jessie Altman again upheld the Committee’s decision to grant permit 404 (Arnall Golden Gregory, LLP, 2003). This time, the ALJ ruled that the entire project had been given due consideration and that it indeed passed the public interest test. Specifically, the court opinion stated that the project would not result in an unreasonably harmful obstruction to the natural flow of waters, increase erosion, etc., or interfere with the conservation of fish, shrimp, or other marine wildlife. The permitted plans for the residential developments also incorporated vegetated swales along roads, vegetated buffers around the perimeter of hammocks, and monitoring of storm water runoff during construction activities, and these efforts were deemed adequate to mitigate impacts under the current legislation. Judge Altman noted that the loss of 0.48 acres of marsh grass (due to the bridge’s construction) was the most significant impact to the marsh, but that this was insufficient to demonstrate unreasonable interference. He also made the point that constructing bridges to the hammocks is the least environmentally damaging method to access these areas. Petitioners appealed this decision to the Georgia Supreme Court on February 19, 2004, leaving Emerald Pointe Development, LCC, unable to proceed with the project until further determination.

Another recent court case has also influenced coastal wetland permitting and policy decisions in Georgia. Although it was not specific to marsh hammocks, it is relevant to the issue of the cumulative impacts to marshlands, which is the larger context for the Emerald Pointe debate. On August 7, 2001, the Coastal Marshland Protection Committee granted permit (No. 418), to Manhead Marina Inc, to build 109 wet slips on the Mackey River in Glynn County, which also raised concerns regarding the conservation of public trust resources. Residents and environmental organizations questioned whether the cumulative impacts to state-owned marshland were adequately considered during the permit process. In May 2003, a Superior Court Justice in Glynn County stated that the permit applicant provided insufficient evidence to address impacts from upland activities to surrounding marshlands, specifically with regard to transportation access and sewage disposal (Civil Action No. 02-01323 and 02-01311). Furthermore, Justice Amanda Williams remarked in the court's Final Order that "it was a legal error for the Committee to not consider traffic, waste, and runoff concerns and their potential impacts to the public interest as defined by OCGA § 12-5-826(g). To find otherwise would render the function of the Committee as intended by the General Assembly ineffective and meaningless." These comments suggest that the Committee had not been exercising its full authority regarding permit decisions in sensitive areas. The case was remanded to the ALJ for further review, but has since been settled out of court.

A total of twenty-one suits have been filed regarding the Coastal Marshland and Shore Protection Acts since 1992; however, most of these have involved the owners of lands adjacent to the permitted projects in question or disputes regarding ownership. Emerald Pointe is the only lawsuit that challenges impacts to marshlands caused by the bridging of marsh hammocks. Two other permits recently have been issued that propose impacts to marsh hammocks (Terra Firma and Little Satilla River developments), but neither has been appealed (by environmental groups). These recent lawsuits, together with the two Superior Court rulings considered here, have led to further discussion regarding the protection of Georgia marshlands.

The Board of Natural Resources met in late October 2003 to consider recommendations put forward by the authors of the June 30, 2003, Coastal Marsh Hammock Stakeholder's Dialogue Report. Two recommendations that have received Board support include 1) prohibiting new bridges or causeways to back-barrier islands of less than 3 acres and farther than 50 feet from the mainland or a barrier island, and 2) prohibiting new bridges or causeways to back-barrier islands that are between 3 and 15 acres if the marshlands affected are at least one-tenth acre (Shelton, 2003). These will be more closely examined in Chapter 3. One recommendation that passed the legislature included increasing the number of members to serve on the Marshland Protection Committee from three to five. Final decisions on other issues are expected in the upcoming months.

RELATED STATE POLICIES

Other southeastern states are currently facing or have faced similar policy issues with regard to small island access and bridge permitting. Each state has evolved a set of rules to address such activities due to potential and realized problems related to increased development. While the legal terminology and authority vary widely among states, the following discussion of statutes from South Carolina and Florida provides some comparisons with those that exist in Georgia.

The South Carolina Department of Health and Environmental Control (SCDEH), Office of Ocean and Coastal Resource Management (OCRM) adopted rules in May 2002 specific to small island access within critical areas (SC Code § 48-39-145 R30-12(N)). These rules prohibit filling tidelands[4] or coastal waters, except for expanding existing causeways. Bridges are permitted on an individual basis by SCDEH OCRM staff. A suite of conditions are considered, including the bridge type and dimensions, shoreline configuration, island size and distance to the nearest land mass, alternative access, public need, impacts to protected resources, the ability to tie into existing sewer lines, impacts to values set forth by SC Code § 48-39-20(E), island storm water and management policies, and submittal of master plans for docks and developments. The state has not implemented rules regarding minimum bridge lengths or island size to date, but they have been considered by the legislature.

Florida has attempted to streamline permitting activities by delegating permit issuance related to wetlands to their five water management districts, while the Department of Environmental Protection is responsible for permits within the sovereign submerged land. Generally, the use of sovereign lands[5] for the purpose of providing road access to islands where such access did not previously exist is prohibited, except where road access is the least damaging alternative and it is within the public interest (in the case of barrier islands) or not contrary to the public interest (in the case of other islands) (18-21.004(1)(i), FAC). As of December 18, 1990 Florida statutes explicitly prohibited the use of sovereign submerged land adjacent to or surrounding an unbridged, undeveloped coastal island or undeveloped coastal island segment

[4] Tidelands are all areas, which are at or below mean high tide and coastal wetlands, mudflats, and similar areas that are contiguous or adjacent to coastal waters and are an integral part of the estuarine systems involved. Coastal wetlands include marshes, mudflats, and shallows and means those areas periodically inundated by saline waters whether or not the saline waters reach the area naturally or through artificial water courses and those areas that are normally characterized by the prevalence of saline water vegetation capable of growth and reproduction (SC § 48-39-145).

[5] Sovereign submerged lands means those lands including but not limited to, tidal lands, islands, sand bars, shallowbanks, and lands waterward of the ordinary or mean high water line, beneath navigable fresh water or beneath tidally-influenced waters, which the State of Florida acquired title on March 3, 1845, by virtue of statehood, and which have not been heretofore conveyed or alienated (18.21-003(50), FAC).

unless it meets strict criteria outlined in Section 18-21.004(1)(j), FAC. Development for human habitation of spoil islands is also prohibited (18-21.012, FAC). Recently, water management districts have been mandated to conduct secondary and cumulative impact analyses for all wetland-related projects (isolated and non-isolated) due to a legal dispute that began in 1992 (Sierra Club vs. St. Johns River Water Management District, and Florida Department of Transportation; Case No. RFR-92-001; Section 373.114, FS). The Florida Land and Water Adjudicatory Commission stated that the purpose and necessity of cumulative impact analysis is to prevent the piecemeal destruction of the environment.

While this review was not meant to be a comprehensive analysis of all island-related regulations, it does provide examples of similar administrative codes within which state permitting must operate.

OVERVIEW

This chapter has provided a policy background for the work detailed within the next two chapters. Chapter 2 presents information on the vegetation composition and forest structure of Georgia marsh hammocks, examined within the context of the theory of island biogeography. In the third chapter, I discuss the policy implications of my findings.

CHAPTER 2

ISLAND BIOGEOGRAPHY AND ITS APPLICATION TO GEORGIA'S COASTAL BACK-BARRIER ISLANDS

INTRODUCTION

Geomorphology of Georgia Barrier Islands

A complex of primary and secondary barrier islands stretches along Georgia's 100-mile coast. Barrier islands are dynamic habitats resulting from geologic interactions driven by long-term sea level rise and retreat, wave-driven erosion, accretion, and overwash processes caused by storms and seasonal tidal events (Johnson and Barbour, 1990; Hoyt, 1967). Johnson et al. (1974) described some of Georgia's Sea Islands as compound barrier islands of relatively recent (4000-5000 years) Holocene land masses welded onto a core of older Pleistocene ridges.

Georgia's secondary, or back-barrier islands, may be completely or partially encircled by salt marsh and are often referred to colloquially as "marsh hammocks." According to geological studies, the origin of these marsh-encircled islands is related to overwash processes or accretion in echelon spits and marshes in conjunction with shifting inlets (Oertel, 1979). Other research suggests hammocks are erosional remnants of more extensive barrier island beach ridges which have been segmented by meandering tidal creeks and rivers (DePratter and Howard, 1977). According to the state's most recent mapping efforts[6], there are 1657 back-barrier islands, totaling over 20,108 hectares (49,688 acres). About 87% of these are about 4 ha (10 acres) in size. In addition, about 240 are comprised of dredge spoil and are associated with the Atlantic Intracoastal Waterway (AIW). These areas are generally under a restrictive covenant that

[6] The Georgia Coastal Resource Division has been developing a comprehensive inventory of back-barrier islands based on initial CMHAC 2002 estimates. It currently includes 32 substantially developed back-barrier islands (listed in the appendix of Consensus Solutions, 2003) and smaller BBIs as information becomes available (Fred Hay, pers. comm.).

authorizes the Georgia Department of Transportation to place dredge-spoil material on-site, but there has been some confusion regarding their actual ownership (CMHAC, 2002).

The present study was done in McIntosh County, which is one of six counties that border the Atlantic Ocean in Georgia. It includes three primary barrier islands (Sapelo, Blackbeard, and Wolf Islands) and 294 back-barrier islands, which total 4036 ha (Fred Hay, pers. comm.). According to these estimates, back-barrier islands located in McIntosh County comprise about 20% of the total area of all back-barrier islands along the Georgia coast. The Altamaha River flows along the county's southwestern boundary, creating delta islands near the river's mouth (USDA, 1961). The county is in the lower coastal plain (elevation <10 m above sea level; USGS 1954, 1979 and 1993 topographic-bathymetric maps of Doboy Sound Quadrangle) and has very low relief (USDA, 1961). Any relief can be attributed to dune ridges or their relicts, to ballast stone piles, or to ancestral shell mounds. The USDA soil survey (1961) provides the most thorough description of the county's soil profiles. Coastal island soils are generally poorly drained, slightly acidic, and include Ona, Scranton, Rutledge, and St. Johns soil series. Ona and Scranton soils were once used to grow sea-island cotton, indigo, and many kinds of vegetables, whereas St. Johns sands are less fertile. All are fine sands thought to be formed from marine sediments.

Historical Human Uses of Georgia Marsh Hammocks

The back-barrier landscape in Georgia has experienced anthropogenic disturbances that have modified the region. The earliest occupation of the coast probably took place near the end of the Pleistocene, about 15,000 BP (R. Rogers and D. Crass, GDNR Historical Preservation Division, pers. comm.). Shell middens and ancient artifacts provide archeological evidence for seasonal and semi-permanent occupation of Georgia islands by aboriginal tribes 3000-4000 BP

(Vanstory, 1970; Simpkins, 1975; Torres, 1977; Crook, 1980). With European settlement came more extensive modification of the landscape. Spanish missionaries introduced fruit trees and domesticated goats and hogs to Georgia's barrier islands between 1566 and the late 1590s (NOAA and DNR, 1997). Slaves were brought to Georgia in the 1740s and many large plantations were established. Dikes and old fields can be attributed to the era of rice, indigo and cotton cultivation, which began to decline with the Civil War. Timber production has been an important industry on Georgia's coastal barriers since the late 1700s, when large areas of swamp and coastal forest were cleared to harvest live oak for shipbuilding (NOAA and GDNR, 1997). The felling of red cedar for pencils and the cutting of palms for their edible hearts also impacted maritime forest strand communities (Wharton, 1978). In the 1870s lumber mills began to harvest cypress, pine and other oaks. In the early 1990s, the timber industry produced $110.5 million annually and supported more than 7,000 local jobs (NOAA and GDNR, 1997). Today, the commercial pine plantations remain an important land use, although secondary forests have regenerated on some areas of Sapelo Island and its associated uplands (Chalmers, 1997).

As modern residential development and tourism continue to encroach upon natural lands, the sustained losses of biological diversity due to ecosystem fragmentation have become an issue that is important from both biological and political viewpoints (i.e., Harris, 1984). Georgia's population grew over 25% in the last decade, surpassing the national average (US Bureau of Census, 2002). It is expected to increase to 9.87 million by 2025, resulting in continued sprawl and conversion from rural to urban landscape patterns.

Biological Communities of Georgia's Barrier Islands

Although the beach, dune, and marsh areas of some of Georgia's primary barrier islands have been well studied (see reviews by Johnson et al., 1974; Chalmers, 1997), the biodiversity of the approximately 1,200 back-barrier islands is poorly documented in the scientific literature. The general nature of small island forests has been described as mixed species of maritime forest strand dominated by mature live oak, palmetto and shrubs (Eyles, 1939; Wharton, 1968) interspersed with pine plantations and abandoned clearings in various stages of succession (Chalmers, 1997). Although Bozeman (1975) refers to the oak-juniper-palm forest community that covers small islands in the salt marsh in Georgia, relatively little attention has focused on quantifying the vegetation of small islands (Ehrenfeld, 1990; Young, 1992) and the fauna they support. In 1986, Odum and others identified research needs specifically related to the physical characteristics of interior wetlands of barrier island communities, including microtopographic surveys and mapping to locate wetland habitat. In response to the paucity of scientific information with regard to Georgia's back-barrier islands, the Southern Environmental Law Center and The Georgia Conservancy organized a survey of 23 hammocks from October 2001 to September 2002. This effort found that small islands (5 to 10 acres) support a diversity of plant and bird species, including 15 birds of the highest conservation priority (i.e., wood stork, painted bunting) and that hammock biota varied greatly depending on island size, location, and origin (Fabrizio and Calvi, 2003).

Although back-barrier island communities have not received a lot of attention, there is information about the flora and fauna of the major barrier islands of Georgia and the southeastern region in general. Duncan (1982) completed a species list of vascular vegetation for Sapelo Island and divided the vegetation into 14 types, including "hammocks" which are described as live oak and palmetto associations surrounded by pineland. Bratton and Miller (1994) surveyed abandoned fields on Cumberland Island and determined that their live oak-palmetto forest structure was related to historical land use and soil type. Another Cumberland

Island study investigated the role that fire plays in structuring maritime communities and showed that live oak burns infrequently compared to scrub pine (Turner and Bratton, 1987; Myers, 1985). Surveys following a hurricane that struck Bull Island, S.C., revealed that live oak is uniquely resistant to hurricane and fire disturbances (Smith et al., 1997). Regionally, southeastern deciduous maritime forests are distinguished by the occurrence of *Quercus virginiana* and *Q. hemisphaerica* as the dominant and often only canopy hardwoods. *Sabal palmetto* also becomes more prevalent in the southernmost extent to Florida (Bellis and Keough, 1995). The diverse landscapes surrounding barrier islands provide habitat for numerous bird species which include threatened and endangered species like brown pelicans (*Pelecanus occidentalis*), wood storks (*Mycteria americana*), bald eagles (*Haliaeetus nycticorax*), and painted buntings (*Passerina ciris*), and several common species of shorebirds, wading birds, and hawks (Chalmers, 1997). Commonly sighted mammal species include white-tailed deer, raccoons, and opossums. Feral hogs and armadillo were introduced to Sapelo Island in the 1990s and have become increasingly abundant.

Plant growth, survival and reproductive success depends on the availability and effective acquisition of carbon, water and nitrogen in the soils. The acquisition of these essential resources depends on their availability in the microenvironment where the plant is rooted and on the plant's requirement for each particular resource. Although studies have examined marsh vegetation along environmental gradients in the Sapelo Island area (Chalmers, 1979; Pomeroy and Wiegert, 1981), surprisingly few have addressed the responses of maritime forest species to the limitations of essential resources that define these endemic coastal communities. Zonation of maritime forests in the southeast has been attributed to salt spray tolerance of evergreen oaks (Wells and Shunk, 1937; Oosting, 1954; Bordeau and Oosting, 1959; Bellis and Keough, 1995), but back-barrier areas do not typically front the ocean and may have other factors structuring the community. One barrier island study in Georgia examined the possible expansion of marsh or scrub communities into maritime forest due to repeated burning and revealed that the boundaries between the two were relatively stable through time and controlled primarily by moisture gradients (McPherson and Bratton, 1991).

Species Diversity and the Island Biogeography Theory

There exists a copious body of literature pertaining to the study of biodiversity and island biogeography, largely inspired by the work of MacArthur and Wilson (1967). Interest in their theory has generated thousands of papers that have far reaching applications, from reserve design to emerging principles in metapopulation biology and other allied fields (Hubbell, 1999). Species richness is the fundamental measure in biodiversity and is simply the number of species per sample unit at a given time (McIntosh, 1967). Some of the most widely applied principles in island biogeography attempt to explain variations in species richness among island biota based on relations of spatial scales to immigration, extinction, birth and death rates (Preston, 1962, MacArthur, 1967, Whitehead and Jones, 1968). These mathematical estimates provide the framework upon which island biogeography research has been built.

MacArthur and Wilson's island biogeography theory was based on three intuitive principles: 1) A positive relationship exists between equilibrium species richness and island area (equation 1).

(1) $\log S = \log C + z \log A$, where $\log S$ is species richness, A is island area, C is a constant that varies among taxa and with unit of area measurement, and z is a constant that typically lies between 0.15 and 0.40.

2) All things being equal, an inverse relationship exists between species richness and distance to source propagules. 3) Given a newly-formed island, species diversity will increase with age to a point of equilibrium (or species saturation), at which time the colonization curve will plateau. Thus, important predictors for island diversity are island size, proximity to seed sources, and age.

The objectives of this study were threefold. First, I examined the floristic composition, forest structure, and species richness among a subset of back-barrier islands of different sizes near Sapelo Island, Georgia to characterize plant distributions within the region as a whole. Second, I tested the predictors for the equilibrium theory of island biogeography. I expected that species richness of vascular plants would increase with island size, proximity to source populations, and decrease on islands of younger successional age (i.e., dredge spoil origin). Third, I measured edaphic variables and examined how they relate to compositional and biogeographic patterns. Although this study was limited in scope because it was a "snapshot" of the current community in time and space, an overarching goal was to establish an initial inventory of the vegetation and soil characteristics of back-barrier islands (BBIs), thus providing a standardized framework for monitoring the long-term conditions of back-barrier islands in the region.

METHODS

Site Selection

I conducted a series of field observations at back-barrier islands located near Sapelo Island, Georgia, USA (Figures 1-4). These islands lie between the areas of intertidal marsh and salt pans. They are cut by many tidally-influenced rivers, creeks, and sloughs associated with the Duplin River to the west and the Altamaha River to the south. The region has a subtropical climate with mean annual rainfall of 128.5 cm (May 1957 to Aug. 2003), about 40% of which occurs during the summer months, and a mean annual air temperature of 20°C (GCE-LTER, 2002). This study was done in 2002, during which time coastal Georgia was beginning to rebound from a drought. The mean annual rainfall was 110.6 cm from Jan. 1999 to Dec. 2002, 14% lower than historical data.

A series of 14 back-barrier islands were included in this study (Figure 1). They were identified using an ESRI ArcView v.3.2 map database provided by the Georgia Dept. of Natural Resources Coastal Research Division (GADNR CRD). The BBIs studied were selected on the basis of accessibility, minimal impact from recent residential or agricultural development, origin (natural and dredge spoil), and size, which ranged in size from 0.01 to 41.8 hectares (ha) (Table 1). Twelve were formed through natural geological processes; two were formed through dredged materials deposited during naval commerce during the Civil War era and the creation of the Intracoastal Waterway. Nine of the sites are within the Sapelo Island National Estuarine Research Reserve (SINEER), and are used for research and limited public access, like hunting; one site serves as a federally owned and protected bird sanctuary; the remaining four sites are privately owned, including the two dredge spoil islands.

Vegetation Sampling

From July to October 2002, I conducted vegetation surveys at each of the 14 back-barrier islands identified (Figure 1-4). Back-barrier islands were accessed via the Georgia Coastal Ecosystems Long-Term Ecological Research (GCE-LTER) V-tech boat. Some sites were only accessible during high tide, when the tidal creeks were deep enough for passage. A series of 0.01 ha temporary plots was constructed on each back-barrier island. Topographic maps for each island were subdivided into 0.1 ha quadrats and a random number table was used to select the general plot locations. From 1 to 7 plots were sampled on each island; more plots were typically sampled on larger islands in order to obtain a more representative assessment of these areas (Table 1). Due to inclement weather and restricted boat access, I was only able to visit Egg Island (EI) on one occasion, so only one plot was constructed at this site. Plots were randomly placed at or above the marsh-upland treeline as indicated by the first woody tree or shrub. Due to the long narrow topography and relatively lower elevation in some areas (especially on smaller back-barrier islands), marsh plants were often present within the plot. In these cases, I noted the proximity of the plot to the edge of the marsh, salt pan, or water body. The plots were marked semi-permanently using 1.5” diameter x 12” length metal conduit stakes, so future observation in these areas may be possible. A total of 52 plots were sampled.

Latitudinal and longitudinal coordinates of each plot were recorded using a hand-held Global Positioning System unit. This information was used to project plot locations onto the GADNR CRD database using ArcView 3.2 GIS mapping techniques. The ArcView measuring tool was used to estimate distances from each of the sites to the mainland and to Sapelo Island. This technique was also used to estimate the distance between each plot and the nearest salt marsh, salt pan, or water body. This information was used in conjunction with field notes to differentiate edge plots from insular plots. Where possible, sites were photo-documented with a 35 mm Nikon N65 camera and these photos are available at the UGA herbarium.

The inventory design was based on a sampling protocol developed for North Carolina Vegetation Surveys (NCVS) (Peet et al., 1998). This methodology was chosen due to its flexibility, ease of use, and successful application for rapid assessment in the southeastern region. A standard 100 m^2 module was used for vegetation sampling (Figure 5). This size was selected based on areal constraints of the smaller back-barrier island sites. A 100 m measuring reel was used to demarcate the perimeter of a 10 x 10 m plot, and a hand held tape measure and 2 meter sticks were used to divide it into quadrats. The vegetation was sequentially assessed by nested quadrats in each of the corners of the module (Figure 5). Sampling areas were 0.01 m^2, 0.10 m^2, 1.00 m^2, and 10.00 m^2. Plants in the remaining cross-shaped area were also evaluated.

Vascular species were recorded as present (if rooted) or absent within each subset of nested quadrats, which is consistent with the NCVS protocol. Percent cover was determined for each species by visually estimating the vertical projection of plants for each 100 m^2 module. These were scored by cover classes designed by the NCVS authors to maximize accuracy, precision, and sampling speed. The cover values double over each interval as follows: 1-trace, 2 = 0-1%, 3 = 1-2%, 4 = 2-5%, 5 = 5-10%, 6 = 10-25%, 7 = 25-50%, 8 = 50-75%, 9 = 75-95%, 10 = >95%. No one plant species can have a cover range that exceeds 100%; however, summed cover ranges for all plant species in a plot may easily exceed 100% due to differences in vertical structure (strata).

Stem counts and diameter at breast height (dbh) measures were recorded for all woody trees, shrubs, and vines (>1.4 m height) present within each 100 m^2 module. Canopy plants with a diameter <10 cm were considered understory whereas those >10 cm were considered overstory. Understory stems were recorded within the following ranges: 0-1 cm, 1-2.5 cm, 2.5-5 cm, and 5-10 cm in diameter. Overstory stems were recorded within the following ranges: 10-15 cm, 15-20 cm, 20-25 cm, 25-30 cm and 35-40 cm in diameter. Those stems ≥ 40 cm were measured to the nearest one-tenth centimeter. In addition, the dbh of palmetto trees that had reached a size sufficient to develop a “woody” trunk were also measured. For palmettos >1.4 m in height that lacked a “woody” trunk, I tallied the number of palm leaves for each plant instead of dbh for these plants. I also recorded the presence of snags (standing dead trees), overhanging epiphytes, mosses, and lichens within each plot. Evidence of recent natural or human induced disturbances to the site (i.e., fire, litter) was noted.

All vascular plants within plots were keyed to species whenever possible using standard keys for floristic identification for the region (Radford et al., 1968, Duncan and Duncan, 1987; Godfrey and Wooten, 1979 and 1981; Wunderlin, 1998) and comparisons to the UGA herbarium collection; recent taxonomic changes followed USDA NRCS (2002) classification. Floristic samples were collected for identification as necessary. In these cases, plants were dried and stored in plant presses, frozen for 5 days to prevent contamination, and keyed and mounted at the University of Georgia (UGA) Plant Sciences Herbarium, Athens, GA.

Soil Sampling

In order to acquire information regarding soil fertility and hydric conditions, one soil core was collected from the center of each 100 m^2 plot using a 10 cm width hand-held trowel dug to a depth of 10 cm. Soil samples were weighed, dried at 105°C to a constant weight, and reweighed to determine percent soil moisture (%SM). Dried samples were compared to the Munsell color chart to determine general soil qualities related to flood frequency and iron reduction due to anoxic conditions (Schoenberger et al., 2002). Samples were split into two subsamples and sorted through a 2 mm sieve to remove large organic matter like leaves, twigs, and shell fragments. One subsample from each site was ground using a ball mill. These samples were used to determine loss-on-ignition (%LOI) (Storer, 1984). Total percent carbon (%C), percent nitrogen (%N), and soil nutrient ratios (C:N) were also measured on these samples using a Flash EA 112 Series NC Soil Analyzer (University of Georgia, Athens, GA). The second subsample was reserved for preliminary compositional analyses of the coarse fraction using standard soil sieves, and the fine fraction using sedigraph techniques in coordination with Georgia State University geologists (See Appendix).

Data Analyses

Several different approaches were used to summarize plant characteristics across all sites sampled in this study. First, floral lists were compiled to describe overall plant community composition. Second, cover values (1 to 10) were summed across all plots in which the particular plant occurred to arrive at average cover ranges (ACR) for each taxon. Third, plants were grouped based on habit (graminoid, herbaceous, shrub, and tree) to examine differences in diversity and average cover ranges among types. Finally, patterns in canopy structure were examined for the overstory and understory strata, as described below.

<u>Canopy analyses</u>

Overstory and understory stem densities were tallied to determine the relative densities of trees, shrubs and vines. An arithmetic mean can lead to overestimates for basal areas when using size categories as those described by the North Carolina Vegetation Survey (Peet, pers. comm.); therefore, I calculated the geometric means within each DBH size category as recommended by the survey authors in order to arrive at more conservative estimates. For each taxon, these values were summed across all plots to find total dbh ($\sum$DBH). These data were then divided by the total number of stems to calculate mean stem diameters and by the number of plots to calculate mean DBH per plot. Tree basal area (TBA, m^2) was calculated and summarized by species for both overstory and understory stems within each plot (equation 2).

(2) [$TBA = \pi r^2$], where r (in cm) = dbh /2*100 (in m)

Stand basal area (SBA, m^2/ha) was calculated by summing TBA for stems of each strata (overstory and understory) across all plots and dividing by the total area for all plots in this study (0.52 ha; equation 3). This provides a measure of dominance for each species.

(3) [SBA = $\sum$TBA/area]

Relative frequency (RFreq), relative density (RDen), and relative dominance (RDom) were calculated for overstory and understory stems (equations 4-6, respectively).

(4) [RFreq = Percentage of sample plots (Frequency) in which a given species is present/ $\sum$ percentage of sample plots in which each species is present * 100] (Note that as with cover percentages, the sum total percentages for all species may exceed 100%.)

(5) [RDen = Average number of stems of a given species per ha / $\sum$ average number of stems per ha for all species*100]

(6) [RDom = SBA of a given species / $\sum$ SBA for all species* 100]

These percentages were summed to arrive at the Species Importance Value (SIV; equation 7) which was calculated on a scale of 300 (SIV = 300 represents a monotypic stand) and is often used as a standardized scale for comparing trees in eastern North American Forests (McCune and Grace, 2002).

(7) [SIV = RFreq + RDen + RDom]

<u>Species richness analyses</u>

I assessed the adequacy of my sample size by generating a species area curve using the statistical package PC-ORD Version 4.10 (McCune and Medford, 1999). This technique has been employed since the early 20th century and uses species presence data to calculate the cumulative effect of adding subsequent sample units to a study. I also applied Palmer's (1990) first-order jackknife estimator for true species richness and compared it to my actual species richness results (equation 8).

(8) $\left[Jack_1 = S + \frac{rl(n-1)}{n} \right]$,

where S = observed number of species,
n = the number of plots, and
rl = the number of species occurring in only one sample unit.

Since sample observations almost always result in the underestimate of true species richness (McCune and Grace, 2002), this technique may be useful in determining the adequacy of the sample size, especially in areas of low heterogeneity.

Species richness was used to examine diversity within and among back-barrier islands. Plot diversity, species turnover, and landscape diversity measures were compared for back-barrier islands of different origin (i.e., natural and dredge spoil) as well as among all study plots (Whittaker, 1972). Plot diversity (α-diversity) was measured as the average species richness among plots on the same BBI. Total species richness for the study was used as a measure of landscape diversity (λ-diversity). Species turnover (β-diversity) was obtained by the ratio of λ- to α- diversity.

Biogeography and edaphic analyses—diversity

Multiple linear regression analyses were used for statistical comparisons for the biogeography component of the study. The distributions of all dependent and independent variables were checked for normality and transformed using log or log + 1 transformations, as necessary. First, I used Pearson's product moment correlation coefficient to examine the log of the size of the back barrier islands to the log of α-diversity and determine if there was a relationship. Based on these results, I further examined potential links among 6 biogeographical variables (BBI area, distance to mainland, distance to Sapelo Island, distance to nearest neighbor

BBI, edge orientation, and origin; Table 2) and diversity, average cover values, and 5 edaphic variables (percent carbon, percent nitrogen, soil nutrient ratio, percent soil moisture, and percent loss on ignition) for 52 back-barrier island plots using multiple regression models. I determined the amount of variation in diversity and soil data that could be explained by these measures using stepwise linear regression (forward backward; $P = 0.05$ to enter and leave model) for the six biogeography indices. All regression analyses were performed using SYSTAT Version 8.0 statistical software (SPSS, Inc. 1998).

Biogeography and soils analyses—composition

Variation in flora across sites was also examined using hierarchical cluster analysis (Ward, 1963) and nonmetric multidimensional scaling (NMDS; Mather, 1976 and Kruskal, 1964) with the statistical package PC-ORD Version 4.10 (McCune and Medford, 1999). The objective of these analyses was to determine patterns due to floristic composition, as opposed to diversity. For example, Kadmon and Pulliam (1993) demonstrated how two islands having the same number of species might vary considerably in their composition. The reason for using cluster analysis was to illustrate similarities (or differences) between independent plots based on plant composition. Because the plots from the same BBI were closer together than those on different BBIs, floristic patterns may become apparent in the resultant dendrogram.

I applied NMDS ordination because it is mathematically powerful and can assess the full suite of biogeographical and edaphic variables that may be important in driving patterns in community composition. NMDS builds ordination axes using eigenvectors. The relative euclidean distances between scores along the axes represent floristic similarities. With 40 randomized runs of real data, and 400 iterations to reach a final solution, I correlated individual taxa with the 6 biogeographical metrics and the 5 edaphic parameters listed above with ordination axes to determine which taxonomic associations best accounted for separation of plots in ordination space. This method does not assume linear relationships among variables and is well suited for non-normal data typical of studies in community ecology where zero values (presence/absence) can be problematic (Kent and Coker, 1992).

RESULTS

Vegetation Composition

I identified a total of 83 plant taxa among the 14 BBIs sampled in this study, representing 43 families in 68 genera (Table 3). This included 53 dicots, 25 monocots, 3 gymnosperms, and 2 ferns. When categorized by plant habit, the plants observed in this coastal community are comprised of 20 vine, 17 graminoid, 16 tree, 16 shrub, and 14 herbaceous species. *Ilex vomitoria* (ILVO, yaupon holly) was the most common shrub present in the study, *Quercus virginiana* (QUVI, live oak) was the most common tree, and *Smilax bona-nox* (SMBO, catbrier) was the dominant vine, occurring in 92%, 71%, and 50%, of the 52 plots sampled, respectively. *Tillandsia usenoides* (TIUS, spanish moss) is an epiphyte that occurred in 86% of all plots. About half of the species occurred in less than 5% of the individual plots (Table 4). Twelve of 14 jurisdictional tidal wetland plants (Georgia Coastal Marshland Protection Act 1970; § 12-5-280) were represented in this survey, most of which are designated as obligate or facultative wetland plants for this region (USDA NRCS, 2002).

I also observed three plants that are recognized as species of concern by the state of Georgia. *Sageretia minutiflora* (SAMI, shell-mound buckthorn) and *Forestiera segregata* (FOSE, Florida privet) had relative frequencies of 9.6 and 7.7%, respectively (Table 4). *Bumelia anomala* (BUAN, silver buckthorn) was observed on one of the smaller back-barrier islands (SCL, <1.62 ha) in this study. This plant is critically imperiled globally, and has been observed on sandy hammock islands in the Okefenokee Swamp (GDNR NHD, 2003; Anderson, 2000). This rare buckthorn tends to grow exclusively in maritime forests or on shell middens.

This survey recorded additional information that is not reflected in the floristic data, but which may be important in shaping the forest ecosystem. Lichens and bryophytes occurred with relative frequencies of 98 and 54%, respectively. Standing dead trees or snags (*Pinus* species. and *Juniperus virginiana;* JUVI, southern red cedar) were observed in 14% of the plots surveyed.

Average cover ranges (ACR) revealed some of the overall patterns in the structure of the maritime forest community (Table 4). Emergent pines reached heights of >30 m in some sites, with *Pinus taeda* (PITA, loblolly pine) averaging 5-10% cover within plots. Canopy trees, like Q*uercus hemisphaerica* (QUHE, laurel oak) had among the highest average cover (10-25%) when present, followed by *Q. virginiana* (QUVI, live oak; 5-10%). The understory was generally dense with shrubs, palmettos, and entangling vines, with *Serenoa repens* (SERE, saw palmetto) having the highest average cover (10-25%) in this stratum. The herbaceous layer was generally sparsely vegetated, but when present, *Juncus roemerianus* (JURO, black needlerush) had relatively high cover (5-10%).

Across the study area, twenty-five taxa were identified in the canopy, including both overstory and understory strata (Tables 5-8). These totaled 1658 woody stems and vines and 584 palmettos. Estimated SBA for all trees, shrubs, and vines was 37.9 m^2 ha^{-1}, which is analogous to other oak-dominated forests (see discussion).

The overstory was composed of 11 woody dicots and 1 palmetto species (Table 5). It was dominated by *Q. virginiana* (QUVI, live oak) and *J. virginiana* (JUVI, southern red cedar), which contributed 16.24 and 5.60 m^2 $ha^{-1}$of the 35.90 m^2 ha^{-1}overstory SBA, respectively. *Ilex* *vomitoria* (ILVO, yaupon holly) and *S. palmetto* (SAPA, cabbage palm) were subdominants. All woody overstory species were ranked based on their relative frequencies, relative densities, and relative dominances to determine their proportionate species importance value (SIV; Table 6). The results show that live oak is a strong contributor to forest structure (SIV= 99.6), due to its high stem densities (111.5 ha^{-1}) and relatively large trunk diameter (mean dbh = 37.7 cm). Only *Q. hemisphaerica* (QUHE, laurel oak) and *P. taeda* (PITA, loblolly pine) had larger trunk diameters (53.8 and 45.5 cm, respectively), but these were less common. *Juniperus virginiana* (JUVI, southern red cedar) and *S. palmetto* (SAPA, cabbage palm) were also strong contributors to the forest with a combined species importance value of 88.4.

The understory had greater diversity than the overstory, with 22 woody dicot and vine species and 2 palmettos (Table 7). Although *S. palmetto* (SAPA, cabbage palm) and *S. repens* (SERE, saw palmetto) were common understory forest plants, they were excluded from understory basal area estimates due to the difficulty in accurately measuring dbh on palmately-leaved trunks (# fronds/plant were tallied instead). (Note: *S. palmetto* does attain a distinct "woody" trunk diameter when mature, so it was included in overstory estimates.) Tables 7 and 8 present data summaries that show that *I. vomitoria* (ILVO, yaupon holly) dominates the understory with 65% (1.3 m^2 ha^{-1}) of the total stand basal area (SBA=2.0 m^2 ha^{-1}) and is top ranked in importance with a value of 174. I observed this plant to have both abundant fruit and vegetative shoots, and this reproductive strategy probably contributes to its overall dominance. *Persea borbonia* (PEBO, red bay), *F. segregata* (FOSE, Florida privet), and *Vitis spp.* (VITIS, grapevine) are subdominants. Together, these species ranked in the top five for relative importance and comprise another 52% of the total SBA value, due in part to their relatively large trunk diameters (dbh = 3.1, 3.6, and 4.1, respectively). *Smilax spp.* (SMIL, briar species) also rank among the top five contributors to this stratum. In this case the higher rank is due to its high density in the understory, which was evident when navigating through the entangled underbrush in several sites, but its small stem diameter reduced its relative importance.

Species Richness

I generated a species area curve to determine the adequacy of my sample size (Figure 6). With a total of 83 species in 52 plots, a Sorensen distance of less than 0.1 (<10%) measured between the centroid of the subsample and the centroid of the entire sample occurred at 28 plots (McCune and Grace, 2002). These values indicate that further increases in the number of plots render the subsample only slightly more similar to the entire sample. I also generated first-order jackknife estimates (Palmer, 1990) to determine the "true species richness" among back-barrier islands in my study. This analysis revealed that my survey was able to capture 78% of the species within the study area, despite the estimator's sensitivity to rare species (n=52; $Jack_1$ = 107.5).

Alpha, beta and gamma diversity indices were calculated for each back barrier island in this study. Average alpha-diversity was 11.6 species at the 100 m^2 scale (Table 9). Landscape level diversity was markedly lower on dredge spoils (λ=29) compared to BBIs of natural origin (λ=78) (Table 10). Species turnover was low on dredge spoil islands (β=2.0) indicating that the plants tended to be fairly similar to one another with regard to composition. However, the limited number of dredge spoil plots (n=5) on just two islands, both within the small size class (SCS=0.13 ha; SCL=1.62) should warrant conservative interpretation of these data. Differences among BBIs related to size and origin are presented in the biogeography section, below.

Soil Characteristics

The soils collected in this study were primarily fine quartz sand (<2 mm) and often intermixed with shell fragments, particularly from oysters. Soil loss on ignition (%LOI) averaged about 20% (Table 11). Percent soil moisture ranged from about 8% in extremely dry, sandy sites to over 50% in a few low peatland sites. Soil carbon values were highly variable, ranging from 1.6 to 48.7%; whereas percent nitrogen was very low (average = 0.6 ± 0.4), with values generally less than 2.0%. Mean carbon to nitrogen ratios were 22.5 ± 6.8. Comparisons with Munsell soil notations (Schoenberger et al., 2002) indicated that 50%, 35% and 10% of soil samples were characterized in the 5YR, 10YR, and 7.5YR hue category. Color value was normally >4. Only 6% of the samples in this study fell below this value, indicating iron depletion. However, all soil samples were characterized with low chroma values (≤ 2), suggesting redoximorphic features, which are used as hydrologic indicators for determining hydric soils.

Biogeography Analyses—Diversity

All sample sites were plotted on ArcView georeferenced maps provided by GADNR. Their latitudes ranged from 31.2938 to 31.4848 and longitudes ranged from -81.2735 to -81.3508. ArcView measurements from each of the fourteen back-barrier islands sampled in this study showed that distances to the closest point on the mainland ranged from 1,109 to 13,328 m and distances to the closest point on Sapelo Island ranged from 435 m to 10,185 m (Table 2). Distances between each BBI in this study and the nearest neighboring back-barrier island (DNN) ranged from 36.8 m to 548.5 m. Nine of the 52 plots were identified as edge plots (<5.5 m from the high marsh according to ArcView measurements and verified with field notes). One-third of these edge plots resulted from sampling on small islands (<2.0 ha); the long, narrow, and often irregularly shaped nature of the upland topography made it particularly difficult to avoid sampling in close proximity to the surrounding marsh. These edge plots captured species composition information at the upland margin, where salt marsh and forest habitats overlapped.

There was a slight but positive relationship between the log of α-diversity and the log area of back-barrier islands for all plots ($y = 0.07x + 1.68$. $r^2=0.09$; Figure 7). When log area of back-barrier islands was plotted against log λ-diversity the relationship was stronger ($y = 0.15x + 1.43$; $r^2=0.49$; Figure 8) and had a slope within the range predicted by island biogeography theory (MacArthur and Wilson, 1968).

Island size explains only a portion of the variance in diversity and I wanted to examine other biogeographical factors that may also affect it. I applied regression models to further examine variances in plant diversity (DIV) as related to six biogeographical metrics: BBI area (AREA), distance to mainland (DML), distance to Sapelo Island (DSAP), distance to nearest neighboring BBI (DNN), origin (D—dredge spoil or N—natural), and edge orientation (EDG) (Table 2). An edge plot was characterized as within 5.5 m of salt marsh, salt pan or water body. I also examined the variances in diversities and average cover values (ACV) within each plant category (graminoids, herbs, shrubs, vines and trees) as related to the same biogeographic metrics.

Stepwise multiple regression analyses revealed significant relationships between the biogeographic metrics and overall plant diversity as well as the cover and diversity values of plant categories (Table 12). Both back-barrier island area and dredge origin were important factors in explaining the variance in total diversity. In particular, shrub cover decreased and graminoid cover increased, whereas herbaceous, vine and tree diversity all increased on larger BBIs. Dredge spoil sites also tended to have lower shrub cover, but increased vine diversity.

Marginal areas designated as edges were positively related to shrub diversity and graminoid diversity and cover, but negatively related to tree diversity and vine diversity and cover. Factors related to the distance to other land masses were significant predictors for shrub diversity and cover (i.e., distance to nearest neighboring BBI) and to tree diversity (i.e., distance to mainland).

Some of these results are consistent with the theory of island biogeography. For example, back-barrier island size was related to plant diversity, which is in keeping with the theory. It also predicts greater diversity in earlier stages of succession. Dredge spoil islands, which are geologically younger, tended to have greater overall plant diversity. Also, distance to the mainland, and distance to nearest neighboring BBIs were important in explaining the variances in tree and shrub values, but not overall diversity. These results suggest that the importance of proximity to seed sources is specific to the habit of plants observed on back-barrier islands.

I also applied the multiple regression models to examine variances in plot and plant habit diversities as related to five edaphic metrics: percent carbon (%C), percent nitrogen (%N), carbon to nitrogen ratio (C:N), loss on ignition (%LOI), and percent soil moisture (%SM) (Table 13). The results from these models suggest that plant diversity tends to increase with increased %C and decreased %N and soil C:N ratios, especially with regard to both vine and tree diversity. Percent soil moisture was also a predictor for both vine and tree diversity. Other diversity indices were weakly correlated to edaphic variables or not significant.

Finally, soil parameters were regressed with the same biogeographic variables as above (Table 14). All soil variables (%C, %N, %LOI, and %SM) were negatively related to both distance from the mainland and with dredge spoil origin (Table 14), which indicates that soils were of poorer quality the further the site was from the mainland or if it was on an island of dredge spoil origin. Percent soil moisture (%SM) was also negatively related to these factors, but variances were also explained by distance to nearest neighboring BBI and edge. Soil C:N ratios showed a weak relationship to biogeographical variables.

Biogeographic Analyses—Composition

Hierarchical cluster analysis of all plots revealed two distinct groups based on their plant composition (Figure 9). Interestingly, the dendrogram identified patterns in composition that were not explicitly incorporated in the analyses. Group 1 encompassed 71% of the plots sampled on BBIs greater than 8.0 ha. The plots also sorted according to which island they were located on (Jack's Hammock, Little Sapelo, Mary's Hammock, and Pumpkin Hammock). Group 2 included all plots sampled on BBIs less than about 4.5 ha and the remainder of those from larger BBIs. More than half the plots designated as edge clustered tightly to make up a subgroup within group 2. Another subgroup was comprised of 5 dredge spoils plots and they too sorted according to their associated BBI (S. Creighton S and S. Creighton L). The clustering of plots based on size and origin suggests that geospatial factors are important in structuring vegetation communities on these islands. Moreover, the tight clustering among plots of the same hammock point to dispersal effects. Edge plots show compositional distinctions that were not evident in diversity analyses. Note that there exists a fairly distinct division of plots between those islands ≥8.0 ha and those islands ≤ 4.2 ha based on vegetation assemblages.

NMDS was used to examine whether vegetation patterns could be related to the combined group of biogeographic and edaphic variables used in multiple regression analyses. Two axes were able to adequately describe a total of 78% of the variance, with 26% on the first axis and 52% on the second (Table 15, Figure 10). The most important variables on axis 1 were soil C:N ratios, which explained 30% of the variance, and BBI area, which explained an additional 27%, proportionately. On axis 2, the classification of a plot as edge was most important, accounting for 47% of the variance, with distance to Sapelo accounting for an additional 21%, proportionately. None of the other variables explained more than 15% of the variance. The relative lengths of the biplot lines indicate the strength of the correlation (Table 15). Several plants like *I. vomitoria* (ILVO, yaupon holly) and *S. bona-nox* (SMBO, catbrier) clustered where the biplots vectors meet, suggesting they may be community generalists. Six of the nine plots designated as edge plots are clearly more distant in ordination space from plots that were classified as insular island plots. Plants that generally fell out along the EDGE biplot line included 11 jurisdictional marsh plants that are used to delineate Georgia's salt marsh (i.e., *J. roemerianus* (JURO, black needlerush), *B. frutescens* (BOFR, sea ox-eye), and *Spartina* species (SPCY, salt reed grass; SPAL, smooth cord grass; SPPA, salt meadow grass). When the NMDS output is depicted in terms of plot designation, rather than by plant taxa, there is a general clustering among plots sampled from the same BBI (Figure 10).

NMDS was also applied to stem densities to see if the same patterns hold for canopy plants. In this case, differences in stem densities were explained in three axes, with axes 1 and 2 describing about 30% each (for a total of 64%) and axis 3 describing an additional 20% of the variance (Table 16). According to these results, those plots designated as edge and soil C:N ratios explained the largest proportion of the variation for axis 1 (27% and 15%, respectively). Soil C:N ratios and percent soil moisture (%SM) explained the largest proportion of variation for axis 2 (32% and 17%, respectively). Back-barrier island area best explained the variation accounted for by axis 3 (19%). None of the other variables explained more than 15% of the variance, proportionately. The relative lengths of the biplot lines indicate the strength of the correlation (Figure 11). Tree species that fell out along the soil C:N ratio biplot line included *S. repens* (SERE, saw palmetto) and *Q. virginiana* (QUVI, live oak); whereas *J. virginiana* (JUVI, southern red cedar) and *Iva frutecens* (IVFR, marsh elder) tended to have higher stem densities in those plots designated as edge. As in Figure 10, when the NMDS output is depicted in terms of plot designation, rather than by plant taxa, there is a general clustering among plots sampled from the same BBI (Figure 11).

In summary, multiple regression and NMDS results suggest that both biogeographic and edaphic factors contributed to variations in species diversity (the number of plants present) and plant community patterns (the type of plants present). Overall, back-barrier island area and origin were the strongest biogeographic predictors for diversity measures, whereas soil C:N was the strongest edaphic predictor for plant community patterns in this study. The edaphic factors measured here were also related to certain biogeographic factors; all of which decreased with increasing distance from the mainland and on BBIs of dredge spoil origin.

DISCUSSION

Composition

The vegetation communities observed on back-barrier islands in this study are comparable to subxeric maritime forest and shrub lands as described by Peet (2003) and maritime strand communities (Bellis and Keough, 1995; Wharton, 1978). The strong associations between *Q. virginiana* (live oak) and *I. vomitoria* (yaupon holly) and subdominants, like *S. palmetto* (cabbage palm) and *J. virginiana* (red cedar) are indicative of upland evergreen forests unique to intact areas of the southeastern coastal plain. The compositional similarity among sites and the estimates of species richness observed in this study indicate that study coverage was adequate, despite the relatively small plot size.

The oak dominated canopy of back-barrier islands (BBIs) is generally consistent with that on larger barrier islands (Duncan, 1982; Bratton and Miller, 1994) and northeastern Florida hydric hammocks (Monk, 1968). However, there were differences between this study and a study by Bratton and Miller on old fields on Cumberland Island. They did not report *J. virginiana* trees in the canopy, but instead noted large red cedar stumps as evidence of cedar harvesting during the cotton era. In addition, *I. vomitoria* was notably absent, whereas it was the dominant understory shrub in this study. The authors did report that *P. borbonia* (red bay) and *S. repens* (saw palmetto) were frequent in areas with no history of agriculture. These trees were also commonly observed in this study, which may suggest that some back-barrier island areas may share a similar history.

The average basal area for the overstory trees in this study (36 m^2 ha^{-1}) was comparable to those reported for bottomland hardwood swamps in the southeast, which range from 29-37 (Robertson, et al. 1978; Marks and Harcombe, 1981; Held and Winstead, 1975). The average *Q. virginiana* basal area observed here (16.4 m^2 ha^{-1}) was higher than those recently reported in remnant evergreen oak forests in South Carolina (10.4 m^2 ha^{-1}; Smith et al., 1997) and Louisiana (10.7 m^2 ha^{-1}, White and Skojac, 2002). *Sabal palmetto* and *J. virginiana* were important overstory trees and this agrees with Wharton's (1978) observations that these species are more common with proximity to the coast. Both tree species are among those most tolerant of increased salinity based on greenhouse experiments (Perry and Williams, 1996; Williams et al., 1998). A USGS report on Florida tidal floodplains indicated that *S. palmetto* can be used to differentiate riverine wetland forests from lower tidal wetland forests and their establishment may be a good indicator for salinity changes in estuarine-wetland forested systems as salt water encroaches upstream (Light et al., 2002).

Ilex vomitoria dominates Georgia's back-barrier island's understory. This shrub was observed to grow in dense thickets with estimated stem densities (2144 stems ha^{-1}) three times greater than all other understory plants combined (694 stems ha^{-1}). Historical records indicate that Native American tribes in the Southeastern US used *I. vomitoria*, which is the only native plant in North America that contains caffeine, for a medicinal tonic and social drink (USDA NRCS, 2002). *Ilex vomitoria* is well adapted to fire, salt spray and heat (Coladonato, 1992). It is also an important wildlife and songbird attractant, providing year-round cover and bountiful berries (Johnson, et al., 1974). Little is known regarding its successional patterns, vegetative reproductive abilities and physiological responses within its native range. Young and others (1995) suggest that maritime forests eventually replace shrub thickets, which may persist for more than a century. This study revealed that although shrub diversity tended to increase in edge plots and with increased isolation from other back-barrier islands, *I. vomitoria* was observed to have greater stem densities on natural BBIs and in insular plots.

Woody vines are also common in the understory of back-barrier islands. Woody vines play an important role in forest ecology (i.e., filling tree gaps, contributing to tree mortality, physically linking trees and providing food sources for arboreal animals; see review by Schnitzer and Bongers, 2002), yet they are often excluded from forestry estimates because they have little commercial value. Woody vines (*Smilax, Vitis,* and *Parthenocissus spp.*) tended to have increased diversity on dredge spoil islands, but lower diversity and decreased cover in edge areas of the forest (those in close proximity to a salt marsh or tidal creek). These results suggest that plants with certain growth forms may exhibit different colonization and long-term survival strategies in areas of disturbance (i.e., dredge spoil islands). Future studies are needed to understand successional patterns of these understory plants.

Three rare species were observed on various sized back-barrier islands in this study. Botanist Wilber Duncan first collected *S. minutiflora* (shell-mound buckthorn), a thorny, laterally-climbing deciduous shrub, in Georgia on Sapelo Island in 1956. It was present on larger back-barrier islands (which may also likely have larger shell middens), including Mary's Hammock (9.9 ha) and Jack's Hammock (8.2 ha). *Forestiera segregata* (Florida privet) is a small semi-deciduous shrub that is tolerant of drought, salt and alkaline soils (University of Florida Cooperative Extension Service, 2002). Insects, like bees and butterflies pollinate the flowers and songbirds feed on the fruit (Workman, 1980; Brochat and Verkade, 2002). Florida privet was present on both large and small back-barrier islands, including Mary's Hammock, "Atwood Creek A" (0.01ha), "Atwood Creek B" (1.5 ha), and "South Creighton Large" (1.6 ha). *Bumelia anomala* (silver buckthorn) was also observed on "South Creighton Large"; whereas *Bumelia tenax* (tough bully), its congener, which is more common, was found on "Atwood Creek B", "South Creighton Large", "South Creighton Small" (0.13), and "Little Sapelo" (41.8 ha). The fact that two of three of these rare species were inventoried on "South Creighton Large", which is a dredge spoil island is interesting. Perhaps these species are effective colonizers when disturbance events allow their invasion. Once established, at least some rare species may become locally more abundant. For example, *F. segregata* was observed in small but dense thickets. In addition, *Cynanchum scoparium* (minute-flowered sand vine) was observed in two plots on Mary's Hammock. Although this sand vine is not currently regarded as a rare plant in the state, it is infrequent and this observation adds a second county to those recorded in Georgia.

Although these forests do harbor species also found on larger barrier islands in Georgia, the back-barrier islands are different in many ways. First, they are smaller in size and therefore less speciose. Second, back-barrier islands are generally more protected from severe storm surges and salt spray by ocean-fronted barrier islands. However, they are still geomorphically dynamic, depending on local rates of accretion and erosion. Because of their orientation landward of the barrier islands, they also typically lack recent dune formations as found on barrier island beaches, although some do harbor relic dunes and shell middens.

Diversity

There is very little information available regarding plant diversity of back-barrier islands with which to compare the data from this study. However, a recent report by the Southern Environmental Law Center indicated that hammock islands have diverse floral and avian faunal communities (Fabrizio and Calvi, 2003). They visited 23 back-barrier islands along the northern and central coast of Georgia, including six of those sampled in the current study (Fishing, Pumpkin, Little Moses, Jack's and Mary's Hammocks, and Little Sapelo Island). Research teams canvassed entire islands during the fall and spring seasons in 2001 and 2002 and recorded all plants they observed, but the amount of time spent on each BBI varied, as did the amount of land surveyed, so it is difficult to normalize these observations.

My study was similar to that of Fabrizio and Calvi, but there were some marked differences. My study was restricted to the central coastal region near Sapelo Island, Georgia and occurred during the summer and fall months of 2002. More importantly, the survey technique I used was designed to evaluate the vegetation community in standardized plots. Fabrizio and Calvi (2003) found that species richness increases with BBI size: small hammocks (<2 ha) had an average of 20 species per island while larger hammocks (2 to 152 ha) had an average of 50 species. I found fewer plants (an average of 20 species for all BBIs (0.01 to 41.8 ha) and a maximum of 45 species on an 8 ha hammock), but my research supports the finding that plant species richness tends to increase with increased BBI size. Also, both studies point to variation among islands. Within the six islands common to both studies, Mary's Hammock had the highest diversity, even though Little Sapelo Island is over three times larger. This suggests that factors other than size (i.e. variation in habitats) are controlling diversity on back-barrier islands, especially on larger islands and warrants further research.

My data suggest a positive relationship between back-barrier island area and vascular plant diversity, as predicted by the theory of island biogeography. However, the effect is not particularly strong. Biogeographic regression models on total alpha-diversity explained only 23% of the variance among plots (Table 12). There was no clear relationship between total species richness and proximity to larger land masses (i.e., the mainland to the west and Sapelo Island to the east), although NMDS ordinations did indicate that distance to Sapelo Island was important in explaining variances in species composition. One reason why the regression analysis might have failed to detect a relationship is because the distances to mainland and distances to Sapelo Island are inherently collinear, thereby violating an assumption of the analysis. With the exception of EI (Figures 1 and 4), the back-barrier islands in this study were sandwiched between the mainland and Sapelo Island. Thus, there was a general inverse relationship between independent variables: a back-barrier island that lies proximal to the mainland is distant to Sapelo Island and vice versa. The same statistical problem exists when evaluating nearest neighbor effects, due to the geomorphology of the landscape: several of the back-barrier islands were equally minimally distant from one another, so the metrics among nearest neighbors were positively correlated. On the other hand, distance factors appeared to be specific to the plant type. For example, trees and shrubs had lower richness with increased isolation (distance from the mainland and distance from the nearest neighbor, respectively). While these trends were not strong enough across all plant types to contribute to total plant diversity, Sapelo Island was detected as a contributor to variation in plant composition by the NMDS ordination. In a study of seven lake islands on the Savannah River, there was no correlation between distance from the mainland and woody plant species richness; however, there was a distance effect on species composition (Kadmon and Pulliam, 1993). Therefore, isolation may be important in determining patterns of species composition, and such an effect can be found even in the absence of a corresponding effect on species richness.

Back-barrier island origin was another significant predictor of diversity. Dredge plots tend to have slightly higher species richness as compared to those on BBIs of natural origin of similar sizes and this is likely due to the fact that they are ecologically younger in terms of plant succession. Although the exact ages of the dredge spoil islands is not clear, at least some portion of these spoils may have been in existence since the early 1800s (Buddy Sullivan and Fred Hay, pers. comm.). Opportunistic plants tended to colonize the plots sampled on the dredge spoil islands in this study. Pine saplings were prevalent in the smaller spoil site (SCS) surveyed and it was the only location where a non-native invasive plant was observed (*Lonicera japonica,* Japanese honeysuckle). However, the larger of the two spoils (SCL) had the largest live oak (DBH = 114 cm) present in this study. In a study of vacant urban lots, Crowe (1979) compared the species richness of flowering plants among lots of different ages (from time last mowed) and found that richness increased with lot age and then leveled off as it reached equilibrium. Further increases in species richness became a function of lot area and the extent of lot isolation. Immigration-extinction rates and the availability of seed sources from adjacent lots were believed to be the cause of the increased species richness in young lots. It is possible that the dredge spoil islands examined here have not yet reached a state of island-equilibrium. Additionally, some coastal states that manage spoil islands for wildlife have reported that many spoil islands have become too heavily vegetated to be suitable as nesting bird habitat (Erwin, et. al., 2003). Whether or not the results presented here are robust, both diversity and compositional differences were observed between back-barrier islands of dredge spoil and natural origin in this study. This suggests that successional changes are occurring on dredge spoil islands.

Although area and origin were the most important biogeographic factors controlling total diversity, other factors like the proximity to the forest-marsh margin (edge plots) appeared important when assessing plant diversity by categories. For example, regression results suggested that vine and tree diversity decreased near the marginal edge, whereas graminoids and shrubs increased. NMDS and cluster analysis results provided further support that back-barrier island plant composition is influenced by edge effects. This is likely due to the relatively small interior of back-barrier islands. This study showed those plots sampled at the marginal edge of a marsh or waterbody had a similar α-diversity at the 100 m^2 scale to insular forest plots. However, the compositional analyses showed a tendency for grouping among edge plots (Figure 9), or at least a tendency for edge plots to be different from insular plots in ordinal space (Figures 10 and 11). Such patterns indicate an ecological gradient from marsh to insular forest vegetation and similar zonation patterns have been observed in coastal habitats (Pennings and Bertness, 2001). The upland margin was obvious and abrupt at most sites, but marsh species are evidently able to persist up to 15.5 m beyond the treeline (10 m plot within 5.5 m of the upland edge). Regression analyses showed that variance in soil moisture can be partly attributed to edge effects on diversity (number of species), whereas NMDS results suggest that soil C:N ratios may play a more important role in differentiating edge from insular vegetation (type of species). Turner (1989) cites the importance of edge habitat for the movement of various species and points out that monitoring spatial and temporal changes in edges may be valuable on a landscape level. Edge areas probably inherently incorporate much environmental variation (i.e., elevation, light availability, and salinity). Although these variables were not directly measured, statistical and ordination analyses provided a way to illustrate differences between edge and insular areas. The specific factors controlling these differences warrant further study.

In general, species richness is low in highly stressful environments (Mitsch and Gosselink, 1993). Studies of southeastern coastal vegetation community studies provide some data on species richness. For example, a total of 105 species were observed across 190 1-m^2plots in a Louisiana salt marsh, and variations among plots were attributed to abiotic factors such as low soil fertility and light availability (Grace and Pugesek, 1997). In another Louisiana study, only 32 plant species were observed following a hurricane which had transformed a back-barrier marsh into a dune-like environment, significantly fewer than in predisturbance conditions (Courtemanche et al., 1999). While differences in vegetation types, extent of spatial and temporal scales, and inventory techniques make direct comparisons difficult, coastal areas show a relatively low level of plant diversity compared to other terrestrial systems (i.e. tropical forests; Turner, 1996; Silver et al.; 1996).

The comparatively few locally abundant and endemic species observed on back-barrier islands is indicative of both the homogeny of the region itself and the frequency of disturbance events. These are xeric sites and plants that proliferate have apparent adaptations to deal with moisture and salt stress (i.e., evergreen leaves). Monk (1965) showed that north Florida hammocks dominated by live oak were more xeric and had fewer tree species than those hammocks in west Florida. Moreover, 81% of those were evergreen, as compared to 40% for west Floridian stands. He attributed the difference in evergreen trees to soil moisture and nutrient stress, which he related to geomorphology. He also observed charred palmetto trunks, which is evidence of fire. A review of Florida hydric hammocks that have similar species associations to this study noted that less frequent and intense fires favor live oak and palmetto and are important in shaping the community structure (Vince et al., 1989).

Island diversity is likely capped by functional constraints dictated by hydrologic features. Whitehead and Jones (1968) theorized that small oceanic islands (less than 3 acres) have a less obvious species-area curve due to several factors, including a low species pool of salt-tolerant plants, barriers to dispersal, and the lack of island heterogeneity. Heterogeneity is constrained by the absence of a freshwater lens (Niering, 1963; Wiens, 1962). These authors observed sharp increases in diversity on islands larger than 3.8 acres (1.5 ha). They attributed this to the fact that larger islands are likely to have a fresh water lens. Diversity indices in this study indicated a general increase in species richness with increased BBI size; however, the distinction was not clear among those BBIs larger than 1.5 ha. Instead, the hierarchical cluster analysis done here indicated that BBIs in this study that were greater than 8 ha (19.8 acres) were more compositionally similar to one another than those less than 4 ha (~10 acres). They were also more speciose. In fact, the only BBI in this study that has a fresh-brackish pond (Mary's Hammock) is among the largest BBI (9.9 ha). Mary's Hammock had the highest observed vascular plant diversity among the sites, even higher than the largest island and it supported an active wood stork rookery. In a study of Channel Island shrublands, sites on the same island were observed as having more similar species composition as compared to sites on other islands and this was in part attributed to different rainfall patterns (Westman, 1983). Similarly, the presence or absence of a fresh water source may influence vascular plant communities on back-barrier islands as well.

Soil Nutrients

The observations made in this study indicate that back-barrier island soils have very low nitrogen values and highly variable carbon values. Low soil nitrogen results in slowed decomposition and reduced N mineralization rates, and has been shown to be one of the most frequently limiting soil nutrient in coastal environments (Dougherty et al., 1990). In areas such as the southeast coastal plain, low plant diversity at the local level may be indicative of these regional physiogeographic constraints. Furthermore, those plants that thrive in coastal areas may be specifically adapted to these soil types. Results from this study suggest that abiotic factors like biogeographic and soil characteristics are regulating plant diversity and plant composition. For example, %C, %N and soil C:N ratios were significant predictors of diversity measures and NMDS models showed that soil C:N ratios were particularly important in explaining variances in the vegetation composition and canopy structure of back-barrier islands. These data also showed relatively lower soil nutrients with increased distance from the mainland and on BBIs of dredge spoil origin. There have been recent concerns regarding the effects of elevated total deposition on natural systems (Adams, 2003) and recent data indicate that 15-35% of nitrogen in 40 U.S. estuarine areas is derived from both wet and dry deposition (Alexander, et al., 2000). It is presently unclear whether the apparent nutrient trend I detected is an anthropogenic signal, a natural phenomenon, or an artifact of the sampling method. There was no direct relationship however, between soil characteristics measured here and back barrier island size.

Organic soils have a higher water-holding capacity than sandy mineral soils. Some plots had high peat concentrations and these may serve to retain water in floodplain soils, thereby mitigating the effects of dry periods (Light et al., 2002) and serving as important water reserves for wildlife. Generally, soil moisture was higher in BBI plots with close proximity to other land masses, to the marsh-forest margin (edge) and in non-dredge sites.

Two separate scientific approaches have been developed over the past 30 years in an attempt to elucidate patterns predicted by island biogeography: niche assembly and spatial dynamics. Niche assembly models are ecologically driven and involve population dynamics (i.e., resource partitioning among competing species along an environmental or climatic gradient). Spatial models are driven by biogeographic metrics such as the relative size and isolation of the habitat. Biogeographers and ecologists have made recent attempts to reconcile the two fields (Hubbell, 1999; Nekola et al. 1999; Harte and Kinzig, 1999). The mathematical applications require large data sets that are beyond the scope of this work, but their theoretical applications may still apply. Many researchers have concluded that the log-log relationship of area and diversity underestimates the true species diversity of a region. Hubbell explains that this phenomenon occurs because of differences in dispersal abilities among taxa and issues associated with rare species. In regional assessments, rare species tend to become increasingly rare (not more abundant) with size, contrary to predictions of the log-log relationship. Hubbell (2001) also argues that as a larger area is surveyed, different rare species are observed, so those that were locally abundant in one area become increasingly rare over the whole region. Therefore, there tends to be a large attenuation of rare species in the metacommunity and the more refined the survey, the more diversity unveiled.

It has been suggested that plant growth forms (trees, shrubs, and herbs) have different dispersal abilities and account for long-term colonization within metapopulations (Nekola and White, 1999). My data also suggest that biogeographical factors are significant predictors for back-barrier island tree, vine and shrub diversities. A comparison between North American and

Appalachian spruce-fir forests showed that fruit or nut bearing (animal-dispersed) tree stands had significantly decreased similarity among sites with greater distance from one another, and this was due to their relative inability to migrate as compared to wind-dispersed plants. Only an intertidal salt pan separated several of the BBIs in this study. Game trails were evident between these "stepping stones" and thus contribute to the distribution of plants among them. Stepping stone islands may be important to the long-term viability of fruit and nut bearing plants and this has conservation implications.

Design Constraints

This study could have been improved in several ways. Additional sample plots, seasonal variation in sampling, more thorough surveys of the intermediate and large islands, and a larger scope to include more southerly and northerly back-barrier islands would have allowed more robust statistics and a better coverage of habitat types (i.e., islands with small wetlands). In addition, I was unable to specifically measure how elevation influences community structure because differences in elevation are on the scale of 10s of centimeters to a few meters (although elevational and salinity changes may be inferred from observed differences in edge plot plant composition). Microtypic scale changes may strongly influence the root access in a region where the water table fluctuates with tidal cycles (MHT ≅ 7.5 ft.). Those species less tolerant to drought may be the first to be affected. Gough and Grace (1998) showed that coastal marsh species disappear from the community with additional stressors (i.e., flooding and salinity), and return at a much slower rate than they had dropped out after the stressors are removed. In addition, standing dead pine and red cedar were observed at densities of 21 ha^{-1}. Tree snags may be used as a benchmark to reflect local disturbances (i.e., changes in the water table). Snag densities of 46 ha^{-1} were reported in Florida forested wetlands and were attributed to changing conditions due to sea level rise or salts deposited by storm surges (Light et al., 2002). Because initial attempts to reliably collect groundwater samples were unsuccessful due to drought, I was not able to address this issue directly. A broader suite of edaphic variables that included soil minerals (i.e., Ca, K, P) would have allowed me to examine site-specific requirements (i.e. rare shell midden plant associations).

CONCLUSIONS

This research has established that both biogeographical and edaphic features help to shape the diversity and composition of vascular plant communities of back-barrier islands. While the overall plant diversity of back-barrier islands is low compared to less stressful environments, species richness tends to increase with island size. It is also related to island origin and soil fertility. The dominant vegetation types are maritime forest species that are mostly long-lived and evergreen in nature, like live oak. These plants are well suited to a xeric, nitrogen-poor environment. While island size, origin and soil fertility had effects on plant species richness, the compositional differences among plant communities were related most closely to edge effects, soil nutrient ratios, island size and the proximity to Sapelo Island, which likely serves as a seed bank for nearby BBIs. Back-barrier islands are geographically unique areas that also provide habitat for rare plants (and birds) that have a patchy distribution. While not all back-barrier islands are created equally, these results provide some insight to some of their distinguishing features, like rare isolated wetlands, which may also influence diversity. Also, dredge spoils in this study had lower soil fertility and moisture content and different vegetational patteerns than back barrier islands of natural origin. These findings provide a better description of vascular plant diversity, composition and forest structure of small islands in coastal Georgia. They will also be useful for monitoring the long-term conditions of back-barrier islands.

Table 1. Summary of the 14 back-barrier islands (BBIs) included in this study. BBI code, name, size, number of 100 m^2 plots surveyed and plot codes are presented. BBIs marked with a cross (†) denotes dredge spoil origin; those with an asterisk (*) denotes private ownership at the time of the study. Note that not all BBIs are named on maps, so those names that were created for this study are indicated in quotation marks.

BBI Code	BBI Name	BBI Size (ha)	Plots (#)	Plot Code
ACA*	"Atwood Creek A"	0.01	1	ACA1
SCS*†	"S. Creighton S"	0.13	2	SCS1 – SCS2
LSP	"Little Sapelo P"	0.92	2	LSP1 – LSP2
FH	Fishing Hammock	1.53	5	FH 1 – FH5
ACB*	"Atwood Creek B"	1.55	3	ACB1 –ACB3
SCL*†	"S. Creighton L"	1.62	3	SCL1 – SCL3
LM	Little Moses	1.82	4	LM1 – LM4
LSD	"Little Sapelo D"	1.94	3	LSD1 – LSD3
PH	Pumpkin Hammock	3.26	4	PH1 – PH4
LSM	"Little Sapelo Minor"	3.95	5	LSM1 –LSM5
EI	Egg Island	4.16	1	EI1
JH	Jack's Hammock	8.19	6	JH1 – JH6
MH	Mary's Hammock	9.87	7	MH1 – MH7
SAP	Little Sapelo Island	41.80	6	SAP1 –SAP6
Total		80.75	52	

Table 2. Back-barrier island (BBI) metrics used in multiple regression models are listed for each island. These include BBI area (AREA), distance to Sapelo Island (DSAP), distance to mainland (DML), distance to nearest neighbor BBI (DNN), number of edge plots (EDG), and origin (ORG; N—natural, D—dredge spoil). Edge plots were characterized as <5.5 m from a marshland, salt pan, or water body. For BBI codes, see Table 1.

BBI	AREA (m^2)	DSAP (m)	DML (m)	DNN (m)	EDG (#)	ORG
ACA	112	6377	1494	389	1	N
SCS	1272	5272	1970	42	0	D
LSP	9174	1275	6300	112	2	N
FH	15273	1071	6306	370	0	N
ACB	15457	6856	1109	284	1	N
SCL	16188	5105	1959	42	0	D
LM	18204	435	6666	136	1	N
LSD	19433	1377	6184	37	0	N
PH	32561	812	6081	540	0	N
LSM	39449	1528	6076	64	2	N
EI	41567	10185	13328	52	1	N
JH	81891	1033	5641	548	0	N
MH	98736	1533	5788	64	1	N
SAP	417997	905	6396	37	0	N

Table 3. Alphabetical listing by species of plants observed on the back-barrier islands sampled in this study. Family, epithet, species code, group (M–monocot, D–dicot, G–gymnosperm, F – Fern), and habit (T–tree, S–shrub; H–herbaceous, V–vine; G–graminoid; USDA, NRCS 2002) are also presented. An asterisk (*) denotes 1 of the 14 designated jurisdictional tidal wetland species by the Georgia Coastal Marshland Protection Act (§ 12-5-280). Two asterisks (**) indicate plants of "special status" by the Georgia Dept. of Natural Resources.

Family	Genus species author	Species Code	Group	Habit
ARACEAE	*Arisaema dracontium (L.) Schott*	ARDR	M	H
ARISTOLOCIACEAE	*Aristolochia serpentaria L.*	ARSE	D	H
ASPLENIACEAE	*Asplenium platyneuron (L.) B.S.P.*	ASPL	F	H
ASTERACEAE	*Baccharis halimifolia L. **	BAHA	D	S
CHENOPODIACEAE	*Batis maritima L. **	BAMA	D	S
BIGNONIACEAE	*BignonIa capreolata L.*	BICA	D	V
ASTERACEAE	*Borrichia frutesens (L.) DC. **	BOFR	D	S
SAPOTACEAE	*Bumelia anomala (Sarg.) R.B. Clark ***	BUAN	D	S
SAPOTACEAE	*Bumelia tenax (L.) Willd.*	BUTE	D	S
BIGNONIACEAE	*Campsis radicans (L.) Seem ex Bureau*	CARA	D	V
ULMACEAE	*Celtis laevigata Willd.*	CELA	D	T
POACEAE	*Chasmanthium laxum (L.) Yates*	CHLA	M	G
POACEAE	*Chasmanthium sessiliflorum (Poir.) Yates*	CHSE	M	G
CHENOPODIACEAE	*Chenopodium album L.*	CHAL	D	H
MENISPERMACEAE	*Cocculus carolinus (L.) DC.*	CLVI	D	V
RANUNCULACEAE	*Clematis virginiana L.*	COCA	D	V
ASCLEPIADACEAE	*Cynanchum angustifolium Pers.*	CYAN	D	V
ASCLEPIADACEAE	*Cynanchum scoparium Nutt.*	CYSC	D	V
CYPERACEAE	*Cyperus retrorsus Chapman*	CYRE	M	G
CYPERACEAE	*Cyperus sp. L.*	CYPER	M	G
POACEAE	*Dichanthelium sp. (A.S. Hitchc. & Chase) Gould*	DICHA	M	G
POACEAE	*Distichlis spicata (L.) Green **	DISP	M	G
ASTERACEAE	*Eupatorium sp. L.*	EUPAT	D	H
POACEAE	*Eustachys petreae (Sw.) Desv.*	EUPE	M	G
CYPERACEAE	*Fimbristylis carolinia (Lam.) Fern.*	FICA	M	G
CYPERACEAE	*Fimbristylis castanea (Michx.) Vahl*	FICA4	M	G

OLEACEAE	*Forestiera segregata (Jacq.) Krug and Urban* **	FOSES	D	T
FABACEAE	*Galactia elliottii Nutt.*	GAEL	D	V
RUBIACEAE	*Galium hispidulum Michx.*	GAHI	D	H
LOGANACEAE	*Gelsemium sempervirens (L.) St. Hil.*	GESE	D	V
HYPERICACEAE	*Hypericum hypericoides (L.) Crantz*	HYHY	D	S
AQUIFOLIACEAE	*Ilex opaca Ait.*	ILOP	D	T
AQUIFOLIACEAE	*Ilex vomitoria Ait.*	ILVO	D	T
ASTERACEAE	*Iva frutescens L.* *	IVFR	D	S
JUNCACEAE	*Juncus roemerianus Scheele* *	JURO	M	G
CUPRESSACEAE	*Juniperus virginiana L. var. silicicola (Small) J. Silba*	JUVIS	G	T
BRASSIACEAE	*Lepidium virginicum L.*	LEVI	D	H
PLUMBAGINACEAE	*Limonium carolinium (Walt.) Britt.* *	LICA	D	H
CAPRIFOLIACEAE	*Lonicera japonica Thunb.*	LOJA	D	V
MAGNOLIACEA	*Magnolia grandiflora L.*	MAGR	D	T
ASCLEPIADACEAE	*Matelea carolinensis (Jacq.) Woods.*	MACA	D	V
RUBIACEAE	*Mitchella repens L.*	MIRE	D	H
MYRICACEAE	*Morella cerifera (L.) Small*	MOCE	D	S
MORACEAE	*Morus rubra L.*	MORU	D	T
CACTACEAE	*Opuntia pusilla (Haw.) Nutt*	OPPU	D	S
OLEACEAE	*Osmanthus americanus (L.) Benth. & Hook. f. ex Gray*	OSAM	D	T
POACEAE	*Panicum virgatum L.*	PAVI	M	G
VITACEAE	*Parthenocissus quinquefolia (L.) Planch.*	PAQU	D	V
PASSIFLORACEAE	*Passiflora lutea L.*	PALU	D	V
LAURACEAE	*Persea borbonia (L.) Spreng.*	PEBO	D	T
VERBENACEAE	*Phyla nodiflora (L.) Green*	PHNO	D	H
PINACEAE	*Pinus elliottii Engelm.*	PIEL	G	T
PINACEAE	*Pinus taeda L.*	PITA	G	T
POLYPODIACEAE	*Polypodium polypodioides (L.) Andrews & Windham*	PLPO	F	H
ROSACEAE	*Prunus caroliniana (P. Mill.) Ait.*	PRCA	D	T
ROSACEAE	*Prunus serotina Ehrh.*	PRSE	D	T

FAGACEAE	*Quercus hemisphearica Bartr.*	QUHE	D	T
FAGACEAE	*Quercus virginiana P. Mill.*	QUVI	D	T
ROSACEAE	*Rubus trivialis Michx.*	RUTR	D	V
ARECACEAE	*Sabal minor (Jacq.) Pers*	SAMI	M	S
ARECACEAE	*Sabal palmetto (Walt.) Lodd. ex J.A. & J.H. Schultes*	SAPA	M	T
CHENOPODIACEAE	*Sarcocornia perennis (P. Mill.) A.J. Scott **	SAPE	D	H
CYPERACEAE	*Scleria triglomerata Michx.*	SCTR	M	G
RHAMACEAE	*Sageretia minutiflora (Michx.) C. Mohr ***	SAMI	D	S
ARECACEAE	*Serenoa repens (Bartr.) Small*	SERE	M	S
POACEAE	*Setaria parviflora (Poir.) Kerguélen*	SEPA	M	G
SMILACEAE	*Smilax auriculata Walt.*	SMAU	M	V
SMILACEAE	*Smilax bona-nox L.*	SMBO	M	V
ASTERACEAE	*Solidago sempervirens L.*	SOSE	D	H
POACEAE	*Spartina alterniflora Loisel. **	SPAL	M	G
POACEAE	*Spartina cynosuriodes (L.) Roth **	SPCY	M	G
POACEAE	*Spartina patens (Ait.) Muhl.*	SPPA	M	G
POACEAE	*Sporobolus virginicus (L.) Kunth. **	SPVI	M	G
CHENOPODIACEAE	*Suaeda linearis (Ell.) Moq.*	SULI	D	S
BROMELIACEAE	*Tillandsia usenoides (L.) L.*	TIUS	M	H
ANACARDIACEAE	*Toxicodendron radicans (L.) Kuntze.*	TORA	D	V
EUPHORBIACEAE	*Tragia urticifolia Michx.*	TRUR	D	V
ERICACEAE	*Vaccinium arboreum Marsh.*	VAAR	D	S
VITACEAE	*Vitis aestivalis Michx.*	VIAE	D	V
VITACEAE	*Vitis labrusca L.*	VILA	D	V
VITACEAE	*Vitis rotundifolia Michx.*	VIRO	D	V
AGAVACEAE	*Yucca aloifolia L.*	YUAL	M	S
RUTACEAE	*Zanthoxylum clava-herculis L.*	ZACL	D	S

Table 4. For each taxon identified in this study, the number of plots in which it was observed is expressed as both an absolute number (PRES) and a percentage of the total 52 plots (FREQ). The average percent cover for those plots in which the plant occurred is listed. For an index of species codes, see Table 3.

Species Code	PRES	FREQ (%)	Average Cover (%)
ILVO	48	92.3	2-5
TIUS	45	86.5	0-1
QUVI	37	71.2	5-10
SAPA	36	69.2	2-5
PEBO	28	53.8	1-2
JUVIS	26	50.0	2-5
SMBO	26	50.0	0-1
DICHA	22	42.3	0-1
SERE	21	40.4	10-25
CHSE	20	38.5	2-5
PRCA	19	36.5	1-2
CYRE	16	30.8	0-1
TORA	13	25.0	0-1
CELA	12	23.1	1-2
SAMI	12	23.1	0-1
SMAU	11	21.2	0-1
GAHI	11	21.2	0-1
PIEL	10	19.2	1-2
PLPO	10	19.2	0-1
JURO	9	17.3	5-10
PAQU	9	17.3	0-1
SCTR	8	15.4	0-1
VIRO	8	15.4	0-1
SPVI	7	13.5	2-5
SPPA	7	13.5	1-2
BOFR	7	13.5	1-2
QUHE	6	11.5	10-25
BICA	6	11.5	0-1
BUTE	6	11.5	0-1
PITA	5	9.6	5-10
FICA4	5	9.6	0-1
SAMI	5	9.6	0-1
FOSES	4	7.7	1-2
RUTR	4	7.7	0-1
VAAR	3	5.8	1-2
CHLA	3	5.8	1-2
OSAM	3	5.8	1-2
GAEL	3	5.8	0-1
BAHA	3	5.8	0-1
CARA	3	5.8	0-1
DISP	3	5.8	0-1
IVFR	3	5.8	0-1
CYPER	3	5.8	0-1
MAGR	2	3.8	5-10

EUPE	2	3.8	1-2
MACA	2	3.8	1-2
VILA	2	3.8	0-1
SAPE	2	3.8	0-1
BAMA	2	3.8	0-1
CYAN	2	3.8	0-1
CYSC	2	3.8	0-1
LICA	2	3.8	0-1
MOCE	2	3.8	0-1
OPPU	2	3.8	0-1
ARSE	2	3.8	0-1
SOSE	2	3.8	0-1
SPAL	2	3.8	0-1
ASPL	2	3.8	trace
PRSE	1	1.9	5-10
YUAL	1	1.9	5-10
ILOP	1	1.9	2-5
VIAE	1	1.9	0-1
MORU	1	5.8	0-1
BUAN	1	1.9	0-1
CHAL	1	1.9	0-1
COCA	1	1.9	0-1
FICA	1	1.9	0-1
GESE	1	1.9	0-1
LEVI	1	1.9	0-1
MIRE	1	1.9	0-1
PAVI	1	1.9	0-1
PHNO	1	1.9	0-1
SEPA	1	1.9	0-1
SPCY	1	1.9	0-1
SULI	1	1.9	0-1
ZACL	1	1.9	0-1
ARDR	1	1.9	trace
CLVI	1	1.9	trace
EUPAT	1	1.9	trace
HYHY	1	1.9	trace
LOJA	1	1.9	trace
PALU	1	1.9	trace
TRUR	1	1.9	trace

Table 5. Summary of statistics of overstory trees sampled on back-barrier islands in this study. These include total stems tallied (N) frequency of occurrence among plots (FREQ), estimated stem density (DEN), mean and maximum tree diameter at breast height (dbh), total and average diameter breast height for all plots (DBH), total and average tree basal area (TBA) and stand basal area (SBA). For an index of species codes, see Table 3. An asterisk (*) denotes total woody stem values used for calculating Species Importance Values (SIV; Table 6).

Species Code	N	FREQ (%)	DEN (# / ha)	Mean tree dbh (cm)	Max tree dbh (cm)	ΣDBH (cm)	Ave. plot DBH (± s.d.) (cm)	Σ TBA (m^2)	Ave. TBA (± s.d.) (m^2)	SBA (m^2/ ha)
QUVI	58	44.2	111.5	37.7	114.0	2188.0	42.1 ± 71.6	8.5	0.16 ± 0.3	16.4
JUVI	50	36.5	96.2	24.7	51.0	1234.4	23.7 ± 44.5	2.9	0.06 ± 0.1	5.6
SAPA	23	11.5	44.2	32.9	53.0	757.7	14.6 ± 51.1	1.8	0.03 ± 0.1	3.4
PIEL	20	11.5	38.5	21.4	46.0	427.9	8.2 ± 26.3	0.9	0.02 ± 0.1	1.8
PEBO	13	19.2	25.0	16.9	27.5	219.8	4.2 ± 10.3	0.3	0.01 ± 0.0	0.6
PRCA	11	9.6	21.2	15.0	17.5	165.2	3.2 ± 13.1	0.2	0.00 ± 0.0	0.4
CELA	10	13.5	19.2	27.7	66.0	277.3	5.3 ± 16.0	0.8	0.02 ± 0.1	1.6
QUHE	8	11.5	15.4	53.8	93.0	430.1	8.3 ± 24.7	2.1	0.04 ± 0.1	4.1
ILVO	5	5.8	9.6	12.2	12.5	61.2	1.2 ± 5.6	0.1	0.00 ± 0.0	0.1
PITA	5	5.8	9.6	45.5	60.0	227.7	4.4 ± 24.3	0.9	0.02 ± 0.1	1.8
MAGR	1	1.9	1.9	22.4	22.5	22.4	0.4 ± 3.1	0.0	—	0.1
OSAM	1	1.9	1.9	12.2	12.5	12.2	0.2 ± 1.7	0.0	—	0.0
Total	205	173.0*	394.2*					18.6		35.9*

Table 6. Summary of species importance values (SIV) for overstory trees sampled on back-barrier islands in this study. Relative frequency (RFreq), relative density (RDen) and relative dominance (RDom) values are summed to arrive at SIV. The maximum species importance value = 300. For an index of species codes, see Table 3.

Species Code	RFreq (%)	RDen (%)	RDom (%)	SIV
QUVI	25.6	28.3	45.8	99.6
JUVI	21.1	24.4	15.6	61.1
SAPA	6.7	11.2	9.4	27.3
QUHE	6.7	3.9	11.4	21.9
PIEL	6.7	9.8	5.0	21.4
PEBO	11.1	6.3	1.8	19.2
CELA	7.8	4.9	4.4	17.1
PRCA	5.6	5.4	1.1	12.0
PITA	3.3	2.4	5.0	10.8
ILVO	3.3	2.4	0.3	6.1
MAGR	1.1	0.5	0.2	1.8
OSAM	1.1	0.5	0.1	1.7
Total	100	100	100	300

Table 7. Summary of statistics of understory trees sampled on back-barrier islands in this study. These include total stems tallied (N) frequency of occurrence among plots (FREQ), estimated stem density (DEN), mean stem diameter at breast height (dbh), total and average dbh for all plots (DBH), total and average tree basal area (TBA) and stand basal area (SBA). For an index of species codes, see Table 3. An asterisk (*) denotes total woody stem values used for calculating Species Importance Values (SIV; Table 8). Note that monocots (⊕) were excluded from these calculations; the number of palm fronds is presented instead of dbh for these species.

Species Code	N	FREQ (%)	DEN (# / ha)	Mean stem dbh (cm)	ΣDBH (cm)	Ave. plot DBH (± s.d.) (cm)	Σ TBA (m^2)	Ave. TBA (m^2)	SBA (m^2/ ha)
ILVO	1115	82.7	2144.2	2.0	2192.9	42.2 ± 44.4	6.8E-01	1.3E-02	1.3E+00
SMIL	75	15.4	144.2	0.6	41.8	0.8 ± 2.4	2.2E-03	4.2E-05	4.2E-03
PEBO	53	26.9	101.9	3.1	164.9	3.2 ± 10.9	7.1E-02	1.4E-03	1.4E-01
FOSE	47	5.8	90.4	3.6	169.7	3.3 ± 18.4	6.5E-02	1.2E-03	1.2E-01
VITIS	44	21.2	84.6	4.1	181.9	3.5 ± 11.0	7.7E-02	1.5E-03	1.5E-01
JUVI	24	13.5	46.2	3.6	85.2	1.6 ± 5.9	3.4E-02	6.5E-04	6.5E-02
PIEL	23	7.7	44.2	2.5	56.9	1.1 ± 6.3	1.6E-02	3.1E-04	3.1E-02
PAQU	19	11.5	36.5	1.8	33.8	0.7 ± 3.2	8.6E-03	1.7E-04	1.7E-02
BICA	18	5.8	34.6	0.5	9.0	0.2 ± 1.1	3.5E-04	6.8E-06	6.8E-04
OSAM	12	5.8	23.1	5.9	71.2	1.4 ± 9.3	3.7E-02	7.2E-04	7.2E-02
IVFR	10	1.9	19.2	0.5	5.0	0.1 ± 0.7	2.0E-04	3.8E-06	3.8E-04
PRCA	10	7.7	19.2	6.2	61.7	1.2 ± 4.8	3.3E-02	6.3E-04	6.3E-02
QUVI	6	5.8	11.5	3.8	22.7	0.4 ± 2.2	1.2E-02	2.3E-04	2.3E-02
CELA	6	7.7	11.5	5.3	31.8	0.6 ± 2.2	1.5E-02	2.8E-04	2.8E-02
MAGR	3	3.9	5.8	3.4	10.2	0.2 ± 1.1	4.3E-03	8.3E-05	8.3E-03
ZACL	3	1.9	5.8	1.2	3.7	0.1 ± 0.5	4.1E-04	7.9E-06	7.9E-04
VAAR	2	3.9	3.8	7.1	14.1	0.3 ± 1.4	7.9E-03	1.5E-04	1.5E-02
CLVI	2	1.9	3.8	1.6	3.2	0.1 ± 0.4	3.9E-04	7.6E-06	7.6E-04
PITA	1	1.9	1.9	1.6	1.6	0.0 ± 0.2	2.0E-04	3.8E-06	3.8E-04
BUTE	1	1.9	1.9	1.6	1.6	0.0 ± 0.2	2.0E-04	3.8E-06	3.8E-04
CARA	1	1.9	1.9	0.5	0.5	0.0 ± 0.1	2.0E-05	3.8E-07	3.8E-05
MORU	1	1.9	1.9	1.6	1.6	0.0 ± 0.2	2.0E-04	3.8E-06	3.8E-04
Woody Total	1476	238.5*	2838.5*				1.1		2.00*
SAPA⊕	243	53.9	467.3	5.3	1286	24.7 ± 0.1	—	—	—
SERE⊕	318	34.6	611.5	10.7	18.3	35.1 ±.1	—	—	—
Monocot Total	561	84.5	1078.8						

Table 8. Summary of species importance values (SIV) for sampled understory trees. Relative frequency (RFreq), relative density (RDen) and relative dominance (RDom) values are summed to arrive at SIV. The maximum species importance value = 300. For an index of species codes, see Table 3.

Species Code	RFreq (%)	RDen (%)	RDom (%)	SIV
ILVO	34.7	75.5	63.9	174.1
PEBO	11.3	3.6	6.7	21.6
VITIS	8.9	3.0	7.3	19.1
SMIL	6.5	5.1	0.2	11.7
FOSE	2.4	3.2	6.1	11.7
JUVI	5.7	1.6	3.2	10.4
PRCA	3.2	0.7	3.1	7.0
PAQU	4.8	1.3	0.8	6.9
OSAM	2.4	0.8	3.5	6.7
PIEL	3.2	1.6	1.5	6.3
CELA	3.2	0.4	1.4	5.0
QUVI	2.4	0.4	1.1	3.9
BICA	2.4	1.2	0.0	3.7
VAAR	1.6	0.1	0.7	2.5
MAGR	1.6	0.2	0.4	2.2
IVFR	0.8	0.7	0.0	1.5
ZACL	0.8	0.2	0.0	1.1
CLVI	0.8	0.1	0.0	1.0
PITA	0.8	0.1	0.0	1.0
BUTE	0.8	0.1	0.0	1.0
MORU	0.8	0.1	0.0	1.0
CARA	0.8	0.1	0.0	1.0
Total	100	100	100	300

Table 9. Alpha (α), beta (β), and gamma (λ) diversities for each back-barrier island (BBI) arranged by increasing island area and number of plots (N). Alpha-diversity is the average number of plant species observed per plot, beta-diversity estimates species turnover rates (λ/α), and gamma-diversity indicates the species richness at the landscape level. For BBI codes, see Table 1. An asterisk (*) denotes BBIs of dredge spoil origin.

			Diversity		
BBI	Area (ha)	N	α	β	λ
ACA	0.01	1	8.0	1.0	8.0
SCS*	0.13	2	13.0	1.5	19.0
LSP	0.92	2	8.5	1.9	16.0
FH	1.53	5	10.6	1.8	19.0
ACB	1.55	3	9.7	1.9	18.0
SCL*	1.62	3	15.0	1.4	21.0
LM	1.82	4	7.3	2.5	18.0
LSD	1.94	3	7.0	1.4	10.0
PH	3.26	4	16.3	1.6	26.0
LSM	3.95	5	8.8	2.0	18.0
EI	4.16	1	15.0	1.0	15.0
JH	8.19	6	9.8	2.1	21.0
MH	9.87	7	16.0	2.8	45.0
SAP	41.8	6	13.3	2.4	32.0
Average	5.8	3.7	11.3	1.8	20.4

Table 10. Alpha (α), beta (β) and gamma (λ) diversities based on back-barrier island origin (dredge or natural). Alpha-diversity is the number of plant species observed per plot (N = number of plots), beta-diversity estimates species turnover rates (λ/α), and gamma-diversity indicates species richness at the landscape level.

		Diversity		
Origin	N	α	β	λ
Natural	48	11.3	6.9	78.0
Dredge	5	14.2	2.0	29.0
All	52	11.6	7.2	83.0

Table 11. Values for edaphic variables measured from 10 cm cores on back-barrier island plots in this study (n=52). Variables include percent nitrogen (%N), percent carbon (%C), soil nutrient ratio (C:N), percent loss on ignition (%LOI), percent soil moisture (%SM) and standard Munsell® soil notation for hue, value, and chroma, (H/V/C). Plots marked with a cross (†) denotes sites of dredge spoil origin; those with an asterisk (*) denotes those that were designated as edge sites.

BBI code	%N	%C	C:N	%LOI	%SM	H/V/C
ACA*	1.2	16.0	16	30.4	25.3	5YR/3/1
ACB1	2.0	48.7	28	90.8	56.8	5YR/3/2
ACB2	1.0	20.4	24	37.8	37.3	10YR/3/1
ACB3*	1.8	47.0	31	85.8	80.7	10/YR/1/1
EI*	0.1	1.7	17	4.0	31.6	10YR/5/2
FH1	0.3	8.0	29	13.6	15.0	5YR/4/1
FH2	0.3	6.3	29	11.6	8.9	5YR/4/1
FH3	0.6	12.3	25	24.0	31.9	5YR/3/1
FH4	0.5	11.9	27	19.8	33.2	10YR/3/1
FH5	0.2	5.4	28	9.2	19.9	10YR/4/1
JH1	0.2	3.1	15	6.4	11.5	2.5Y/5/0
JH2	0.8	9.3	14	16.8	13.2	2.5Y/3/0
JH3	1.0	14.7	17	22.6	23.9	7.5YR/0
JH4	1.4	15.8	13	26.8	32.5	5YR/4/1
JH5	0.8	9.0	13	17.6	23.0	2.5Y/3/0
JH6	0.2	3.1	20	5.2	9.1	5YR/6/1
LM1	0.1	3.3	25	6.8	9.2	10YR/4/1
LM2	0.1	1.7	17	4.0	27.1	10YR/4/1
LM3	0.4	6.3	21	12.2	8.4	10YR/4/1
LM4	0.6	11.3	23	20.4	29.0	5YR/4/1
LM5	0.8	28.9	40	49.8	57.0	7.5YR/3/0
LSD1	0.9	20.6	27	37.0	49.2	5YR/2.5/1
LSD2	0.4	9.3	30	16.6	43.9	5YR/3/1
LSM1	0.3	8.8	34	14.8	20.0	7.5YR/3/0
LSM2*	0.3	6.7	22	13.4	33.7	5YR/3/1
LSM3	0.6	14.8	30	25.4	31.8	5YR/3/1
LSM4*	0.8	17.5	25	33.4	48.5	10YR/2/1
LSM5	1.0	28.5	32	47.2	56.6	5YR/2.5/1
LSP1*	0.5	7.9	19	14.8	43.2	5YR/4/1
LSP2*	0.4	9.7	31	17.0	33.6	10YR/3/1
MH1*	1.9	32.7	20	60.4	56.4	7.5YR/2/0
MH2	0.3	3.3	15	6.8	16.4	5YR/4/0
MH3	0.4	5.2	15	9.0	25.3	5YR/4/1
MH4	0.4	4.2	14	8.4	13.4	5YR/3/1
MH5	0.5	8.1	19	15.4	27.0	5YR/6/1
MH6*	0.6	19.8	37	31.2	32.0	5YR/4/1
MH7	0.3	4.3	15	7.8	17.2	7.5YR/4/0
PH1	0.4	9.5	29	15.8	19.2	5YR/3/1
PH2	0.3	4.5	20	8.4	12.0	5YR4/1
PH3	0.4	7.3	20	11.6	11.0	5YR/5/1
PH4	0.2	4.1	22	7.6	7.7	5YR/5/1
SAP1	1.0	25.1	30	66.6	41.8	10YR/2/2

SAP2	0.5	6.0	14	12.4	20.3	5YR/2.5/1
SAP3	0.3	3.9	16	8.2	17.9	5YR/3/1
SAP4	0.4	8.6	24	14.2	22.1	5YR/3/1
SAP5	0.1	1.6	19	4.4	12.8	10YR/4/2
SAP6	0.3	4.1	17	24.8	14.9	10YR/3/2
SCL1†	0.3	4.5	17	10.0	25.0	10YR/5/2
SCL2†	0.4	4.5	15	6.8	21.7	10YR/4/1
SCL3†	0.3	4.6	17	10.6	23.5	10YR/5/1
SCS1†	0.3	5.3	22	12.8	22.4	10YR/5/2
SCS2†	0.3	6.8	26	15.4	22.2	10YR/4/2
Average.	0.6	11.2	22.5	21.0	27.5	
s.d.	0.4	10.4	6.8	19.4	15.6	

Table 12. Summary of stepwise linear regression analyses of total diversity (TTL DIV) and average cover values (ACV) by plant category against selected variables of biogeographic metrics (n=52). Biogeographic metrics include back-barrier island area (AREA), distance to mainland (DML), distance to Sapelo Island (DSAP), distance to nearest neighbor BBI (DNN), BBI dredge origin (DRG) and edge plot (EDG). Table entries are regression coefficients for significant values; $P < 0.05$ unless otherwise noted [(*) $P \leq 0.001$, NS—Not significant, (—) indicates metric did not reach criterion to be included in the model]. Note: Biogeographic data and total diversity were log transformed; all other variables were log +1 transformed to achieve normality.

Independent	TTL	SHRUB		VINE		TREE		GRAM		HERB	
variable	DIV	DIV	ACV	DIV	ACV	DIV	ACV	DIV	ACV	DIV	ACV
AREA (m^2)	0.461*	—	-0.582*	0.368	—	0.391	—	—	0.345	0.407	—
DML (m)	—	—	—	—	—	-0.507*	—	—	—	—	—
DSAP (m)	—	—	—	—	—	—	0.278	—	—	—	—
DNN (m)	—	-0.345	-0.554*	—	—	—	—	—	—	—	—
DRG	0.406	—	-0.696*	0.390	—	—	—	—	—	—	—
EDG	—	0.404	—	-0.415*	-0.536*	-0.478*	—	0.391	0.334	—	—
Model R^2	0.233	0.293	0.421	0.484	0.287	0.529	0.077	0.153	0.165	0.166	NS

Table 13. Summary of stepwise linear regression analyses for total diversity (DIV) and diversities by plant category versus soil measurements, including percent carbon (%C), percent nitrogen (%N), soil nutrient ratio (C:N), percent loss on ignition (%LOI), and percent soil moisture (%SM) for for back-barrier island plots (n=52). Table entries are regression standardized coefficients for significant values; $P < 0.05$ unless otherwise noted [(*) $P \leq 0.001$, NS—Not significant, (—) indicates metric did not reach criterion to be included in the model]. Note: DIV data were log transformed; all other variables were log +1 transformed to achieve normality.

	TTL DIV	GRAM DIV	HERB DIV	SHRUB DIV	VINE DIV	TREE DIV
% C	35.451*	—	—	—	23.596	30.432
% N	-30.921*	—	—	—	-20.530	-25.889
C:N	-13.550*	—	—	—	-9.010	-11.352
LOI	—	—	—	—	—	—
% SM	—	—	—	0.290	-0.372	-0.519
Model R^2	0.345	NS	NS	0.084	0.373	0.333

Table 14. Summary of linear regression analyses of edaphic variables and selected biogeographic metrics for back-barrier island (BBI) plots (n=52). Table entries are regression standardized coefficients for significant values; $P < 0.05$ unless otherwise noted [(*) $P \leq 0.001$, (—) indicates metric did not reach criterion to be included in the model]. Note: Data were log transformed to achieve normality.

	%C	%N	C:N	LOI	% Soil Moisture
BBI Area (m^2)	—	—	—	—	—
Distance to Mainland (m)	-0.617*	-0.659*	-0.457	-0.619*	-0.471
Distance to Sapleo (m)	—	—	—	—	—
Distance to NN (m)	—	—	-0.317	—	-0.430
Dredge Origin	-0.529*	-0.529*	-0.421	-0.496*	-0.368
Edge	—	—	—	—	0.338
Model R^2	0.302	0.331	0.187	0.292	0.399

Table 15. Nonmetric multidimensional (NMDS) analysis was used to relate the suite of biogeographical and edaphic variables to two main ordination axes scores for back-barrier island plant composition. Seventy-eight percent of the variance was explained within two axes (see Figure 10). Correlation coefficients are expressed as linear, proportional, and rank relationships between the individual variables and the ordination scores, (Pearson's r (r), R-squared (R^2) Kendall's tau (tau)), respectively. Six biogeographical variables include back-barrier island area (AREA), distance to Sapelo Island (DSAP), distance to mainland (DML), distance to nearest neighbor back-barrier island (DNN), edge plot (EDG), and dredge spoil origin (DRG). Five edaphic variables include percent carbon (%C), percent nitrogen (%N), soil nutrient ratio (C:N), percent soil moisture (%SM) and percent loss on ignition (%LOI).

	Axis 1			Axis 2		
	r	R^2	tau	r	R^2	tau
C:N	-0.554	0.307	-0.379	-0.063	0.004	0.090
AREA	0.523	0.274	0.377	-0.345	0.119	-0.409
EDG	-0.367	0.135	-0.295	0.682	0.465	0.412
DSAP	-0.003	0.000	-0.019	0.456	0.208	0.288
%SM	-0.341	0.117	-0.236	0.287	0.082	0.266
DRG	0.291	0.085	0.238	0.141	0.020	0.274
%C	-0.236	0.055	-0.238	0.057	0.003	0.138
%LIO	-0.208	0.043	-0.198	0.056	0.003	0.114
DML	-0.170	0.029	-0.199	0.080	0.006	-0.155
%N	-0.081	0.006	-0.067	0.082	0.007	0.082
DNN	0.036	0.001	-0.097	-0.053	0.003	0.060
Total		0.26			0.52	

Table 16. Nonmetric multidimensional (NMDS) analysis was used to relate the suite of biogeographical and edaphic variables to the three main ordination axes scores for stem densities of canopy trees. Sixty-four percent of the variance was explained within two axes (see Figure 11). Correlation coefficients are expressed as linear, proportional, and rank relationships between the individual variables and the ordination scores, (Pearson's r (r), R-squared (R^2) Kendall's tau (tau)), respectively. Six biogeographical variables include back-barrier island area (AREA), distance to Sapelo Island (DSAP), distance to mainland (DML), distance to nearest neighbor back-barrier island (DNN), edge orientation (EDG), and dredge spoil origin (DRG). Five edaphic variables include percent carbon (%C), percent nitrogen (%N), soil nutrient ratio (C:N), percent soil moisture (%SM) and percent loss on ignition (%LOI).

	Axis 1			Axis 2			Axis 3		
	r	R^2	tau	r	R^2	tau	r	R^2	tau
EDG	0.517	0.267	0.267	0.324	0.105	0.255	-0.041	0.002	-0.043
C:N	-0.384	0.147	-0.3	0.568	0.322	0.392	0.353	0.125	0.184
DSAP	0.345	0.119	0.196	-0.043	0.002	-0.006	-0.059	0.003	-0.028
AREA	-0.292	0.085	-0.100	-0.176	0.031	-0.155	-0.435	0.189	-0.261
%SM	0.104	0.011	0.036	0.416	0.173	0.267	0.064	0.004	0.080
DRG	0.149	0.022	0.217	-0.139	0.019	-0.099	0.138	0.019	0.041
%N	0.121	0.015	0.017	0.047	0.002	0.072	-0.101	0.010	-0.039
DNN	0.106	0.011	0.243	-0.175	0.031	-0.119	-0.135	0.018	0.018
%LIO	-0.046	0.002	-0.106	0.224	0.05	0.198	-0.050	0.003	0.002
%C	-0.027	0.001	-0.077	0.225	0.051	0.217	-0.002	0.000	0.054
DML	-0.002	0.000	-0.357	0.334	0.112	0.243	-0.006	0.000	0.102
Total		0.31			0.33			0.20	

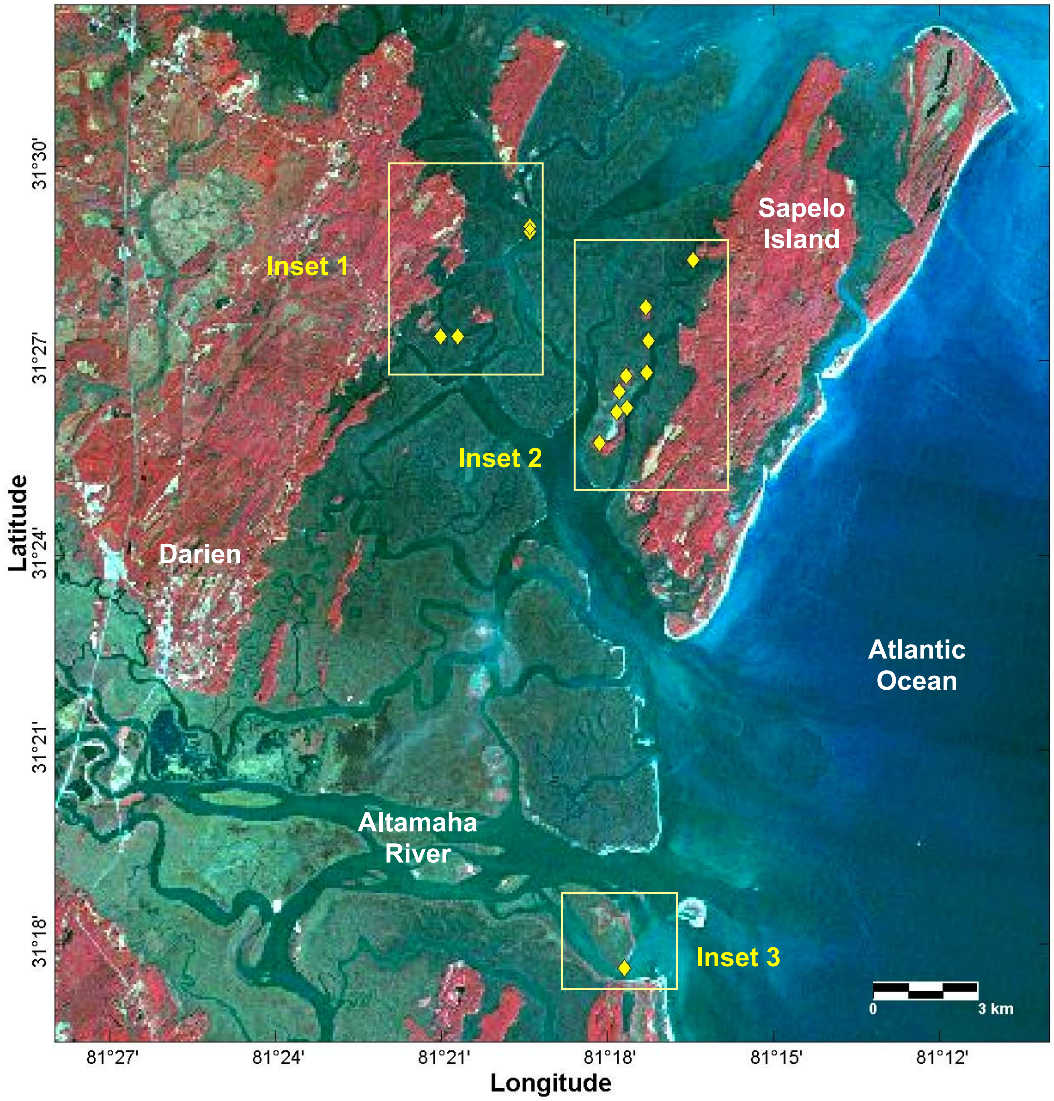


Figure 1. Satellite image of Long-Term Ecological Research (LTER) domain near Sapelo Island, Georgia. Diamonds indicate 14 back-barrier islands (BBIs) where vegetation sampling occurred for this study. Close-up images of inset areas 1-3 are shown in Figures 2-4, respectively. Upland vegetation appears red; salt marsh and water bodies appear blue.

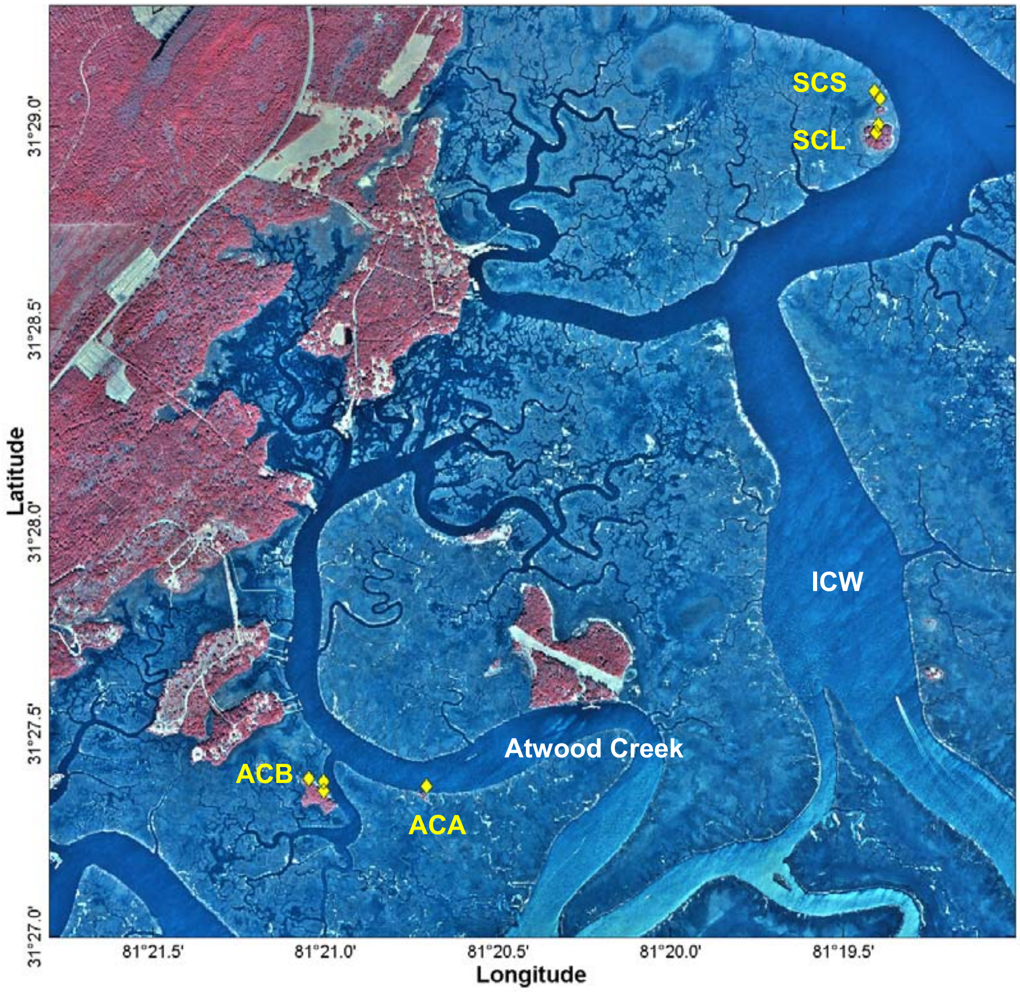


Figure 2. Satellite image of inset 1 from Figure 1. Diamonds indicate plot locations on 4 BBI sites (ACA, ACB, SCS, SCL) surveyed in this study. SCS and SCL are dredge spoil islands along the Intracoastal Waterway (ICW). Upland vegetatation appears red; salt marsh and water bodies appear blue.

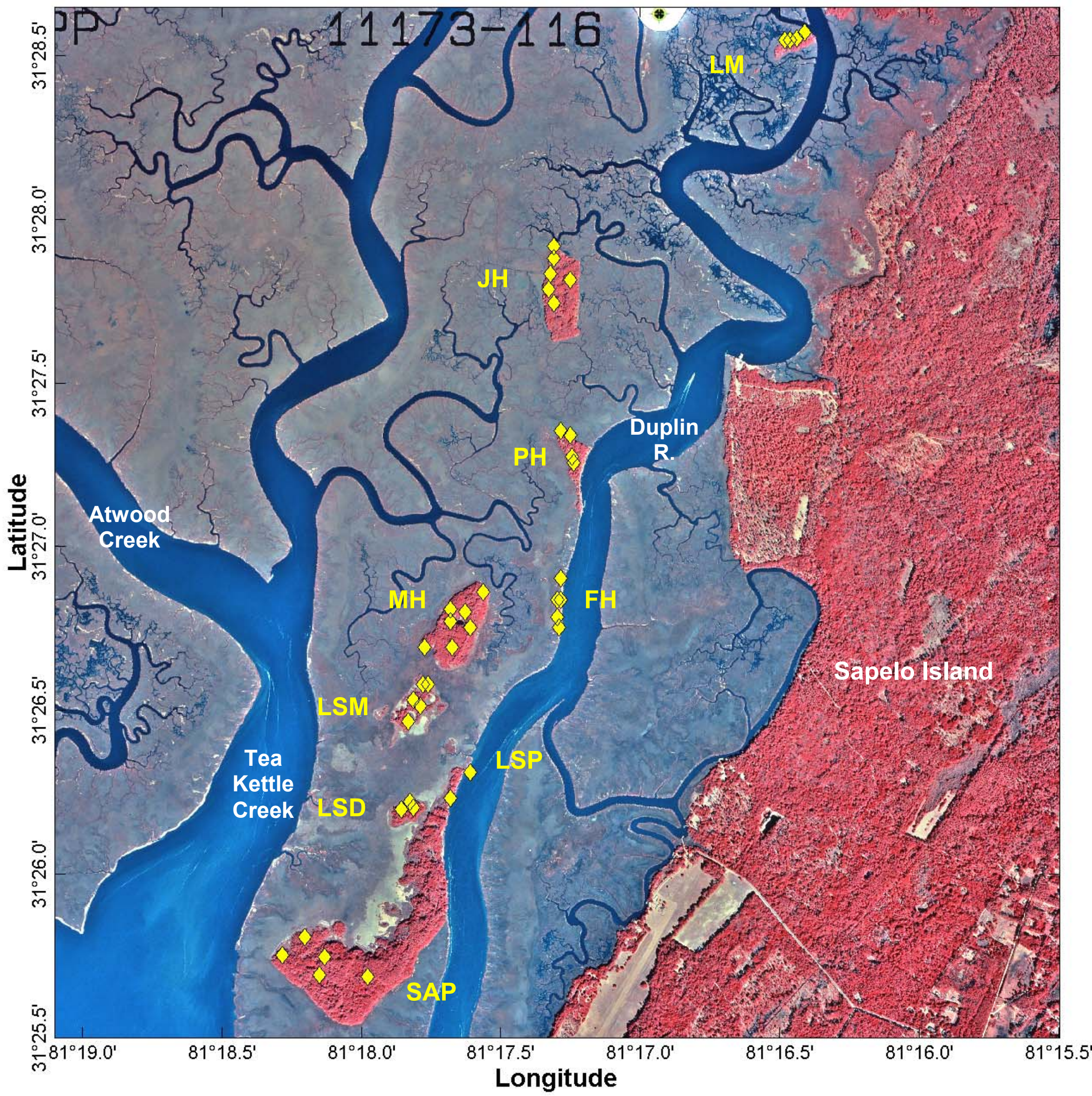


Figure 3. Satellite image of inset 2 from Figure 1. Diamonds indicate plot locations on 9 BBI sites (LM, JH, FH, MH, LSM, LSP, LSD, SAP) surveyed in this study. The Duplin River separates Sapelo Island from the back-barrier areas shown. Upland vegetatation appears red; salt marsh and water bodies appear blue.

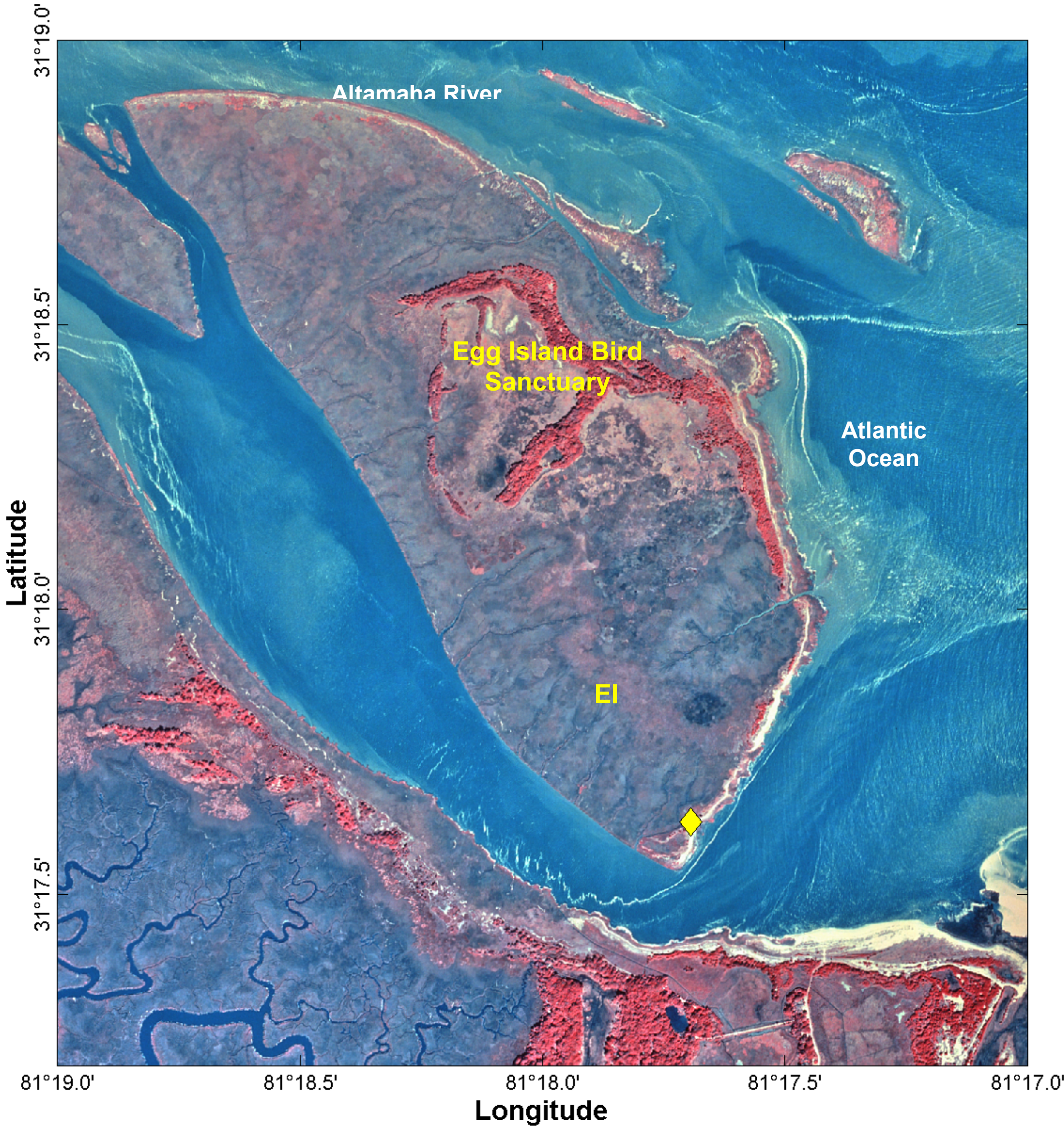


Figure 4. Satellite image of inset 3 from Figure 1. A diamond indicates the plot location on BBI site (EI) in this study. This was the only back-barrier site in this study to front the ocean. Upland vegetatation appears red; salt marsh and water bodies appear blue.

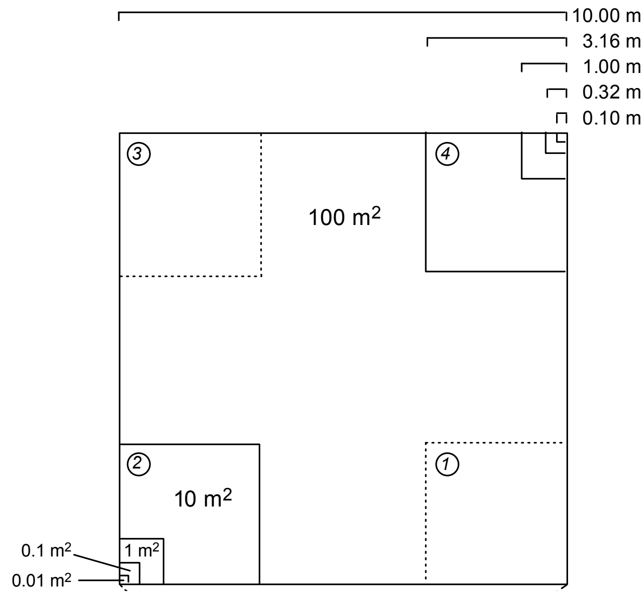


Figure 5. Standard North Carolina Vegetation Survey (NCVS) survey plot design showing nested subplots in each of 4 corners (Peet, et al., 1998). Overall plot area is 0.01 ha (100 m^2), with subplot areas of 0.01 m^2, 1.0 $m^2$and 10 m^2.

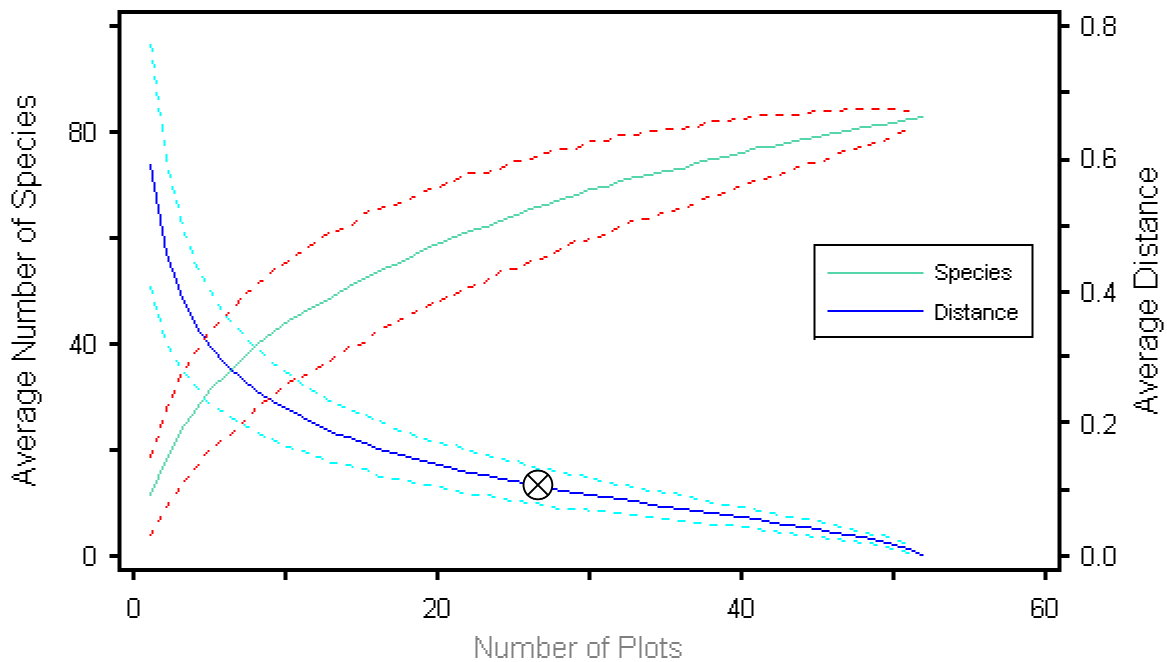


Figure 6. Species area curve showing the average number of species and average Sorensen distance versus the number of plots sampled. Dotted lines indicate standard error. A circled "X" indicates the point (28 plots) where the Sorensen distance is less than 0.1 (<10%). Further increases in the number of plots sampled improve the model only slightly.

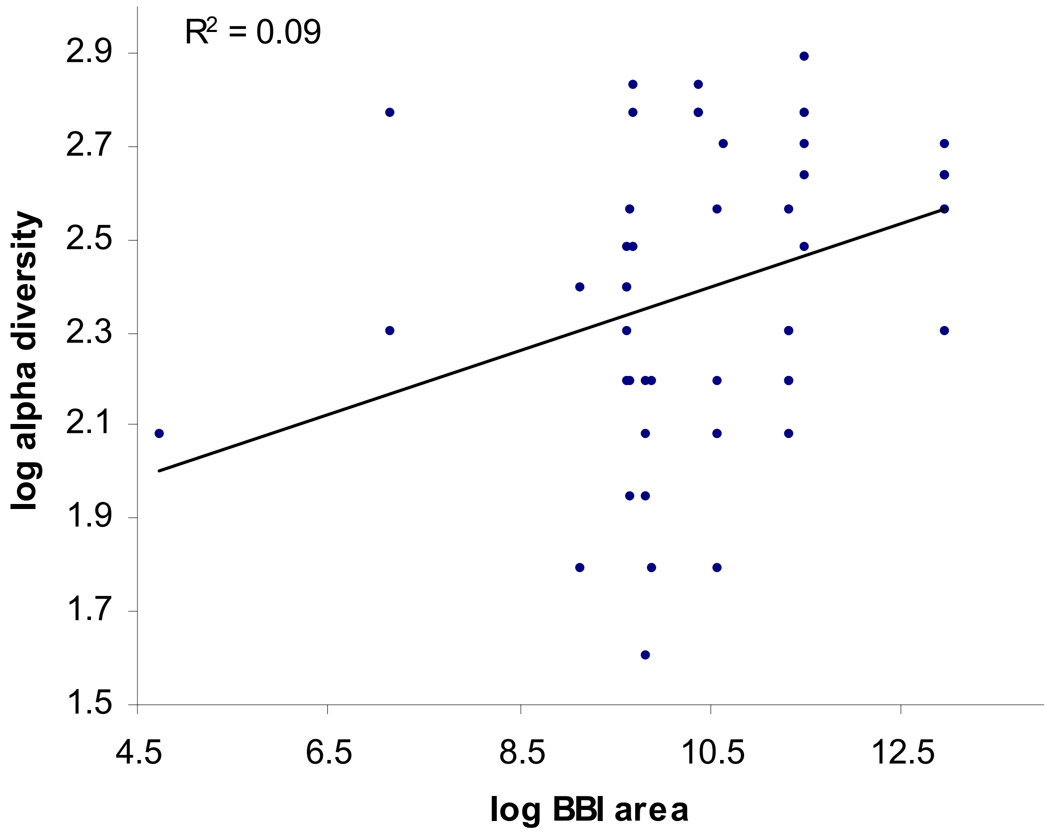


Figure 7. Log-log scatter plot of alpha-diversity and back-barrier island (BBI) area for all sample plots (n=52). The regression line (y = 0.07x + 1.68) indicates a slight increase in alpha diversity with increased BBI area.

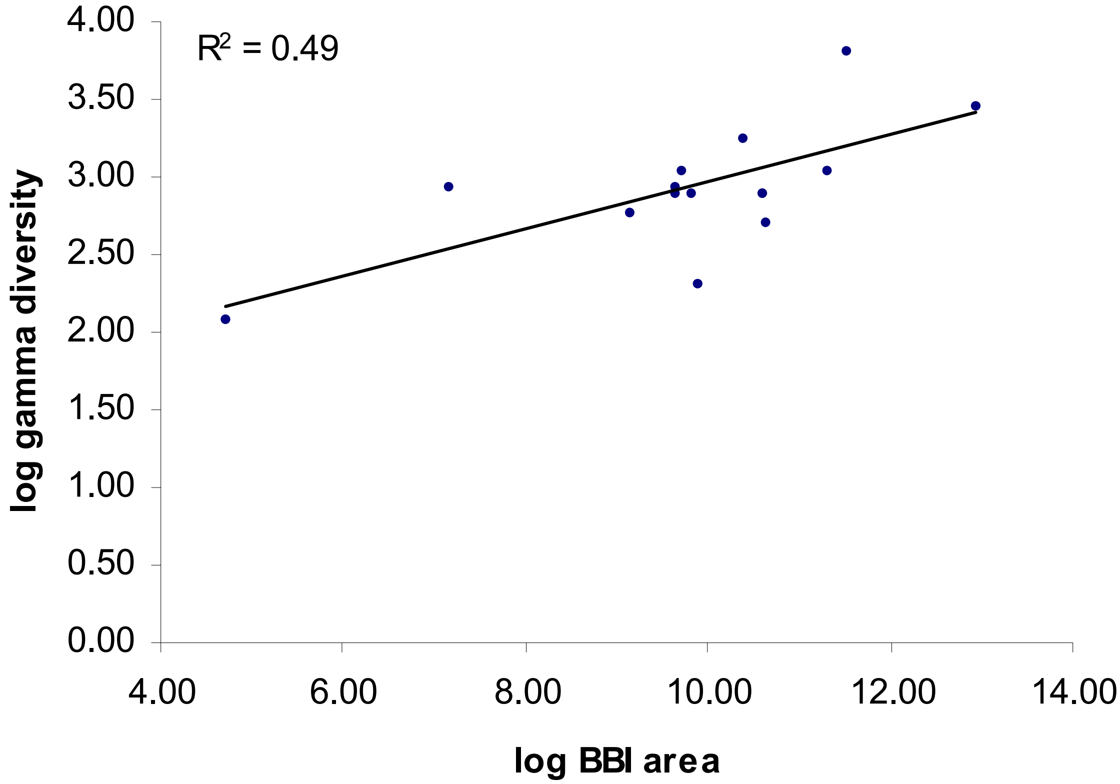


Figure 8. Log-log scatter plot of gamma-diversity and back-barrier island (BBI) area for each island (n=14). The regression line (y = 0.15x + 1.43) indicates an increase in landscape-level diversity with increased BBI area.

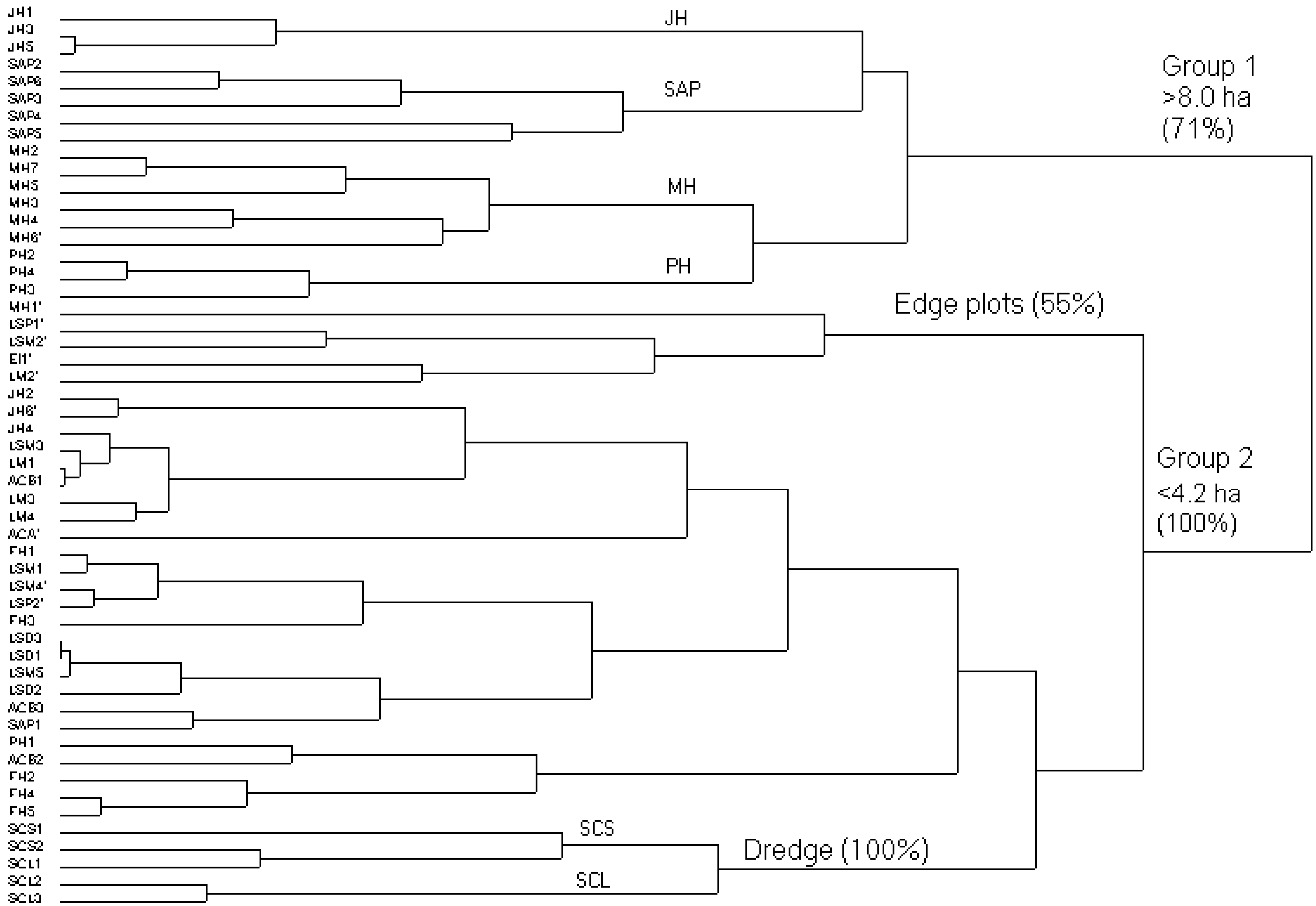


Figure 9. Dendrogram for Ward's hierarchical cluster analysis of composition for all plots (n=52). Plots separated into 2 distinct groups based on back-barrier island (BBI) area (> 8 ha and < 4.2 ha) as measured by euclidean distance. Group 1 captured 71% of plots sampled from BBIs > 8.0 ha and had strong clustering effects among plots from the same BBI: JH, SAP, MH, and PH. Group 2 captured 100% of all plots sampled from BBIs < 4.2 ha (and 29% of plots from BBIs >8.0 ha) and separated further based on plot orientation (edge), and BBI origin (dredge). Subgroups within group 2 captured 55% of all edge plots and 100% of all dredge plots. Edge plots are denoted with the symbol ('). For an index of BBI codes, see Table 1.

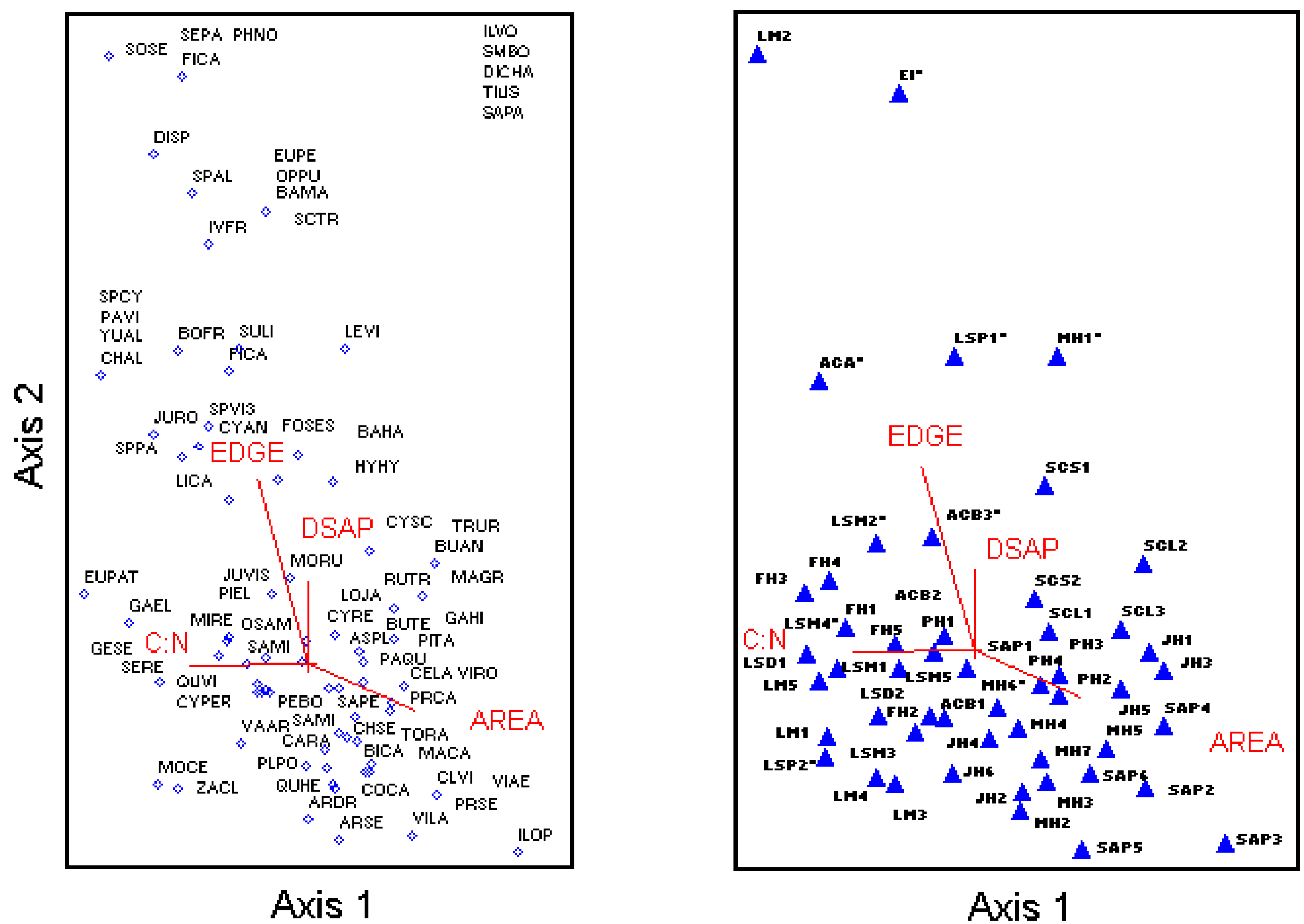
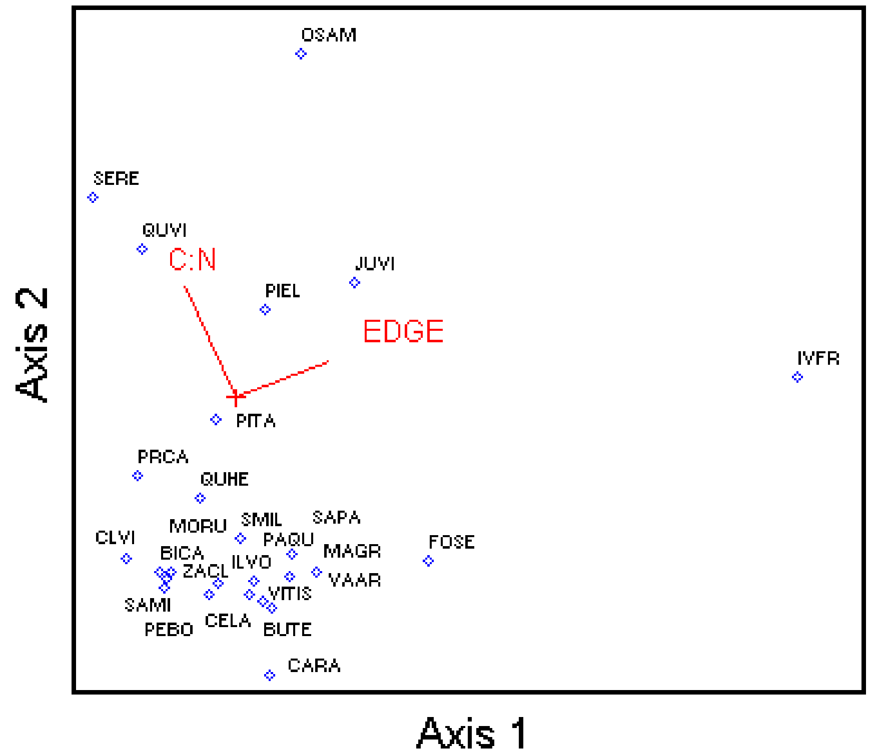


Figure 10. Nonmetric multidimensional scaling (NMDS) results illustrating differences in plant composition among plots (n=52) based on plant presence by taxa along the biogeographical and edaphic variables. Variance in plant composition was explained in 2 axes, describing 26% and 52%, respectively for a total of 78%. Biplot vectors indicate variables that correlated strongly with compositional data, including edge (EDGE), BBI area (AREA), distance to Sapelo Island (DSAP), and soil nutrient ratio (C:N). Labels on the left figure correspond to species codes (see Table 3). Codes in the upper right corner were species located in the center of the biplot; labels on the right figure correspond to individual plots on the 14 BBIs (see Table 1). Edge plots are denoted with the symbol (‘).



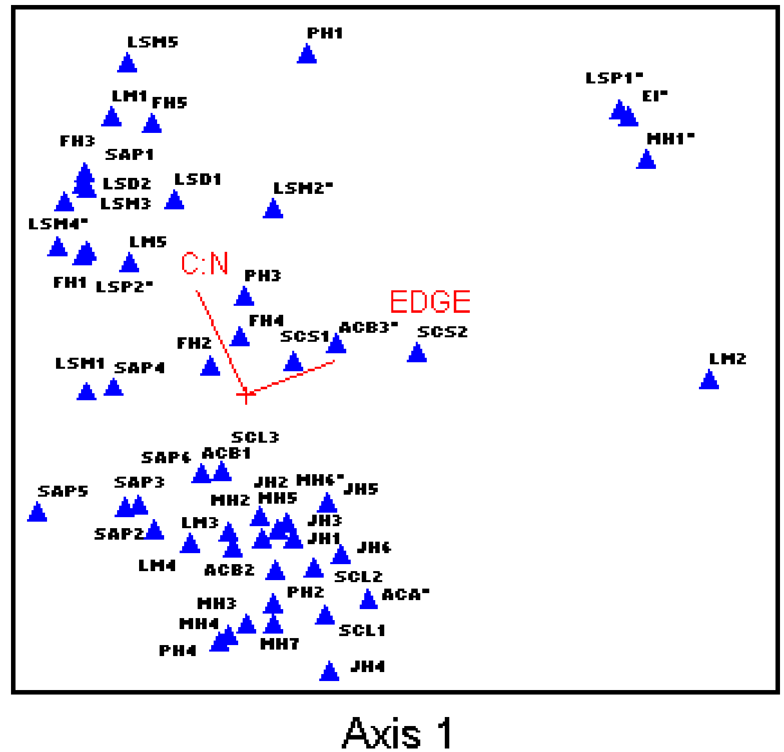


Figure 11. Nonmetric multidimensional scaling (NMDS) results illustrating differences in plant composition among plots (n=52) based on stem densities by taxa along the biogeographical and edaphic variables. Variance in stem densities for canopy plants was explained in 3 axes. The two axes shown describe 31% and 33% respectively, for a total of 64%. Biplot vectors indicate variables that correlated strongly with stem density data, including soil nutrient ratio (C:N) and edge (EDGE). Labels on the left figure correspond to species codes for the 26 species codes measured in the overstory or understory (see Table 3); labels on the right figure correspond to plots on the 14 BBIs (see Table 1). Edge plots are denoted with the symbol (‘).

CHAPTER 3

MANAGEMENT CONSIDERATIONS

> "I plead for positive and substantial public encouragement, economic and moral, for the landowner who conserves the public values – economic or aesthetic – of which he is the custodian. A solution apparently calls for a synthesis of biological, legal, and economic skills, or, if you will, a social application of the physical sciences…"
>
> —Aldo Leopold, 1935

As population pressures and coastal development continue to grow, the need for sustainable development has become increasingly evident. How to adequately balance economic growth and the adequate protection of important coastal landscapes remains a challenge, but one that may be managed with appropriate foresight and planning. Sustainable development, as defined by the United Nations World Commission on Environment and Development, is said to 'meet the needs of the present without compromising the ability of future generations to meet their own needs' (WCED, 1987). For a community to be sustainable, it must adopt an approach that considers economic, environmental, and cultural resources, both in the short and long term. With half the nation living along the coast and millions more visiting each year, we are fundamentally changing the natural ecosystems that attract us to the coast (Clark, 1997). While only about 32% of coastal Georgia land is currently developed, most land use changes have centered on the economic areas of Savannah and Brunswick (NOAA and DNR, 2003). In many areas, sprawl development is consuming land at a rate five times that of the population growth (POC, 2003). Coastal marshes, which trap floodwaters, filter out pollutants and serve as nurseries for wildlife, are disappearing at a rate of 20,000 acres per year in the U.S. (POC, 2003), and Georgia needs to develop comprehensive growth management plans to retain its habitability.

Georgia marsh hammocks are part of an attractive coastal landscape that is increasingly targeted for upscale development to meet the demands of potential homebuyers and the growing tourism industry. Because of their realized and potential values, a recent legal dispute regarding permitting bridge access across state protected marshlands has engendered much debate (see Chapter 1). Back-barrier islands have been identified by the Georgia Coastal Management Program as special management areas that are important features because they help to prevent coastal erosion, provide endemic and rare wildlife and plant habitat, and are archeological sites for Indian shell middens (NOAA and DNR, 2003; Fabrizio and Calvi, 2003). Currently, only 8% of Georgia's back-barrier islands are in state ownership; the remaining 92% are in private ownership (Susan Shipman, pers. comm.).

The Georgia Department of Natural Resources has been forthright in their approach to dealing with the contentious issue of back-barrier island bridge and development projects. Their commitment to support a participatory process, whereby key stakeholders in the local issue have been involved, is commendable: two advisory committees have convened to develop recommendations regarding back-barrier islands. These efforts provided a platform for more effective and efficient communication and considerable progress has been made. Stakeholder council members have been successful in reaching consensus on, among other things, the definition of a 'back-barrier island' (but not a 'marsh hammock'). They also agreed to specific governmental roles that the General Assembly and state and local agencies would have regarding back-barrier island management. The responsibilities of each governing body was delegated within the following areas: proof of ownership, access rights, archaeological surveys, strategies to create and streamline financial incentives for protection, and increased efficiency for issuing stormwater and land-disturbing permits. For example, council members recommended that the General Assembly pass legislation to staff and fund the appropriate state agencies to conduct title reviews and develop a comprehensive inventory for Georgia's back-barrier islands with regard to their ownership. The stakeholder council identified the role of GDNR with regard to BBIs to include satisfying the mandates of the Coastal Marshland Protection Act, implementing and enforcing new state level policies, and coordinating with comprehensive planning departments. Other state agencies and local governments were also delegated specific roles with regard to ownership issues. This exercise was repeated for each of the areas stated above (see Consensus Solutions, 2003 for details) and was meant to provide state-wide consistency and minimize bureaucracy among governmental bodies. Many recommendations required new legislation that was to be framed within a Marsh Hammock Protection Act.

Several topics remained unresolved because of dissenting viewpoints among council members and time constraints (Consensus Solutions, 2003). These included the development of approaches for addressing the following issues: adequately preserving the aesthetic qualities (viewshed) of coastal marshlands, whether or not to permit hardening structures like bulkheads that prevent natural erosional processes, developing environmentally sound guidelines for best management practices (i.e., limiting impervious surface coverage), and preventing or compensating for habitat degradation and losses. The state committed to continue efforts to discuss public policy in these areas by establishing working groups and holding public hearings into 2004. There are additional issues that were not addressed by either advisory council, but which could be critical for the successful management of back-barrier islands. These include developing guidelines for on-site mitigation for proposed marsh impacts, providing the Coastal

Resource Division of GDNR with adequate funding and staff to monitor secondary and cumulative impacts to the coastal ecosystem (in addition to providing external research grants), establishing a review process for adaptive management of coastal regulatory programs and designating appropriate fees and administrative procedures associated with non-compliance.

The process of developing recommendations that address the myriad of concerns surrounding marsh hammocks is still underway, but several management approaches have been proposed. One stakeholder council recommendation is to set minimum requirements for bridge permits for back-barrier islands of a certain size or within a certain distance from the mainland. Two options for this recommendation that have received support from some of the members of the Board of Natural Resources include 1) prohibiting new bridges or causeways to BBIs that are less than 3 acres and farther than 50 feet from the mainland or a barrier island, and 2) prohibiting new bridges or causeways to BBIs that are between 3 and 15 acres in size should the bridge impacts to the marsh total more than one-tenth acre (Shelton, 2003). These proposals would protect smaller, more remote BBIs, but provide no access guidelines for larger, more distant islands that comprise the majority of the total area (an estimated 73% of the total BBI area is embodied in only about 60 back-barrier islands, all of which are greater than 50 acres; CMHAC, 2003).

The stakeholder council also proposed the implementation of new buffer regulations. Currently, the Georgia Sedimentation and Erosion Act (O.C.G.A. 12-7-1 et seq.) requires a 25 ft. buffer for any land change that may result in soil erosion to state waters or wetlands. Variances are often granted and the Georgia Congress has recently moved to weaken provisions related to piping streams by passing Senate Bill 460. The stakeholder council suggested a mandatory 50 ft. setback from a marsh or tidal creek for all impervious surfaces and septic systems, with a twotiered vegetated buffer. The first 25 ft. from the water or marshland would consist of undisturbed natural vegetation, whereas the second 25 ft. would be a transitional zone where landscaped vegetation and 5% impervious surface would be permitted. Additionally, they recommended that a view corridor could not exceed 50% of the frontage width per lot, except in subdivisions where those allowances can be made up elsewhere within the project. Although these recommendations have not been adopted, the results of my study can be used to evaluate the pros and cons of these types of proposals.

The stakeholder council's proposal to establish a minimum back-barrier island size for limiting bridge access can be evaluated in light of different size thresholds related to plant biodiversity. If we use the 3 and 15 acre thresholds recommended by the stakeholder council, I sampled 3 BBIs that were less than 1.2 ha (3 acres), and 8 that were between 1.5 ha and 6 ha (3-15 acres). My observations concurred with previous assessments (Fabrizio and Calvi, 2003) that species richness increases with back-barrier island size. My study also points to a difference in vascular plant species composition for larger back-barrier islands greater than 8 ha (~ 20 to 100 acres) as compared to smaller ones, those less than 4.2 ha in size (~10.4 acres). All of the BBIs < 15 acres clustered together within the small category, suggesting they were compositionally more similar to one another than to those in the large category (> 20 acres). Generally, larger BBIs had many of the same plants that were observed on smaller ones, but both size categories also had upland plants that were unique. If bridge access is limited on small hammocks, but allowed on larger ones, that would mean that the larger islands with more heterogeneous habitats would be unprotected. This is in part due to the fact that larger islands often have a better developed fresh water lens (or an isolated wetland, as was the case for Mary's Hammock). Regulations that take isolated wetlands on back-barrier islands into account would likely help to preserve back-barrier island biodiversity. On the other hand, many small island interiors support plants regarded as rare in the state. Thus, bridge restrictions to small islands will also help to prevent the loss of some rare plant species.

Several studies have questioned the blind use of diversity estimates to determine the ecological significance of a region (Kareiva and Marvier, 2003) or to determine adequate refuge size (Simberloff, 1998, 1999). Disturbance events (i.e., erosion, forest cutting, etc.) can increase biodiversity in the short-term, simply by allowing the introduction of non-native and often invasive pioneer species (Ewel, 1996; Burke and Grime, 1996; Kwit et al., 2000). For instance, my study results indicated that dredge spoil islands had higher species diversity than those of natural geological origin. However, both exotic and rare plants were also observed on dredge spoil sites. These results suggest that colonization opportunities exist on dredge spoil islands, but it is unclear which plants will persist over the long-term. Additionally, several reports point to the importance of dredge spoil islands for nesting bird habitat as natural coastal habitats become increasingly unsuitable due to recreational and development activities (Erwin et al., 2003; Soots and Landin, 1978; Watts, 1994). Further information on dredge spoil islands and disturbance effects on back-barrier islands is required to make management decisions in these areas.

All of the BBIs in my study were well over 50 feet from the mainland or Sapelo Island, so I cannot directly evaluate the proposal to allow bridge permits to locations closer to land. However, I did find that proximity to Sapelo Island tended to influence plant community composition and this may be related to seed dispersal (i.e., wind, migratory birds). In addition, the soil properties I measured (nutrient concentration and soil moisture) tended to decrease with increasing distance from the mainland. These results suggest that BBIs closer to land may have both different plant composition and different soil characteristics than those further away. It should be noted that researchers at Savannah State University and GDNR are currently conducting a study to determine whether barrier island live oak populations are genetically distinct from those on the mainland. If so, this would further support the notion that barriers to dispersal affect plant population dynamics. Barrier islands are unique coastal features having characteristic flora and fauna (NOAA and DNR, 2003). Although back-barrier islands close to Sapelo Island tended to be similar to one another, more research is needed to fully understand back-barrier island floristic patterns as related to those found on adjacent barrier islands.

Another recommendation for marsh hammock management involves changes in buffer requirements. Vegetated buffers are a proven land-use practice that can help to reduce secondary and cumulative impacts caused by development. For example, properly designed (10 to 100 m) vegetated buffers can decrease sediment and nutrient runoff to adjacent water bodies (see review by Wenger, 1999). Coastal residential development has been recognized as an important source of non-point nutrients to southeastern watersheds (due to lawn fertilizers, septic and pet waste, etc), which can lead to eutrophication and algal blooms (Mallin, et al., 1999; Holland, 2001). Forested riparian buffers in coastal areas are particularly effective at nutrient uptake and denitrification, from both terrestrial and atmospheric sources (Lowrance, et al., 1997; Valiela and Bowen, 2002). Forested nearshore areas also decrease the cumulative effects of waterfront development by maintaining habitats that provide higher levels of woody debris and aquatic vegetation (Jennings, et al, 2003). Some states have recognised the adverse impacts of development to water quality and therefore require relatively large buffers. For example, Florida requires a 100 ft. buffer in riparian habitat protection zones in areas adjacent to water bodies designated as Official Florida Waters, and reasonable assurances that construction activities will not adversely affect areas 550 ft. upland of the stream edge (Chapter 40C-41, F.A.C.; Section 11.0, SJRWMD, 2003). However, most state buffer widths are insufficient to adequately provide biologically meaningful habitats. For example, in a review of core riparian habitat ranges for wetland species, reptiles needed a habitat area that extended 127 to 289 m (> 900 ft.) beyond the edge of the wetland for a part of their life cycle (Semlitsch and Brodie, 2003). Although appropriate buffers can have multiple benefits, they cannot remedy all human impacts and their implementation on private and public lands is often political (Shafer, 1999).

In terms of buffers, my findings suggest that larger naturally vegetated buffers than those currently required by state law are appropriate for several reasons. I found that back-barrier island soils had relatively low nitrogen and variable carbon values, but that BBIs closer to the mainland had significantly higher soil nutrient levels. This may be an indication of the increased input of nutrients in these areas as anthropogenic nutrient inputs can potentially alter the natural nutrient balances and plant assemblages over time (Singh and Tripathi, 2000). Given that soil C:N ratios were related to plant community assemblages, this suggests that alterations to the landscape can alter plant composition on BBIs and may already be doing so. Narrow buffers would not alleviate this situation.

Another consideration for the establishment of buffer requirements is the protection of both edge and interior forest habitat. Edge plots in my study were compositionally distinct from insular island areas, and included marsh plants (including salt marsh plants used to delineate jurisdictional salt marsh boundaries) that penetrated the forest at least 5 m and up to 15 m (~16 to 50 ft.) from the forest's edge. Edges are also important to animal movements as they provide cover for terrestrial animals that feed on the marsh during low tide, and they are particularly important to certain birds that are considered edge preferential (Noss, 1991). A naturally vegetated buffer of 15 m would encompass marsh transitional areas. Also, in order to provide interior forest habitat (which is floristically different from the edge plots) a second-tier of naturally vegetated buffer needs to be maintained. Taking both edge and insular habitat into consideration would provide a more comprehensive approach to buffer applications. It is unclear what width would be appropriate to maximize ecosystem functions aside from prohibiting all land disturbing activities, but a combined 30 m (~93 ft.) buffer (equal width of marsh edge and forest interior) is greater than that proposed by stakeholder council members, but less restrictive than some states. To be consistent, a more restrictive 30 m setback should also be applied to septic systems.

A larger buffer would not only increase habitat preservation, but would also serve to reduce nutrient loading from new development to the marsh or waterbody and provide some protection from storms, sea level rise, and shoreline erosion. It should be noted however, that human induced edge areas fragment the natural vegetation and alter ecosystem functions. For example, newly created edges cause increased temperatures and tree mortality due to windthrow, and changes in animal movements; however, more research is needed to better understand these effects (see review by Murcia, 1995). In a study of land use patterns in tropical forests, forest clearing decreased ecosystem functions and resiliency by decreasing tree richness (Silver, et al., 1996). However, even moderate riparian zones will help to maintain some forest functionality, even if edge effects are created. Of course, buffers would restrict development activities to a greater extent on smaller islands due to simple geometric relationships between surface area to volume: the smaller the island, the greater the proportionate amount of edge. Thus, geometric calculations indicate that a minimum island size of 3.4 acres is necessary to accommodate a 30 m continuous buffer, assuming a minimum interior buildable area (A_I) of 1 acre.

(9) $A_{INT} = \pi r^2$,

where A_{INT} = 1 acre (or 4046.87 m^2), then the maximum development footprint (r^2) is 35.9 m x 35.9 m (or 13, 860 $ft.^2$). Furthermore, the minimum back-barrier island area (A_{BBI}) necessary to accommodate a 1 acre development site is found by plugging in the radius of the development footprint (r) and recommended buffer width (b).

(10) $A_{BBI} = \pi [\frac{1}{2} (2r + 2b)]^2$,

where r = 35.9 m and b = 30 m, then A_{BBI} equals a minimum of 3.4 acres. Moreover, the amount of edge is greater in irregularly shaped objects as compared to circles. Since most back-barrier islands (excluding dredge spoils) are long and narrow (or irregularly shaped), they have more extensive edges (greater perimeter) and a smaller interior suitable for development, so a minimum size restriction based on buildable upland acerage for permitted access would be appropriate. Therefore, by increasing the required buffer width to encompass both edge and interior habitats, development impacts may be controlled on small islands that are unsuitable to sustainable development. In this case, back-barrier islands smaller than 3.4 acres are clearly not spacious enough to mitigate for the cumulative ecological impacts caused by planned development, especially given the generous variances for view corridors and impervious surface as recommended by the stakeholder council. These consist of allowing 50% trimming of the marsh frontage per lot and 5% impervious surface within the second-tier of a 50 ft. buffer zone, respectively.

Marsh hammocks are an integral component of the marsh ecosystem and provide a vital link between the aquatic environment and the upland ecosystems. It was apparent from my research that these islands support endemic maritime forest species, which tend to be long-lived (i.e., live oak, shrub thickets). They are important in maintaining fresh groundwater supplies and providing forage and habitat for many species, including rare water-dependent and migratory birds (Bellis and Keough, 1995; Fabrizio and Calvi, 2003). Back-barrier islands also have diverse micro-topography, including shell middens, relict dunes and freshwater sloughs that provide heterogeneity in this coastal landscape. Any intensive development of these areas will lead to secondary impacts like degraded insular island habitats and species losses. The cumulative impacts caused by small-scale construction of homesites, roads, bridges, and septic fields may alter the environment to such an extent that natural hydrologic and ecological processes are no longer possible. Such permitted access would increase the likelihood of more intense development on larger back-barrier islands, which could result in major upland habitat losses as well as secondary and cumulative impacts to marshlands. In this regard, it is important to remember that the original impetus to legally protect Georgia's expansive salt marshes under the CMPA was not based on biodiversity, but rather on the services that this unique ecosystem provides and the fact that once seriously impacted, it would be impractical if not impossible to restore (Craig, 2001). Although the Georgia Superior Court twice upheld the public trust by stating that Georgia's three-member Marshland Protection Committee has the authority to consider cumulative impacts to the marsh when granting or denying permits, consistent guidelines are needed to steer future permitting decisions in sensitive coastal areas. In addition, strong partnerships among all levels of government, community and business organizations are critical for landscape level habitat protection.

SUMMARY

There are important policy reasons for evaluating the maritime vegetative communities found on Georgia's back-barrier islands. Both marsh hammocks and maritime forests are recognised as having physiogeographic significance by Georgia's Coastal Management Program and are listed as special management areas (NOAA and GDNR, 1997, 2003). In recognition of their significant ecological value, the state's Marshland Protection Act of 1970 protects Georgia's coastal marshlands from development; but adjacent back-barrier islands are not currently offered the same safeguards. We know, however, that rare and endemic plants and wildlife inhabit back-barrier islands, so conservative measures to protect these sensitive areas are in the public interest. Although back-barrier island development can be expensive, the potential to attract affluent buyers has stimulated interest in these areas. In addition, private property owners of back-barrier islands are concerned that their rights may be threatened, so many are seeking permits to secure future access to their land. The Georgia Coastal Management Program is in need of guidelines to steer future permitting decisions in these sensitive coastal areas.

The state may consider protecting a range of sizes with a set goal for areal cover. This could be done in the context of an ecological framework, wherein BBIs least impacted by human activities or exotic invasions and those that have high habitat heterogeneity would be given high priority. The proximity to Sapelo Island had an effect on plant community composition in that those plants may more closely reflect the unique vegetation found on major barrier islands than the mainland, and this should be considered when identifying back-barrier islands for protection. Colonization by rare or exotic plants should also be considered in this context. Since few back-barrier islands, especially large ones, are in public ownership, those rated as high priority for protection could be targeted for acquisition. Another management approach might be to require larger vegetated buffer widths where development is likely as a way to offset anthropogenic impacts from upland areas to the surrounding marshlands and tidal creeks. A larger buffer would also help to address the secondary impacts of upland development to wetland dependent species that inhabit back-barrier islands. The cumulative impacts from development must be taken into account, and perhaps a cap to impervious surface coverage would be the fairest approach.

Although it is also in the public interest to support economic growth, the state must not allow the piecemeal destruction of its valued ecological resources on the basis that there is insufficient scientific data to protect them. Therefore, those standing to profit from adversely impacting a public resource should be required to help to fund the research, monitoring, and reporting so that state and local governments can determine when a sustainable threshold has been reached. This study took place during the summer and fall seasons on a limited number of centrally located back-barrier islands and future observations that address broader seasonal, annual and geographical fluctuations in plant and soil characteristics would be useful. Also, direct comparisons between mainland, barrier island and developed back-barrier island upland habitats would help determine whether the trends detected in this study can be applied more generally. However, the baseline information we do have is important for understanding ecological linkages within the coastal landscape and contributes to our knowledge of island biogeography.

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APPENDIX

A – SOIL GRAIN SIZE DISTRIBUTION

Six soil subsamples were selected to measure the grain size distribution from the soil samples collected on 14 back barrier islands near Sapleo Island, Georgia. These subsamples were examined at the Geology Department at Georgia State University from April to May 2003 under the direction of Dr. Beth Christensen. The subsamples chosen (MH3, JH1, LSM2, LM3, SCL and FH2) were randomly stratified to represent a cross section of back-barrier island sizes and origins.

Both mechanical and chemical methods were used to to separate the fine silts and clays (< 4.0 phi units or <62.5 µm) from the coarse material (-1.0 to 4.0 phi units or 2 mm to 62.5 µm). Large organic materials were manually removed from each of the approximately 35 g subsamples. Carbonates were precipitated by adding a 1N sodium acetate – acetic acid solution (82 g sodium acetate and 26 mL acetic acid) buffered to a pH of 5. Samples were then centrifuged for 10 minutes at 3000 rpm, and the precipitate was decanted. The remaining organics were acid digested in a 30% hydrogen peroxide solution in a 50º C bath for several hours, centrifuged and decanted. Each subsample was wet seived through a 63 micron seive using a rinse dispersent of sodium hexametaphosphate (0.5 gm/L) to separate the silts and clays from the coarse materials. The fine fraction subsamples were collected and stored in open 400 ml beakers to allow for evaporation. The coarse materials were collected onto filter paper and dried at 80º C. These were sorted using a standard RoTap procedure for the mechanical separation of sediments. The fine fraction was measured using a Micrometrics Sedigraph 5100 instrument to calculate the relative proportions of silt and clay material based on Stoke's Law.

The results from the coarse and fine fractions indicated that back-barrier island soils are characterized as fine sands with some silt and clay materials. The mean distribution for the coarse fraction was approximately 3% coarse sand, 7% medium sand, 28% fine sand, 61% very fine sand and <1% silt (Table 17). Results also indicated that the soil subsample from plot SCL3 that was from a back-barrier island of dredge origin had a different grain size distribution signature than those from BBIs of natural origin (Figure 12). The mean distribution for the fine fraction was approximately 4% fine sand, 44% silt and 52% clay (Table 18). The results for the grain size distribution of the silt and clay fraction for the six subsamples examined are shown in Figure 13.

Table 17. Summary of the 6 back-barrier island (BBI) soil subsamples used for the coarse fraction grain size analysis as cumulative mass percent finer. Grain size class, BBI plot code, BBI size, and grain size diameters (mm and phi units) are presented. For a list of BBI names and sizes, see Table 1. A cross (†) denotes a plot from a BBI of dredge spoil origin; an asterisk (*) denotes an edge plot.

Grain Size Class	BBI Plot Code and BBI size (ha)		MH3 9.87	JH1 8.19	LSM2* 3.95	LM3 1.82	SCL3† 1.62	FH2 1.53	Total (%)
	Grain Size mm	Grain Size Phi	Cumulative Mass Finer (%)						
Coarse Sand	2.00	-1.00							
	1.41	-0.50					100.00		
	1.00	0.00					98.85		
	0.71	0.50		100.00		100.00	94.94	100.00	3
Medium Sand	0.50	1.00	100.00	99.60	100.00	99.58	85.10	99.69	
	0.35	1.50	99.66	99.36	99.09	99.58	69.54	99.27	7
Fine Sand	0.25	2.00	98.87	98.64	97.82	98.17	52.72	98.27	
	0.177	2.50	94.19	94.69	93.93	92.94	40.13	94.69	28
Very Fine Sand	0.125	3.00	61.65	67.80	69.30	74.44	25.34	71.42	
	0.888	3.50	10.27	13.70	19.17	27.18	9.46	19.04	
	0.063	4.00	2.09	2.00	5.70	3.14	3.90	5.31	61
Silt	0.044	4.0+	0.45	0.24	1.15	0.42	0.60	1.96	<1

Table 18. Summary of the 6 back-barrier island (BBI) soil subsamples used for the fine fraction grain size analysis as cumulative mass percent finer. BBI plot code, BBI size, and grain size diameters (µm and phi units) are presented. For a list of BBI names and sizes, see Table 1. A cross (†) denotes a plot from a BBI of dredge spoil origin; an asterisk (*) denotes an edge plot.

Grain Size Class	BBI Plot Code and BBI size (ha)		MH3 9.87	JH1 8.19	LSM2* 3.95	LM3 1.82	SCL3† 1.62	FH2 1.53	Total (%)
	Grain Size µm	Phi	Cumulative Mass Finer (%)						
Fine Sand	250.00	2.0							
	177.00	2.5	100.0			100.0			
	125.00	3.0	95.0	100.0		97.3			
	88.00	3.5	95.7	99.2	100.0	97.3		100.0	
	62.50	4.0	97.5	97.2	97.6	96.6	100.0	98.8	4
Silt	44.00	4.5	96.6	95.6	91.6	96.2	99.4	96.4	
	31.00	5.0	94.0	93.4	87.0	96.1	97.7	88.1	
	15.60	6.0	88.3	77.9	73.6	83.9	92.0	69.7	
	7.80	7.0	77.0	62.7	58.9	71.9	87.1	51.1	
	3.90	8.0	68.7	52.7	48.5	64.2	79.9	38.7	44
Clay	2.00	9.0	62.8	44.0	44.2	56.6	72.1	31.0	
	0.98	10.0	54.2	34.9	38.8	47.9	61.1	23.8	
	0.49	11.0	40.0	37.7	43.0	46.3	43.4	21.5	52

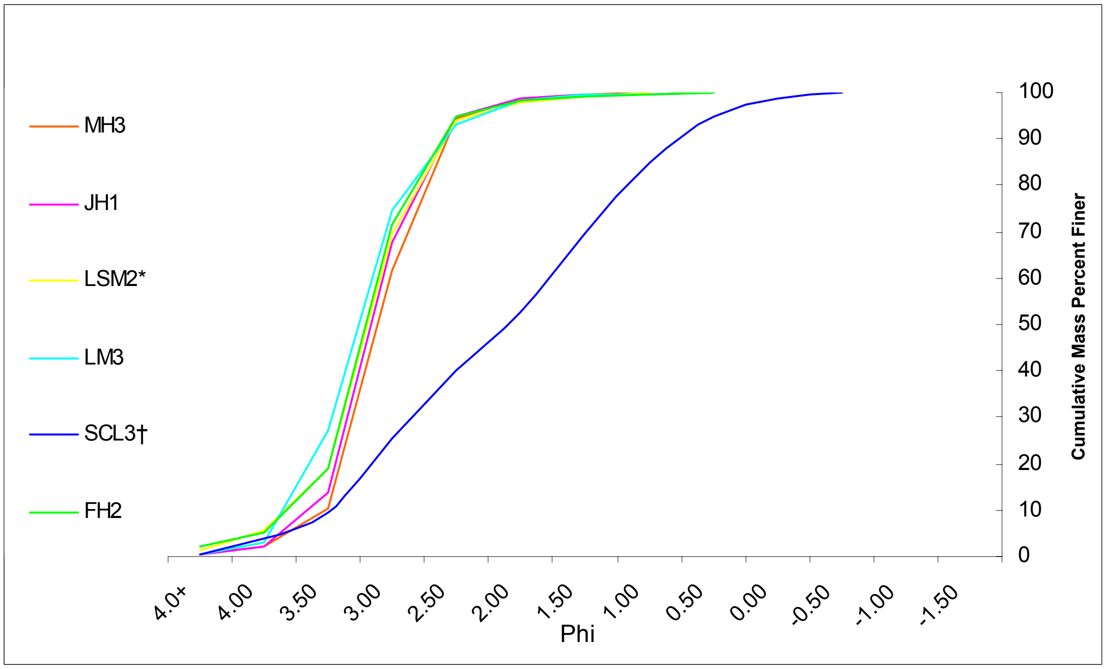

Figure 12. Soil coarse fraction grain size (phi) illustrated as cumulative mass percent finer for a subset of back-barrier island plots (n=6). The BBI plots are arranged in descending order of their corresponding BBI's size. For a list of BBI names and sizes, see Table 1. A cross (†) denotes a plot from a BBI of dredge spoil origin; an asterisk (*) denotes an edge plot.

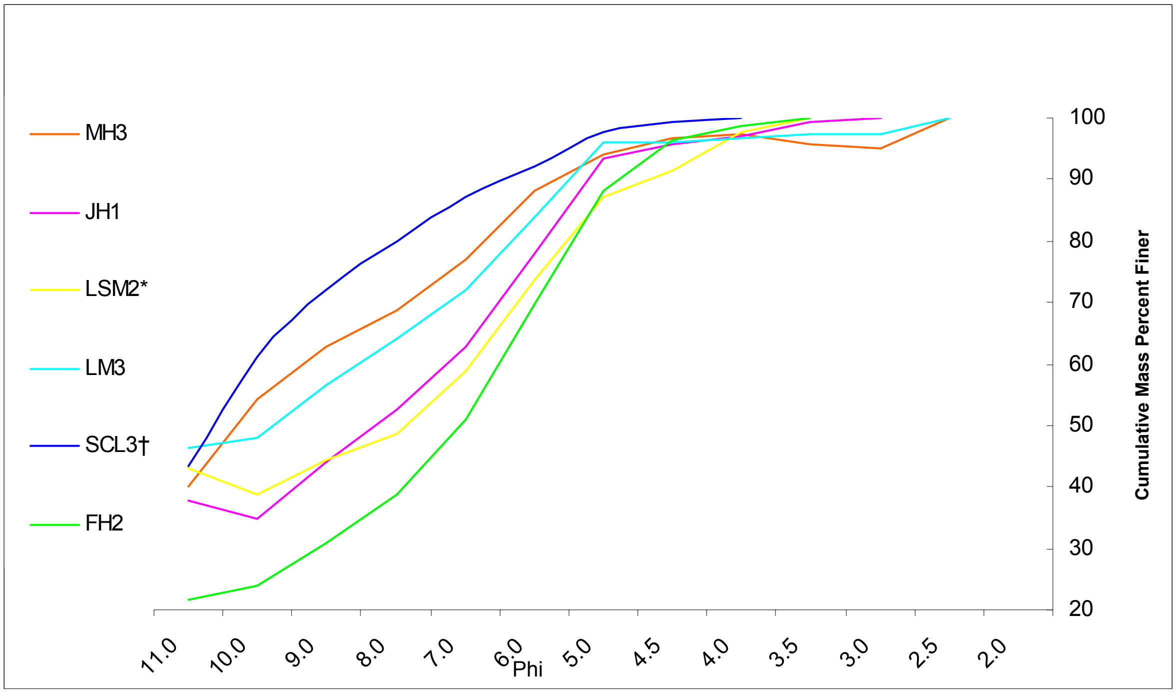

Figure 13. Soil fine fraction grain size (phi) illustrated as cumulative mass percent finer for a subset of back-barrier island plots (n=6). The BBI plots are arranged in descending order of their corresponding BBI's size. For a list of BBI names and sizes, see Table 1. A cross (†) denotes a plot from a BBI of dredge spoil origin; an asterisk (*) denotes an edge plot.